The Socio-Technical Construction of Precision Bombing:
A Study of Shared Control and Cognition by Humans, Machines, and Doctrine
During World War II

by

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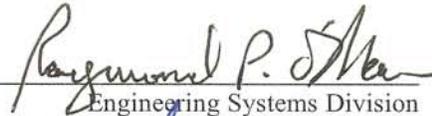
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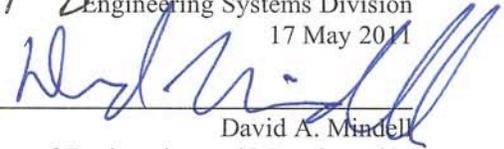Massachusetts Institute of Technology
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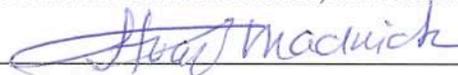
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Abstract

This dissertation examines the creation and initial use of the precision bombing system employed by the United States Army Air Forces during World War II in the opening phase of the Combined Bomber Offensive against Germany. It presents the system as distinctly *socio-technical*, constructed of interdependent specially trained humans—the pilot, navigator, and bombardier—purpose-built automated machines—the Norden bombsight and the Minneapolis-Honeywell C-1 Autopilot—and the high-altitude, daylight bombing (HADPB) doctrine, all of which mutually shaped each other's creation and use.

The first part of the study establishes the relationship between the HADPB doctrine, the humans, and the machines, presenting the bombardment system as a three-level socio-technical system designed for optimum control at all levels. It describes the elements at each level, their design for use as a system, how they initially employed the system, and how their actions caused a revision of the HADPB doctrine, in the process redefining precision from a system perspective and significantly changing the system's social structure.

The second part of the study examines the actions performed by the three principal socio-technical members the bomber crew, and determines the specific tasks and roles accomplished both the humans and machines within the system. It establishes what the crewmembers *did*, analyzing their professional construct, the machines that shaped their professional identities, how the humans and machines, through distinct processes of shared control and cognition, accomplished the tasks associated with precision bombing—flying, navigating, and bombing—and how the HADPB doctrine affected their actions. It focuses on how technology, by granting varying levels of control over the task of flying the aircraft, created conflict over control of the system itself, and how command, a uniquely military function granted organizationally and doctrinally to the pilot, served as arbiter of that conflict.

This study establishes a perspective for the future study aerial combat systems, and a better understanding of the organizational and social impact of the increased use of automation in those systems, particularly relevant to the discussion surrounding the expanded use of remotely piloted aircraft by the United States Air Force in the conflicts in Iraq and Afghanistan.

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Acronyms and Abbreviations

8th AF	Eighth Air Force
AAF	Army Air Forces
AB	automatic bombing computer
ACTS	Air Corps Tactical School
AEA	Aerial Experimentation Association
ACQE	Aviation Cadet Qualifying Examination
AFCE	Automatic Flight Control Equipment
AFHRA	Air Force Historical Research Agency
AFRI	Air Force Research Institute
AFSC	Air Force Systems Command
ANT	Actor-Network Theory
C2	command and control
CEP	circular error probable
COP	community of practice
DoD	Department of Defense
DR	dead reckoning
ETO	European Theater of Operations
GPS	Global Positioning System
HADPB	high-altitude, daylight precision bombing
hp	horsepower
H.R.	House Resolution
IAS	indicated airspeed
ICBM	intercontinental ballistic missile
INS	inertial navigation system
IP	Initial Point
lb	pound
LGB	laser-guided bomb
M-H	Minneapolis-Honeywell Corporation
MH	magnetic heading
RAF	Royal Air Force
RBR	Radio Bomb Release
RPA	remotely piloted aircraft
SBAE	Stabilized Bombing Approach Equipment
STS	Science, Technology, and Society
TAS	true airspeed
TC	true course
TFR	terrain following radar
TH	true heading
TR	Training Regulation
UAV	unmanned aerial vehicle
US	United States
USAF	United States Air Force
USAAF	United States Army Air Forces
WSO	Weapons System Officer

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Chapter 1

Introduction

You lived and died alone, especially in fighters. Fighters. Somehow, despite everything, that word had not become sterile. You slipped into the hollow cockpit and strapped and plugged yourself into the machine. The canopy ground shut and sealed you off. Your oxygen, your very breath, you carried with you into the chilled vacuum, in a steel bottle. If you wanted to speak, you used the radio. You were as isolated as a deep-sea diver, only you went up, into nothing, instead of down.

James Salter, *The Hunters*[1]

Remote warfare has changed the enduring truth of the past 5,000 years of war. A growing number of soldiers wake up, drive to work, sit in front of computers and use robotic systems to battle insurgents 11,300 kilometers away. At the end of a day "at war," they get back in their cars (and) drive home…. The most dangerous part of their day is not the dangers of the battlefield but the commute home.

Peter Singer, *War of the Machines*[2]

The two accounts above describe the same thing—air warfare and the relationship between the humans and machines involved. The first, penned by James Salter, a former U.S. Air Force (USAF) fighter pilot during the Korean War, reflects a romantic view of aerial warfare—the notion of the solitary warrior, the pilot the master and the machine the servant becoming one to form a singular, lonely flying being. It envisions the Knight of the Air venturing off to fight single, mortal combat. The second, written over five decades later by Peter Singer of the Brookings Institution, reflects a more contemporary, sterile view of air warfare— the 'unmanned,' automated aerial killing machine, tenuously tethered through the ether to a control station thousands of miles away from the scene of the violence, with the faceless pilot protected safely within. It is the science fiction-inspired battle of the future. Studies in contrast, each view captures an aspect of modern air warfare, but both mischaracterize the complexity of the socio-technical systems that employ airpower and the relationship that exists between humans, machines, and ideas that comprise them.

In Salter's Korean War-era novel, *The Hunters*, protagonist Cleve Connell typifies the romantic, literary-influenced portrait of the fighter pilot—the steely-eyed killer with exceptional

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[1] James Salter, *The Hunters* (New York: Vintage Books, 1956), 193.
[2] P. W. Singer, "War of the Machines," *Scientific American*, July 2010, 62.

eyesight and coordination who is the master of a highly complex, deadly machine. An expert at aerial gunnery, Connell is defined by his skill at jockeying his aircraft through the sky, exploiting its strengths and accommodating its limitations while seeking victory against his North Korean opponent in one-versus-one combat. Risking death at every turn, professional recognition comes through superior individual performance in battle. Connell's pursuit of the ultimate professional aviator status—that of fighter ace, an aviator with five air-to-air kills—drives and consumes him, for achieving that rare milestone is the surest confirmation of his flying skill and the route to professional validation and personal glory.[3] In this endeavor, he competes not only with his North Korean foe, but with his compatriots as well, for they doggedly pursue the same recognition that he seeks. It is a savage competition, with great rewards for the most skillful, victorious elite and professional anonymity for those who fail. For James Salter, air combat is a human-centric activity, with the aircraft serving as an inanimate tool, pressed into service, its only function to enable the pilot to attain his goal, and the aircraft operator plays the lead role. It is a perspective reflected in much air combat literature, from fiction to biography to historical narratives.

Cleve Connell's human-versus-human world stands in stark contrast with Peter Singer's view of air warfare. In *Wired for War: The Robotics Revolution and Conflict in the 21st Century*, Singer describes a very different type of combat, one in which automated machines—those that enable robotics—replace the human in warfare systems and themselves become "the very agent of war."[4] Singer describes an air combat that is conducted through "remote split operations," where automated machines allow faceless aircraft operators to remain thousands of miles away from their aircraft, protected from the violence of the battlefield while their machines assume all of the physical risks of warfare.

In these remotely piloted aircraft (RPA) systems, the humans' role is far more ambiguous than that of Salter's Korean War fighter pilot. RPA operators observe the battlefield on television screens while sitting in a metal box, much like a shipping container, connected to a large communication system through several umbilical cables. These cables are the operators'

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[3] The elite status of the fighter ace was established in World War I and played a large role in the glorification of airmen. See Lee B. Kennett, *The First Air War 1914-1918* (New York, NY: Simon & Schuster, 1999); Peter Fritzsche, *A Nation of Fliers: German Aviation and the Popular Imagination* (Cambridge, MA: Harvard University Press, 1992).

[4] Peter W. Singer, *Wired for War: The Robotics Revolution and Conflict in the 21st Century* (New York, NY: The Penguin Press, 2009), 194.

connection to the world, providing all of their sensory input—video captured from a camera on the RPA, voice communication between and with personnel involved in or supporting the battle, internet chat rooms with other participants who have no voice communication. They also carry the operators' commands to RPAs flying over the battlefield—speed up, slow down, turn, point the camera at a particular threat, employ weapons—and all of it depends upon an elaborate, complex datalink communication system consisting of cables, antennas, transmitters, and receivers hosted on a constellation of satellites. For Singer, aerial warfare has become machine-centric, where the human plays the supporting role.

In Singer's machine-centric force, the humans' role as a combatant is no longer clear, and as the RPA operators have no opportunity to face their opponent in the traditional sense, the route to professional distinction even less so.[5] In the RPA system, only the machines are actually at the scene of the battle. Whereas Connell earned accolades and recognition for acts of superior tactical prowess and bravery, RPA operators are far removed from the battlefront, distant and detached, unrecognized as anything more than a faceless element in a complex network of humans and machines. Yet, RPA operators too fight, but it is the machine that plays the lead role—and increasingly so as RPAs assume a progressively larger role in modern combat.

But is either perspective correct? More importantly, does either perspective accurately capture the truly complex relationship between humans, machines, and the ideas that guide the use of these socio-technical systems? Fifty years ago, was the pilot truly the independent master of aerial system? Have automated machines in current systems replaced humans to the extent that they have become the new "agents of warfare" and the human is minimized to a mere system component? Why should we care?

The USAF has dramatically increased its use of RPAs in the past fifteen years as advances in automation and remote and supervisory control have steadily increased their

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[5] Greg Jaffe, "Combat Generation: Drone operators climb on winds of change in the Air Force," *The Washington Post* (Washington, DC, February 28, 2010), sec. A, http://www.washingtonpost.com/wp-dyn/content/article/2010/02/27/AR2010022703754_pf.html (accessed 1 March 2010); Houston R. Cantwell, "Beyond Butterflies: Predator and the Evolution of the Unmanned Aerial Vehicle in Air Force Culture" (Master's Thesis, School of Advanced Airpower Studies, 2007); Mark Thompson, "Air Force Predator Drone Pilots: A New Kind of 'Top Gun'," *time.com*, October 5, 2009, http://www.time.com/time/nation/article/0,8599,1927766,00.html (accessed 6 October 2009); Edward Helmore, "US Air Force prepares drones to end era of fighter pilots," *guardian.co.uk*, August 23, 2009, http://www.guardian.co.uk/world/2009/aug/22/us-air-force-drones-pilots-afghanistan (accessed 6 August 2010).

warfighting capabilities.[6] RPA systems have evolved from unarmed surveillance-only systems to strike-capable platforms able to carry multiple types of ordnance, and demand for their presence in combat theaters has skyrocketed. From 2008 to 2009, the USAF increased its number of fielded RPAs by 330 percent, and converted 87.8% of manpower billets freed up through the retirement of legacy, human-piloted fighter systems to support increased RPA operations.[7] In fact, the USAF's new emphasis on RPAs is so great that in fiscal year 2009, it trained more pilots for RPAs than pilots for manned aircraft, and by 2011, the RPA pilot community will be second in size only to the F-16 pilot community.[8] This distinct shift toward an RPA-centric air force, where the *aircraft operator* is removed from the aircraft itself, has caused the pilot-dominated USAF to have to consider some of the issues raised by Peter Singer's version of air combat, principle among them the role of the pilot in the organization and the role of airpower as a military instrument.

The conflicts in Iraq and Afghanistan over the past decade have created a demand for persistent airborne surveillance over the battlefield, necessitating long missions that extend beyond normal human pilot endurance limits. Technological improvements in automation and remote and supervisory control, however, have enabled the transfer to complex machines many of the previously human tasks and skills required for flying and employing aircraft. This transfer has allowed RPA systems to perform missions that were previously unachievable by traditional human-piloted systems. The automatic pilots that control RPAs for much of the time that they are airborne, "flying" the aircraft for the human operator on the ground, are not subject to those same physiological limits, and are thus able to fly these longer missions, making them more useful and flexible in application.[9] In short, the automatic pilot is able to fly these missions

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[6] In FY97, the total USAF RPA fleet consisted of two MQ-1 Predator RPAs. By FY09, that total had grown to 126 M/RQ-1 Predator/Reapers and RQ-4 Global Hawks. See Col. James C. Ruehrmund, Jr., USAF (Ret.) and Christopher J. Bowie, *Arsenal of Airpower: USAF Aircraft Inventory, 1950-2009*, Mitchell Institute Studies (Arlington, VA: Mitchell Institute Press, 2010), 47.

[7] Michael B. Donley and General Norton A. Schwartz, *2010 Air Force Posture Statement: Presentation to the Committee on Armed Services United States Senate* (Washington, DC: United States Air Force, February 9, 2004), 9-10.

[8] Lt Col Lawrence Spinetta, "Letters - Air Force Community - Air Force Times--The Coming UAS Revolution", August 10, 2009, http://www.airforcetimes.com/community/opinion/airforce_opinion_letters_081009/ (accessed 2 September 2009).

[9] RPAs can stay airborne much longer than human-piloted aircraft, as they are limited only by the amount of fuel and ordnance that they can carry. Human-piloted systems are additionally limited by the amount of time that the pilot can remain alert, how much oxygen the aircraft can carry, and the pilots basic physical stamina. While physical limitations are largely eliminated, RPAs continue to be the focus of a great deal of

"better" than a human pilot, which creates an uncomfortable situation for some in the USAF, as flying skill has historically played a strong role in the professional identity, organizational culture, and leadership structure of the organization.[10]

Removing the pilot from the aircraft has also significantly improved the safety of the human in the system by further removing the aircraft operator from the 'point of execution' on the battlefield. This increased distance has virtually eliminated concern about operator exposure to risk from enemy fire, which challenges the traditional concept of the aerial warrior, as typified by Salter's fighter pilot.[11] The extensive use of automation in RPA systems also raises other penetrating questions, and appears to openly challenge the traditional view of the pilot and of flying itself. If we separate the humans from the aircraft and allow machines to fly, do we even need pilots, who are the traditional warrior class and leaders of the Air Force, to operate them?[12]

In 2009, the Chief of Staff of the USAF commissioned a study to examine that very issue, looking at "current (RPA) manning paradigms and their ability to accommodate rapidly evolving

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human factors research. See "The Persistence-Plus Cockpit," *AirForce-magazine.com*, July 24, 2009, http://www.airforce-magazine.com/DRArchive/Pages/2009/July%202009/July%2024%202009/ThePersistence-PlusCockpit.aspx (accessed 27 July 2009).

[10] Throughout its history, the USAF has cultivated a flying culture, and aviators, specifically pilots, have traditionally led the organization. See Vance O. Mitchell, *Air Force Officers: Personnel Policy Development, 1944-1974* (Washington, DC: Air Force History and Museums Program, United States Air Force, 1996); Brian J. Collins, *Behind the Cyberspace Veil: The Hidden Evolution of the Air Force Officer Corps* (Westport, CT: Praeger Security International, 2008).

[11] Distance from the battlefield enemy eliminates battlefield risk to the RPA operator, but exposes them to other potential threats. Deployed combatants are able to control their exposure to enemy threats to varying degrees through force protection measures that manage risk. However, the fact that many RPA operators work from locations in the United States, living at home and commuting to work, reducing the ability to apply traditional force protection measures. However, to date there have been no reported attacks on U.S.-based RPA operators. See David Axe, "A man and his drones: on the front line of robotic warfare," *Wired.co.uk*, December 2, 2009, http://www.wired.co.uk/news/archive/2009-12/02/a-man-and-his-drones-on-the-front-line-of-robotic-warfare.aspx (accessed 3 December 2009); David Zucchino, "Drone pilots have a front-row seat on war, from half a world away," *Los Angeles Times* (Los Angeles, CA, February 21, 2010), http://www.latimes.com/news/nation-and-world/la-fg-drone-crews21-2010feb21,0,5789185,full.story (accessed 31 March 2010).

[12] Carol Ann Alaimo, "Will drones push fighter pilots out of the cockpit?," *Arizona Daily Star* (Tucson, AZ, July 26, 2009), http://azstarnet.com/news/local/govt-and-politics/article_877afc9c-a0ce-5f4b-b690-760b0ce74fa9.html?mode=story (accessed 21 May 2010); Peter Almond, "Manning Unmanned Aerial Vehicles: Fighter Pilots or Geeks?," *RUSI Defence Systems* (June 2009): 79-82, http://www.rusi.org/downloads/assets/Unmanned_Vehicles_Fighter_Pilots_or_Geeks_RDS_Summer_09.pdf; Joshua Gramm and Steven Papp, "An Insatiable Demand: 'Manning' the US Air Force'sUnmanned Aircraft Systems with Capable Pilots", March 31, 2009; Thompson, "Air Force Predator Drone Pilots: A New Kind of 'Top Gun'."; Julian E. Barnes, "Training the Top Guns of drone aircraft," *latimes.com*, June 7, 2009, http://articles.latimes.com/2009/jun/07/nation/na-topgun-drone7 (accessed 6 August 2010).

and emerging missions."[13] Conducted by the Air Force Research Institute (AFRI), its principal finding was that

> The RPA is a new *paradigm* of airpower (that)
>   A) Disrupts the status quo and requires new thinking, and
>   B) Redefines the "pilot" role.[14]

The study went further to conclude that, as a new paradigm of airpower, the RPA demands "organizational and cultural transformation."[15] The conclusion that the RPA is a new paradigm is significant and it portends great potential upheaval and change. The concept of the paradigm, much abused, originates in Thomas Kuhn's classic book, *The Structure of Scientific Revolutions*. Kuhn advanced the paradigm as the foundational belief structure held by a particular social group that informs its view of the world and how it solves problems, binding together a group of otherwise "disparate" humans.[16] The RPA as a new paradigm is thus inherently disruptive, as it implies that the "old" paradigm is no longer valid and that the underlying beliefs of the current social group require reconstruction in accord with the new worldview.

If the RPA is, indeed, a new paradigm, the USAF must undergo seismic organizational change in its structure and leadership in order to adapt to the new world. Who becomes the new "pilot" and leads the organization? What role will pilots play in that new world? The new foundational belief implied by a new paradigm, however, extends beyond organizational leadership and personnel issues to the very fundamental ideas, or doctrine, that have guided airpower's use for the past century. As Singer points out in *Wired for War*, doctrine "shapes everything that the military does," and if RPAs represent a new paradigm for the USAF, then its doctrine must change.[17] Doctrinal change is difficult and expensive for a military force, as it influences weapon system acquisition and determines the types of people it recruits and trains. What is more, if you get doctrine wrong, the consequences can be catastrophic, as the military may be unable to perform its mission.

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[13] Colonel Tim Schultz, "UAS Manpower" (PowerPoint presentation presented at the Future Operators Symposium, Maxwell AFB, AL, July 21, 2009), notes, slide 2.

[14] Colonel Tim Schultz, "UAS Manpower Strategy" (PowerPoint presentation presented at the Future Operators Symposium, Maxwell AFB, AL, July 21, 2009), slide 4 (emphasis added).

[15] Schultz, "UAS Manpower," slides 2, 4, and 7.

[16] Thomas S. Kuhn, *The Structure of Scientific Revolutions*, 3rd ed. (Chicago, IL: University of Chicago Press, 1996), x, 10, 294.

[17] Singer, *Wired for War*, 208.

Has the RPA truly changed the way that the USAF must organize, train, and equip its forces to the extent that a century of experience in employing airpower is no longer valid? The answer to that question is critical, as it means the difference between tearing down the institutional house, destroying the foundation, and rebuilding at great expense, versus merely adding a new wing onto the existing structure that accommodates the new, unique capabilities supplied by RPA systems. However, before we may answer it, we must identify and understand the phenomena underlying the issue. Essential to Singer's and AFRI's conclusions is the assumption that the aircraft operator's *physical location* is a critical factor. For Singer, the RPA breaks thousands of years of warfare tradition and replaces the operator as the very agent of war. For AFRI, the RPA actually redefines the pilot's role in the aerial combat system. Is their assumption correct? Therein lies the central question.

> *How has the physical dislocation of the operator, enabled by automation technology, changed what the RPA operator does as compared to what a manned-aircraft operator does?*

Answering that question requires an historical understanding of how humans have used machines and automation in aerial combat systems, and how the institutional beliefs held by the organization shaped and were shaped by those same humans and machines.

The Research Project

The research project started as an effort to provide a more complete answer to the above question by establishing what manned-aircraft operators do and why they do it from a broader historical perspective, examining how aircraft operators used machines and automation to accomplish their jobs within several socio-technical aerial combat systems that performed a specific aerial combat mission—precision bombing—and how USAF doctrine shaped and was shaped by their actions. The initial project proposal included a detailed examination what aircraft operators actually *did* while accomplishing their jobs, tracing their actions and interactions with the major automated machines during a typical combat mission, across three major manned precision strike systems that spanned an historical period that included major doctrinal change, and establishing how their relationship with those machines developed. Upon

completion, the results of the research could then be paired with a similar study of RPA operations to determine how, or if, automation has changed the role of the aircraft operator.

The weapon systems chosen for inclusion represented both significant doctrinal change and incorporated major automated machines that affected how the aircraft operators accomplished their jobs. These included:

1. Period: World War II
   Doctrine: High-altitude, daylight precision bombing (HADPB)
   Technology: The B-17 Flying Fortress/four-engined heavy bomber
                  The Norden bombsight
                  The Minneapolis-Honeywell (M-H) C-1 Autopilot

2. Period: Vietnam era
   Doctrine: Low-altitude, day/night, all-weather precision strike
   Technology: The F-111 Aardvark
                  The Terrain Following Radar
                  The Integrated Navigation/Weapon System Computer

3. Period: Post Vietnam
   Doctrine: Medium altitude, night, high-threat, surgical strike
   Technology: The F-117 Nighthawk
                  Forward/downward-looking Infrared targeting system
                  Automatic pilot
                  Stealth

The results from the analysis of these independent socio-technical systems was then to be compared to establish whether there was an identifiable relationship between humans, machines, and doctrine within the precision strike mission that could inform the discussion surrounding the significance and use of automation in RPA systems.

It soon became apparent that the proposed project suffered from two critical flaws. First, it was far too broad for completion in a single study. Second, no prior research had established a conceptual mutual relationship between humans, machines, and doctrine. Nothing had been done to link them in a systematic fashion that demonstrated how they functioned together as a *socio-technical system*, influencing and shaping each other as reflected in how the humans in the system did their jobs.

The second flaw presented an opportunity—establish a conceptual mutual relationship between humans, machines, and doctrine from a socio-technical system perspective and, as this is an historical study, the logical choice to fix the first flaw was to "begin at the beginning." The

scope of the research was thus narrowed to address the first case only: the high-altitude, daylight precision bombing (HADPB) doctrine, the B-17 four-engined heavy bomber, the Norden bombsight, and the M-H C-1 Autopilot. This study is thus designed to take the necessary first step toward understanding what aircraft operators do—how they perform their jobs, how they accept and use automated machines in those jobs, how those machines influence and shape their professional identities, and how military doctrine shapes and is shaped by human action within the system.

Research Scope

This study examines the creation and initial use of the precision bombing system employed by the United States Army Air Forces (USAAF) during World War II in the opening phase of the Combined Bomber Offensive (CBO) against Germany. It presents that bombing system as a distinctly *socio-technical* entity, constructed of specially trained humans, purpose-built automated machines, and the HADPB doctrine, all of which mutually shaped each other's creation and use. The study establishes the relationship between the HADPB doctrine and the humans and machines chosen to execute it by examining first the structure of the system, presenting it as a three-level socio-technical system, describing the socio-technical elements at each level, how the system was designed to be used, including the primary automated machines involved, and how it was actually used in practice. It then examines the actions and tasks performed by the three principal socio-technical elements of the heavy bomber crew—the pilot, the navigator, and the bombardier—describing and analyzing the professional construct and creation of the individual human crewmembers, the machines that shaped their professional identities, how those humans and machines accomplished the necessary tasks associated with the precision bombing mission—flying, navigating, and bombing—and how the HADPB doctrine affected their creation and use.

The decision to examine this particular case is appropriate beyond the fact that it is the first chronologically. The HADPB doctrine was the USAF's first clearly developed and expressed doctrine. Its development and execution served as the basis for the decision to separate the USAF from the U.S. Army after the war and create a separate air force, and the

doctrine itself is central to the organization's cultural self-identity to this day.[18] Understanding how doctrine affects technological choice and human action in the USAF *requires* an examination of HADPB doctrine.

The four-engined bomber is appropriate for the study because its crew performed all of the tasks within the precision bombing mission accomplished in all past and present USAF precision strike aircraft systems—flying to the target, navigating to the target, and bombing the target. Additionally, it was in these aircraft that those roles were first performed by separate human-machine elements. For this study, I have chosen to examine the B-17 Flying Fortress as the particular aircraft system. Although the United States built more B-24s during the war, B-17s saw more action in the early phase of the CBO that is under examination, and it possesses an iconic status and is perhaps the best-known aircraft flown during the war.[19] The B-17 was also the first aircraft equipped with the Norden bombsight and the M-H C-1 Autopilot, the two principal automated machines addressed in this study. Additionally, there is no evidence that indicates that the experiences of the B-24 crewmembers were appreciably different from that of the B-17 crewmembers, thus we can generalize any conclusions drawn across the systems.

The Norden bombsight and the M-H C-1 Autopilot were two of the first automated machines to get wide use in military aviation and tied tightly to the HADPB doctrine. The Norden bombsight is the forefather of the precision targeting systems presently in use in combat and was the first fielded bombsight with an automatic bomb release mechanism. Its precision bombing capacity to put a bomb "in a pickle barrel" from 20,000 feet was the critical capability at the ideological center of the HADPB doctrine. The M-H C-1 Autopilot requires examination, because it was the key machine that made the Norden bombsight as accurate as it was, and it had a significant impact on the professional existence of both the bomber pilot and bombardier. Also, the autopilot is the machine that enables the RPA to perform its mission without an

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[18] Some argue that the HADPB doctrine was actually the last clearly expressed USAF doctrine, as well. Its long-term effect on the USAF structure diminished as mission emphasis shifted away from strategic attack, but it remains a foundational element is the service's identity. See Carl H. Builder, *The Icarus Syndrome: The Role of Air Power Theory in the Evolution and Fate of the U.S. Air Force* (New Brunswick, NJ: Transaction Publishers, 1994); James Mowbray, "Air Force Doctrine Problems: 1926-Present," *Airpower Journal* VIV (Winter 1995), no. 4 (1995).

[19] The United States built 12,692 B-17s and 18,190 B-24s during the war. I. B. Holley, Jr., *Buying Aircraft: Matériel Procurement for the Army Air Forces* (Washington, DC: Office of the Chief of Military History, Dept. of the Army, 1964), Table 11, p. 550.

operator on board the aircraft, thus understanding its historical context is essential for extending this study to the present day issue.

The human elements chosen for study include the pilot, the navigator, and the bombardier. The bombardier and pilot were obvious choices, as they operated the two primary automated machines mentioned above. The navigator was not initially included, as at the start of World War II there was no automated machine associated with navigation. However, navigation is a technology-dependent, critical task accomplished within the bombardment system, and looking beyond World War II has been the subject of much automation. Additionally, it soon became apparent that limiting the definition of automation to *mechanical or electrical* automation neglected this key part of the bombardment system from a socio-technical perspective, as the maps, charts, and forms used by the navigator played a key role in mechanizing both navigation and the navigator, thus making the navigator worthy of inclusion.

Notably absent from this study is consideration of the use of radar in the precision bombing mission. During the later stages of World War II, radar emerged as an integral part of the precision bombing system as well as the Allied and German air defense systems, but those who created the HADPB doctrine during the 1930s were unaware of its existence when they developed the formation tactics that were integral to the doctrine. They constructed the HADPB doctrine for visual bombing only, and did not consider the potential effect that early warning radar or radar-aided anti-aircraft gun systems might have on the German ability to defend against bomber attacks.[20] The tasks, roles, and machines examined in this study were developed specifically for visual bombing, and when radar was introduced, it changed significantly the tasks accomplished by both the bombardier and the navigator. Examination of that change is the next logical step in the longer-term effort to determine how humans use machines and how machines shape human actions and professional identity.

When addressing a topic as broad as this, even with the stated limitations, it is important to include what the study *is not.* It is not a history of the Combined Bomber Offensive. That

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[20] Well after the war, Major General Heywood Hansell, one of the principal architects of the HADPB doctrine, was quoted as saying "If our air theorists had had knowledge of radar in 1935, the American doctrine of strategic bombing in deep daylight penetrations would surely not have evolved." See Thomas H. Greer, *The Development of Air Doctrine in the Army Air Arm, 1917-1941* (1985. Reprint, Office of Air Force History, U.S. Air Force, 1953), 60. For more on the impact of radar on the course of World War II, see Robert Buderi, *The Invention That Changed the World: How a Small Group of Radar Pioneers Won the Second World War and Launched a Technological Revolution* (New York: Simon & Schuster, 1996).

history has been written many times, with the best effort made in 1970 by author Noble Frankland in his classic book *Bomber Offensive*.[21] It is also not an account of all of the American bombing operations during the war. The opening phase of the CBO, prior to the introduction of radar, was chosen as it was the clearest expression and execution of the HADPB doctrine as developed before the war, although the air campaign in the Pacific shared similarities with the CBO in Europe.[22]

Although it is a sequential examination of the major tasks that the pilot, navigator, and bombardier accomplished during the mission, as related to the primary machines under consideration, this study is not an end-to-end narrative of a bombing mission. Nor are the actions and events examined taken from the same mission. The sequence and actions are assembled from numerous sources from official directives and histories to personal interviews and narratives to construct a "typical" picture of what the crew accomplished during a bombing mission. Each chapter, however, does open with a narrative from a single mission, Mission #111, flown against targets in and around the city of Bremen on 8 October 1943, told from the perspective of the subject under examination in that chapter to set the appropriate context for the discussion.

The study is also not a human-centric tale of the strong social relationship that developed between the members of the bomber crew during the highly-charged, emotional atmosphere of the bombing campaign, although that is an essential part of the experience of the men who fought in the CBO. Again, many authors have provided excellent accounts along these lines, including Donald Miller's outstanding *Master's of the Air: America's Bomber Boys Who Fought the Air War Against Nazi Germany*, and Stephen Ambrose's *The Wild Blue: The Men and Boys Who Flew the B-24s Over Germany, 1944-45*.[23] While this study in no way minimizes the very human context of aerial warfare, it instead concentrates on the relationship between the crewmember, his machine, and the HADPB doctrine.

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[21] Noble Frankland, *Bomber Offensive: The Devastation of Europe* (New York: Ballantine Books, 1970).

[22] For more on the airpower war in the Pacific Theater, see Alvin D. Coox, "Strategic Bombing in the Pacific, 1942-1945," in *Case Studies in Strategic Bombardment*, ed. R. Cargill Hall (Washington, DC: Air Force History and Museums Program, 1998), 253-382.

[23] Donald L. Miller, *Masters of the Air: America's Bomber Boys Who Fought the Air War Against Nazi Germany* (New York: Simon & Schuster, 2006); Stephen E. Ambrose, *The Wild Blue: The Men and Boys Who Flew the B-24s Over Germany 1944-45* (New York: Simon & Schuster, 2002).

Theoretical Foundations

This research and analysis for this project draws upon several bodies of literature, including the sociology of scientific knowledge, human factors engineering, and science and technology studies. These bodies of literature provide the theoretical building materials that enable us to understand the nature of military doctrine as a social construct and establish its relationship to the humans and machines that physically make up the socio-technical bombing system. They also provide insight into how humans and machines interact in socio-technical systems and understand the relationship between them.

Doctrine is to military operations what scientific theory is to academic research. Each provides the intellectual foundation upon which practitioners pursue and build new capability or knowledge. Scientific theory is the accepted knowledge, or paradigm, that leads a coherent group of practitioners through the exploration of 'normal science.' It defines the art of the possible and acceptable, firmly guiding the research direction and objectives of the adhering community of practitioners.[24] Rooted in the sociology of scientific knowledge, this perspective reveals that theory is a fundamentally social construct, subject to the acceptance and approval of the dominant scientific group. Similarly, doctrine is a socially constructed body of knowledge, supported and advanced by the dominant military community of practice that guides the conduct of military operations. Just as important, it guides how the community of practice considers new problems and defines the field of acceptable solutions, which consequently affects what methods and technologies are acceptable to implement those solutions.

The relationship between doctrine and technology is a subject well explored by historians, with a general focus on the failures associated when the two are not harmonized, or how one shapes the development of the other.[25] Political scientists, likewise, have explored the relationship, but generally within the larger context of organizational behavior, international

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[24] Ludwik Fleck, *Genesis and Development of a Scientific Fact* (Chicago, IL: University Of Chicago Press, 1981); Kuhn, *The Structure of Scientific Revolutions*; Edward W. Constant, *The Origins of the Turbojet Revolution* (Baltimore: Johns Hopkins University Press, 1980).

[25] I. B. Holley, Jr., *Ideas and Weapons: Exploitation of the Aerial Weapon by the United States During World War I: A Study in the Relationship of Technological Advance, Military Doctrine, and the Development of Weapons* (1953. Reprint, Washington, DC: Office of Air Force History, 1983); Builder, *The Icarus Syndrome*; I. B. Holley, Jr., *Technology and Military Doctrine: Essays on a Challenging Relationship* (Maxwell Air Force Base, AL: Air University Press, 2004); Stephen L. McFarland, *America's Pursuit of Precision Bombing, 1910-1945* (Washington, DC: Smithsonian Institution Press, 1995); Martin L. Van Creveld, *Military Lessons of the Yom Kippur War: Historical Perspectives* (Beverly Hills, CA: Sage Publications, 1975).

relations, or innovation.[26] What remains unexplored is how doctrine shapes not only the technologies chosen, but how the humans in the system use them. This human-machine relationship reveals itself in the way that humans share tasks with machines based upon expertise—how they work together to accomplish their mission, and central to this is the concept of humans and machines working together within a *socio-technical system*.

Human factors engineering, which grew out of scientific management and cybernetics theory, examines the human-machine relationship through a systems approach, focusing on the physical and cognitive interface between the humans and machines.[27] However, the strong tendency toward modeling humans within the system as uniform elements avoids the 'messy' social inputs, outputs, and artifacts, cloaking the impact that professional identity or organizational cultures have on the way that operators use or view machines. However, as modern systems have incorporated more automation, new understandings of how humans and machines relate have progressed beyond simplistic work models. The concepts of shared and supervisory control, where humans and machines share tasks based upon their particular expertise evoke a more cooperative relationship, with all elements working together toward a common goal.[28] In spite of this advance in concept, human factors still generally underplays the social effect of the increased use of automation to perform tasks and skills that have traditionally been hallmarks of highly-skilled professionals, such as aviators. There is also a tendency in this field to "black box" a machine, and neglect its own social structure—the designer's ideas and beliefs embodied in the final design that influence how and why the machine is used.

Opening up that socio-technical "black box" is central to this study's examination of the bombardment system. To open the box and examine its contents, we turn to theorists in the Science, Technology, and Society (STS) field, who examine the creation of knowledge. STS

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[26] Stephen Peter Rosen, *Winning the Next War: Innovation and the Modern Military* (Ithaca, NY: Cornell University Press, 1991); Barry Posen, *The Sources of Military Doctrine: France, Britain, and Germany Between the World Wars* (Ithaca, NY: Cornell University Press, 1984); Owen Coté, "The Politics of Innovative Military Doctrine: The U.S. Navy and Fleet Ballistic Missiles" (Ph.D. Thesis, Massachusetts Institute of Technology, 1996).

[27] Frederick Winslow Taylor, *The Principles of Scientific Management* (New York: Harper & brothers, 1911); Norbert Wiener, *Cybernetics: Or, Control and Communication in the Animal and the Machine*, 2nd ed. (Cambridge, MA: MIT Press, 1965); Thomas B. Sheridan, "The System Perspective," in *Human Factors in Aviation* (San Diego, CA: Academic Press, 1988), 27-50.

[28] Thomas B. Sheridan, *Telerobotics, Automation, and Human Supervisory Control* (Cambridge, MA: MIT Press, 1992); Raja Parasuraman, Thomas B. Sheridan, and Christopher D. Wickens, "A Model for Types and Levels of Human Interaction with Automation," *IEEE Transactions on Systems, Man and Cybernetics, Part A: Systems and Humans* 30, no. 3 (May 2000): 286-297.

scholars investigate the social construction of scientific and technological knowledge, exposing the assumptions, negotiations, trades, compromises, and physical realities and limitations that distinctly mold the technology's form and make it a social object.[29] They examine the whole of the socio-technical system, refusing to acknowledge any separation of the social and technical, emphasizing the influence of context and culture on the development and use of technology.[30] It is a system construct that does not unnecessarily privilege the human over the technical, but one that enables a clearer understanding of how the elements function as a system, sometimes working together and other times at odds with each other. It is STS that enables us to construct a socio-technical system that extends beyond human and machine, incorporating the doctrine that unifies the bombardment system under examination.

Method and Structure

As an historical study covering the development of a socio-technical system comprised of several interdependent doctrinal, human, and machine elements, several options present themselves for organization. One approach is to structure it in the order described and examine first the doctrine, then the human bomber crewmembers, and then the machines that they used. This approach, however, serves poorly the very interdependent nature of those elements that is under examination. A second option, the one chosen, is to organize the study by the *tasks* accomplished during a precision bombing mission—*flying, navigating, and bombing*—but first address the doctrine that defined the tasks, then the tasks individually by looking at the humans and machines that together accomplished them. This approach lends itself more readily to a logical discussion of the bombardment system from its structure through its employment, and as such the entire project consists of six chapters, including this introduction, broken down as follows.

Chapter 2 examines the doctrinal creation and structure of the socio-technical bombardment system built by the U.S. Army Air Corps after World War I and used by the USAAF in the opening phase of the CBO against the Germans during World War II,

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[29] Bruno Latour and Steve Woolgar, *Laboratory Life: The Construction of Scientific Facts* (Princeton, NJ: Princeton University Press, 1986); Bruno Latour, *Science in Action: How to Follow Scientists and Engineers Through Society* (Cambridge, MA: Harvard University Press, 1988).

[30] Latour and Woolgar, *Laboratory Life*; Donald A. MacKenzie, *Inventing Accuracy: An Historical Sociology of Nuclear Missile Guidance* (Cambridge, MA: MIT Press, 1990); Donald A MacKenzie, *Mechanizing Proof: Computing, Risk, and Trust* (Cambridge, MA: MIT Press, 2001).

concentrating on the intermediate and highest levels of the system.[31] It presents the bombardment system as a set of interdependent human, machine, and doctrinal socio-technical elements that all worked together to accomplish a common purpose, each shaping the function and structure of the others. First, it opens the bombardment system "black box," and defines it as a socio-technical system of interdependent humans, machines, and ideas, describing the role that those ideas serve as military doctrine, the guiding beliefs that shape the humans and machines in military systems, and how doctrine shapes and integrates them. Second, it describes the foundations and structure of the doctrine of High-Altitude, Daylight Precision Bombing (HADPB), exploring how it laid the ideological foundation for the creation of the bombardment system used during World War II. Third, it describes the structure of the bombardment system as a three-layer system, comprised at the lowest level of individual human-machine elements, at the intermediate level of the bomber aircraft, typified by the B-17, and at the highest level of the bomber formation. Finally, it examines how the system, initially employed as intended in accordance with the doctrine, was changed in response to operational realities, and how that change affected the way in which the system was controlled. These concepts lay the foundation for the succeeding chapters.

Chapters 3 through 5 cover flying, navigating, and bombing, describing the historical development of the individual socio-technical elements of the bombardment system—the pilot, the navigator, the bombardier, and their associated machines—and how certain machines and their unique ability to use those machines helped form their professional identities. The actions of each are described and analyzed, focusing on how the human used machines to determine what he really *did* during the mission to accomplish his task, and how those actions were shaped by and shaped the HADPB doctrine. Finally, each chapter draws conclusions about the relationship between the humans, their machines, and the doctrine. There is overlap in these chapters, as each individual human was a member of the bomber crew, itself a socio-technical unit and with extensive interaction between the constituent elements, and it is often not possible to understand the actions of one crewmember outside of the context of the actions of the other crewmembers. Additionally, some of the pertinent machines, the M-H C-1 Autopilot in

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[31] The U.S. Army Air Corps and the U.S. Army Air Forces are the two immediate predecessors of the current United States Air Force. The Air Corps existed from 2 July 1926 to 20 June 1941, when it became the United States Army Air Forces. The USAAF became the USAF on 17 September 1947. This study refers to the organization to as the Air Corps during the period leading up the initiation of the CBO, and to it as the USAAF after the initiation of the bombing campaign.

particular, are relevant to more than one crewmember, and understanding their role in the system requires expanding the discussion beyond the primary crewmember under examination.

Chapter 3 examines the flying and control element of the bombardment system and focuses on the bomber pilot. It describes system control at the single aircraft and larger formation levels as a process of shared control between a specially trained human operator, the pilot, and several humans and machines based upon their unique capabilities. First, it describes the development of the bomber pilot from initial creation as a technical specialist, valued for his flying skill, to a generalist and commander, valued for his skill as a system controller and military commander. Second, it describes the pilot's actions on a bombing mission, exploring the complex nature of controlling the bombardment system at the aircraft and formation levels, and how the doctrine of HADPB and the machines he used to execute that doctrine shaped those actions. Third, it explores how the pilot, as the aircraft commander, shared control with the copilot, navigator, and bombardier to accomplish the mission. Finally, it examines the introduction of the autopilot and the pilot's acceptance of it as a machine that enhanced his command of the aircraft through the ability to share control of the flying task, and how its use created the need for the pilot to develop a new skill set.

Chapter 4 examines the navigation socio-technical element in the bombardment system and focuses on the bomber navigator. It describes aerial navigation on a bombardment mission as a complex, automated process of shared cognition, conducted by a human technical specialist and the unique computational machines and navigational technologies that defined him professionally. First, it describes the creation of the bomber navigator as a single-task, technical specialist, reluctantly accepted as a non-pilot member of the bomber crew only under the demands of the HADPB doctrine and rapid wartime expansion, whose skills were rooted in the tradition of maritime navigation and who was defined by his mastery of a complex set of specialized instruments. Second, it describes aerial navigation as a shared cognitive process, wherein the navigator used purpose-built calculating tools to translate and integrate several sets of diverse data in what Bruno Latour called a "centre of calculation" to build idealized textual, temporal, and spatial models of the bomber mission, which then served as execution-level instructions for the conduct of the mission. Third, it examines the navigator's flight working environment as a second "centre of calculation" and the tools that he used to try to recreate those models in the air to navigate his aircraft to the target of the day. Finally, it examines how the

HADPB doctrine shaped his actions in flight based upon his position in the overall bombing system, and how unique calculating machines mechanized those actions.

Chapter 5 examines the bombing socio-technical element in the bombardment system. It describes bombing as a singular, socio-technical task, accomplished by a human-machine system consisting of a bombsight designed to make up for human shortcomings in real-time integration, calculation, and precision flying, and the bombardier, a specially trained human, defined professionally by his ability to operate that bombsight, whose primary function was to act as an environmental and contextual sensor and interpreter for the bombsight, providing it the data it required to do its job. It examines how the mastery of the bombsight defined the bombardier and created him as a professional being, and how the subsequent evolution of the doctrine of high-altitude, daylight precision bombing (HADPB) dismantled that identity. First, it describes how bombsights developed to make up for the human inability to solve the bomb dropping problem in real-time. Second, it presents the Norden bombsight as the solution to that problem, describing how it developed as a complex mechanical computer that automated as much of the bombing process as possible, how it solved the bomb release point problem by creating an real-time, dynamic analog of the aircraft-target physical relationship, and how its integration with the aircraft autopilot enabled the bombardier to realize that solution. Third, it describes the engineering of the bombardier as a single-task, technical specialist whose professional identity was completely defined by his mastery of the bombsight, how his ability to find, identify, and track the target made him an interdependent part of the socio-technical bombing element, and how his actions were mechanized to enable that element to function during the most high-stress portion of the bombing mission. Fourth, it describes the bombardier's role as an essential cognitive element in the system and how he built visual and mental models that enabled him to interpret the physical environment and provide the bombsight the necessary data to solve the bombing problem. Finally, it examines how the HADPB doctrine and drop-on-leader formation bombing largely dismantled the bombardier as a professional entity by requiring that his unique professional skill exist only in one small part of the overall bombardment system. Chapter 6 concludes the study, drawing general conclusions from the previous four chapters and forecasting them forward, laying the groundwork for the next phase of the research.

Sources

This study drew on research from both primary and secondary sources. Archival work was done at the U.S. Air Force Historical Research Agency (AFHRA), the National Museum of the United States Air Force, the archives of the Mighty Eighth Air Force Museum, the digital archives of the National Archives and Records Administration, the Rutgers University Oral History Archives of World War II, the 390th Bomb Group Museum, the Office of the Air Combat Command Historian, and the Office of the Air Force Materiel Command.

Research regarding the development of the HADPB doctrine and the structure of the bombardment system draws mostly upon primary sources, including the original writings of early airpower theorists, foundational Army Air Corps doctrine documents, the *Bombardment Aviation* instructional texts used at the Air Corps Tactical School (ACTS) during the two decades between World Wars I and II, and interviews with and memoirs written by USAAF officers who developed, evolved, and executed the doctrine. Much has been written about the HADPB doctrine, assessing both its validity and effectiveness, but quite often, the foundational ideas that led to its creation are either biased or misrepresented, leading to inaccurate assessments and erroneous conclusions.[32] The early theorists' writings were particularly valuable, as they provided an undistorted view of how the first airpower visionaries perceived the capabilities of the newest weapon of warfare, enabling us to see how those ideas were realized in both the HADPB doctrine as well as the humans and machines designed to execute it.

The foundational doctrine documents and the instructional texts were valuable, as they captured the state of airpower thought at the time, and also reflected what was taught to airpower practitioners. They, of course, represent the institutional view of what airpower practice *should* be, and are not necessarily a perfect reflection of what those who actually practiced it thought. However, it was the institution as a whole that went to war, and the ideas captured within these sources were the dominant influence on how the individuals executed their mission. The oral histories and personal memoirs rounded out the institutional view, illuminating the process of doctrinal adaptation to the realities of warfare, providing the depth and color to the debate that surrounded that process, and how the doctrine changed with experience. These sources,

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[32] Distortions are frequently found in writings that wish to address the "morality" of the bombing campaigns against Germany and Japan, portraying them as bombing campaigns against the civilian populations. See A. C Grayling, *Among the Dead Cities: The History and Moral Legacy of the WWII Bombing of Civilians in Germany and Japan* (New York: Walker & Co, 2006).

however, present their own biases and distortions, as they were written and told by men concerned with their own personal legacies and the perception of their roles and actions in a very contentious military campaign. Personal rivalries between participants also colored their perceptions, and great care was taken to verify claims of thought or action with multiple sources.

Research on the pilot, navigator, and bombardier draws on both primary and secondary resources. Primary sources included official directives, training, and instructional manuals that described what each crewmember did and was responsible for during a bombing mission. These official documents provided the structure for the model of the human action, but again, presented what each crewmember was *supposed* to do. The actual actions of the humans participating in the bombing missions were sure to vary, but overall, these documents defined their tasks and responsibilities most thoroughly, and linked them to the overall mission purpose. Bomber crewmember memoirs, oral histories, and videotaped interviews provided the personal element and color lacking in the official manuals and rounded out the official description of their tasks. These sources provided the personal perspective, illuminating the professional and social relationships that the bomber crewmembers had with each other as well as with the machines that they used to accomplish their jobs.

Secondary source research included several Air Force Historical Studies, many written very soon after the events that they described using primary source data. These studies provided excellent focused summaries and access to data that otherwise scattered through multiple locations and archives, and the quality of the research that went into them is generally outstanding. Also used were several well-researched volumes written by Roger Freeman, *the* expert on Eighth Air Force Operations in Europe during World War II.[33] His work has proven beyond reproach and provided an excellent foil against which to compare other works for both accuracy and content.[34]

The written memoirs, oral histories, and interviews used for research during this study deserve a final, separate comment. There is no shortage of published personal memoirs covering the bombing campaign during World War II, the AFHRA, the Mighty Eighth Air Force

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[33] The archives at the Mighty Eighth Air Force Museum in Savannah, Georgia, are named in honor of Roger Freeman.

[34] See Roger A. Freeman, *The Mighty Eighth: Units, Men and Machines (A History of the US 8th Army Air Force)* (Garden City, NY: Doubleday and Company, Inc., 1970); Roger A. Freeman, *The Mighty Eighth War Manual* (London: Jane's Publishing Company, Ltd, 1984); Roger A. Freeman, *The Mighty Eighth War Diary* (Motorbooks Intl, 1990); Roger A. Freeman, *B-17 Fortress at War* (London: Ian Allen Ltd, 1977).

Museum, and the Rutgers University Oral History Archives of World War II all have extensive collections of oral histories recorded by veterans of the CBO, and in recent years, individual bomb group associations have flourished and made great efforts to capture the history and experiences of the men who fought in those units during World War II, recording and transcribing hundreds of videotaped interviews with these veterans. These sources vary greatly in quality, but virtually all share one characteristic—they *do not* describe what the author or interviewee was actually doing during the mission. It is infrequent that one describes in any detail the seemingly mundane individual actions necessary for performing the mission that are of interest for this study. More often, they relate stories that revolve around the bomber crew and the experiences that they shared—how they fought, killed, and died together. They capture, better than any other source, the sharp, personal, and visceral nature of aerial combat, and prevented this study from becoming a sterile, distanced examination of some event in the distant past, defined only by words printed on dusty pages.

This research study is necessarily incomplete, but provides the intellectual groundwork for the discussion surrounding the increased use of automation in warfare. It is only the first step, but contributes to the fuller understanding of how human operators in other highly technical systems are affected by the adoption of automated machines, particularly those associated with strong professional identities, dominant organizational culture, or potent guiding doctrine or theory, such as commercial aviation, manned spaceflight, or undersea exploration.

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Chapter 2

Assembling the Socio-technical—The Birth and Structure of the Bombardment System

8th Air Force Mission Number 111: Bremen

     Friday, 8 October 1943. The beginning of "Black Week." The 8th Air Force launched 399 heavy bombers from the 1st, 2nd, and 3rd Bombardment Wings from over a dozen air bases scattered around England, destined for targets around the German cities of Bremen and Vegesack in one of the largest Combined Bomber Offensive missions to date. The B-17s from the 3rd Bombardment Wing, each flown by a crew of specially trained aerial warriors, assembled over the English town of Lowestoft, first into Squadrons, then Groups, and finally into the massive 3rd Combat Wing, before they departed for the European continent on time, precisely as planned.

     Led by the crew of B-17 42-3393, Just-A-Snappin', *of the 100th Bomb Group's 418th Bomb Squadron out of Thorpe Abbots, England, the 3rd Bombardment Wing flew over the English Channel in near-perfect formation toward the island of Borkonny, where they would enter the European continent. The Luftwaffe launched several waves of fighters to challenge the massive bomber force, but most were intercepted by the 274 P-47 Thunderbolt escort fighters accompanying the formation for defensive protection. As the three Combat Wings turned over Borkonny toward Bremen, however, the German defensive anti-aircraft flak batteries came to life, and began to batter them.*

     Crossing the Initial Point for the bomb run over the city of Emden, the Wings split into individual Combat Box formations for the bomb run. Ahead, the bomber crews could see black flak clouds ahead, hovering above the city of Bremen, and the bomber pilots tucked their aircraft more tightly into the formation, decreasing the distance between aircraft to mere few feet, while the bombardiers prepared the bomb run. Stricken by the flak, several bombers fell enroute to the target, many taking their crews with them to the unforgiving ground below. In a span of eight minutes over Bremen, the 3rd Wing B-17s dropped 130 tons of bombs on their targets, many scoring direct hits. During that time, the anti-aircraft fire intensified and struck several more bombers, including the lead aircraft, Just-A-Snappin', *which could not maintain the pace and fell out of formation.*

     Following the attack, the formations turned west for their unescorted return trip to England, and as the P-47s had already left short of fuel, they had to fend for themselves against successive waves of attacking defensive fighters. Although they shot down several, the fighters soon shifted their attention to the wounded, straggling bombers that could not keep up, and destroyed several more as they struggled to get home. When the survivors finally returned to England, the 8th Air Force leadership evaluated the results. The mission was a success, as the bombers had accurately dropped 544.74 tons of bombs on their targets, and the crews claimed to have shot down 167 enemy aircraft and damaged 85 more. But that success had come at a significant cost. Thirty bombers were destroyed, including Just-A-Snappin', *and 236 more suffered significant damage. Four men were known dead, 56 wounded, and another 301 missing in action, last seen as their aircraft went down in flames. Nevertheless, the next day, they took to the skies once again, destined for new targets in their bombing campaign against Germany.*[1]

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[1] Adapted from Edward Jablonski, *Flying Fortresses: The Illustrated Biography of the B-17s and the Men Who Flew Them* (Garden City, NY: Doubleday & Company, Inc., 1965), 184-195; Frank D. Murphy, *Luck of the*

Introduction

      This chapter examines the doctrinal creation and structure of the socio-technical bombardment system built by the U.S. Army Air Corps after World War I and used by the U.S. Army Air Forces (USAAF) in the opening phase of the Combined Bomber Offensive (CBO) against the Germans during World War II, concentrating on the intermediate and highest levels of the system.[2] It presents the bombardment system as a set of interdependent human, machine, and doctrinal socio-technical elements that all worked together to accomplish a common purpose, each shaping the function and structure of the others. First, it opens the bombardment system "black box," and defines it as a socio-technical system of interdependent humans, machines, and ideas, describing the role that those ideas serve as military doctrine, the guiding beliefs that shape the humans and machines in military systems, and how doctrine shapes and integrates them. Second, it describes the foundations and structure of the doctrine of High-Altitude, Daylight Precision Bombing (HADPB), exploring how it laid the ideological foundation for the creation of the bombardment system used during World War II. Third, it describes the structure of the bombardment system as a three-layer system, comprised at the lowest level of individual human-machine elements, at the intermediate level of the bomber aircraft, typified by the B-17, and at the highest level of the bomber formation. Finally, it examines how the system, initially employed as intended in accordance with the doctrine, was changed in response to operational realities, and how that change affected the way in which the system was controlled. These concepts lay the foundation for the succeeding chapters.

Draw: Reflections on the Air War in Europe (Trumbull, CT: FNP Military Division, 2001), 141-142; Harry Crosby, *A Wing and a Prayer: The "Bloody 100th" Bomb Group of the U.S. Eighth Air Force in Action Over Europe in World War II* (New York: Harper Collins Publishers, 1993), 127-135; "Black Week - Bremen", n.d., http://www.100thbg.com/mainpages/history/history4/bw_bremen.htm, accessed 26 December 2010; *Combat Chronology, 1941-1945* (Washington, DC: Center for Air Force History, 1991), 199; Ian L. Hawkins, *B-17s over Berlin: Personal Stories from the 95th Bomb Group (H)* (Brassey's Inc, 1995), 170-171; Roger A. Freeman, *The Mighty Eighth War Diary* (Motorbooks Intl, 1990), 123; Arthur B. Ferguson, "POINTBLANK," in *The Army Air Forces in World War II, Vol. 2-Europe: Torch to Pointblank*, ed. Wesley Frank Craven and James Lea Cate (Washington, DC: 1983. Reprint, Office of Air Force History. Originally published Chicago: University of Chicago Press, 1949), 695.

[2] The U.S. Army Air Corps and the U.S. Army Air Forces are the two immediate predecessors of the current United States Air Force. The Air Corps existed from 2 July 1926 to 20 June 1941, when it became the United States Army Air Forces. The USAAF became the USAF on 17 September 1947. This study refers to the organization to as the Air Corps during the period leading up the initiation of the CBO, and to it as the USAAF after the initiation of the bombing campaign.

The Colossal Network of Machines and Objects

The Anglo-American CBO conducted against the Axis powers in Europe during World War II, one of the largest single military campaigns of the war, was the result of a Herculean effort in the air and on the ground. Begun in September 1939 by the British Royal Air Force (RAF) Bomber Command and joined in August 1942 by the USAAF 8th Bomber Command, later 8th Air Force, it lasted through the German surrender in May 1945, a total of 973 days. During that period, American forces employed a revolutionary new bombardment system that paired the most advanced four-engined bomber aircraft in the world with the most accurate high-altitude bombsight available, flying more than 410,000 effective sorties and dropping over 1,000,000 tons of bombs on enemy targets in the European Theater of Operations (ETO), the Mediterranean, and North Africa.[3] To field the machines necessary to execute the CBO and the bombing campaign in the Pacific theater, the United States devoted 40 percent of its war production to aircraft, building almost 34,000 heavy bombers between 1940 and 1945, almost 13,000 of them Boeing B-17s, as well as an estimated 52,000 precision Norden bombsights.[4]

The heavy, four-engined bomber, best represented by the Boeing B-17, and the Norden bombsight formed the technological centerpiece of the USAAF bombardment system, creating a dominant view of a distinctly American technological method of warfare. Historian Timothy Moy described it thus:

> Broadly conceived, the bomb delivery system was a colossal network of machines and objects, including bombs, bomb racks, defensive machine guns, radios, navigational slide rules, and insulated flight clothing—not to mention the production engineering needed to manufacture all that hardware. At its simplest level, the system consisted of a relatively fast, high-altitude, long-range airplane, and a precise optical bombsight.[5]

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[3] Richard G. Davis, *Bombing the European Axis Powers: A Historical Digest of the Combined Bomber Offensive, 1939-1945* (Maxwell Air Force Base, AL: Air University Press, 2006), 565.

[4] I. B. Holley, Jr., *Buying Aircraft: Matériel Procurement for the Army Air Forces* (Washington, DC: Office of the Chief of Military History, Dept. of the Army, 1964), Table 11, p. 550; Davis, *Bombing the European Axis Powers*, 33; Albert L. Pardini, *The Legendary Secret Norden Bombsight* (Atglen, PA: Schiffer Military History, 1999), 342. The bomber production numbers include B-17, B-24, B-29, and B-32 aircraft. The bombsight total includes production for both the Army Air Forces and the United States Navy.

[5] Timothy Moy, *War Machines: Transforming Technologies in the U.S. Military, 1920-1940* (College Station: Texas A & M University Press, 2001), 33. Russell Weigley discusses the American use of airpower technology during World War II as representative of the American way of war. See Russell Frank Weigley, *The American Way of War: A History of United States Military Strategy and Policy* (New York: Macmillan, 1973).

This focus on the system as machines, however, limits a true appreciation of its extent. Certainly, there were dominant machine elements. The B-17 aircraft and the Norden bombsight are two of the most well known machines used during the war outside the atomic bomb. But what of the men who operated those machines? The United States trained over 27,000 crews, most of which consisted of ten men each, to fly the bombers and operate the bombsights.[6] The CBO took a large human toll, and during its execution in the ETO alone over 24,000 men were killed and another 38,000 were wounded or went missing. By way of comparison, 19,733 United States Marines lost their lives during the entire war in *both* the European and Pacific theaters of operations.[7] Surely, the crews who operated the bombers and bombsights were a part of the bombardment system. Just as significantly, what of the doctrine, that set of codified beliefs that encompassed the philosophy and principles of warfighting that brought human and machine together into this massive system?

Viewing the USAAF bombardment system only as a collection of technological objects that, given a certain task operate together to complete it, fails to capture the true makeup and complexity of the system. This "black boxing," drawing a line around the most visible and identifiable elements of the system, the bomber aircraft and the bombsight, greatly oversimplifies it, placing at risk any attempt to understand its operation or role in a larger context. To truly understand the system, we must open the black box and examine *how* the system was designed, *why* it was designed the way that it was, and *who* designed and operated it.[8]

Opening the "Black Box"—The Socio-technical and the Bombardment System

The first step toward opening the black box of the bombardment system and examining its contents is defining what the system should include. Noted systems thinker Russell Ackoff broadly defined a system as "*any entity, conceptual or physical, which consists of interdependent*

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[6] Jerry White, *Combat Crew and Unit Training in the AAF: 1939-1945*, Army Air Forces Historical Study 61 (Washington, DC: Air Historical Office, Army Air Forces, August 1949), 29.

[7] Davis, *Bombing the European Axis Powers*, Table 4, p. 586; "Marine Corps Casualties," *United States Marine Corps History Division*, 2010, http://www.tecom.usmc.mil/HD/Frequently_Requested/Casualties.htm (accessed 19 January 2011).

[8] The concept of opening the black box of a technology or system to examine the ideas, concepts, beliefs, and assumptions that shaped its creation comes from French sociologist and anthropologist. He advances that this is the only way to really understand not only the system, but also the outputs that it produces. See Bruno Latour, *Science in Action: How to Follow Scientists and Engineers Through Society* (Cambridge, MA: Harvard University Press, 1988), 2-4.

parts."[9] Systems exist in many forms, including philosophical systems, mechanical systems, communication systems, and many more. All share the characteristic that they have interdependent elements that influence each other in the process of producing an outcome. Of particular interest for defining the bombardment system used during the CBO is the human-machine system—a human-controlled collection of interdependent humans and machines that uses machines in a significant way in order to achieve its objectives.[10] By inspection, the collection of aircraft, bombsights, and the human operators who used them to bomb German targets during World War II certainly qualifies as a human-machine system. However, even that definition remains incomplete, and by applying the system concept more thoughtfully, we may construct a more thorough description of that bombardment system.

Ackoff advanced that a human-machine system is a specific type of *behavioral system*, one that can display activity and where "the outcome of its behavior is conceptualized as the product of the interaction of its parts."[11] As production of an outcome is an integral part of the definition of the human-machine system above, we may extend the system boundaries to encompass *any* part that affects the outcome of the system as the result of *intentional* or *preconceived* interaction. In other words, a human-machine behavioral system includes anything that, by design or intent, affects the behavior or output of the system as a whole. As such, a distinct set of ideas or principles that intentionally shapes the purpose, structure, or use of a set of interdependent parts must itself be included within the boundaries of a system.

The ideas and principles that shape the purpose, structure, or use of a human-machine system are a distinctly *social* construct, in that they embody the beliefs and knowledge of the human group that defined them. To borrow from Walter Vincenti, what a distinct human social group *does* depends upon what it collectively *knows*.[12] Those beliefs, however derived, thus influence the interaction of the parts of the system and the behavior of the system overall. Similarly, they are open to modification based upon system performance and any learning that may ensue. The inclusion of these ideas and principles, then, changes the nature of the human-machine system from merely one within which humans use machines in a significant way to

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[9] R. L. Ackoff, "Systems, Organizations, and Interdisciplinary Research," in *Systems Thinking: Selected Readings*, ed. F. E. Emery (Harmondsworth: Penguin, 1969), 332.

[10] Ibid., 333.

[11] Ibid., 332.

[12] Walter G. Vincenti, *What Engineers Know and How They Know It: Analytical Studies from Aeronautical History* (Baltimore: Johns Hopkins University Press, 1990).

produce an outcome to a *socio-technical* system, within which humans and machines work together in a manner shaped by the beliefs and knowledge of the social group that defined the system's purpose, structure, and use.

The USAAF bombardment system was a distinctly socio-technical system. Although the term "weapon system" was decades from use when the Air Corps began building bombers and bombsights and training humans to use them in the 1920s, the human-machine system relationship between them is clear. Aerial bombardment was simply not possible without bombers and bombsights, and the machines themselves were useless without trained humans to operate them. However well designed, manufactured, and trained, though, this human-machine system was incomplete without a binding focus and purpose that brought all of the human and machine elements into a coherent whole. That binding and focus evolved as bombardment *doctrine,* the set of guiding precepts and knowledge that shaped not only the purpose and objective of the bombardment system, but the actual physical and cognitive construction of the system, as well as how the humans and machines in the bombardment system acted and interacted both physically and socially.

Military Doctrine and Shaping the Human Mind

Doctrine is a form of purposive knowledge. It provides a set of intellectual and prescriptive guidelines that address a specific purpose or objective for a particular social or organizational group, which is itself defined by the acceptance of the correctness and authority of those guidelines. Codified into laws and precepts derived from the results of the experience of those in the past, doctrine is "an authoritative rule…(representing) the 'tried and true'…hammered out by trial and error (and) officially recognized as such."[13] As a form of codified knowledge or beliefs sanctioned by adherents as "what is right," doctrine is taught to future generations and provides the guidance for how those adherents act and interact. It is particularly useful where the official codification of sanctioned beliefs or knowledge can provide guidelines that enable a community to achieve a commonly defined purpose.

Military doctrine is a form of doctrine that deals explicitly with military means. Developed primarily by the military services, it is the set of codified beliefs that encompass the

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[13] I. B. Holley, Jr., "The Doctrinal Process: Some Suggested Steps," in *Technology and Military Doctrine: Essays on a Challenging Relationship* (Maxwell Air Force Base, AL: Air University Press, 2004), 7.

"philosophy and principles for waging war *as held by the military* (italics in original)."[14] A powerful tool, military doctrine shapes not only *how* armed forces should conduct warfare, but also how military professionals should *think* about warfare. According to Joint Publication (JP) 1, *Doctrine for the Armed Forces of the United States*, the capstone doctrine publication of U.S. joint armed forces, doctrine "promotes a common perspective from which to plan, train, and conduct military operations. **It represents what is taught, believed, and advocated as what is right** (i.e., what works best) (emphasis in original)."[15] In essence, military doctrine provides a level of intellectual control that enables military forces to focus their thoughts and efforts constructively toward a commonly defined goal.

A critical element of the JP 1 definition is that doctrine is *taught.* The members of the United States' military forces are taught doctrine through a professional education system that ensures that they understand how the United States intends to employ military power when necessary. As they exist in an ever-changing geopolitical context, the military services must certainly adapt their approach toward how to employ military power to that changing context, but the official doctrine taught at these service schools ensures that individual service members understand how their service intends to employ military power in general—it is the way that is understood and accepted as the best at that time.

As it is taught in the service's professional education institutions in a codified form, service doctrine becomes an integral part of the service's culture. It forms the core of the service member's beliefs about their mission. Much in the way that Thomas Kuhn presented the codified scientific facts and laws belonging to a specific scientific tradition of practice as "received beliefs" that shape how that tradition of practice views and interprets the world, service doctrine shapes the service member's view of the world and defines the acceptable realm of ideological and technological solutions available to solve problems.[16]

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[14] Dale O. Smith, *U.S. Military Doctrine: A Study and Appraisal* (New York: Duell, Sloan and Pearce, 1955), 4.

[15] Joint Publication (JP) 1, *Doctrine for the Armed Forces of the United States*, May 14, 2007, ix.

[16] Thomas S. Kuhn, *The Structure of Scientific Revolutions*, 3rd ed. (Chicago, IL: University of Chicago Press, 1996), 4-5, 175. Kuhn's concept of received beliefs is frequently used in a negative sense, as representing a rigid, inflexible credo that dictates and limits creative thought, particularly in reference to the development of the strategic bombing doctrine developed by the Air Corps before World War II. See Thomas J. Green, *Bright Boys* (Natick, MA: A.K. Peters, Ltd., 2010). However, the use in this study is more in line with Kuhn's vision of received beliefs as an intellectual model that shapes thought, orienting it in a particular direction, but not imposing strict, unbreakable limitations.

Doctrine, however, cannot remain effective or relevant if it stagnates and does not respond to experience and change. As it embodies deeply rooted cultural beliefs and ideals, doctrinal change is inherently difficult.[17] However, when experience presents results that demonstrate the ineffectiveness of a particular doctrine and new knowledge is acquired, that doctrine must evolve and incorporate that new knowledge. Radical doctrinal change, though, is rare, as it generally requires a reassessment of an organization's very core beliefs. Change, when recognized as necessary, is more often evolutionary in nature, wherein an organization adapts its beliefs and ideals to incorporate the new knowledge in a way that is acceptable within their existing ideological view of the world.

Doctrinal influence is far reaching in the military. It overtly influences how the individual services prepare for combat, both cognitively and physically. Faced with a given problem, doctrine presents the intellectual framework that guides the creation of the solution. Doctrine is, however, not to be confused with *strategy*. Strategy is concerned with *what* is to be done—achieving certain *ends*. Doctrine involves *how* those ends are going to be met—the *means* used to achieve the ends.[18] As purposive knowledge, it extends beyond just an intellectual framework for how to solve problems. It also guides the creation of the tools used to achieve strategic ends. In 1968, General Curtis LeMay, former Chief of Staff of the Unites States Air Force and architect of the bombing doctrine used during World War II, captured the essence and of military doctrine:

> At the heart of warfare lies doctrine. It represents the central beliefs for waging war in order to achieve victory. Doctrine is of the mind, a network of faith and knowledge reinforced by experience which lays the pattern for the utilization of men, equipment, and tactics. It is the building material for strategy. It is fundamental to sound judgment.[19]

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[17] Harold R. Winton, "On Military Change," in *The Challenge of Change: Military Institutions and New Realities, 1918-1941*, ed. Harold R. Winton and David R. Mets (Lincoln: University of Nebraska Press, 2000), xii.

[18] I. B. Holley, Jr., "The Role of Doctrine," in *Technology and Military Doctrine: Essays on a Challenging Relationship* (Maxwell Air Force Base, AL: Air University Press, 2004), 3.

[19] James Mowbray, "Air Force Doctrine Problems: 1926-Present," *Airpower Journal* VIV (Winter 1995), no. 4 (1995): 1.

Doctrine, as the codified body of beliefs that defines military missions and shapes the thought regarding who and what should execute them, is thus clearly linked to the humans within the organization that adheres to it.

Military Doctrine and Shaping the Technological Ideal

Technology plays a significant role in the development of doctrine. To a great extent, it determines what *can* be done with military force. The clearest example of this is the existence of separate military services within most developed countries' military forces. Each service has a separate, distinct mission within the overall context of the mission of the military service as a whole. They exist largely based upon command of the primary medium in which they operate: air, land, or sea. Control of that medium, as well as the technologies used to gain and exploit that control, are prime concerns for each service. Thus, the methods and technologies by which they gain that control determine how each service views a particular problem, and influence the range of possible solutions that they may produce, and each service "organizes, trains, equips, and sustains" its forces in order to best accomplish its individual mission.[20] Accordingly, each service develops its own doctrine, based on the capabilities individually possessed, and pursues technologies that enable them to execute that doctrine.

While doctrine may significantly affect the type of technology developed by each service and how it *should* be used, it is not a unipolar relationship. The specific characteristics of a technology determine largely *what* it can be used for, and may thus limit doctrinal options. Just as an M-9 automatic pistol does not lend itself to use in nuclear deterrence doctrine, neither do intercontinental ballistic missiles lend themselves to close range, urban combat operations. The type of technology available limits doctrinal options to those achievable within the capabilities of the technologies themselves.

I. B. Holley's landmark study of the United States Army's aviation efforts during World War I, *Ideas and Weapons*, demonstrates that when either doctrinal development outstrips technological capability, or technological development does not respond to doctrinal advance, the effectiveness of military forces suffers. Holley clearly expressed the necessity of a coherent approach to developing *both* technology and doctrine together.

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[20] Barry Posen, *The Sources of Military Doctrine: France, Britain, and Germany Between the World Wars* (Ithaca, NY: Cornell University Press, 1984), 14; Air Force Basic Doctrine, *Air Force Doctrine Document (AFDD) 1*, November 17, 2003, ix.

> Superiority in weapons stems not only from a selection of the best ideas from advancing technology but also from a system which relates the ideas selected with a doctrine or concept of their tactical or strategic application, which is to say the accepted concept of the mission to be performed.[21]

Doctrine and technology are thus inextricably linked. Doctrine may adapt to technological development as new capabilities emerge, or, conversely, technological development may be focused to fulfill a doctrinal vision, as we shall see was the case for the Air Corps' development of precision bombing doctrine and technology before World War II.

The military's codified knowledge and beliefs, doctrine shapes the purpose, structure, and use of military socio-technical systems. It is linked to the human elements of those systems because it shapes both the knowledge and beliefs that drive their behavior. It is linked the technological elements in those systems because it shapes their creation and use. It is thus an integral part of those socio-technical systems. While doctrine must change in response to unfavorable system behavior in order to remain effective, it establishes the initial conditions and requirements for the system's use by defining its purpose as well as the constituent human and machine elements. Any consideration of the interactions between those constituent elements must begin with an examination of the doctrine that helped transform them from separate components into integrated, interdependent parts of a socio-technical system.

High-Altitude, Daylight Precision Bombing—The Construction of Purpose

Doctrine exists at multiple levels. At the highest level, it links theory to practice by defining a system's purpose, its component parts, and how those parts are to be employed writ large. Entering World War II, the United States pursued the doctrine of high-altitude, daylight precision bombing (HADPB) as the primary offensive against Germany while building and preparing sufficient ground forces for an invasion of Europe. Simply put, HADPB envisioned large forces of heavily armed bombers, flown by specially trained aircrews employing precision bombsights attacking vital centers of the German war-making infrastructure in order to destroy

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[21] I. B. Holley, Jr., *Ideas and Weapons: Exploitation of the Aerial Weapon by the United States During World War I: A Study in the Relationship of Technological Advance, Military Doctrine, and the Development of Weapons* (1953. Reprint, Washington, DC: Office of Air Force History, 1983), 14.

their ability to fight. It defined the system purpose (destroy the enemy's ability to fight), the system components (bombers, aircrews, and bombsights), and how they were to be used (attacking vital industrial centers in large force). A controversial doctrine, HADPB evolved at the Air Corps Tactical School (ACTS) during the 1930s in contravention with official U.S. Army doctrine of the period, and was based largely upon theories about the potential effectiveness of strategic bombing and rested upon a very thin base of British experience gained during World War I.

The HADPB doctrine developed in the Air Corps Tactical School (ACTS) during the 1930s. Originally founded on 1 November 1920 as the Air Service Field Officer School at Langley Field, Virginia, it became the Air Service Tactical School the next year and eventually the ACTS in 1926, with the establishment of the Air Corps. Chartered to prepare Air Corps officers for duties and command, the school's curriculum taught the U.S. Army's airpower doctrine, focusing on "the tactics and techniques both of the Air Service and of the other branches of the Army and the Navy."[22]

Ordinarily, doctrine develops as the result of experience and is the embodiment of the "tried and true." However, as the newest form of military power, airpower had been used only during World War I, and then only on a relatively small scale. There was no broad base of experience upon which to build a coherent doctrine, and the ACTS rapidly evolved into a doctrine *development* center, where the instructors generated nascent ideas about how to use airpower and, most significantly, taught them to the students. As such, the ACTS became a de facto brain trust and the instructors held a unique and powerful position, able to develop new ideas and convey them directly to the Air Corps' future leaders, often without oversight from, and in direct contravention with, their parent organization, the U.S. Army.

The history of the development of official Army airpower doctrine after World War I is extremely complex and is complicated by the very public efforts of many airmen, most notably Brigadier General William "Billy" Mitchell, to force the United States government to establish a military air arm separate from the Army or Navy, and is beyond the scope of this study. However, an examination of the ideas that led to the creation of the bombardment system used during World War II is instructive, as it explains how that system was constructed, the role of

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[22] Robert T. Finney, *History of the Air Corps Tactical School: 1920-1940* (Washington, DC: Air Force History and Museums Program, 1998), 8-11.

precision bombing in the system, and how and why the component human and machine elements were developed.[23]

HADPB doctrine evolved at the ACTS out of the ideas of Italian airpower theorist Giulio Douhet and the American and British experience during World War I. Douhet, an Italian artillery officer born in 1869, was the first airpower theorist. He formed his ideas on airpower during World War I, and published them in his landmark treatise on airpower, *The Command of the Air*, in 1921. Douhet recognized that airplanes had the potential to significantly change the way that nations would fight wars in the future. He developed and advanced his theories in an effort to build a case for a national air force, independent of the control of his nation's army, believing that airpower's true potential could not be realized if it remained under the control of those concerned primarily with the employment of ground forces. The desire for an independent air force pushed Douhet's ideas to extremes, and criticism of them is abundant. However, he remains perhaps the most significant airpower theorist of all, as most of his successors used his ideas, knowingly or not as the basis of their own theories or as the point of departure for their own thoughts.[24]

Douhet realized that the airplane could have a revolutionary effect on warfare, believing that its inherent speed and ability to reach any point within an enemy's country meant that an attacking air force could bypass their fielded forces and provide a shortcut to victory.[25] Rather than targeting enemy military forces, as had been the primary method of waging war for centuries, Douhet favored taking the war directly to the enemy nation's civilian populace, advocating violent, destructive attacks against such targets as

> peacetime industrial and commercial establishments; important buildings, private and public; transportation arteries and centers; and certain designated areas of civilian population as well. To destroy these targets three kinds of bombs are

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[23] The most authoritative study done on doctrine development in the Air Corps is Thomas H. Greer, *The Development of Air Doctrine in the Army Air Arm, 1917-1941* (1985. Reprint, Office of Air Force History, U.S. Air Force, 1953). Greer focuses on doctrine development, but weaves the story of the drive for an independent air force into the narrative most effectively. Other sources that address the topic from multiple perspectives, for example ; Tami Davis Biddle, *Rhetoric and Reality in Air Warfare: The Evolution of British and American Ideas About Strategic Bombing, 1914-1945* (Princeton, NJ: Princeton University Press, 2002); Moy, *War Machines*; David E. Johnson, *Fast Tanks and Heavy Bombers: Innovation in the U.S. Army, 1917-1945* (Ithaca, NY: Cornell University Press, 1998).

[24] Phillip S. Meilinger, *Airmen and Air Theory: A Review of the Sources* (Maxwell AFB, AL: Air University Press, 2001), 103.

[25] Ibid., 104.

needed—explosive, incendiary, and poison gas—apportioned as the situation may require. The explosives will demolish the target, the incendiaries set fire to it, and the poison-gas bombs prevent fire fighters from extinguishing the fires.[26]

These attacks formed the core of a new concept of airpower as *strategic* instrument of warfare, able to directly affect the outcome of a conflict, rather than as an adjunct or supporting element of ground armies. This new warfare, as Douhet envisioned it, would involve masses of heavily armed, combat-survivable aircraft conducting such strategic attacks against the enemy population until their will to resist crumbled.

Machines played a starring role in Douhet's theory. He proposed the creation of a new aerial weapon—the *battleplane*—a bomber aircraft with an extensive combat radius, speed sufficient only to enable it to avoid attack from other aircraft, enough armor to protect the crew, and enough bombs to destroy its targets and complete the mission. Although intended to avoid aerial combat, he envisioned that this battleplane would include some defensive weaponry for the sake of the crew's morale.[27] Douhet had faith in the battleplane's ability to get to the target because he believed that the small, slow, lightly armed fighter aircraft of the time could be avoided, negating their ability defensive capabilities. As an artillery officer, he likewise had little faith in the effectiveness of anti-aircraft artillery defenses, dismissing their fire as inaccurate, ultimately believing that it was impossible to defend against an air attack that could come from any direction at any time.[28]

Douhet paid little attention to the difficulties of precision bombing. His belief in the battleplane's invincibility permitted low-altitude bombing attacks, and the bombsights then available performed sufficiently well in that environment. He also advocated the use of weapons with area-wide, destructive effects, which largely compensated for any potential inaccuracies. His three-phase attack plan that combined first explosive, then incendiary, and finally poison-gas bombs was intended to destroy large areas of enemy cities, rather than concentrating on individual targets. Douhet's choice of weapons was driven by his plan to target specifically the enemy civilian population's will to fight, rather than a specific industry or vital center, and he wished to affect maximum destruction, rather than minimum. Douhet's ideas regarding airpower

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[26] Giulio Douhet, *Command of the Air*, trans. Dino Ferrari (1942; reprint, Washington, DC: Office of Air Force History, 1983), 20.

[27] Ibid., 117.

[28] Ibid., 18.

were very controversial at the time of his writing, particularly his agitation for a strong, independent air force, and the Italian government jailed him in 1915 for expressing his views too strongly.[29] Although ridiculed by many, his major theoretical contributions, including the concepts of airpower as an offensive instrument of war, the battleplane, and attacking vital centers other than fielded military forces, proved very influential in the development of the HADPB doctrine developed by the Air Corps.

Douhet's ideas largely paralleled those of the first American airpower advocate, William "Billy" Mitchell. Like Douhet, Mitchell was consumed with the idea that airpower could be a decisive military force that offered cheaper, more rapid victories in wartime than could conventional land or sea forces, but only when employed separately and independently, not constrained by the need to support those same forces. He cultivated the concept that massed bombers attacking "an enemy nation's war-making capability and will to fight…would yield a victory that was quicker and cheaper than one obtained by surface forces."[30]

Mitchell's ideas were rooted in the experience he gained as the chief of the Air Service branch of the American Expeditionary Force during World War I, influenced greatly by the thinking of Major General Hugh Trenchard, the head of the British Royal Flying Corps, who believed intensely in the idea of airpower as an offensive force. Trenchard thought it best "to exploit the moral effect of the airplane on the enemy, but not to let him exploit it on ourselves," which could only be done "by attacking and continuing to attack."[31] During the war, Mitchell advocated the use of airpower in support of the allied ground forces, but was captured by Trenchard's ideas about using airpower as an independent force against "strategical" targets and destroying the enemy's ability and will to fight.[32]

Following the war, Mitchell began aggressively campaigning for an independent air service in the United States military and, in the words of airpower historian Mark Clodfelter,

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[29] Phillip S. Meilinger, "Giulio Douhet and the Origins of Airpower Theory," in *The Paths of Heaven: The Evolution of Airpower Theory*, ed. Phillip S. Meilinger (Maxwell AFB, AL: Air University Press, 1997), 5-6.

[30] Mark A. Clodfelter, "Molding Airpower Convictions: Development and Legacy of William Mitchell's Strategic Thought," in *The Paths of Heaven: The Evolution of Airpower Theory*, ed. Phillip S. Meilinger (Maxwell AFB, AL: Air University Press, 1997), 79.

[31] Alfred F. Hurley, *Billy Mitchell: Crusader for Air Power* (Bloomington, IN: Indiana University Press, 2006), 26.

[32] Clodfelter, "Molding Airpower Convictions: Development and Legacy of William Mitchell's Strategic Thought," 86-89.

"reform the most violent of man's activities—war."[33] Mitchell proposed a technological solution to what he believed was a technological problem. Rifled artillery, poison gas, and the machine gun had made warfare into the horror witnessed on the Western Front, but be believed that the newest machine, the bomber, had the potential to reverse the horrific trend of increasing human slaughter.[34]

Mitchell saw modern warfare as dependent on industry, and the bomber's ability to attack virtually anywhere in an enemy's country presented the opportunity to destroy their capacity to make war, thus shortening the conflict, rather than engaging in bloody contests between opposing armies. He envisioned a new type of warfare, where fleets of bombers would attack

> centers of production of all kinds, means of transportation, agricultural areas, ports and shipping; not so much the people themselves. They will destroy the means of making war because now we cannot cut a limb from a tree, pick a stone from a hill and make it our principal weapon. Today to make war we must have great metal and chemical factories that have to stay in one place, take months to build, and, if destroyed, cannot be replaced in the usual length of a modern war.[35]

This sharper, quicker, and more decisive form of warfare would, in his mind, "result in a diminished loss of life and treasure and…thus be a distinct benefit to civilization."[36] As with Douhet, however, destroying this target set did not require precision bombing, and it was highly likely that many civilians would die as Mitchell's fleets of bombers dropped their bombs on the middle of cities in their efforts to destroy their industrial targets.[37]

Mitchell's ideas were supremely unpopular within the traditional U.S. Army, and ran in direct contravention to the official airpower doctrine laid out in *Training Regulation (TR) No. 440-15, Fundamental Principles for the Employment of the Air Service*, published in 1926. *TR 440-15* stated that the mission of the Air Service was to

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[33] Ibid., 90.

[34] William Mitchell, *Skyways: A Book on Modern Aeronautics* (Philadelphia, PA: J. B. Lipincott Company, 1930), 261-263.

[35] William Mitchell, *Winged Defense: The Development and Possibilities of Modern Air Power, Economic and Military* (New York: 1988. Reprint, Dover Publications, Inc., 1925), 16-17.

[36] Ibid., 16.

[37] Donald L. Miller, *Masters of the Air: America's Bomber Boys Who Fought the Air War Against Nazi Germany* (New York: Simon & Schuster, 2006), 36.

assist the ground forces to gain strategical and tactical success by destroying enemy aviation, attacking enemy ground forces and other enemy objectives on land or sea, and in conjunction with other agencies to protect ground forces from hostile aerial observation and attack.[38]

Independent strategic action against the enemy's war-making infrastructure was clearly out of the question, as *TR 440-15* succinctly declared that the organization and training of all Air Service units was

> based on the *fundamental doctrine* that their mission is to aid the ground forces to gain decisive success (emphasis added).[39]

In spite of the official Army position regarding the use of airpower, Mitchell continued to ferociously advance his views regarding the need for an independent air force to maintain the United States' national security.[40]

Although his relentless pursuit of independence was professionally costly, causing the Army to court-martial him in 1926, Mitchell's campaign for an independent air force was joined by a core group of Air Corps officers who shared his views, many of whom wound up as instructors at the ACTS. By the early 1930s, this group of officers, known as "the Bomber Mafia," had gained control of the intellectual development and the curriculum at the school, and both Mitchell's and Douhet's ideas about strategic bombing and the offensive potential of airpower had taken root, as had the concept of the battleplane.[41] However, these ideas underwent one significant modification.

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[38] *Training Regulation (TR) No. 440-15, Fundamental Principles for the Employment of the Air Service* (Secretary of War, January 26, 1926), paragraph 3.

[39] Ibid., paragraph 4.

[40] Mitchell wrote numerous articles and published several books on the topic of airpower. They are most clearly expressed in the following William Mitchell, *Our Air Force: The Keystone of National Defense* (New York: E. P. Dutton & Company, 1921); Mitchell, *Winged Defense*; William Mitchell, "Airplanes in National Defense," *Annals of the American Academy of Political and Social Science* 131 (May 1927): 38-42; Mitchell, *Skyways: A Book on Modern Aeronautics*. Mitchell's life and crusade was as interesting as it was polarizing. The most even treatment he receives is in Hurley, *Billy Mitchell*.

[41] The extent of Douhet's influence Mitchell's thinking and on the ACTS was debated for many years after the end of World War II, however, Raymond Flugel made a very strong case in 1965 demonstrating a clear connection between Douhet's writings and the HADPB doctrine developed by the ACTS. See Raymond R. Flugel, "United States Air Power Doctrine: A Study of the Influence of William Mitchell and Giulio Douhet at the Air Corps Tactical School, 1921-1935" (The University of Oklahoma, 1965).

While the Bomber Mafia, led by Lieutenant Harold George, agreed that the enemy's industrial production should be the central focus of any strategic bombing campaign, they rejected the idea that the bombing would have a greater effect on civilian morale than on industrial output capacity.[42] Civilian morale *was* considered as an objective, but in the words of Major General Haywood Hansell, one of the architects of the CBO,

> we carefully considered the validity of…civilian morale as an objective. We concluded, however, that it was not a proper objective until widespread defeatism had been engendered by heavy air attacks against the systems which supported the means to fight and the means to live, coupled with despondency concerning the prospects of victory.[43]

Rather, the Bomber Mafia developed a doctrinal construct for the employment of airpower as an independent decisive force that could force an enemy to acquiesce, based upon four possible uses for bomber forces.

(1) To destroy the social-economic-industrial systems on which a major enemy state was dependent for its life as a modern great power—the intricate, sensitive, interrelated systems which supply power, fuel, transportation, communications, water, and food; Or,
(2) to destroy the industrial means of providing munitions and supplies which the enemy armed forces must have in order to fight; Or,
(3) to destroy the means by which finished munitions are delivered to the enemy troops; Or,
(4) to attack enemy armed forces directly—especially enemy air forces.[44]

Although at odds with the Army's approved doctrine of airpower as a supporting element for ground forces, destruction of enemy industrial infrastructure became the central focus, the *purpose*, of strategic bombing at the ACTS.

Destruction of the enemy industrial infrastructure was contingent upon the ability to accomplish three major tasks: flying to the target, finding the target, and dropping bombs accurately enough and in sufficient numbers to destroy the target. Clearly, accomplishing these tasks would require a system of humans and machines, employed together in a way to achieve

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[42] Miller, *Masters of the Air*, 39.

[43] Haywood S. Hansell, Jr., *The Air Plan That Defeated Hitler* (Atlanta, GA: Higgins-McArthur/Longino & Porter, Inc., 1972), 85.

[44] Ibid., 37.

the overall objective of destroying individual industrial targets. The Bomber Mafia developed such a socio-technical system through the 1930s, refining the basic ideas supplied by Douhet and Mitchell, but integrating the concept of precision attack to minimize rather than maximize attacks on the civilian populace. They shaped and matured their ideas in the *Bombardment Aviation* class taught at the ACTS, and the text used during the class, while serving as an instructional tool captured their thoughts and beliefs about how to design and employ this bombardment system. However, because these thoughts and beliefs were then taught to the members of the Air Corps, they actually evolved into Air Corps doctrine. Examining this text, then, provides the clearest picture of the service's precision bombing doctrine. The doctrine itself developed through the 1930s, but the 1938 version of the text, the last one produced before the United States closed the school in preparation for World War II, is the culmination of that evolution and clearly defines how the Air Corps intended to perform the precision bombardment mission, and it provides a clear picture of the system the United States took to war in Europe at the beginning of the CBO.

Bombardment Doctrine and System Definition

Physically and cognitively, the Air Corps' bombardment doctrine structured the bombardment system as an interdependent network of humans and machines at three levels, unified by their doctrinal mission of precision bombing. At the system's lowest level, the component level, individual, specially trained members of the bomber crew worked with specifically designed machines to perform the tasks necessary to bomb precisely, including flying, bombing, and navigating. At the intermediate, aircraft level, these humans and machines formed a coherent individual team, defined by the physical dimensions of the bomber aircraft that itself, based on its capabilities, then became an integral part of the system. At the highest, or bomber formation level, groups of these aircraft-level systems worked together to mitigate the limitations and shortcomings displayed at the lower level and improve system effectiveness.

The Component Level—Humans and Machines

At the bombardment system's component level, it was physically constructed from interdependent human and machine elements. Each mutually defined the other based upon a specific task that bound them together, derived from the overall purpose—precision bombing.

The principal human elements were the bomber pilot and the bombardier, who together comprised the human "bombing team" that delivered and dropped the bombs, and the navigator, who ensured that the bombing team arrived at the correct target and made it back home. These three specially trained human crewmen were inseparable from the machines that they used to perform their part of the bombardment mission, which included the bombardment aircraft, the bombsight and bomb release mechanism, which made up the "fire control system," and the specialized navigation and calculation instruments.[45]

The Human Elements—The Bomber Crew

Although at the component level, the bombardment system consisted of individual humans and machines, the humans together formed an integral unit—the bomber crew. The bomber crew formed the core human organizational and social unit of the bombardment system, consisting of an aircraft commander (pilot), copilot, navigator, bombardier, and other men including a radio operator and several aerial gunners. Throughout the preparation for the war and during the war itself, the USAAF assembled these individual crewmembers to specific crews that, for the most part, remained together as a team. They trained as a crew before they deployed to any combat theater, working together to perfect their mission and form a "closely knit, well organized team of highly trained specialists," and then flew together often in combat.[46]

The USAAF emphasized building, training, and maintaining the bomber crew as a team, as experience during World War I demonstrated the positive effect that maintaining crew integrity during combat operations had on its bombing efficiency. The "increased morale resulting from the close association of the personnel performing a coordinated and common mission, particularly under the stress of active operations" greatly increased their effectiveness as a combat unit.[47] Pre-World War II bombing doctrine recognized the utility of keeping bomber crews together as a unit, and directed that commanders should make maximum effort to keep them intact during combat operations, stating

> the maximum degree of efficiency in bombardment operations will be
> considerably enhanced if the policy of maintaining intact the combat crews of

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[45] *Bombardment Aviation: 1931* (Langley Field, VA: Air Corps Tactical School, 1931), 33.

[46] White, *Combat Crew and Unit Training in the AAF: 1939-1945*, 25.

[47] William C. Sherman, "Tentative Manual for The Employment of Air Service (1919)," in *The U.S. Air Service in World War I: Volume II, Early Concepts in Military Aviation*, ed. Maurer Maurer, vol. 2 (Washington, DC: The Office of Air Force History, 1978), 397-398.

bombardment airplanes is not violated unless the breaking up of the crew becomes necessary in the interest of increased efficiency as viewed from other considerations.[48]

Although the bomber crew formed the human core of the bombardment system and crew integrity improved their effectiveness as a single unit, individual crewmembers who displayed individual excellence were often assembled from separate crews during combat to improve the overall effectiveness of the larger bombardment system, as will be seen in subsequent chapters.

Combat crew training was an extensive process comprised of three phases, all oriented toward teaching the bomber crewmembers how to individually perform their tasks and work together as a team to accomplish their mission. The first phase focused on individual proficiency in the bomber aircraft, enabling the crew to gain familiarity with their aircraft and equipment. The second phase focused on more mission-oriented training, including bombardment, gunnery, and elementary formation flying, and began developing the crew into a coordinated team. The final phase, conducted just before the crew deployed to a combat theater, was devoted principally to simulating combat missions and employing as part of a larger squadron, group, or wing unit.[49] By the end of training, they had transformed from a group of individuals into what John Steinbeck described as a team with "each member responsible to the whole and the whole responsible to its members."[50]

While they formed a cohesive human team during combat crew training, these human elements of the bombardment system were at the same time forming an integral relationship with their necessary machines. As they worked together to hone their performance as a human unit, they did so with the machines that they needed to perform their jobs, integrating themselves with them through the performance of their individual tasks. In the process, they ceased to exist as individual human elements of the bombardment system, transforming instead into individual socio-technical elements, with each human defined by his mastery of a specific machine that enabled him to perform his function on the bomber crew.

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[48] *Bombardment: 1933* (Maxwell Field, AL: Air Corps Tactical School, 1933), 20.

[49] Leslie F. Smith, *Development of AAF and USAF Training Concepts and Programs: 1941-1952*, U.S. Air Force Historical Study 93 (Washington, DC: USAF Historical Division, Air University, 1953), 321, Call 101-93, IRIS No. 01004508, US Air Force Historical Research Agency.

[50] John Steinbeck, *Bombs Away: The Story of a Bomber Team*, 2nd ed. (New York: 2009. Reprint, Penguin Books. Originally published New York: The Viking Press, 1942), 4.

Building the Socio-technical—The Human Pilot, Bombardier, and Navigator

The bomber pilot was the leader of the bomber crew, defined by his ability to fly the bomber aircraft, but was also the crewmember least constrained by the mastery of a specific machine. The 1938 *Bombardment Aviation* text defined his primary function as to fly the bomber aircraft to the target, demonstrating

> excellence in blind flying, navigation, formation flying, and the ability to conduct flights under all types of weather conditions, during daylight and during darkness…at distances of many hundreds of miles from his base and in the face of every possible type of defense which an alert major power will utilize in the air defense of its vital establishments.[51]

Certainly defined by his mastery of a specific machine—the bomber aircraft—the pilot's responsibilities extended far beyond flying to control of the system at the next, or aircraft level. The pilot served as the system controller at the lowest level, and he had the broadest responsibility for the completion of the mission.

The pilot was designated the "aircraft commander," and was charged with ensuring that the combat crew of his airplane had "reached the highest possible standards of proficiency in the performance of those duties which are so vitally essential in the carrying out of successful bombardment operations," which included understanding the role and function of every other member of the bomber crew.[52] When this text was written, as will be discussed in subsequent chapters, the bomber pilot was actually trained to perform the role of every other member of the crew, including the bombardier and navigator, and was expected to ensure that each performed adequately well to accomplish their joint mission.

The pilot also served as the moral leader of the bomber crew. As the one in control of the aircraft, he was responsible for ensuring that it and the crew made it to the enemy target, in spite of the expected hazards and danger associated with warfare. The earliest bombardment doctrine, as expressed in the *1924-1925 Bombardment* text, made this role clear when addressing the pilot's duties:

> He must not be overcautious and allow inconsequentials to turn him back when he could go on. In time of war every pilot who returns to the airdrome should be held to rigid account for his action; yet he must be given the benefit of the

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[51] *Bombardment Aviation: 1938* (Maxwell Field, AL: Air Corps Tactical School, 1938), 8-9.

[52] Ibid., 11.

doubt in passing judgment on his action. It may be necessary to take
disciplinary action in rare cases, but in general the moral pressure of the
disapproval of his comrades will be sufficient. If he is a coward they will know
it.[53]

Later versions of the text eliminated mention of cowardice, but included a discussion on the

importance of leadership in instilling the "offensive spirit" in the bomber crew, the willingness to

"carry on in spite of opposition."[54] The pilot had physical control of the bomber crew as a socio-

technical unit because he flew the aircraft that contained them, but he also had to maintain moral

control of the human elements of the system. We examine the pilot's role as the system

controller in Chapter 3.

The bombardier had a much more narrowly defined function—dropping the bombs on the

target—and he was tied more closely to the specific machine necessary to do his job than any

other crewmember, the bombsight. The *Bombardment Aviation* text explained that a bombardier

must be

thoroughly familiar with the operation of our modern intricate bomb sights,
release mechanism, and bomb racks. He must be thoroughly acquainted with
the effectiveness of the several types of bombs and the targets against which
each should be used. Each bombardier must be trained in bombing for precision
with the minimum time interval for the conduct of the sighting operation. *The
skill of the bombardier determines the success or failure of his combat crew and
their powerful airplane. If he fails at the critical moment, the entire mission
with the effort, hazard and possible casualties entailed, are of no avail*
(emphasis added).[55]

The bombing machines and the bombardment mission were themselves an integral part of the

definition of the bombardier, as will be explored in Chapter 5, and outside of the context of the

bombing mission and the machines used to drop bombs, he did not exist.

The navigator on the bomber crew had a similarly narrowly defined function based on

technological mastery—knowing where the aircraft was and ensuring that it flew to the correct

target and returned home—but was less closely associated with a single, specific machine than

the bombardier. The *Bombardment Aviation* text charged him with

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[53] *Bombardment: 1924-1925* (Langley Field, VA: Air Service Tactical School, 1924), 41.

[54] *Bombardment Aviation: 1938*, 12.

[55] Ibid., 9.

all responsibility for air navigation. He is especially provided the latest equipment for air navigation and must devote constant study and practice to this science. His precision may assure the success of the mission or his failure may defeat the efforts of all other members of the crew.[56]

While air navigation was not a task limited to the bombardment mission alone, it was clearly critical for mission success. As will be seen in Chapter 4, the navigator and his tools were an inseparable team, and he spent more time working with the specific tools of his trade than any other member of the bomber crew did.

Building the Socio-technical—Technology and the Fire Control System

As dropping bombs was the primary function of the bombardment system, at the component level, the most important machine element was the fire control system. First identified as such in the 1931 version of the ACTS *Bombardment Aviation* text, the fire control system consisted of the set of interrelated machines that enabled the dropping of accurate bombs, including the bombsight and the bomb release mechanism in the aircraft.[57] The bombsight, which calculated the bomb release point necessary to hit a target, played the central role in the fire control system, and thus in the overall bombardment system itself, as shown by its description in the 1938 text.

> When one realizes that the most proficient airplanes in the world, the most powerful bombs obtainable, and the highest specialized personnel are useless unless the bombs can be so placed as to insure the destruction of the objective, it must be appreciated that the bomb sight does not constitute mere a "gadget" but actually is of major importance. It is as essential as the motors of the airplane, since the success of the bombardment mission might well depend upon the degree of accuracy and precision possible of attainment by the bomb sight.[58]

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[56] Ibid., 9-10.

[57] *Bombardment Aviation: 1931*, 33. While specifically used in 1931, the term disappeared from subsequent texts. However, the discussion of the bombing technologies in those texts was arranged to make it clear that all of the elements were interrelated and worked together to drop accurate bombs.

[58] *Bombardment Aviation: 1938*, 40-41.

Certainly critical for mission success, the bombsight required a skilled human, the bombardier, to operate it. Much as the bombardier himself was nothing without the bombsight, the bombsight was useless without the bombardier.

The other critical element in the fire control system was the bomb release mechanism. While the *Bombardment Aviation* text initially described the bomb release mechanism as a device designed to "release the bomb from its rack at the will of the bombardier," its real purpose was to "reduce to an absolute minimum any delay in the release of the bomb after the bomb release point has been reached."[59] The bomb release point was a specific, unique point in space, and the bomb had to be released at that point in order to hit the target. Delays caused by human reaction time in triggering that release signal were a significant source of bombing error, and the bomb release mechanism was intended to eliminate that source of error. By 1938, electrical bomb release mechanisms that were operated by electrical contacts in the bombsights themselves were being installed in all bomber aircraft. Together, the bombsight and the bomb release mechanism comprised a separate system, controlled by the bombardier as he operated the bombsight. The relationship between the bombardier and the bombsight and the effect of this automated bomb release method will be explored in Chapter 5.

The bomber crew and their associated machines came together into a single socio-technical team, focused on performing the tasks necessary for the precision bombing mission. It was not, however, a team of equals. The navigator and the bombardier played critical roles in the bombardment mission, but were limited by their narrowly defined tasks and the specific machines that they used to perform them. The pilot, on the other hand, was the crewmember least defined by his mastery of a machine and responsible for the overall performance of the crew and thus the leader. The bombardment doctrine designated him as the aircraft commander and leader, thus establishing a distinct social hierarchy within the system.[60]

Although hierarchical, the bomber crew structure enabled *shared control* of the mission. Each of the primary crewmembers had a distinct function, and no single individual could accomplish them all. The pilot maintained overall control, but relinquished some measure of that control depending upon the phase of the mission, taking direction from the navigator to and from the target and giving him control of the flight path, or giving the bombardier control of the

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[59] Ibid., 41.

[60] White, *Combat Crew and Unit Training in the AAF: 1939-1945*, 332-333.

aircraft during the bombing phase so that he could place the aircraft where the bombsight told him in order to hit the target. As we shall see in subsequent chapters, these crewmembers shared their control with "their" machines. Shared control of the system was necessary for mission success.

The Intermediate Level—The Bomber Aircraft as a Socio-technical Unit

The socio-technical bombardment team came together as a unit defined by the bombardment aircraft. The bomber had been a central part of precision bombing doctrine from the days of theoretical infancy, and its fundamental purpose was to unify all of the component elements of the bombardment system into a single, composite component that could perform the mission. As stated in the 1938 *Bombardment Aviation* text,

> the basic function of the bombardment airplane and its equipment is to effectively transport and apply destructive agencies upon materiel objectives. *Upon this task are based all requirements* (emphasis added).[61]

From the beginning, it was envisioned and defined as a socio-technical system that integrated the mission and the socio-technical components, making clear provisions for both the humans and machines necessary for precision bombing.

The design roots of the aircraft used by the American forces during the CBO are found in Douhet's battleplane. Air Corps bombardment doctrine called for a large bomber aircraft with strong offensive and defensive characteristics that could carry large amounts of bombs long distances and drop them on enemy targets, while defending from enemy attack during the mission. Offensively, the first and foremost requirement was to be able to "carry a sufficiently heavy load of bombs, chemicals, or torpedos (sic), and release them accurately upon objectives vital to an enemy."[62] From a technical perspective in 1938, a sufficiently heavy load of bombs was determined to be 2,000 lbs, as

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[61] *Bombardment Aviation: 1938*, 33.
[62] Ibid.

a 2,000-lb. bomb and probably a 1,100-lb. bomb, *properly placed*, will create satisfactory destructive effect on any military establishment so far conceived by man (emphasis added).[63]

However, embedded in the above statement is also the need to be able to release those bombs *accurately*. To meet this accuracy requirement, the bomber aircraft had to accommodate the entire bombardier-bombsight element and, as such, the aircraft had to provide a position for the bombardier that "permits a bomb sight to be installed and conveniently operated and which permits excellent vision toward the target."[64] Similarly, the aircraft had to be easy to fly, particularly in formation, as will be discussed below, providing the pilot a cockpit that afforded good forward vision, otherwise it could not be "an effective bombardment airplane."[65]

Maintaining crew efficiency so that they could perform their mission was also a primary design driver for the optimum bomber aircraft. The doctrine developers desired an aircraft

as comfortable as possible to avoid producing any unnecessary fatigue. It is imperative that oxygen be provided conveniently at high altitudes. The crew must be kept warm if efficiency is to be maintained over long periods. As range increases, comfort becomes of greater importance in avoiding unnecessary fatigue.[66]

A comfortable aircraft would also reduce fatigue produced by long flights over enemy territory under the constant stress of possible or actual enemy attack. Providing stations for effective bombardment and reducing fatigue, however, met only the primary offensive requirement for the battleplane.

When the Bomber Mafia at the ACTS developed the HADPB doctrine, they envisioned attacking targets that were both highly valuable and deep within enemy territory, which forced a secondary, defensive requirement that the aircraft be able to "overcome determined resistance" from airborne and ground threats.[67] Defense against airborne attack was provided by two key capabilities—speed and defensive gunfire. Though through 1930, pursuit aircraft easily outperformed bombers in flight and, with the proper direction, could provide a measure of

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[63] Ibid., 36.
[64] Ibid., 37.
[65] Ibid.
[66] Ibid., 36.
[67] Ibid., 33-34.

defense against their attack. However, the arrival of the Boeing B-9 and the Martin B-10 monoplane bombers changed the offense-defense equation. During the late 1920s and early 1930s, the development of pursuit aircraft technology had stagnated in the United States and Great Britain, as aircraft manufacturers focused on improving the speed and range of larger aircraft, partially at the urging of the bombardment supporters in the Air Corps. The B-9 and the B-10 were both all-metal monoplanes with retractable landing gear and powerful engines, and were 60 to 80 miles per hour faster than any previous bomber. At its roll out, the B-10 was the fastest, highest flying bomber in the world, easily able to outrun any existing pursuit aircraft.[68] High speed became the bomber's greatest defense against airborne attack, as it made it more difficult for defensive fighters to attack them and reduced their chances of conducting multiple attacks, as well. In the event of fighter attack, however, the bomber was also to have defensive guns for self-protection, covering multiple axes of attack, making any such attempt costly and dangerous for the defender.[69]

While speed was an effective defense against airborne attack, it was also a bomber aircraft's primary protection against ground defenses, along with high altitude and maneuverability. Anti-aircraft artillery (or *flak*) was unguided during World War I, and not tremendously accurate, and bomber crews found that higher speeds made the bombers more difficult to hit and further reduced flak accuracy.[70] Altitude also provided a defense against flak, because aircraft that flew higher were more difficult to hit. However, as the effective range of anti-aircraft artillery improved during the years following World War I, bombers had to fly continually higher to decrease their effectiveness. While flying at higher altitudes increased aircraft survivability, it decreased bombing precision. The higher altitudes introduced greater variance into the problem that the bombardier and the bombsight had to solve, as will be explained in Chapter 5, and accurate bombing results were more difficult to attain.

Since flak was unguided, aircraft maneuvers were another effective defense against getting hit, and ease of maneuvering was identified as another key bomber capability. Bombardment doctrine called for an aircraft that was "easy to fly," and that the response and

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[68] Greer, *The Development of Air Doctrine in the Army Air Arm, 1917-1941*, 47-48, 58-60; Bernard Boylan, *Development of the Long-Range Escort Fighter*, USAF Historical Study 136 (Maxwell AFB, AL: USAF Historical Division, Research Studies Institute, Air University, 1955), 14-18.

[69] *Bombardment Aviation: 1938*, 38-39.

[70] See William C. Sherman, *Air Warfare* (New York: Dover Publications, Inc., 1926), Chapter 8.

controls should be "quick, positive, and easy in their operation" so that the pilot could quickly and easily perform defensive maneuvers when under fire from ground defenses.[71] By 1932, the bomber aircraft's advantage in speed, altitude, and maneuvering capability gave it such a huge perceived advantage over pursuit and anti-aircraft defenses that many believed that there was no effective way to defend against a determined bomber attack, and on 11 November 1932, Stanley Baldwin, the British Prime Minister, said as much in a speech to Parliament when he famously stated that "the bomber will always get through."[72]

The ideal bomber defined by the Air Corps bombardment doctrine was conceived as a socio-technical system, integrating technical elements that enabled the individual socio-technical elements perform their jobs as effectively as possible. Shaped by the need to fly long distances at high speeds and drop bombs from high altitudes, the HADPB doctrine developers envisioned it as a complete system that brought all of the component socio-technical elements into a single, larger composite component that could perform the precision bombing mission. Its design provided specifically for both the human and machine elements necessary to perform the mission, while incorporating the ideas of precision bombing from high altitude. Prior to the 1930s, while Billy Mitchell was still agitating for an independent air force, such a system was technologically infeasible as the state of aviation technology at the time simply could not support the design and production of such an aircraft, making the realization of the doctrine seem unlikely. However, as aviation historian Arthur Price explained, the early 1930s saw the development of all-metal, stressed-skin aircraft that could fly higher, farther, and faster than any before.[73] That new machine, accompanied by the invention of the Norden bombsight and more powerful aircraft engines, led to the development of perhaps the most well-known aircraft from World War II, and the one that moved precision bombing from theoretical musings at the ACTS to the reality that became the CBO.

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[71] *Bombardment Aviation: 1938*, 40.

[72] Stanley Baldwin, "Aerial Warfare: A Fear for the Future," *The Times* (London, November 11, 1932), 8. It is important to remember that at the time of Baldwin's speech, radar was nothing more than a laboratory experiment, and that as the HADPB doctrine was developed over the next several years at the ACTS, none of its architects were aware of its ongoing development, and could therefore not forecast its effect on the bomber's ability to defend itself.

[73] Alfred Price, *Bomber Aircraft* (London: Arms and Armour Press, 1989), 10.

The B-17—The Socio-technical Embodiment of an Idea

At the time that the 1938 *Bombardment Aviation* text was written, the United States had only one operational heavy bomber aircraft, the Boeing B-17 "Flying Fortress" (Figure 2.1). It was, however, the physical embodiment of the ACTS precision bombing doctrine and would be the most used bomber during the CBO.[74] Designed in 1934, with the first prototype flown that same year, the B-17 was the workhorse of the USAAF during the CBO, and went through many modifications during the war that improved its performance. The final version, the B-17G, was powered by four turbo-supercharged engines, had an operational ceiling of 35,000 feet, a maximum speed of 220 miles per hour (mph), could carry a 6,000-pound bomb load over 1,100 miles, and carried thirteen .50-caliber machine guns for self defense.[75]

Figure 2.1
Boeing B-17C[76]

A modern aeronautical marvel, the B-17 was designed specifically for high-altitude, long-range bombing missions and, when initially fielded, was the most advanced bomber aircraft of its time. Structurally, it reflected the current state of the art, offering nothing new or untested, however, as B-17 authority and aviation historian Peter Bowers points out, it was the manner in which the aircraft went together that made it unique.[77] Boeing's designers designed and laid out

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[74] During the war, more B-24s were built (18,190) than B-17s (12,692), but more B-17s saw service during the CBO. See Holley, Jr., *Buying Aircraft*, p. 550, Table 11.

[75] *Jane's All the World's Aircraft* (London: Jane's Publishing Company, Ltd, 1946), 210.

[76] *Boeing B-17C*, Photograph, n.d., AirForceMagazine.com, http://www.airforce-magazine.com/MagazineArchive/Pages/2008/September%202008/0908GHQ.aspx (accessed 5 April 2011). Note that this model of the B-17 lacks a tail gun and the distinctive dorsal spine installed on later models.

[77] Peter M. Bowers, *Fortress in the Sky* (Grenada Hills, CA: Sentry Books, Inc., 1976), 18.

the semi-monocoque aluminum fuselage specifically to accommodate the bomber aircrew and their machines, optimizing it both offensively and defensively for the strategic bombardment mission (Figure 2.2).
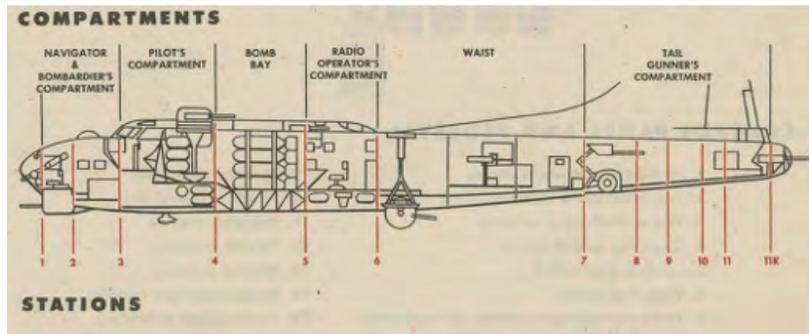
Figure 2.2
The B-17 crew compartment layout[78]

Offensively, the B-17 enabled the crew to accomplish their jobs with the maximum ease attainable. The cockpit, fully enclosed and located high atop the aircraft, had room for two pilots, the aircraft commander and a copilot, and provided excellent forward visibility, making it easy to see other aircraft in formation. The inclusion of the copilot's position was a clear nod to the HADPB doctrine, as it implied that the anticipated range of precision bombing missions would be beyond the physical capability of a single pilot.[79] Uniquely, forward and below the cockpit was a dedicated compartment for both the bombardier and navigator. The bombardier and the bombsight were located in the very front of the aircraft behind a Plexiglas nose that provided excellent forward and downward visibility, giving the bombardier the best possible view of the target. While a separate bombardier's station was common in bomber aircraft, the B-17 was the first bomber to have a dedicated navigator's compartment.[80] The navigator's station, designed specifically to accommodate all of the tools of modern aerial navigation, was located immediately behind the bombardier, conveniently close the pilots, as well, allowing easy access to both during flight.

Although Boeing designed the B-17 to operate at high altitude, out of the reach of enemy defensive fire, the aircraft was unpressurized. Unlike its successor, the B-29, the interior of the

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[78] *B-17: Pilot Training Manual for the Flying Fortress, AAF Manual No. 50-13* (Headquarters AAF, Office of Flying Safety, 1945), 29.

[79] Henry H. Arnold, *Global Mission* (New York: Harper, 1949), 155-156.

[80] Norris B. Harbold, *The Log of Air Navigation* (San Antonio, TX: The Naylor Company, 1970), 77.

B-17 was not sealed, and thus exposed to the outside environment. During bombing missions, temperatures plunged well below zero degrees Fahrenheit, exposing the crew to brutal conditions. To compensate for this situation, the B-17 had a limited heating system designed primarily to enable the crew to perform their primary mission. It pumped hot air into the pilot's cockpit, as well as onto the Plexiglas nose to prevent it from frosting up during flight and preventing the bombardier from using his bombsight, but also included a limited number of heating vents distributed back through the fuselage to the tail section at the crewmembers' positions. Each crew position also had an electrical outlet, designed for use with the electrically heated flight suits that many bomber crewmembers wore during high-altitude missions. Each position also had a connection point so that the crewmembers could plug into the oxygen system, designed for use up to 40,000 feet. Crewmembers were required to use supplemental oxygen whenever flying above 10,000 feet above sea level. A full intercom system enabled the crewmembers to communicate with each other at any time, as long as the aircraft generators were functioning.[81] The B-17 formed a small human-machine organism, providing life-support for the human elements while connecting them with each other and with their machines so that they could perform their jobs in the hostile environment of the high altitude bombing missions.

Defensively, the B-17 was designed for speed and was very heavily armed. With a top speed over 200 mph, it was extremely fast and it could outrun the pursuit aircraft of the early 1930s, limiting them to either head-on or stern attacks. The bomber earned its "Flying Fortress" moniker from the many machine guns placed throughout the fuselage, providing multiple-axis defense and ready to challenge any such threat. Designers placed the machine guns to provide the maximum amount of defensive cover, and a dedicated gunner, trained in aerial gunnery, operated each. Interestingly, although the aircraft's speed enabled the bomber to outrun attacking fighters and limit them to stern attacks, the first several models of the aircraft did not have a machine gun installed in the tail section, and even though the Air Corps' own doctrine for attacking bombers was based on stern attacks, in a distinct case where technology and doctrine did not come together, this left the bomber defenseless in the very area where it was most likely, by design, to *be* attacked.[82] Later versions of the aircraft included a tail gun, and throughout the

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[81] *B-17F Pilot's Flight Operating Instructions, T. O. No. 01-20EF-1* (U.S. War Department, 1942); *Pilot Training Manual for the B-17*.

[82] I. B. Holley, Jr., "Insights on Technology and Doctrine," in *Technology and Military Doctrine: Essays on a Challenging Relationship* (Maxwell Air Force Base, AL: Air University Press, 2004), 81.

war, Boeing made improvements to the size and location of the machine guns, greatly increasing the bomber's ability to survive aerial attack.

The B-17 brought the ACTS strategic bombing doctrine to life, integrating the socio-technical elements of the bombardment team into a complete whole, effectively encapsulating them as a single unit. It was, in the words of General Henry H. "Hap" Arnold, the man who would command and lead the USAAF through World War II, "the first positive answer to the need arising from the United States' modification of the Douhet theories, which we had been teaching as an abstract science at the Air Corps Tactical School," and the first "real American airpower...that you could put your hand on."[83] It placed each crewmember in a position to enable the system to drop bombs as precisely as was possible, and provided for a great degree of self-defense.

As a single unit, however, the B-17 was not able to execute the doctrine of strategic bombing. As well conceived and implemented as was the design, a single B-17 could neither carry enough bombs to ensure the destruction of an enemy's vital targets, nor defend itself from determined attack by multiple defensive fighters. Since creating a larger aircraft able to carry more weapons was not feasible with the technology available at the time, doctrine provided the remedy. The HADPB doctrine not only defined the bombardment system purpose and the socio-technical elements, but also how the system was to be used at the intermediate level. It did so by assembling numerous intermediate elements, the aircraft, into a larger whole, creating a higher-level system more capable of achieving the massive, precision bombing attacks that were at the heart of the strategic bombing doctrine.

The Formation—Construction, Control, and Execution at the Highest Level

As mentioned previously, the industrial infrastructure target set that the creators of the HADPB doctrine envisioned attacking was very likely to be well defended, in addition to potentially being very large. This was particularly the case during the CBO, as the German war-making industrial base was, indeed, comprised of very large factories and industrial centers that were extremely well-defended by an extensive air defense network of defensive fighters and heavy flak batteries. To execute the doctrine, it was necessary not only to be able to drop bombs precisely, but survive the trip to and from the target and drop *enough* precise bombs to destroy

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[83] Arnold, *Global Mission*, 154-157.

the target. To achieve this, the bombardment doctrine constructed a higher-level system, the bomber formation, comprised of several of the intermediate-level components, the bomber, itself comprised of the individual human-machine socio-technical elements in the bomber crew. The bomber formation combined the precision bombing capability of the individual bombers with the concept of *mutual defense* in order to deliver the mass of weapons necessary to destroy their industrial targets.

Construction and Control

For bombing missions, the bombardment doctrine assembled groups of bomber aircraft into formations, creating a larger system of interdependent components that operated as a single entity to accomplish the mission. Formations were designed to provide the bombardment system either defensive or offensive capability, and varied in size and construct to address the particular requirements of each individual mission.[84] Assembled from progressively larger groups of aircraft, the formation provided the maximum amount of control over the system at various levels.

The basic formation unit, which contained "the largest number of airplanes that can be precisely controlled and commanded by one individual," was the squadron, and varied in size from three to six aircraft.[85] The squadron commander controlled the squadron as a single unit, but it was shared control, as the individual pilots were still in command of their own aircraft. Three to six squadrons assembled into Groups, commanded by a group commander, again providing layered, shared control for the growing system. Up to three groups, likewise, assembled into the largest unit, the Wing, again with a single individual commander, the Wing commander, in control of the overall formation system, which could contain up to fifty four individual aircraft. Although the size and physical arrangement of the final formation was dependent on the mission, the configuration was guided by the need to remain flexible so that it could respond to changing operational conditions during the flight. It needed to be simple, so that individual pilots could "maintain easily their assigned positions and be susceptible to efficient control by the commander" at all levels.[86]

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[84] *Bombardment Aviation: 1938*, 79.

[85] Ibid.

[86] Ibid., 79-80.

Formation simplicity was a key requirement for the individual pilot, because he could effectively fly formation only with the one aircraft immediately to his right or left. Maintaining formation position, which varied from as far away as a few hundred feet to as close as ten feet of separation between aircraft, could be very physically demanding and required a great deal of concentration. As such, the aircraft flying and handling qualities had a direct impact on the effectiveness of the formation. Aircraft that were easier to fly made maintaining position easier, which enabled the formation leader more flexibility to maneuver in response to changing conditions, such as weather or enemy defenses. Regardless of the final size of the formation, individual pilot ability to maintain his aircraft's position was the key to its overall effectiveness.

Defense and Survival

The overall purpose of the formation, whether for defense or offense, drove the physical arrangement of the aircraft. Defensively, formations could provide protection for the individual aircraft from either attacking pursuit or fighter aircraft or from defensive flak batteries. Against fighter attack, doctrine arrayed the bombers so that they provided each other mutually supporting defensive machine gun fire. In addition to covering more axes of attack, the massed effect of the multiple guns was far more threatening and deadly than that possible for a single aircraft. In this type of formation, the aircraft flew as closely together as possible, ensuring maximum overlap between individual aircraft machine gun coverage. It was the most demanding for the pilots, and used only when there was a threat of enemy air attack.

When entering areas heavily defended by flak batteries, such as over cities or target areas, the bombers employed a different formation. The aircraft spread out, increasing the distance between the individual elements so that a single flak burst could not damage multiple aircraft. The intent of this formation was to overload the ground defenses with multiple targets, with the underlying philosophy that at least some of the formation would survive to reach and attack the target.

Offense, Daylight, and the Mission

Once in the target area, the bombardment system's focus shifted from survival to destruction, and the aircraft transitioned to a formation more conducive to precision bombing,

based upon the particular target for the mission. The specific target type, precision or area, determined the method of attack used by each aircraft. Precision targets, "those which, to be destroyed, require either a direct hit by a bomb of the proper size or a hit within a limited distance therefrom (sic)," such as naval vessels or bridges, demanded that each aircraft drop its bombs individually, ensuring the greatest accuracy.[87] This necessitated a looser formation that allowed the individual bombers to maneuver to the correct bomb release point, which transferred control to the aircraft level in the system, but decreased the defensive protection afforded the individual aircraft. While the USAAF did attack targets of this type during the CBO, the majority of the campaign focused more on what were classified as "area" targets.

Area targets were those targets that required "a distribution of bombs of the proper size throughout the area in which the definite targets lie…including large rail terminals, extensive industrial plants, and large supply depots."[88] Attacking area targets successfully required a more dispersed bombing pattern, but the method of employment was very similar to that used to attack precision targets. The bombers generally remained in close formation, continuing to follow the formation lead to the target, but each individual bomber was still responsible for bombing a particular *part* of the area target. Area bombing *did not* automatically imply the saturation of a general target area, and doctrine directed that the individual bomber crew treat each target as a precision target and employ their aircraft in the manner that guaranteed the greatest bombing accuracy.[89] As with precision targets, bombing area targets necessitated a looser, less defensive formation, which increased the risk of a bomber getting shot down.

Bombing as a single formation with every aircraft dropping at the same moment was, in fact, envisioned as a rare occurrence, reserved for instances when uniform coverage of an entire target area was desired, such as during the employment of chemical bombs.[90] In this case, each bomber in the formation would release their bombs upon a signal from the lead aircraft, such as when the lead bombardier released his bombs. Precision bombing was rarely attainable through this technique, however, as it was almost impossible to ensure that each aircraft in the formation dropped their bombs at the same instant. The limits of human reaction time prevented

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[87] Ibid., 44.

[88] Ibid., 44-45.

[89] Ibid., 45.

[90] Ibid., 46. Chemical and gas weapons were a major part of Douhet's attack theory and were not outlawed during World War II. However, neither side employed them during the war.

simultaneous release, and the system as a whole was not equipped to operate in this fashion. For this reason, pure formation bombing was not considered a primary mode of employment in the Air Corps' prewar bombardment doctrine.

The desire for precision employment with mass had another significant effect on the overall concept of the HADPB doctrine—the bombers had to fly during the light of day. The desire to hit targets precisely meant that the bomber crews needed to be able to see their targets. While the cover of darkness provided a measure of defense against hostile attack from the air or the ground, it also made it very difficult to locate the targets, particularly those blacked out or camouflaged. This made night bombing impractical as a precision bombing doctrine.[91] While flying during the day made precision bombing more practical, it also made bombing itself more dangerous, as the bombers were plainly visible to enemy defensive forces. As explained later, this vulnerability caused a significant change in American bomber operations during the CBO.

The bomber formation comprised the top level of the bombardment system designed by the Bomber Mafia in the 1930s to execute the HADPB. As a purposeful assemblage of interdependent socio-technical elements, the formation itself was a distinct socio-technical system, structured in a fashion to provide the human formation commanders layers of shared control that enabled them to use and alter the system in response to the immediate context, while still performing the bombing mission. The different formations themselves were designed to take advantage of the mutual defense capabilities of the individual intermediate elements, the bomber aircraft, but more importantly the individual precision bombing capabilities of those aircraft. It was their ability to precisely hit targets, enabled by the successful cooperative efforts of the socio-technical bombing teams that made up those aircraft, that made the HADPB doctrine theoretically feasible.

It was this system of doctrine, machines, and humans that the United States brought to England in 1942 to execute the CBO. However, it was based upon theory, rather than the "tried

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[91] The American decision to pursue daylight bombardment during the CBO was hotly debated at the time, as the British, who began bombing the Germans before the USAAF even entered the war, had been markedly unsuccessful with daylight bombing. They shifted almost immediately to night operations, taking an area bombing approach in their operations. It was not until the Casablanca Conference in January 1943 that both sides came to the agreement that the Americans would bomb during the day and the British continue to bomb at night, attempting to implement "around the clock bombing." The decision to pursue a daylight campaign has been examined many times since the end of the war. For two of the best, see Noble Frankland, *Bomber Offensive: The Devastation of Europe* (New York: Ballantine Books, 1970); Anthony Verrier, *The Bomber Offensive* (London: Batsford, 1968).

and true," and when the first attempts to employ the system provided evidence of performance contrary to that which was expected, the USAAF commanders quickly changed how they used the system, in turn changing how the elements were organized and employed. These changes, as will be seen in subsequent chapters, directly affected how each of the individual human-machine elements in the system performed their jobs, with unanticipated social and technological effects.

When the "Tried and True" Isn't

The USAAF bomber force that arrived in England in August 1942 as the 8th Air Force (8th AF) had a system of doctrine, machines, and humans designed to attack and destroy Germany's industrial infrastructure while defending itself against attack from enemy fighters and defensive flak that was based almost solely on theory. It had never proven itself in practice. Experience soon demonstrated that some of the assumptions used to construct the formations were incorrect. German defensive fighters proved far more deadly than anticipated and caused a great deal of bomber attrition both on the way to and returning from the target. Bombing accuracy was far worse than expected, as the heavy flak batteries around the German targets proved more effective than anticipated, and they disrupted the bomber crew's normal, peacetime-learned bombing procedures, forcing them to maneuver defensively in such a fashion that the bombardier had insufficient time to aim the bombs before the aircraft arrived at the target. As a result, a great number of bombs fell extremely far from their intended impact point.

Shortly after starting the bombing campaign, 8th AF bomber crews discovered that the German defensive fighters were more effective than they expected. After a short period of experimentation, the Germans developed tactics that exploited weaknesses in the American bomber design as well in the bomber formations. The initial version of the B-17 was only lightly armed in the in the forward quarter of the aircraft, with a single .30-caliber machine gun operated by the bombardier providing limited coverage against attack. The Germans exploited this frontal vulnerability and developed head-on attack tactics that were so effective that they caused, by far, the majority of bomber losses. In November 1942, bomber losses to fighter attack averaged 3.7 percent of the attacking force, but rose to 8.8 and 8.7 percent in December and January, respectively, and nearly brought the American daylight offensive to a halt.[92] Efforts to improve

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[92] Jean H. DuBuque and Robert F. Gleckner, *The Development of the Heavy Bomber: 1918-1944*, U.S. Air Force Historical Study 6 (Washington, DC: USAF Historical Division, Air University, August 1951), 119; Arthur

the defensive armament were initiated in the United States, but they could not be implemented right away and a more immediate solution was necessary.

The initial formations used by the 8th AF were intended to provide protection against aerial attack, but were obviously lacking. Although the prewar bombardment doctrine described specific formations up to the largest, or Wing level, the initial 8th AF bombing operations were conducted only at the Group level, with a maximum of twenty seven aircraft. These Group formations were controllable, but did not combine enough firepower to deter enemy air attack. Additionally, the formation's defensive capability was compromised because most bomber crews arrived in the ETO poorly trained in formation flying, and they were consistently unable to fly their aircraft in the tightly packed configuration necessary to provide maximum defensive support. To remedy these problems, 8th AF commanders immediately established a formation training program for new bomber crews and reconfigured the formation to provide more effective defensive support.[93]

Several different formation configurations were considered and tested before the 8th AF units settled on a single, standard solution. Called the "Combat Wing" (Figure 2.3), the new formation consisted of up to 54 aircraft, organized into three "Combat Boxes" of 18 aircraft each (Figure 2.4). The Combat Box consisted of a "wedge" of three squadrons, each of which had six aircraft grouped into two elements of three individual aircraft flying in a "V" formation within about 100 feet of each other. Each successive element in the formation had a designated "lead" aircraft, with the pilot of that aircraft in charge of that part of the formation. This arrangement, as constructed in the prewar doctrine, shared control of the formation hierarchically, and maintained an acceptable workload for those in the lead.

The squadrons echeloned in altitude, as did the groups, which provided excellent maneuverability for the whole formation, as well as a great degree of defensive coverage for the sides and rear of the formation. Forward protection was increased, as well. Because of the placement of the guns in the individual aircraft, the lower squadrons received less coverage from

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B. Ferguson, "The War Against the Sub Pens," in *The Army Air Forces in World War II, Vol. 2-Europe: Torch to Pointblank*, ed. Wesley Frank Craven and James Lea Cate (Washington, DC: 1983. Reprint, Office of Air Force History. Originally published Chicago: University of Chicago Press, 1949), 264-265. The B-24 was more heavily armed in the forward quarter than the B-17, as it had a .50-caliber chin turret located in the nose. However, its coverage was limited by the fact that it could only engage targets below the horizon, leaving the bomber vulnerable to attack from above in the front quarter.

[93] Curtis E. LeMay, *Mission with LeMay: My Story* (Garden City, NY: Doubleday, 1965), 233-235.

the front and were more vulnerable to attack from that quarter. While the low, rear squadron in the Combat Wing came to be known as the "Coffin Corner" or the "Purple Heart Corner" because of this vulnerability, the overall protection afforded the bombardment system as a whole was increased by the new formation.[94]

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[94] Hansell, Jr., *The Air Plan That Defeated Hitler*, 116; LeMay, *Mission with LeMay: My Story*, 257.

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Side View

Tail View

3rd (LOW) SQUADRON

1st (LEAD) SQUADRON

2nd (HIGH) SQUADRON

Plan View

Combat Box Stagger

3rd COMBAT BOX 26,000

LEAD COMBAT BOX 25,000

2nd COMBAT BOX 24,000

Combat Wing-Three Combat Boxes

STANDARD BOMBER FORMATION
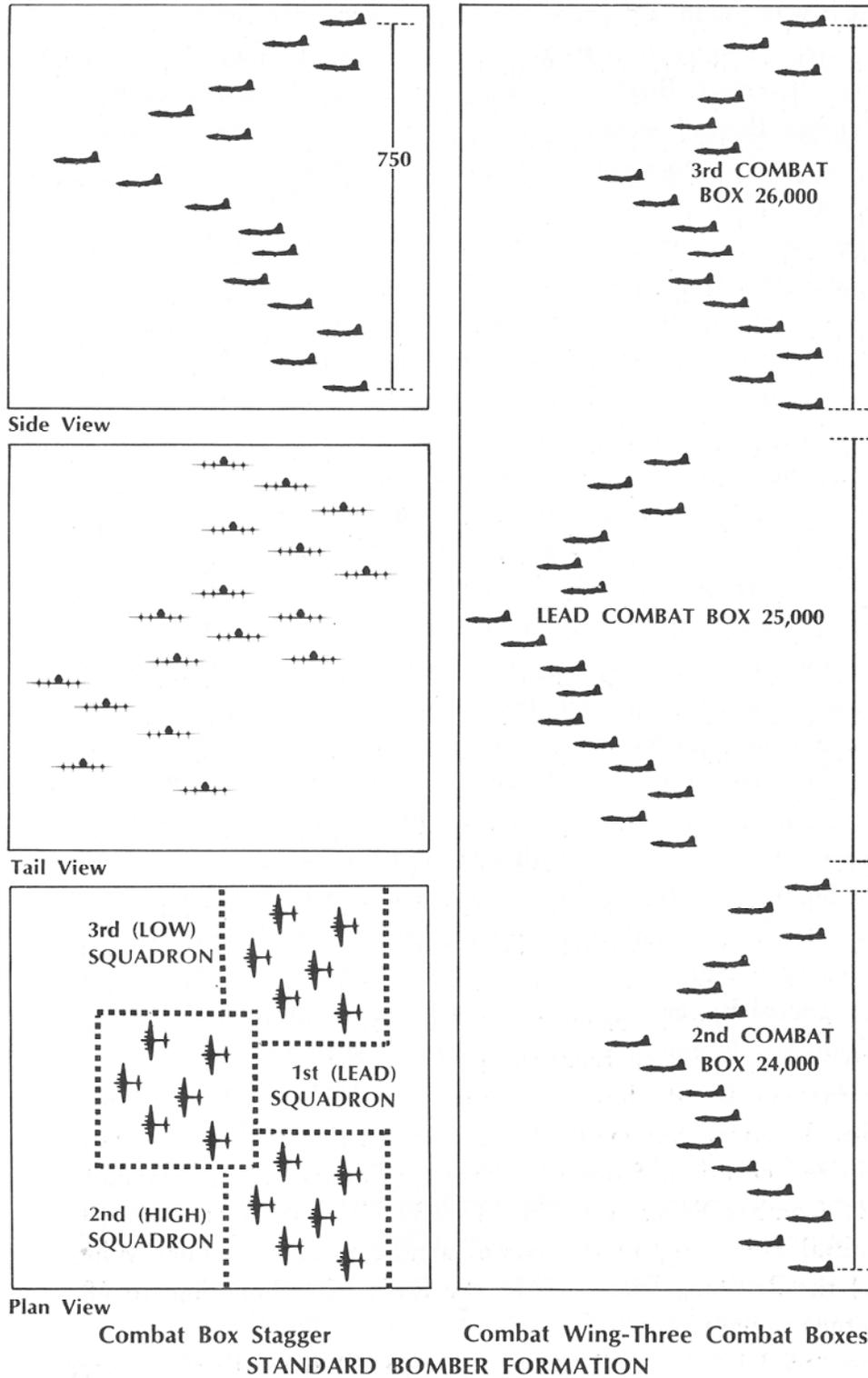
Figure 2.3
Combat Box and Combat Wing formations[95]

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[95] Hansell, Jr., *The Air Plan That Defeated Hitler*, Chart 1, p. 117.

WEDGE FORMATION OF 18-AIRCRAFT GROUPS

ELEMENT
(3 Aircraft)

SQUADRON
(2 Elements of 3 Aircraft)

18 AIRCRAFT GROUP
(3 Squadron of 6 Aircraft)
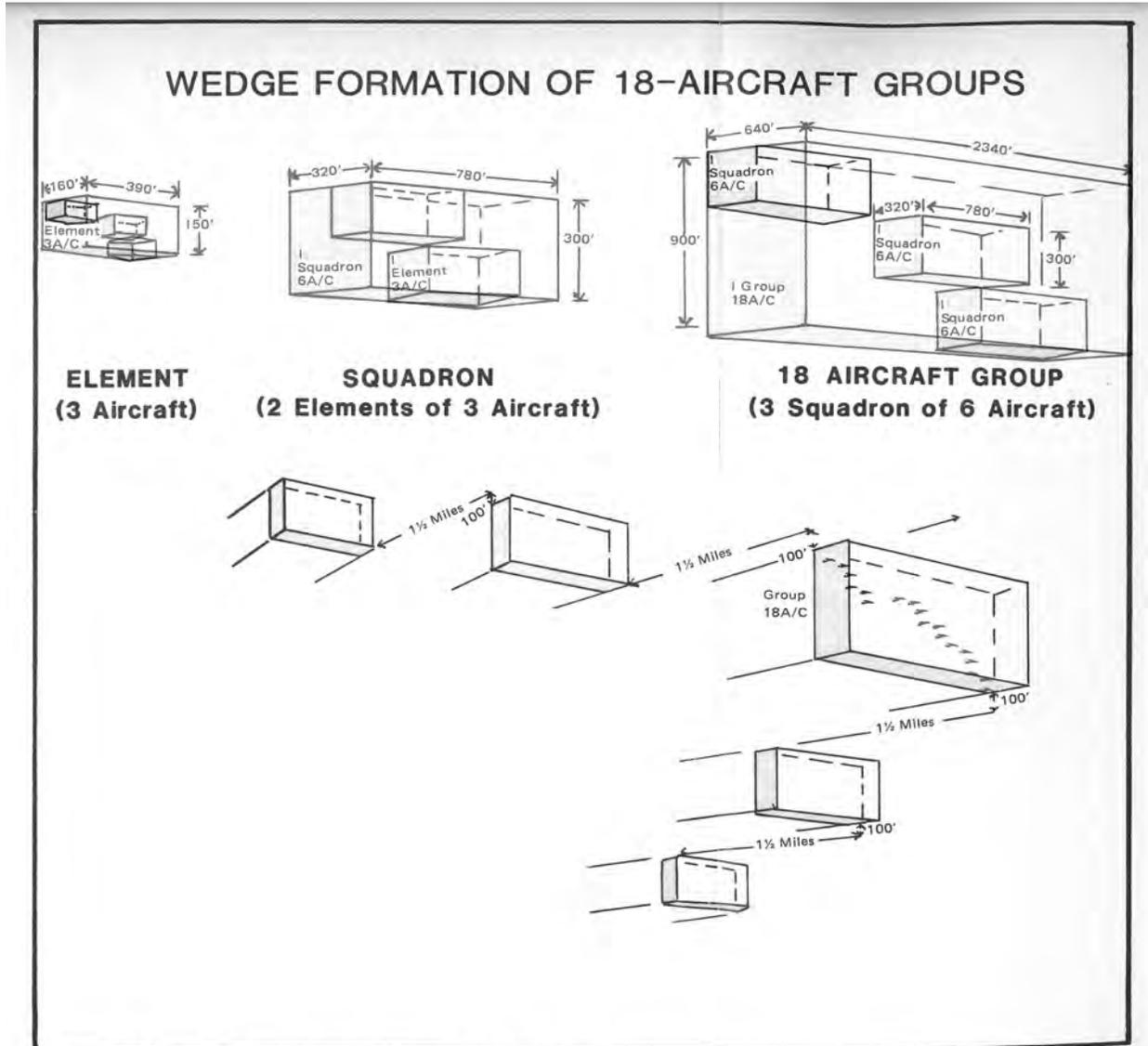
Source: Eighth Air Force and Army Air Forces Evaluation Board, *Eighth Air Force Tactical Development, August 1942-May 1945*, 1945.

Figure 2.4
Combat Box Wedge formation[96]

Precision?

Offensively, 8th AF leaders had to increase the effectiveness of their bombing. Post-mission photographs revealed that from August to December of 1942 only 5 percent of their

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[96] Richard H. Kohn and Joseph P. Harahan, eds., *Strategic Air Warfare: An Interview with Generals Curtis E. LeMay, Leon W. Johnson, David A. Burchinal, and Jack J. Catton* (Washington, DC: Office of Air Force History, U.S. Air Force, 1988).

bombs fell within 1,000 feet of their intended aimpoint.[97] In fact, an average of only 50 percent of the bombs dropped on any given mission could even be identified in the photographs, indicating many extreme misses.[98] This caused little intended destruction, and was certainly not sufficient to execute the plan of destroying enough of the German war-making infrastructure to cause them to stop fighting. They had to increase the accuracy of their attacks if the CBO was to work as planned. Part of the problem, though, was determining how to measure bombing accuracy.

In the early stages of development, the HADPB doctrine had been built on very optimistic assumptions about bombing accuracy. Through the 1920s, precision bombing was unachievable, but with the arrival of the Norden bombsight in 1931, bombing results improved steadily, and some airmen began proclaiming that they could put a bomb "right in a pickle barrel" from high altitude, implying a level of precision that was really attainable only under optimum conditions. Bombing results *did* improve, however, as demonstrated by the performance of the 19th Bomb Group over a period of forty-one days of training during 1935. On the first day, operating at 15,000 feet, they managed only to drop their bombs within 520 feet of the target. Gradually, though, crew performance improved, and by the end of the training period they were able to place their bombs regularly within 164 feet of the target. Missing the target from 164 feet is not a direct hit, but to the men in the Air Corps, "a near bull's-eye from almost three miles up struck us being pretty good."[99]

Evaluating bombing results was not a simple matter of determining whether or not a bomb hit its intended target. In fact, most bombs *missed* their targets. Against many targets, however, it is not necessary to score a direct hit in order to destroy it, because a close enough miss with a bomb of sufficient size may produce enough explosive effect to cause destruction. Bombing accuracy evolved as a concept of determining not only *how far* a bomb fell from its target, but also how far a bomb could be *expected* to fall, probabilistically, from its target. As explained by historian David McFarland, 1st Lt. Kenneth Walker, while an instructor at the ACTS in the early 1930s, developed the concept of the *circular error probable*, or CEP. CEP was a measure of the radial distance from a target within which a given number of bombs could

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[97] Stephen L. McFarland, *America's Pursuit of Precision Bombing, 1910-1945* (Washington, DC: Smithsonian Institution Press, 1995), 173.

[98] Ferguson, "The War Against the Sub Pens," 270.

[99] Arnold, *Global Mission*, 150.

be expected to fall. Using actual bombing data gathered during 329 practice bomb drops from 5,000 feet, Walker determined that the Air Corps could expect that while 25-31 percent of the bombs would hit the target, 50 percent of them would fall within 147 feet. The 50 percent CEP became the standard measure for bombing accuracy.[100]

During the first five months of the bombing campaign, the 8th AF average CEP was 900 feet, which was *twice* the prewar average attained during training missions flown at the same altitudes. One of the principal sources of error was excessive maneuvering in the target area, as the bomber pilots attempted to avoid the heavier-than-expected defensive fire from flak batteries stationed around the target. Prewar doctrine did call for the bombers to shift from their defensive formation to a looser formation in the target area to enable maneuvering, but the doctrine was adversely affecting bombing accuracy. Conventional wisdom among the first group of bomber crews to see combat was that any bomber that flew in a straight line for more than 10 seconds was likely to be hit.[101] However, the bombardier needed a bomb run of at least 50 seconds with the aircraft flying straight and level to correctly operate the Norden bombsight. Maneuvering every 10 seconds made precision bombing virtually impossible and accuracy became inversely proportional with the strength of the resistance at the target.[102]

The solution to the bombing inaccuracy problem came from two sources: changes to the formation used while bombing and the mandatory use of the autopilot during the bomb run. The closely-knit Combat Wing formation proved more effective for survival against air attack, but according to the prewar doctrine, the minimal distance between the individual aircraft made it less than optimal for bombing targets protected by ground-based anti-aircraft defenses. In theory, the close spacing made more aircraft in the formation vulnerable to the enemy fire. Colonel Curtis LeMay, commander of the 305th Bomb Group, questioned the wisdom of this assumption, believing that flak batteries were actually less effective than they were being given credit for. Using the data in a World War I air defense manual, he calculated the probability of an 88mm artillery shell hitting a B-17-sized target at 25,000 feet and determined that it should take 372 rounds to achieve a hit, which made the event seem pretty unlikely.[103]

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[100] McFarland, *America's Pursuit of Precision Bombing*, 84.
[101] Ibid., 169; LeMay, *Mission with LeMay: My Story*, 230.
[102] "The War Against the Sub Pens," 270.
[103] LeMay, *Mission with LeMay: My Story*, 237-239.

Given that, he directed that his bombers remain in the defensive, more closely spaced Combat Box rather than shifting to the looser formation called for by doctrine during the bomb run, and mandated that the formation not maneuver until the bombardiers dropped their bombs. While this gave the bombardiers ample time to operate their bombsights, the dictates of maintaining the tighter formation meant that the individual bombers would not be able to maneuver to drop their bombs in the individual precision manner in which they had been trained, so LeMay implemented the "drop-on-leader" bombing doctrine. During drop-on-leader, only the bombardier in the group's lead aircraft used his Norden bombsight, and when he released his bombs, the rest of the bombardiers in the formation did the same.[104] This new procedure transformed the bombardment system from a conglomeration of 54 individual bombing elements into a single bombing element. The drop-on-leader doctrine was soon adopted by all of the 8th AF bomber groups, and became the standard bombing procedure for the USAAF forces participating in the CBO. As will be seen in succeeding chapters, LeMay's decision had a significant impact not only on how the bomber crews accomplished their jobs, but also on the social and physical structure of the crew as a socio-technical system.

Since the individual bombardiers no longer aimed their bombs, the traditional measure of accuracy, the CEP, became irrelevant, and the adoption of the drop-on-leader doctrine forced a redefinition of accuracy. The results of the individual aircraft were not germane, except within their role as a part of the formation overall. It was no longer a matter of determining how close bombs fell on fifty-four individual aimpoints, rather, how close the formation's bombs as a whole fell in relation to a single aimpoint. The new measure of bombing accuracy became the formation's "mean point of impact," or where the majority of its bombs hit the ground. After a bombing mission, photo interpreters drew a 1,000-foot circle around the greatest concentration of bomb hits, and the distance from the center of that circle to the intended aimpoint became the new measure of the formation's accuracy. Additionally, they measured the percentage of bombs that fell within that 1,000-foot circle, as a measure of formation bombing effectiveness.

For maximum effectiveness, the drop-on-leader doctrine required that the lead aircraft fly as precisely as possible while leading the rest of the bombers to the aiming point. As will be explained in Chapters 4 and 5, the Minneapolis-Honeywell C-1 Autopilot in the B-17, coupled to the Norden bombsight and controlled by the bombardier, produced the most accurate bombing

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[104] Ferguson, "The War Against the Sub Pens," 272.

results. LeMay mandated that each lead aircraft fly the bomb run with the autopilot engaged, enabling the bombardier to control the aircraft until he released the bombs.

The final major change LeMay implemented was the creation of the "lead crew." He realized that lack of preparation for the day's mission was making it difficult for bomber crews to find and identify the target. Most of the time, the first time a bombardier found out which target he was bombing was at the mission brief the morning of the mission, so there was little time to get familiar with the particular civil and geographical features that would help him find it. In LeMay's words, "there's a lot of difference between bombing circles in the desert and bombing the northeast corner of a factory building in the midst of an industrial buildup with industrial haze, bad weather, and poor visibility, etc."[105] The crews were rushed during the bomb run, and frequently identified the target too late to conduct an accurate bomb drop.

Although doctrinally each formation had a designated leader before the implementation of the drop-on-leader doctrine, he was only the lead *pilot* in the formation, responsible for orchestrating its airborne maneuvers. There was no formal equivalent lead bombardier or navigator position in the formation. LeMay created positions for lead bombardiers and lead navigators and gave them the responsibility for becoming intimately familiar the targets in a particular geographical area, and when a mission called for an attack on one of those targets, they would fly in the lead aircraft.[106]

The lead crews were selected based upon merit, rather than rank. They were the best at their jobs, and while some crews earned the distinction as an entire crew, others were assembled from members of different crews. Selection as a lead crew or for membership on a lead crew was a direct acknowledgment of demonstrated skill and ability, and it separated those individuals from the "rank and file" of the other bomber crews. It also carried a heavy burden of responsibility and increased danger. If the navigator missed a checkpoint or the bombardier misidentified the target, it affected the entire formation, and the whole mission could end in failure.[107] Since they flew in the front of the formation, the lead crews were the most exposed to the Luftwaffe fighter's head-on attack tactics, and they suffered a disproportionate number of

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[105] General Curtis E. LeMay, "Interview with General Curtis E. LeMay," interview by Col. Bill Peck, Oral History Transcript, March 1965, K239.0512-785 C.1, IRIS No. 1000342, US Air Force Historical Research Agency.

[106] LeMay, *Mission with LeMay: My Story*, 256-257.

[107] Thomas Childers, *Wings of Morning: The Story of the Last American Bomber Shot down Over Germany in World War II* (Reading, MA: Addison-Wesley, 1995), 148-149.

losses. As such, lead crews were required to fly only 30 missions to complete their tours of combat duty, rather than the 35 required of non-lead crews.[108]

The combined effect of adopting the Combat Wing and Combat Box formations for both offensive and defensive employment, the decision to enforce longer bomb runs and use of the autopilot during them, and the creation of the lead crew improved 8th AF bombing accuracy. Through the first nine months of 1943, as the new changes were being implemented, the average formation CEP was 1,130 feet and 24% of the bombs fell within the desired 1,000 foot circle. Over the next six months, accuracy improved to an 820-foot CEP, and 40 percent of the bombs fell within the circle.[109] Certainly improved, but far from the "pickle-barrel" bombing anticipated in the 1930s. During 1943, out of 100 bombers attacking a target, on average only 16 dropped their bombs within 1,000 feet of the target.[110]

Entering the war in 1942, the 8th AF employed a bombardment system constructed from and guided by a prewar bombardment doctrine based upon years of theoretical development and essentially no operational experience. It was neither tried nor, as experience would show, true. When initial bombing results proved less than satisfactory, 8th AF leadership could not change the human or machine elements of the system, so they had to change the way that those elements were used. They could not immediately improve bomber defensive capability or invent a new, more accurate bombsight, but by rearranging the elements and altering their use, they sacrificed individual performance and improved the system's overall performance.

The prewar doctrine imposed insufficient control on the bombardment system given the realities of the defenses faced during the CBO. Changing the formations employed by the bombers and implementing the lead crew construct improved that control, as evidenced by the increase in bombing accuracy, and also fundamentally changed how bombing accuracy was measured, with overall system accuracy and effectiveness taking precedence over individual bombing accuracy. In addition to changing the physical structure of the bombardment system, it also changed the social structure by identifying an elite group, designated as such by their

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[108] "2d Bombardment Wing Instructions No. 35-13B: Personnel, Military, Relief of Combat Crew Personnel", January 5, 1945, 1, Microfilm roll B5337, File 526.179, US Air Force Historical Research Agency. In the early phases of the CBO, a crew completed its combat tour after flying 25 combat missions. As the allies gained air superiority over the European continent and bomber losses diminished, the required number of missions was increased. The crew of the *Memphis Belle* was the first to complete their 25 combat missions during the CBO.

[109] Hansell, Jr., *The Air Plan That Defeated Hitler*, 119.

[110] McFarland, *America's Pursuit of Precision Bombing*, 173.

demonstrated superiority over their peers, who had different jobs and a larger role in the control of the system. Bombing accuracy did not improve as much as was desired, but the change in how the system was employed, the doctrine guiding its use, did have a positive effect on system precision.

Conclusion

The bombardment system employed by the 8th Air Force during the CBO was a true socio-technical system, consisting of a set of interdependent parts—ideas, humans, and machines—all working together to achieve a common purpose. The technologically focused view of the system at its simplest level as "a relatively fast, high-altitude, long-range airplane, and a precise optical bombsight" ignores the fundamental relationship between those machines and the humans that operated them.[111] It was not machines that that made up the system at the simplest level, but human-machine systems, teams of humans and machines that were incapable of performing their mutual task without one another.

John Steinbeck, in *Bombs Away*, his wartime account of the creation of the human team that occupied and operated the bomber aircraft and bombing machines, presented a more inclusive view, acknowledging the link between human and machine.

> The long-range bomber is an intricate an marvelous machine capable of climbing to great altitude, capable of tremendous range, capable of carrying great bomb loads; but it is still only as good as its bomber crew. It is only a machine. It can only fly as well as its pilot can fly it an only arrive at the point toward which its navigator can direct it.[112]

However, this view of a human-machine system still excludes a vital element—the beliefs and ideas that formed these humans and machines into a mutually defined team—the doctrine of precision bombing that gave them a reason to exist. Opening the black box that defines the system's physical limits allows us to see how this doctrine is part of the system—how the ideas and beliefs that it encapsulated led to the creation of the system and how the experience gained using the system modified those very same ideas and beliefs.

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[111] Moy, *War Machines*, 33.

[112] Steinbeck, *Bombs Away: The Story of a Bomber Team*, 9.

The precision bombing doctrine developed in the 1930s gave shape to the bombardment system, defining its purpose, its components, and how those components were to be used. Formed from unproven theories and beliefs, the HADPB doctrine constructed a three-level system of socio-technical elements and ideas about how to employ them. At the lowest level, it created individual socio-technical elements, focused on a single task. At the intermediate level, it combined those elements into a single socio-technical unit, defined by the specially designed bomber aircraft that encapsulated them. At the highest level, it combined those units into a single, more powerful socio-technical system whose employment was guided by the ideas that created it. The HADPB doctrine created a hierarchy of capability, embedding control at each level to ensure that the system could operate in harmony to achieve its purpose. It also created a social hierarchy, privileging certain humans over others based upon their role in the system.

While the prewar HADPB doctrine shaped how the system was used in the opening stages of the CBO, failure to achieve the desired results with the system as constructed forced a reevaluation of the underlying ideas about how the system *should* be used. Changing the offensive formation doctrine decreased the performance of the individual system elements but increased the overall system performance, in turn redefining the measure of accuracy. It also redefined the roles of individual elements in the system, in some cases fundamentally changing how humans and machines interacted at the individual level to accomplish their task within the system, and changing how the humans did their jobs and how they fit into their professional social structure. The manner in which the HADPB doctrine shaped this human-machine relationship is the focus of the next three chapters.

Chapter 3

Command and Shared Control—Flying and the Pilot as the System Controller

Bremen. Friday, 8 October 1943. In the left seat of the cockpit of B-17 42-3393, Just-A-Snappin', *pilot 1ˢᵗ Lt. Everett Blakely took the runway ahead of the entire 3ʳᵈ Combat Wing. He guided the heavy bomber down the runway, eased it into the air, and followed the heading passed by his navigator, Harry Crosby, that would take them to the formation rejoin point. As the lead, he had to arrive at the rendezvous first, as all of the bombers in the 100ᵗʰ Bomb Group, and eventually the 3ʳᵈ Combat Wing, were to join on his aircraft.*

In the right seat, Major John Kidd, the mission command pilot, worked closely with Crosby and Blakely, orchestrating the aerial ballet that was the formation rejoin. He watched as the 100ᵗʰ Group's bombers took their positions, giving direction over the radio when necessary to clear up any confusion. Clear weather facilitated the assembly process, and they finished in a record eighteen minutes. Shortly thereafter, the 390ᵗʰ and 95ᵗʰ Bomb Groups took their positions in the Combat Box, completing the 3ʳᵈ Combat Wing.

At the appointed time, Blakely departed east over the English Channel, following the course set by Crosby. Maintaining a steady 150 mph, he left the formation pilots a power margin that enabled them to easily keep their aircraft in the safety of the Combat Box. Approaching the Initial Point, enemy fighters attacked, but Blakely continued toward the target under Crosby's direction, and he engaged and adjusted the autopilot to maintain level flight.

Once past the Initial Point with the target area in sight, Blakely transferred control of Just-A-Snappin' *to his bombardier, James Douglass, for the bomb run. Thirty seconds before the bomb dropping point, a burst of flak struck the aircraft and penetrated the Plexiglas nose, but Douglass remained steady, controlling the aircraft through his Norden bombsight. As the bombs fell from the aircraft, Blakely retook control, immediately turning away from the target. At that same instant, another burst of flak destroyed the number four engine and damaged several flight control surfaces, forcing the bomber into an aggressive dive.*

The stricken aircraft fell 3,000 feet, tossing the crew about the aircraft while Blakely and Kidd wrestled to control it. As Blakely recovered level flight, Kidd alertly transferred lead of the formation to the deputy lead aircraft, since they could no longer maintain that position in their damaged condition. With only three engines, they fell out of the protection of the formation, and from that point, they were on their own for the 200 miles journey back to England. Following Crosby's direction, Blakely nursed the damaged bomber westward, all the while orchestrating a running battle against attacking defensive fighters.

Limited 120 mph and continually losing altitude, Blakely considered ditching in the English Channel, however, several of the crew were severely injured and unlikely to survive such an event. Unable to reach Thorpe Abbots, he chose to land at an abandoned airfield near Coltishall. Upon touch down, the brake cables snapped and Blakely could neither steer nor stop the aircraft. Careening down the runway, Just-A-Snappin' *hit a tree, coming to an abrupt, crunching halt. Although the aircraft was destroyed, Blakely was successful—the formation had reached the target, bombed it, and everyone in his aircraft had returned safely to England (one crew member died later from wounds suffered during the mission).*[1]

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[1] Adapted from Edward Jablonski, *Flying Fortresses: The Illustrated Biography of the B-17s and the Men Who Flew Them* (Garden City, NY: Doubleday & Company, Inc., 1965), 184-195; Frank D. Murphy, *Luck of the Draw: Reflections on the Air War in Europe* (Trumbull, CT: FNP Military Division, 2001), 141-142; Harry

Introduction

This chapter examines the flying and control element of the bombardment system and focuses on the bomber pilot. It describes system control at the single aircraft and larger formation levels as a process of shared control between a specially trained human operator, the pilot, and several humans and machines based upon their unique capabilities. First, it describes the development of the bomber pilot from initial creation as a technical specialist, valued for his flying skill, to a generalist and commander, valued for his skill as a system controller and military commander. Second, it describes the pilot's actions on a bombing mission, exploring the complex nature of controlling the bombardment system at the aircraft and formation levels, and how the doctrine of HADPB and the machines he used to execute that doctrine shaped those actions. Third, it explores how the pilot, as the aircraft commander, shared control with the copilot, navigator, and bombardier to accomplish the mission. Finally, it examines the introduction of the autopilot and the pilot's acceptance of it as a machine that enhanced his command of the aircraft through the ability to share control of the flying task, and how its use created the need for the pilot to develop a new skill set.

Getting to the Target—and Back

During the Combined Bomber Offensive (CBO), a typical bomber mission began with the General Briefing, held in a large briefing room in the Group Operations building. There, the bomber crews gathered after eating breakfast to find out the details of their upcoming mission. Depending on the size of the mission, up to two or three hundred men might pack themselves into the room, and for most of them, the General Briefing was the first time that they would be told the location of the target for the day's mission. At the start of the briefing, much as portrayed in the movies, the Group Commander or Group Briefing Officer walked to the front of the room, perhaps up onto a stage, and pulled back a curtain, behind which was hidden a map of Britain and western Europe. On the map, a red woolen line connected one dot that represented their home base to another dot, likely hundreds of miles away, that represented their intermediate

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Crosby, *A Wing and a Prayer: The "Bloody 100th" Bomb Group of the U.S. Eighth Air Force in Action Over Europe in World War II* (New York: Harper Collins Publishers, 1993), 127-135; "Black Week - Bremen", n.d., http://www.100thbg.com/mainpages/history/history4/bw_bremen.htm, accessed 26 December 2010; *Combat Chronology, 1941-1945* (Washington, DC: Center for Air Force History, 1991), 199; Ian L. Hawkins, *B-17s over Berlin: Personal Stories from the 95th Bomb Group (H)* (Brassey's Inc, 1995), 170-171.

destination—the target (Figure 3.1).[2] Their final destination was, they hoped, the same place that they started the day. In that moment, the map defined their universe for the next twelve hours or so.

Figure 3.1
The large-scale mission map for Mission No. 327 to Berlin, 29 April 1944[3]

Every crewmember in the room had a particular interest in that line. The navigators were concerned with the line's direction, turns, and length. The bombardiers were concerned with the line's midpoint, its sharp reversal marking the target location. The pilots in the room were concerned with what the line represented, the mission as a whole, and how they were going to *fly* that line, orchestrating and controlling the massive formation of groups, squadrons, elements, and individual bomber aircraft so that they could achieve their objective—precision bombing of the target for the day. They were an elite group, both technically skilled specialists and team leaders, chosen from among the best flight training candidates for their skill and judgment, and ultimately responsible not only for the achievement of the mission's objectives, but for the safety of the men on their crews all the way to the target and back, as well.

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[2] Elmer Bendiner, *The Fall of Fortresses: A Personal Account of the Most Daring-and Deadly-American Air Battles of World War II* (New York: Putnam, 1980), 90-92. This scene played out at all of the bases in the ETO, and is described with minor variations in virtually every memoir covering bombing operations during the war.

[3] This is a picture of the map revealed to the B-24 crews of the 392d Bomb Group, stationed at Wendling, near Norwich, England, on the morning of their 29 April 1944 mission to Berlin. "The Berlin Bombing Mission Flown by The 8th Air Force on April 29, 1944--Map 392 route Berlin.jpg", April 29, 1944, http://www.b24.net/stories/annette.htm (accessed 4 March 2011).

The Pilot as the Technical Specialist

The age of the military pilot began on 30 July 1909, when the United States Army bought its first powered, heavier-than-air aircraft from the Wright brothers, a Wright A that became *Army Aeroplane No. 1* (Figure 3.2). On that day, Orville Wright took off from Fort Myer, Virginia, accompanied by passenger and navigator Lieutenant Benjamin D. Foulois, for a ten-mile round trip speed trial, with Alexandria, Virginia, marking the halfway point.[4] Orville's purpose was to demonstrate to the U.S. Army Signal Corps that he and his brother, Wilbur, could produce a controllable aircraft that met the Army's requirements to lift 350 pounds, including fuel enough for a 125-mile flight, and achieve a top speed of at least thirty-six miles per hour (mph).[5] Foulois, assigned as the Army's official observer for the trial, was one of the few Army officers who had shown an interest in aviation. Initially believing that he had been selected for the task because of his intellectual and technical abilities, Foulois later found out that he was chosen for his "short stature, light weight, and map-reading experience."[6] His diminutive size and skill with a map boosted the Wrights' chance for success, as extra weight was sure to slow down the aircraft and getting lost would add time to the trip.

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[4] Benjamin D. Foulois, *From the Wright Brothers to the Astronauts: The Memoirs of Benjamin D. Foulois* (New York: McGraw-Hill, 1968), 1-2; Alfred F. Hurley and William C. Heimdahl, "The Roots of U.S. Military Aviation," in *Winged Shield, Winged Sword: A History of the United States Air Force (Volume I: 1907-1950)*, ed. Bernard C. Nalty, vol. 1 (Washington, D.C: Air Force History and Museums Program, 1997), 13-14.

[5] Brigadier General James Allen, Chief Signal Officer of the Army, "Signal Corps Specification, No. 486: Advertisement and Specification for a Heavier-Than-Air Flying Machine (23 December 1907)," in *How Our Army Grew Wings: Airmen and Aircraft Before 1914*, by Charles deForest Chandler and Frank P. Lahm (New York: The Ronald Press Company, 1943), 300.

[6] John F. Shiner, *Foulois and the U.S. Army Air Corps, 1931-1935* (Washington, DC: Office of Air Force History, U.S. Air Force, 1983), 2; Foulois, *From the Wright Brothers to the Astronauts*, 63.
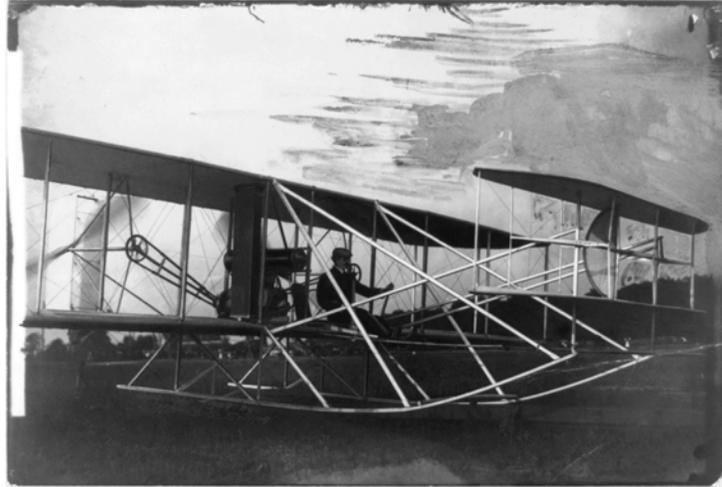
Figure 3.2
Orville Wright in *Army Aeroplane No. 1* at Fort Meyer, Virginia[7]

Orville completed the first half of the trial course averaging 37.735 mph, but had trouble finding the balloon that marked the turn point in Alexandria. It had blown close to the ground and was very difficult to detect, causing him to fly beyond the prescribed limits of the course. Regardless, he averaged 47.431 mph during the return leg for an overall average of 42.583 mph, easily establishing a new world record for a two-man flight. Wright and Foulois set two other world records on the flight: one for accomplishing a 10-mile cross-country flight, and the other for attaining the record altitude of 400 feet.[8] The success netted the Wright brothers the contract award of $25,000, as well as an additional $5,000 for exceeding the desired top speed of 40 mph by a full two miles per hour.[9] In return, the U.S. Army received the aircraft and an agreement that the Wrights would instruct two men in "the handling and operation of (the) flying machine."[10] Foulois was one of those two men.

Learning to fly the Wright aircraft was a significant physical and cognitive challenge for Foulois. Handling and operating the flying machine in the way that Orville Wright had during the trial was no simple task. Although missing the turn point at the middle of the course had

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[7] *Orville Wright at start of flight, Fort Meyer, Va.*, Photograph, June 29, 1909, George Grantham Bain Collection (Library of Congress), Library of Congress Prints and Photographs Division Washington, DC.

[8] Foulois, *From the Wright Brothers to the Astronauts*, 65.

[9] Tom D. Crouch, *The Bishop's Boys: A Life of Wilbur and Orville Wright* (New York: W.W. Norton, 1989), 399; Foulois, *From the Wright Brothers to the Astronauts*, 59.

[10] Allen, Chief Signal Officer of the Army, "Signal Corps Specification, No. 486: Advertisement and Specification for a Heavier-Than-Air Flying Machine (23 December 1907)," 297.

nearly upset the Wrights' chances of success during the trial flight, neither navigation nor finding the target had been Orville's principal challenge. In his memoirs, Foulois noted

> The air was bumpy, and I had the feeling that there were moments when Orville didn't have full control of the machine as we dipped groundward. It was as if someone on the ground had a string attached to us and would pull it occasionally as they would a kite. But each time Orville would raise the elevators slightly, and we would gain back the lost altitude.[11]

The Wright A represented the leading edge of aeronautical technology, but it was truly primitive. Designed for no mission other than powered flight, maintaining basic aircraft control was a huge task in itself.

Army Aeroplane No. 1 was a very close derivative of the *Wright Flyer*, and as such its flight control system was a complex technological array comprised of cables, rods, pulleys, and levers which required extensive study and practice to master. More "mechanical than instinctive," it consisted of two levers which governed the aircraft's flight path, one for each of the pilot's hands.[12] The left-hand lever, which moved fore and aft along the aircrafts longitudinal axis, controlled the aircraft pitch by moving the elevator. Intuitively, when the pilot pushed the lever forward, the nose of the aircraft pointed toward the ground causing it to descend, while pulling the lever back pulled the nose up, causing the aircraft to climb.

The operation of the right-hand lever was far less intuitive. Used to control the aircraft roll by warping the wings, it too moved along the aircraft's longitudinal axis, although it induced motion along the lateral axis. The pilot moved the lever forward to induce left bank and backward to induce right bank. The top portion of the lever was hinged laterally, providing the pilot control of the aircraft rudder. Rotating the stick to either side of the aircraft caused the rudder to move in the same direction, enabling the pilot to perform coordinated turns in flight. This complex control arrangement meant that in order to turn to the right, the pilot had to pull *back* on the right hand lever while twisting his wrist to the right. Left hand turns were performed

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[11] Foulois, *From the Wright Brothers to the Astronauts*, 64.

[12] Juliette A. Hennessy, *The United States Army Air Arm, April 1861 to April 1917* (Reprint. Washington, DC, 1985: Office of Air Force History, U.S. Air Force, 1958), 93.

by pushing *forward* on the lever while twisting the wrist to the left. This "scarcely intuitive" arrangement caused at least one aircraft accident in the first year of Army aviation.[13]

Foulois took *Army Aeroplane No. 1* to Fort Sam Houston, Texas and established the Army's first heavier-than-air flying operation, essentially teaching himself to fly, as he had received less than an hour of flight instruction from the Wright brothers, none of it solo. It was his eventual mastery of the complex flight control system and his ability to control the aircraft in flight and make it respond to his will—to fly the aircraft—that changed him from an Army officer interested in aviation into a *pilot*. That ability to control the aircraft became, and remains, the skill that defined the pilot.

As explained by Wolfgang Langewiesche in his classic book on the art of flying, *Stick and Rudder*, aircraft operate in opposition to many conventional notions. They are safer when they are faster rather than slower, when they are higher rather than lower. The pilot must learn to accept many overtly contrary notions, such as when faced with an emergency such as a stall or a spin with the aircraft plummeting toward the ground, the only way to recover controlled flight and keep from crashing is to actually point its nose at the ground.[14] Learning to fly involves the mastery of a discrete body of knowledge, and flying is a distinct skill—a process of learning and accepting those notions and translating them into the physical environment of flight.

Early Army flight training focused on the basics of aircraft control—takeoff, turning, and landing—but accidents and death were common. From 1909 to 1914, twelve airmen out of a total flying corps of fifty-five were killed in aircraft accidents.[15] Army leadership recognized the dangerous nature of flying, and restricted flight training to young volunteers, "ideally captains of not more than five years of service in that grade, or unmarried lieutenants, of medium weight."[16] Neither prior experience nor knowledge of aviation was a prerequisite for selection, although courage, dexterity, and enthusiasm were desired attributes. Additionally, an exceptional sense of

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[13] Crouch, *The Bishop's Boys*; Hennessy, *The United States Army Air Arm, April 1861 to April 1917*; Henry H. Arnold, *Global Mission* (New York: Harper, 1949), 18-19.

[14] Wolfgang Langewiesche, *Stick and Rudder: An Explanation of the Art of Flying* (New York: McGraw-Hill Book Company, Inc., 1944), 3.

[15] Hennessy, *The United States Army Air Arm, April 1861 to April 1917*, 101-102, Appendix 14, 236-238. To this day, the initial phase of pilot training focuses on takeoff, landing, and the basics of aircraft control.

[16] Rebecca Hancock Cameron, *Training to Fly: Military Flight Training, 1907-1945* (Washington, DC: Air Force History and Museums Program, 1999), 30.

equilibrium was valued, as detecting and quickly correcting the rapid, minute changes in attitude and balance helped pilots maintain aircraft control.[17]

Thomas DeWitt Milling, one of the Army's premier polo players and a 1909 graduate of West Point, fit the developing profile of the military pilot—"the independent young man who embraced excitement and the element of risk."[18] Milling quickly distinguished himself as one of the Army's best pilots, exhibiting skill in all phases of flight. Grover Loening, an aeronautical engineer employed by the Wright Company, remembered him as "one of the first real natural-born flyers. He had a cool daring, a fine hand, and a very keen set of senses…he soon had become the leading and most skillful pilot at that time in the government service."[19] Milling became the first Army pilot to fly at night, and was the only pilot in the early group of aviators who became comfortable flying airplanes with completely different control mechanisms.[20]

Although Foulois spent nearly all of his time in Texas learning to fly *Army Aeroplane No. 1*, he also gained a great deal of experience fixing it. Since he had little instruction, most of his landings were actually controlled crashes, and the Army had no trained aircraft mechanics to repair the resultant heavy damage.[21] Since he alone was responsible for keeping the aircraft in safe flying condition, understanding how it was built and how its systems operated enabled him to make the frequent repairs, and became as important to his survival as learning how to fly. In this respect, Foulois' experience mirrored that of all of the Army's early aviators.

Early pilot training was both a physical and technical education, and the acquisition of flying skill and technical knowledge became intertwined, essentially merging into a single skill set. Trainees spent long hours learning how to assemble, disassemble, and repair aircraft, while at the same time learning how to control them in the air.[22] Knowledge of engine and flight control operation was necessary not only to fix the aircraft on the ground, but also a critical part of understanding how the aircraft as a system worked in the air. Pilots were trained to recognize any slight change in oil or water pressure or the flicker of an ammeter needle and interpret its

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[17] Vance O. Mitchell, *Air Force Officers: Personnel Policy Development, 1944-1974* (Washington, DC: Air Force History and Museums Program, United States Air Force, 1996), 351.

[18] Cameron, *Training to Fly*, 30; "Biographies: Brigadier General Thomas D. Milling", n.d., http://www.af.mil/information/bios/bio.asp?bioID=6480 (accessed 30 September 2010).

[19] Grover Loening, *Our Wings Grow Faster* (Garden City, NY: Doubleday, Doran & Co., Inc., 1935), 19-20.

[20] Foulois, *From the Wright Brothers to the Astronauts*, 96; Cameron, *Training to Fly*, 33.

[21] Foulois, *From the Wright Brothers to the Astronauts*, 70-78.

[22] Arnold, *Global Mission*, 17; . For a comprehensive account of early flying training, see Cameron, *Training to Fly*.

meaning. While such a change might mean nothing, it could presage disaster, and the pilot had to learn which and "govern his actions accordingly."[23] The emphasis on technical knowledge became a central part of flight training as it could save the pilot's life, but thorough aircraft knowledge was also seen as necessary for mission success.[24]

Army leadership recognized the importance of aircraft technical knowledge as an integral part of the pilot's skill set, but also its importance to the success of the Army's aviation mission, as well, and formally established him as a technical expert in Air Corps doctrine by making him alone responsible for ensuring that his aircraft could perform the assigned mission. The 1924-1925 *Bombardment* text used at the Air Corps Tactical School explained that, as the bombardment pilot "habitually takes his plane deep into hostile territory," it was necessary that he prepare for such flights by "making sure that every part of his motor and his plane is functioning properly" so that he did not lose such a valuable piece of equipment or fail at his mission.[25] The doctrine made the pilot personally responsible for testing the aircraft and seeing to it that it was "full of gas, oil and water and all ready to take off."[26] This emphasis on thorough technical knowledge remained a consistent theme in bombardment doctrine through the 1920s, but as will be seen, subtly shifted as the necessary number of tasks grew and the bombardment system grew in complexity.

Skill and Professional Distinction

Soon after it began aviation operations, the Army recognized that pilots developed specific skills that separated them from their peers, just as skill with horses separated cavalry officers from infantry or artillery officers. On 23 February 1912, War Department Bulletin No. 2 established the rating of "Military Aviator," a distinction limited to those commissioned officers of the Regular Army or Organized Militia who could, in a powered aircraft,

> attain an altitude of at least 2,500 feet, fly in a 15-mile-per-hour wind, carry a
> passenger to a height of at least 500 feet and immediately make a dead-stick

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[23] *Bombardment: 1924-1925* (Langley Field, VA: Air Service Tactical School, 1924), 41.

[24] The emphasis on technical and aircraft systems knowledge persists to this day in USAF pilot training. Pilots learn basic aerodynamics as well as how the individual systems are constructed and operate. Although pilots no longer fix their own aircraft, thorough knowledge of system operation is necessary in flight, particularly when handling a system malfunction or emergency.

[25] *Bombardment: 1924-1925*, 41.

[26] Ibid.

landing within 150 feet of a previously designated point, and make a military reconnaissance cross-country flight of at least 20 miles at an average altitude of 1,500 feet.[27]

This new rating firmly established the aviator, by definition a pilot at that time, as a technical specialist possessing measurable skills and associated with a specific machine—the aircraft. It also formally established pilots as a separate social group within the Army, with membership limited to those who possessed those skills. That skill and distinction, however, was not regarded universally well within the service. Many in the Army perceived these early pilots as "irresponsible, irrepressible playboys" who preferred to operate as loners, and viewed them with a certain measure of professional disdain.[28]

On 18 July 1914, Congress passed a law that further distinguished the pilot as a separate, technical specialist and in the process further alienated aviators from much of the mainstream Army. House Resolution (H.R.) 5304, enacted as *Public Law Number 143, An Act to Increase the Efficiency of the Aviation Service of the Army, and for Other Purposes*, established the Aviation Section of the Signal Corps, giving aviators a small measure of organizational autonomy by charging it with

> the duty of operating or supervising the operation of all military aircraft, including balloons and aeroplanes, all appliances pertaining to said craft, and signaling apparatus of any kind when installed on said craft; also with the duty of training officers and enlisted men in matters pertaining to military aviation.[29]

The law limited the selection of aviation officers to those below the rank of Captain and limited the selection of new trainees to "unmarried lieutenants of the line of the Army not over thirty years of age." It also established a one-year time limit for flying trainees to demonstrate "their fitness or unfitness for the detail as aviation officers."[30] If a trainee could not develop the necessary skills and learn to fly within one year, he returned to his former duty.

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[27] Hennessy, *The United States Army Air Arm, April 1861 to April 1917*, 58-59.

[28] Major General James E. Fechet, *Flying* (Baltimore, MD: The Williams & Wilkins Company, 1933), 69.

[29] *An Act To Increase the Efficiency of the Aviation Service of the Army, and for Other Purposes (H.R. 5304)* (Public Law Number 143, 18 July 1914 63rd Cong., 2nd sess., 1914), quoted in Chase C. Mooney and Martha E. Layman, *Organization of Military Aeronautics: 1907-1935 (Congressional & War Department Action)*, Army Air Forces Historical Study 25 (Washington, DC: Assistant Chief of Air Staff, Intelligence, Historical Division, December 1944), Appendix 1, p. 110, hereafter H.R. 5304.

[30] *H.R. 5304*, Sec. 2.

In recognition of the inherent dangers associated with aviation duty, H.R. 5304 mandated that "no person, except in time of war, shall be assigned or detailed against his will to duty as an aviation student or an aviation officer."[31] In order to keep the Aviation Section manned at the required level, it also enacted a measure to attract officers to aviation duty in spite of the danger. The law authorized aviators extra pay for aviation duty, over and above their regular Army salaries. Aviation trainees received a twenty five percent pay raise and, when they became fully qualified, were awarded a promotion of one grade in rank, provided they were not currently above the rank of first lieutenant. Qualified aviators received a fifty percent raise when their duties required them "to participate regularly and frequently in aerial flight."[32] This special treatment generated a great deal of ill will among Regular Army officers, as the new promotion policy moved younger officers ahead of many senior to them, affecting their chances of advancement and promotion. They also strongly resented the additional pay, a sentiment that remains to this day among many non-aviators in the military.[33] Technical specialty, promotion, and extra pay, however, had a price. Pilots bristled at the age limitations imposed upon them by H.R. 5304, as well as the marriage restriction.[34]

These two events, the creation of the of the Military Aviator rating and the Congressional recognition of aviators as a distinct group within the Army, served to solidify the pilot's early identity as a technical specialist. Pilots became valued for their ability to fly aircraft and, as such, became identified with aircraft. However, "flying" had evolved into more than a physical skill to include the necessary understanding of the machine itself and its component parts. The creation of the Aviation Section within the Signal Corps to handle all Army aviation matters gave credence to that knowledge, establishing flying as a technical specialty rather than just a physical skill.

The Emerging Role of Command

While H.R. 5304 formally recognized the pilot as a technical specialist, it did not restrict non-pilots from commanding flying units. The Army recognized flying as a technical skill, but

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[31] Ibid.

[32] Ibid.

[33] Hurley and Heimdahl, "The Roots of U.S. Military Aviation," 26.

[34] Thomas H. Greer, *The Development of Air Doctrine in the Army Air Arm, 1917-1941* (1985. Reprint, Office of Air Force History, U.S. Air Force, 1953), 2.

had not yet determined that flying, as a part of the larger mission of *military aviation*, constituted a fundamentally different form of military power than already existed. Army leadership did not believe that either flying experience or qualification as a pilot was necessary to command a flying unit, leaving the opportunity open to all Signal Corps officers. However, the extensive use of airpower during World War I and the rapid development of tactics and doctrine soon made it apparent that the effective use of airpower did require flying experience, just as the effective use of seapower required naval experience. Of particular importance was the development of large formation tactics for both bombardment and pursuit missions, which required leading large groups of men and machines into combat in a coordinated manner to accomplish a specific mission.[35]

Following the war, Congress enacted the National Defense Act of 1920 that, in addition to establishing the Army Air Service as an officially recognized combatant arm of the Army, mandated that at least 90 percent of the officers in the Air Service hold an aeronautical rating. Recognizing that the successful employment of airpower required specialized knowledge, the Act also established that only such rated officers could command flying units. At that time, this included pilots as well as aircraft observers.[36] The law addressed the issue of flyers commanding flying units at the lower levels in the Air Service, but did not mandate that the Chief of the Air Service hold an aeronautical rating. While not surprising, as this was a very senior command position and none of the early aviators were old enough or senior enough in rank to warrant consideration, it left the senior command position in the Army's aviation organization open to any Army officer of sufficient rank and seniority, regardless of his professional qualifications regarding aviation.

Neither of the first two leaders of the Air Service, Major General Charles Menoher and Major General Mason Patrick, were pilots when they assumed command of the Air Service. Menoher was largely unsuccessful for two reasons, both related. First, while he was a very well regarded and experienced infantry officer, he had no experience with airpower. He did not

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[35] For an account of the American air experience in World War I and the tactics and doctrine that grew out of that experience, particularly in relation to formation employment, see William C. Sherman, "Tentative Manual for The Employment of Air Service (1919)," in *The U.S. Air Service in World War I: Volume II, Early Concepts in Military Aviation*, ed. Maurer Maurer, vol. 2, 4 vols. (Washington, DC: The Office of Air Force History, 1978), 313-410.

[36] R. Earl McClendon, *Autonomy of the Air Arm* (Washington, DC: Air Force History and Museums Program, 1996), 10; Mitchell, *Air Force Officers*, 353. Aircraft observers were non-pilot aviation officers.

understand the particular supply, personnel, and doctrinal challenges facing the Air Service, which made him an ineffective leader. Second, this ineffectiveness led to his inability to control Billy Mitchell, his deputy, whose public agitation for an independent air force was causing the Army a good deal of embarrassment. Mitchell had no regard for Menoher because he was not a pilot.[37]

Mason Patrick replaced Menoher on 5 October 1921, and fared much better because he already had some experience leading an aviation organization. He had served as the Chief of the Air Service of the American Expeditionary Force under General John J. "Black Jack" Pershing during World War I, and in that role, gained a great deal of experience with both the organization and employment of airpower. Patrick remained as Chief of the Air Service until 2 July 1926, and although not a pilot when he took command, actually learned to fly and qualified as a pilot while in the position. As he explained in his memoirs, Patrick understood the important role that flying played in the psyche and culture of the Air Service.

> I have never known any men who so persistently, insistently, "talk shop" as do air pilots, and they have a language of their own which none but the initiated can understand. This had been borne on me during my service in France and impressed me anew when I took charge of the Air Service of the United States. At that time the Air Service was filled with cliques and it was necessary to gain the confidence of this personnel. None but a flying man could hope to succeed in such a task.[38]

Upon taking command, Patrick attended flight training, achieving the rating of "Junior Aviator" at the age of fifty-nine.[39] While in command, he took every opportunity to fly, which had a very positive impact on his effectiveness as a leader. He related

> Nothing did more than this continual flying to win the confidence of the men, much younger, with whom I was in contact, trying to direct and guide them in an effort to make of the Air Service united body of men *all working toward one end* (emphasis added).[40]

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[37] Robert P. White, *Mason Patrick and the Fight for Air Service Independence* (Washington, DC: Smithsonian Institution Press, 2001), 70-71; McClendon, *Autonomy of the Air Arm*, 10.

[38] Major General Mason Patrick, *The United States in the Air* (Garden City, NY: Doubleday, Doran & Co., Inc., 1928), 111.

[39] White, *Mason Patrick and the Fight for Air Service Independence*, 85.

[40] Patrick, *The United States in the Air*, 112-113.

Significantly, qualification as a pilot also gave Patrick some moral authority over Mitchell, and he was able to exert some control, albeit limited, over the petulant officer. Patrick's experience illustrates why flying and command came together in the Air Service. More specifically, it shows why the role of the *commander* and the *pilot* came together as a necessary combination for effective leadership of the Air Service.

On 2 July 1926, the United States Congress formally fused the role of commander and pilot by passing the Air Corps Act. While not establishing a separate air service, the Act established the Air Corps as an organization capable of military action both as an auxiliary force and as "an independent force operating alone on a separate mission," further defining airpower as a separate form of power.[41] Recognizing that independent mission, it mandated that the Chief of the Air Corps, a major general, at least two of his assistants, brigadier generals, and at least 90 percent of the officers in the grades below be "flying officers."[42] Additionally, the Act reaffirmed that only flyers could command flying units, but added a restriction that during peacetime, only *pilots* could command. This was significant, because during peacetime the military force was much smaller than it would be during war, making command opportunities much more rare. The Act ensured that pilots would get those rare opportunities. Non-pilot opportunity to command flying units completely disappeared in 1940 during the build up to World War II, when Congress extended the restriction to include command during wartime as well as peacetime.[43] These moves reflected a trend following World War I where pilots performed more of the airborne duties necessary in the relatively simple aircraft of the era, gradually reducing the role of the non-pilot rated flying officer, the observer, as will be discussed below.

The Aircraft Commander and the Generalist

As flying became associated with higher-level leadership in the organization, a similar trend occurred at the basic level, fundamentally changing the role of the pilot, particularly in the

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[41] Mooney and Layman, *Organization of Military Aeronautics*, 78.

[42] *An Act to provide more effectively for the national defense by increasing the efficiency of the Air Corps of the Army of the United States, and for other purposes* (Public Law Number 446 69th Cong., 1st sess., 1926), Section 13a.

[43] Mitchell, *Air Force Officers*, 353.

bombardment mission. Writing between the World Wars, Major General James Fechet, former commander of the Air Corps, summed up it up thus:

> Originally the flyer was a lone actor. He lived or died by his own initiative. There was no one aloft to counsel or advise him. He survived or perished by his own initiative. This led to a criticism of the pilot, particularly in warfare. It was said that he did not cooperate, that it was difficult to induce him to join in the general scheme, participate for a common purpose. Changes in air tactics and new inventions have completely altered all this. Airplanes no longer roam the skies alone. They fly and fight in huge formations, the single pilot maneuvering his plane coincident with many others and subject to the signal or radio voice command of a common leader.[44]

Just as commanding air forces was changing, flying itself was changing, becoming a more complex task influenced by the growth of an increasingly complex system of multiple humans and machines.

World War I witnessed the birth of bombardment on a large scale, with large aircraft, manned by multiple members of a bomber crew, participating in large formations that required a great deal of cooperation and coordination to be effective. This placed new demands on the aircraft pilot. He now had to coordinate the efforts of the men on these crews while ensuring that, as a team, they fulfilled their role in the larger formation, whether that role was to lead or participate as a follower (wingman). Achieving technical proficiency in flying was no longer sufficient to become a "good" pilot. The good pilot had to evolve and become a leader, and to do so, had to become a generalist who understood all aspects of his crew's mission. Evolve, in effect, as the controlling element of a growing, complex system.

During World War I, bomber aircraft design progressed rapidly from small, single-seat, single-engine aircraft to multi-seat, multi-engine behemoths with several crewmembers, each performing a particular task (Figure 3.3). These crewmembers had to function together, along with their associated bombsights and navigational instruments, to form a single team focused on accomplishing the mission. The 1933 ACTS *Bombardment* text made the pilot's role as the leader of that team, designating him "the commander of that highly skilled group of individuals" with responsibility for their training.[45] As the *aircraft commander*, the

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[44] Fechet, *Flying*, 68-69.

[45] *Bombardment: 1933* (Maxwell Field, AL: Air Corps Tactical School, 1933), 20.

pilot had two responsibilities: flying the aircraft and commanding the crew to ensure that they could accomplish their mission.

Figure 3.3
The Glenn Martin GMB bomber, the first U.S.-designed bomber procured in quantity by the U.S. Army during World War I[46]

Through the 1920s, bomber aircraft were simple enough that the pilot could readily understand the roles played by each of the other members of the bomber crew. In fact, pilots generally filled both the pilot and bombardier positions, and by 1930, the Congressionally mandated limitations on manpower and the policy that 90 percent of officers be rated meant that most of the Air Corps officers were pilots, and in bombardment units, *all* of the officers were pilots, filling all of the flying officer positions on the aircraft. In these units, every officer was required to qualify as both bomber pilot and bombardier, making it such that the aircraft commander could readily coordinate the crew's actions because each member was very familiar with the others' responsibilities.[47]

In 1939, however, that situation had changed, as will be explored in greater depth in Chapters 4 and 5. The advent of the four-engined bomber earlier in the decade, the need for a ten-man crew to operate it, and the personnel pressures associated with the rapid build up for

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[46] *Martin GMB Bomber*, Photograph, n.d., http://www.af.mil/shared/media/photodb/photos/040315-F-9999G-013.jpg (accessed 11 February 2011).
[47] *Bombardment Aviation: 1931--Draft* (Langley Field, VA: Air Corps Tactical School, 1930), 21-22.

World War II found the Air Corps facing a severe shortage of qualified pilots on the eve of the war. It could no longer use pilots as bombardiers and navigators, opting instead to use non-pilot specialists in those positions. With the arrival of these non-pilot specialists, bomber pilots were no longer required to qualify as bombardiers or navigators and, consequently, were less qualified to perform all of the crew duties on the bomber, but were still responsible for their satisfactory completion.[48] Aircraft command meant *command*, and the *B-17 Pilot Training Manual* described the aircraft commander's duties thus:

> Your assignment to the B-17 airplane means that you are no longer just a pilot. You are now an airplane commander, charged with all the duties and responsibilities of a command post.
> You are now flying a 10-man weapon. It is your airplane, and your crew. You are responsible for the safety and efficiency of the crew at all times—not just when you are flying and fighting, but for the full 24 hours of every day while you are in command.[49]

The emphasis on command over flying and the growing difference between them carried over to the B-24, as well. Its Training Manual clearly pointed that a pilot could "be one of the best B-24 pilots ever trained and still fail as an airplane commander."[50]

The aircraft commander was, however, still the pilot. He was still responsible for the safe operation of the aircraft, including takeoff, landing, instrument flying, and navigation in both normal and emergency situations. He still had to maintain in depth knowledge of all of the aircraft systems, including the flight controls, hydraulics, fuel system, engines, and communication systems. He was the commander on the aircraft, but flying skill was still a central defining characteristic and critical for success in that role. A steady, skillful pilot imparted confidence in his crew, making them a more effective team. Harry Crosby, a navigator in the 100th Bomb Group, stated that he would follow his aircraft commander, Everett Blakely anywhere because he was a good pilot, one who "could keep the (instrument) needles steady," and thus be counted on to make the right decision for the crew.[51]

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[48] As will be explained further in Chapter 4, pilots learned navigation as a part of their normal training, but did not specialize in the task.

[49] *B-17: Pilot Training Manual for the Flying Fortress, AAF Manual No. 50-13* (Headquarters AAF, Office of Flying Safety, 1945), 13.

[50] *B-24: Pilot Training Manual for the Liberator* (Headquarters AAF, Office of Flying Safety, 1944), 6.

[51] Crosby, *A Wing and a Prayer*, 173.

Since formations were a central part of the HADPB doctrine, one of the aircraft commander's responsibilities as a bomber pilot was maintaining proficiency in flying formation with other aircraft. By regulation, he was required to be able to hold his aircraft in formation at all altitudes, maintaining a position within one wingspan, or just over 100 feet, of the aircraft in front, and "be able to take evasive action without getting more than 300-400 feet from the (formation) leader."[52] This type of flying was demanding both physically and mentally, calling for instant reaction to any change in attitude, altitude, course, or speed, requiring constant adjustment of the throttles and wrestling with the flight controls. The demands of formation flying, combined with the anticipated long missions associated with the HADPB doctrine and the added pressure of being responsible for the completion of tasks that he was no longer as well equipped to accomplish, prompted bomber aircraft designers to make provisions for the aircraft commander to be able to share some of his burden with another pilot during the bombing mission—the copilot.

The Copilot

The heavy bombers designed during the 1930s and flown in the CBO had two pilot positions in the cockpit. The aircraft commander sat in the left seat and the copilot in the right seat.[53] Initially designed for use by a "relief pilot," the right seat was installed because aircraft designers believed that the demands of flying formation during long-duration bombing missions would likely be beyond the physical endurance of a single pilot.[54] However, the relief pilot's job soon evolved from that of a substitute "set of muscles," to that of an active co-participant in who aided the aircraft commander in controlling the aircraft as he both flew and led the crew. The copilot served as the aircraft commander's executive officer, his "chief assistant, understudy, and strong right arm."[55] Although he was officially the assistant pilot, the copilot was an aircraft commander-in-training, gaining the experience necessary to take command of a crew of his own

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[52] Leslie F. Smith, *Development of AAF and USAF Training Concepts and Programs: 1941-1952*, U.S. Air Force Historical Study 93 (Washington, DC: USAF Historical Division, Air University, 1953), 332-335, Call 101-93, IRIS No. 01004508, US Air Force Historical Research Agency; *Pilot Training Manual for the B-17*, 113.

[53] This convention is still used today. The aircraft commander is often referred to as "the left-seater," connoting the position of authority.

[54] Arnold, *Global Mission*, 155-156.

[55] *Pilot Training Manual for the B-17*, 14.

in the future, and one of the aircraft commander's primary responsibilities was ensuring that the copilot had the chance to develop the necessary skills so that he could assume that position.[56]

Generally less experienced than the aircraft commander, the copilot was still responsible for being able to fly the aircraft in all phases of flight and had to be prepared to take over the control of the aircraft if the aircraft commander became unable to do so. While his primary duty was to share the flying responsibilities, he had to be extremely proficient in engine operation, as he maintained control of the throttles during formation flying while the aircraft commander controlled the flight controls, both pilots working together to keep the aircraft in the correct position.

Close, effective cooperation between the two pilots was crucial, as they had to coordinate their actions and work as if they were a single control element. A good aircraft commander learned to share his flying responsibility and trust his copilot, and a good copilot learned to anticipate his aircraft commander's actions and shape his own actions to complement them accordingly. When this intimate relationship developed fruitfully, they could keep their aircraft tucked into position almost effortlessly. When it did not, formation flying could become a severe strain on the aircraft commander as he struggled to both control the aircraft and command the other members of the crew as they performed their jobs.[57] As will be seen, sharing of control during a task-intensive portion of the mission became a hallmark of how the aircraft commander performed his job.

The Formation Commander

Since the bomber formation was the USAAF's primary striking element during the CBO, operating and controlling that formation was, perhaps, the most important task during a bombing mission. The Air Corps learned from its experience during World War I that the person leading the formation had to have certain characteristics to be successful.[58] Early post-war bombardment doctrine stated that leadership, aggressiveness, coolness under fire, good judgment, initiative, and "accurate knowledge of the capabilities and limitations" of the formation were essential traits, ideally found in the bombardment unit's commander. Successful bombardment unit

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[56] Ibid., 15.

[57] Bert Stiles, *Serenade to the Big Bird* (New York: W.W. Norton, 1952), 83.

[58] Sherman, "Tentative Manual for The Employment of Air Service (1919)," 395-396.

commanders made good formation leaders, and good formation leaders made good unit commanders.[59] Holding the command position, however, was not sufficient to qualify as a formation leader.

Bombardment doctrine imposed one overriding requirement on a formation leader—that he be a pilot. The 1924-1925 ACTS *Bombardment* text clearly stated

> *There is one qualification of the formation leader to which there must be no exception:* HE MUST BE A PILOT. If possible, it is more important that a formation leader be a pilot than that a commander be one, for unless he be a pilot he cannot intelligently direct the maneuvers of the formation nor can he gain the confidence of its personnel (emphasis in original).[60]

The text went on further to explain that, as formation flying was essentially "a game of follow the leader," the pilot in the lead aircraft was the *de facto* leader. If the formation leader was *not* that pilot, he would have to communicate his direction and leadership through the pilot in the lead aircraft, in all likelihood causing delays and inefficiencies that could jeopardize the success of the bombing mission.[61]

Successfully leading formations took a particular type of flying skill that included an awareness of the environment that extended far beyond the physical limits of a single aircraft. The formation leader had to consider all of the aircraft in the formation when he maneuvered, not just his own. He had to ensure that he did not operate at full throttle, as this made it difficult, or impossible, for his wingmen to maintain their position, and left them to power margin to catch up if they did fall behind. Formations of aircraft were also less maneuverable than single aircraft. As can be seen in Figure 3.4 below, aircraft on the "outside" of the turn, the side of the formation away from the direction of turn, have to travel a farther distance than aircraft on the "inside" of the turn. The formation leader could not turn too aggressively, or those on the outside might fall behind, unable to fly fast enough to maintain position, while those on the inside might be forced to slow down excessively, and fall below their aircraft stall speed. Flying effectively as the formation leader required thinking beyond a single aircraft, seeing the formation as a fluid, integrated whole made up of interdependent parts.

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[59] *Bombardment: 1924-1925*, 43-44.

[60] Ibid., 44.

[61] Ibid.
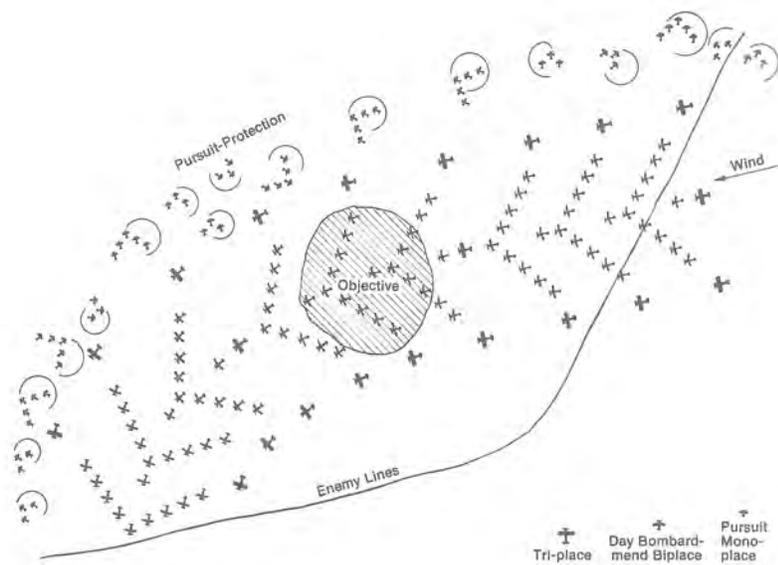
Figure 3.4
A typical bomber formation used during World War I[62]

In addition to flying the lead aircraft, doctrinally, the formation leader was the mission commander, responsible for knowing and understanding the purpose of the mission and making the necessary plans for its execution. He had to communicate the plan of attack to the sub-elements of the formation, ensuring that each individual aircraft commander understood the mission intent and their role in achieving it, and provide them the details necessary for the assembly and employment of the bomber formation. Most significantly, as the mission commander he was responsible for the successful execution of the attack. Just as the mantle of command expanded the role of the bomber pilot beyond just flying the aircraft to controlling it as a socio-technical system to accomplish its mission as a team, so too did it expand the role of the formation leader beyond that of lead pilot to formation system controller, responsible for all elements in the larger socio-technical system and for their success as a whole, and doctrine changed accordingly.

During the 1930s, the doctrinal requirement for designation as a formation commander changed from pilot to that of "flying officer," but as explained earlier, in a bombardment

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[62] Sherman, "Tentative Manual for The Employment of Air Service (1919)," 396.

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squadron all of the flying officers *were* pilots. However, there was a significant change in the definition of the formation commander's duties—no longer was he to *pilot* the leading aircraft. The 1931 version of the ACTS *Bombardment Aviation* text explained

> To control the formation and to supervise its navigation, defense, and method of attack (the formation commander) should be relieved of the duties of piloting. He should be in position to observe the conduct of the formation, the action of the hostile pursuit, and the manner in which the bombardment attack is made. He is responsible for the tactics employed and the air discipline of his command, and to fulfill this responsibility, he must actually observe the conduct of the mission. He must have first-hand knowledge gained by close observation, before he may improve the tactics or take corrective measures to insure compliance with the adopted methods. <u>The commander must be a flying officer</u>. Only by piloting proficiency, by experience in flying all positions of a formation, may a commander have that background which will insure proper air leadership (emphasis in original).[63]

Once again, the technical ability to fly was central to the formation commander's role, but his position as the controller for the entire bombardment system transcended that single skill.

During World War II, mission commanders, or command pilots, generally did not fly in the lead aircraft as the aircraft commander. They either flew in the right seat in the copilot position or went along as an extra crewmember.[64] In all cases, the command pilot monitored the formation assembly, configuration, and employment to and from the target. Good command pilots worked with the lead aircraft commander, much the same way that the aircraft commander worked with the copilot, allowing him to do his job as the lead pilot to ensure that they made it as easy as possible on the rest of the pilots in the formation by flying intelligently. When they were successful as a team, the effort was greatly appreciated, as Harry Crosby relates

> Jack Kidd let his lead crew fly a steady course, and the wing crews could stack in tight, no whipping around, no burnt out engines. He let the bombardier do his job from the IP to the target. He was the 100th's best command pilot.[65]

Although a pilot, and a highly qualified one, the command pilot had to forego control of the aircraft to perform his job, and just as the aircraft commander shared the flying duties with the

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[63] *Bombardment Aviation: 1931* (Langley Field, VA: Air Corps Tactical School, 1931), 91.

[64] Philip Ardery, *Bomber Pilot: A Memoir of World War II* (Lexington: University Press of Kentucky, 1978), 83.

[65] Crosby, *A Wing and a Prayer*, 68.

copilot, the command pilot shared the command responsibilities associated with "flying" the formation with the lead aircraft commander.

Entering World War II, the bomber pilot's task was a complex one. He had to possess the technical skill and expertise to fly his aircraft, but the demands of command fundamentally changed his role in the bombardment system. At the aircraft command level, he was responsible for the conduct of his entire crew, many of whom performed tasks for which he was either not qualified or too busy to accomplish on his own. This required him to share control of the aircraft with the crew. He shared flying duties with the copilot, and, as we will see below, other aspects of control such as taking direction from both the navigator and the bombardier depending on the phase of the mission.

As the command pilot and formation commander, the bomber pilot had to share control of the aircraft with the aircraft commander and, as explained in Chapter 2, share control of the formation with the leaders of the smaller group or squadron elements that comprised and subdivided his command. To be effective, the bomber pilot had to be both a good pilot and a good commander at all levels of the bombardment system, and these requirements shaped how pilots were selected on the eve of the war and how they were trained.

Pilot Selection

World War I established the Army pilot as something of a cultural icon. The notable accomplishments of men such as Eddie Rickenbacker, fighter pilot and ace, cemented the romantic vision of the independent, rough-and-tumble "Knight of the Air," and the Army had no problems finding applicants interested in flight training.[66] With more volunteers than opportunities to train them, the real difficulty lay in determining which of the applicants was most likely to successfully complete flight training, and trainee selection focused mostly on physical coordination. Men who could ride horses or motorcycles, sail a fast boat, or who were football players were considered good candidates, particularly if they demonstrated intelligence,

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[66] For more on Rickenbacker's rise and struggles with his iconic status, see Hans Christian Adamson, *Eddie Rickenbacker* (New York: The Macmillan Company, 1946); W. David Lewis, *Eddie Rickenbacker: An American Hero in the Twentieth Century* (Baltimore: Johns Hopkins University Press, 2005); Eddie Rickenbacker, *Rickenbacker* (Englewood Cliffs, NJ: Prentice-Hall, 1967). The rise of the pilot as a cultural icon was not limited only to the United States. For an excellent account of the German experience with the issue, see Peter Fritzsche, *A Nation of Fliers: German Aviation and the Popular Imagination* (Cambridge, MA: Harvard University Press, 1992).

self-confidence, alertness, and maturity, and demonstrated good equilibrium when spun in a "spin chair."[67]

Following the war, when the Army returned to its pre-war reduced manning levels, there was an even greater shortage of flying training opportunities, and the Army added an applicant's education level as a discriminator when selecting flying cadet candidates.[68] The initial post-war standards for admittance as a flying cadet were quite high, and over time, the emphasis on education grew. 1n 1920, applicants were required to be unmarried male citizens of the United States between the ages of twenty and twenty-seven at the time of entry into training, and have completed high school or its equivalent. As the popularity of aviation grew through the decade, particularly after Charles Lindbergh's transatlantic flight in 1927, the number of applicants for flying training continued to grow, and in 1928, the Air Corps raised its educational standards in an effort to limit the number of qualified candidates, requiring proof of at least two years of college education before accepting any cadet into flight training.[69] Those without proof of formal education could still be admitted to training if they passed a comprehensive examination that tested their knowledge of United States and general history, English grammar and composition, geography, arithmetic and higher algebra, plane and solid geometry, plane and spherical trigonometry, and elementary physics. The test was very difficult and, as it focused on education rather than flying aptitude, few candidates without some college education were able to pass it.[70]

By 1928, the excess number of qualified applicants required that the Air Corps establish a formal priority list for admission into training as follows:

> a. (1) Graduates of the United States Military Academy, the United States Naval Academy, and the United States Coast Guard Academy who apply for appointment as flying cadets within 1 year from date of graduation, who

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[67] Mitchell, *Air Force Officers*, 351. After the war, the emphasis on athletic recruits decreased, although physical fitness was still a requirement. See Brigadier General Henry H. Arnold and Major Ira Eaker, *This Flying Game* (New York: Funk & Wagnalls Company, 1936), 108-109.

[68] Natalie Grow, *Procurement of Aircrew Trainees*, Army Air Forces Historical Study 15 (Washington, DC: U.S. Army Air Forces Assistant Chief of Staff, Intelligence Historical Division, August 1944), 1-2.

[69] Robert L. Thompson, *Initial Selection of Candidates for Pilot, Bombardier and Navigator Training*, Army Air Forces Historical Study 2 (Washington, DC: U.S. Army Air Forces Assistant Chief of Staff, Intelligence Historical Division, November 1943), 7-8. In 1926, the maximum age was briefly raised to twenty eight years old, but was lowered back to twenty seven the following year. See Ibid. p. 11 note 14.

[70] Grow, *Procurement of Aircrew Trainees*, 3.

fail to receive commissions because of lack of vacancies and are recommended for appointment as flying cadets by the respective superintendents of those academies.

   (2)   Enlisted men of the Air Corps of the Regular Army who at time of appointment have served at least 11 months.

b. Other enlisted men of the Regular Army who at time of appointment have served at least 11 months.

c. Officers and enlisted men of the National Guard who at time of appointment have been assigned to Air Corps units for at least 11 months and who are favorably recommended by their commanding officers.

d. College graduates who are graduates of the Air Corps Reserve Officers' Training Corps units.

e. College graduates who are graduates of Reserve Officers' Training Corps units of other arms or services.

f. Graduates of recognized colleges and universities.

g. Other officers and enlisted men of the National Guard who at time of appointment have had at least 11 months' service.

h. Students in Air Corps Reserve Officers' Training Corps units who have completed their junior year.

i. Reserve officers and members of the Enlisted Reserve Corps who at time of appointment have served at least 11 months.

j. Students in good standing of recognized universities who have completed their sophomore year.

k. Others.[71]

This priority list remained in use until the Air Corps expansion programs before World War II were implemented, and the average formal education level for flying cadets remained high. Over fifty per cent of the candidates admitted into training over the next decade came from categories (e) and (f), both of which required a college degree.[72]

In 1939, on the eve of World War II, the Air Corps had an available pool of over 800 academically and physically qualified applicants available to fill 549 flying cadet positions.[73] Ordinarily, this would pose no problem, however, the Air Corps expansion programs leading up to the U.S. involvement in the war established an unprecedented demand for pilot trainees. The execution of the initial American air war plan against Germany, AWPD/1, required a total of

[71] *Flying Cadets of the Army Air Corps* (Washington, DC: Adjutant-General's Office, U.S. Government Printing Office, 1927), 10-11 cited in Grow, *Procurement of Aircrew Trainees*, 4.

[72] Grow, *Procurement of Aircrew Trainees*, 4.

[73] Thompson, *Initial Selection of Candidates for Pilot, Bombardier and Navigator Training*, 18.

103,482 pilots.[74] With the launch of the first expansion program on 1 July 1939, the list of eligible candidates was exhausted, and for the first time, the Air Corps had to relax its entry standards in order to produce the required number of aviators.

After determining that neither lowering the physical standards nor raising the maximum age limit was an acceptable way to increase the number of qualified candidates, the decision was made to lower the education requirements for admittance into the flying cadet program. The Air Corps reduced the difficulty level of the entrance examination, and men with less than two years of college were encouraged to take the test. While the examination was altered slightly, it remained focused on measuring the applicant's level of education and training rather than his aptitude for flying.[75] Physically qualified applicants who passed the test entered into flight training.

As the war progressed, the USAAF developed a new test to try to better assess a candidate's potential to complete flying training. The improved test, the Aviation Cadet Qualifying Examination (ACQE), evaluated a recruit's aptitude for *all* flying training, including the pilot, navigator, and bombardier crew positions. Developed through the USAAF Aviation Psychology Program, the ACQE evolved throughout the war and proved to be an accurate predictor of trainee success for all flying training, and measured the following characteristics: comprehension and judgment, mathematical ability, mechanical comprehension, alertness, and leadership qualities.[76] Performance on the judgment section proved the best indicator of potential success in pilot training, and almost as effective was performance on the mechanical comprehension section. Both reading comprehension and knowledge of recent events correlated with success, as well, but not as strongly, but performance on the vocabulary and mathematics sections showed little correlation with the successful completion of pilot training.[77]

The ACQE results paint an interesting portrait of the successful pilot trainee. Judgment and comprehension of complex subjects were important capabilities for a pilot to possess, but technical knowledge, such as mathematics, less so. While the overall ACQE scores for those

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[74] Arthur R. Kooker, "Broadening the Basis of Procurement," in *The Army Air Forces in World War II, Vol. 6-Men and Planes*, ed. Wesley Frank Craven and James Lea Cate (Washington, DC: 1983. Reprint, Office of Air Force History. Originally published Chicago: University of Chicago Press, 1955), 433.

[75] Grow, *Procurement of Aircrew Trainees*, 6-7; Thompson, *Initial Selection of Candidates for Pilot, Bombardier and Navigator Training*, 19-22.

[76] See A. Jack Jernigan, *Selecting the Best: World War II Army Air Forces Aviation Psychology* (Bloomington, IN: 1st Books, 2003).

[77] Thompson, *Initial Selection of Candidates for Pilot, Bombardier and Navigator Training*, 39-44.

sent to pilot training were, on average, lower than those sent to navigator training, the sections were the pilots scored more highly indicated the ability to make decisions and handle complexity. In his memoir, *Ad Lib: Flying the B-24 Liberator in World War II*, B-24 pilot William Carigan quipped that "pilots were chosen from those who gave quick and correct answers; bombardiers were chosen from those who gave quick and erroneous answers; navigators were those that gave slow and correct answers."[78] While Carigan's comment is perhaps glib, the test results do seem to reflect that the pilot had, in fact, evolved from his earlier role as a technical specialist, where technical knowledge was prized, to that of a commander and leader, where decisiveness and the ability to handle complex systems were more valuable.

Bomber Pilot Training

Those selected as pilot candidates attended three phases of training: primary, basic, and advanced. All candidates completed the same primary and basic programs, which focused on developing basic flying skills and learning "the technique and judgment required of military pilots."[79] Following completion of the basic program, students were assigned to specialized advanced training programs based upon the assignment that they were likely to receive upon completion of that phase. Assignment allocation was based upon student preference and performance during the basic program, and the instructors made the final recommendation.[80]

Those students selected for four-engine, heavy bomber training first attended an advanced twin-engine training program that focused on providing them "combat proficiency as pilot of a twin-engine military aircraft."[81] In that program, students worked on instrument, navigation, and formation flying during both day and night. Although the syllabus was directed at individual proficiency, it also prepared the pilot trainee to work with a multi-man crew, instilling the understanding that he would have to be able to communicate with the other members of the crew while performing his own tasks, and that he would have to rely on their ability to perform their tasks in order to accomplish the collective mission as an aircraft crew.[82] The advanced twin-engine training program certainly trained pilots, but by conscious design

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[78] William Carigan, *Ad Lib: Flying the B-24 Liberator in World War II* (Manhattan, KA: Sunflower University Press, 1988), 74.

[79] Smith, *Development of AAF and USAF Training Concepts and Programs: 1941-1952*, 52.

[80] Ibid., 64.

[81] Ibid., 83.

[82] Cameron, *Training to Fly*, 405.

began training pilots to become aircraft commanders.

Following advanced twin-engine training, heavy bomber students proceeded to a transition school, where they learned to fly their assigned aircraft, whether the B-17, the B-24, or, later in the war, the B-29. They spent four weeks learning about the aircraft and how to fly it, and more about how to act as the aircraft commander. The training covered topics such as the importance of air discipline, the code of military law, and the duties, obligations, and responsibilities to crewmembers. Early in the war, all pilots completed the full training, but later in the war, the USAAF developed a shorter course that focused on engineering issues for those trainees who would start out as copilots.[83] Following this phase, pilots were matched with their crews, and together they completed their final training as a single combat unit until they deployed overseas.

Later in the war, this crew training included all anticipated phases of a combat mission: formation, day and night instrument flying, navigation, and combat bombing, and crews were better prepared for combat. Early in the war, however, there was precious little training opportunity, as the USAAF desperately needed even minimally qualified bomber crews in the combat theater to replace combat losses. Many crews deployed with little or no combat training, but were still expected to be able to immediately fly through the defensive fighters and flak in the large bomber formations attacking the German industrial infrastructure. This inexperience, particularly with formation flying, led to many of the operational difficulties faced by the commanders in the ETO as they tried to determine the most effective bombing doctrine.[84]

The bomber pilot who arrived in the ETO in late 1942 was a distant cousin of Lieutenant Benjamin Foulois. He was still a technical specialist, proficient in flying, the skill that provided a significant portion of his identity, but his required skill set had grown far beyond aircraft control. The responsibility of commanding the increasingly complex bomber aircraft system demanded that he evolve into a generalist, able to understand the various tasks accomplished by his crewmembers and control their collective actions so that they could accomplish their collective doctrinal mission. The demands of controlling that increasingly complex

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[83] Jerry White, *Combat Crew and Unit Training in the AAF: 1939-1945*, Army Air Forces Historical Study 61 (Washington, DC: Air Historical Office, Army Air Forces, August 1949), 24-29; Smith, *Development of AAF and USAF Training Concepts and Programs: 1941-1952*, 116.

[84] Richard H. Kohn and Joseph P. Harahan, eds., *Strategic Air Warfare: An Interview with Generals Curtis E. LeMay, Leon W. Johnson, David A. Burchinal, and Jack J. Catton* (Washington, DC: Office of Air Force History, U.S. Air Force, 1988), 26.

bombardment system at the aircraft level demanded that he share some of the control of the system, trusting each crewmember to do their respective jobs, but still responsible for their successful performance. Significantly, the demands of command and control also required that he share his fundamental task—flying—with a copilot. At the formation level, the demands of command and control altered the bomber pilot's role even further, and while flying remained a core required skill, the command pilot had to effectively relinquish his role as a *pilot* in order to command the entire formation and mission. While still an aircraft pilot, and the most capable and qualified one either in the aircraft or in the formation, he had grown into the central control element for a much more complex system, and that role distinctly shaped how he completed his task during a bombing mission.

Bombing in the European Theater of Operations
The Mission Brief

On the morning of a CBO mission, the pilots listened as intently as any of the other crewmembers present during the General Briefing, concentrating on the larger picture so that they understood the overall plan and purpose for the mission, but each one also gathered the specific details of its orchestration, as well. They noted details such as the rejoin point, rejoin plan, and push time, and paid particular attention to the specifics of the formation plan, as it was the primary determinant of what they would do for the day. The pilots received a number of data sheets, or "flimsies," with information about the mission, including one that showed the group formation and the position that each aircraft would assume (Figure 3.5).
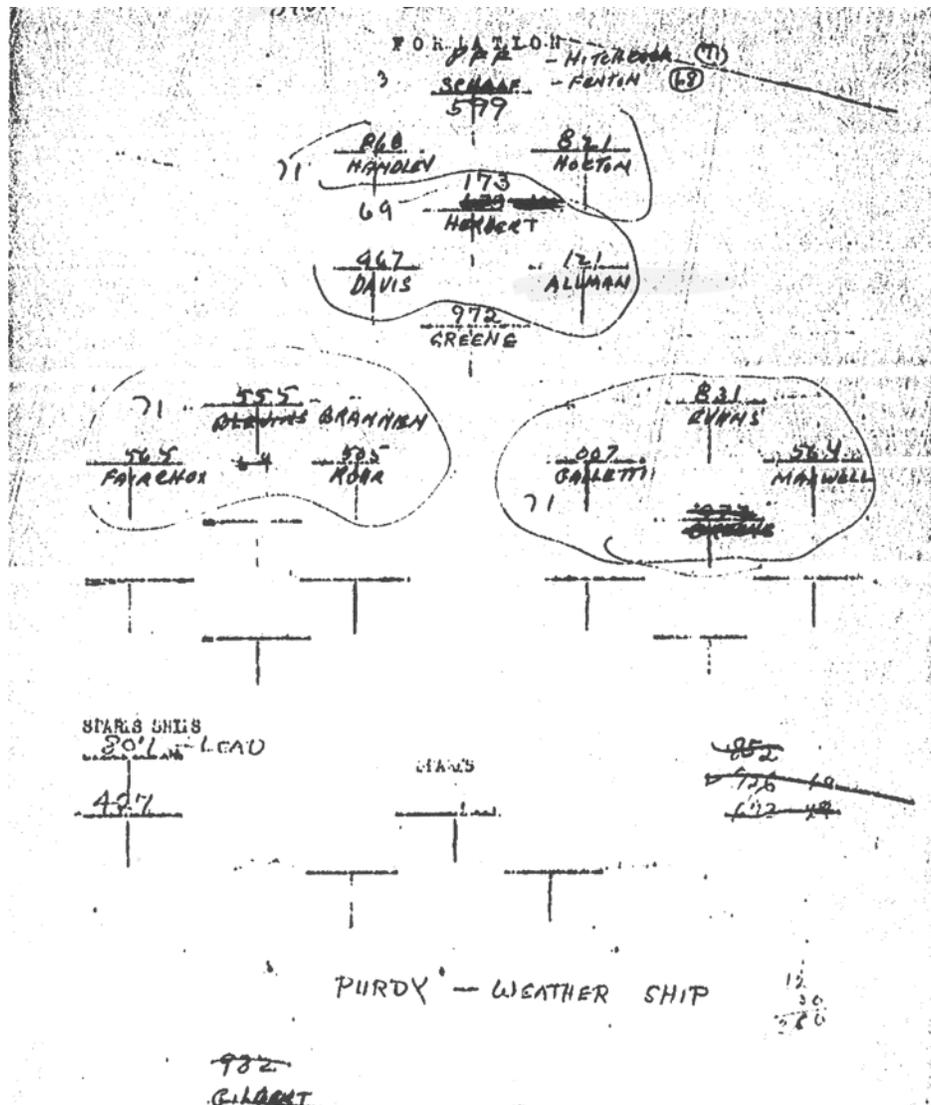
Figure 3.5
390th Bomb Group Formation Flimsy, Mission #173, 14 August 1944[85]

The flimsy depicted the formation from above, showing groupings of three-aircraft elements (Figure 3.6) that were grouped into six to nine aircraft squadrons, and, finally, the entire group formation (Figure 3.7). The position of each individual aircraft determined which way the aircraft commander would spend the day looking. Those in the front of the individual "vee" elements served as the leader for that grouping and primarily looked forward. Those on the right side of the formation would have a clear, unobstructed view of their leader to their left,

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[85] "390th Bomb Group Formation Flimsy--Mission #173, Ludwigshafen, Germany", August 19, 1944, 390th Bomb Group Memorial Museum Archives. Note that the positions are identified by aircraft tail number and the aircraft commander's last name. Also, the hand drawn figures around the groups of three aircraft denote the element configurations.

upon whom they were flying formation, while those on the left side would spend the day looking across the cockpit and the copilot with a poorer view of their leader.
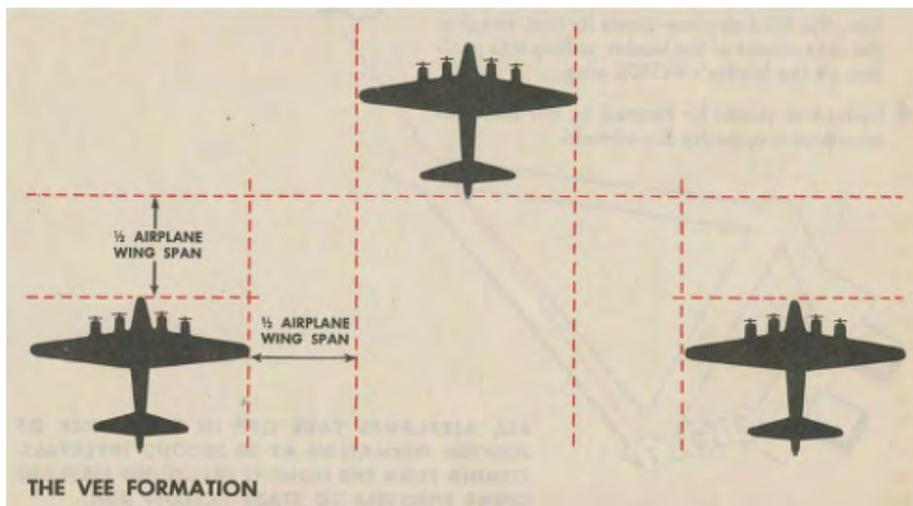
Figure 3.6
Three aircraft element formation[86]

       The group lead pilot noted how the formation would maneuver throughout the mission, paying particular attention to how he and the lead pilots from the other groups flying the mission would form together into their Combat Boxes, and how the Combat Boxes would then form into the Combat Wing for the trip to the target. He also noted how the Combat Wing would split up for the bomb run, and how it would reform at the mission rendezvous point after the bombing for the return trip home. For the group lead pilot, the entire mission was a complex process of assembling, disassembling, and reassembling a massive multi-element socio-technical system into different configurations that would enable it to best execute its purpose, while providing itself the maximum amount of protection.

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[86] *Pilot Training Manual for the B-17*, 111.
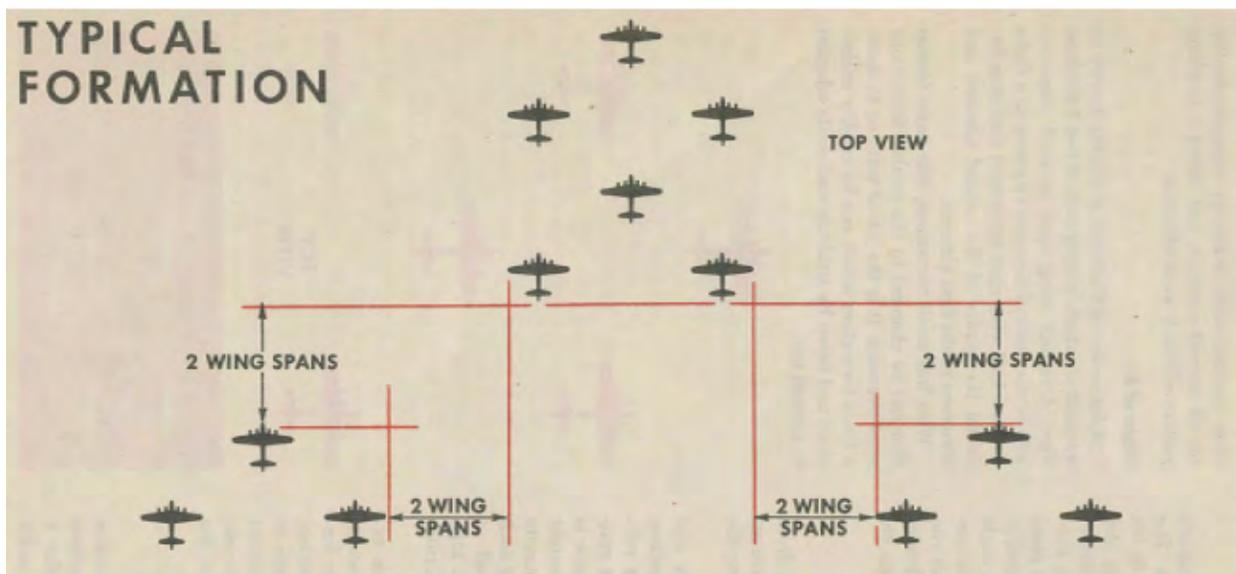
Figure 3.7
Twelve aircraft formation[87]

After the General Briefing, the pilots remained in the briefing room and reviewed pertinent engine control data for the day and waited for any last minute instructions before they gathered their oxygen masks and cold weather flying gear and proceeded to their aircraft.[88] The copilots departed to gather the escape kits for the crew, pocket-sized, waterproof packages that included silk maps of Northern Europe, compasses, French money, and rations for use in the event that they were shot down on the mission. They also received ten chocolate Mars bars, one for each crewmember, although they often froze solid and became inedible during the mission if left out exposed to the extreme cold of high altitude during the mission.[89]

At the aircraft, the aircraft commander ensured that both the aircraft and the crew were ready for the mission. He checked the aircraft status with the ground crew, confirming that they had accomplished the necessary servicing, and then performed his preflight inspection, a walk around the aircraft exterior to visually confirm its readiness. After the walk around, the aircraft commander "accepted" the aircraft, personally taking responsibility for "the safety and efficiency

[87] Ibid., 114.

[88] Roger A. Freeman, *The Mighty Eighth War Manual* (London: Jane's Publishing Company, Ltd, 1984), 13.

[89] Jesse Richard Pitts, *Return to Base: Memoirs of a B-17 Copilot Kimbolton, England, 1943-1944* (Charlottesville, VA: Howell Press Inc., 2004), 39; J. Thompson Freeman, "J. Thompson Freeman," interview by Ryan Fairfield, Video, 2001, J. Freeman Collection (AFC/2001/001/66840), Veterans History Project, American Folklife Center, Library of Congress, http://lcweb2.loc.gov/diglib/vhp/bib/loc.natlib.afc2001001.66840.

of (the) valuable equipment and the lives of the crew."[90] He then gathered the crew together, ensuring that they had all necessary equipment, and had the navigator brief them on the mission plan for the day. With the preflight preparation complete, he and the crew climbed into the aircraft.

Figure 3.8
B-17F Flying Fortress[91]

The Cockpit

The pilot proceeded to the cockpit, which in the B-17 cockpit was located above and behind the navigator/bombardier compartment. Arrayed around the two leather seats in the cockpit, six windows provided the aircraft commander and copilot adequate forward and sideways visibility, although the aircraft nose blocked their view below and in front of the aircraft, and two other windows, one above each seat, provided limited upward visibility (Figure 3.8). Two control yokes and sets of rudder pedals gave both pilots full control of the aircraft through a system of mechanical linkages—rods, bells, cranks, and pulleys that connected their hands and feet to the flight control surfaces.[92] A single throttle quadrant between the seats

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[90] *Pilot Training Manual for the B-17*, 40.

[91] *B-17 Flying Fortress*, Photograph, n.d., http://www.af.mil/shared/media/photodb/photos/020903-o-9999j-005.jpg (accessed 15 February 2011).

[92] *B-17F Pilot's Flight Operating Instructions, T. O. No. 01-20EF-1* (U.S. War Department, 1942), 44-47.

controlled the aircraft's four engines (Figure 3.9).
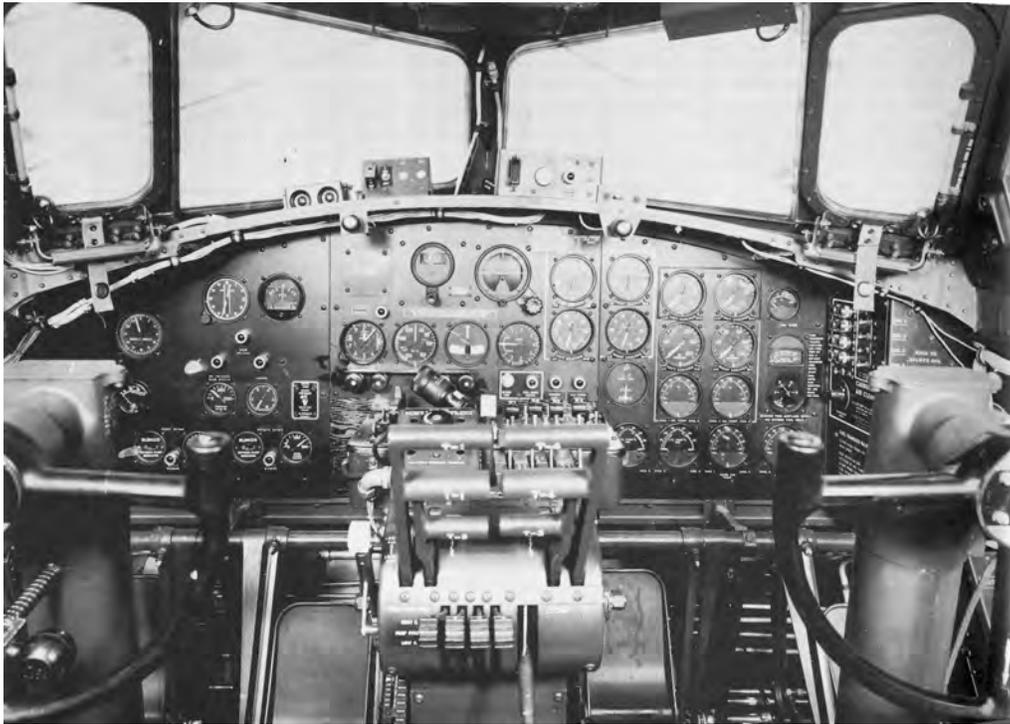
Figure 3.9
B-17 Cockpit[93]

The forward instrument panel served as the aircraft control and information center, and contained all of the aircraft flight instruments and engine, oil, and hydraulic system gauges that provided the pilots all of the information needed to fly the aircraft (Figure 3.10). The flight instruments were concentrated in the center of the panel, easily visible to both pilots. These instruments displayed the aircraft attitude, altitude, airspeed, and heading, acting as the pilot's "senses" in flight, enabling him to assess and control the aircraft's physical state. On the left side of the panel, in front of the aircraft commander, were navigation and mission-oriented instruments, such as the radio and flux gate compasses, and the Pilot Direction Indicator (PDI), which transmitted turn direction signals from the bombardier during the bomb, discussed later. The right side of the instrument panel contained the engine, oil, and hydraulic gauges, providing information on the health of the aircraft, conveniently located in front of the copilot, enabling him to easily accomplish his duties as the engineering officer.

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[93] Steve Birdsall, *Famous Aircraft: The B-17 Flying Fortress* (New York: Arco Publishing Co., Inc., 1965), 2.
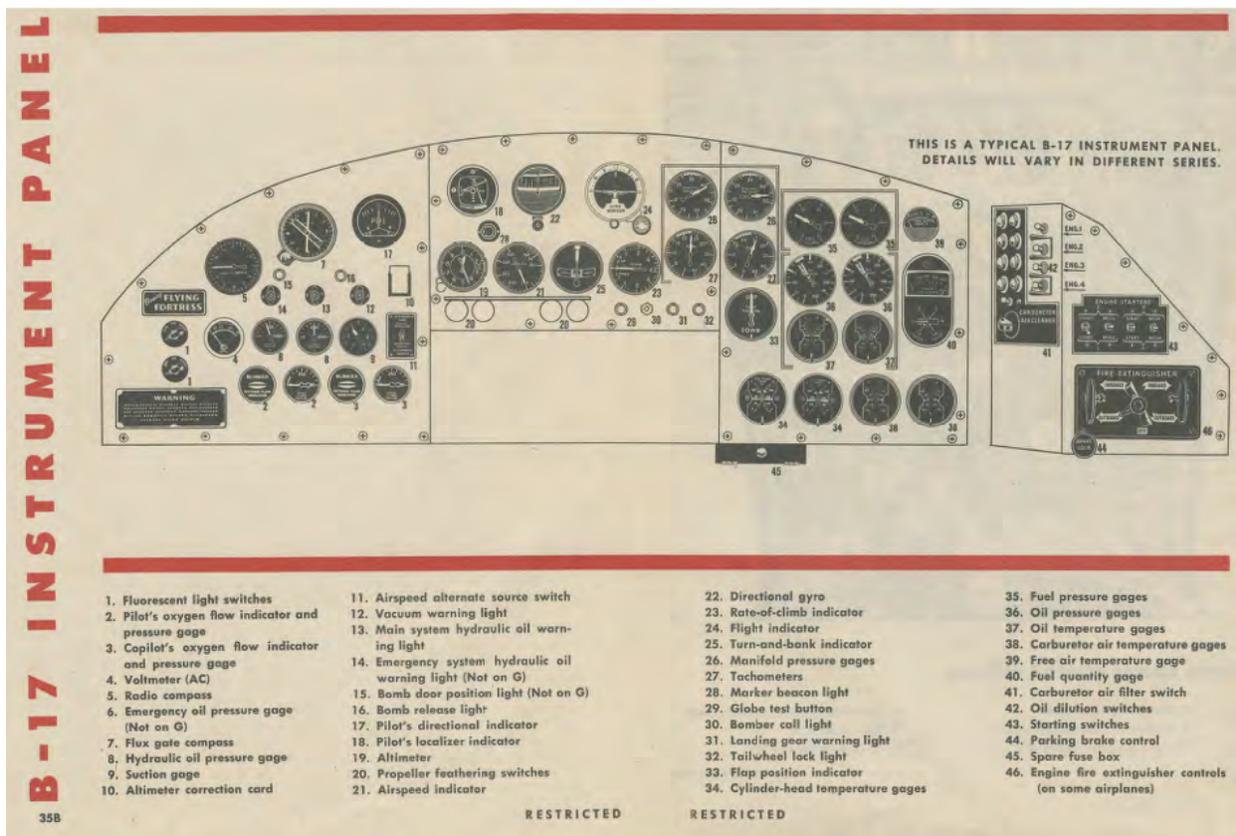
Figure 3.10
B-17 Pilot Cockpit Instrument Panel[94]

The arrangement of the instruments and gauges on the B-17 instrument panel is interesting, in that it required that the aircraft commander and the copilot share information in order to create a full picture of the aircraft status when in operation. By design, it split the cognitive burden of flying the airplane between the two pilots. The aircraft commander had easy access to the information that enabled him to control and execute the crew's bombardment mission, while the copilot had access to the information regarding the aircraft's internal engineering status. However, both pilots had equal access to the flight instruments, enabling them to share the task of physically flying the aircraft.

Building the System

Constructing the formation that would carry the bombs to their targets in Europe was a

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[94] *Pilot Training Manual for the B-17*, 35B.

long, elaborate process of aligning, sorting, and arranging the individual elements. The aircraft commander began that process on the ground for his crew, assembling them into the team that would operate their aircraft, but soon they became an element in the larger system. All of the bombers in the bomb group started at a single, scheduled time, and then taxied to the runway in their takeoff order, which was also the order that they would rejoin in the air. This orderly departure was essential for a smooth formation assembly. The lead aircraft took off first, its crew intending to arrive at the rejoin point first, since all of the other aircraft joined on them. Following the lead at thirty to forty-five second intervals, each aircraft, took the runway, the copilot advanced the throttles and the aircraft commander steered the aircraft down the runway for about 3,000 feet until the bomber rose into the air.[95]

In clear weather, formation assembly was a relatively simple process, as the pilots could easily maintain visual contact with the aircraft immediately in front. All of the aircraft climbed away from the ground at the same speed and rate—150 miles per hour and 300 feet per minute— which enabled them to maintain even spacing until they reached the rejoin point, where they would close up and take their positions.[96] The lead aircraft, arriving at the rejoin point first, set up an orbit around the point at an altitude generally between 5,000 and 10,000 feet, and the other bombers gathered and arranged themselves into position. If the carefully planned takeoff sequence was disturbed for any reason, however, disorder could easily ensue. On 22 February 1944, during a Big Week mission scheduled against aircraft production centers in Bernberg, the lead aircraft of the 381st Bomb Group had a problem on the ground. Delayed by the move to a spare aircraft, they were forced to takeoff last, at the rear of the procession. In the air, extremely hazy weather decreased visibility, and the group's pilots had great difficulty locating the late lead aircraft, approaching from below. Despite the lead aircraft launching several signal flares, the group pilots could not find their leader to complete the rejoin and assemble the formation and, consequently, sixteen aircraft aborted the mission and did not participate, reducing both the bombardment system's offensive and defensive power.[97]

Inclement weather always made formation assembly a greater challenge, and precision

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[95] Freeman, *The Mighty Eighth War Manual*, 17-18.

[96] *Pilot Training Manual for the B-17*, 113.

[97] "Operations Report on Tactical Mission of 22 February 1944. To Commanding Officer, 1st Combat Bombardment Wing, APO 634.", February 24, 1944, WG-1-HI 3 Feb 1944-29 Mar 1944, US Air Force Historical Research Agency.

flying became a top priority bringing flying to the fore. With no radar aids to guide them, pilots could only rejoin in visual conditions, so they had to climb above the clouds before they could assemble the formation. To get above the clouds into visual conditions, the aircraft commander had to fiercely concentrate on the flight instruments, ensuring that he maintained the exact airspeed and climb rate and followed the headings given him by the navigator, so that they would arrive precisely at the rejoin point at the briefed altitude. Once at the point, he flew a prescribed orbit and continuing climbing until the aircraft broke out on top above the weather. The entire formation assembly deconfliction plan, designed to keep the bombers from running into each other in the weather, was predicated on each aircraft flying the exact same flight path, separated by time. Through early 1944, strict radio silence was observed during formation assembly to avoid giving the Germans any advance warning of the impending attack, so there was no opportunity to inform other aircraft if a bomber was not where expected.[98] Deviation from any of the flight parameters put a bomber out of sequence in space and time, and risked collision with another aircraft.

If the weather was particularly bad, the final assembly altitude could be above 20,000 feet, and the aircraft commander might have to maintain this precise flight attitude, airspeed, and climb rate for up to two hours, which was incredibly taxing physically and mentally. In the words of one B-17 navigator,

> Think of the strain on (the pilot)…For 120 minutes he can see nothing…All he can do is stare at his instruments. He must keep his airspeed at 150 miles per hour. He must keep his turn and bank indicator at a single needle width…He must be sure all four engines are exactly synchronized, each showing the correct manifold pressure. He is probably watching fifteen instruments. He must make sure his radio compass needle is about fifteen degrees off center, to make sure that the circumference of our climb keeps us out of Horham and Framlingham, where the two other groups are ascending. At 10,000 feet, without permitting any change in anything, he has to put on his oxygen mask.[99]

During that time, the copilot monitored and operated the engines and the navigator provided position updates and headings, but as the leader of the crew, the aircraft commander still had to perform his own task perfectly so that the bomber team, as a unit, could accomplish its mission.

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[98] Freeman, *The Mighty Eighth War Manual*, 21.

[99] Crosby, *A Wing and a Prayer*, 46.

His flying skill remained a key part of their ability to succeed.

In spite of the best efforts to the contrary, aircraft did occasionally collide during the formation assembly process. General Curtis LeMay recalled

> Every now and then there was that grim moment when you broke out of the overcast…there you were on top of it, in brilliant sunlight, and just ahead or maybe off to one side there'd be a couple of black columns of smoke puffing right through the clouds. A couple of Forts had plowed into each other. It was something that you didn't like to see….If you were a commander you lay awake at nights, trying to figure out ways and means to keep those bubbly black smoke columns from being born.[100]

Poor weather that caused collisions and the inability to assemble could have severe consequences for the entire mission. On 22 February 1944 during assembly for a Big Week mission, several groups failed to form up due to clouds and haze, as described above, and a number of bombers collided, causing LeMay to cancel the 3rd Bombardment Division's attack on the German city of Schweinfurt. Their absence left a greater portion of the German defenses available to attack the force of 15th Air Force B-24s that were conducting a raid on Regensburg, and fifteen bombers were lost.[101]

Precision flying in the weather during the rejoin was critical. The aircraft instruments were the aircraft commander's immediate senses, shaping his actions, but he could not sense everything necessary for a safe rejoin. The navigator monitored their course and calculated their position, providing aircraft heading adjustments as necessary, and the copilot monitored the engine condition and the status of the other systems on the aircraft. The aircraft commander's real skill was integrating all of these inputs and still maintaining control of the aircraft. As will be described below, each aircraft commander struggled to control his individual element, but the formation commander, likewise, struggled to control the entire system, and precision flying was the key to control at that level, as well.

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[100] Curtis E. LeMay, *Mission with LeMay: My Story* (Garden City, NY: Doubleday, 1965), 291-292.

[101] Arthur B. Ferguson, "Big Week," in *The Army Air Forces in World War II, Vol. 3-Europe: Argument to V-E Day*, ed. Wesley Frank Craven and James Lea Cate (Washington, DC: Office of Air Force History, 1983), 36-37.

Operating the System

Leading the Formation

As described in Chapter 2, the Combat Box formation could include up to three groups of 18 bombers, for a total of 54 aircraft. Bomb Groups assembled their formations at separate points, with the command pilot monitoring the rejoin from the front, correcting any discrepancies in the position of the component squadrons, elements, or individual aircraft. Although the lead pilot, sitting beside the command pilot in the left seat of the lead aircraft, was the first airborne and ran little risk of colliding with another bomber, his flying skill had a great impact on the formation's ability to assemble and maneuver.

As the formation lead, he had to provide a stable platform for all of the other pilots to reference. "If the orders said 150 miles per hour, it was not 149 or 151, but 150!" related one B-17 pilot.[102] Changes at the front of the formation could easily create a "whiplash" effect in the formation, as the wingmen adjusted their power to maintain position, slowing down or speeding up in response to any lead maneuvers. The farther an aircraft was away from the leader, the greater the effect, with those on the outer edges potentially suffering the most. The formation leader had to make smooth, shallow turns to keep the aircraft on the outside of the turn from being slung all over the sky at the end of a cracking whip, while at the same time keeping those on the inside of the turn from slowing down to the point of stalling and falling out of the air. Flying as a successful group lead pilot required thinking not as an individual aircraft, but as an extended system of eighteen aircraft, and flying precisely in his aircraft enabled the formation to stay together and fly precisely.

Depending on the overall mission plan, a group formation might have to orbit over their assembly point for over an hour before departing on time for the Combat Wing rejoin point and the Combat Box assembly. As each group assumed its place and formed the Combat Box, the bombardment system expanded, and the importance of precision flying on system integrity multiplied. The lead pilot of the lead group became the lead pilot for the Combat Wing, and his actions now affected an even larger group of individual bombers, as changes in airspeed or turns had a much wider effect. He had to extend his "system sense" to include up to 54 aircraft to maintain the formation integrity.

Just as flying the rejoin in the weather was a team effort between the aircraft commander,

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[102] Pitts, *Return to Base*, 97.

the navigator, and the copilot, maneuvering these formations was a team effort. Combat Boxes frequently held over their rejoin point waiting while other Combat Boxes completed their formation before they pushed to the target as a combined group or Bomb Division. These division formations could contain several Combat Wings, and some of the largest missions during the war comprised over 1,000 aircraft. Maneuvering a formation of 54 aircraft so that it departed a fixed point at an exact time was a mental and physical challenge for both the lead pilot and the lead navigator.

John Howland, a lead navigator in the 324th Bombardment Squadron, one of the Pathfinder squadrons, related how early in the war timing and maneuvering were largely accomplished by "rules of thumb," and that the prevailing technique was to "allow plenty of time and jog left or right to kill time while your are heading for the checkpoint."[103] This solution was unsatisfactory, as the jog turns created problems for all of the aircraft in the formation, making it difficult to stay in position. Howland and his pilot, Jim Tyson, developed a procedural technique for departing a fixed point on time, using a combination of timing and precise flying.

> It took about four minutes and a circle 8 miles in diameter to turn a Combat Box formation 180 degrees. This is a turn of ¼ needle width on (the pilot's) turn and bank indicator. If we wanted to fly over a checkpoint on a course of 90 degrees at exactly 0920 hours in the morning, (we) flew a reciprocal heading of 270 degrees. Then made certain that (we) passed 8 miles right or left of the checkpoint at least 4 minutes prior to the scheduled departure time.[104]

By passing the point in the opposite direction, the lead pilot and lead navigator could time their turn back toward the point to ensure that they passed over it on time.

Accomplishing this maneuvering technique required that the navigator know precisely where he was in relation to the point, and that he communicate that information to the pilot along with the required heading and airspeed. The pilot had to hold a constant airspeed, and maintain between approximately 7 and 10 degrees of bank for 180 degrees to ensure that the turn took precisely four minutes to complete. The amount of bank necessary to complete the turn in a given amount of time varied with altitude, as it was dependent upon true airspeed, therefore the pilot's primary attitude reference instrument, the attitude indicator or "flight indicator," was

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[103] John Howland, "The 324th Pathfinder Force in the 91st Bomb Group: How it Came to Be", 2006, http://www.91stbombgroup.com/91st_tales/Pathfinder.html (accessed 17 February 2011).

[104] Ibid.

insufficient for the task. To accomplish the turn, the pilot used the turn and bank indicator (Figure 3.11), a gyroscopically driven instrument that displayed the rate and direction of turn, rather than the degree or amount of turn to control his turn rate. A single needle width turn, or standard rate turn, produced a 180-degree turn in one minute. The turn and bank indicator enabled the pilot to use what he could directly control, the aircraft bank, to indirectly control the performance he desired, the aircraft turn rate. Teamwork enabled the formation to maneuver as an integrated system, but precision flying still remained at the center of this elaborate, sometimes deadly, aerial ballet at the beginning of every mission.
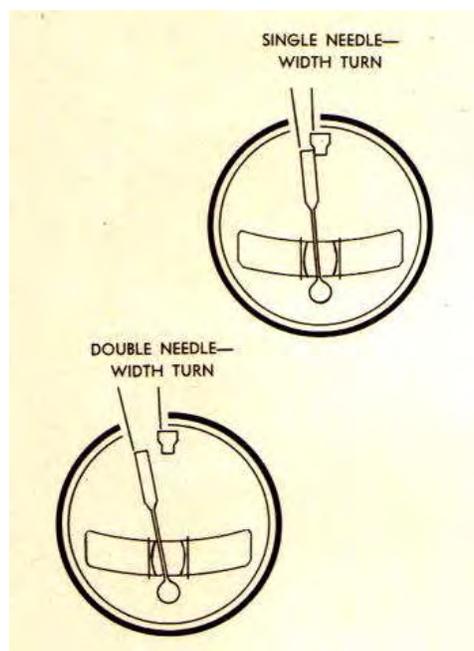
Figure 3.11
Turn and bank indicator[105]

Following the Leader

Once the fully assembled formation departed for the target area in Europe, the lead pilot's job became relatively easier. He followed the navigator's direction and maintained a steady lead aircraft-flying platform—if he was a good leader. The command pilot monitored the status of the entire formation and the weather, for it was his job to determine whether the mission should continue to the target. Once beyond about 150 miles from the English coast, the formation was

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[105] *Instrument Flying: Basic Without Radio Aids*, 1943, 34.

out of radio contact with headquarters and the decision authority to continue rested with him.

For all of the rest of the aircraft in the formation, the quality of the lead pilot's flying dictated the ease of their job. The B-17 was a beautiful aircraft—sleek, smooth, and modern. It was, however, difficult to handle at the high altitudes used by the bomber formations when penetrating German airspace. Bert Stiles, a B-17 copilot during the war related that it was "a big heavy monster that had to be heaved around the sky," and certainly "no fun to fly."[106] Correcting position required large, physically tiring flight control movements by the aircraft commander and constant power adjustments by the copilot. Even with a good leader, there could be a great deal of maneuvering to stay in position, and on long missions, the aircraft commander and copilot would take turns flying to mitigate the effects of fatigue.

Aircraft position within the formation could also affect how easy it was to stay in position. Each group generated a large amount of prop wash, and if a lead pilot was not careful, he could lead his entire formation into an area of severe turbulence generated by the group ahead. In some of the very big raids of multiple hundreds of bombers, this turbulence was a significant problem, and even led to some fatalities. On the 3 February 1945 mission against Berlin, one group lead pilot kept his formation in turbulence that caused "tossing of the plane…violent enough to be frightening" for so long that it caused one of the group's aircraft to break into pieces and crash into another aircraft, killing all but two of the crewmembers.[107]

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[106] Stiles, *Serenade to the Big Bird*, 75-76.

[107] Bill Frankhouser, *World War II Odyssey: Pennsylvania Dutch Farm Boy Becomes 8th Air Force Navigator* (Bedford, VA: Hamilton's, 1997), 133-136.

Figure 3.12
B-17s in high-altitude formation.[108]

Flying in the formation required flying skill at every level, from the leader out front to the aircraft commander in the last bomber in the lowest group, but every pilot in the formation, whether leader or follower, surrendered some measure of control to another element of the system. The lead pilot followed the lead navigator's directions, the wing pilots followed their leader, but each aircraft commander was still physically flying his own aircraft. It was, however, over the target during the bomb run that the idea of sharing control became a conflict over control, brought about by technology, between the aircraft commander and bombardier and the effort to drop precision bombs.

Flying and Bombing—Who is Driving?

As described in Chapter 2, bombing evolved as a team pursuit. The ACTS bombardment doctrine clearly defined the pilot and bombardier together as the bombing team and emphasized the importance of cooperation between the two during a bombing mission. As will be explained in detail in Chapter 5 on the bombardier, there is only one point in space from which an unguided bomb dropped from an aircraft will hit a specific point on the surface of the earth. In early bomber aircraft, the pilot, although steering the aircraft, was generally unable to see below

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[108] *B-17 vapor trails fill the sky*, Photograph, n.d., US Air Force Historical Research Agency, http://www.afhra.af.mil/shared/media/photodb/photos/080306-f-3927A-056.jpg (accessed 5 April 2011).

and in front of it, and as he was unable to either see the target or calculate the position of the bomb dropping point, he could not steer the aircraft to it. The bombardier, sitting in a better position to see the target, could use his bombsight to calculate and identify the bomb dropping point, but because he was not flying, could not steer the aircraft to it. The bombardier had to provide directions to the pilot and bombing was, by necessity, a cooperative effort between the two crewmembers.

Early efforts at signaling directions between the two men during World War I consisted of the bombardier yelling directions to the pilot, but were largely ineffective in the open, noisy cockpits of early aircraft. To overcome this limitation, signaling reins were attached to each side of the pilot, and the bombardier could pull on the reins to signal a right or left turn, as necessary (Figure 3.13). This was, of course, very imprecise, as there was no way to indicate the amount of turn necessary, and it also required the bombardier to remove his hands from the bombsight to signal the turn, reducing his accuracy. By 1921, the U.S. Navy was testing a "Pilot Directing Bombsight" in some of their aircraft, which used a bank of electrical lights installed in the pilot's cockpit, controlled by the bombardier to indicate the need to turn and the direction.[109]

Figure 3.13
A bombardier and pilot demonstrate the signaling reins used to communicate turn commands during a bomb run.[110]

[109] Virginia Toole, *The Development of Bombing Equipment in the Army Air Forces*, May 22, 1945, 2, Call 201-13, US Air Force Historical Research Agency.

[110] Maurer Maurer, ed., *The U.S. Air Service in World War I: Volume II, Early Concepts in Military Aviation*, vol. 2 (Washington, DC: The Office of Air Force History, 1978), 398.

Pilot direction indicators, or PDIs, evolved through the 1920s, undergoing several improvements until the Sperry Gyroscope Company developed the D-1, which became the Army standard instrument. The D-1 allowed the bombardier to manually turn a knob that, through a flexible coupling, controlled the position of a needle contained in a gauge in the pilot's cockpit. The needle's position indicated the necessary direction and magnitude of turn. While more precise than indicator lights, it was rather primitive and still required that the bombardier use one hand to operate it while operating the bombsight with the other. It was not until the Navy fielded Carl Norden's revolutionary Mark XI bombsight in the late 1920s that PDIs became practical and effective aids to bombing.[111]

Norden improved the PDI's accuracy by integrating it directly into his bombsight design. As the bombardier moved the gyroscopically stabilized bombsight to align it with the target, it simultaneously moved a brush over a resistor coil, and a voltmeter measured the direction and magnitude of the turn by measuring the strength of an electrical signal passing through that brush. This signal actuated an electromagnet that deflected a needle on the PDI gauge in the pilot's cockpit (Figure 3.14).[112] The pilot turned in the direction of the needle, and since the bombardier kept the bombsight aligned with the target, the needle moved toward the center of the gauge as the aircraft heading moved closer to the correct heading to the target. When the needle was centered on the dial, the aircraft was on the correct course and the pilot rolled out of his turn and maintained that heading.

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[111] Stephen L. McFarland, *America's Pursuit of Precision Bombing, 1910-1945* (Washington, DC: Smithsonian Institution Press, 1995), 35-36.

[112] Ibid., 36.

Figure 3.14
Pilot Direction Indicator (PDI)[113]

Norden's automatic PDI/bombsight integration was a significant improvement over previous attempts at coordination, but was not embraced universally by the pilots. Many felt that the PDI interfered with their prerogatives as pilots because it gave constant, quantified direction, mandating how they flew their aircraft, whereas they wished to continue to "fly by the seat of their pants."[114] Since the PDI was linked directly to the Norden bombsight, which had proven to be the most accurate bombsight yet produced, it now indicated the "correct" course for the aircraft. The idea that there was a "correct" course meant, obviously, that if the pilot did not fly that course, he was flying an "incorrect" one. The idea of a machine, under the direct control of another non-pilot crewmember, providing mandatory directions that dictated the pilot's actions implied a loss of control over the aircraft.

This idea of a correct course, determined by the bombsight/bombardier/PDI socio-technical system, assailed the pilot's position as the aircraft system controller and directly implied that he could neither determine nor fly the correct course based upon his skill alone. In the past, the pilot could override the bombardier's crude directions if he thought that his instincts and flying skill would produce a more accurate result, but now, the bombsight/bombardier/PDI combination produced and indicated a new level of "correctness" for the flight path, and thus for the pilot's actions. Deviations from the PDI's direction, critically assuming that the bombardier was operating the bombsight correctly, meant that the bombs would miss their target. The

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[113] *Pilot Direction Indicator (PDI), C-1 Autopilot - Smithsonian National Air and Space Museum*, Photograph, n.d., http://www.nasm.si.edu/collections/artifact.cfm?id=A20001057000 (accessed 19 February 2011).

[114] McFarland, *America's Pursuit of Precision Bombing*, 36.

bombardier now *knew* better where the aircraft had to fly because the bombsight was so much better than in the past, therefore, the pilot *had to* follow the bombardier's direction. This had the potential effect of redefining the pilot's role during the bomb run from being the pilot who was the aircraft commander, to an entity acting simply as a flight control actuator, responding to external input from another controlling source—the bombardier.

In practice, however, the PDI improved bombing accuracy only marginally. It did not compensate for aircraft oscillation, which was a significant source of bombing error, and the system still relied upon the pilot reacting to the directions of what was really still an imprecise instrument. Despite the accuracy of the solution derived by the bombardier and bombsight, the directions passed to the pilot were too crude to allow him to execute them precisely and, as will be seen in Chapter 5, even the smallest deviations from the necessary course led to bombing errors. The communication between the computing element—the bombardier/bombsight—and the execution element—the pilot and aircraft—was not good enough to reliably achieve the precision bombing system solution. The next logical step, then, was to fix that communication link, and the solution to the problem was the integration of another new machine, one that would further question the pilot's role as the system controller by taking over his centrally defining skill—flying the aircraft.

Pilots, Autopilots, and Bombing—Losing Control?

On 14 February 1935, Carl Norden delivered to the U.S. Navy what he believed to be the solution to the coordination problem between the bombardier and the pilot. Called Stabilized Bombing Approach Equipment (SBAE), it was an electrically driven, gyrostabilized, mechanically actuated system that linked the Norden bombsight directly to the bomber aircraft flight controls (Figure 3.15). The SBAE was a single-purpose system that gave the bombardier the ability to control the bomber's flight path by transmitting steering commands generated when he moved the bombsight directly to the flight controls, bypassing the pilot in the process.[115] The result of three years of development and the first successful coupling of the bombsight to the flight controls, the SBAE was not the first attempt to do so, as efforts to combine the systems had begun a decade earlier.

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[115] Toole, *The Development of Bombing Equipment in the Army Air Forces*, 86-87; McFarland, *America's Pursuit of Precision Bombing*, 120. The U.S. Navy controlled the contract with Norden's company. All of his business dealings were through them, including his production for the Air Corps.
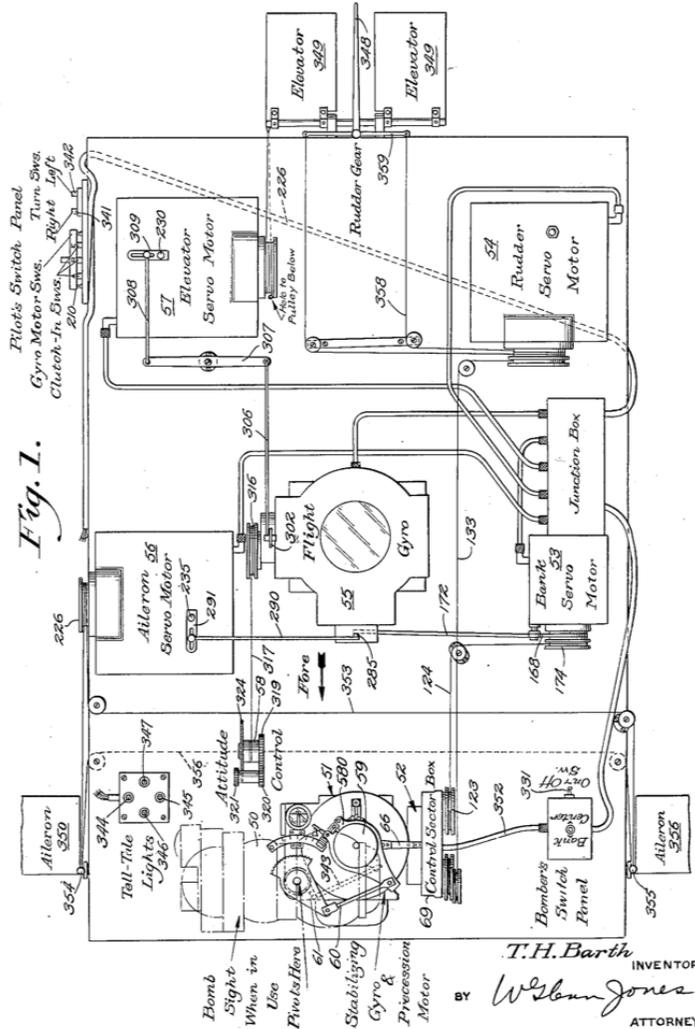
Figure 3.15
The SBAE as shown in "Aircraft Control System" Patent No. 2,485,953, filed by Theodore Barth.[116]

Since at least as early as 1926, the Air Corps had been specifically interested in using automated machines to improve bombing accuracy. The first attempt to do so through bombsight/flight control linkage occurred in 1927, when the Air Corps Materiel Division contracted with Alexander de Seversky, a Russian pilot, aeronautical engineer, and sometime

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[116] Theodore H. Barth, "Aircraft Control System, U.S. Patent 2,485,953" (New York, NY, October 24, 1940), 1.

airpower theorist, to build the Seversky Automatic Azimuth Drift Control, an experimental autopilot that he proposed to connect to a Sperry C-1 bombsight. Seversky intended his device to give the bombardier the ability to directly counter the effect of drift, a significant source of bombing error, by allowing him to move the flight controls when he moved the bombsight. However, the design never matured, and Seversky was unable to produce a functioning system and the Air Corps severed its relationship with him in 1930.[117] In the interim, however, the Sperry Gyroscope Company made the first concrete advance in the area.

The Sperry Gyroscope Company, founded by Elmer Sperry in 1910, had a long history with aircraft autopilots. Elmer Sperry and his son, Lawrence, designed and installed the first aircraft stabilization system in 1910, in an effort to help reduce the high rate of fatalities associated with powered flight. Recognizing that air was a very "unstable medium" and that the aircraft pilot had to "work constantly to maintain the stability of the (flying) machine about all three axes," the Sperry's built a system designed to help the pilot maintain controlled flight using concepts developed during the design of their gyroscopic ship stabilization system two years earlier.[118] The system consisted of a large gyroscope suspended underneath a Beach monoplane, but was not connected to the aircraft flight controls. The concept was that the force of the spinning gyroscope would counter any flight disturbance, using inertial force to return the aircraft to an upright, level attitude.[119] Although the experiment with the Bates monoplane failed, in 1912, the Sperrys did build the first successful stabilization system, Sperry Gyroscopic Stabilizer, and installed it on a Curtiss Hydroplane (Figure 3.16).

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[117] Toole, *The Development of Bombing Equipment in the Army Air Forces*, 35-39.

[118] Elmer A. Sperry, "Engineering applications of the Gyroscope," *Journal of the Franklin Institute* 175, no. 5 (May 1913): 474-475.

[119] Thomas Parke Hughes, *Elmer Sperry: Inventor and Engineer* (Baltimore, MD: Johns Hopkins Press, 1971), 110-112, 173-175.
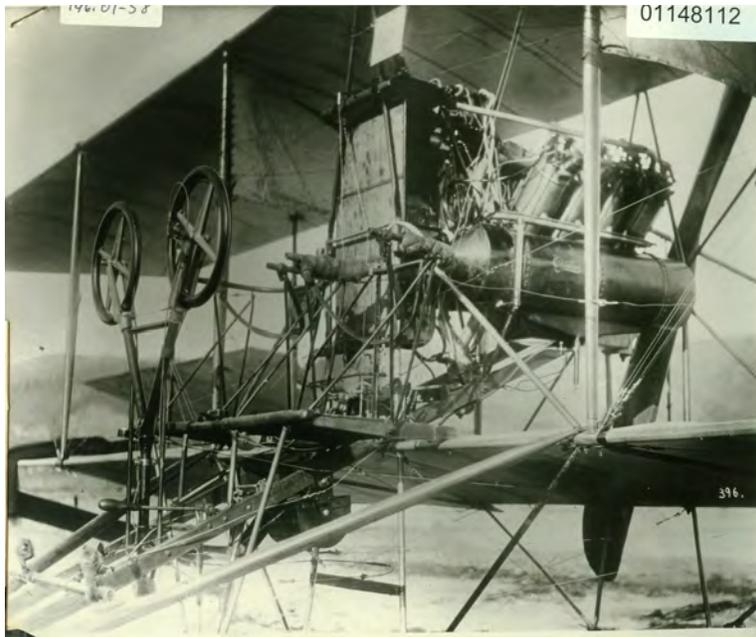
Figure 3.16
The world's first gyroscopic automatic pilot, the Sperry Gyroscopic Stabilizer, developed by Lawrence Sperry and installed and flown on this Curtiss "Hydroplane" in flight tests at Hammondsport, NY in 1912[120]

The Sperry Gyroscopic Stabilizer consisted of four gyros that provided both longitudinal and lateral stability. When engaged, the gyros detected changes in aircraft attitude and, in response, immediately actuated compressed air-powered servomotors that moved the flight control surfaces to return the aircraft to level flight. The gyros, servos, and linkages performed the same tasks as a human pilot. They sensed changes in the aircraft in the aircraft attitude and then actuating the flight controls to counter that change—thus becoming the first *automatic pilot*. The system was publicly well-received, and a 1914 *New York Times* article even presented as superior to the human pilot, explaining

> One of the great difficulties in hand operation of both the elevating planes and side controls is that the machine has to make a very appreciable deviation from the normal flying position before the operator is conscious of it, and he, in turn, makes a correspondingly large corrective setting of the planes. So the average lying in any strong wind is a series of dips to and fro, or sideways. As the skill of the aviator becomes greater the dips become smaller. But to some extent they are always there.

[120] *World's First Gyroscopic Automatic Pilot (Sperry)*, Photograph, 8" x 10", 1912, 146.01-58, IRIS No. 1148112, Envelope-Sperry Gyroscope Co., 8 X 10" Photographs (7), US Air Force Historical Research Agency.

With the gyroscopic stabilizer the servo-motors are brought into play at the first tendency of the machine to tilt or dip, and the deviation is corrected without the airman having any knowledge of its start.[121]

The system was a great success, and when Lawrence Sperry demonstrated it in flight at the *Concourse par l'Union pour la Sécurité en Aeroplane* in Paris, he won the 25,000-franc "Safety-Flight" prize (Figure 3.17).[122]

Figure 3.17
Lawrence Sperry winning the 25,000-franc *Concourse par l'Union pour la Sécurité en Aeroplane* "Safety-Flight" prize in Paris in 1914. Sperry, the pilot, displays his hands while his mechanic stands on the wing.[123]

The Sperry Company continued developing the autopilot after World War I, spurred by interest from William B. Mayo, Chief engineer of the Ford Motor Company, who saw potential applications for commercial flight. Ford installed the first successful "robot pilot" in a Ford C-9 commercial transport in 1929, where it occupied the right seat position normally reserved for the copilot. Measuring 14" x 14" x 10", it weighed about fifty pounds and consisted of both horizontal and directional air-driven gyros, and "servo motor units with three double acting clutches with the necessary attachments for them to operate the elevators, ailerons and rudder

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[121] Harold Hoeber, "LONG-SOUGHT AEROPLANE STABILIZER INVENTED AT LAST; Lawrence B. Sperry Performs Seemingly Impossible Feats by Aid of His Father's Gyroscope Device," *The New York Times* (New York, NY, July 19, 1914), sec. Magazine Section.

[122] Hughes, *Elmer Sperry: Inventor and Engineer*, 179-199.

[123] *No hands!*, Photograph, 8" x 10", 1914, 146.01-58, IRIS No. 1148112, Envelope-Sperry Gyroscope Co., 8 X 10" Photographs (7), US Air Force Historical Research Agency.

controls."[124] Those necessary attachments were long cables, attached directly to the aircraft flight control surfaces and essentially comprising a duplicate set of flight controls independent of the human pilot. The great advance made by this autopilot was that it connected the rudders to the ailerons so that in a turn, the aircraft could maintain coordinated, level flight. Up to that point, coordinated movement of the ailerons and rudder was achievable only by a human pilot.[125]

The system proved very successful in test flights during 1929, and greatly impressed the Air Corps leadership, which promptly announced that

> The Automatic Pilot has arrived. Large airplanes may now be controlled by the untiring metallic arm of an ingenious mechanism – a mechanism which pilots airplanes straight and level and will hold them on a given course indefinitely.[126]

Over fifty hours of testing, the Sperry system demonstrated that it could "fly more accurately than even a seasoned pilot," and showed promise for improving aerial navigation as well as reducing the physical burden placed on pilots during long-duration missions. The Air Corps, after dealing with Seversky's failure, soon adopted it as their standard autopilot, named it the A-1, and installed it in several of its bombers (Figure 3.18).[127]

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[124] Edward O. Purtee, *Development and Adaptation of Aircraft Instruments for Military Use* (Historical Division, Intelligence, T-2, Air Technical Service Command, 1946), 180.

[125] Interestingly, it was the Wright Brothers' implementation of a mechanical device that moved the rudder in concert with their wing warping mechanism that enabled them to conquer the challenge of controlled flight almost three decades earlier. See F. E. C. Culick and Henry R. Jex, "Aerodynamics, Stability, and Control of the 1903 Wright Flyer," in *The Wright Flyer: An Engineering Perspective*, ed. Howard S. Wolko (National Air and Space Museum, 1987), 19-43.

[126] Toole, *The Development of Bombing Equipment in the Army Air Forces*, 64.

[127] Ibid.

Figure 3.18
Major Hugh Knerr demonstrates "hands off" flying in this Curtiss Condor B-2 bomber during Air Corps maneuvers in 1930. He is sitting up, out of the cockpit to show that he is not touching the controls. This picture also shows how difficult it was for the pilot to see anything below and in front of the aircraft.[128]

Knowing that the Air Corps had contracted with Seversky to couple an automatic pilot and bombsight to improve bombing accuracy, the Sperry Company, also in the bombsight design business, was also working on a design for such a system as it developed the A-1 autopilot. On 18 October 1929, Mortimer Bates, a Sperry employee, patented a device called the "Bomb Sight Alignment and Rudder Control," which paired the A-1 with a Sperry C-4 bombsight, which was a modified C-1, the same bombsight that Seversky had used. Bates' design was the first to present a fully integrated system that purposely *eliminated* the human from portions of the bombing process to increase accuracy. Unique provisions and capabilities incorporated into patent number 1,880,671 included

- The provision of means whereby the steering of an aircraft may be directly under the control of the bomber at the bombsight. More particularly it is an object of this invention to enable the bomber to steer the dirigible craft in the act of sighting upon a target.
- The pilot is relieved of the duty of steering the craft during the time of sighting and alignment on the target, and the alignment is accomplished more quickly and more effectively.

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[128] *Knerr-Condor B2 autopilot*, Photograph, 1930, US Air Force Historical Research Agency.

- The bomber can relieve himself of the duty of steering the craft when the latter is headed for the target by switching over the control of said steering to an automatic means such as a gyroscopically maintained baseline.[129]

The system thus attempted to accomplish three key functions: provide the bombardier the ability to fly the aircraft while sighting the target, eliminate the pilot from the process to speed up aircraft reaction time, and transfer flight control from the bombardier to the automatic pilot once the target was sighted in the bombsight, eliminating the bombardier from flying the aircraft. In effect, the system took over as much of the flying responsibility as was technologically possible at the time.

The Air Corps was very interested in the Sperry system, and on 22 January 1930, contracted to acquire first twenty-five, and then thirty-five, of the units. At this time, the Air Corps was not aware that the U.S. Navy had contracted with Carl Norden to build his Mark XI bombsight, as the Navy maintained a heavy veil of secrecy over the program. Consequently, the Air Corps committed itself to the Sperry Company for both autopilot and bombsight development. The Sperry Company delivered the first C-4 bombsight with the autopilot on 12 March 1931, but it proved disappointing. The bombsight itself was too large and cumbersome and performed poorly, while the autopilot directional system was inefficient and difficult to synchronize with the target. The autopilot also was also temperamental and required a great deal of adjustment in flight. The long cables used to manipulate the flight control surfaces constantly lost tension when exposed to the rapid temperature drops at high altitude, causing the controls to become "mushy" and imprecise. The entire system also suffered from electrical problems, caused by inconsistent power generation from its air-driven generators. Disappointed, the Air Corps soon cancelled its orders for the system and chose to pursue other bombsights that might be coupled to a modified version of the autopilot.[130]

In spite of the setback, the Sperry Company continued its autopilot development, modifying the A-1 by replacing its mechanical linkages with hydraulic hoses. The result was a slower acting, smooth-response system, much more successful, but more appropriate for the comfort-driven demands of commercial travel rather than the precision-driven needs of the Air

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[129] Mortimer R. Bates, "Bomb Sight Alignment and Rudder Control, U.S. Patent 1,880,671" (Brooklyn, NY, October 18, 1929), 1, lines 3-31.

[130] Toole, *The Development of Bombing Equipment in the Army Air Forces*, 38-39; McFarland, *America's Pursuit of Precision Bombing*, 39.

Corps.[131] It was a tremendously capable system, but was not suitable for the precision bombing mission. Sperry continued improving upon it and by the late 1930s had built several new versions, each better than the last. By 1941, they had evolved the technology to the point that they produced the first all-electric autopilot, the A-5. The A-5 was very advanced technologically, using three dual-element vacuum tube amplifiers to amplify signals produced by the autopilot gyros in the three axes of flight: roll, pitch, and yaw. The amplifiers sent correction signals electronically to electrohydraulic servomechanisms that responded more quickly and accurately than the electromechanical systems used in earlier autopilots.[132] While the A-5 was a great autopilot, Sperry was still not able to produce a precision bombing *system* that met the Air Corps' needs.

Although the Sperry Company held an obvious lead over all of their peer competitors in autopilot technology, they struggled with bombsight development, as will be explored in Chapter 5. When the Air Corps contracted with Carl Norden through the Navy in 1933, it should have knocked Sperry out of the bombing business. However, Norden's SBAE was not a true autopilot. It only linked the bombsight to the flight controls and could not serve as a more complete aircraft stabilization system that could improve navigation performance and relieve a fatigued pilot on long missions. Since the Air Corps was interested in a system that they could use for both bombing and as an autopilot, Sperry maintained their efforts to try to develop such an integrated system.

Sperry continued its bombsight development through the 1930s, and in 1940, presented the Air Corps the S-1 bombsight as an alternative to the Norden, which was in short supply due to production problems. Paired with the A-5 autopilot, the system appeared to hold great promise, leading one Air Corps Materiel Division officer to conclude that the system might become the sole one used on bombardment aircraft in the near future.[133] However, both the S-1 and A-5 were beset with technical problems, ranging from excessive jitter in the optics to difficulty maintaining turn and altitude control in flight. It was only due to an acute shortage of Norden bombsights in January 1942 that the system was installed in many B-24 bombers destined for immediate combat operations. Substandard performance and continued problems

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[131] McFarland, *America's Pursuit of Precision Bombing*, 118.
[132] Loyd Searle, "The Bombsight War: Norden vs. Sperry," *IEEE Spectrum* 26, no. 9 (1989): 63.
[133] McFarland, *America's Pursuit of Precision Bombing*, 144.

led the Air Corps to cancel all current and future orders for the systems in August 1943.[134] Fortunately for the Air Corps, by that time a crucial breakthrough had turned the Norden bombsight into the type of precision bombing system that they so desired, one that combined the benefits of both electrically controlled and electromechanical systems.

SBAE and AFCE—Task Control vs. System Control

When Carl Norden set out to solve the communication problem between the bombardier and pilot in 1933, he produced a system that did just that. His SBAE system that connected the bombsight to the flight controls gave the bombardier limited control over the aircraft flight path, and reduced the pilot's role in the aircraft control loop. The SBAE used two gyroscopes: one for aircraft azimuth control and one for pitch control. When the gyroscopes detected any deviation from their level, aligned position, electrical signals transmitted correctional instructions to centrally located servomotors that, in turn, pulled long wire cables attached to the flight control surfaces, moving them as necessary to change the aircraft attitude until the gyroscopes returned to their horizontal and vertical aligned positions.[135] These cables ran the length of the aircraft from the servomotors to the control surfaces, comprising a separate flight control system from the primary one used by the pilot, but were located in the same area as the primary flight control rods, cranks, and pulleys.

The SBAE mechanically linked the bombsight to the azimuth gyro, and when the bombardier rotated the bombsight in azimuth, as when aligning it with the aim point, those linkages generated the necessary electrical signals through a series of brushes and transmitted them to the servomotors that actuated the ailerons and rudder.[136] The aircraft turned in response until it was heading in the direction indicated by the bombardier, giving him control of the aircraft flight path, but in roll and yaw only. Although the SBAE turned the aircraft to the direction indicated by the bombardier, it was not useful for navigation, as it could not hold a particular heading other than that commanded by the bombardier through the bombsight. Additionally, once established on a given heading, it would maintain that heading until commanded to change, but only as a heading relative to the bombsight position. Since it had no

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[134] Toole, *The Development of Bombing Equipment in the Army Air Forces*, 67-70.
[135] McFarland, *America's Pursuit of Precision Bombing*, 120.
[136] Barth, "Aircraft Control System, U.S. Patent 2,485,953."

connection to any azimuth-indicating instrument, such as a magnetic compass, it could not hold a directional heading, just one in relation to the bombsight.

Neither did the SBAE did not give the bombardier any control over the aircraft pitch. Pitch was controlled independently by the vertical flight gyro, which was not connected to the bombsight but did respond to its movement if necessary during a turn to keep the aircraft in level flight.[137] In addition to not being able to control the aircraft altitude, the bombardier's control was further limited by the fact that he had no control over the aircraft speed, a characteristic common to all of the systems under examination. The SBAE was just that—*stabilized bombing approach equipment*. It was a single-function, task-specific system designed to improve bombing accuracy. Carl Norden was not interested in relieving the pilot of any burden and, in his own words, was concerned only with "*precision* flight regardless of weather conditions and *only* for the purpose of improving bombsight performance."[138]

As an aid to bombing, the SBAE was successful. In Navy tests, bombing results were 30-40 percent more accurate with the system than under manual control in smooth to bumpy air, and in very rough air, when the bombardiers using the bombsight alone would not drop for fear of bombing off of the bomb range, the results were as good as the manual bombing results in smooth air.[139] However, the SBAE was subject to some severe shortcomings, particularly when used in the high-altitude environment. Just as with the Sperry A-1 autopilot, the SBAE control cables lost their tension and ability to actuate the flight controls in the extreme cold of high altitude bombing missions, making the system at best non-precise and at worst, useless. It also suffered from a lack of mechanical coordination and refinement, often skidding through turns in uncoordinated flight and its abrupt control inputs provided a sometimes violent ride for the bomber's crew.[140] It was, however, the only option available for improving bombing accuracy.

Based upon the Navy test results, the Air Corps acquired an SBAE in 1938, and installed it in a Martin B-18 bomber for testing. They also renamed the system Automatic Flight Control Equipment (AFCE) to circumvent the Navy's SECRET classification of the SBAE, which was

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[137] Ibid.

[138] Quoted in McFarland, *America's Pursuit of Precision Bombing*, 120.

[139] Toole, *The Development of Bombing Equipment in the Army Air Forces*, 88; McFarland, *America's Pursuit of Precision Bombing*, 121.

[140] Albert L. Pardini, *The Legendary Secret Norden Bombsight* (Atglen, PA: Schiffer Military History, 1999), 93-94.

hindering the Air Corps' acquisition process.[141] At the conclusion of the tests, Air Corps
engineers concluded that since it gave more accurate aircraft control to the bombardier than
existing PDI systems, it would likely

1. decrease the amount of training required by novice bombardiers
2. decrease greatly the errors of the less efficient bombing teams,
3. would probably decrease to a lesser degree the errors of the better bombing
   teams,
4. would allow the bombing run to be decreased materially
5. would allow the bombardier to direct the airplane on a zigzag course to the
   target.[142]

The AFCE was an obvious improvement to the bombardment system, but it remained a task-
specific system, suitable for bombing only, and even while testing it, the Air Corps was
simultaneously pursuing other options that more closely met their needs.

 While Norden was developing the SBAE, the Air Corps had been installing Sperry
autopilots in all of its bombers to help with navigation and reduce pilot fatigue on long missions.
Air Corps leadership had long since decided that they needed autopilots in bombers, but that they
needed it to function as both an autopilot and a precision bombing aid.[143] Even the renaming of
the bombing-specific SBAE to a more general flight-control oriented AFCE was consistent with
their wishes to obtain a more complete, capable system. By the time the engineers installed the
AFCE in the first Martin bomber, the Air Corps was already using the Sperry A-3 system in its
bombers, which was an improved version of the A-1. Not satisfied with having to use two
automatic flight control systems on aircraft where every pound of equipment meant one less
pound of bombs, the Air Corps Materiel Division aggressively pursued integrating the Norden
bombsight with the Sperry autopilot.

 The Air Corps tried and failed in 1937 to integrate a Sperry A-2 autopilot with the
Norden bombsight, and by January 1940, as war clouds loomed on the horizon, informed the
Navy that they were going to pursue integrating the all-electric Sperry A-5. This also proved a
failure, as the A-5 had numerous previously mentioned problems, and the power requirements

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[141] Raymond Walters, *Bombsight Maintenance Training in the AAF*, Army Air Forces Historical Study 8
  (Washington, DC: U.S. Army Air Forces Assistant Chief of Staff, Intelligence Historical Division, June
  1944), 4, US Air Force Historical Research Agency.

[142] Toole, *The Development of Bombing Equipment in the Army Air Forces*, 88-89.

[143] McFarland, *America's Pursuit of Precision Bombing*, 38.

for the autopilot and bombsight were incompatible. The bombsight operated on direct current, as did all of the bomber instruments at the time, and the autopilot operated on alternating current.[144] In response, the Navy began an effort to integrate the Sperry A-3 with the bombsight, achieving partial success by the middle of 1941. However, the integration was incomplete and to operate correctly, the *human* pilot had to control the aircraft ailerons because the bombsight could not produce a proportional banking signal.[145] This hybrid solution was hardly better than the PDI system it was supposed to replace, and probably worse. In the mean time, Air Corps engineers in the Materiel Division stumbled across a key machine, developed by the Minneapolis-Honeywell (M-H) Corporation, which not only greatly improved the AFCE, but made it into a highly functional autopilot, as well.

The Honeywell C-1 Autopilot—System Control in a Box

At the turn of the twentieth century, the Minneapolis Heat Regulator Company began developing electrical proportional control systems for building heating and cooling systems. By the 1930s, the company, now Minneapolis-Honeywell, had developed the Modutrol, a controller that was very effective at modulating the heating and cooling of buildings through the proportional mixing of hot and cold air, and in late 1940, their engineers developed a version of it for use in controlling the ambient environment in aircraft. This servo-amplifier system controlled the temperature through a system of multiple, proportional settings and constant output that was constantly regulated, as opposed to the old damper-flapper system design which was either open or closed. The design enabled the system to handle the challenging environment created in aircraft, which were typically subject to extreme changes in temperature as they climbed or descended thousands of feet in a short period.[146]

M-H pitched the control system to the Army in January 1941, but received little initial interest. However, a month later, representatives from the Photographic Division at Wright Field contacted them about adapting the system to provide precise motor control for keeping airborne reconnaissance cameras level in flight. In a matter of a few weeks, M-H engineers had developed a system that not only kept the camera level, but enabled remote control of its attitude,

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[144] Carl Frische, "Carl Frische Interview - Percy Halpert History," Video, n.d., http://vimeo.com/9677367 (accessed 5 April 2011).

[145] McFarland, *America's Pursuit of Precision Bombing*, 124.

[146] Jeffrey L. Rodengen, *The Legend of Honeywell* (Ft. Lauderdale, FL: Write Stuff Syndicate, Inc., 1995), 65-66.

as well. This capability caught the attention of the Army Air Forces engineers working on the autopilot/Norden integration project.[147]

In mid-1941, USAAF personnel showed M-H engineers "a device mostly covered by a white sheet, and asked if they could adapt potentiometers to an exposed gyroscope, creating an electronic transference of motion from the potentiometers" through their amplifier to a servo motor.[148] The device was the AFCE azimuth stabilizer, and in ten days, M-H developed a system that worked almost flawlessly on the pitch axis of a mock up autopilot system. After modifying the system with a larger amplifier to enable the controller to actuate the large servos necessary to move the massive flight control surfaces of a B-17 bomber, the USAAF installed the pitch controller in a test aircraft. In his history of the Honeywell Corporation, *The Legend of Honeywell*, Jeffrey Rodengen relates that Captain Don Diehl, the pilot of the test aircraft, was somewhat skeptical of the system and asked M-H technician George Borell to "sit in the tail of the plane with a pair of bolt cutters and cut the servo line if it failed to work."[149] It turned out that Diehl's understandable request was unnecessary, but it was possible because of the M-H system's revolutionary design.

Instead of using mechanical rods or cables to connect servos to the aircraft flight control surfaces, the new autopilot used electrical wires that ran from the control unit that was connected to the gyros to servos that were located near the flight controls. If the wires were cut, the system could not actuate the flight controls. In the final design, M-H engineers routed the electrical wires through different areas of the aircraft than those used by the primary flight controls, essentially creating a fully functioning backup flight control system for the bomber. This was extremely useful, as in the event that the primary system was damaged in combat, the backup system might escape damage and allow the pilot to still control the aircraft. The *B-17 Pilot Training Manual* actually advocated the use of the autopilot in an emergency (Figure 3.19), and there are several stories of B-17s returning to land safely with the pilot using the autopilot for control after the primary controls were damaged by enemy fire.[150]

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[147] Ibid., 65-67.

[148] Ibid., 71.

[149] Ibid.

[150] See Peter M. Bowers, *Fortress in the Sky* (Grenada Hills, CA: Sentry Books, Inc., 1976); Roger A. Freeman, *B-17 Fortress at War* (London: Ian Allen Ltd, 1977).

Figure 3.19
Emergency Use of Autopilot entry in the *B-17 Pilot Training Manual*[151]

The USAAF flight test of the M-H prototype system was an unqualified success, and a redesigned, fully functional system was installed in a B-17 a few months later for more testing. After only 160 hours of flight test, the USAAF was convinced that this new system, the C-1 Autopilot, was the solution to their requirement for an integrated autopilot/bombing system. By the fall of 1942, it was approved for use in bombing missions and in 1943, became the service's standard autopilot system and was installed in all of the heavy and very heavy bombers used by the United States during World War II.[152]

Automating Flying

The C-1 Autopilot was a hybrid system of mechanical and electronic elements that could control an aircraft attitude in the pitch, roll, and yaw axes, described as "an electromechanical robot which automatically flies the aircraft in straight-and-level flight or maneuvers it in response to fingertip controls operated by the pilot or bombardier" (Figure 3.20).[153] Its primary components were

- The directional gyro, located in the Norden bombsight stabilizer in the bombardier's compartment that *sensed* changes in the aircraft azimuth
- The flight gyro, located near the center of the aircraft that *sensed* changes in the aircraft pitch or roll
- A series of potentiometers that *translated* the flight attitude deviations generated by the gyros into electrical correction signals

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[151] *Pilot Training Manual for the B-17*, 178.

[152] This included the B-17, B-24, and B-29. Early in the war, many B-24s had the Sperry S-1 bombsight and A-5 autopilot installed due to a shortage of Norden bombsights and the, as yet, unresolved autopilot problem. Many of these aircraft used those systems through the entire war.

[153] *Handbook of Operations and Service Instructions: Automatic Pilot Type C-1 (AN 11-60AA-1)* (Dayton, OH: The Otterbein Press, 1943), 3.

- An amplifier that boosted those signals and translated them into electrical *commands* sent to servomotors connected to the flight controls
- Servomotors that actuated the flight controls in response to the commands received from the amplifier
- Two autopilot control panels, one each for the pilot and bombardier, used to engage the autopilot and adjust its operation[154]

These components formed a closed-loop control system that, once set and adjusted by the human pilot, could maintain a steady state flight attitude commanded by the pilot or bombardier. It could maintain a constant attitude, whether wings-level or in a turn, and a constant heading in a straight line. However, like the SBAE, the early versions of the system were not an effective aid to aerial navigation, as they were not integrated with a true direction-indicating instrument, such as the aperiodic compass, and thus could not hold a specific navigational heading.
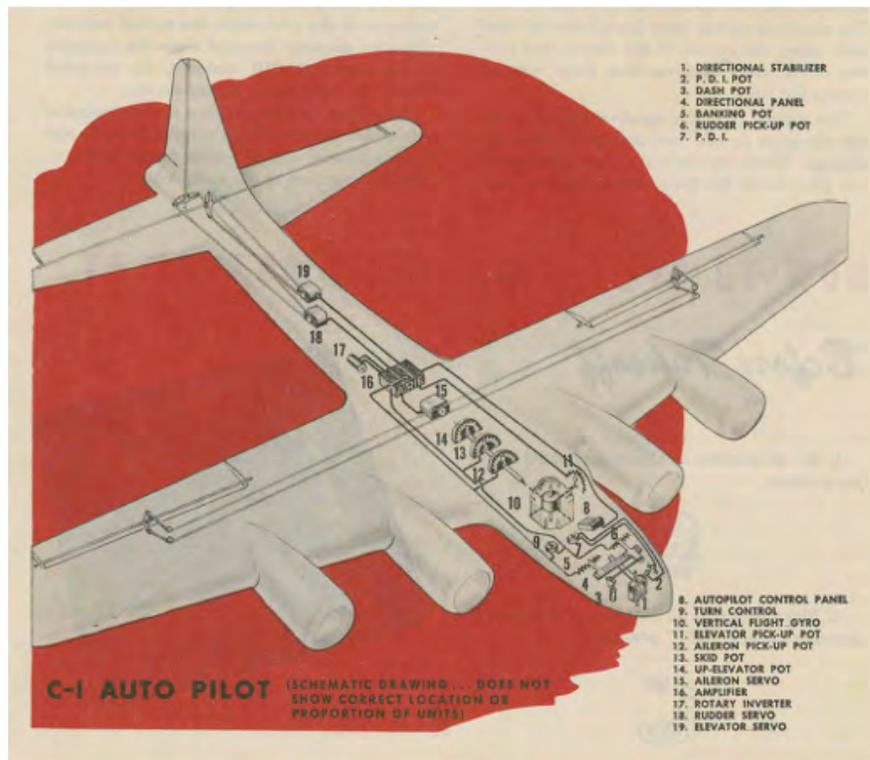
Figure 3.20
B-17 C-1 Autopilot schematic drawing[155]

[154] *Here's How: Operation of the C-1 Autopilot* (Minneapolis Honeywell Aeronautical Division, n.d.), 2-5.
[155] *Pilot Training Manual for the B-17*, 175.

The C-1 Autopilot was represented as a device that worked "much the same way as a human pilot," but one that flew much more precisely and accurately (Figure 3.21).[156]
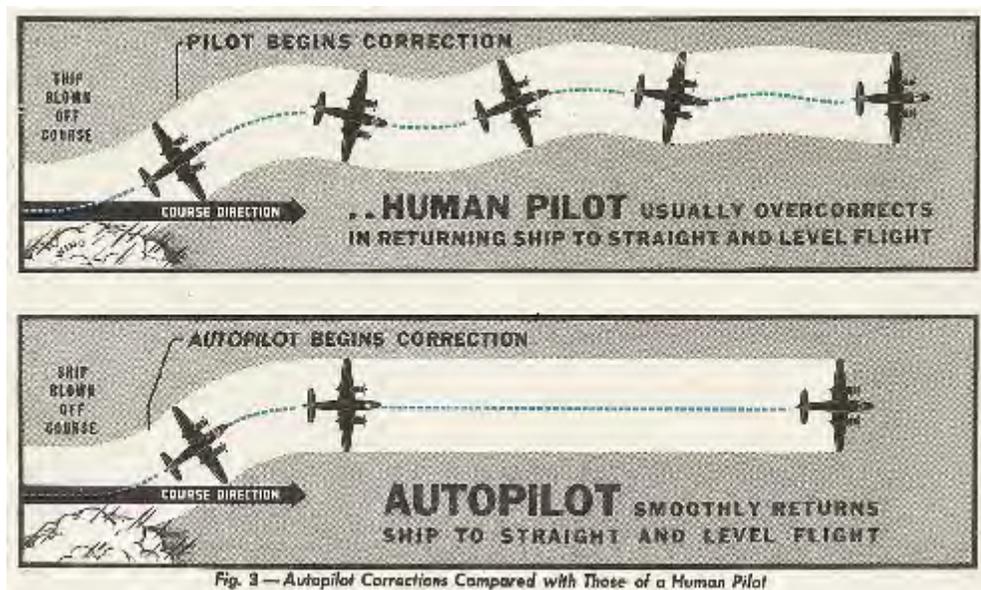
Figure 3.21
Precision flying and the pilot vs. the autopilot[157]

In describing how the autopilot worked, the 1944 *Student's Manual: Bombing* used to train USAAF bombardiers actually presented the autopilot as a direct human analog. It explained that the gyros worked like the pilot's "eyes," sensing the environment, and when they detected a change, sent control signals to the amplifier, the autopilot's "brain." The amplifier transmitted the signals through electric bridge circuits and wires, the autopilot's "nervous system," to the servos that manipulated the flight controls, the system's "muscles" (Figure 3.22).

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[156] *Handbook of Operations and Service Instructions: Automatic Pilot Type C-1*, 4.
[157] *Handbook of Overhaul Instructions: Automatic Pilot Type C-1 (AN 11-60AA-2)* (Marion, IN: Central Press, Inc., 1944), 4.
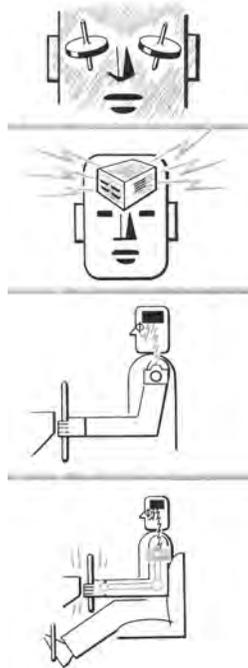
Figure 3.22
The cybernetic autopilot[158]

This distinctly human, physiological portrait basically characterized the electromechanical autopilot as a set of perceptual organs that transmitted commands to a set of effector organs through a central nervous system. Today, this analogy seems, if not obvious, at least understandable. Interestingly, in 1944, this view of a technological system as a human analog was far from common. In fact, it was not until after the war, in 1948, that Norbert Weiner formally advanced the concept with the publishing of his book *Cybernetics: or Control and Communication in the Animal and the Machine*.[159] Wiener notably drew parallels between the process of communication in the human nervous system to that used in servomechanical control systems. Wiener went on to become regarded as the father of the field of cybernetics, but the structure of his ideas was evident well before he published his book. Interestingly, this progressive notion evolved in the military, the organization that Lewis Mumford famously

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[158] *Students' Manual: Bombing* (Army Air Forces Training Command, 1944), 3-1-2.

[159] See Norbert Wiener, *Cybernetics: Or, Control and Communication in the Animal and the Machine*, 2nd ed. (Cambridge, MA: MIT Press, 1965).

viewed as resistant to innovation and invention and regarded as "the refuge of third-rate minds."[160]

Controlling the Controller—C-1 Autopilot Operation and Building a Partnership

The C-1 Autopilot was controlled through one of two control panels, one located in the pilot's cockpit and one in the bombardier's compartment. Either one could control the system in flight, but the pilot's panel was the master control, providing the system power, more capability, and it could override commands from the bombardier's panel (Figure 3.23). The panel contained all of the controls necessary to set up the system, adjust and engage it in flight, and turn the aircraft, as well as a series of lights that indicated whether the system was set up and operating properly.
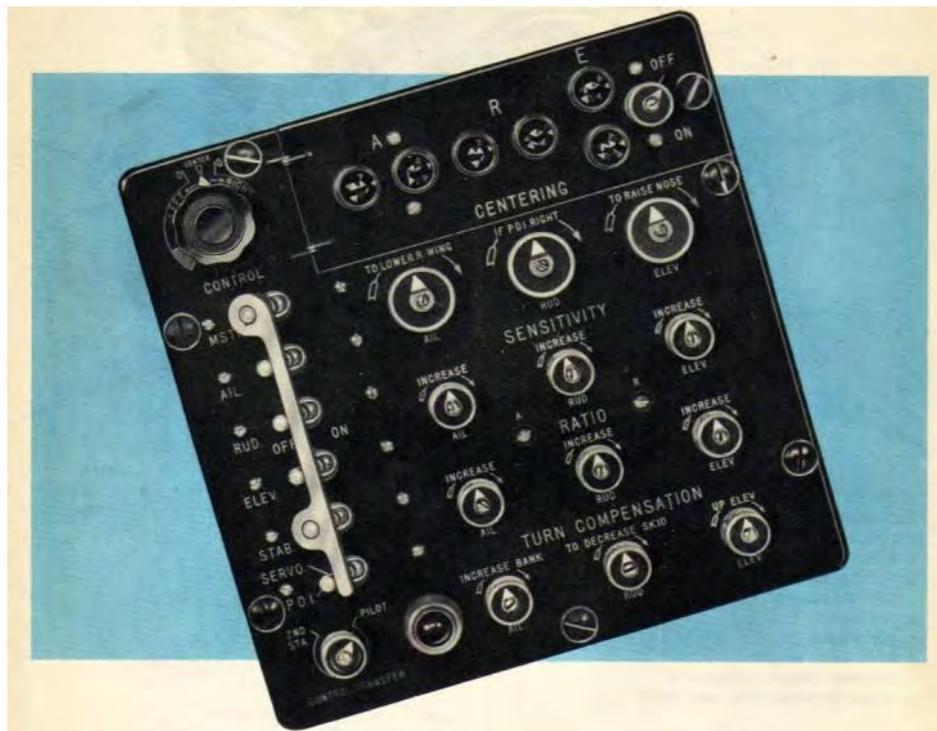
Figure 3.23
The pilot's autopilot control panel[161]

The C-1 Autopilot took a great deal of setup and adjustment throughout the mission. Once airborne, the aircraft commander's first concern was powering up the system and teaching

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[160] Lewis Mumford, *Technics and Civilization* (New York, NY: Harcourt, Brace and Company, Inc., 1934), 95.
[161] *Bombardiers' Information File (AAF Form 24B)* (U.S. War Department, 1944), 5-1-3.

it which way was up. To do so, he first turned on the system and waited for the gyros to spin up and erect. Once complete, he leveled the aircraft, established a stable cruising airspeed, and trimmed it for level flight. This step was critical, because it established the initial conditions for the autopilot, essentially constructing its "universe," the reference frame from which it would make all of its decisions. The human pilot had to create as close to a true vertical and horizontal reference for the flight and azimuth gyros as possible, because they would become the autopilot's definition of the true vertical and horizontal, and all autopilot maneuvers would be in relation to these settings. The pilot used his own flight instruments to establish and confirm that true horizontal and vertical position, and it was *his* skill at doing so that established how good the autopilot *could* be.[162]

Once the aircraft was trimmed for level flight, the aircraft commander had the bombardier center the PDI so that it showed a good heading reference. The PDI was still used with the C-1 Autopilot as a backup system in the event of an autopilot failure. With the PDI set, the pilot engaged the autopilot in stages, first the ailerons, then the rudder, and finally the elevator. He then analyzed the autopilot's performance, checking to see if it kept the aircraft in a level attitude. If necessary, he made fine adjustments to the autopilot settings trim knobs on the control panel that could correct any deviations. Once again, it was the pilot's perception that established the autopilot's understanding of its own universe.

Next, the pilot determined the autopilot's behavior through setting *how* it would react to its created environment by adjusting the system Sensitivity and Ratio settings. Sensitivity was comparable to a human pilot's reaction time. High settings brought quick responses to the slightest change in aircraft attitude, while low settings delayed the reaction. High settings meant that the crew was in for a jerkier, but more precise flight, while low settings were smoother, but less precise. The Ratio setting determined the amount of control surface movement the autopilot commanded in response to a deviation. Set too high, the autopilot would over control the aircraft, and "hunt" for the correct attitude with large control movements that continually overshot the desired condition. Set too low, the autopilot would under control the aircraft, and control movements would be too slow. Proper setting of the Sensitivity and Ratio controls was critical for a smooth, precise flight on autopilot.

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[162] The autopilot procedures in this and the following paragraphs are drawn from *Handbook of Operations and Service Instructions: Automatic Pilot Type C-1*; *Here's How: Operation of the C-1 Autopilot*; *Pilot Training Manual for the B-17*; *Bombardiers' Information File*.

Finally, the pilot adjusted the turn compensation setting to ensure that the aircraft performed coordinated turns, with the ailerons and rudder working correctly in unison. To do this, he had the bombardier use the turn controller on his bombsight to command a turn. The aircraft was supposed to assume an 18º bank coordinated turn, and the pilot confirmed the attitude on his instruments, if necessary, adjusting the aileron, rudder, or elevator turn settings to achieve coordinated flight (Figure 3.24). This setting was crucial, as it affected how precisely the autopilot flew the aircraft in a turn, which would most likely occur when the bombardier was controlling its actions during the most critical part of the flight—the bomb run. Once again, the pilot's perception of the correct aircraft attitude was central to the autopilot performing its role when flying the aircraft.
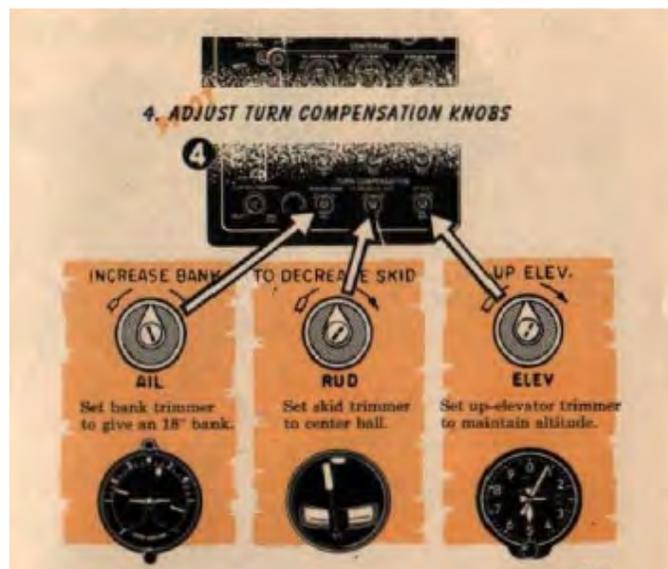
Figure 3.24
Autopilot turn compensation[163]

With the final adjustments made, the pilot or bombardier could use the autopilot in flight. However, as the setup and adjustment process described above indicate, the autopilot was only as good as the pilot allowed it to be. A misadjusted autopilot would not sense or react properly in flight, and accomplishing the process correctly became a new measure of skill. Just as the ability to stay closely tucked in the correct position in formation demonstrated that a pilot had good flying skills, setting up the autopilot so that it provided a smooth, stable platform was a skill in

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[163] *Here's How: Operation of the C-1 Autopilot*, 13.

itself equally worth mention, as illustrated by one B-17 copilot's assessment of his aircraft commander.

> He could fly his airplane too. He could sock in close in formation and hold it there all day long. He never got sore and started kicking the airplane around. And he knew plenty about engines and flaps and landing gear and hydraulic systems and electrical systems. He could set up an auto-pilot the way the Honeywell Company intended.[164]

In an odd twist, the ability to use an automated system that appeared to take away the fundamental task that defined the pilot—flying—became a mark of skill at that very task.

The process of setting up and adjusting the C-1 Autopilot was a process of creating a relationship between the pilot and the autopilot. The pilot, through his flying skill, established the physical references that the autopilot used to define its environment. His definition of the true vertical and horizontal became the autopilot's definitions—its "ground truth." It used those references to detect any deviations from that truth, and then corrected them through a series of control reactions, also defined by the pilot. While engaged, the autopilot was flying the aircraft to the extent that it was designed—it could hold a flight attitude and respond to change commands transmitted from the autopilot control panel or bombsight, as will be discussed. However, it was flying the way that the pilot *told* it to fly, adjusted to his perceptions and reacting as he programmed. As those perceptions varied from individual human pilot to individual human pilot, the autopilot was essentially an *extension* of the human pilot that programmed it and was an embodied version of that pilot.

The autopilot created a new way of controlling the aircraft and thus a new "piloting" skill. With the pilot in direct control of the aircraft, flying skill involved the pilot's ability to control the aircraft with physical reflexes triggered by his own sensory input. With the autopilot, however, the pilot was one step removed from direct control. No longer was it his sensory input that triggered the reflex action that moved the flight controls, nor was it his reflex that was flying the aircraft—it was the autopilot's. He had to understand how the autopilot operated, how it sensed and responded. The new skill involved putting the machine in a position where it could excel, establishing the correct initial conditions so that it could respond to a correct sensory input, as well as dictating that response.

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[164] Stiles, *Serenade to the Big Bird*, 56.

This new skill, however, was linked directly to the pilot's own flying skill. An imprecisely set up autopilot responded imprecisely and flew imprecisely. If the human pilot could not establish the correct initial conditions or dictate the appropriate response, the autopilot response, while correct for what it had been "told" by the pilot, would be incorrect. Additionally, the human pilot had to continually monitor the autopilot, as gyroscope precession could affect its ability to maintain level flight or a straight course. Thus, the pilot became an intermediary in the process, evaluating the autopilot's response to sensory input against his own and adjusting the "ground truth" as necessary to maintain precision flight. The pilot never stepped out of the aircraft control system, merely shifted his place within it, allowing the autopilot to perform some of "his" tasks.

Flying With the Autopilot

The autopilot could be commanded to perform turns through both the autopilot control panel and, when engaged, the Norden bombsight. To turn the aircraft, the pilot rotated the Turn Control knob located in the upper left corner of the autopilot control panel in the desired direction of turn (Figure 3.25). The pointer on the knob commanded a bank attitude, with the beginning of the shaded areas at the 3:30 and 8:30 positions indicating 30º of bank. Turning beyond this point into the shaded areas commanded over 30º of bank, and pilots were warned against doing so in rough air, as it ran the risk of upsetting the vertical flight gyro. Coming out of a turn, the instruction manual likewise warned pilots to pause at the "0º" setting until the aircraft reached a wings level attitude, otherwise, the recovery to level flight would not "be smooth."[165] As with setting up and adjusting the autopilot, there was a certain skill involved in using it to control the aircraft, as well.

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[165] *Here's How: Operation of the C-1 Autopilot*, 14-15.

Figure 3.25
The C-1 Autopilot Turn Control Knob[166]

Although the autopilot control panel gave the pilot the ability to turn the aircraft, it could not command the aircraft to climb or descend. Its application was limited to straight and level flight, which it did very well. In the words of copilot Bert Stiles

> If you can set up the auto-pilot and coast along alone, a Fort is a dream girl.
> You could have a cocktail party in the nose and a dance in the bomb bay and it
> would fly on the same heading and go on and on till the gas ran out.[167]

While useful for reducing fatigue on long, single ship missions, the autopilot could not aid the pilot in the most demanding type of flying, though—maintaining position in a fluid, sometimes violent formation. That type of flying, heaving a "big monster" around the sky, made Stiles and other bomber pilots dream of "fighters and Cubs and gliders, anything little that flies by the touch system."[168] Although there was no hope of decreasing the size of the bomber to make it easier to fly, Minneapolis-Honeywell greatly improved how they flew later in the war when they invented the "Formation Stick," an improvement to the C-1 Autopilot that gave men like Stiles the "touch system" control that they desired, but also further complicated the answer to the question of who was really flying the aircraft.

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[166] Ibid., 14.
[167] Stiles, *Serenade to the Big Bird*, 75.
[168] Ibid., 76.

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The Formation Stick—*Now* Who is Flying?

The Formation Stick was a top-secret addition to the C-1 Autopilot, first installed on 11 April 1945. A miniature control stick that controlled the aircraft through the autopilot, the Formation Stick enabled the pilot or copilot to maneuver the aircraft "with a minimum of effort" (Figure 3.26).[169] In an aircraft that sometimes required significant physical effort to fly, this was a tremendous improvement. At the time, the 27 April 1945 M-H Company newsletter proudly proclaimed

> The advantage is that where manual control of a heavy bomber requires a force of perhaps 100 pounds, electronic control through the Formation Stick requires less effort than a child uses in turning a bicycle.[170]
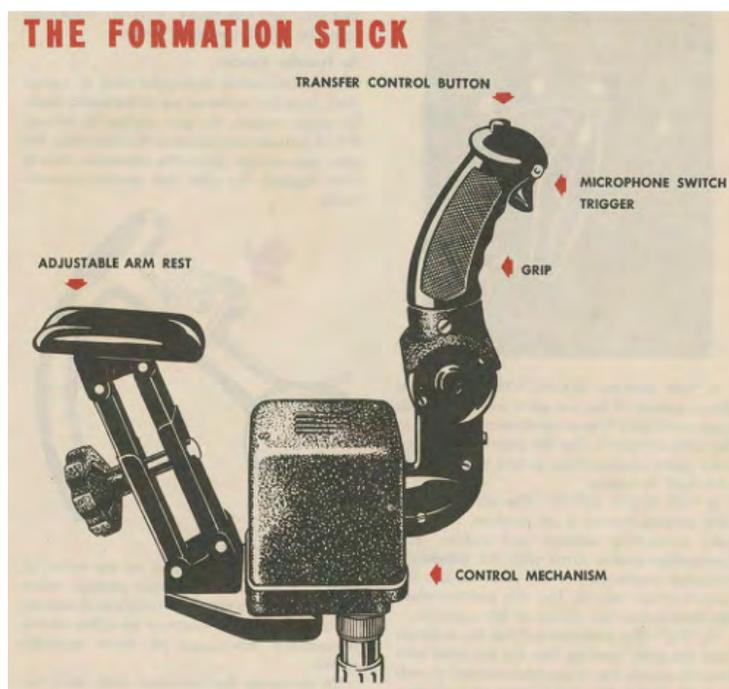
Figure 3.26
The C-1 Autopilot Formation Stick[171]

The aircraft commander and copilot each had a separate Formation Stick, with the aircraft commander's installed to the left of his flight control yoke and the copilot's to the right of his yoke. The Formation Stick was designed to fly the aircraft in the same manner as the stick in a

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[169] *Pilot Training Manual for the B-17*, 181.

[170] Quoted in Rodengen, *The Legend of Honeywell*, 80.

[171] *Pilot Training Manual for the B-17*, 181.

trainer or fighter aircraft—pulling back commanded a climb, pushing forward commanded a dive, and pressure to either side commanded a roll in the same direction. Sensors in a control box located at the base of the stick detected the pilot's commands and electrically actuated the autopilot servos to move the flight controls. Although the pilot commanded the flight control movement, the autopilot executed the actual movement.

The Formation Stick actuated the flight controls through a set of electromechanical assemblies contained in the control mechanism box below the stick (Figure 3.27). These assemblies, one for pitch that controlled the aircraft elevator and one for roll that controlled the aircraft ailerons, consisted of a potentiometer, gear train, and centrifugal brake that worked together to translate pilot stick movements to electrical signals sent to the autopilot. When the pilot moved the stick, a cam moved a wiper on the potentiometer, generating a signal that was then sent to the autopilot control amplifier through the C-1 control box.[172] As with turns initiated with the autopilot Turn Control Knob, the amplifier controlled the servos connected to the appropriate flight controls. Although the system provided control in only the pitch and roll axes and used mechanical as well as electrical controls, the Formation Stick assembly was the direct forefather of the fly-by-wire flight control systems developed in the 1960s and 1970s.

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[172] *Operation, Service and Overhaul Instructions with Parts Catalog for Formation Stick Control System for C-1 Autopilot (AN 11-60AA-9)* (Commanding General, Army Air Forces, 1945), 3-4.
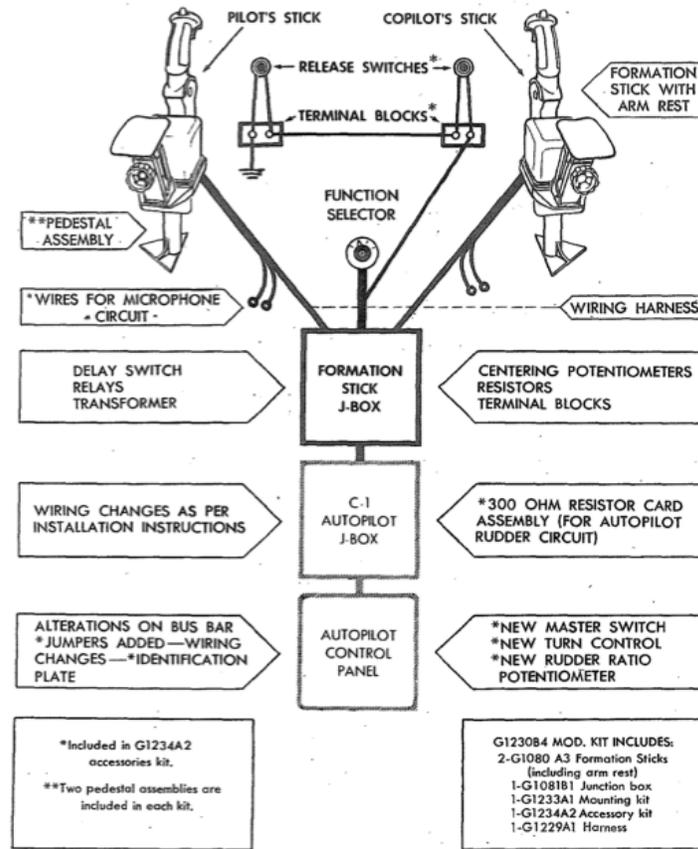
Figure 3.27
C-1 Autopilot Formation Stick system schematic diagram[173]

The system had three settings, each dictating the amount of autopilot involvement in the flying process while using the stick. The "ON SERVO BOOST" mode put the stick in direct control of the autopilot and was used for quick maneuvering, such as when flying in a wing position in a tight formation. The "ON ELEV. ONLY" mode provided the pilot only pitch control while the autopilot itself maintained control of the ailerons and rudder. This mode was used during the bomb run when the bombardier was controlling the autopilot through the bombsight. In the "ON" mode, the autopilot flew the aircraft as set up through the autopilot control panel, but gave the pilot the same turn control that he previously had with the Turn Control Knob while adding the ability to control the aircraft pitch, as well. This mode was for use when little maneuvering was expected, such as when leading a formation or flying in a loose

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[173] Ibid., ii.

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wing position.[174] The three different modes gave the pilot the option how much help he desired to have flying the aircraft. Designed to give the pilot more control in the fluid formation environment, the Formation Stick enabled precision flying to a degree that had been rarely possible and greatly reduced pilot fatigue.

Control, Sharing Control, and the "N plus 1 Factor"

From the earliest Sperry Gyroscopic Stabilizer to the C-1 Autopilot with the Formation Stick, the autopilot never had complete control of the aircraft, only that control which the aircraft commander ceded to it. When it was used, the pilot shared his control with the machine, using its particular strengths to increase the pilot's own ability to control the aircraft. He was able to regain full control at any point, however, by either overpowering the autopilot's controls or by turning the system off altogether. Certainly, in many cases the autopilot was a more precise flyer than the human pilot, able to detect and correct deviations from the desired flight attitude more quickly, however, that precision was defined by the pilot's own setting and adjustment of the system. By setting the autopilot's referential frame, the pilot made the machine an extension of himself. In truth, the autopilot was better at *maintaining* the level of precision that the human pilot established.

The autopilot evolved as another tool for the pilot and aircraft commander—a critical tool. While he gave up certain flying tasks to the autopilot, the act actually gave the pilot greater control over the system as a whole, because it allowed him to devote some of his limited cognitive capacity to other concerns, such as the condition of the aircraft crew, systems, or its position in the formation or mission as a whole. William Lear, legendary aviation pioneer and developer of the lightweight autopilot, explained this concept in a 1960 interview

> People have what is known as an "N factor"---I call it an N plus 1 factor. In other words, every man can do N number of things. He can do two things, three, four, five, six, at once, but whatever his N factor is, he can do all those things and do them pretty well. Now, then, if you give him N plus 1, which is 1 more thing to do than he's capable of doing, you confuse him so badly that instead of being able to do the number of things that he's able to do plus the extra thing, he can't do any of the things now, because his computer, his brain, bogs down because it got one more signal in than it will tolerate. You may have an N factor of 15, but 16 will bog you down….In general, an autopilot is the

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[174] *Pilot Training Manual for the B-17*, 182.

real answer to (the problem of pilot task saturation), for the simple reason that it leaves the pilot in the ideal position of not using up his N factors.[175]

In short, the autopilot increased the aircraft commander's capacity to act as the *system* controller.

Although the pilot allowed the autopilot to perform some of the flying tasks, he did not really become "less" of a pilot—his is role merely changed. He shifted from being in direct control of the tasks to *supervising* the autopilot's execution of those tasks.[176] Just as his role as the aircraft commander demanded that he monitor the performance of each human member of the crew, his role as the pilot demanded that he monitor the performance of the autopilot. He was no more giving up control of the aircraft to the autopilot when it was in use than when he took navigational direction from the aircraft navigator. The nature of this relationship between the pilot and the autopilot, however, was not a simple case of easy acceptance and equal teamwork, as became obvious when the C-1 Autopilot was put to its other use—giving the bombardier control of the aircraft during the bomb run.

The Pilot and the Autopilot

The Sperry Gyroscopic Stabilizer arrived less than ten years after the Wright brothers' first flight at Kitty Hawk, and the autopilot has existed almost as long as the human pilot in

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[175] William Lear, "William Lear (Flight Interviews)," interview by Kenneth Leish, Transcript, May 1960, K146.34-63, IRIS No. 471800, US Air Force Historical Research Agency.

[176] The nature and role of human supervisory control over automated systems has been explored in depth by numerous scholars, and is a current topic of research among many examining human-machine relationships in the operation of highly automated systems, such as the remotely piloted vehicle systems in use by many militaries. See Raja Parasuraman, Thomas B. Sheridan, and Christopher D. Wickens, "A Model for Types and Levels of Human Interaction with Automation," *IEEE Transactions on Systems, Man and Cybernetics, Part A: Systems and Humans* 30, no. 3 (May 2000): 286-297; Thomas B. Sheridan, *Telerobotics, Automation, and Human Supervisory Control* (Cambridge, MA: MIT Press, 1992); Thomas B. Sheridan, "Task Analysis, Task Allocation, and Supervisory Control," in *Handbook of Human-Computer Interaction*, ed. Martin Helander, Thomas K. Landauer, and Prasad V. Prabhu, 2nd ed. (Amsterdam: Elsevier, 1997), 87-105. There are varying levels of supervisory control, based upon the capabilities of both the automated systems and the humans supervising them. The C-1 represents a system that required a great deal of supervision, as the system itself had only rudimentary automation capability. Autopilots have evolved into much more complete flight management systems, in extreme cases capable of conducting an entire flight from takeoff to landing, with the human pilot acting only as a monitor. The pitfalls and consequences of ceding this much control to automated machines is another area of interest and concern among researchers, as the dangers of complacent human behavior become evident in events such as in October 2009 when Northwest Flight 188 flew far beyond its destination on autopilot while the two pilots onboard were preoccupied with extraneous tasks. See Micheline Maynard and Matthew L. Wald, "Experts Puzzle Over How Flight Overshot Airport," *The New York Times*, October 24, 2009; Arnold Reiner, "Pilots on Autopilot", December 16, 2009, http://www.nytimes.com/2009/12/17/opinion/17reiner.html?_r=1&emc=eta1 (accessed 17 December 2009).

powered aircraft. However, acceptance of the use of an automated machine to maintain control in flight was far from universal. The role of automation in aviation was debated from the very start, as shown in a 1910 British book on aerial navigation that describes how the question of the use of automation to obtain stability in flight divided aviators into two groups.

> One school holds that equilibrium can be made automatic to a very large degree; the other, known as the American school, following the methods of the Brothers Wright, claims that equilibrium is a matter for the skill of the aviator, who, with practice, acquires perfect control of his machine.[177]

Building on a classification of these groups as *chauffeurs* and *airmen*, engineer and historian Walter Vincenti advanced that the chauffeurs "conceived that the airplane should be a highly stable vehicle, a kind of winged automobile that simply required steering by the pilot."[178] As expressed by historian David Mindell, this primarily European attitude essentially separated the aviators from their machines, and cast the aviator's role as to "guide, rather than direct" the aircraft.[179] This attitude was very favorable toward the use of automation, and extended, to the idea of shared control.

The airmen, primarily American pilots, building on the Wright brothers' ideas about control viewed the ability to control the aircraft as a central identifying characteristic of the aviator himself. Again, Mindell illustrates that it was the Wright brothers' solution to the problems of control that enabled powered flight to begin with. In solving that problem, they invented "not simply an airplane that could fly, but also the *very idea* of an airplane as a dynamic machine under the control of a human pilot (emphasis in original)."[180] For the Wrights, the aircraft and aviator were an integral part of a single system, with one element defined by the ability *to be controlled*, and the other by the specific ability and skill *to exert that control*.

As described earlier, the Wrights trained many of the initial U.S. Army pilots, and their "airman" attitude became an integral part of the identity of the Army aviator. Even though the

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[177] Quoted in Walter G. Vincenti, *What Engineers Know and How They Know It: Analytical Studies from Aeronautical History* (Baltimore: Johns Hopkins University Press, 1990), 57.

[178] Ibid.. The classification of chauffeurs and airmen comes from Charles Harvard Gibbs-Smith, *Aviation: An Historical Survey from Its Origins to the End of World War II* (London: H.M.S.O., 1970).

[179] David A. Mindell, *Digital Apollo: Human and Machine in Spaceflight* (Cambridge, MA: The MIT Press, 2008), 21.

[180] Ibid.

pilot rapidly grew beyond just being an aircraft flyer as the role of command grew, flying was still a central identifying characteristic. The concept of the autopilot ran counter to the pilot's view of himself—the use of a machine to exert control was a direct questioning of the his own skill. It was at the beginning of the bomb run over the heavily defended Axis targets on European soil during the CBO that this attitude came in conflict with the need to execute the precision bombing mission.

The Autopilot and Bombing—Flying the Bomb Run

The C-1 Autopilot did not become the standard autopilot system until the middle of 1943, and it was Carl Norden's AFCE that saw the first combat use. The original AFCE was designed only to give the bombardier the ability to directly maneuver the bomber to the point in space where the bombsight could release the bombs and hit the aimpoint, replacing the PDI. Ideally, the aircraft commander would turn over the control of the aircraft heading to the bombardier at the start of the bomb run, which will be described in depth in Chapter 5, and while the bombardier steered the aircraft to the bomb release point, the aircraft commander manually controlled the airspeed, and the AFCE kept the aircraft level. Early attempts at using the system, however, met with little success. The system was mechanically unreliable and, critically, when it was functioning the pilots would not allow it to work as designed.[181]

As described in Chapter 2, during the opening stage of the CBO, the USAAF bombers used formation tactics developed during the 1930s, which emphasized bombing by individual aircraft from loose formations, designed to give each aircraft room to maneuver and still provide some protection from the defensive flak batteries stationed around the target. Because the pilots believed that if they flew straight and level for more than ten seconds they were bound to be shot down, they maneuvered as much as possible within the constraints of the formation to survive.[182] This maneuvering, unfortunately, gave the bombardier, at best, ten seconds to come up with a bombing solution and maneuver the aircraft to the bomb dropping point so that the bombsight could drop the bombs, a process that usually took at least *fifty* seconds in training to complete

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[181] "The War Against the Sub Pens," in *The Army Air Forces in World War II, Vol. 2-Europe: Torch to Pointblank*, (Washington, DC: 1983. Reprint, Office of Air Force History. Originally published Chicago: University of Chicago Press, 1949), 271-272.

[182] LeMay, *Mission with LeMay: My Story*, 230.

with any hope of precision results. Even though the bomber had the advantage of control with the AFCE, he had little chance to hit the target.

The decision to fly tighter, straighter formations and bomb out of the Combat Box fixed the problem of over maneuvering by the pilots, but a significant hurdle remained that blocked the bombardiers ability to use the AFCE and bombsight to bomb precisely—the pilots themselves. Because of the problems associated with the system, including the mechanical malfunctions and the imprecise way that the AFCE controlled the aircraft, they believed that they could fly more precisely than Norden's machine. Indeed the AFCE itself lent some credence to their beliefs, as related by B-17 Navigator Harry Crosby, who was a passenger during the bomb run portion of the mission.

> The plane felt different. Instead of the smooth corrections that Blake (the pilot) would make, the bombsight was jerking the plane around….The compass needle bounced around, with the plane skidding back onto our heading without the usual dip of the ailerons. The Norden bombsight was running the automatic pilot, but Blake was a smoother flyer.[183]

Nevertheless, precision bombing required a stable platform, and the AFCE was the only way to improve stability.

Soon after adopting the Combat Box formation and the drop-on-leader bombing method, 8th AF leadership mandated that the lead crews use the AFCE during the bomb run. Major General Haywood Hansell, Jr., commander of the 1st Bombardment Wing at the beginning of 1943, related how the lead pilots reacted to the directive.

> It was exceedingly difficult to force the pilots of lead aircraft to submit to this procedure. It meant turning the airplane—indeed the whole formation—over to a bombardier who was not a pilot and who viewed the world through the restricted field of a bombing telescope. And this had to be done at a time when the combat was at its height and enemy fighters were boring straight into the formation….It took all the disciplinary power at our disposal to make this procedure work.[184]

Hansell's comments highlight how the idea of the autopilot seemed to conflict with the pilot's

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[183] Crosby, *A Wing and a Prayer*, 12.

[184] Haywood S. Hansell, Jr., *The Air Plan That Defeated Hitler* (Atlanta, GA: Higgins-McArthur/Longino & Porter, Inc., 1972), 118-119.

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view of himself as a flyer, and, perhaps more significantly, as the aircraft and formation commander. The use of the AFCE turned over not only the task of flying, which was central to the pilot's *personal* identity, but also the task of command, which was central to his *professional* identity. However, the 8th AF leadership continued to press their lead crews to use the system, and soon, the benefits of that use were revealed.

On 18 March 1943, during a mission against the submarine pens at Vegesack, Germany, the 8th Air Force achieved its first significant success while bombing with the AFCE.[185] Seventy-three B-17s and twenty-four B-24s attacked a small, obscure collection of sheds and shops covering an area that measured only 2,500 by 1,000 feet beside the Wesel River, near Bremen. The bombers attacked from Combat Box formations and bombed on the leaders' signal, all of whom used their autopilots during the bomb run. Post-strike photographic analysis of the bombing showed that seventy-six percent of the bombs fell within 1,000 feet of the aim point, and that seven submarines suffered significant damage.[186]

Both British and American and leaders hailed the mission as a great success. Winston Churchill sent Lieutenant General Ira Eaker, the commander of the 8th Bomber Command, a letter of congratulation with "all my compliments to you and your officers and men on your brilliant exploit…," and Eaker himself sent a message to all of the members of his command, saying

> To my mind the Vegesack raid is the climax; it concludes the experiment. There should no longer be the slightest vestige of doubt that our heavy bombers with their trained crews can overcome any enemy opposition and destroy their targets.[187]

Colonel Archie Old, commander of the 45th Combat Bomber Wing and decorated pilot-leader of the historic raid against Schweinfurt in August 1943, was an instant convert, and described why his crews were successful in combat.

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[185] It is unclear which type of equipment was used on the Vegesack raid, Norden's AFCE or the Honeywell C-1 Autopilot. 8th AF bombers were modified in the field as the new equipment became available, and it was not until later that year that it became the standard autopilot equipment.

[186] Roger A. Freeman, *The Mighty Eighth War Diary* (Motorbooks Intl, 1990), 46-47; James Parton, *"Air Force Spoken Here": General Ira Eaker and Command of the Air* (2000. Reprint, Air University Press. Originally published Bethesda, MD: Adler & Adler Publishers, Inc., 1986), 243-244.

[187] Both statements quoted in Parton, *"Air Force Spoken Here": General Ira Eaker and Command of the Air*, 244.

> We had it on automatic pilot; that's where you could do the best piloting
> because the bombardier is flying the airplane. Some of my lead crews, I
> would have to threaten to court-marital them if they didn't do that because
> they thought they could fly it better. They couldn't. It was all geared
> together.[188]

By the middle of 1943, all of the B-17s in the ETO were equipped with the C-1 Autopilot, and the system's consistent performance slowly converted the bomber pilots into believers. The human-machine team of the bombardier and bombsight could produce better results than the human-human team of the bombardier and pilot.[189] The combination of the change in bombing formation tactics and the use of the autopilot clearly improved 8th AF bombing effectiveness. After 1 October 1943, the average dimensions of a formation's bombing pattern on the ground improved from 3,080 to 2,400 square feet, and the percentage of bombs within 1,000 feet of the center of that pattern improved from 24 to 40 percent.[190]

Conclusion

Command and Shared Control—The Pilot, Machines, and Doctrine

In the United States, the military pilot was born a technically skilled specialist, created from the Wright brothers' concepts of the aircraft as a machine that could be controlled and the airman as that controller. Within the U.S. Army, the skill of exerting that control—flying—became the centrally defining characteristic of the military pilot, conveying upon him a singular social status that brought with it extra rank and pay. However, the requirements placed on the pilot soon evolved beyond the physio-cognitive skill of controlling an aircraft in the air to include the knowledge and skill of *employing* the aircraft in a military role.

Employment of the aircraft demanded a new skill—that of *system control*—the ability to achieve and maintain control over a group of humans and machines all working toward a common goal. While command of the aircraft and the skill of flying remained a necessary skill, mandated by Congressional action, the ever increasing complexity of both aircraft and weapons technology and the evolving doctrinal missions for which they were used demanded a wider range of expert knowledge and skill. This forced the pilot to evolve from a technically skilled

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[188] Gerald Astor, *The Mighty Eighth* (Dutton Adult, 1997), 164; "Biographies: Lieutenant General Archie J. Old Jr.", n.d., http://www.af.mil/information/bios/bio.asp?bioID=6650 (accessed 23 December 2010).

[189] Rodengen, *The Legend of Honeywell*, 74-75.

[190] Hansell, Jr., *The Air Plan That Defeated Hitler*, 119.

specialist to a generalist who could control different human-machine elements and focus their efforts toward achieving a doctrinally defined mission.

The precision bombing mission demanded that the pilot control at several levels, from the individual aircraft to the large-scale formation. Effectively controlling at each of these levels required *sharing* control with humans and, eventually, machines. Initially, the pilot had to cede some control to the bombardier, as he had the responsibility for operating the bombsight, which was the "business end" of their mission. Accepting direction from the bombardier with the primitive early methods of signaling between the two was acceptable, because the pilot's skill at following those directions was the determining factor in bombing accuracy. Even when using the PDI, the pilot's flying skill was still a critical factor. However, when it became apparent that imprecise flying remained a large limiting factor in bombing accuracy and the autopilot was presented as the solution, there was resistance to ceding control to a machine.

Resistance to the autopilot, however, was short lived. Through the bombardment doctrine developed during the Interwar years, the bomber pilot had evolved into the aircraft commander. In this role, he learned to share flying duties and thus some control of the aircraft with a human—the copilot. By working together and sharing flying duties, the aircraft commander could employ the aircraft more effectively. In fact, it was the leaders of the Air Corps, *themselves pilots*, who were the strongest advocates for the development and use of automatic pilots so that they could improve the accuracy of their bombing. Once it became apparent that the autopilot could fly critical portions of the mission more precisely than the pilot, acceptance was assured.

Additionally, the autopilot was not autonomously automatic—it had to be set up and adjusted by the human pilot, and thus became his extension when in operation. It actually demanded that the human develop a new skill—the precise set up and continued operation of the autopilot. Still based on his central ability to fly, this new skill was a mixture of precise flying and supervisory control. The pilot still remained responsible for flying, but his role changed. The autopilot became no more a threat to the aircraft commander's identity than the copilot did. Both were extensions of his control over the aircraft system, as was the bombardier, to be seen in the following chapter.

Changes in employment doctrine following World War I that emphasized large formation tactics imposed the need for control sharing outside the individual aircraft. The large formation

was broken down into manageable elements, and the overall leader ceded control of those elements, whether at the group, squadron, element, or individual aircraft level, to the leader at that level. Each controlled their part, focused on playing their role in the system at the next level. Each element, however, had a commander, whether at the lowest aircraft level or the highest formation and mission commander level, and with this command came the final and ultimate responsibility for controlling their element and achieving the mission objective.

A machine initially shaped and defined the pilot, but evolving bombardment doctrine wrought changes that redefined him into a system controller and commander. That evolution created an individual that accepted the sharing of control with both humans and machines, as they all comprised a single system. Rather than the individual, rebellious Knight of the Sky, he became, as depicted below in Figure 3.28, the master controller of a socio-technical team of humans and machines.

Figure 3.28
The System Controller[191]

[191] *Pilot Training Manual for the B-17*, 174.

Chapter 4

Shared Cognition—Aerial Navigation and the Navigator as the Integrator

Bremen. Friday, 8 October 1943. Navigator Harry Crosby sat in the nose of B-17 42-3393, Just-A-Snappin'*, ready to lead the entire Third Combat Wing against the heavily defended city of Bremen. He and his crew had spent the past two days with the rest of the mission's lead crews at the 3rd Air Division Headquarters preparing for this maximum effort mission, ensuring that they could find, identify, and destroy their targets located around the city of Bremen.*

After reviewing the mission planning data during the Navigator's Brief that morning, he met with his crew at the aircraft and briefed them on the plan for the day, including the route that they would follow, the weather they could expect, and the type and location of the defenses that they would face. Following an uneventful takeoff, Crosby directed his pilot, Everett Blakely, to the formation rejoin point over the town of Lowestoft, using the Splasher radio beacon and ground references to determine the aircraft heading and arriving there within 40 seconds of his planned arrival time. The rest of the formation joined them at the point, and at the appointed time, they turned out over the English Channel for the European continent.

Navigating by dead reckoning the entire way, Crosby directed the formation to a point near the island of Borkonny, where the formation would cross the German coastline. Constantly busy, Crosby calculated his position every ten minutes, recorded it in his Flight Log, plotted it on his air plot chart, and adjusted the formation lead aircraft's heading to stay on course. Although enemy defensive fighters harassed the formation, Crosby paid little attention to either them or the .50-caliber machine gun hanging over his head, as he focused entirely on determining where the formation was and where it needed to go. As they crossed over the Initial Point for the bomb run near the city of Emden, Bremen and the target area was visible in the distance beneath a dense cloud of angry flak. Crosby pointed out the target to his bombardier, 2nd Lt. James Douglass, at the same time noting the location of the enemy fighters and flak in his Flight Log.

Crosby sat and watched Douglass as a burst of flak penetrated the Plexiglas nose of the aircraft 30 seconds short of the target. Right after bomb release, Crosby was violently tossed around the nose compartment when they were struck by another burst of flak. Immediately after the pilot recovered the aircraft, Crosby computed the shortest course home, directly across over 200 miles of hostile German-held territory. Harassed by enemy fighters all the way to the coast, he feverishly navigated, giving Blakely directions the whole way, but paying little attention to his own machine gun as the rest of the crew fired theirs at the attacking fighters.

After nearly ditching in the English Channel, Crosby located an abandoned airfield just beyond the English coastline and successfully guided Blakely to it. With the flight controls ineffective and brakes inoperative, Blakely crash landed Just-A-Snappin'*, sliding down the runway and hitting the only tree on the airfield, totaling the aircraft, but surviving to fight another day.*[1]

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[1] Adapted from Edward Jablonski, *Flying Fortresses: The Illustrated Biography of the B-17s and the Men Who Flew Them* (Garden City, NY: Doubleday & Company, Inc., 1965), 184-195; Frank D. Murphy, *Luck of the Draw: Reflections on the Air War in Europe* (Trumbull, CT: FNP Military Division, 2001), 141-142; Harry Crosby, *A Wing and a Prayer: The "Bloody 100th" Bomb Group of the U.S. Eighth Air Force in Action Over Europe in World War II* (New York: Harper Collins Publishers, 1993), 127-135; "Black Week - Bremen", n.d., http://www.100thbg.com/mainpages/history/history4/bw_bremen.htm, accessed 26 December 2010; *Combat Chronology, 1941-1945* (Washington, DC: Center for Air Force History, 1991),

Introduction

This chapter examines the navigation socio-technical element in the bombardment system. It describes aerial navigation on a bombardment mission as a complex, automated process of shared cognition, conducted by a human technical specialist and the unique computational and navigational technologies that defined him professionally. First, it describes the creation of the bomber navigator as a single-task, technical specialist, reluctantly accepted as a non-pilot member of the bomber crew only under the demands of the high-altitude daylight precision bombing (HADPB) doctrine and rapid wartime expansion, whose skills were rooted in the tradition of maritime navigation and who was defined by his mastery of a complex set of specialized instruments. Second, it describes aerial navigation as a shared cognitive process, wherein the navigator used purpose-built calculating tools to translate and integrate several sets of diverse data in what Bruno Latour called a "centre of calculation" to build idealized textual, temporal, and spatial models of the bomber mission, which then served as execution-level instructions for the conduct of the mission. Third, it examines the navigator's flight working environment as a second "centre of calculation" and the tools that he used to try to recreate those models in the air to navigate his aircraft to the target of the day. Finally, it examines how the HADPB doctrine shaped his actions in flight based upon his position in the overall bombing system, and how unique calculating technologies mechanized those actions.

The Line

Of all of the challenges facing bomber crews in the European Theater of Operations (ETO) on the morning of a Combined Bomber Offensive (CBO) mission, none was more immediately pressing than finding the target for the day's mission. The target was their purpose. If they could not find it, the complex bombardment system, of which they were an integral part, could not drop its bombs and all of the Herculean effort that went into planning and executing the massive raids that were the centerpiece of the Allied strategy against the Third Reich were for naught. Ensuring that they found that target was the responsibility of one crewmember—the navigator—the specially trained human who, with his maps, calculators, and instruments, would guide the bomber crews individually and collectively to their target and back home again.

199; Ian L. Hawkins, *B-17s over Berlin: Personal Stories from the 95th Bomb Group (H)* (Brassey's Inc, 1995), 170-171.

Most of the navigators on a CBO mission found out where they were going on the morning of the mission during the General Briefing. They sat in the briefing room, waiting along with the rest of the members of their bomber crews for the briefing officer to pull back the curtain covering the big mission map to reveal the long red woolen line that would be their guide for the next several hours—the route to the target. For the pilots, whose job it was to get their aircraft to the target and back, the length of the line determined how long they were going to have to wrestle their B-17s through the air, commanding their own piece of the bombardment system. For the bombardiers, the midpoint represented the location where they would put months of specialized training to use when they dropped their bombs on the target. For every man in the room, its path determined the type and strength of the resistance that they could expect from the defending German fighters and anti-aircraft batteries, providing him a sense of his chance of surviving the mission. For the navigators, however, the line itself represented more. The red woolen line was their job. They would spend the rest of the day directing their aircraft along the line's path, working diligently to establish their position relative to it and calculating any necessary navigational changes to correct any diversions from it. While the other crewmembers had their unique jobs, the navigator's job was to make sure that they arrived in the right location at the right time to accomplish them.

Those navigators gathered in the briefing room were a unique group of men. With their mechanical computers, navigational charts, plotters, and pencils, they were "the only officer on the crew who had nothing whatsoever to do with operation and control of the plane."[2] Chosen largely for their talents in mathematics and dial and chart reading, they were technical specialists, and their very presence was largely a product of the Air Corps decision to pursue the HADPB doctrine. They would spend the rest of the day using a set of specialized tools and instruments in a shared cognitive process to first plan where they would go, then integrating together a diverse set of observations and measurements, continually translating between an idealized navigational world to the physical reality of the bombing mission, to calculate the correct direction for the pilot to steer the aircraft so that they could find their target and then their way home, all the while ready to operate a .50-caliber machine gun when under attack or step in and "pinch hit" for another crew member, if necessary. They and their instruments formed a cohesive socio-technical element focused on a single task—aerial navigation.

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[2] Murphy, *Luck of the Draw*, 76.

Aerial Navigation and the Birth of the Specialist

At the U.S. entry into World War II in 1941, the navigator, as a non-pilot, technical specialist, was a relatively new and underrepresented member of the U.S. Army Air Forces (USAAF). The U.S. Army had been flying powered aircraft since 1909, but it was not until thirty years later, in 1939, when the pre-World War II Air Corps expansion programs began the great increase in the size of the bomber aircraft force, that the role of the non-pilot navigator was formally established and a robust institutional training program developed.[3] Indeed, after almost four decades of powered flight, aerial navigation itself remained an immature scientific art, still building upon its maritime roots.

At the start of World War II, aerial navigation was almost as much an art as a science. Monte Wright, in his history of aerial navigation, described it as

> a hybrid science that uses a variety of instruments and techniques to determine three things: the present position of a vehicle, the direction to steer to reach a desired position, and the estimated time of arrival at that desired position.[4]

At that time, it required specialized knowledge in the use of "precision" instruments that gave imprecise answers, and the ability to artfully interpret those answers through mathematics to determine an estimated position on the face of the earth—all while moving at speeds well over 100 miles per hour.

Aerial navigation sprung directly from maritime navigation, and by the time man took to the air in the twentieth century, mariners had mastered the art and science navigation to a great degree, using charts, compasses, sextants, and other specialized instruments to routinely navigate sea craft around the globe. Navigation was a requisite skill for all naval officers, and the ability to operate those complex instruments and solve the complicated mathematical problems that they created was an integral part of their professional repertoire and identity. The instruments were complex and required a great deal of skill to use, but were well adapted to the slow pace of sea travel and the stable work environment aboard ships. In the event of a particularly difficult

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[3] Ben R. Baldwin, *Individual Training of Navigators in the AAF*, Army Air Forces Historical Study 27 (Washington, DC: U.S. Army Air Forces Assistant Chief of Staff, Intelligence Historical Division, January 1945), 2-6.
[4] Monte Duane Wright, *Most Probable Position: A History of Aerial Navigation to 1941* (Lawrence, KS: The University of Kansas Press, 1972), 3.

problem, this slow pace enabled navigators to take the time to confer with each other and reach a solution without unduly endangering their ship.[5]

With the advent of powered flight, navigation took on a new dimension. Speed, or, more properly, the lack of it, was no longer an ally in the face of confusion, as even the earliest aircraft had to fly much faster than ships sailed in order to remain aloft. Time also became an enemy, as the limited fuel supply carried by an aircraft defined the amount of time it could remain in the air before having to return to earth, placing even greater importance on knowing an aircraft's position, particularly in relation to the very limited number of areas where it could safely land. Aerial navigation, or *avigation* as it was called through the mid-1930s, required the use of many of the same instruments as maritime navigation, but demanded that they be used more quickly and without the benefit of centuries of accumulated knowledge of the location and behavior of dominant oceanic currents and prevailing wind patterns that affected, with at least some predictability, the travel direction of the sailing vessel.[6]

Initially, aviators learned to orient themselves in the air by looking at the ground for references or objects that they could recognize on a map, but as they ventured out on longer flights over water or other areas with insufficient map coverage, it became necessary to adapt existing navigation instruments to flight. The use of the compass was an obvious first step toward navigating as it could only tell an aviator where he was *going*, but it could not tell him where he *was*, and the unique environment of flight made the adoption of other primary maritime navigation instruments difficult. Instruments such as the sextant required two hands and a lot of attention to operate, making them unusable by a pilot flying an aircraft that required two hands and a great deal of attention to keep from crashing, and, additionally, it took time to operate them correctly. While this was of little consequence in a slow moving ship, an aircraft could travel several miles in the time it took to use a sextant, rendering its position reading obsolete almost immediately. This problem plagued virtually every navigation instrument, and aerial navigation grew as a discipline where the navigator determined where the aircraft *was*, rather than where it *is*.[7]

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[5] Ibid., 16.

[6] Norris B. Harbold, *The Log of Air Navigation* (San Antonio, TX: The Naylor Company, 1970), 35-37.

[7] Wright, *Most Probable Position: A History of Aerial Navigation to 1941*, 16.

Gradually, aviators developed specialized instruments that could help them estimate and calculate their progress through the air. However, the inherent speed and inability to stop mid-flight to clear up any confusion made aerial navigation an art and science unto itself, requiring the acquisition of a great deal of knowledge about those instruments and how to use them. Arthur Hughes, an early historian of aerial navigation, characterized aerial navigation as a *crisis*, the successful resolution of which required the development of an instinct regarding sense of direction and the use of navigational tools. He summed this up in a set of rough precepts that he believed, if followed, made good navigators:

> (weigh) the pros and cons quickly, and making a final judgment—never panic, and be sure to have it all worked out beforehand—keep constant check with steady improvement as the outcome—believe in the sense of direction, which is more prominent in some than others, but can be acquired and preserved by fitness of body and mind.[8]

Hughes precepts paint a picture of the aerial navigator as a close relative of the maritime navigator, but also more as a specialist who, due to the rapidly moving context in which he operated, required special training to succeed at his task through levelheaded planning, dogged persistence in observation, and a decisive nature, constantly working toward iterative improvement and precision.

As aircraft technology developed, enabling longer flights over farther distances, aerial navigation became an increasingly important part of aviation itself, and a pilot was literally lost if he could not navigate effectively. Successful navigation required that the aviator develop a new skill set, oriented toward understanding the unique environment of flight and interpreting that environment through the mastery of some very specialized instruments. However, in spite of its mission focus on flying and the military use of aircraft, the U.S. Army Air Corps showed little particular interest in navigation as a skill, and did little to develop navigation skills in its aviators or foster navigation professionals through its first three decades of existence.

The Growth of Aerial Navigation in the Air Corps

From 1909 through October 1933, the Air Corps had no formal training program for teaching aerial navigation. Early military aircraft had limited range, making navigation between

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[8] Arthur J. Hughes, *History of Air Navigation* (London: George Allen & Unwin, 1946), 30.

takeoff and landing relatively easy, and as Air Corps pilots rarely flew in the weather, their aircraft were not equipped with the instruments to do so. Since little navigation was necessary, neither was there an established requirement for a non-pilot navigation specialist as a part of an aircraft's aircrew. Navigation existed as merely one of the many skills that pilots learned as a part of their normal training, and although a few specialized in it, just as others specialized in bombing, it received little attention.[9] Within the bombardment mission particularly, navigation and bombardment were "simply another degree of specialization for (some pilots) to concentrate on."[10]

As will be explained further in Chapter 5, early Air Corps bombardment doctrine clearly defined the role of the pilot-bomber, or bombardier, identifying him as a critical member of the bombing team. The navigator, however, was far less prominent, and the role appeared in discussion only in the earliest versions of the Air Corps Tactical School's (ACTS) *Bombardment* text, and then only in a limited role "when the distance to the target warrants it."[11] Even then, it did not identify the navigator as a separate member of the bomber crew; rather, navigation was a duty assigned to the bombardier in the formation leader's aircraft, and specific discussion of the role disappeared with the publishing of the 1930 version of the text.

As discussion of the navigator disappeared from bombardment doctrine, advances in aviation technology during the 1920s greatly increased the range over which aircraft could operate, revealing a growing importance of aerial navigation. Events such as Charles Lindbergh's solo flight across the Atlantic Ocean and the Air Corps' first long distance flight between Oakland, California, and the Hawaiian Islands, on 28-29 June 1927 using celestial and radio beam navigation methods, raised awareness that military aircraft could soon start operating over much longer distances. This prompted the Air Corps Information Division to propose that it might be useful to establish a school for training "aerial navigators," but a proposal to the Chief of the Air Corps the following year to establish such a school foundered, a victim of budget and equipment shortages, and the Air Corps paid little attention to the development of formal, institutional navigation training for the next five years.[12]

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[9] Baldwin, *Individual Training of Navigators in the AAF*, 2.

[10] Wright, *Most Probable Position: A History of Aerial Navigation to 1941*, 184.

[11] *Bombardment: 1924-1925* (Langley Field, VA: Air Service Tactical School, 1924), 42.

[12] Baldwin, *Individual Training of Navigators in the AAF*, 46-59 In 1933, the importance of navigation skills was highlighted when the Air Corps began delivering airmail when the president cancelled civilian airmail

By 1933, aircraft technology had advanced to the point that bombers were flying much longer distances, lending more credence to the idea of carrying a specially trained navigator as part of the bomber aircrew. At the same time, the Air Corps was justifying its request for long-range bomber aircraft to Congress based on the needs of the coastal defense mission, which meant long flights over water, out of sight of land, making the need for a navigation specialist even more apparent.[13] In October of that year, the Air Corps began experimental advanced navigation training programs at Langley Field, Virginia, and Rockwell Field, California, with the purpose of producing those navigation specialists. The program focused on applying known navigation procedures and adapting them to the more accurate air navigation instruments that were becoming available. The attendees were principally instrument rated pilots who received a special navigator flight qualification upon graduation, but a very limited number of non-pilot, aircraft observers also attended and graduated from the program.[14]

The navigation training program consisted of a total of 160 hours of instruction, with 83 hours of that time spent on the ground, and the students focused on navigation techniques and the care, use and calibration of navigational instruments. Care and calibration of the instruments were a central part of the curriculum, as the graduates would be responsible for the accuracy of those same instruments in their aircraft once they graduated, and they had to be fully capable of ensuring their correct operation. As military aircraft of that era were neither designed nor built to carry a navigation specialist, the Air Corps had to make special provisions to accommodate the aerial instruction portion of the curriculum. To make room for the navigator, floorboards were installed in modified Keystone B-3A bombers, turning the bomb bays into a functional

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contracts in the wake of corrupt practices in the contract award process in the Postmaster General's office. In what World War I ace and then-vice president of Eastern Air Transport Eddie Rickenbacker termed "legalized murder," the Air Corps lost sixty six aircraft and twelve pilots were killed as they flew in some of the worst winter weather seen in years. Air Corps aircraft did not have adequate flight instruments for flying in bad weather or at night, when most of the mail was transported, nor did they have the necessary equipment to enable them to navigate via the newly installed radio-beacon navigation system. While airline pilots were used to adverse weather conditions, the Air Corps pilots were not, as they had little experience and less training flying and navigating on flight instruments alone. See John F. Shiner, *Foulois and the U.S. Army Air Corps, 1931-1935* (Washington, DC: Office of Air Force History, U.S. Air Force, 1983), 125-149; Eddie Rickenbacker, *Rickenbacker* (Englewood Cliffs, NJ: Prentice-Hall, 1967), 185. For more on the development of blind flying techniques, see Richard Hallion, *Legacy of Flight: The Guggenheim Contribution to American Aviation* (Seattle: University of Washington Press, 1977); James H. Doolittle, *I Could Never Be So Lucky Again: An Autobiography* (New York, NY: Bantam Books, 1991).

[13] Wright, *Most Probable Position: A History of Aerial Navigation to 1941*, 181.

[14] Baldwin, *Individual Training of Navigators in the AAF*, 54.

navigation crew compartments (Figure 4.1).[15] Trainees spent 77 hours in the bellies of these aircraft, practicing and developing new navigational techniques, including celestial navigation. Although the students and instructors made several advances in aerial navigation, the under funded, poorly equipped program lasted only two years, and ultimately produced few graduates.[16]

Figure 4.1
Keystone B-3A bomber[17]

The schools at Langley and Rockwell ceased operation by July 1935, and navigator training once again became the responsibility of individual tactical units. The graduates of the programs taught navigation at those individual units, instructing both qualified instrument pilots and non-pilot commissioned officers, although again, there was little interest among the pilots toward receiving advanced navigation training. In the words of Colonel Henry Potter, Jimmy Doolittle's navigator on the famed Tokyo bombing raid, pilots viewed navigation as something that they practiced "when it was necessary but very, very little of it on their own volition."[18] Through the latter half of the 1930s, these local programs produced only enough trained graduates to meet their own local needs. However, the Air Corps did not completely neglect

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[15] Harbold, *The Log of Air Navigation*, 31-33.

[16] Baldwin, *Individual Training of Navigators in the AAF*, 45-46, 56.

[17] *Keystone B-3A bomber*, Photograph, n.d., National Museum of the United States Air Force,
        http://www.nationalmuseum.af.mil/shared/media/photodb/photos/060421-F-1234P-004.jpg (accessed 1
        December 2010).

[18] Henry A. Potter, "Interview with Col. Henry A. Potter," interview by James C. Hasdorff, Oral History Transcript,
        June 8, 1979, 20, K239.0512-1129 C.1, IRIS No. 01049853, US Air Force Historical Research Agency.

navigation, as the 19th Bombardment Wing at Rockwell continued to develop "the art of celestial navigation and its application to long range bombardment missions," because it showed promise for navigating over long flights out of sight of land.[19]

Through the latter half of the 1930s, the continued increase in the complexity of aircraft and the instruments used to fly and employ them led some in the Air Corps to question the magnitude of the burden imposed upon the pilot in a bomber aircraft, who was still expected to understand and perform all of the functions of the bomber crew. As will be explored further in Chapter 5, one Bombardment Wing commander, a pilot, proposed in 1936 the consideration of training of non-pilots to perform the non-pilot additional duties required during a bombardment mission, including bombing, gunnery, and radio operation.[20] While indicating that there was a growing recognition of the need for non-pilot specialists in bomber aircraft to perform the bombing mission, it is telling that he did not mention navigation, a function performed on *every* flight, regardless of mission, further emphasizing that the Air Corps still viewed it as an additional duty and not a primary concern. In a separate effort to develop non-pilot navigation specialists the following year, the Chief of the Air Corps Plans Section proposed the training of 240 non-pilot bombardier-navigators to address an existing personnel shortage, suggesting that students eliminated from pilot training should be screened for potential.[21] While the Air Corps did not adopt the recommendation at that time, it foretold the plan that would soon be implemented to build the massive bombardment force that would engage the Axis powers in World War II.

In 1939, when the Air Corps began the first of a series of enormous expansion programs in response to the war in Europe, there were only 166 qualified navigators in the service, most of who were pilots.[22] These expansion programs, executed from 1939 through 1942, called for a massive increase over pre-war levels in the number of aircraft in the service, and as the HADPB doctrine was first and foremost in the minds of Air Corps leadership, this meant a dramatic increase in the number of bombers. By the time the Japanese attacked Pearl Harbor on 7 December 1941, the Air Corps had activated a total of seventy tactical aircraft groups, including

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[19] Harbold, *The Log of Air Navigation*, 66.

[20] Lt. Col. C. L. Tinker to Lt. L. Kuter, "Ltr. to Lt. Kuter re: Text on Bomb Aviation", April 24, 1936, Enclosed in ACTS 1935 Bombardment text.

[21] Wright, *Most Probable Position: A History of Aerial Navigation to 1941*, 185.

[22] Baldwin, *Individual Training of Navigators in the AAF*, 2.

fourteen heavy bombardment and nine medium bombardment groups.[23] Already far short of the number of pilots needed to *fly* these aircraft (many of which had not yet been built), the Air Corps was nowhere close to being able to fill the rest of the crew positions of these aircraft with trained pilots, as had been the policy in the past. A subsequent policy decision to include a "competent officer navigator in the crew of each airplane" further magnified the shortage and created an immediate need for *thousands* of trained aerial navigators.[24] Sheer necessity forced the Air Corps to accept the use of non-pilots on its bomber crews, and the age of the non-pilot navigation specialist was begun.

Recruiting Human Calculators

Filling the immediate and growing need for navigators, which soon would require training over 20,000 men per year, presented the Air Corps a significant challenge. How would they find and select recruits for navigation training? Initially, little thought was put into the candidate selection process, and trainees were chosen from among recruits who had been eliminated, or "washed out," of pilot training. Those responsible for training these recruits criticized the policy for placing the importance of the navigator below that of the pilot on the aircrew, and they believed it had a negative impact on morale in the navigation schools.[25] Indeed, echoes dissatisfaction carried over after training in some cases, as observed by one bomber pilot during the war.

> Giving a washed-out pilot a shot at navigating…has its faults. I lived to see in the combat zone the frustration of a would-be pilot relegated to…a navigator's computer. It was a problem with no adequate answer.[26]

In October 1941, the navigator selection policy changed, and since early experience had shown that a strong academic background appeared to increase the chance of a recruit completing the

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[23] James Lea Cate and E. Kathleen Williams, "The Air Corps Prepares for War, 1939-1941," in *The Army Air Forces in World War II, Vol. 1-Plans and Early Operations*, ed. Wesley Frank Craven and James Lea Cate (Washington, DC: 1983. Reprint, Office of Air Force History. Originally published Chicago: University of Chicago Press, 1948), 105.

[24] Baldwin, *Individual Training of Navigators in the AAF*, 2.

[25] Robert L. Thompson, *Initial Selection of Candidates for Pilot, Bombardier and Navigator Training*, Army Air Forces Historical Study 2 (Washington, DC: U.S. Army Air Forces Assistant Chief of Staff, Intelligence Historical Division, November 1943), 22.

[26] Philip Ardery, *Bomber Pilot: A Memoir of World War II* (Lexington: University Press of Kentucky, 1978), 20.

navigation training course, the USAAF began selecting candidates based upon education and aptitude. As with pilots, those selected for navigator training were required to have a high school education, but also obtain satisfactory scores on a battery of three aptitude tests that were administered to all Air Corps recruits: a physics test, the Army General Classification Test, and the Army Mechanical Aptitude Test. On average, those entered into navigation training had stronger educational backgrounds than their pilot or bombardier peers.[27]

As the war progressed, the emphasis on selecting better educated navigator trainees continued, and once the Aviation Cadet Qualifying Examination (ACQE) was developed, the USAAF used it to evaluate incoming recruits' aptitude for navigator training, just as it did for evaluating aptitude for pilot and bombardier training.[28] As with predicting pilot training success, the ACQE proved to be an accurate predictor of navigator training success. Performance on the mathematics, vocabulary, and reading comprehension sections correlated most strongly with a recruit's chance of successfully completing navigation training. Those with a strong academic background made good navigators, and while the USAAF considered the candidate's personal choice during the selection process, those with high scores in these areas were steered toward navigation. In fact, the standards for assignment of a recruit to navigation training were higher than those established for any other crewmember.[29]

Pilot training was, by far, the preference for recruits before and during the war, and the USAAF initially had difficulty finding volunteers for navigator training. As part of a wartime recruiting program that simultaneously downplayed the role of the bomber pilot and emphasized the role of the rest of the bomber crew, the USAAF specifically targeted individuals inclined toward mathematics for navigator training. A period USAAF recruiting brochure pitched the successful navigator candidate as someone whose education had included sound fundamental groundwork in mathematics and who had an interest in astronomy. It glowingly described the navigator as "the man behind the man at the controls" whose vital responsibility enabled the pilot to guide the ship directly to its objective.[30] A 1943 recruiting ad in *Popular Science* portrayed the navigator as "the quarterback," while simultaneously linking him to the charts and

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[27] Thompson, *Initial Selection of Candidates for Pilot, Bombardier and Navigator Training*, 22-23.

[28] The Air Corps became the Army Air Forces in June 1941.

[29] Thompson, *Initial Selection of Candidates for Pilot, Bombardier and Navigator Training*, 39-44; Baldwin, *Individual Training of Navigators in the AAF*, 33.

[30] *Aviation Cadet Training for the Army Air Forces*, n.d., 16.

instruments that served as the tools of his trade (Figure 4.2). The choice of the analogy of the quarterback is interesting and somewhat misleading. The quarterback is usually viewed as the leader of the football team, but the USAAF clearly designated and valued the pilot as the leader of the bombardment team, as explained in the previous chapter.

Figure 4.2
1943 Air Corps recruiting advertisement in *Popular Science*[31]

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[31] U.S. Army Recruiting Service, "You'll be on the Greatest Team in the World!," *Popular Science*, December 1943, 19.

Equality among the members of the bomber crew, however, was a dominant recruiting theme, and in a 1942 John Huston-directed recruiting film, *Winning Your Wings*, actor Jimmy Stewart, himself a decorated B-17 and B-24 pilot who flew combat sorties in the ETO, extolled the virtues of each of the members of a bomber crew, explaining that they were each "equally important members of the team." After only briefly mentioning the pilots as the "guys (who could) take the plane off and put it back down again," he described the navigator, pictured in the film hunched over a small map-covered desk, in much more depth as "the man with his pencils and calculators…responsible for getting the giant bomber to its destination and back again."[32] Stewart's description and the accompanying visual depiction captured the prototypical image of the navigator as man-machine computer, inseparable from the tools that enabled him to perform his job (Figure 4.3).

Figure 4.3
The Navigator at his workstation.
Note the map, the dividers in his right hand, and the bag containing his E6-B computer to his left.[33]

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[32] John Huston, *Winning Your Wings*, Recruiting (U.S. Army Air Forces, 1942),
http://www.archive.org/details/WinningYourWings (accessed 12 December 2010); Starr Smith, *Jimmy Stewart: Bomber Pilot* (St. Paul, MN: Zenith Press, 2006).

[33] *Lt. Grant H. Benson, B-17 Navigator*, Photograph, October 7, 1944, 342-FH-3A49656-K4197, National Archives and Records Administration, http://www.footnote.com/image/#161288809 (accessed 1 December 2010).

That image, the marriage between the man and his tools, developed so strongly that popular culture captured it in a song, *"The Navigator,"* which was popular in 1943.

The Navigator

With a mercator and a pencil and an A-10 octant too,
He will get you there and get you back with the praise of all the crew,
When the E.T.A. is running out and destination's due,
The pilot turns to him and says, "Where the hell are you?"

CHORUS (repeat after each verse)
But it's the navigator who keeps you on the track,
The navigator, the navigator who gets you there and back,
If you want to go Tokyo or the road to Mandalay,
Who shows you the way? The navigator.

When they can't see down below and they don't know what to do,
He will look up to the heavens and he'll shoot a star or two,
With a speed line and a course line, he'll get himself a fix,
For he's the navigator, with his little bag of tricks.

Oh, there's variation, deviation, calibration too,
But the compensation errors are the ones that see him through,
His computer is the instrument on which he stakes his life,
Don't ask for his computer, for he'd sooner lend his wife.

When you start evasive action to avoid the bursts of flak,
The gunner works without a care, he knows who'll bring him back.
The pilot will cavort about and dodge around the sky,
But there is only one, they know, on whom they can rely.

If you want to know just where you are, at any time at all,
He will take out his dividers and he'll show he's "on the ball."
He hasn't time for smoking, relaxation is taboo—
He never takes a nap, because he has a job to do.

From the World War II song "The Navigator"[34]

This was likely a staged photograph, as Lt. Benson is not wearing gloves, and the propeller from the #2 engine, which can be seen out the window above his head, is stationary.

[34] Tom Childs and Danny Roth, "The Navigator," in *The Wild Blue Yonder: Songs of the Air Force*, ed. C. W. Getz (San Mateo, CA: Redwood Press, 1981), N-1, song copyright 1943.

Although navigation training was not the most popular choice among AAF recruits, these efforts were a success. Some men were drawn to the profession by an interest in maps or mathematics, while others, who were well qualified, saw it as an opportunity to serve their country after washing out of pilot training. Regardless of their motivation, the USAAF had no difficulty procuring enough qualified candidates after 1942 to meet operational requirements.[35]

Training the Integrator

To train this massive volume of new recruits, the USAAF had to depart from its practice of training pilots as navigation specialists at the unit level, and in August 1940, established the first formal non-pilot navigation specialist school at Coral Gables, Florida, contracting with Pan American Airways to train 850 navigator students. Obviously well short of meeting their forecast requirements, the USAAF subsequently established five navigation schools of its own by late 1943 to meet the huge operational demand for trained navigators in the operational theaters. By the middle of 1944, these schools had graduated over 26,000 trainees.[36]

Those selected for navigation training were subjected to a rigorous curriculum that, by December 1944 had grown to twenty weeks in length. Recruits spent most of the time on the ground, learning the principles of dead reckoning (DR), pilotage, radio, and celestial navigation, focusing on how to use, calibrate, and care for the necessary tools.[37] Instruction in DR navigation occupied much of the training syllabus, as it was considered "the basis of all (aerial) navigation."[38] The 15 July 1941 Aerial Navigator Training syllabus used at USAAF navigation schools mandated 203 hours of classroom instruction in DR out of a programmed total of 403 hours dedicated to navigation methods. Trainees learned the basic operation and care of their

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[35] Thomas Greer, "Individual Flying Training," in *The Army Air Forces in World War II, Vol. 6-Men and Planes*, ed. Wesley Frank Craven and James Lea Cate, vol. 6 (Washington, DC: 1983. Reprint, Office of Air Force History. Originally published Chicago: University of Chicago Press, 1955), 589; Harbold, *The Log of Air Navigation*, 89; Potter, "Interview with Col. Henry A. Potter."; Howard M. Fish, "Interview with Lt. Gen. Howard M. Fish," interview by Mark C. Cleary, Oral History Transcript, February 3, 1982, K239.0512-1304 C.1, IRIS No. 01052947, US Air Force Historical Research Agency.

[36] Baldwin, *Individual Training of Navigators in the AAF*, 2-6, Chart 1; Greer, "Individual Flying Training," 585-586.

[37] "Navigation Training, General Training Program (T.C. Memorandum Number 50-12-1, 22 July 1943)," in *Individual Training of Navigators in the AAF - Army Air Forces Historical Studies: No. 27* (Washington, DC: U.S. Army Air Forces Assistant Chief of Staff, Intelligence Historical Division, 1945), Appendix 2 p. 1.

[38] *Navigators' Information File, AAF Regulation No. 62-15* (U.S. War Department, 1945), 2-0-1.

instruments, including the compass, drift meter, and radio compass, as well as how to read and construct maps.

The remaining 200 hours of instruction covered celestial navigation, which was treated as a specialized technique for determining aircraft position for use in establishing a DR navigation solution.[39] In combat in the ETO, celestial navigation was the least used navigation method of all, but it remained a large part of the training syllabus because it was so complex, requiring special navigation instruments such as the sextant and octant, and it took a great deal of instruction and practice to become even moderately proficient.[40]

Dead reckoning and celestial navigation both required extensive use of mathematics. Navigators had to solve many different types of problems, from geometrical vector problems that resolved the drift effect caused by flight level winds to trigonometric functions that translated the position of a specific heavenly body in the sky to a position on the surface of the earth. Trainees spent three months attending math and engineering classes at civilian universities before arriving at the navigation schools, preparing for the brisk pace of instruction driven by the exigencies of wartime. Even with that preparation, however, navigation training proved quite intensive and demanding, as trainees learned several different subjects at the same time. The difficulty of this training is a dominant theme in navigator memoirs that cover the period, and the accelerated pace at which it was conducted posed a challenge even to those who were inclined toward the subject prior to their arrival.[41]

The trainees also spent a great deal of time learning how to calibrate their instruments, as those in use at the time were subject to many forces that influenced their accuracy. The ferromagnetic and electromagnetic fields generated by the aircraft and its electrical equipment could produce significant errors in the magnetic and gyroscopic instruments, and the navigator had to understand how to correct for those errors. These instruments essentially became an extension of his "senses" in flight, as will be discussed below, and he had to understand how each instrument worked so that he could anticipate how the changing environment in flight could affect his perception of it.

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[39] "Program of Instruction: Training of Aerial Navigators for military students to be given in Air Corps Flying Schools (15 July 1941)," in *Individual Training of Navigators in the AAF - Army Air Forces Historical Studies: No. 27* (Washington, DC: U.S. Army Air Forces Assistant Chief of Staff, Intelligence Historical Division, 1945), Appendix 1 p. 1-2.

[40] Crosby, *A Wing and a Prayer*, 71.

[41] Frank Farr, *B-17 Navigator* (Bloomington, IN: AuthorHouse, 2009), 125.

At the end of his training, the navigator was unique among airmen. He was a technical specialist, heir to a profession steeped in mathematics, charts, and instruments, but performing a task that the Air Corps had long treated as an additional duty for pilots. Although professionally he had effectively not existed before the war, he was given the key responsibility of ensuring that his aircraft found its way to the target and back, a function that was central to mission success, and yet was initially selected from among those who had failed in their attempt to learn to fly. It was his ability to perform that job that defined him professionally and distinguished him from his peers on the bomber crew.

Navigating in the European Theater of Operations (ETO)—The "Centre of Calculation"

The navigators in the ETO used DR navigation as the primary means to get their aircraft to the target and back. Not only was it the method in which they were most qualified, higher headquarters Operational Instructions mandated that they rely on it and that they use "all available aids to the maximum in checking (their work)," which included technical means such as radio fixes and pilotage.[42] Dead reckoning was theoretically the most dependable form of navigation, as the navigator needed no other tools or technologies than those he carried with him to the aircraft or those installed in virtually every bomber.

Dead reckoning navigation is a process of continual estimation where the navigator constantly calculates aircraft position given that he knows how far, how fast, and for how long it has traveled its last known, confirmed position. Navigators in the ETO used two types of DR on bombing missions during the war. The first, known as *pilotage*, is a basic, or "no-instrument," type of navigation where the navigator determined the aircraft position by visual reference to the ground, and passed course and speed adjustments to the pilot to correct any deviation from the desired course. During the bomb run, the navigator used "pin-point pilotage," working to establish the aircraft position to within ¼ of a mile so that he could direct the aircraft to a position where the bombardier could locate, identify, and bomb the target.[43] Pilotage was visual navigation, and required visual contact with the ground, the ability to identify ground references, and the ability to locate them on the map. Anything that obscured the view of the ground, such

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[42] "2d Bombardment Wing Instructions No. 55-10 Operations: Navigation", March 10, 1943, 2 A.D. Instructions Sep/43-May/45 Call 526.179-80, US Air Force Historical Research Agency.

[43] *Air Navigation* (Army Air Forces Training Command, 1944), 34; *B-17: Pilot Training Manual for the Flying Fortress, AAF Manual No. 50-13* (Headquarters AAF, Office of Flying Safety, 1945), 15.

as cloud cover or smoke from a burning target, could easily prevent the navigator from navigating with this method.

For the majority of the bombing mission, the navigator used another form of DR that did not depend upon the ability to see the ground—*precision dead reckoning*. Precision DR involved a lengthy process of preplanning the intended flight, calculating, tracking, and recording the aircraft progress, plotting that progress on a special chart, and directing the pilot to make necessary course and airspeed corrections to maintain the planned route.

Dead reckoning navigation was a complex process that demanded constant attention and required the use of specific navigational tools that acted as the navigator's extended "senses," providing him data that represented different aspects of the aircraft's movement through physical space, such as airspeed, direction, and altitude. In turn, the navigator interpreted and integrated that data using specialized computational tools to manipulate it to build a rational representation of the aircraft movement and position. As such, navigation was what cognitive anthropologist and ethnographer Edwin Hutchins calls a distinctly *computational* activity, problem solving accomplished by harnessing the different cognitive capabilities resident in humans and specialized computational tools, bringing them together to transform different sets of information into a navigational solution.[44] This process happened several times during a mission, both on the ground and in the air, in what Bruno Latour called a "centres of calculation."[45] Examining what happened in these centers of calculation provides the avenue through which we may understand how the navigator used his specialized knowledge and tools together to navigate on a bombing mission.

In his book *Science in Action*, Latour examines how scientists *do* science, describing it as a process of gathering samples of data and transforming them into other forms by organizing them into new elements, such as tables or charts, which enable a new and meaningful representation of the world that solves a problem. With each translation, something is gained—a new way to interpret the data as a new representation. It is this process of translation, Latour insists, that one must understand if you are to understand how scientists do science. It is the gathering and assembling data into meaningful representations that tells us what is going on, and

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[44] Edwin Hutchins, *Cognition in the Wild* (Cambridge, MA: The MIT Press, 1996), 50.
[45] Bruno Latour, *Science in Action: How to Follow Scientists and Engineers Through Society* (Cambridge, MA: Harvard University Press, 1988), 232.

it occurs in the centres of calculation.[46]

To understand how a navigator *does* navigation, we must examine what happens in his centres of calculation—the mission planning room on the ground and the navigator's compartment in the bomber aircraft. We must examine how he gathered data and what he did with it. What tools does he use to gather it? What did he do with it once it is gathered? How did he organize it? What did he transform it into and, most importantly, what is the representation that he built and what did it tell him? Precision DR involved several Latourian translations, the first of which the navigator accomplished on the ground before the mission in the centre of calculation defined by the mission planning room, and it was the most critical as it established the interpretive framework for the rest of the mission.

The Bombing Mission—Living the Routine

The navigator's responsibilities on the day of a mission were plainly spelled out in the *Navigators' Information File,* an official manual that contained a comprehensive set of instructions that captured not only the basics of navigation, but also applied wisdom, garnered from the experience of combat-tested navigators. Issued to every navigator in the USAAF, it was his "playbook." It established a routine that he followed on every mission that ensured that he accomplished all of the actions necessary for the successful completion of his job,.

At the conclusion of the General Briefing on the morning of a mission, the Group Navigator or his designated representative gathered all of the mission navigators in a Navigator's Briefing, held in first centre of calculation—the Mission Planning Room. The Group Navigator was the bomb group's chief navigator, usually someone with a good deal of experience and chosen based upon demonstrated excellent performance, and was responsible for much of the group's mission planning. During the briefing, he presented the mission plan that he and his staff had developed the night before, when the Group headquarters had received initial notification of the mission. He gave each navigator all of the materials necessary to DR for the day's mission, including a map that contained the details of the route to the target, the coordinates of all of the turning points, the navigational course and distance in nautical miles between them, and the expected time of arrival (ETA) at each point.

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[46] Ibid., 236-237.

Although the Group Navigator had already planned the mission and they would all fly to the target together in formation, every navigator in the room recorded the information, for each was responsible for planning the mission as if flying to the target and back alone.[47] This enabled him to become more familiar with the route to and from the target as well as check the Group Navigator's work. However, it was not unknown for navigators to merely do a cursory check of the pre-calculated data and accept the Group Navigator's solution.[48] For most of the navigators, this was the first time that they got a chance to examine the details of their task for the day. A smaller group of lead navigators, however, generally met an hour before the main briefing to review the plan and spend more time getting familiar with their task.[49]

Where Are We Going?—Mission Planning and Creating the Ideal out of Reality

> *Before the flight the navigator shall:*
> > *Plan his flight in detail*
> > *Check and know the weather along and adjacent to*
> > > *the line of flight*
> > *Check and know the fuel consumption of his plane*
> > > > > *Navigators' Information File, p. 1-1-1*

Mission planning was the navigator's first step in DR. It was a shared cognitive process, during which the navigator used his knowledge and training in navigation to use purpose-built computing devices that themselves contained specialized navigation knowledge to create a systematic description of the steps necessary to execute the mission for the day, in the process establishing mental and physical frames of reference that would define and guide his actions for the day. The two primary products of the mission planning process, the Flight Plan and the mission map, were idealized numerical and spatial representations of the mission, created through a complex process where the navigator translated data from the physical space in which the aircraft operated with unique computing devices to the ideal space defined by specialized navigational charts in which he himself operated. Together, they constituted a model of the mission, a model that the navigator would attempt to recreate in the air.

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[47] Elmer Bendiner, *The Fall of Fortresses: A Personal Account of the Most Daring-and Deadly-American Air Battles of World War II* (New York: Putnam, 1980), 93.

[48] *Navigators' Information File*, 4-13-1; Crosby, *A Wing and a Prayer*, 3-4.

[49] The specific role of the lead navigator is discussed later in this chapter.

The focus of the first part of the mission planning process was the preparation an AAF Form 21, *Aircraft Flight Log*, which served as the official planning document and record of the flight (Figure 4.4). The Form 21 was split into three parts: the top section was reserved for important mission data, the middle section contained the Flight Plan, and the bottom section, discussed later, contained the Flight Record. In the top section, the navigator recorded critical data, such as the date, the names of the pilot and navigator, the scheduled engine start and takeoff times, the airplane's tail number and position in the formation, sun and moon rise and set times, and information about the alternate landing base in case of poor weather at the home airfield upon return.

Figure 4.4
AAF Form 21 Flight Plan and Log[50]

The Form 21 was the navigator's first unique "computing device," enabling him to combine known information, such as the takeoff time, enroute waypoints, and engine

[50] *Navigators' Information File*, 4-7-2.

performance data with key environmental data, such as the forecast winds at the mission flight altitude into a new, combined data set. This new data set, a product of the first Latourian translation, was the Flight Plan, a set of instructions that, if followed, would get the aircraft from the home base, to the target, and back home without running out of fuel. The Flight Plan served as a continuous numerical and textual reference for where the airplane should be in space, time, and fuel level during the mission.

The 1st Translation—Constructing the Mission in Direction, Distance, Time, and Fuel

The Flight Plan was the navigator's DR planning guide. It detailed each portion of the bombing mission in terms of direction, distance, time, and fuel. It provided the bomber crew an idea of "what to expect enroute and what to do about it when the expected (or unexpected)" happened.[51] As the textual and numerical record of the planned mission, the Flight Plan separated the mission into individual segments, called legs, defined by discrete, named navigational departure and destination points along the intended flight route, such as towns, islands, or numerical coordinates. The leftmost column of the form listed the individual legs of the mission in the order that they would be flown, and the columns that followed across the form to the right described the headings that must fly, the speed that they must travel, and the amount of time and fuel that they would expend.

The first six columns on the Flight Plan defined the mission leg in *direction*. The first column contained the True Course (TC), which was the desired ground track for the leg, referenced from True North (the North Pole). The next column contained the Drift correction, which was the anticipated amount of heading correction necessary to counter the effects of the forecast winds at the mission altitude that would cause the aircraft to deviate from the True Course. The navigator recorded the forecast winds so that he could assess the accuracy of his preflight calculations once the actual Drift was calculated in the air, or use them for any enroute calculations while airborne if actual Drift readings were unavailable.[52]

The next column contained the True Heading (TH), which was the heading that the aircraft would have to maintain to follow the True Course for that leg. The navigator calculated the True Heading by applying the Drift correction to the True Course. The distinction between

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[51] *Instrument Flying: Advanced With Radio Aids, T.O. No. 30-100B-1* (Headquarters, Army Air Forces, 1944), 63, parenthesis in original.
[52] *Air Navigation*, 131-135.

course and heading is critical, as the course was the direction that the navigator wanted the aircraft to follow, while the heading was the direction that the aircraft had to point in order to follow that course. Unless the winds at altitude were right on either the nose or the tail of the aircraft, producing zero drift, the course and heading must differ.

The final direction column on the Flight Plan contained the Magnetic Heading (MH) for the leg, which was the True Heading adjusted for the known magnetic variation for that portion of the mission. The earth's magnetic field caused the aircraft's magnetic compass to read erroneously, but since the variation was known, the navigator applied it to the True Heading to obtain the heading that the pilot could fly on his magnetic compass so that the aircraft would follow the true course over the ground.[53]

The Flight Plan served as an execution-level description of the upcoming mission, containing instructions that the navigator gave the pilot to execute *physically* using the instruments and controls available on the aircraft to accomplish the mission. It was a complex computing device that allowed the navigator to transform different data sets, by themselves insufficient, into a new data set that thoroughly described the mission in direction in discrete, understandable terms. The generation of the courses and headings that made up that data set, however, was another shared cognitive process consisting of complex calculations and translations enabled by more unique computing devices.

Construction of the Ideal—True Course and the Mercator Chart

The navigator's first challenge in defining each mission leg in direction was determining the True Course. The Group Navigator's planning staff chose the points that defined the mission segments during the initial mission planning. Operational requirements, such as the need to avoid location of known threats such as enemy anti-aircraft batteries, the need to conserve enough fuel to complete the mission, and tactics or feints intended to deceive the enemy about the target location in order to complicate their air defense efforts drove their selection.[54] They

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[53] East magnetic variation was subtracted from the True Heading to get the Magnetic Heading, and west variation was added. To remember the mathematical function, aviators use the phrase "East is least, West is best." See *Instrument Flying: Basic With Radio Aids, T.O. No. 30-100A-1* (Headquarters, Army Air Forces, 1943).

[54] Benjamin Thomas Jeremiah, "Benjamin Thomas Jeremiah," interview by Jerri R. Donohue, Audio, February 12, 2008, Benjamin Jeremiah Collection (AFC/2001/001/57024), Veterans History Project, American Folklife Center, Library of Congress, http://lcweb2.loc.gov/diglib/vhp/story/loc.natlib.afc2001001.57024/ (accessed 15 November 2010).

plotted the points on a special mission map, creating an initial spatial representation of the mission. The points on the map represented real locations on the surface of the earth, and the straight line that connected them represented the ground track that the aircraft must fly to complete the mission segment. The navigator used mathematics and translation enabled by a specialized navigation map—the Mercator Chart—to compute the courses for the ground track.

The earth is spherical, rather than flat, and the shortest route between two points is a "great circle" course, defined by the intersection of the earth's surface and plane that passed through the points as well as the center of the earth. Although they are the shortest distance, great circle courses are impractical, as they are difficult to calculate and fly. The convergence of the meridians of longitude as they approach the planetary poles requires that the aircraft constantly change heading at the rate of that convergence to remain on course to the destination.[55] Calculating that course is tedious and repetitive, and no navigational flight instrument existed during World War II that could display the constantly changing course for the pilot to follow in flight. To simplify both the flight planning and execution, the navigator used the Mercator chart to calculate a straight, or rhumb line, course between two points (Figure 4.5).
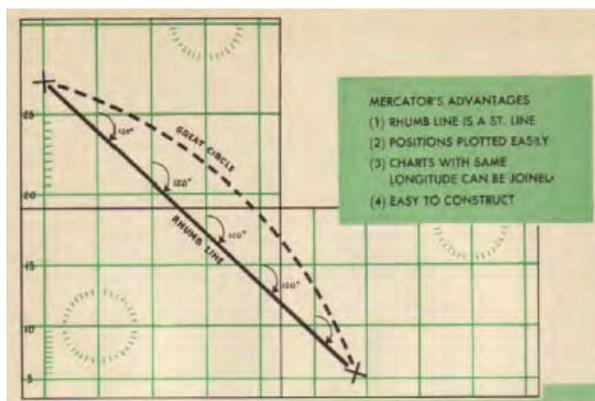
Figure 4.5
Great circle vs. rhumb line course on a Mercator Chart[56]

Mercator charts, the most widely used charts in aerial navigation, are complex computational devices that effectively translate the curved surface of the earth into a flat plane.[57]

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[55] Harry C. Carver, *An Introduction to Air Navigation* (Ann Arbor, MI: Edwards Brothers, Inc., 1943), 6.

[56] *Air Navigation*, 92.

[57] The concept of navigational charts as computational devices is developed in detail in Hutchins, *Cognition in the Wild*.

They create a spatial representation where the convergent lines of longitude maintain parallel spacing, creating a constant angular relationship to True North on the map, in turn constructing an ideal representation of the relative position of all points on the map. By orienting all points on the map in this ideal space, the calculation of a constant course between any two points becomes easy.[58]

The navigator used a Weems Plotter to determine that course. It was a combination protractor and straight edge that, when aligned along the desired course line, displayed the angular difference between True North and that course line (Figure 4.6). The resultant angle represented the True Course between the two points that defined the mission leg in the idealized space created by the Mercator chart. The course measurement itself was a simple operation, but the Mercator chart's translation of spherical space to idealized planar space made the measurement possible.
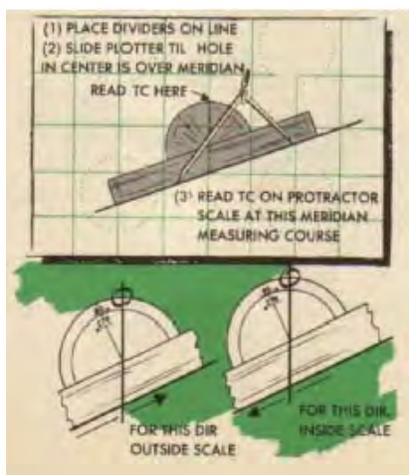
Figure 4.6
Weems plotter and course measurement[59]

Slowly Moving from Ideal to Real—Winds, Drift, True Heading, and the E6-B Computer

The Mercator chart's True Course represented the ideal straight-line path for the mission leg. Next, the navigator had to determine the True Heading that the aircraft would have to fly in order to follow that course. Inflight, aircraft are subject to the effect of winds that, if not aligned with its course, will cause it to be "blown off course." A wind vector not aligned with the

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[58] Above 60 degrees latitude, the Mercator projection becomes too distorted for navigation purposes, and special navigation charts are used in these regions. See *Air Navigation*, 92.

[59] Ibid., 95.

aircraft heading pushes it off course in the direction of the wind. The angular difference between the desired course and the actual course, caused by the effect of the wind, is called Drift. Counteracting Drift requires steering into the wind sufficiently to negate the imposed force (Figure 4.7). Incorporating the Drift component was the first step toward combining the ideal world of the Mercator chart with the real, physical world in which the navigator and the rest of the bomber crew had to operate, where many forces, environmental and otherwise, would influence their actions.
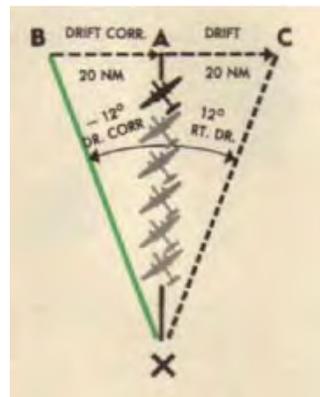
Figure 4.7
Drift correction[60]

Calculating the angular Drift correction requires solving a basic vector triangle problem. While easily accomplished by plotting vector triangles on graph paper while on the ground in the Mission Planning room, this method was impractical in flight because flight instruments, ammunition, and machine guns limited the amount of room in the navigator's workspace. He could not store, organize, and lay out numerous sheets of graph paper over his small desk area, already covered by his maps, charts, and Flight Log. Instead, he used a specially designed calculator, the E6-B Aerial Dead Reckoning Computer, to perform the Drift calculations.[61]

The E6-B Computer—"The Airman's Bible"[62]

The E6-B Aerial Dead Reckoning Computer, a two-sided, manual computer, was the primary navigational computer issued to navigators, bombardiers, and pilots during World War

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[60] Ibid., 83.

[61] Carver, *An Introduction to Air Navigation*, Chapter 3, Wind Diagrams.

[62] J. W. Smallwood, *Tomlin's Crew: A Bombardier's Story* (Manhattan, KA: Sunflower University Press, 1992), 21.

II. Small enough to fit into a jacket pocket, it was designed to accomplish almost all navigation and bombing computations necessary to complete a Flight Plan, as well as for use while navigating during flight.[63] One side consisted of a circular slide rule, which enabled the user to perform several flight-related computations, such as distance, time, and speed calculation, conversion from pressure altitude to true altitude, true, indicated, and calibrated airspeed conversion, and computation of fuel consumption (Figure 4.8). The reverse side of the computer enabled the user to rapidly solve vector problems, such as deriving wind vectors and drift corrections. Navigator trainees spent many hours learning to use the E6-B. The 1941 *Air Corps Navigation School Program of Instruction for Training of Aerial Navigators* dedicated 10 hours specifically to its correct operation, and the trainees used it continuously throughout the rest of the program.[64] Complicated but useful, it was, in the words of one B-17 navigator, "a remarkable instrument" that required "many hours (of practice) before we achieved mastery."[65]
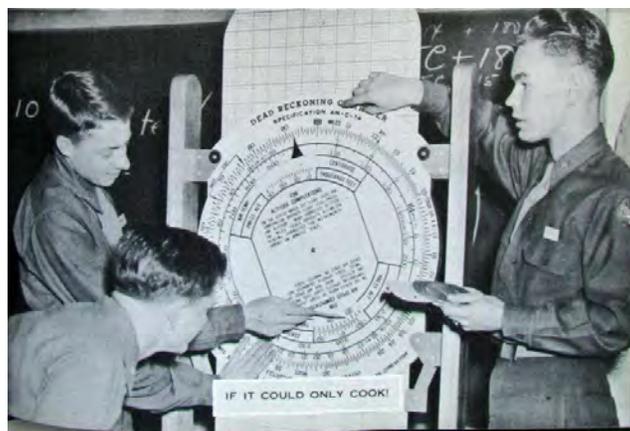
Figure 4.8
Navigator trainees practicing using the front side of an E6-B computer[66]

The E6-B, or "whiz-wheel," was a unique aerial navigation cultural artifact, and one that is still in use to this day.[67] Designed for DR navigation computations, it was the latest addition to a series of mechanical computers designed specifically for aerial navigation. These computers arose from the need for a reliable, compact, lightweight, easy to use method to compute rapid

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[63] *Bombardiers' Information File (AAF Form 24B)* (U.S. War Department, 1944), 1-3-0.
[64] "Air Corps Navigation School Program of Instruction (15 July 1941)," 3-7.
[65] Farr, *B-17 Navigator*, 166-167.
[66] *Departure Point: Class of 44-4* (San Marcos Army Air Field, San Marcos, TX: AAF Navigation School, 1944).
[67] "Whiz-wheel" is a faintly derogatory slang term aviators use to describe the E6-B and its successors.

solutions to navigation problems. Because aircraft flew fast, the computer had to solve problems quickly, to allow the navigator to narrow the distance between knowing where he *is* and where he *was*.

The navigator could solve the time-distance problems and perform the altitude and airspeed conversions necessary for DR navigation with the slide rule side of the E6-B, all within the tight confines of an aircraft cockpit while wearing heavy gloves. The vector-solving side had a compass rose that contained a translucent disk, upon which the operator could draw vector problems with a pencil. Overlaying a sliding computational grid, this side of the computer enabled the operator to quickly solve for drift, course, and ground speed (Figure 4.9).[68] Because the navigator could easily erase a previous solution, it was very flexible and could solve an unlimited number of problems. The E6-B was an indispensable tool for aerial navigation used for mission planning and in flight calculations. Just as the slide rule became a "status symbol" for engineering students in the 1950s and 1960s, it became an enduring symbol of the navigator, even earning a place in a stanza in the Childs and Roth song "*The Navigator*":

> *His computer is the instrument on which he stakes his life,*
> *Don't ask for his computer, for he'd sooner lend his wife.*[69]
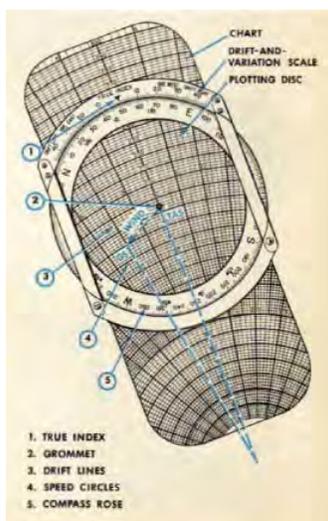
Figure 4.9
E6-B wind triangle solution[70]

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[68] Paul McConnell, "Some Early Computers for Aviators," *IEEE Annals of the History of Computing* 13, no. 2 (June 1991): 155-156.

[69] Michael R. Williams, "Early Calculation," in *Computing Before Computers*, ed. William Aspray (Ames, IA: Iowa State University Press, 1990), 33; Childs and Roth, "The Navigator," N-1.

During mission planning, the navigator used the vector side of the E6-B, with its transparent plotting disk, sliding chart, and drift-and-variation scale to calculate the wind Drift effect. Provided he knew any two of three directions—wind, True Heading, or True Course—and any two of the three speeds—wind speed, True Airspeed (TAS), or groundspeed—he could solve for the third, unknown value. The navigator used the wind and True Course values to derive the True Heading value for each leg of the mission, and entered the values on the Flight Plan.

With the True Heading value known, the navigator could calculate the final, and most critical, directional value—the Magnetic Heading. Applying the known magnetic variation along the mission leg to the True Heading produced the Magnetic Heading, which was the heading that the pilot would actually fly during the mission. With this last calculation, the navigator, having translated the idealized angular definition created in the idealized space defined by the Mercator chart back into the physical world within which the bombing mission would occur, finished defining the mission in direction and entered all of the values on the Flight Plan.

Distance

In addition to defining the mission in direction, the navigator defined it in distance. The navigator had to know how far it was between the destination points because it determined how long the pilot would fly his computed headings. Although the Mercator chart greatly simplified the calculation of the aircraft course for each leg, it complicated the calculation of the length. The distance scale on a Mercator chart is not constant, as it would be on a spherical map, or globe. The process of making the longitude lines parallel demands that the lines of latitude on the chart, which are equidistant on a sphere, must increase in their spacing as the plotted position moves farther from the equator toward the polar regions. Thus, the display of one mile at the equator is shorter than the display of one mile farther north. While the Mercator chart simplifies the navigator's task in angle (course), it complicates it in distance.

To compensate for the non-constant distance scale, the navigator used the "mid-latitude" formula, wherein he derived an average distance measurement for each leg of the mission based

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[70] *Bombardiers' Information File*, 3-1-3.

on the distance scale at the midpoint of that leg.[71] He accomplished this by examining the line that connected the points of the leg and visually choosing the middle. He then used the distance scale on the latitude line at that point to set the scale for the entire leg and could easily calculate the leg's distance by measuring with that scale. He performed this for each leg of the mission and entered the value on the Flight Plan. Once again, the navigator performed a translation from the idealized space of the Mercator chart to the physical world of the bomber.

Time

The navigator then used the geographic length of each leg to calculate the amount of time required to fly that leg. In the air, the navigator could measure the distance flown over the ground directly only when the aircraft passed over two points whose distance apart was known. When the ground was obscured, as was often the case for large portions of bombing missions in the ETO, the navigator had to measure distance by measuring *time*, so that he knew when the aircraft completed each leg and when to assume a new heading. The navigator calculated the anticipated time for each leg of the mission on the Flight Plan, and recorded it as the Estimated Time of Arrival (ETA). He also kept a running total for the flight's elapsed time, which served as a schedule of when they were supposed to be at each point.

To calculate the time for each leg, he did a simple time-distance calculation on his E6-B using the aircraft groundspeed and length of the leg. He first calculated the groundspeed with his E-6B by solving another vector problem that determined what effect the forecast mission winds would have on the aircraft speed over the ground (the same winds used for the Drift calculation), and either added or subtracted that value from the aircraft true airspeed that he the pilot would fly during the mission. Bomber formations generally flew at about 150 miles per hour, and by combining the two values, he determined how fast the aircraft should travel over the ground. By translating distance to time through the groundspeed, the navigator defined the aircraft position during the mission in another set of terms that he could use both on the ground and in the air.

When the ground was visible, the navigator could maintain a *ground plot* of the aircraft position over the earth's surface on a chart, and calculate the distance flown by measuring the distance between the points. However, in situations where ground references were absent, such as over water or when clouds obscured the ground, such measurements were not possible, and

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[71] Carver, *An Introduction to Air Navigation*, 192.

the navigator kept track of his position with an *air plot*, which was a record of the aircraft's dead reckoning position in the air. [72] Weather was a big problem during the CBO, and clouds often obscured the ground for large portions of the mission, but using the air plot method made visual contact with the ground less important and allowed the navigator to perform his job.

By regulation, navigators in the ETO were required to maintain an air plot, constantly computing aircraft position by performing time-speed-distance calculations from the last known dead reckoning position and plotting them on a navigational chart, recording the time of the plot, as well.[73] At any time after that reading, he could determine how far the aircraft had flown by dividing the amount of time from the last dead reckoning position by the aircraft ground speed and determine how far the aircraft had flown. Knowing the aircraft position and maintaining the air plot was the focus of all of the navigator's efforts during the mission. Later in the war, air position indicators, which could calculate the aircraft position throughout the flight, were installed in bomber aircraft, but the navigator still had to maintain a dead reckoning log of the aircraft position.[74]

Fuel

During mission planning, the navigator also had to ensure that the aircraft had sufficient fuel to complete the planned mission. He did this by multiplying fuel consumption values that he obtained from specific aircraft performance charts that indicated how much fuel the aircraft should use while flying at the planned mission altitude. He calculated the amount of fuel that would be consumed on each leg with the slide rule side of his E6-B, recorded it in the last column on the Flight Plan, and kept a running total of how much fuel the aircraft should have at the end of each leg. He referred to these critical values often during the mission, as any evidence of fuel consumption greater than that planned could mean that the aircraft might not have enough fuel to make it back home. By translating time into fuel quantity through the fuel consumption performance charts, the navigator constructed yet another cognitive model of the mission.

Once completed, the Flight Plan comprised a complete textual record of the mission plan. It defined the mission in direction, distance, time, and fuel quantity, and contained a record of the

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[72] *Air Navigation*, 127.

[73] "2d Bombardment Wing Instructions No. 55-16: Operations-Navigation", August 3, 1944, 2 A.D. Instructions Jan 1944-May 1945 Call 526.179-55, US Air Force Historical Research Agency; *Air Navigation*, 127-128.

[74] *Navigators' Information File*, 2-7-1 - 2-7-3.

forecast winds, which were the navigator's major flight planning assumption, so that he could assess the validity of the plan after measuring the actual winds at the mission altitude. It formed a complete frame of reference for the mission, one that would be the constant yardstick by which the navigator and pilot would assess the mission as they flew it (Figure 4.10).

Figure 4.10
Flight Plan and Flight Record from Mission No. 173, 14 August 1944, Ludwigshafen, Germany[75]

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[75] "Flight Plan and Flight Record, Mission No. 173, Ludwigshafen--Bruce Lowe, Navigator", August 14, 1944, 390th Bomb Group Memorial Museum Archives. This flight plan was used on 14 August 1944 on a

While it appeared to be a simple bureaucratic form filled with text and numbers, the Flight Plan was really a complex translation device that brought separate sets of data together that, after the navigator had further manipulated them, formed a new set of data. That new set of data, arranged chronologically on the Flight Plan, allowed the navigator to construct five models of the mission. The first was a textual list of the waypoints along the mission, recording in words where the aircraft would travel. The second through fourth models were numerical, constructing the mission in direction, distance, time, and fuel quantity. Each was a discrete but related model that predicted where the aircraft would be during the mission. Together, they became a single set of instructions, executable by the pilot, which would get the aircraft to the target and back home to complete the mission. With the textual and numerical models of the mission complete, the navigator next built a spatial model of the upcoming mission.

The 2nd Translation—Constructing the Mission in Space and the Mission Map

With the Flight Plan complete, the navigator performed the next key planning task—the creation of the mission map (Figure 4.11). The mission map was the navigator's primary spatial reference during the mission. It integrated the space and time elements of the Flight Plan, and combined them with other key mission events. In addition to displaying the entire planned flight route, it showed the locations of key events and places, such as formation rejoin points, fighter escort rendezvous and departure points, and the location of known enemy anti-aircraft (flak) gun emplacements.[76] However, the map had very few ground references, and those were limited primarily to coastlines and large cities. It was also the chart that the navigator would use in flight to construct the air plot, enabling him to track his dead reckoning position relative to the planned position.

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bombing mission to Ludwigshafen. Note that the top portion is completely filled out, defining twenty one discrete legs for the mission. The names of the legs are a mix of location names as well as navigational coordinates.

[76] Jeremiah, "Benjamin Thomas Jeremiah."
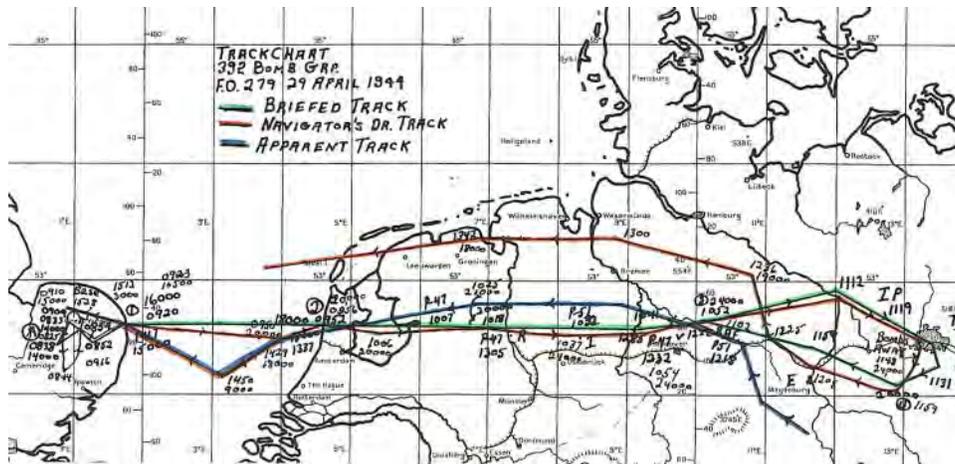
Figure 4.11
Mission Map for Mission No. 327 to Berlin, 29 April 1944[77]

The map provided a manageable frame of reference that enabled the navigator to visually anchor the airplane's physical position on the face of the earth in a limited fashion, since there was little detail. When Edwin Hutchins examined maritime navigation in his book *Cognition in the Wild*, he described navigational charts as spatial analogies, where "positions on a map or chart have correspondence with positions in a depicted large scale space."[78] The mission map created that spatial analogy for the aerial navigator by representing the entire mission flight route within the context of the ETO, as well as how individual positions related to the flight route itself. Since it included elapsed times it created a temporal analogy, as well, anchoring the aircraft to a time line that captured the aircraft's temporal route through the mission.

By plotting the physical and temporal route, the navigator transformed the chart into another complex calculation device that greatly simplified his job in the air. It became a form of permanent memory for the aircraft. By using it to create the air plot during the mission, the navigator could instantaneously determine how they were progressing, and then make any necessary adjustments in their actions to remedy any discrepancies in their performance. As a referential device, it also changed the navigator's perception of space and time. No longer did it matter where they were as referenced by a position on the face of the earth, nor was the actual time, as read on a watch, any longer relevant. The line on the map and the times associated with

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[77] "The Berlin Bombing Mission Flown by The 8th Air Force on April 29, 1944--Map 392 route Berlin.jpg", April 29, 1944, http://www.b24.net/stories/annette.htm (accessed 4 March 2011). The increasing distance between the horizontal longitude lines as you move north on the map show that this is a Mercator chart.

[78] Hutchins, *Cognition in the Wild*, 61-63.

it became the spatial and temporal reality. They were either on or off course, and either on, ahead, or behind the timeline. As related by B-17 navigator Emmett Herndon,

> I used to draw the courses on…the maps…and wrote times that we were supposed to be at certain places, and then I sort of did like a golfer. I was plus or minus, I was behind or ahead and I was right or left of the course. So I put little Xs on my map.[79]

While the map maintained an overall spatial relationship, the ability to simply and rapidly assess local relative position made the navigator's job of correcting course errors much easier.

The Flight Plan and Mission Map as Cultural Artifacts

Before discussing mission itself, it is interesting to note how the Flight Plan and mission map became unique navigational cultural artifacts that extended beyond their role as a list of transformed instructions or a visual representation of the mission. They also captured the unique language necessary to understand and perform aerial navigation. Direction and time, both in particular, were recorded in a specific format, designed to convey as much information as possible. The USAAF *Air Navigation* Manual directed that

> true direction should be indicated always by three numerals (068); magnetic or compass directions, by three numerals followed by the letter *M* or *C* (090 M; 086 C). Time of day always is indicated on a 24-hour basis in four figures (1348); elapsed time, by hours, minutes, and seconds ($3^h\ 45^m\ 30^s$).[80]

In this fashion, the same numbers became distinctly different representations based upon how they were written, and could thus be used to capture and define multiple pieces of data. By using this unique language during their construction, the navigator transformed the Flight Plan and mission map from mundane record keeping devices or visual depictions into something representative of their profession, uniquely navigational tools.

Mission planning was a shared cognitive process, during which the navigator used his knowledge and training in navigation to use purpose-built computing devices that themselves

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[79] Emmet B. Herndon, "Emmet B. Herndon," interview by Troy Reeves, Audio/transcript, February 5, 2002, Emmet Herndon Collection (AFC/2001/001/473), Veterans History Project, American Folklife Center, Library of Congress, http://lcweb2.loc.gov/diglib/vhp/bib/loc.natlib.afc2001001.00473 (accessed 15 November 2010).
[80] *Air Navigation*, 125-126.

contained specialized navigation knowledge to create two distinct representations of the upcoming mission—the Flight Plan and the mission map. The Mission Planning room served as a Latourian "centre of calculation," where diverse data sets were combined in a unique way to create new understandings of the physical world. The Flight Plan and the mission map were idealized numerical and spatial representations of the mission, created through a complex process where the navigator translated data from the physical space in which the aircraft operated with unique computing devices to the ideal space defined by specialized navigational charts in which he himself operated. Together, they constituted a model of the mission, a model that the navigator would attempt to recreate in the air.

The Mission

Sharing Knowledge—Briefing the Crew at the Airplane

> *At the airplane, brief your crew on particulars of the flight.*[81]
> > *Navigators' Information File, p. 4-13-1*

After mission planning, the navigator proceeded to his assigned aircraft, joining the rest of his crew. Flight crews generally arrived at their aircraft at least an hour before takeoff to allow enough time to complete all of the preflight preparation for the mission. At that time, the navigator briefed the rest of the crew on the particulars of the flight, covering the formation plan, the times that they would cross both friendly and enemy coast lines on departure and return, the rendezvous time with any fighter escort, and the locations of anticipated enemy fighter attack (Figure 4.12). He also described key checkpoints along the route that he wanted assistance in locating during the flight, and how he wanted them reported.[82] This verbal briefing provided the crew an idea of what to expect during the flight, clarifying and providing more detail than the big picture presented in the General Briefing. It also created a common mental model and frame of reference for what they, as a crew, could expect to experience together on the mission.

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[81] *Navigators' Information File*, 4-13-1.

[82] Ibid.; Roger A. Freeman, *The Mighty Eighth War Manual* (London: Jane's Publishing Company, Ltd, 1984), 13-16; Crosby, *A Wing and a Prayer*.

Figure 4.12
Crew Members Of The 379th Bomb Group Study A Map Of The Target Area Before Taking Off From Their Base In England For A Mission Over Enemy Territory. 20 January 1944.[83]

Along with the verbal brief, the navigator often gave the pilot a prepared mission aid. This "small-scale track chart with predicted times, courses, and distances" enabled the pilot to keep track of the mission progress, as well as anticipate upcoming directions or events.[84] By creating a common expectation, it eased coordination between the two human elements in the bombardment system that communicated most frequently during the mission, increasing the potential for effective coordination. Once he completed his ground briefings, the navigator entered the aircraft and took his place in the second "centre of calculation" to prepare for the flight portion of the mission.

The Office—The Navigator's Compartment and Navigation Tools

> *Before the flight the navigator shall: Have all his equipment in the plane*
> *Check his instruments*
> *Navigators' Information File, p. 1-1-2*

The navigator entered the aircraft and proceeded forward to the navigator's compartment to finish preparing for the mission. The B-17 was the first Air Corps bomber to have a dedicated

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[83] *Crew Members Of The 379th Bomb Group Study A Map Of The Target Area Before Taking Off From Their Base In England For A Mission Over Enemy Territory. 20 January 1944. England.*, Photograph, January 20, 1944, 342-FH-3A14051-71673AC, National Archives and Records Administration, http://www.footnote.com/image/#39016268 (accessed 1 December 2010).

[84] *Navigators' Information File*, 4-13-1.

section for both the navigator and the bombardier, and it was located in the front of the aircraft, where the two crewmen shared the space from the aircraft's Plexiglas nose back to the bulkhead that formed the forward end of the pilots' compartment.[85] The bombardier occupied the forward area, and the navigator occupied the portion of the compartment that extended from rear of the bombardier's seat to the rear bulkhead, placing him between the bombardier and the pilots (Figure 4.13).[86]
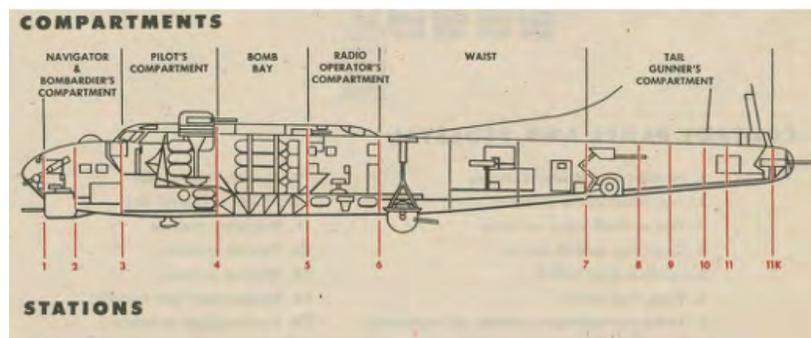
Figure 4.13
The crew compartment layout in the B-17[87]

The men accessed this area by either entering the aircraft through the rear fuselage door and walking the length of the aircraft, through the bomb bay, or by swinging themselves up through a hatch in the nose, located just below the flight deck forward of the landing gear. Entering through the hatch required "a kind of chin-up maneuver," executed by grasping the inside edge of the opening and swinging the legs up and into the aircraft. It was never easy, and those choosing to enter this way usually required assistance, particularly when wearing heavy flying gear designed for cold, high altitude flight.[88]

Generously described as "snug," or more accurately as "cramped," the navigator had to stoop over when entering the compartment door to avoid hitting his head on the underside of the flight deck where the aircraft commander and copilot sat. The compartment itself contained a small swivel chair, permanently attached to the floor in front of a work table, a 36-inch long, 18-inch wide shelf attached to the left rear corner of the compartment (facing forward in the

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[85] Harbold, *The Log of Air Navigation*, 77.

[86] *B-17F Pilot's Flight Operating Instructions, T. O. No. 01-20EF-1* (U.S. War Department, 1942), 93.

[87] *Pilot Training Manual for the B-17*, 29.

[88] *Pilot Training Manual for the B-17*; Freeman, *The Mighty Eighth War Manual*, 16; Murphy, *Luck of the Draw*, 91.

aircraft), and numerous aircraft and navigation instruments, described below. His view outside the aircraft was limited to four windows, two on each side of the fuselage.

The two left-side windows, positioned above the work table, provided a view of the left wing and the No. 2 engine (left inboard). A .50 caliber machine gun, suspended above the table and constantly "in the way," protruded from the forward window in early B-17 models, and took up a significant amount of room.[89] The gun's ammunition box, attached to the upper left-rear corner of the compartment, further reduced headroom (Figure 4.14). The windows on the right side provided a similar, but less obstructed view. Late-model B-17s had a Plexiglas astrodome, located forward of the navigator's table and centered on the top of fuselage, which housed an astrocompass and provided a 360-degree view from which to take celestial navigation observations.
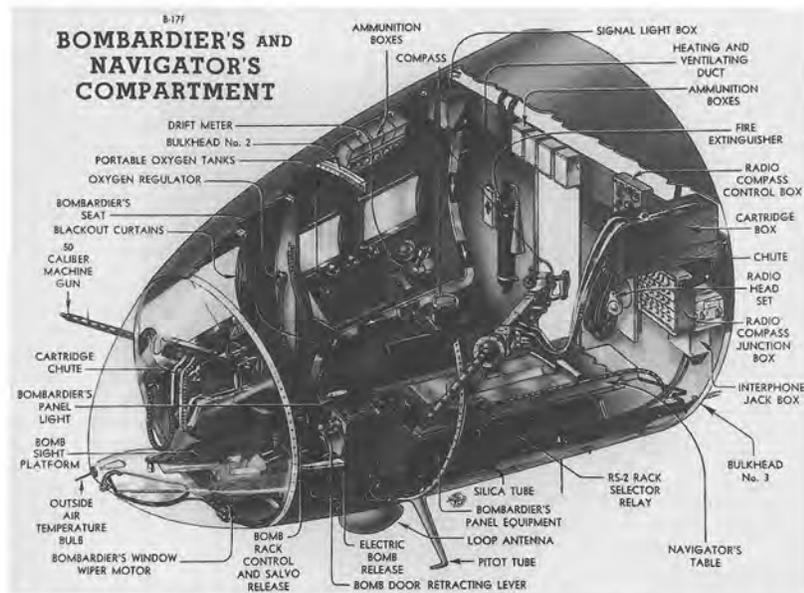
Boeing B-17F cutaway showing the bombardier's and navigator's compartment.
Courtesy of the Boeing Business Services Company

Figure 4.14
The B-17F bombardier and navigator's compartment[90]

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[89] The B-17E and -F models had .50 caliber guns in the navigator position. B-17C and -D aircraft had .30 caliber machine guns that could be installed in one of six positions in the nose, including the navigator position. A few B-17Fs and all B-17Gs (the last in the line of aircraft models) had the navigator's guns removed and a powered chin turret with twin .50 caliber machine guns was installed instead. See Peter M. Bowers, *Fortress in the Sky* (Grenada Hills, CA: Sentry Books, Inc., 1976); Crosby, *A Wing and a Prayer*, 44.
[90] Murphy, *Luck of the Draw.*

In addition to navigation instruments and machine guns, the navigator's compartment contained the necessary equipment for survival and communication in the oxygen-deprived, extremely cold conditions routinely experienced on high-altitude bombing missions. An oxygen regulator provided oxygen inflight above 10,000 feet, and an electrical outlet, located above the aperiodic compass, provided electrical power to provide warmth through an electrically heated flight suit. Below that outlet, a heat vent pumped an inadequate supply of warm air into the compartment. A radio headset and interphone connection enabled him to talk to anyone in the crew, as well as listen to the radio transmissions during the mission.

Sensing and Measuring Performance—Altitude, Temperature, and Airspeed

The navigator spent most of the mission seated at his work table, from which his view of the world outside the aircraft was very limited. He could see very little of the ground, and his view out the front of the aircraft was obscured by the bombardier and his equipment. In place of sight, the navigator had special instruments at his station, all within easy reach, that acted as his "senses." The navigator and these instruments formed a united socio-technical element in the aircraft, with the instruments acting as part of the sensing element, extending the navigator's senses beyond the limits of the aircraft and enabling him to gather necessary data, and the navigator acting as the integrating and calculating element, both working together to navigate the bomber.

Just above the table, attached to the outer fuselage, were a set of repeater flight instruments, including an air temperature indicator, an airspeed indicator, and an altimeter. These three instruments provided him critical information about the aircraft's physical performance and environment that he needed to navigate precisely. Their readings, however, required interpretation and conversion before they became useful. The air-temperature indicator displayed the outside air temperature sensed by a small probe that extended out of the aircraft fuselage. Air temperature was an important piece of data, as it helped the navigator correct erroneous readings from some of his other instruments. However, the temperature readings themselves were inaccurate, distorted by the friction of the air passing over the probe inflight. The navigator read the temperature from the gauge and converted it using a conversion table found in a table in his *Navigators' Information File*, performing the calculation with his E6-B

computer (Figure 4.15). He used this new value to convert the readings from the airspeed gauge and the altimeter.

TAS (knots)	Decrease (C°)	TAS (knots)	Decrease (C°)
60	0.4	260	7.2
80	0.7	280	8.3
100	1.1	300	9.5
120	1.5	320	10.9
140	2.1	340	12.3
160	2.7	360	13.7
180	3.4	380	15.3
200	4.2	400	17.0
220	5.1	420	18.7
240	6.1	440	20.5

Figure 4.15
TAS-Temp conversion factors from the *Navigators' Information File*[91]

The airspeed indicator displayed indicated airspeed (IAS) rather than true airspeed (TAS), which was what the navigator really needed for DR navigation. TAS varies based upon temperature and altitude, so he used his E6-B to convert the gauge's displayed value to get an accurate value. He obtained the altitude for the computation from the altimeter, but had to convert its value first, as well. The altimeter displayed the barometric altitude, but he needed pressure altitude, which he again converted with his E6-B. These three "sensors" provided basic information about the aircraft environment, but like eyes with astigmatism, their readings had to be corrected before they could be used for precision calculation. The E6-B, designed for such correction, acted as the navigator's glasses, presenting a more accurate view of the environment. With the aircraft performance values established, the navigator used the other instruments at his work station to determine where the aircraft was going.

Sensing and Direction—The Aperiodic Compass, Directional Gyro, and Magnetic Gyro Fluxgate Compass

Situated around the compartment were several direction-indicating instruments, including the aperiodic magnetic compass, the directional gyro, or gyro compass, and the magnetic gyro

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[91] *Navigators' Information File,* 2-1-1.

flux gate compass.[92] The aperiodic compass, the least accurate of the heading instruments, indicated the aircraft's magnetic heading. An incremental improvement over the basic magnetic compass, the aperiodic compass minimized the stabilization delay, or period, in the heading display induced by an aircraft turn or acceleration. Known as the "navigator's compass" for its slow movement, it was resistant to aircraft motion, but its accuracy suffered from exposure to ferrous metals in and around the navigator's compartment, as well as magnetic fields produced by aircraft electronic equipment.[93] The *Navigators' Information File* dedicated two pages to describing how to calculate various algebraically derived compensation coefficients that the navigator could apply to the compass reading to obtain a more accurate aircraft heading.[94]

The directional gyro was a more stable instrument that functioned as a turn indicator rather than a heading indicator. Consisting of a gyroscopically stabilized platform, it remained aligned with the longitudinal axis of the aircraft and helped the navigator maintain flight direction by indicating the number of degrees of aircraft heading change when the pilot turned the aircraft. Although it did not lag, swing, or oscillate during the turn, as a magnetic compass would, the gyro precessed, or drifted, over time, and no longer indicated an accurate heading. Per the equipment specifications, drift rates of up to 2½° every fifteen minutes were acceptable.[95] Effective use of the directional gyro required that the navigator determine the instrument's drift rate every flight and then compensate for it. He did this by "recaging" the gyro occasionally, reorienting it along the aircraft's longitudinal axis. While useful, it provided a specific type of information and required an understanding of gyroscopic principles to be effective.

The magnetic flux gate compass combined the gyroscope's stability with a compass's ability to indicate heading. Equipped with an electrically driven gyroscope, the flux gate compass determined the aircraft magnetic heading by using a remote magnetic sensing device installed in a location that minimized magnetic interference. A remote transmitter sent the heading via an electrical signal that several compass units could receive at once, providing both the navigator and pilot access to the heading data. The fluxgate compass had an adjustable outer dial on its case that the navigator could set to display true rather than magnetic heading, making

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[92] *B-17F Pilot's Flight Operating Instructions*, 90-93; Murphy, *Luck of the Draw*, 92. The specific location of some of the instruments varied in different models of the aircraft, but the basic instruments remained the same.

[93] Edward O. Purtee, *Development and Adaptation of Aircraft Instruments for Military Use* (Historical Division, Intelligence, T-2, Air Technical Service Command, 1946), 39-40.

[94] *Navigators' Information File*, 2-9-1, 2-9-2.

[95] Ibid., 2-10-1.

it very useful for creating his air plot. A complex instrument, the magnetic flux gate compass required frequent alignment and testing, and had a dedicated test unit that would test its accuracy and compensate for errors.[96]

The aircraft instruments in the navigator's compartment were his surrogate senses, providing information that he otherwise could not obtain. They supplied useful, but incomplete, data about aircraft performance, displaying values that he had to convert continually in order to navigate precisely. Likewise, the stand-alone heading indicators provided useful data, but needed continual adjustment to maintain their accuracy, as well as a well-developed skill in interpreting the data that they displayed. As such, sensing accurate data evolved as a cooperative process within the socio-technical element defined by the navigator and his tools, neither one effective without the other. With airplane heading solved, the navigator finally had to determine how the environment—wind and weather—affected its movement across the surface of the earth.

Sensing and Translation—The B-5 Driftmeter and Automatic Bombing Computer

The flight instruments and navigation instruments provided the navigator data, but he also had instruments that helped process that information. The B-5 Driftmeter and the Automatic Bombing (AB) Computer, part of the Norden bombsight, helped the navigator determine the aircraft drift rate in the air, which he then used to calculate the aircraft groundspeed. The B-5 Driftmeter, installed in virtually all bombers during World War II, was a non-stabilized, non-synchronous visual instrument used to observe and record aircraft drift across the ground (Figure 4.16).[97] It consisted of a telescope that extended out the side of the aircraft used to observe stationary objects below. The navigator traced the progress of those objects across the objective lens with an index, linked mechanically to a pencil that recorded the movement on a glass plate overlaid on parallel horizontal timing reference lines (Figure 4.17). During a mission, once the navigator had recorded the movement of several objects on the glass plate, he rotated it and read the angle that they formed with the aircraft longitudinal axis from a scale at the top of the instrument. This graphical analog-to-digital conversion gave him the aircraft drift angle.

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[96] Purtee, *Development and Adaptation of Aircraft Instruments for Military Use*, 46-50; *Navigators' Information File*, 2-9-2 - 2-9-4.

[97] Purtee, *Development and Adaptation of Aircraft Instruments for Military Use*, 112-113.

Figure 4.16
B-5 Driftmeter[98]

In addition to calculating the drift, the B-5 Driftmeter enabled the navigator to measure and calculate groundspeed. The parallel lines on the instrument were equally spaced, and after timing the passage of an object between these timing reference lines, he set that value, along with the aircraft altitude on a small circular mechanical computer, which can be seen on the lower left section of the device in Figure 4.16. The computer performed a simple geometric calculation that produced a groundspeed value, completing another analog-to-digital conversion that translated movement into useful data. The B-5 Driftmeter was difficult to operate and not very accurate. Since it was not gyroscopically stabilized, the navigator would often have to perform several readings and average them to obtain a reasonably accurate measurement in bumpy weather or at low altitude. It took "time and patience to gain confidence in its use," and was not popular with bomber navigators, many of whom had trained with much more capable systems in the United States before deploying to the ETO.[99]

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[98] *B-5 Drift Meter*, n.d., http://www.questmasters.us/B-24_Page_5.html (accessed 24 November 2010).

[99] *Navigators' Information File*, 2-8-2 - 2-8-3; Rebecca Hancock Cameron, *Training to Fly: Military Flight Training, 1907-1945* (Washington, DC: Air Force History and Museums Program, 1999), 426-427. The B-3 Driftmeter, used during navigation training was gyroscopically stabilized and preferred over the B-5. See Purtee, *Development and Adaptation of Aircraft Instruments for Military Use*, 111-113.
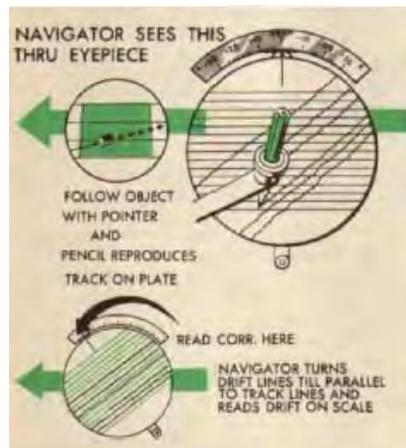
Figure 4.17
Using the Driftmeter[100]

On aircraft equipped with the Norden bombsight, the navigator could use the bombardier's AB computer, a more sophisticated mechanical computer than the one on the driftmeter, to compute drift and groundspeed directly (Figure 4.18). The AB computer was a complex slide rule connected to the gyroscopically stabilized bombsight. To calculate the drift and groundspeed, the navigator directed the pilot to fly the aircraft at a constant altitude and airspeed while the bombardier sighted and tracked a stationary object on the ground, "zeroing out" its movement in the bombsight's optical telescope.[101] The bombardier obtained the angle between the bombsight sight line and the aircraft longitudinal axis from a scale on the bombsight, which equaled the aircraft drift angle. The bombardier then set that value on the AB computer along with the aircraft true airspeed, which he either obtained from the navigator or calculated himself with his E6-B, and the computer indicated the aircraft groundspeed. The Norden bombsight and AB computer used together produced more accurate drift and groundspeed calculations, but required the participation and cooperation of other members of the bomber crew.

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[100] *Air Navigation*, 88.

[101] This process is described in Chapter 5.
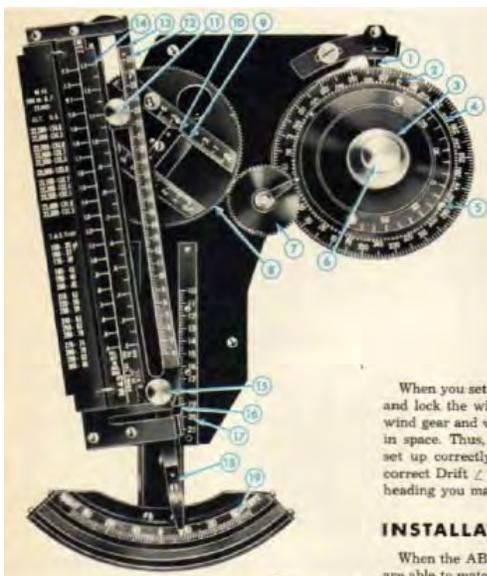
Figure 4.18
The Automatic Bombing Computer[102]

The AB computer provided a redundant drift-computation capability, in the event that the navigator's primary instrument, the B-5, was inoperable. Just as the copilot could replace the aircraft commander as the bomber pilot, the autopilot control system could replace the primary flight control system, or, as will be seen in the following chapter, the bombardier could replace the navigator, the bombardment system at the aircraft level had built in adaptive capabilities that enabled it to still perform in the event of some partial failure. In this case, however, the "redundant" instrument was actually more accurate than was the primary instrument. The AB computer calculated drift more accurately than the B-5, in part because it was integrated with the gyroscopically stabilized bombsight, enabling more precise tracking of targets on the ground and thus more precise drift calculation. Interestingly, the USAAF had developed the B-3 gyroscopically stabilized drift meter during the late 1930s, with performance far superior to that of the B-5 and hailed in 1937 as "one of the finest instruments of its class known in the world."[103] However, in the rush to procure sufficient drift meters to equip all of the new bombers being built for the war, the USAAF decided to purchase instead the cheaper, less complex, and easier to build B-5. As a consequence, in a clear comment about how the HADPB doctrine and the importance of precision bombing affected even such matters as navigation

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[102] *Bombardiers' Information File*, 3-2-1.

[103] Purtee, *Development and Adaptation of Aircraft Instruments for Military Use*, 111.

instrument acquisition, the bombardier actually had a better navigation instrument than the navigator, because he needed it for precision bombing.

The aircraft flight instruments, the directional instruments, and the drift instruments installed in the navigator's compartment all provided data that he needed to perform his job. They acted as his extended senses and, in the case of the B-5 Driftmeter and the AB computer, his extended computational ability. Individually, however, the data they produced was insufficient, and he often had to estimate, interpret, or convert it before it became useful. Once converted, however, whether from an indicated or magnetic value to a true value or from an analog line to a digital drift angle, he could combine the new values with other converted data and create navigation data—the same data that he used during the mission planning process, only now it was *observed* rather than *assumed* data, and it indicated what *was* happening rather than what was *planned*.

Together, the navigator and his instruments formed a contained socio-technical navigational element in the bombardment system. With the data that the instruments produced, the navigator could create enough information to precision dead reckon navigate, and other than using the AB computer which required the participation of the bombardier and pilot, it was a self-contained element. The navigator, however, was an integral part of the bombardment system, and he routinely reached out beyond this narrowly-defined system to other elements of the larger aircraft system to perform his job.

Position Fixing From Outside—The Radio Compass, Gee, and LORAN

While the navigator spent most of his time with his own navigational instruments dead reckoning the aircraft position, he also updated his position using electronic and visual means to establish position fixes. These fixes, when available, provided additional navigational information that not only updated the aircraft position, but served as a check on the navigator's work. At each fix, he compared his DR-calculated position with the fix position and, based on any errors, could update the wind assumptions he was using to navigate, increasing the accuracy of his future computations.

The frequently poor weather conditions in the ETO affected the type of fix that the navigator could establish. Studies showed that over the eight years prior to 1943, cloud cover over the European continent obscured typical targets frequently, providing, on average, fewer

than six days per month suitable for high-altitude visual bombing. During the months from November to February, that number dropped to two or three days per month.[104] Inability to see the ground meant that the navigators could not visually update their positions or verify their DR-calculated position. Weather similarly affected the ability to use celestial navigation techniques, often obscuring the sky above the bombers, as did the contrails produced by the massive formations as they trekked across the continent. Even on clear days, these contrails could put the majority of the formation in obscured conditions, preventing the navigator from "shooting" the sun. As such, navigators in the ETO did not use celestial navigation on bombing missions, but did use other systems that electronically extended their navigational senses.[105]

The B-17 had a radio compass installed that could receive broadcast electronic signals from dedicated radio navigation beacons or any broadcast radio station. When the receiver operator tuned to the appropriate frequency, the bearing pointer indicated the transmitter's direction relative to the aircraft. As long as the navigator knew the identity and location of transmitter, he could establish the aircraft position on a radial spoke emanating from it. The receiver displayed the bearing on a radio compass indicator inset into the navigator's table, as well as on duplicate indicators in the pilot's cockpit and at the radio operator's station.[106] A duplicate set of controls also existed in each location, giving the navigator, pilots, and radio operator the ability to tune the radio receiver.[107] The radio operator, however, usually maintained control of the radio, tuning to the frequency requested by the navigator or pilot.

While the radio compass indicated bearing, it could not indicate the range of the aircraft from the transmitter. Thus, the navigator could establish only that the aircraft was *somewhere* on the radial. To establish a more precise fix, he had to tune to at least two different transmitters and plot their bearing radials on a map. He could then establish the aircraft position at the intersection of those radials—sort of. Since the aircraft was continually moving, the plotted intersection was not an indicator of where the airplane actually was in space, rather a combination where it *had been* at the first reading and where it was at the final reading. The

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[104] John W. Stormont, *The Combined Bomber Offensive: April Through December 1943*, U.S. Air Force Historical Study 119 (Washington, DC: U.S. Army Air Forces Historical Office, March 1946), 150.

[105] Crosby, *A Wing and a Prayer*, 71; Baldwin, *Individual Training of Navigators in the AAF*, 92.

[106] Heavy bombers had dedicated radio operators on their crews, responsible for operating all of the bomber's radio equipment. The radio operator also served as a gunner, and manned a .50-caliber machine gun when not operating the radio equipment.

[107] *Pilot Training Manual for the B-17*; *Instrument Flying: Advanced With Radio Aids, T.O. No. 30-100B-1*, 29-30.

aircraft also continued traveling as he plotted the bearings, further decreasing the accuracy of his answer. Thus, the navigator had to be cautious about adjusting his DR solution based upon a radio fix. Much as a Kalmann filter operates today, he had to be ready to reject a position fix that was too far outside what he considered a reasonable amount of error in his DR solution.

Navigators used radio navigation as a navigational aid rather than a primary navigation technique, as on most combat missions in the ETO, the bombers were out of range of radio stations in England.[108] Navigators could take fixes from radio transmitters on the European continent, but their bearing information was always suspect. The enemy used deceptive, or "meaconing," techniques, to attempt to lead the bombers off course, where they surreptitiously transmitted seemingly genuine signals that actually produced false compass readings. These difficulties became greater the deeper the bombers penetrated into enemy territory, but navigators were trained to recognize the effects of both of these electronic attack techniques so that they could recognize their effects and know when not to trust them.[109]

While radio navigation was not dependable over the European continent, bomber navigators used it very frequently during the formation join up process over England, as well as during the return portion of the mission. The British set up a network of 15 medium frequency radio beacons called "Splashers," each with four transmitters, that defined specific bomber group rejoin points.[110] When the weather was poor, navigators would tune in to the correct transmitter for the day and direct the pilot to a predefined rejoin point. Each beacon rotated which of its four transmitters it used throughout the day, attempting to minimize the potential effect of jamming or meaconing. Navigators or radio operators received the transmission schedule during the morning briefing, enabling them to tune to the correct frequency when necessary. In 1943, the British expanded the radio navigation network with "Bunchers," installing 33 of the lower power, more difficult to detect and jam transmitters near U.S. bomber bases (Figure 4.19). By the end of the war, the radio-based rejoin procedures they were so effective that they were used for all formation rejoins, regardless of the weather.[111]

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[108] *Navigators' Information File*, 2-23-3.

[109] Ibid., 2-23-3 - 2-23-4.

[110] The formation rejoin process is discussed in Chapter 4.

[111] Freeman, *The Mighty Eighth War Manual*, 35.

Figure 4.19
Splasher and Buncher beacon locations used for formation assembly[112]

GEE

The British used another radio navigation system in the war called "Gee," which was an abbreviation for "grid." Initially developed as an aid for bombing in non-visual conditions (night or weather), the Gee system consisted of a chain of several master-slave radio station sets, with two or three slaves per master located about 150 kilometers apart. The master sets broadcast radar-like pulses that the slave sets rebroadcast after modulating the signal with predetermined, accurate delays. In aircraft equipped with Gee receivers, the navigator tuned in both sets of signals and the system measured the difference between them. Unlike normal radio transmitters

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[112] Ibid., 36.

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that indicated bearing only, the Gee system displayed range only, which it calculated from the delay between the signals. The navigator plotted the range-arc on a special map containing the Gee station locations, and by taking readings from two or more stations could determine his position with relative accuracy. The system, however, operated with a very short wavelength, and was limited to line-of-sight operation, thus, coverage did not extend very far over the European continent.[113]

Like all of the navigator's other sensing instruments, the Gee system required a good deal of training and practice to operate, and interpreting the display was an art in itself (Figure 4.20). Since it was a British system, navigators received their training only after they arrived in the combat theater, and many flew numerous bombing missions before they learned how to use it effectively. Until trained, Gee was merely "a clumsy gadget that occupied half of (the) navigator's table and offered only blips on a screen that had to be interpreted on a multicolored map criss-crossed with grids resembling isobars on a weather map."[114] One of Gee's major shortcomings was its short range, but a new system, developed by an American team, led by Alfred Loomis at the Massachusetts Institute of Technology's Radiation Laboratory, soon overcame that limitation.

[113] Louis Brown, *A Radar History of World War II: Technical and Military Imperatives* (Bristol: Institute of Physics Publishing, 1999), 288-289.
[114] Murphy, *Luck of the Draw*, 135-136.

(a) Main time base.
B and C pulses strobed.

(b) Strobe time base.
Pulses lined up for reading.

(c) Main time base.
Pulses removed.
Calibration pip display.
$B = 11$; $C = 33$.
(No interpolation.)

(d) Strobe time base.
Pulses removed.
Calibration pip display.
$B = 11 + 0.38 = 11.38$.
$C = 33 + 0.73 = 33.73$.
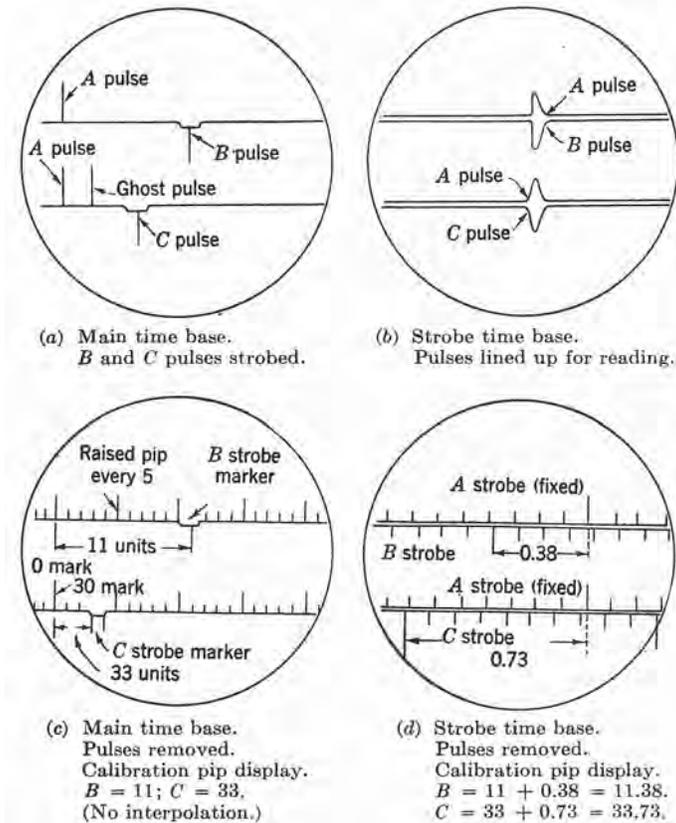
Figure 4.20
Gee display[115]

LORAN

LORAN, or long range navigation sets, worked in much the same way as the Gee system, with time encoded signals providing the receiver an arc line of position relative to a transmitter. Again, the navigator could fix his position by obtaining separate readings from two stations, but LORAN was useful over a longer range, as it operated at a much lower frequency than Gee. It had an effective range of about 700 nautical miles during the day and 1,400 nautical miles at night, and by the end of the war, LORAN navigation coverage extended over most of Europe.[116] Its performance was generally better than that expected from celestial navigation fixes, but accuracy depended upon numerous factors, including the aircraft's position relative to the transmitters as well as the navigator's ability to match and read the signals on the receiver-

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[115] J. H. Buck and J. A. Pierce, "Nonradar Navigational Methods," in *Radar Aids to Navigation*, ed. John S. Hall, M.I.T. Radiation Laboratory Series (New York: McGraw-Hill Book Company, Inc., 1947), 62.
[116] Ibid., 64.

indicator. A skilled navigator could expect location errors ranging from less than one-half mile to up to ten miles, depending upon the conditions.[117]

As with Gee, the LORAN system required a great deal of adjustment, calibration, and skill to use effectively. Before use, the navigator had to ensure that the system was functioning properly, which entailed a lengthy process of adjusting the receiver, tuners, and the display. Accurately interpreting the signals required an understanding of the system's technical limitations as well as the ability to identify the station to which the system was tuned, as many LORAN stations operated on the same frequency (Figure 4.21). The navigator carried a special handbook of operating instructions on every flight, containing this and other essential information for system operation.[118] With its greater range and geographic coverage, LORAN was a great technological advance in navigation, enhancing both the navigator's sensing and navigational abilities.

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[117] *Navigators' Information File*, 2-26-1 - 2-26-2; Brown, *A Radar History of World War II*, 430-431.
[118] *Navigators' Information File*, 2-26-1 - 2-26-2.

Master

Fixed pedestal

Slave

Moveable pedestal

(a) Slow sweep.
Both pulses on their pedestals.

(b) Medium sweep.
Pulses aligned vertically.

50 μ sec

This scale
is fixed

This scale
moves as new
settings are
made in c

25   25

(c) Fast sweep.
Amplitude equalized, trace separation
removed, pulses superimposed.

(d) Fast sweep.
Marker display.
Lower trace displaced 25 μsec from
upper trace.

This scale
is fixed

500 μ sec marker
tags

This scale
moves as new
settings are
made in c

50
μ sec

100+

2500
μ sec

Fixed
pedestal

8000+
μ sec

This pedestal
moves as new
readings are
made

(e) Medium trace
Lower trace displacement 100 μsec.
No interpolation.

(f) Slow sweep.
Pedestals displaced 8000 μsec (no inter-
polation).
Reading is $25 + 100 + 8000 = 8125$
μsec.

Figure 4.21
LORAN display[119]

The radio compass, Gee, and LORAN all electronically extended the navigator's senses
and provided some measure of ability to obtain position fixes to confirm his DR navigation
position. All of the systems used off board electromagnetic sources to help the navigator
calculate his position, providing an early glimpse of a distinct technological trend wherein such
systems, removed from the aircraft that used them, would provide increasingly more information
and capability to the crew. While the electronic systems were useful to trained navigators, all

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[119] Buck and Pierce, "Nonradar Navigational Methods," 65.

navigators could use a larger, responsive, non-electronic asset on the aircraft to extend his senses and help him navigate—the rest of the bomber crew.

The Navigator's Eyes

The bomber crew provided the navigator a large set of eyes, distributed throughout the aircraft in many locations that provided a much better view of the ground. Working effectively with the rest of the crew was an essential element of successful navigation, and the *Navigators' Information File* detailed the suggested relationship between the navigator and specific crewmembers.[120] The navigator interfaced most frequently with the pilots, as they were the ones who physically executed his directions. He constantly talked to whoever was flying, whether the aircraft commander or the copilot, coordinating headings and airspeeds, working to ensure that they executed his instructions quickly and accurately, because precise flying was essential for precise navigation. Maintenance of constant airspeeds, headings, and altitudes made accurate instrument reading and position calculation easier. The navigator also enlisted the help of the non-flying pilot, as he had a better view out the front of the aircraft and could help significantly with pilotage navigation by reporting prominent landmarks for visual fixes.

The navigator worked closely with the bombardier, who could supply or verify drift readings or, in a pinch, perform some of the navigation calculations on his own E6-B computer. He also had the best view of the ground through the aircraft's Plexiglas nose and could most easily identify ground references. During the bomb run, the navigator and bombardier worked as a team, identifying the landmarks and references that would lead them to the target. The radioman was a crucial link to the radio navigation systems, and properly instructed, could provide radio position reports on a regular basis. The gunners, occupying positions along the aircraft fuselage, in the aircraft tail, and underneath in the ball turret, provided the navigator a valuable extended visual network, and could provide valuable pilotage input if instructed correctly.

The aircraft instruments and navigation systems in the navigator's compartment provided the navigator the information necessary to establish his aircraft position through dead reckoning and execute his Flight Plan. On board information came from the aircraft performance instruments that provided raw data, including outside air temperature, barometric altitude, and

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[120] *Navigators' Information File*, 4-1-2.

indicated airspeed. He used his E6-B computer to convert this information into more accurate, true values that he could use to compute the solution to the constant time-speed-distance problem that he faced through the entire mission. The drift reading instruments, the B-5 Driftmeter and the Norden AB computer, provided valuable relative motion information, which, through another process of calculation, the navigator used to determine the magnitude and effect of the wind at altitude on the aircraft's flight path. All of these instruments required care, calibration, and skill to use correctly.

The radio navigation instruments provided off board information about the aircraft position, which the navigator used to confirm his dead reckoning calculations. The information provided, which got progressively more accurate as the war progressed, came from systems that were complex to operate and potentially susceptible to jamming or incorrect use. To use the information, the navigator had to understand how the systems worked, how to tune and calibrate them, and how to interpret the information that they supplied. The crew provided valuable information that augmented what the instruments supplied, in many cases establishing a visual link with the outside world not available from the navigator's compartment. All of the instruments in the navigator's compartment, paired with the crew's input and the navigator's ability to transform the information that they provided, gave the navigator the ability to perform his job for the upcoming mission, executing the Flight Plan to direct the bomber to the target and back again.

The navigator gathered many different types of data from many sources, sometimes converting it, but always combining it and in the process transformed it into navigational position data. The navigator's compartment was the second "centre of calculation," where the navigator performed his true function—that of integrator and transformer. His function and existence was tied to his ability to use and master his extended instrument senses, calculate, and transform what they told him into the information that enabled the rest of the crew to perform their jobs, and it was through those instruments and calculations that they saw him as a member of the crew.

Professional Identity

If the bomber crew saw the navigator through his tools and calculations, it also reflected his own perception of his role in the aircraft. Many viewed themselves as "high altitude

bookkeepers," performing what was essentially an academic function, somewhat detached from the rest of the crew.[121] This self-identity was strong, as expressed by navigator Frank Murphy.

> I wondered…whether the rest of the men on bomber crews considered the navigator to be an oddball. He was the only officer on the crew who had nothing whatsoever to do with operation and control of the airplane. He climbed aboard lugging a briefcase crammed with maps, Mercator charts, books, paper, pencils, drawing instruments, a hand-held calculator, and strange looking optical instruments. He was invariably hunched over his narrow shelf-like table in front of which was a repeater set of basic flight instruments and radio controls. He looked at his watch constantly, drew lines, and scribbled notes to himself on the papers, maps and charts in front of him, much like Scrooge's wretched drudge, Bob Cratchet, in Dickens' classic tale, *A Christmas Carol*.[122]

Also much like Dickens' put-upon drudge, the navigator toiled away with little control over the world outside his own compartment in the aircraft.

Although the navigator performed the vital task of getting the bomber to the target and back, he held no position of leadership in the crew. He was an officer like the pilots and bombardier, but he had no official responsibility beyond himself. The aircraft commander led the entire crew and the bombardier was responsible for the aerial gunners on the crew, but the navigator's role was singular. That singular role extended beyond the aircraft, similarly limiting the opportunity for leadership or command in the squadron. As expressed by B-17 navigator Bill Frankhouser:

> Navigators were not participants in decisions at Squadron Operations about crew assignments, etc. These leadership functions were the domain of the pilots, who usually relayed pertinent information to their crews.[123]

As explained in the previous chapter, in addition to flying, the pilots led. The just navigators performed a task—they navigated.[124]

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[121] Robert Clark Culp, "Robert Clark Culp," interview by Jim Culp, Video, August 24, 2008, Robert Culp Collection (AFC/2001/001/63223), Veterans History Project, American Folklife Center, Library of Congress, http://lcweb2.loc.gov/diglib/vhp/bib/loc.natlib.afc2001001.63223 (accessed 28 November 2010).

[122] Murphy, *Luck of the Draw*, 76-77.

[123] Bill Frankhouser, *World War II Odyssey: Pennsylvania Dutch Farm Boy Becomes 8th Air Force Navigator* (Bedford, VA: Hamilton's, 1997), 127.

[124] The lack of leadership opportunities in the Air Corps and its successors for non-pilots is discussed in the next chapter.

Beyond navigation, there was little to identify navigators. Following the war, one navigator, recognizing that he was just a "task," implored his squadron commander to help him get to pilot training, pleading

> Boss, I was a navigator in World War II and came out a nobody. This is my one chance to be someone and to get ahead as a pilot in this Air Force I love.[125]

The self-perception as a "nobody" was rooted in more than a lack of leadership opportunity, though. The task of navigation itself, with its data gathering, conversion, processing, and forms was constructed to be as mechanized as possible. Likewise, the human performing that task was constructed to be as mechanized as possible.

Mechanizing the Man—The Mission and the Act of Navigating

> *During the flight the navigator shall:*
> *At all times use every means available of determining position*
> *Check his compass on every heading*
> *Give position reports on request*
> *Keep a complete log of events*
> *Initiate requests for navigational aids from crew members*
> > *Navigators' Information File, p. 4-12-1*

With the mission planned and his instruments checked, the navigator was ready to perform his job—he would spend the rest of the day "living" the Flight Plan, mechanically observing, calculating, and recording his position from the start of the mission to the finish. His primary job inflight was to know where he was at all times and keep a constant record of that position. In the ETO, that meant DR navigation, maintaining an air plot, and keeping a constant, accurate record on the bottom portion of his AAF Form 21, the Flight Record. He began dead reckoning on the ground immediately, recording the times of engine start, aircraft taxi, and takeoff. Once in the air, he settled into a steady routine of observation, position calculation, and recording that, if uninterrupted by enemy action such as fighter attack that required him to operate his machine gun, he would maintain until they landed back home at the end of the mission. However, although all of the navigators were responsible for the position of their own

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[125] Major General John C. Giraudo, "Interview with Major General John C. Giraudo," interview by Lt. Col. Charles M. Heltsley, Oral History Transcript, January 8, 1985, 97, K239.0512-785 C.1, IRIS No. 1105191, US Air Force Historical Research Agency.

aircraft-bounded element in the bombardment system, they were not all created equal. Their position in the larger system itself, dictated by the formation tactics used in the HADPB doctrine, just as with the pilot, directly influenced their actions and how they navigated during the mission.

Leading, Following, and the Impact of Doctrine

The decision to adopt the drop-on-leader Combat Box formation tactics shaped how much and to what extent the navigators on a mission actually navigated. Although all were qualified in DR, the creation of a lead crew for each wing, group, and squadron dictated largely their actions during the mission. Those designated as lead navigators flew at the front of the formation and were responsible for ensuring that all of the aircraft within it successfully reached their destination.[126] They were the only ones who performed all of the duties involved in precision DR navigation, keeping track of their position, calculating the correct heading to the next checkpoint, and, most importantly, directing the pilot which heading to fly.

Leads were designated at each level of the formation—wing, group, and squadron. At the lower levels, the lead navigators performed their duties until they took their position in the larger formation, and then assumed the subordinate role described below. Since they had the lead responsibility, these navigators were the "brain" of their element of the formation and spent the hour prior to the General Briefing learning more about the day's mission, getting as familiar as possible with the plan.

The Wing lead navigator had the greatest responsibility, as he had the lead for an entire Combat Box of up to fifty-four aircraft. If the Command Pilot and overall mission commander was in his aircraft, he could be leading multiple Combat Boxes and hundreds of bombers to the target.[127] Since the success of the entire bomber force rested upon his ability to guide them to the target, the lead position carried great prestige. Selection as a lead navigator was overt acknowledgement of professional skill and ability, and often accompanied by promotion in rank. It was not, however, a universally sought distinction. The responsibility of leading was great and there was an increased level of personal danger, as defending German fighters, understanding the importance of the lead bomber to the mission, often specifically targeted it. The responsibility

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[126] *Navigators' Information File*, 4-12-1.

[127] The command pilot and his role is discussed in Chapter 4.

and danger caused some crews to refuse the opportunity to lead when offered, preferring to take their chances deeper in the formation. Others, however, viewed it as a challenge and path to professional distinction among their peers.[128]

Each wing, group, and squadron had a deputy lead navigator in the formation, as well. The deputies backed up the leads, ready to take the leadership of the formation if the lead navigator's aircraft aborted the mission or was shot down. The deputies all navigated, but spent most of the mission following the lead navigator, and they, as well as the rest of the navigators in the formation, performed a specific type of DR navigation called "follow-the-pilot."

Follow-the-pilot

Follow-the-pilot was precision dead reckoning without controlling the heading of the airplane—the navigator had to follow precisely the pilot's actions without having control over them, constantly monitoring the aircraft heading, altitude, and airspeed, recording it so that he could calculate drift and groundspeed.[129] Since the pilot was continually maneuvering to maintain his position in the formation, these values fluctuated constantly, making the navigator's job of precision navigating more difficult, as he had to estimate the average heading, altitude, and airspeed between his position calculations, and his resultant dead reckoning position calculations were thus susceptible to many sources of error. Most concerned with these errors were the deputy lead navigators, as they had to be as accurate as possible should they have to assume the lead role.

An accurate estimate of position was critical for each aircraft, though, if they became separated from the formation and had to proceed back to their home base alone. As such, a smooth, precise pilot was the navigator's best friend. The more precisely the pilot flew, the more precisely the navigator could navigate. Follow-the-pilot was the primary form of navigation used by the non-lead navigators for most of the mission, but immediately after takeoff and before accomplishing the rejoin, all of them had to DR on their own.

In one sense, the lead navigator was the only one truly navigating, as only he provided direction to the pilot. However, because of follow-the-pilot DR, all of the navigators knew

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[128] Frankhouser, *World War II Odyssey*, 106-107; Thomas Childers, *Wings of Morning: The Story of the Last American Bomber Shot down Over Germany in World War II* (Reading, MA: Addison-Wesley, 1995), 148-149; Crosby, *A Wing and a Prayer*, 4, 56.

[129] *Navigators' Information File*, 2-0-1.

where they were to some degree. Interestingly, although they constituted a single bombardment system and all performed the same calculations during the flight, using external sources such as radio, Gee, or LORAN as available, and communicating with their own crewmembers to get visual information, they did not communicate with each other. The USAAF imposed a strict policy of radio silence during bombing missions to minimize the amount of warning provided the enemy about an impending attack. Generally, only the command pilot talked to other aircraft in the bomber formation over the command frequency, and navigators were unable to communicate with each other to either confirm their own navigation solution or question that of someone else.

On occasion, this policy of radio silence led to severe mistakes. Several times, lead navigators who had miscalculated their position led their formations off the flight-planned route directly into heavily concentrated German defenses, causing severe bomber losses.[130] On other occasions, lost lead navigators caused entire formations to drop their bombs on the wrong target. Lieutenant Nunzio Addabbo, a navigator in the 601st Bomb Squadron related such an incident.

> The most spectacular raid that we had, that I remember best, was the raid on February 14th, 1945. We were scheduled to bomb Dresden. Well, when we approached what we, everybody, thought was Dresden, I knew that we were flying to the wrong target and I told our pilot, Sam, "You know, we are not headed to Dresden; we are running the wrong heading. We seem to be heading toward Prague." And, as we got closer and closer to the target, apparently because of the radio silence, that message never got to the lead plane. Consequently, instead of bombing Dresden, we bombed Prague, in error. I had it all in my log and, in fact, when we got back to the base, I reported it as being the wrong target….The news that we had bombed the wrong target never came out until the next day and only a few were made known of the fact. I consider that a colossal cover-up.[131]

Bomber navigators used radio technology to gather data so that they could calculate and estimate their position, and yet were unable to use that same technology to exchange processed information between the human calculation units themselves. In another episode, navigator John Howland and his pilot were "chewed out" by their group commander following a mission when they broke radio silence and requested that the

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[130] Bert Stiles, *Serenade to the Big Bird* (New York: W.W. Norton, 1952), 19.

[131] Nunzio Addabbo, "Lt. Nunzio Addabbo, 398th Bomb Group Navigator, 601st Squadron, Eighth Air Force," interview by Marilyn Gibb-Rice, Video/transcript, December 1, 2007, http://www.398th.org/History/Veterans/Voices/Interviews/Interview_Addabbo_Nunzio.html (accessed 23 November 2010).

lead bomber return to the flight plan after having steered off course, which had resulted in the shooting down of another aircraft.[132] While the bomber formation was a single system containing many individual integrating elements, it was not given the capability to perform that same integration at the system level.

Flying the Mission

Upon takeoff, every navigator began a rigorous routine, using his navigational instruments, E6-B, maps, and charts in a fashion that would vary little for the next ten or so hours until they landed back at their home base. The lead navigator's initial concern was guiding the lead pilot to the correct formation rejoin point, defined by either a Splasher or a Buncher beacon, and arriving there on time so that the rest of the formation could rejoin with their aircraft. All of the other navigators did the same thing, striving to guide their pilot to the same point. They took radio fixes, drew the bearings on a map spread out on the work table, and plotted their aircraft position, obtaining those fixes at regular intervals from his own radio compass or, more likely, from the radio operator. Each navigator had his own technique as to how often he wanted these reports, but generally desired them more frequently when the aircraft was in the weather and the crew could not see the ground.[133]

During the trip to the rejoin point, the navigator began evaluating the aircraft's external environment, measuring the actual winds that they were experiencing in flight and comparing them to the forecast winds that he had used to create his flight plan. Regulation directed that they try to obtain accurate wind data during this initial phase of the mission so that they could both determine the accuracy of their mission planning products as well as evaluate any impact on the planned flight route.[134] They measured the wind while the pilot flew a constant heading and airspeed, measuring the drift across the ground and using the E6-B to solve the vector problem. Obviously, he could do this only when the weather did not obscure the ground. They recorded the observed winds and updated their headings appropriately.

Upon reaching the rejoin point, the lead aircraft established an oval-shaped orbit defined by the radio fix, maintaining a constant airspeed and altitude so that the rest of the planes in the

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[132] John Howland, "The 324th Pathfinder Force in the 91st Bomb Group: How it Came to Be", 2006, http://www.91stbombgroup.com/91st_tales/Pathfinder.html (accessed 17 February 2011).

[133] Crosby, *A Wing and a Prayer*, 9.

[134] "2d Bombardment Wing Instructions No. 55-16: Operations-Navigation."

formation could rejoin in preparation for the next phase of the mission. The entire rejoin process could take several hours, and the lead navigator continued to calculate the aircraft position and record it in his Flight Log. Upon rejoining, the rest of the navigators in the formation began their "follow the pilot" navigation, anticipating the time when the entire formation would depart on the trip to the target.

Timing was a critical part of the navigator's job. The Flight Plan modeled the mission in both space and time, and it was not enough to just be at the right place. Bombing missions were large, highly scripted events, with sometimes thousands of aircraft participating. In addition to hundreds of bombers, hundreds of fighter escort aircraft might participate, and they all coordinated their actions in space and time. A missed rendezvous with escort fighters meant that the bomber formation would have to proceed to the target without offensive air support, which could lead to greatly increased losses to the enemy air defenses. The navigator continually referred to his watch, tracking their progress through time and updating the pilot on the next event.

The Flight Plan included the ETAs for all of the navigation points and major events on the mission. Precision was critical, and the navigator used a combination of increasing or decreasing indicated airspeed to influence the arrival time, as well as basic geometry, cutting corners to gain time or overshooting a turn point or even directing additional complete 360º turns to lose time. Adjusting timing was an art and a science, with no hard and fast rules. Getting it right required the acquisition of a special type of judgment, or air sense, through practice and experience. Every navigator practiced timing during the formation rejoin, and the lead navigator continued to do so for the entire mission.

At the scheduled mission push time, the giant stream of bombers set out from England toward their target in Europe, many individual elements comprising a single bombardment system. From this point in the mission, the navigator settled into a rigorous routine dictated by his position in the formation. The lead navigator navigated to the IP using precision DR, spending all of his time reading the aircraft performance instruments, taking what radio, Gee, LORAN, or pilotage fixes he could acquire, and constantly calculating drift and groundspeed. He updated his position regularly and computed new headings that he then passed to the lead pilot for him to fly. He had control of the direction of the formation, and as long as the pilot flew the headings, altitudes, and airspeeds that the navigator desired, he could be reasonably certain of

his position. The rest of the navigators performed their "follow the pilot" navigation, with the added burden of having to estimate their progress based on the pilot's actions, but focused on maintaining track of their position nonetheless.

As the mission progressed, the navigator continued reading his instruments and performing his calculations, his view of the world changing only through what his navigational senses presented to him. He had little regard for the environment outside the aircraft. As the formation climbed above twenty thousand feet for the trip to Europe, however, the environment inside the aircraft changed drastically. Temperatures in the poorly-heated nose of the bomber could plunge well below zero degrees Fahrenheit, making any task difficult, never mind one that required the dexterous use of one's fingers and hands to manipulate small knobs, dials, and calculators, or the use of a pencil and plotter to draw precise lines on a map.

Every crewmember wore heavy, sheepskin-lined flight clothing and heavy gloves as protection from the cold. However, the gloves were bulky and the protection that they provided came at the cost of preventing any fine motor work. Navigators found themselves continually exposed to the danger of frostbite, as they continually removed the gloves so that they could operate their equipment. Some chose to wear less protective silk gloves or nothing at all when they worked, but risked severe cold injury.[135] The cold could be a real distraction, as could attacking enemy fighters, preventing the navigator from effectively performing the task of collecting and integrating the data the enabled precise navigation.

Integration was the key to precision navigation. The navigator had to gather, calculate, and process a great deal of data to navigate precisely. In the air, as on the ground during mission planning, he used another key translation technology to master that process. Just as the Flight Plan dictated the mission planning process, the Flight Log dictated the navigation process.

The Tyranny of Routine—The Flight Log, the Air Plot, and the Mechanization of the Man

The Flight Log was the center of the navigator's activity in flight. Consisting of the lower portion of the AAF Form 21, it contained many of the same data columns that made up the Flight Plan, including heading, speed, drift, fuel, and position data. Every five to fifteen minutes, he recorded compass headings, altitude, temperature, weather, unusual occurrences, or any other

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[135] Donald R. Jenkins, "Donald R. Jenkins, Rutgers College Class of 1944," interview by Shaun Illingworth, Transcript, July 23, 2006, Rutgers Oral History Archives of World War II, http://oralhistory.rutgers.edu/Interviews/jenkins_donald.html (accessed 21 December 2010).

factors affecting the flight, and then calculated his navigational position. On long missions, this constituted a tremendous amount of data, but the Flight Record was large enough that he could record an entry every ten minutes for an eleven-hour flight (Figure 4.22).[136]

Figure 4.22
AAF Form 21 Flight Plan and Log[137]

The Flight Log dictated the navigator's actions in flight. Just as the completed Flight Plan provided a list of executable instructions for the pilot, the columns in the Flight Record provided a list of executable instructions for the navigator. Whether he was in the lead or on the wing, the very process of filling it out required that he perform all of the actions necessary to DR navigate, constantly calculating his position and ETA for the next point on the mission. The

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[136] Leroy W. Newby, *Target Ploesti: View from a Bombsight* (Novato, CA: Presidio, 1983), 23-24; *Navigators' Information File*, 4-7-1.
[137] *Navigators' Information File*, 4-7-2.

process was all-consuming, and the *Navigators' Information File* encouraged navigators to "remain cool and work almost mechanically in recording all that takes place."[138] Indeed, it took so much attention and maintenance that one B-17 navigator to stated

> I could be even more efficient in the clouds because I wasn't distracted by having to do pilotage, checking the ground. I just kept the books.[139]

In "keeping the books," the navigator created a numerical and textual representation of the aircraft position and fuel state in the same format used to create the "ideal" position and fuel state on the Flight Plan. By translating the aircraft's physical position and state into numbers and text, could compare where he *was*, or thought he was, to where he had *planned* to be, and make any necessary corrections. Filling out the Flight Log was the essence of navigation on a bombing mission, for it anchored his physical location to the red woolen line that defined where he had to be.

While the Flight Log provided a direct method of continually comparing the aircraft's actual position with the desired position, it also served as the official record of the flight. Navigators were taught to keep them meticulously because they were admissible in a military court as evidence concerning the conduct of the flight.[140] In at least one instance, diligent adherence to the discipline of record keeping saved one navigator from severe punitive action. While substituting for a bomber crew's regular navigator, Lieutenant Benjamin Jeremiah ran into trouble on a mission. The pilots and the rest of the crew, obviously not wanting to proceed to the target, ignored his navigational directions. Jeremiah recorded every exchange, position, and action as the crew fabricated an aircraft malfunction so that they could avoid flying the mission. Upon landing, Jeremiah turned in his Flight Record to the squadron operations officer, reporting what had occurred. The crew was disciplined and removed from the combat theater, but Jeremiah was exonerated.[141]

The above incident is interesting because it illustrates some of the how social order and control could be enforced on a bomber crew. As described in Chapter 2, the aircraft commander was the "moral controller" for the bomber crew. He was to be conscious of any attempt by the

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[138] Ibid., 4-13-2.

[139] Crosby, *A Wing and a Prayer*, 11.

[140] *Air Navigation*, 41.

[141] Jeremiah, "Benjamin Thomas Jeremiah."

crew to avoid the hazards of the bombing mission and instill the "offensive spirit" in them so that they would perform their jobs. In reality, the entire crew shared this burden because the navigator kept record of all events, normal or abnormal. Any deviation from the plan required that *all* of the crewmembers be complicit, willing not only to fabricate a malfunction that would keep them out of the mission, but cause one of their own to falsify an official record. In the above case, the navigator was not "one of their own," but a substitute and not under the same moral pressure perhaps as a navigator who had trained from the beginning with the crew and formed a tighter social bond. Would the situation have been different with the crew's regular navigator? The navigator, through his normal duties as part of his assigned task, exerted a great deal of informal moral control and authority over the bomber crew element of the bombardment system.

The Flight Record was not the only record that the navigator kept in flight. He also continually updated his air plot on his Mercator mission map. The map's primary function was to enable the navigator to track the aircraft position in relation to the mission in its idealized space. As he calculated his position or obtained fixes from radio or pilotage updates, he converted them into a position on the map, continually translating the aircraft position from the physical to the idealized world in which he largely existed. As with the Flight Record, the air plot served as another method of measuring how well the aircraft was conforming to the plan created earlier that morning.

This process of maintaining this position in both the temporal space of the Flight Log and the idealized space of the mission map drew the navigator into what was almost a different world. Certainly, he physically existed in the aircraft with the rest of the crew, but also in the idealized world of points, courses, fuel quantity, and straight latitude lines. For some, the transportation was so complete that they began to lose track of their physical location. As one navigator related, he could tell

> exactly where the airplane was located with great precision at the time of takeoff, and again at the time of landing, although (he) might need to ask somebody, on some embarrassing occasion, to confirm the name of (the) arrival airport.[142]

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[142] John Matt, *Crewdog: A Saga of a Young American* (Hamilton, VA: Waterford Books, 1992), 70-71.

The actual physical position of the aircraft became irrelevant. Position was important only in the context of the specific reference frame that he had built for himself in the Flight Plan and on the mission map.

The process of effecting that translation, the position recording in the Flight Record and on the air plot was all consuming—so much so that for some, it even blocked out the stress of aerial combat. In an April 2007 interview, navigator George Skidmore replied upon being asked whether he experienced any physical feeling on his first combat mission replied:

Skidmore:	You're too busy to have any feeling.
Interviewer:	Did you feel, say, nauseous?
Skidmore:	No. You're busy trying to do calculations, busy trying to fill in a log, to keep track of what was going on, and you didn't have any special feelings about anything. You were just too busy trying to get things done.[143]

This was a significantly different experience than that of the other crewmembers, some of who went so far as to insist that the navigator, preoccupied with his job, did not really experience combat at all. Navigator Donald Jenkins recalled post-war conversations with his bombardier about their missions together.

We'd get [to] talking about some mission, this or that, and he finally figured, "No, you didn't really know what combat was like," he'd tell me. "You didn't see this or that or the other thing," [laughter] but that was true, though. The navigator kept pretty busy, but you could hear it on the interphone, people talking about, you know, that somebody got hit or something like that.... No, that's sort of the way it went.[144]

These comments are extremely interesting in the context of the original purpose of this study— the question of whether the physical removal of the operator from the RPA fundamentally changes the tasks accomplished on an air combat mission. In Peter Singer's sterilized machine-centric air combat system, the RPA pilot no longer rates as a combatant because he is removed from the aircraft, and yet, the navigator on the B-17, inarguably a physically present participant

[143] George Bernard Skidmore, "George Bernard Skidmore, WWII Veteran, 15th Air Force, 449th Bomb Group, 718th Bomb Squadron," interview by Shaun Illingsworth and Elaine Blatt, Transcript, April 27, 2007, Rutgers Oral History Archives of World War II, http://oralhistory.rutgers.edu/Interviews/skidmore_george.html.

[144] Jenkins, "Donald R. Jenkins, Rutgers College Class of 1944."

in the thick of one of the bloodiest campaigns of World War II, is perceived to not have experienced combat. What, then, can we really say about the role of physical location in combat?

The navigator navigated—all of the time. At the IP, he shifted to visual navigation, working with the bombardier to locate the target, but as soon as the bombardier dropped them, he resumed his DR tasks.[145] He was trained to use the machine gun hanging above his desk, but his role as the directional brain of the aircraft element often took precedence over using it. He was the one who could get the bomber and its crew back home. He had to be the mechanical direction machine.

Figure 4.23
The Difficulties of Aerial Navigation[146]

In flight, the navigator's every action was oriented toward executing the plan that he had assembled earlier in the day. The tools that he used were designed to extend his senses so that he could gather, calculate, and translate data that allowed him to shift back and forth between the physical reality of the bomber's environment and the idealized environment of the Flight Plan. It was the navigator's compartment, with its concentration of instruments and tools that served as a second Latourian "centre of calculation," where he drew in disparate data, organized it, and effected this translation. It enabled him to serve as the integrator, calculator, and translator for

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[145] The navigator and bombardier's actions are described in Chapter 5.
[146] *Departure Point: Class of 44-4.*

his element of the bombing system, whether at the individual aircraft or formation level. Performing that translation was an all-consuming process, driven by the "technology" of the Flight Record. It guided the navigator's actions, automating them so that he produced a navigation solution that indicated both the aircraft position in the real world as well as the relative position in the missionized ideal world.

Conclusion

Shared Cognition—The Navigator, Technology, and Doctrine

Aerial navigation grew out of maritime navigation, but the contextual differences in application, the aircraft speed, fuel limitations, and ability to land at only select locations made the adaptation of existing navigational instruments insufficient for the task. Aerial navigators developed specialized instruments to accommodate the unique environment of flight, and in the process, they themselves developed as specialists, expert in the care, calibration, use, and mathematical operations necessary for their operation.

Aerial navigation evolved as a complex process of knowledge and capability sharing between these specialized tools and their operators. The navigation instruments in the aircraft could sense things that the navigator could not, while the Mercator map and the E6-B computer enabled him to easily perform complex calculations and translations and build conceptual models so that he could navigate in the context of the bombing mission. The most important technologies within the bombing mission context, however, were the Flight Plan and the Flight Record, as they enabled the navigator to take disparate sets of data, reorganize them, and turn them into a new, more useful data set that enabled the bombardment system as a whole to get to the target.

The technologies and the navigator came together in a single socio-technical element in the larger bombing system. Each of the technologies brought a particular capability, whether sensing, calculation, or translation. The navigator also brought a set of capabilities, including the ability to interpret the instruments' data, integrate that data, and translate it so that it became useful in the context of navigating on a bombing mission. Each, alone, was insufficient to perform aerial navigation, but together, their shared knowledge and capabilities could determine an aircraft position, locate it in both the idealized navigational world and the physical world, and determine how to manipulate the physical variables of flight—heading and airspeed—to reach a

desired destination. Navigation within the socio-technical element was a process of shared cognition between the human and technological elements that took place in the mission planning room and the navigator's compartment in the bomber—"centres of calculation," where all of the data could come together and be transformed into something different.

Aerial navigation is an iterative process, and precision demands rapid iteration. The bomber navigator used no mechanical automated machines to integrate the data that enabled navigation, but the Flight Plan and the Flight Record served to mechanize the navigator/technology socio-technical element by mechanizing the *human* actions in the navigation process. The demands of the necessary observation, calculation, and filling out of the forms on the ground and in the air dictated action to the extent that it limited both the ability to accomplish other tasks and the influence of the external environment on the navigator himself. The forms themselves created a mechanized system for navigation.

The HADPB doctrine also distinctly shaped the bomber navigator and his actions. He largely owed his existence as a member of the bomber crew to the long-range nature of bombing missions, and his location in the overall bomber formation dictated what actions were necessary during the mission. Lead navigators accomplished all navigational tasks, determining where his aircraft was and where it would go. Deputy lead and wing navigators had to determine where they were without the luxury of controlling where they were going, but their actions within their "centre of calculation" were essentially similar to that of the lead navigator. They collected data, processed it, and plotted it. As we shall see in the following chapters, the navigator's actions were the least affected by the bombing doctrine that actually contributed to his existence as a member of the bomber crew.

The bomber navigator was part of a single-task socio-technical element in the bombardment system, defined by his job and the tools that he used to accomplish it. Unlike the pilot, he did not exist beyond the limited skill set that enabled him to use those tools. Although largely created and valued because of the HADPB doctrine, he was the least affected of all of the crewmembers when the USAAF adopted the drop-on-leader doctrine because his task remained fundamentally unchanged. That, however, was not the case for the final crewmember under examination and subject of the next chapter—the bombardier.

Chapter 5

Interpretation, Definition, and Redefinition—Bombing and the Bombardier as the Man in the Machine

Bremen. Friday, 8 October 1943. 2ⁿᵈ Lt. James Douglass, the bombardier on Just-A-Snappin', *stood behind pilots Everett Blakely and John Kidd as they took off ahead of the entire 3ʳᵈ Combat Wing. Douglass was the lead bombardier for the 3ʳᵈ Wing that day, but waited to take his position in the Plexiglas nose of the aircraft until they were safely airborne. Sitting in the nose of the bomber was the worst place to be in the event of a crash on takeoff.*

Otherwise idle after takeoff, Douglass sat in his seat and watched as the Wing formed its Combat Box. As they departed the assembly point, he settled in behind the .30-caliber machine suspended next to him in the nose compartment, defending their right front quarter from attack by German fighters. Making landfall near the island of Borkonny, he saw several of these fighters ferociously attacking the formation, but had no opportunity to retaliate as the P-47s accompanying the bomber formation kept them safe from attack.

Approaching the Initial Point, he shifted his attention away from the air battle and began preparing the aircraft for the bomb run. The flak intensified as they continued toward Bremen, destroying several bombers, but he focused on the ground below, cross-checking his maps and target photographs for the ground references that would lead them to the target. As the lead bombardier, he _had_ to find the target. Every other bombardier in the 3ʳᵈ Wing was going to drop their bombs on his signal. If he hit the target, so would they. If he missed...

Douglass set up his Norden bombsight, entering the data necessary for precision bombing. Dense clouds of black smoke marked the route to the target as he hunched over the sight, pressed his right eye against the rubber cushion, and began working his magic with the Army Air Forces' finest precision bombing instrument. Taking control of the aircraft from Blakely, he rapidly adjusted the Norden's many knobs and gradually set the crosshairs on the target, using the bombsight and autopilot to fly the bomber to the bomb release point.

Thirty seconds before the release point, a burst of flak penetrated the window to the right of Douglass' head, tearing through his clothing and injuring his hand. In spite of this, he continued to fine-tune his bombing solution, manipulating the Norden to bring the aircraft to the perfect position in space so that he could drop his bombs. As the bombsight automatically released the bombs, he called "Bombs away!" and returned control of the aircraft to Blakely, but was immediately tossed about the nose compartment, as another burst of flak knocked the bomber into a steep dive. Later photographic evidence showed that his bombs —and the formation's—were both accurate and destructive.

During the lonely journey back to England, Douglass manned his machine gun and fought off the attacking enemy fighters with the rest of the aircraft's gunners. As a group, they later claimed twelve enemy kills, but received credit for only seven, one of which was credited to Douglass. Suffering more damage from coastal flak batteries as they crossed over the English Channel, they limped back to England and crash landed at an abandoned airstrip, hitting a tree and crushing the nose and one wing in the process. In spite of the damage, the mission was highly successful, as the target in Bremen suffered severe damage. Douglass and his bombsight had done their job for the formation.[1]

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[1] Adapted from Edward Jablonski, *Flying Fortresses: The Illustrated Biography of the B-17s and the Men Who Flew Them* (Garden City, NY: Doubleday & Company, Inc., 1965), 184-195; Frank D. Murphy, *Luck of the*

Introduction

This chapter examines the bombing socio-technical element in the bombardment system. It describes bombing as a singular, socio-technical task, accomplished by a human-machine system consisting of a bombsight designed to make up for human shortcomings in real-time integration, calculation, and precision flying, and the bombardier, a specially trained human, defined professionally by his ability to operate that bombsight, whose primary function was to act as an environmental and contextual sensor and interpreter for the bombsight, providing it the data it required to do its job. It examines how the mastery of the bombsight defined the bombardier and created him as a professional being, and how the subsequent evolution of the doctrine of high-altitude, daylight precision bombing (HADPB) dismantled that identity. First, it describes how bombsights developed to make up for the human inability to solve the bomb dropping problem in real-time. Second, it presents the Norden bombsight as the solution to that problem, describing how it developed as a complex mechanical computer that automated as much of the bombing process as possible, how it solved the bomb release point problem by creating an real-time, dynamic analog of the aircraft-target physical relationship, and how its integration with the aircraft autopilot enabled the bombardier to realize that solution. Third, it describes the engineering of the bombardier as a single-task, technical specialist whose professional identity was completely defined by his mastery of the bombsight, how his ability to find, identify, and track the target made him an interdependent part of the socio-technical bombing element, and how his actions were mechanized to enable that element to function during the most high-stress portion of the bombing mission. Fourth, it describes the bombardier's role as an essential cognitive element in the system and how he built visual and mental models that enabled him to interpret the physical environment and provide the bombsight the necessary data to solve the bombing problem. Finally, it examines how the HADPB doctrine and drop-on-leader formation bombing largely dismantled the bombardier as a professional entity by requiring that his unique professional skill exist only in one small part of the overall bombardment system.

Draw: Reflections on the Air War in Europe (Trumbull, CT: FNP Military Division, 2001), 141-142; Harry Crosby, *A Wing and a Prayer: The "Bloody 100th" Bomb Group of the U.S. Eighth Air Force in Action Over Europe in World War II* (New York: Harper Collins Publishers, 1993), 127-135; "Black Week - Bremen", n.d., http://www.100thbg.com/mainpages/history/history4/bw_bremen.htm, accessed 26 December 2010; *Combat Chronology, 1941-1945* (Washington, DC: Center for Air Force History, 1991), 199; Ian L. Hawkins, *B-17s over Berlin: Personal Stories from the 95th Bomb Group (H)* (Brassey's Inc, 1995), 170-171.

The Bombardier and the Point of the Mission

Of all of the officers on a B-17 crew, the bombardier's job was probably the most unambiguous and clearly defined—the accurate and effective bombing of the target. The *B-17 Pilot Training Manual* defined it as

> the ultimate purpose of (the) entire airplane and crew. Every other function is preparatory to hitting and destroying the target….The success or failure of the mission depends upon what he accomplishes in that short interval of the bombing run.[2]

The giant formations of bombers faced weather, anti-aircraft defenses, and defensive fighters for one purpose—to put their bombs on the target for the day. In the words of one of the first bombardier's to drop bombs on Germany, "a pilot could do a great job of flying the plane for six or even eight hours, and the navigator could plot the course just right. But, the whole thing really boiled down to the bombardier, by taking control as he neared the target and by synchronizing the bombsight to hit the target."[3] The bombardier's job was precision bombing. Upon his shoulders rested the success or failure of the entire mission.

The First Glimpse of Precision

On 9 October 1911, Thomas DeWitt Milling, one of the U.S. Army's first qualified pilots, took off on a test flight from the flying training airfield at College Park, Maryland, accompanied by passenger Riley Scott, a former lieutenant in the Army's Coastal Artillery. Scott carried with him a stopwatch, a barometric altimeter, a table of ballistics figures, and a device that he called a "bomb dropper." The bomb dropper, which Scott invented, was

> an apparatus whereby the operator may place himself in a position directly above the object to be attacked, or if the craft be in motion, to enable the operator to drop or shoot the projectile at a given time before he reaches a vertical position over the target. And in either case to enable the operator…to strike the object aimed at with more certainty and greater accuracy than has heretofore been possible.[4]

[2] *B-17: Pilot Training Manual for the Flying Fortress, AAF Manual No. 50-13* (Headquarters AAF, Office of Flying Safety, 1945), 18.

[3] J. W. Smallwood, *Tomlin's Crew: A Bombardier's Story* (Manhattan, KA: Sunflower University Press, 1992), 20.

[4] Riley Estel Scott, "Means For Dropping Projectiles From Aerial Crafts, U.S. Patent 991,378" (Peekskill, NY, May 4, 1910), 1.

It consisted of a pivoting telescope, used to calculate the aircraft ground speed and act as an aiming device, and a sling underneath the aircraft that held two 18-pound bombs (figures 5.1 and 5.2). As Scott lay prone on the lower wing of the Wright biplane operating the bomb dropper and dropping the bombs, Milling made several passes over a 4-foot-by-5-foot target at an altitude of 400 feet and a speed of 40 miles per hour, landing and reloading in between. On the first pass, Scott's two bombs missed the target by 62 feet. On the second, he cut his error nearly in half, missing by just 32 feet. On Scott's third and final pass, he placed his bombs within 10 feet of the target.[5]

Figure 5.1
A single bomb suspended from Riley Scott's "bomb dropper"[6]

Scott's results were remarkable, and caused a great stir among the Army aviators at College Park. He and his "bomb dropper" had produced far more accurate results than their very limited experiments with bomb dropping to that point. Following the flight, the *Washington Post* recorded Milling's almost unbridled optimism about the new system's performance and its potential benefit for military aviation.

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[5] Richard Hallion, *Taking Flight: Inventing the Aerial Age from Antiquity Through the First World War* (New York: Oxford University Press, 2003), 300-301; Henry H. Arnold, *Global Mission* (New York: Harper, 1949), 34; Stephen L. McFarland, *America's Pursuit of Precision Bombing, 1910-1945* (Washington, DC: Smithsonian Institution Press, 1995), 9. Most sources set the date of Scott's flight as 10 October 1910. However, Richard Hallion records the date as 9 October, based upon the fact that the Washington Post reported the mission results on 10 October. See Hallion, Taking Flight, note 22 p. 482.

[6] *Lieut. Scott's Aero Bomb*, Photograph, 1911, Library of Congress Prints and Photographs Division Washington, DC, http://www.loc.gov/pictures/item/ggb2005012025/ (accessed 14 October 2010).

With the device that Lieut. Scott has invented I am sure that it will not be long before the army will be able to completely destroy any large fortress or fort in the world. A fleet of rapidly moving aeroplanes, at the height of 2,000 feet, could drop each a 250-pound bomb of nitroglycerin upon the enemy below, and escape unharmed, while the shells would wreak death and destruction.[7]

Given that the aircraft of the time were unable to lift more than three hundred pounds over and above the weight of the pilot and that operation of the bombsight required carrying an additional passenger, Milling's prediction seems quite optimistic. However, he and the other Army airmen recognized great military value in providing aircraft "the power of destruction."[8]

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[7] "Aero Drops a Shell," *The Washington Post*, October 10, 1910, 1.

[8] Arnold, *Global Mission*, 34.
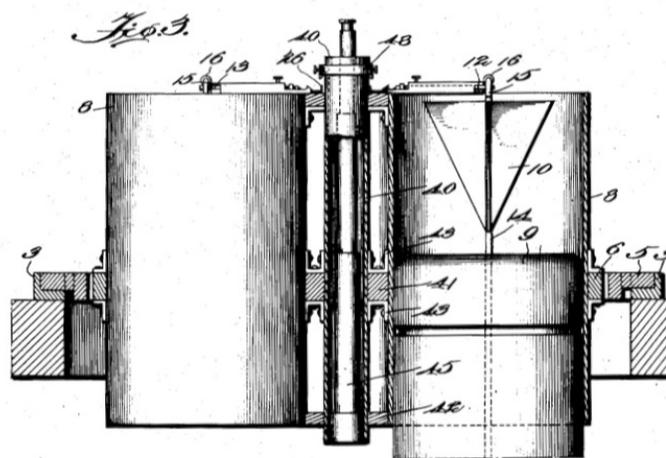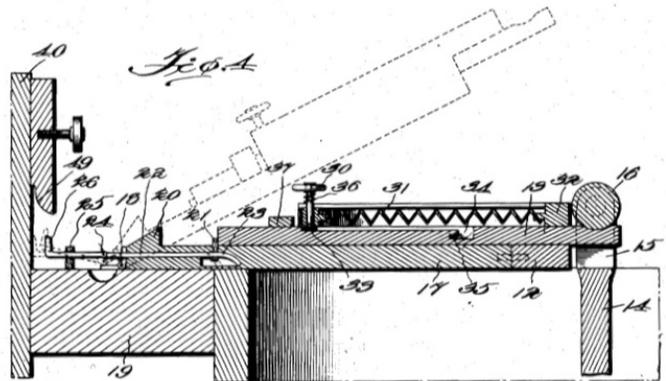
Figure 5.2
Riley Scott's "bomb dropper" device, as represented in U.S. Patent No. 991,379[9]

As noteworthy as Scott's results may have been, U.S. Army leadership showed little interest in the bombsight and refused to purchase it. Undaunted, Scott entered his invention in the Michelin bombing competition at the Villacoublay airdrome in France the next year, beating all other competitors and winning the $5,000 prize. His results generated a great deal of interest among the European military observers present, particularly from the German and French

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[9] Scott, "Means For Dropping Projectiles From Aerial Crafts, U.S. Patent 991,378," drawings, page 2.

General Staffs. The French promptly bought the bombsight, as did the Germans, who further developed the device and were soon using it against the Allies during World War I.[10]

The First Socio-technical Bombing System

Scott's bombsight was a revolutionary advance in the nascent science of aerial bomb dropping, but its significance extended beyond its ability to allow airmen to drop bombs more precisely. It was the first true socio-technical bombing system that combined the unique human abilities to find, identify, and track the target with unique machines with the abilities to measure speed, altitude, and ballistic performance into a single, interdependent entity.

The earliest attempts at bombing had been limited to "seat of the pants" efforts, where the pilot or aircraft passenger dropped hand-held bombs over the side of the aircraft, guessing the release point based upon estimates of aircraft speed, altitude, and the bomb's ballistic fall time. The results were predictably poor and accurate hits were more a result of luck rather than skill, as they relied entirely upon the extremely imprecise human perception and interpretation of a very dynamic environment. The first "technological" aid for the human bomb dropper was very basic, consisting of a line painted on a bomber aircraft fuselage that assisted the pilot in lining up with the target. While it provided a rudimentary spatial reference for the pilot, it showed little improvement in accuracy, as it worked only for one speed, altitude, and bomb type, and success again depended much more upon luck than skill.[11]

Scott substantially improved upon this concept by using specific machines to eliminate some of the element of luck and replace it with skill. By integrating the aneroid barometric altimeter, the pivoting telescope and stopwatch, and the pre-calculated ballistic tables, Scott brought together machines that were more expert at their tasks than were humans. These instruments were able to quantify some elements the bomber's environment, albeit without great precision, by providing data that reduced some of the uncertainty associated with bomb dropping. Simply knowing the aircraft altitude and airspeed enabled the bombardier to use the ballistic tables to determine the *angle* at which the bomb must be dropped to hit the desired

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[10] Hallion, *Taking Flight*, 301-302; Arnold, *Global Mission*, 34. The Scott bombsight was used for the first time in combat one year later by American mercenary Bert Hall, flying for the Hungarians in the Balkan War of 1912. See Hallion, *Taking Flight*, 302. Belatedly, the Air Corps purchased 10 Riley-Scott type sights after World War I, as they "incorporated the best known principles of general sight design." See Virginia Toole, *The Development of Bombing Equipment in the Army Air Forces*, May 22, 1945, 23-24, Call 201-13, US Air Force Historical Research Agency.

[11] McFarland, *America's Pursuit of Precision Bombing*, 8-9.

target (Figure 5.3). The pivoting telescope enabled him to set and measure that angle, and when the target appeared under the crosshairs in the eyepiece, indicated when to drop the bomb.
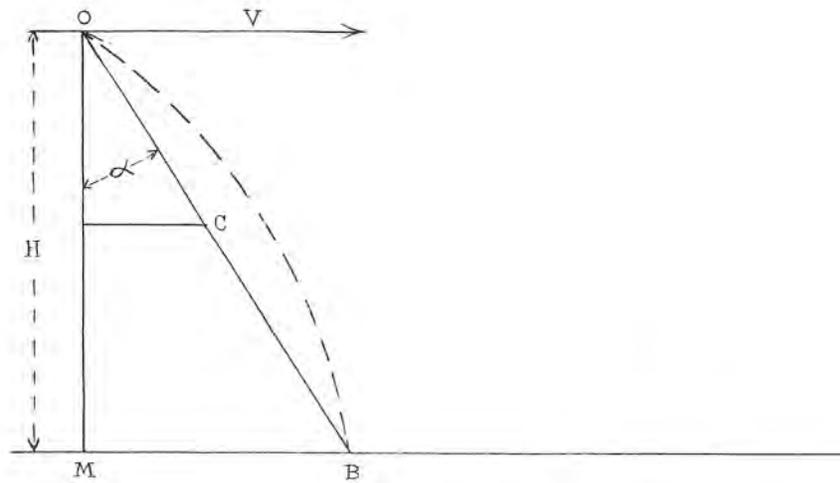
Figure 5.3
The bomb-sighting angle, α, as depicted in the 1918 *Notes on Aerial Bombardment*[12]

The bombsight, however, was not infallible. It was complex and cumbersome to operate, required skilled humans to operate both the bombsight and the aircraft carrying it, and neglected several significant variables, such as the effect of wind on both the aircraft and bomb. The bombsight operator had to complete numerous actions in rapid sequence, including sighting the target, operating the stopwatch, calculating the groundspeed, reading the altimeter, looking up the ballistics data, and finding the target in the sighting telescope. Even at forty miles per hour, it required much practice and training to develop the skills necessary to operate it correctly on a consistent basis. Likewise, the bombing solution was only as good as the data used to compute

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[12] *Notes on Aerial Bombardment*, 1918, 11.

it, which meant that the aircraft pilot had to keep the aircraft steady, at a constant altitude and airspeed during the entire process while the bombsight operator performed his tasks.

Neither did the bombsight compensate for the effect of wind on the path of the falling bomb, which could cause it to fall short, long, or push it off line away from the target. Granted, the aircraft of that era could not climb very high, particularly carrying a load of bombs and a couple of airmen, and given that the bombsight could be used only at low altitude, wind made, in Scott's words, "but little difference."[13] Likewise, low altitude compensated for pilot imprecision, as the bomb time of fall was short enough that these errors were small in magnitude. Soon, however, the increasingly capable anti-aircraft defenses that developed with the reality of combat bombing would force bomber aircraft to higher altitudes, increasing the magnitude and significance of both types of errors. Although his solution was imperfect, Scott defined and addressed many of the technical challenges of precision bombing, created a socio-technical solution for the problems that he understood, and laid the fundamental design groundwork for virtually all of the bombsight designers who would follow.

The Bombing Problem

Hitting a stationary target on the ground with a bomb dropped from an aircraft is, conceptually, a simple, three-step problem. First, determine the location in space from which the ballistic trajectory of the bomb will carry it to the target, second, fly the aircraft to that point, and third, release the bomb.[14] The difficulty lies in calculating and finding that point, flying precisely to it, and dropping the bomb at the exact instant of arrival. Further complicating the problem is that the aircraft carrying the bomb is likely to have only one opportunity to get it right, as fuel limitations and the danger posed by opposing fighter aircraft and anti-aircraft defenses may well preclude a second chance.

Finding *That* Point in Space—Course, Range, Trail, and Cross Trail

The first step in determining the bomb release point is solving for *range,* or calculating how far in advance of the target to release the bomb. The two key variables that control the

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[13] "Aero Drops a Shell," 1.

[14] *Students' Manual: Bombing* (Army Air Forces Training Command, 1944), 1-2-1. This discussion addresses bombing stationary targets, as they were the focus of the Combined Bomber Offensive during World War II. Bombing moving targets is more difficult still, as more variables enter the problem, all of which are beyond the control of the bombardier.

range are the aircraft groundspeed, determined by the aircraft's true airspeed and the effect of the wind at altitude, and the bomb's time of fall, dictated by the aircraft altitude. At the instant that a bomb drops from the aircraft, it is traveling forward at the same rate as the aircraft. In a perfect vacuum, it would remain directly beneath the aircraft as it falls to earth due to the force of gravity. However, air resistance causes it to decelerate and fall behind the aircraft as it descends, and that increasing distance is called *trail*, defined as "the horizontal distance measured on the ground from the point of impact to a point directly beneath the airplane at the moment of impact" (Figure 5.4).[15] Time of fall obviously increases with aircraft altitude, and as air resistance retards the bomb's progress longer, trail increases correspondingly as well. Wind can also affect trail, with a head with increasing it, or a tail wind decreasing it.
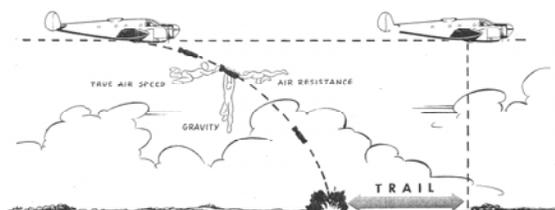
Figure 5.4
Trail[16]

The second step in determining the bomb release point is calculating the aircraft *course* that will compensate for any lateral drift in the bomb's trajectory caused by a crosswind. A crosswind will push the bomb away from the aircraft's track across the ground, and this value, measured as the bomb's lateral distance at ground impact from the aircraft ground track, is called *crosstrail* (Figure 5.5). Again, the longer the time of fall, the greater the amount of crosstrail produced by the wind. The aircraft heading at bomb release must account for the effect of the wind on both the aircraft and the bomb. While turning into the wind compensates for the aircraft drift, as explained in Chapter 4, additional compensation is needed to allow for the wind's effect on the bomb as it falls. Therefore, the final aircraft heading must place the aircraft *upwind* of the target.

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[15] Ibid., 1-2-2.
[16] Ibid., 1-2-3.
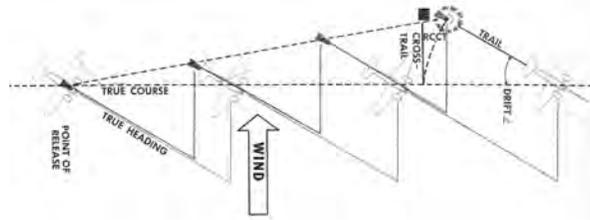
Figure 5.5
Crosstrail[17]

Solving for range and course by compensating for trail and crosstrail is a complex three-dimensional problem, characterized in 1943 by a writer in *Popular Science* as "pitching the bomb toward the target as a pitcher throws a curve across home plate."[18] Figure 5.6, taken from the Army Air Forces Board's 1944 *Revision of Handbook for Bombardiers*, graphically displays the complexity of determining the release point.
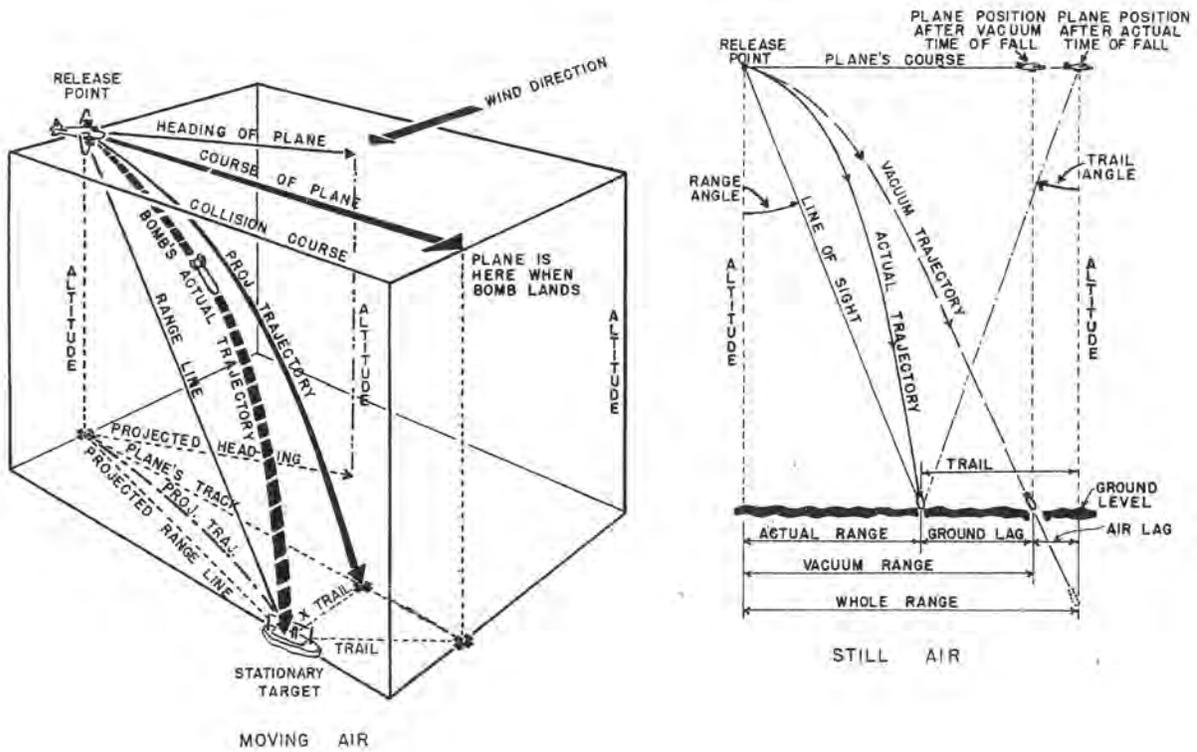
Figure 5.6
The bombing solution[19]

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[17] Ibid., 1-2-10.

[18] Allen Raymond, "Bombsight Solves Problems: Geometry and Ballistics Give it its Deadly Accuracy," *Popular Science*, December 1943, 119.

[19] *Revision of Handbook for Bombardiers* (The Army Air Forces Board, August 9, 1944), Figure 1, Call 245.64, IRIS No. 156569, US Air Force Historical Research Agency.

While the problem is complex, determining the release point requires knowing only four pieces of data.

1. The aircraft altitude above the target, used to calculate the bomb's time of fall.

2. The aircraft ground speed, used to calculate the distance the bomb will travel during that time of fall.

3. The ballistic characteristics of the bomb that define how air resistance will affect its flight through the air, used to modify the calculated distance that the bomb will travel during the fall.

4. The aircraft drift, used to calculate the correct heading for the aircraft to produce the required offset to compensate for the effect of the crosswind on both the aircraft and bomb.

Collecting and converting that data and performing the geometric and vector calculations in real time, however, is far beyond the independent cognitive capability of most humans, requiring the assistance of purpose-built measuring and computing devices.

Even with that assistance and the bomb release point determined, accurately dropping bombs still requires solving two other major problems that involve both humans and machines: flying precisely to the release point and recognizing that the aircraft is there to release the bomb at the correct instant. The creation of a socio-technical device that accomplishes all three of these tasks was, and remains, the focus of every bombsight designer since Riley Scott hit his first target. The bombsight development process that led to the production of the Norden bombsight, used by the USAAF during the CBO, was one of a series of actions that gradually increased the bombardier's ability to measure his physical environment and interpret it for the bombsight, while automating the complex, dynamic mathematic calculations associated with determining the bomb release point and the physical actions necessary to perform precision flight.

Partial Solutions—Simple Machines and the First Bombsights

The first bombsights that evolved beyond painted lines or simple nails pounded into the aircraft fuselage to act as rudimentary aiming devices were vector-type bombsights. Developed in ignorance of the Scott bombsight, these vector type bombsights crudely solved only the range portion of the bomb release point problem using data supplied by the bombsight operator. The

bombardier, or pilot in a single-seat aircraft, adjusted several levers that set the aircraft altitude, ground speed, and bomb ballistic fall time, which set the position of two pins on a sliding scale that, when aligned visually, displayed to the operator the correct angle at which to release the bombs (Figure 5.7). The operator then sighted along the pins, and when they aligned with the target, he manually released the bombs (Figure 5.8).

BOMB SIGHT MARK IA

Figure 5.7
Wimperis Mark IA Bombsight[20]

These sights were extremely imprecise, in part because the data used to set them up was very inaccurate. The operator had to calculate the groundspeed with a stopwatch and, in many cases, had to guess the aircraft altitude, as the altimeters in use at the time were very unreliable and often displayed readings that erred in excess of ten percent of the true altitude.[21] Although the bomb ballistic data was accurate, the bombsight operator chose the setting based upon the estimated groundspeed and altitude, so in fact it was no better than the operator's ability to accurately determine those values. Neither did these bombsights compensate for drift, limiting the aircraft to bomb runs either directly with or against the wind over the target. Like Scott's

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[20] *Mark IA Bombsight*, Technical drawing, n.d.,
http://www.nationalmuseum.af.mil/shared/media/photodb/photos/070205-F-1234P-003.jpg (accessed 13 October 2010). This bombsight was designed and produced after World War I. It was modified for higher altitude operations, but still did not compensate for drift.

[21] Edward O. Purtee, *Development and Adaptation of Aircraft Instruments for Military Use* (Historical Division, Intelligence, T-2, Air Technical Service Command, 1946), 73.

bombsight, they were more effective at lower altitudes where the effect of the wind was less, but virtually useless as the bombing altitude increased.

Figure 5.8
Early, non-drift setting Wimperis bombsight installed on an American DH-4[22]

Lieutenant Commander H. E. Wimperis of the Air Ministry and Imperial College of Science, London, made one of the first attempts at solving the drift problem by modifying one of his own earlier bombsight designs. Wimperis' improved "drift setting bombsight" added an angular drift adjustment bar, which the operator set based upon the crosswind over the target. Determining the crosswind, however, added significantly to the pre-bomb run preparation requirements. The pilot had to fly a timing leg perpendicular to the planned bombing attack course, while the bombardier calculated first the ground speed, again with a stopwatch, and then the crosswind by subtracting the ground speed from the aircraft's indicated air speed. During the bomb run, the pilot again had to fly directly upwind or downwind toward the target while the bombardier lined up the rear sight with the drift bar, the front sight with the altitude bar, and determined what heading would bring the target in line with both. Once that new heading was established, the bombardier signaled it to the pilot so that he could change course.[23] It was a

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[22] *Wimperis Bombsight on a DH-4*, Photograph, n.d.,
http://www.nationalmuseum.af.mil/shared/media/photodb/photos/070205-F-1234P-001.jpg (accessed 13 October 2010).

[23] McFarland, *America's Pursuit of Precision Bombing*, 15.

cumbersome, poor solution, but the Air Corps and Navy aircraft used Wimperis' sight and variations of it for many years after World War I.

The Wimperis bombsight, as with all bombsights, required that the bombsight operator have some method of signaling the pilot so that he could have some control over the aircraft heading once he determined the correct bombing solution. As discussed in Chapter 3, these signals were initially passed by yelling between the aircraft cockpits, then with signaling reins attached to the pilot's sides, and eventually with indicator lights on the pilot's front instrument panel. None of these methods was either satisfactory or precise, and it took a great deal of practice for a bombardier-pilot pair to develop the necessary understanding and coordination to drop even moderately accurate bombs. All told, the Wimperis bombsight provided only a crude solution for the range problem, providing rough compensation for trail and crosstrail based upon very suspect data. Additionally, it made no compensation for imprecise flying on the part of the pilot, nor for the inherent pitch and roll oscillation of the aircraft inflight, and at its best with a well-trained crew, it was moderately accurate only at altitudes below 5,000 feet.[24]

Bombing Errors and the Difficulties of the Socio-technical

Experience with these early bombsights revealed that there were two types of errors that decreased bombing accuracy: *range errors*, where the bomb fell either long or short of the target, and line, or *course errors*, where the bomb fell to the side of the target. A 1918 pamphlet entitled *Notes on Aerial Bombardment*, brought back from Europe by Captain H. B. Inglis of the Army Air Service Armament Division at McCook Field, Ohio, identified the sources of these errors and their effect on accuracy.

Range errors fell into four categories:

1. The bombsight was not horizontal, leading to an inaccurate angle measurement
2. The ground speed was wrongly estimated by the bomber, leading to an inaccurate bomb dropping angle prediction
3. The altitude was measured incorrectly, leading to an inaccurate time of fall value
4. The bombardier delayed in dropping the bomb past the bomb dropping point, leading to bombs falling past the target[25]

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[24] Toole, *The Development of Bombing Equipment in the Army Air Forces*, 9-12; McFarland, *America's Pursuit of Precision Bombing*, 14-16.

[25] *Notes on Aerial Bombardment*, 14-15.

Equipment deficiencies generated the first three sources of error, with the greatest error caused by the sight not being level. *Notes on Aerial Bombardment* detailed that a 2° forward tilt error in the dropping angle led to a 226-foot error in a bomb dropped from just 600 feet. A ground speed error of only 5 miles per hour led to an error of 150 feet in a bomb dropped from 6,000 feet. Altitude errors varied, as they could either cause the bomb to fall short if the altitude was overestimated, or fall long if it was underestimated.[26]

The fourth source of range error, delay in dropping the bomb, was human. The delay between the bombardier recognizing that the bomb must be released and physically releasing it, or his reaction time, caused bombs to fall past the target. In a 1921 lecture to the Air Service Tactical School at Langley Field, Virginia, Frank Short, a bombing expert in the Army Ordnance Department, quantified its effects for the students:

> reaction time for the individual is in the neighborhood of one-tenth to one-fifth of a second for skilled men. The latter figure will cause an error of about 30 ft. if the bomb is released too soon or too late; assuming the same actual ground speed at all heights, this error is independent of altitude.[27]

The range error problem was complex, as the effect of each individual source of error compounded the effect of the others, and since the sources were both technological and human, range error was a distinctly socio-technical problem.

Line errors fell into two categories:

1. The aircraft course was not in line with the target, causing the bomb's path to diverge from the target
2. The aircraft was "listing," or not wings level at the instant the bombardier released the bombs, again, causing the bomb's path to diverge from the target[28]

These errors, more serious than range errors, were attributable to a combination of drift, the human pilot's inability to steer the aircraft course accurately, and his inability to fly precisely enough to keep the wings level. Course errors caused a lateral accuracy error of

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[26] Ibid.

[27] Frank Short, "Bomb Sights, Lecture delivered at Langley Field, Virginia by Frank Short, Expert, Ord. Dept., U.S.A." (lecture, Langley Field, VA, 1921), 10, Box 828 File: F-5G/1921/Bombsights Development of Bombsights and Gyroscopes, National Museum of the United States Air Force.

[28] *Notes on Aerial Bombardment*, 15.

tan (# of degrees off course) × (the distance the bomb travels) = miss distance (ft),

and a roll errors caused a lateral accuracy error of

tan (# of degrees of aircraft roll) × (aircraft altitude) = miss distance (ft).[29]

As with the range errors, line errors were distinctly socio-technical. Drift calculation was dependent upon technical means, but aircraft control was dependent upon the pilot's ability to keep the wings level.

The most significant source of error, however, was *aircraft oscillation*. The bomber aircraft attitude constantly varied in pitch and roll as the pilot moved the flight controls to maintain controlled flight. This constant movement induced both range and course errors because they upset the bombsight's *level reference*.[30] If the bombsight was not level in relationship to the target environment—the surface of the earth—all of its calculations would be in error and the bomb would miss. This, again, was a socio-technical problem, as the solution required increasing the pilot's ability to fly precisely and keep the aircraft stable as well as designing a bombsight that could both determine and maintain a "true" vertical reference with respect to the target.

With these basic sources of error identified, resolving them became a process of accomplishing three steps:

1. Defining the bombsight's physical environment—measuring and quantifying the aircraft airspeed, altitude, and course accurately enough to permit precise calculations of the bomb release point.
2. Controlling the bombsight's physical environment—creating and maintaining a "true" level reference for the bombsight so that it could use that data to calculate the position of the bomb release point.
3. Eliminating sources of human error by developing a method of controlling aircraft altitude, airspeed, and course precisely enough to fly to the bomb release point, as well as releasing the bombs precisely at that point.

The process of accomplishing these steps was difficult and iterative, as it involved solving both technical and human problems in a single system. Although Henry Inglis brought back *Notes on Aerial Bombardment* after World War I, efforts to reduce the bombing errors that it identified

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[29] Ibid.

[30] Ibid., 15-16.

had already begun, with bombsight designers focusing both on stabilization so that they could replicate the true vertical and on solving the problem of calculating drift and groundspeed.

Resolving the Errors—Technology and the Bombsight

The first stabilizing bombsight was a French-developed Michelin sight, used during World War I. Based on Riley Scott's design, the Michelin sight was stabilized both in pitch and in roll by a set of pneumatic shock absorbers that reacted to the position of a pendulum contained within the unit that provided a vertical reference. It was the first sight to stabilize in this manner and the most accurate bombsight used during the war, but it did not compensate for wind drift and was still dependent upon timing to determine ground speed. Calculating the ground speed required the pilot to fly a timing leg of up to 1½ minutes directly at the target, during which the aircraft was exposed to hostile defensive fire.[31] Following the war, the Air Corps procured several Michelin sights and attempted to improve upon their design, however, these attempts, led by bombsight designer George Estoppey, demonstrated that pendulum-stabilization showed little promise, and by 1924, efforts shifted to adapting gyroscopic stabilization to bombsights.

Concurrent with their efforts to develop gyroscopic aircraft stabilizers, described in Chapter 3, the Sperry Gyroscope Company was also working on using gyroscopes to stabilize bombsights. Sperry developed its first gyroscopically stabilized bombsight in 1914, using the same principles to keep the bombsight level used to keep aircraft level in flight. In 1918, the U.S. Navy acquired a few of these sights, but found their performance unsatisfactory, as the gyroscopes were unable to keep the sights level and they soon took them out of service.[32] The root problem was that, unlike the larger gyroscopes used for aircraft stabilization, bombsight gyros had to be small enough to fit into the bombsight. Smaller size meant less rotating mass, and the gyros were either too small to produce enough counterforce to keep the sight level, suffered from excess precession, or just failed.

Although their first attempt failed, Sperry continued their efforts throughout the decade in conjunction with their autopilot development to produce a gyroscopically stabilized bombsight. By 1933, they had made some progress and were producing the Model O-1, which was the predecessor of Sperry's eventual S-1 bombsight. While the Model O-1 was an improvement, it

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[31] Toole, *The Development of Bombing Equipment in the Army Air Forces*, 21; McFarland, *America's Pursuit of Precision Bombing*, 16.

[32] Thomas Parke Hughes, *Elmer Sperry: Inventor and Engineer* (Baltimore, MD: Johns Hopkins Press, 1971), 237.

had several technical that adversely affected its accuracy. Neither the Air Corps nor the Navy was interested in procuring it, as they had discovered a superior bombsight, produced by former Sperry employee Carl L. Norden.[33]

Norden, a promising engineer, had worked for the Sperry Company before World War I on ship stabilization systems, and he remained as a consultant through the end of the war. He began working on bombsights in 1921 as a consultant to the U.S. Navy, and by 1928, had founded his own company, Carl L. Norden, Inc., and was on contract and producing the Norden Mark XI gyrostabilized bombsight.[34] The Navy bought several Mark XI bombsights, as their performance in both testing and operational use was impressive. They maintained a true level reference far better than their competitors and contained an integrated timing device that simplified ground speed calculation and were more accurate any existing bombsight. However, they were complex and difficult maintain, and Norden wanted to produce something better. By 1931, he succeeded, producing the initial test version of the Mark XV/M-Series bombsight—a truly revolutionary gyrostabilized, "synchronous" bombsight.[35] The M-Series sight far outperformed even the Mark XI, and in 1933, just as Sperry produced the inferior Model O-1, both the Army and Navy contracted with Norden as their primary supplier of bombsights.

The M-Series bombsight was remarkable because of its gyro stabilization, but equally remarkable as the first successful synchronous bombsight. Developed during the 1920s as an alternate, more accurate method of determining the aircraft ground speed, synchronization was the process of measuring the telescope's rate of motion as it tracked a fixed point on the ground. When the bombsight operator kept a target stationary under the crosshairs in the telescope lens, the telescope movement rate was "synchronized" with the aircraft groundspeed, and given a known altitude, measuring the bombsight telescope's movement rate enabled the easy derivation of groundspeed through a simple geometric calculation. Synchronous bombsights essentially

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[33] Philip A. St. John, *Bombardier: A History, Volume II* (Paducah, KY: Turner Publishing Company, 1998), 23. Sperry mated the Model O-1 bombsight with their A-2 Autopilot, and although it was a less than satisfactory combination, the system was installed in a group of B-17s that the United States sent to Great Britain as a part of the Lend Lease Program before entering the war. It was the first coupled bombsight/autopilot system used against the Germans in World War II. See this reference, p. 23.

[34] Loyd Searle, "The Bombsight War: Norden vs. Sperry," *IEEE Spectrum* 26, no. 9 (1989): 60.

[35] Albert L. Pardini, *The Legendary Secret Norden Bombsight* (Atglen, PA: Schiffer Military History, 1999), 53-67. Mark XV was the Navy designation for the bombsight. The U.S. Army designated it the M-series bombsight, and as it went through numerous improvements, it received a new number. The most famous version was the M-9, fielded in October 1943. See ; St. John, *Bombardier: A History, Volume II*, 22.

enabled the bombsight operator to construct the aircraft-target spatial relationship within the bombsight by recreating the closing rate between the two in miniature.

While the M-Series bombsight was the first *successful* synchronized bombsight, George Estoppey had actually developed the Air Corps' first one in 1929, the Estoppey D-5, but it was overly complex and difficult to operate. The D-5 required the bombardier to directly control the bombsight optical mechanism's rate of movement by manipulating a set of knobs and gears to mechanically rotate the telescope to track a target on the ground. In addition to its mechanical complexity and cumbersome operation, the D-5 used a less-effective pendulum stabilizer, left over from Estoppey's stabilization efforts earlier in the decade. Although conceptually it showed great promise, it was less accurate than older bombsights and was not produced.[36]

Norden's synchronizing mechanism was far superior. Rather than making the bombsight operator manually control the telescope's rate of movement, the M-Series sight allowed the operator to control the rate of motion indirectly by turning a knob on the side of the bombsight that adjusted the speed of an electric motor, which, through a wheel and disk integrator, drove the sight's optical mechanism. This greatly simplified operation made it much for the operator to synchronize the bombsight on a ground target and made calculating the aircraft groundspeed much easier and more accurate, making the bombsight sight truly useful, rather than just an impressive concept demonstrator.

By inventing a practical leveling, synchronous bombsight, Carl Norden resolved two of the major sources of bombing accuracy error with technology. Gyroscopic leveling compensated for the ever-present aircraft oscillation and allowed the bombsight operator establish and maintain a true vertical reference, controlling the bombsight's physical environment so that it could accurately measure the data needed to calculate the location of the bomb release point. The synchronous mechanism enabled the bombsight to obtain that data, allowing it to measure the aircraft groundspeed and, as will be explained, the amount of drift, and use it to calculate the bomb release point. The M-Series bombsight also eliminated many of the sources of human error that caused bombing inaccuracy, but to understand how it did so, we must examine more

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[36] Julius King, Jr., *Development of Airborne Armament, 1910-1961: Volume I, Bombing Systems*, AFSC Historical Publications Series (Wright-Patterson AFB, OH: Historical Division, Office of Information, Aeronautical Systems Division, October 1961), I-8 - I-9; Toole, *The Development of Bombing Equipment in the Army Air Forces*, 50.

closely the bombsight itself, how it worked, and, most importantly, how the bombsight operator used it.

Recreating Reality in a Machine—The Norden Bombsight and the Autopilot
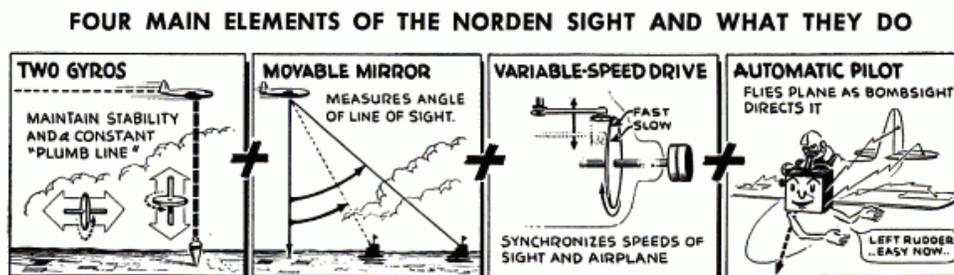
Figure 5.9
The Norden bombsight's major elements and functions, as depicted in *Popular Science*[37]

Norden's bombsight was a true technological marvel, and while it was simpler than Estoppey's D-5, it was still a very complex electro-mechanical computing and control device. Developed originally for the Navy to bomb maneuvering ships from low altitude, its superior accuracy made it, when paired with a long-range bomber, the technological realization of the Air Corps' budding HADPB doctrine.[38] The results of early Air Corps tests with the bombsight were impressive, so much so that Norden and his business partner Ted Barth made the famous claim that the bombsight could drop a bomb into a "pickle barrel" from 20,000 feet.[39] The bombsight

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[37] Volta Torrey, "The War's Most Closely Guarded Secret Revealed: How the Norden Bombsight Does Its Job," *Popular Science*, June 1945, 71.

[38] The M-Series bombsight went through several modifications to adapt it to high-altitude bombing. In addition to allowing for longer bomb times of fall, the mechanism itself had to be machined to much tighter engineering tolerances, as any errors within the bombsight mechanism translated to inaccurate bombing results. Through its entire production run, Norden and the other companies subcontracted to produce the bombsights during the war faced continual challenges maintaining these precise tolerances, and in several cases, the Air Corps refused to buy units that did not meet specification. The entire story of the acquisition and production of the M-Series bombsight is very complicated, encompassing bureaucratic jockeying among the military services, patent infringement among the bombsight designers and developers, and corporate efforts to monopolize the bombsight market. For more detail, see *Case History of Norden Bombsight and C-1 Automatic Pilot, Parts I and II* (Historical Office, Air Technical Service Command, Wright Field, January 1945), 202.2-35 Part I and Part II, IRIS No. 142135 and 142136, US Air Force Historical Research Agency; King, Jr., *Development of Airborne Armament, 1910-1961: Volume I, Bombing Systems*; Searle, "The Bombsight War: Norden vs. Sperry."; McFarland, *America's Pursuit of Precision Bombing*; Paul McConnell, "Some Early Computers for Aviators," *IEEE Annals of the History of Computing* 13, no. 2 (June 1991): 155-177.

[39] This legendary, exaggerated claim was made many times by many people, and became the popular perception of the United States' bombing capability. The pickle barrel and the M-Series bombsight became almost

itself consisted of two major components that performed the functions depicted in Figure 5.9: the stabilizer, containing the directional gyro and mounted on the bombsight pedestal in the bombardier's compartment, and the sight head, the sighting and computing mechanism that attached to the top of the stabilizer (Figure 5.10).
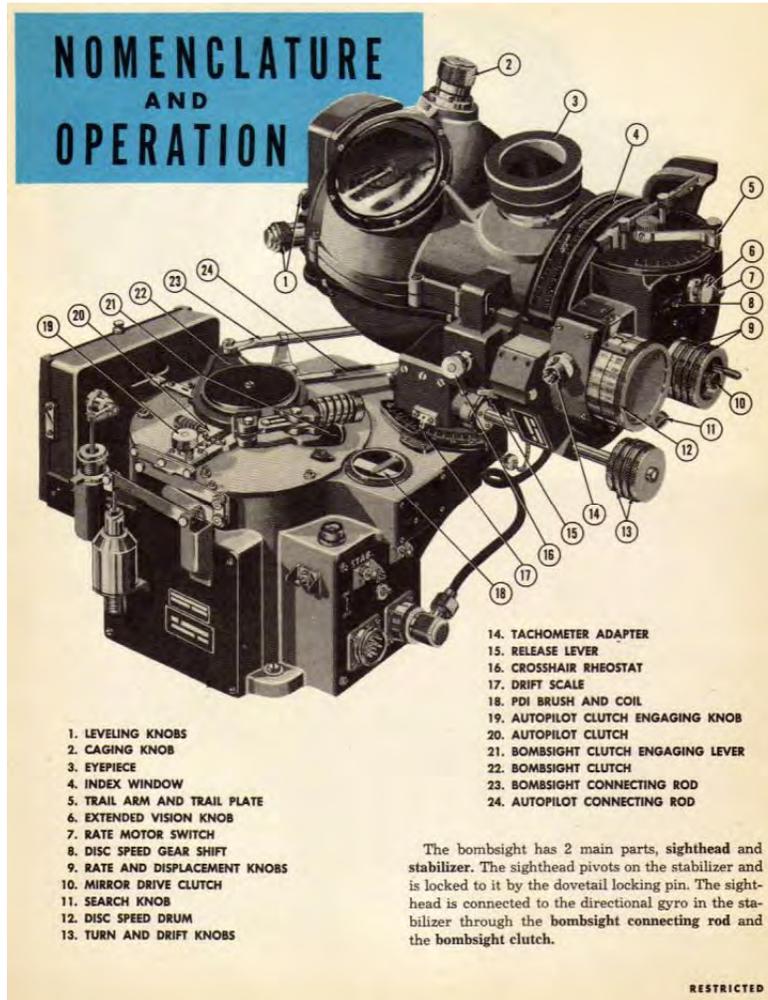
Figure 5.10
The Norden M-Series Bombsight. The sight head is the oblong-shaped unit in the upper right of the figure, and the sight head is the boxy unit in the lower left.[40]

The stabilizer served as the base of the bombsight and remained in the aircraft at all times (Figure 5.11). It contained the *directional* gyro, which stabilized the aircraft on the *yaw* axis when coupled to the Stabilized Bombing Approach Equipment (SBAE), or Minneapolis-Honeywell (M-H) C-1 Autopilot in later aircraft. The stabilizer was an integral part of the

synonymous during World War II. See McFarland, *America's Pursuit of Precision Bombing*, caption, photo 1, page 44.
[40] *Bombardiers' Information File (AAF Form 24B)* (U.S. War Department, 1944), 6-1-1.

method by which the Norden bombsight solved the course portion of the bomb release point problem, and was the key machine that enabled the bombardier to "fly" the aircraft, which he could do one of three ways: by using the controls on the autopilot control panel installed in the bombardier's compartment, by moving the directional panel arm on the exterior of the stabilizer, or by moving the bombsight head. All three methods were separate and used during different phases of the mission.
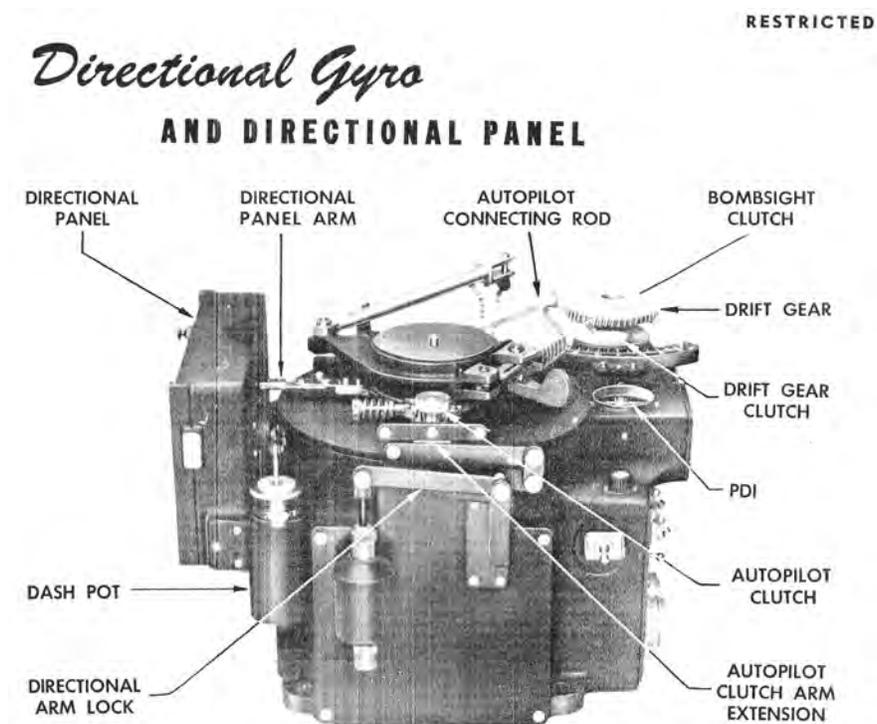
Figure 5.11
The stabilizer unit[41]

The bombardier's autopilot control panel was the same as the one installed in the pilots' cockpit, and active only when the bombardier engaged the autopilot clutch on the stabilizer. Commands from the pilot's panel, however, overrode the bombardier's commands, and it operated as described in Chapter 3. The bombardier generally used the autopilot control panel only if he had to adjust the autopilot settings prior to the bomb run, as it was not designed for rapid, reactive maneuvering. For more reactive maneuvering, he could bypass the panel and turn the aircraft with the autopilot clutch arm extension, located on top of the stabilizer and enabled

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[41] *Students' Manual: Bombing*, 3-2-5.

by disengaging the directional arm lock. In this mode, the autopilot turned the aircraft when the bombardier moved the arm to the side. The autopilot clutch arm extension was small, however, and commanding turns in a bouncing aircraft was difficult when encumbered by the heavy gloves necessary to ward off the extreme cold of high altitude. Later in the war, the arms were modified with turn knobs that were easier to grasp and manipulate (Figure 5.12). In their absence, many bombardiers chose to remove their heavy gloves and wear thinner, silk gloves so that they had better manual dexterity, just as the navigator did when recording data in his Flight Log.[42] Bombardiers used this mechanism to turn the aircraft for evasive maneuvers during the bomb run, until they switched to autopilot control through the bombsight.

Figure 5.12
The autopilot clutch arm extension turn knob[43]

The Norden bombsight provided the third method by which the bombardier could steer the aircraft. With the bombsight clutch engaged, the directional gyro detected changes in the bombsight's lateral orientation as it rotated on top of the stabilizer, translating bombardier's movement of the bombsight head into steering commands for the PDI and autopilot. As the bombardier moved the bombsight to place the target under the crosshairs in the telescope, the autopilot turned the aircraft to fly it to the appropriate bomb release point. While the autopilot control panel, the autopilot clutch arm extension, and the bombsight gave the bombardier limited control of the SBAE or M-H C-1 Autopilot, his human-machine relationship with the system was fundamentally different from the one that developed between the pilot and the autopilot.

The pilot's relationship with the autopilot was one of shared control. The autopilot did not perform a task that the pilot *could not perform*, rather, it performed a task—flying—*more*

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[42] Jack R. Myers, *Shot at and Missed: Recollections of a World War II Bombardier* (Norman: University of Oklahoma Press, 2004), 50.
[43] *Here's How: Operation of the C-1 Autopilot* (Minneapolis Honeywell Aeronautical Division, n.d.), 12.

precisely than the pilot could. Its capability to do so added to the pilot's ability to perform his primary job of aircraft or system control, and was his *aid* in accomplishing that job, but did not change his fundamental role. With the bombardier, however, the autopilot *did* perform a task that the bombardier could not. Without the autopilot, the bombardier *could not* fly the aircraft, or effectively control it. Before the SBAE or C-1, the bombardier could only *direct* the pilot through the PDI, and the pilot had to accept the directions before he acted, which gave him final physical control authority over the aircraft and the mission. With them, the bombardier actually acquired some direct control over the mission.[44] The autopilot, as a machine, did fundamentally change the bombardier's role from one of director to one of controller.

The bombardier *needed* the autopilot to accomplish the task of precision bombing, and the autopilot was his cybernetic *partner* in that task (Figure 5.13). Each had a role in the limited amount of flying that they together accomplished. It was the critical link between the bombardier and the bombsight that made them into an effective, socio-technical bombardment element.
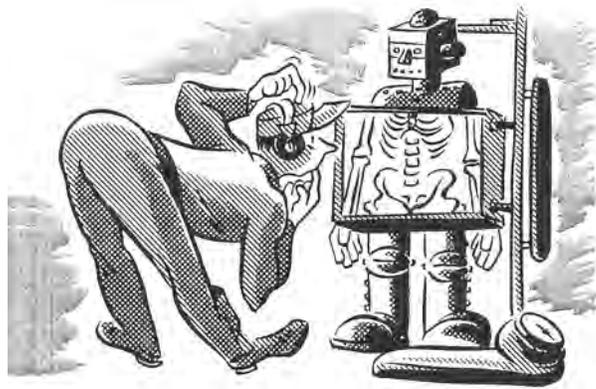
Figure 5.13
The bombardier and his cybernetic autopilot partner[45]

Attached to the top of the stabilizer was the Norden bombsight head, which was an appropriate name because contained the "brains" of the socio-technical bombardment element. Its primary function was to calculate the location of the bomb release point based upon data

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[44] As explained in Chapter 4, that control was limited to the aircraft heading only. The bombardier could not change the aircraft altitude, and the pilot controlled the throttles.
[45] *Bombardiers' Information File*, 3-1-4.

entered by the bombardier, data that defined the bombsight's physical relationship to the target. The sight head was approximately 16 inches wide, 9 inches deep, and 12 inches high, and known colloquially as the "Blue Ox," or the "football," because it was tapered at both ends (Figure 5.14).[46] It contained the sighting optics and telescope, a direct current gyroscope for stabilizing those optics, and the rate end, which was a mechanical computer for determining range, trail, and the bomb release point.

Figure 5.14
The sight head[47]

The rate end was the synchronous part of the bombsight, and the cognitive element in the bombsight head. It solved for range, trail, and the bomb release point when the bombardier, after entering environmental data such as the aircraft true airspeed, altitude, and drift angle, synchronized the movement of the gyro stabilized optical mirror in the telescope with a target on the ground. When the bombardier synchronized the optics with the target, the bombsight determined the exact angle necessary to drop the bombs, and when the optics reached that angle, it automatically released the bombs from the aircraft by transmitting an electrical signal to the

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[46] Philip A. St. John, *Bombardier: A History, Volume I* (Paducah, KY: Turner Publishing Company, 1993), 28; Charles D. Bright, ed., *Historical Dictionary of the U.S. Air Force* (New York: Greenwood Press, 1992), 408; "Boeing Advertisement--Blue Ox," *Life*, January 25, 1943, 77.

[47] *Norden Bombsight*, Photograph, n.d., U.S. Centennial of Flight Commission, http://www.centennialofflight.gov/essay/Dictionary/NORDEN_BOMBSIGHT/DI145G1.htm (accessed 22 March 2011).

bomb rack. Achieving that synchronization, however, was a complex task requiring quick perception and manual dexterity.[48]

Interpreting and Defining the Environment

Before synchronizing on the target during the bomb run, the bombardier had to level the bombsight stabilizer by adjusting a clamp on the base, referring to two bubble indicators while the pilot had the aircraft flying straight and level and on autopilot. Achieving a good initial level before sighting on the target prevented the need for large, time consuming vertical adjustments to the optics during the bomb run. The bombardier then entered the aircraft bomb run altitude with a knob on the side of the rate end. That knob controlled the speed of the electric motor that spun a disk inside the rate end. In a no-wind situation, where the aircraft ground speed equaled the true airspeed, that disk would rotate the bombsight optics at a rate equal to the aircraft movement over the ground, so that an object viewed through the optics would appear stationary in range, thus synchronized.

The bombardier also entered the trail value on the trail lever for the particular type of bomb and the bombing altitude from a set of bombing tables, which positioned a roller on the disk that was proportional to the trail value. This effectively subtracted the trail value from the bombsight range calculation, telling the bombsight when to release the bomb to hit a target synchronized in the telescope, and also provided an input to the crosstrail mechanism, which determined the necessary lateral offset from the target. By setting the altitude and trail values in advance, all that remained for the bombardier to accomplish during the bomb run was to compensate for the aircraft drift so that the bombsight could calculate the final release point.

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[48] The following section on bombsight operation draws upon the following sources: *Students' Manual: Bombing*, Chapter 4; *Bombardiers' Information File*, Chapter 6; McConnell, "Some Early Computers for Aviators."
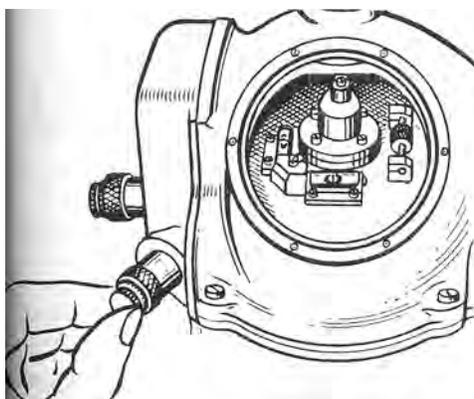
Figure 5.15
The vertical gyroscope leveling knobs[49]

To complete the final synchronization on the target, the bombardier "uncaged" a gyroscope encased in the rate end that stabilized the bombsight optics. This gyroscope made the Norden bombsight "gyroscopically stabilized" by establishing and maintaining a true vertical reference. Before proceeding further, the bombardier adjusted the gyroscope to level the optics, using the same two bubble indicators used earlier to level the stabilizer base. He centered the bubbles using two separate knobs to adjust the gyro in pitch and roll, turning them to place the bubble on the central reference line (Figure 5.15).[50]

In stable air, the leveling process was relatively easy. The bombardier turned the knobs to adjust first one axis, then the other, until both bubbles were centered. However, if the aircraft was buffeted by weather or prop wash from the other aircraft in the formation, or if there was an oscillation in the flight controls caused by a malfunctioning or misadjusted autopilot, the bombardier had to interpret the bubble's motion, estimating the point where the optics were level. Estimating the level from a moving bubble was an acquired skill, and inexperienced bombardiers had to avoid becoming "bubble happy," a condition where they fixated on the bubbles trying to achieve a perfect level to the point of distraction. The official USAAF Norden bombsight training films cautioned against bubble happiness, because the preoccupied bombardier usually failed to complete the rest of his tasks and subsequently missed his target.[51]

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[49] *Students' Manual: Bombing*, 4-3-10.

[50] Harvey C. Cragon, *How the Norden Bombsight Works: From Sighting the Target to Bomb Release* (Plano, TX: Bradley Graphics and Printing, 2010), 59.

[51] *The Norden Bombsight: The Leveling System* (Army Air Forces Training Film Production Laboratory, 1943).

With the bombsight level and the bombing data set, all that remained for the bombardier was to fix the crosshairs in the sighting telescope on the target and drop the bombs. If not already accomplished, he engaged the bombsight clutch, coupling the bombsight to the autopilot, visually acquired the target through the telescope, and attempted to place the crosshairs on the target by "killing the drift" (Figure 5.16). He did this by observing the target movement relative to the vertical crosshair in the sight, and then turned the bombsight in the direction of the motion, in turn, telling the autopilot to turn the aircraft in that direction. Since he had preset the drift angle and trail value prior to beginning the bomb run, the bombsight was already correcting for the calculated aircraft drift, and all that remained was to fine tune the aircraft heading to account for the difference between the predicted and actual crosswind component with a pair of coupled knobs on the lower right side of the sight head.
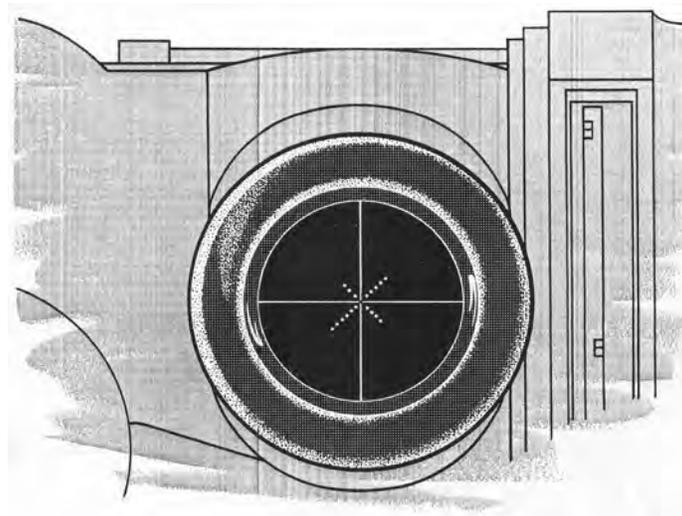
Figure 5.16
The crosshairs in the bombsight telescope[52]

The outer knob changed the line of sight and the aircraft heading the same amount, pointing the aircraft and the bombsight at the same point. The inner knob changed the aircraft heading *without* changing the bombsight line of sight, with the directional stabilizer holding the bombsight alignment (Figure 5.17). To counter any course error, the bombardier rotated both knobs together to center the target under the crosshairs, in the process changing the bombsight line of sight and the aircraft heading to account for drift. When used together, the knobs changed

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[52] *Students' Manual: Bombing*, 5-2-6.

the aircraft heading five times as much as they changed the line of sight, orienting the aircraft into the wind to counter crosswind drift.[53] This simple mechanical coupling greatly simplified the process of killing the drift by automatically compensating for the wind. The 5:1 fixed movement ratio was not the exact solution for every situation, but it did establish a course very close to the final course value, requiring only slight adjustment by the bombardier to get the aircraft lined up on the final, correct course.
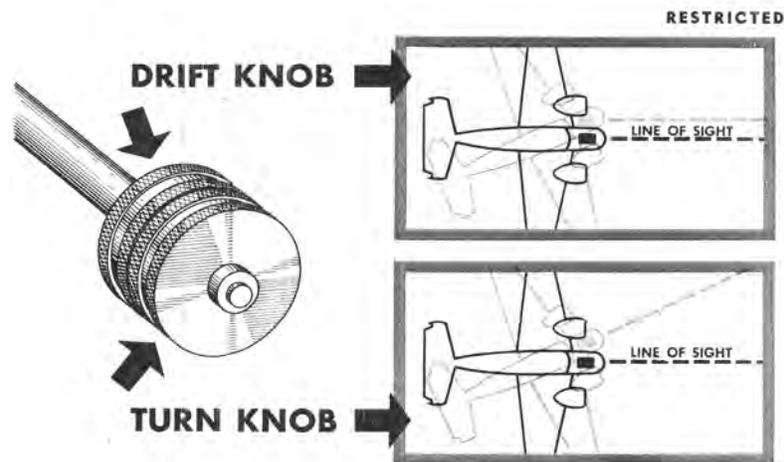
Figure 5.17
The drift and turn knobs[54]

As the bombardier rotated the bombsight, the crosstrail mechanism automatically tilted the optics to maintain their alignment over the position on the ground, which enabled the bombsight to automatically calculate the appropriate amount of total drift correction. Another ingenious mechanical coupling, this mechanism enabled the bombardier to concentrate only on lining up the vertical crosshair on the target, while the bombsight itself calculated and applied the drift correction. Working together, these two mechanical calculators relieved the bombardier from having to solve drift-compensation problems on his E6-B computer during the bomb run while under fire.

After the bombardier established a stable course with little or no drift, he shifted to synchronizing the bombsight in range. With the bombing altitude already set and the aircraft course almost determined, synchronizing for range provided the final value necessary for the Norden bombsight to "hit the pickle barrel"—the aircraft closure rate with the target, or its

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[53] *The Norden Bombsight: Operation* (Army Air Forces Training Film Production Laboratory, 1943).

[54] *Students' Manual: Bombing*, 4-1-5.

ground speed. The bombardier again had two knobs to adjust when solving for range; a displacement knob that moved the sighting mirror in the bombsight telescope along the line of sight that enabled him to place the horizontal crosshair on the target, and a rate knob, which controlled the rate at which the sighting mirror rotated along the line of sight. After placing the horizontal crosshair on the target with the displacement knob, the bombardier adjusted the rate knob, moving the roller on the spinning disk in the rate end until the mirror rotated at a rate equal to the rate of the motion of the target beneath the aircraft. As with the course, he did this through a series of iterative adjustments, moving the horizontal crosshair onto the target with the displacement knob and then adjusting the rate as necessary to keep it there. The sight was synchronized when the crosshairs remained fixed on the target.

Through the process of synchronizing the bombsight in course and range, the bombardier recreated the relationship between the aircraft and the target within the bombsight. The course and crosstrail settings established the lateral displacement from the target, and the sighting angle and bombing altitude established the vertical displacement. When the rate synchronization recreated the aircraft groundspeed, it completed a model of this relationship in the idealized space that the bombardier created when he established the "true" vertical and direction references when he leveled and aligned the flight and directional gyros. It was, as aviation computer historian Paul McConnell points out, a "true analog."[55]

With the bombsight fully synchronized and the data input, the final bomb release point solution was complete. The bombsight automatically calculated the appropriate bomb release angle from the altitude, trail, and ground speed values input by the bombardier, and when the optics reached that angle, a set of electrical contacts came together and triggered the electric signal that released the bombs. The Air Service Armament Laboratory at McCook Field in Dayton, Ohio, tested the first electrical bomb release device in late 1922 or early 1923, and although only a proof-of-concept, the device, which was designed to "release a bomb at an instant unknown to the bomber himself" by setting it to trigger at a predetermined bombing angle, worked perfectly.[56] It represented a viable solution to errors related to human reaction time, and Norden adapted the concept to the M-Series bombsight.

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[55] McConnell, "Some Early Computers for Aviators," 170.

[56] Charles Paulus, *Report on Automatic Bomb Sight for Use With Electrical Bomb Releasing Mechanisms* (McCook Field, Dayton, OH: War Department Air Service Engineering Division, February 8, 1923), 2, Box 829 File:

The electrical release mechanism was automatic, but did not completely remove the human from the bomb release process. The bombardier had to raise a release lever on the sight head that acted as a "consent to release" switch. If the bombardier did not raise the lever, the bombsight could not send the signal. He remained the final release authority for the bombs, so if he deemed it inappropriate to drop them, he could prevent the bombsight from doing so. This provided a measure of safety and the ability to avoid tragic mistakes, as illustrated by the actions of bombardier Everly Crouser, lead bombardier on a post-D-Day strike against an intersection of three roads in France. Upon identifying several hundred French citizens on the target, celebrating and waving flags, Crouser chose to retain his bombs and bypass the target, rather than kill French civilians.[57] When used, however, the electrical release mechanism was a key component of the bombsight, and one that made it as accurate as it was.

The Norden M-Series bombsight was a powerful analog computer, capable of computing the solution to a complex, three-dimensional trigonometric problem far faster than a human being could do so, and when paired with the bombardier, they formed a powerful, complex socio-technical unit focused on precision bombing. The bombsight combined the modern technologies of gyroscopes and electronic switching with a disk and wheel integrator, a mechanical computer whose use of proportional measurement has roots that stretch back through centuries of analog computing devices, to compute the location of the bomb release point.[58] It automated the calculation of that point, simplified the process of flying to it, and automated the release of the bombs, eliminating range errors due to the limitations of human reaction time. However, it could not perform these functions without the bombardier, who interpreted and defined the bombsight's physical environment, providing it both the data that it needed and the capability to calculate that which he could not provide. Mastering that complex process of interpreting and defining the environment—operating the bombsight—required expertise at a specific human skill set, and the need for that expertise led to the creation of an "engineered" human, whose identity would become completely defined by his ability to use the bombsight.

F-5G/1923- /Bombsights Automatic Bomb Sight for Use with Electrical Bomb Releasing Mechanisms/Field Instructions, National Museum of the United States Air Force.

[57] Everly G. Crouser, "People On The Target," in *Bombardier: A History, Volume II*, by Philip A. St. John (Paducah, KY: Turner Publishing Company, 1998), 31.

[58] Allan G. Bromley, "Analog Computing Devices," in *Computing Before Computers*, ed. William Aspray (Ames, IA: Iowa State University Press, 1990), 163-168.
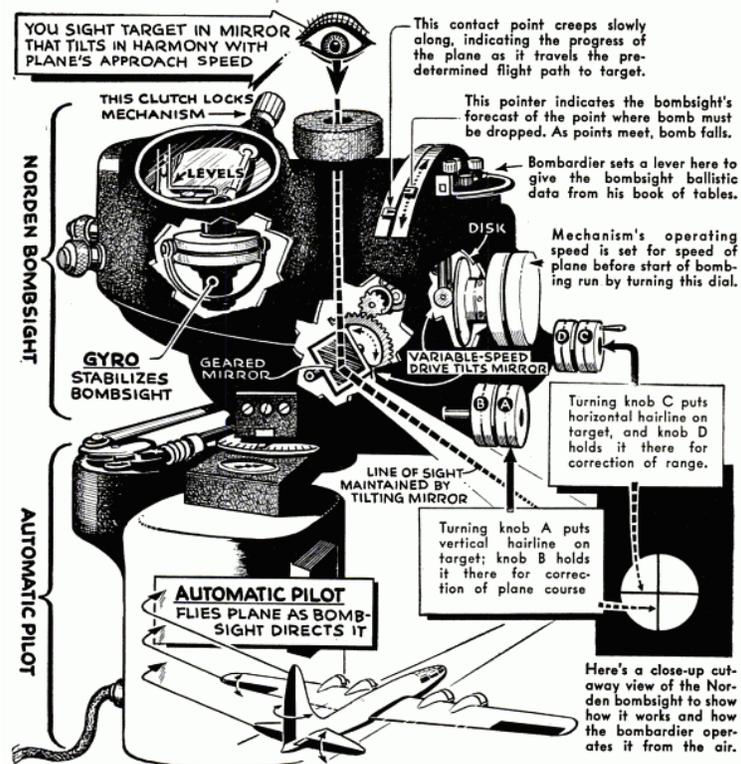
Figure 5.18
The Norden M-Series bombsight in operation[59]

Solving the Problem—Engineering the Bombardier

The history of the development of the bombardier in the Air Corps shares many common themes with the development of the navigator. Like navigation, the Air Corps' leadership long considered bombing just another task for the bomber pilot—a *necessary skill* that he was expected to perform as needed. As with the navigator, the bombardier did not exist as a dominant, single-task, non-pilot technical specialist until the pressures of wartime expansion and the HADPB doctrine forced his creation. Similarly, mastery of a specific machine and task defined him and provided his personal and professional identity. Finally, even more so than navigator training, bombardier training rigorously fused human and machine together into an integrated, socio-technical man-machine.

While the bombardier did not exist as a dominant non-pilot entity before World War II, Air Corps bombardment doctrine recognized the importance of the task of bombing and the need for a specific member of the bomber crew to perform that task far sooner than for navigation.

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[59] Torrey, "The War's Most Closely Guarded Secret Revealed: How the Norden Bombsight Does Its Job," 71.

Whereas the navigator appeared only in the earliest versions of the Air Corps Tactical School (ACTS) *Bombardment* Text, and then only as "the bomber in the formation leader's plane," the text discussed the role of the "bomber" in *all* versions, from the earliest through 1938, the last year of the school's operation.[60]

The doctrinal use of the title "bomber" is itself instructive. It describes a specific *task* rather than a specific *profession*. It is akin to calling a pilot a "flyer" rather than a pilot because he or she performs the task of flying an airplane.[61] The term "bomber" specifically identifies the person as the task. The timing of the official shift to the use of the term bombardier, which identifies the person who performs the task rather than the task itself, is unclear. Doctrinally, bomber appeared at least as late as 1935, but by the publishing of the 1938 version of the ACTS *Bombardment* text, bombardier was in use. Regardless of the exact timing of the shift, it emphasizes that the Air Corps viewed bombing itself as a just a task.

From the earliest iterations of bombardment doctrine, the bomber's role as a technical specialist associated with specific equipment was clear. The 1924-25 *Bombardment* text defined the bomber's duties as follows:

> to see that everything connected with carrying and releasing the bombs is in proper condition. He supervises loading the bombs and the setting of the release mechanism. He watches the fusing and accompanies the armament officer in making a final inspection. He checks the condition of his sight. When the bombs are loaded and fused a considerable time before take-off, the safety pins are left in place in the fuses. The bomber removes these just prior to take-off. He inspects his guns and ammunition. He studies the route to be flown and, like the pilot, prepares himself to know his location at any time during the mission. Particularly, he selects prominent landmarks near the target by means of which he can orient himself at all times despite the confusion which may prevail during the attack. He consults with the pilot regarding altitude and speed of bombing, and arranges signals to be used with the pilot and with the other teams.

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[60] *Bombardment: 1924-1925* (Langley Field, VA: Air Service Tactical School, 1924), 42. The paragraph headings that described the roles of the Pilot and the Bomber both used capital letters in the 1924-25 text. Both the navigator and gunner were listed with lower case letters, implying lesser importance. In the 1926 text and beyond, the capitalization was dropped, but, as discussed previously, the navigator had disappeared by the publishing of the 1930 text. For a history of the Air Corps Tactical School, see Robert T. Finney, *History of the Air Corps Tactical School: 1920-1940*, USAF Historical Study 100 (Maxwell AFB, AL: Research Studies Institute, USAF Historical Division, Air University, March 1955).

[61] The term flyer is used today in the Air Force as a general label for aviators, but applies generically to those involved in flying aircraft, such as pilots, navigators, and combat systems officers.

The bomber must know the mechanism and operation of his bomb rack as thoroughly as the pilot knows his motor. He must know the exact amount of pull necessary to release the particular bomb to be carried. He must understand the arming and safing device. He must be prepared to rid the plane of any bomb which hangs in the rack. His operation of the bomb sight must be *automatic* so that he is required to give it a minimum of thought and attention (emphasis added).[62]

This description is interesting on three specific accounts. First, it narrowly defines the bomber's duties as a list of specific tasks, and does so in terms of his equipment. His primary responsibility was to understand and correctly operate the specific systems related to dropping bombs, but also had a very specific list of actions to perform. Second, it essentially defines the role of the bombardier who would fly in the heavy bombers in the CBO nearly twenty years in the future. As this early text was based upon the experience gained during World War I, it demonstrates that there was little change in the duties or view of the bombardier for several decades. Bombing was a finite, defined task. Finally, it emphasizes the bombardier's operation of the bombsight must be *automatic*, requiring little thought or attention. Even in 1924, when bombsights were relatively simple devices, there was conscious recognition of the complexity of precision bombing and that the bomber and the bombsight comprised a single man-machine unit and that success demanded that they act as one.

Before World War II, the Air Service and Air Corps considered bombing primarily a pilot's job. During World War I, most bombardiers were also qualified bomber pilots, but as with navigation, a limited number of non-pilot Airplane Observers performed the function, as well. Unlike navigation, however, the Air Corps allowed enlisted pilots to train as bombardiers.[63] After the war, as was the case with the navigator, there was strong resistance to training non-pilots as bombardiers, but as bombsights became progressively more complex, that attitude began to change. A belief grew, at least in some circles, that this increasing complexity might eventually require further specialization, and that a need might arise for a technical specialist whose only duty was to operate the bombsight.

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[62] *Bombardment: 1924-1925*, 41-42.

[63] St. John, *Bombardier: A History, Volume I*, 32; The existence and role of enlisted aviators, particularly pilots, in the Air Corps and its successors is somewhat limited and beyond the scope of this project. For more on the topic, see Lee Arbon, *They Also Flew: The Enlisted Pilot Legacy 1912-1942* (Washington, DC: Smithsonian Institution Scholarly Press, 1998).

In 1936, Lieutenant Colonel C. L. Tinker, commander of the 7th Bombardment Group at Hamilton Field, California, wrote a letter to the instructors at the ACTS addressing the role of the bombardier as defined in the draft of the upcoming revision of the school's *Bombardment* text, stating that

> while the theory of each bombardier being a skilled pilot, machine gunner, and radio operator is a desirable one, it is believed that the exigencies of personnel procurement in war time will prohibit this. Particularly with the advent of the large bombardment airplanes, it appears that individual members of the crew must more and more specialize in their particular responsibility, which will make it less probable that the bombardiers can be thoroughly trained in each duty.[64]

When Tinker wrote this letter in 1936, the Air Corps was already using a limited number of Norden bombsights. As the commander of a bombardment wing, he had first-hand experience with the technical complexity and difficulty operating the device, and understood the amount of time and training necessary to make a bombardier's actions *automatic* enough for precision bombing, and his comments about the "exigencies of personnel procurement in war time" would prove particularly prescient.

As with navigator training, the Air Corps did not consolidate or standardize bombardier training until forced by the personnel pressures associated with the World War II Air Corps expansion programs. Until that time, the Air Corps trained bombardiers at the unit level in one of its nine individual bombardment groups, five located in the United States and four overseas. The overwhelming majority of the graduates of these schools were enlisted pilots, and although each program addressed the basics of bombing, the curricula were not standard across groups, and none approached the depth of instruction necessary to create true bombardment experts.[65] These pre-war unit-level schools produced many graduates, as by 1930, Air Corps policy dictated that *all* of the pilots in bombardment squadrons qualify as bombardiers as part of their normal duty responsibilities. However, just like navigation, most pilots viewed bombing as a detractor that took them away from that which they loved—flying aircraft. For most, "dropping

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[64] Lt. Col. C. L. Tinker to Lt. L. Kuter, "Ltr. to Lt. Kuter re: Text on Bomb Aviation", April 24, 1936, Enclosed in ACTS 1935 Bombardment text.

[65] St. John, *Bombardier: A History, Volume II*, 11.

bombs was a secondary occupation…and hitting a target was a sometime thing, and not always important at that."[66] Bombing remained a task, while piloting the aircraft was their profession.

At the outset of the first wartime expansion program in 1939, the Air Corps faced a similar situation with bombardiers as it did with navigators—the need to fill many more requirements than they had pilots with which to fill them. Wartime planners forecast a necessary bombardier-to-pilot ratio of approximately 1 to 5, which under the initial 30,000 pilot program meant that the Air Corps needed to train almost 6,000 new bombardiers. Given time and personnel limitations, the Air Corps could not continue its practice of first qualifying bombardiers as pilots. Consequently, another non-pilot technical specialist was born when they adopted the very idea of training non-pilots as bombardiers advanced five years earlier by Lt. Col. Tinker, with an initial training plan to train 3,300 officer bombardiers and fill out the requirement with enlisted trainees.[67]

The existing group bombardier schools could not handle the increased volume of trainees, and when the forecast 50,000 pilot program called for over 11,000 bombardiers and the 70,000 pilot program over 14,000, the need for a centralized, high-capacity, formal training structure, similar to the one being established for navigator training, became obvious. In April 1941, the inaugural class of 34 trained bombardiers graduated from the first formal bombardment school, established at Lowry Field, Colorado. By the end of the war, the USAAF had opened 16 more schools and trained over 47,200 bombardiers. Interestingly, with the establishment of this first school came the decision to stop training enlisted bombardiers and limit training to officer candidates only, as was being done with pilots and navigators, and the last group of enlisted bombardiers graduated from training on 19 December 1942.[68]

As with the navigation, it took a war to elevate bombing above the level of task and raise it to the level of profession. The *bomber* had become the *bombardier*, and was a necessary member of the bomber crew. However, his association with a specific machine—the bombsight—more so than even the navigator, would define him as a professional and shape his recruitment, training, and ultimately his use in combat.

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[66] Ibid., 12.

[67] Ben R. Baldwin, *Individual Training of Bombardiers*, Army Air Forces Historical Study 5 (Washington, DC: U.S. Army Air Forces Assistant Chief of Staff, Intelligence Historical Division, May 1944), 8, 23.

[68] St. John, *Bombardier: A History, Volume II*, 12-13, 31; Baldwin, *Individual Training of Bombardiers*, 21-25.

Recruiting—Creating the Role and the Construction of the Bombardier

In a familiar theme, the initial plan for sourcing bombardier trainees was the same as the plan for sourcing navigators—using pilot training washouts. Predictably, there were similar concerns about poor morale among trainees and the bombardier training community resisted the practice. However, unlike navigation, the number of recruits who volunteered for bombardier training never met the required quota, as only 4-5% of Aviation Cadet recruits voluntarily opted for bombardier training when given the option.[69] Overwhelmingly, they preferred pilot training, as reflected in the words of one B-29 navigator:

> We were vaguely aware that there were such flying officers as navigators
> and bombardiers, but no one ever joined the Air Corps to become one.
> The pilots were the glory boys. They were the ones who got the publicity,
> and it was their pictures that you saw in national magazines. I wanted to
> be a pilot. In my mind it was either that or wash out. Other alternatives
> had not even occurred to me.[70]

In short, most recruits wanted to drive the plane rather than ride in it. There was also an added element of danger for the bombardier that may have negatively affected the number of volunteers. The bombardier's crew position in all of the World War II heavy and very heavy bombers was right in the front of the aircraft, where the bombardier was protected only by the clear Plexiglas nose. It was the most exposed position in the aircraft, and bombardiers suffered more casualties than any other bomber crewmember during the war.[71] Throughout the war, the USAAF had to continue using nonvolunteers and pilot training washouts as bombardiers.[72]

The Air Corps tried to alter this negative attitude in the same recruiting campaign that had targeted mathematically oriented young men for navigation training. However, the recruiting angle for bombardiers was not as clear, as it was difficult to determine who was best suited for bombardier training. While high school graduates did perform better in bombardier training than non-graduates, there was no clear link between specific academic qualifications and success. Aviation Cadet Qualifying Examination results indicated strong correlation only between performance on the reading comprehension section of the examination and completion

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[69] Baldwin, *Individual Training of Bombardiers*, 6.

[70] Larry Nelson, *Hell for Honshu: An Army Air Corps Navigator Tells the Story of the World War II Bombing Raids on Japan* (Denver, CO: Outskirts Press, Inc., 2007), 19.

[71] McFarland, *America's Pursuit of Precision Bombing*, 153-154.

[72] Baldwin, *Individual Training of Bombardiers*, 7-8.

of bombardier training. This was of little help, however, as it was not unique to bombardiers and showed positive correlation for pilot and navigator training, as well. Performance on the mechanical comprehension section showed some correlation, which makes sense as the bombardiers worked with complex machinery, but this section was actually a better predictor of success in pilot training.

Of interest, performance on the judgment section, which was the best section for predicting pilot success, showed *no* correlation with success in bombardier training.[73] In short, bombardier training was structured to teach the trainee how to execute a set of instructions that did not require the application of judgment. It recalls the quote from B-24 pilot William Carigan, referenced in Chapter 3, that "bombardiers were chosen from those who gave quick and erroneous answers."[74] Action and execution were important, and if the task were appropriately structured and controlled, sufficient.

The USAAF recruiting effort that downplayed the role of the bomber pilot focused attention on the bombardier as the essential team member who reliably accomplished his task. Period recruiting materials emphasized the critical importance of flawless performance at the key moment in the mission, describing the bombardier's duty as

> performed in a matter of seconds—but the most important seconds of the flight. At the crucial moment, when the bomber reaches its objective, the bombardier takes over from the pilot. Upon his skill in landing his bombs on the target depends the success of the entire mission.[75]

Jimmy Stewart, in *Winning Your Wings*, stressed the bombardier's role as the central purpose for the entire mission, describing him as

> the boy who doesn't miss. You see flying the plane is wasted motion unless this lad hits the target on the noggin. The finest pilots in the Air Force would be behind the eight ball if the bombardier couldn't hit straight.[76]

[73] Robert L. Thompson, *Initial Selection of Candidates for Pilot, Bombardier and Navigator Training*, Army Air Forces Historical Study 2 (Washington, DC: U.S. Army Air Forces Assistant Chief of Staff, Intelligence Historical Division, November 1943), 39-44.

[74] William Carigan, *Ad Lib: Flying the B-24 Liberator in World War II* (Manhattan, KA: Sunflower University Press, 1988), 74.

[75] *Aviation Cadet Training for the Army Air Forces*, n.d., 15.

[76] John Huston, *Winning Your Wings*, Recruiting (U.S. Army Air Forces, 1942), http://www.archive.org/details/WinningYourWings (accessed 12 December 2010).

A recruiting ad in *Popular Science* further emphasized the importance of the task itself, portraying the bombardier as

> the fellow who presses the button and "lays the eggs." When your ship is over the target, you'll take charge—and deliver the "knockout punch."[77]

The message was clear and consistent—the bomber and its crew existed so that the bombardier could perform this essential task—bombing. The single task of bombing defined the bombardier.

The ideas presented in the recruiting campaign did influence some recruits to choose bombardier training. Bill Smallwood, a B-17 bombardier who flew in the CBO, recounts that the significance of the task was a factor in his decision. He volunteered after talking to a combat veteran bombardier who made the situation clear when he said "if the bombardier doesn't function successfully on a mission, the whole thing is futile."[78] Some enjoyed the concept of the responsibility, while other factors, such as the desire to get into combat as quickly as possible, also played a role. Although Smallwood was not alone in his decision, the Air Corps' recruiting efforts were not as successful as those aimed at navigator recruits, and the majority remained pilot training washouts and nonvolunteers.

Perception and Professional Identity

The bombardier's self identity was distinctly shaped by the ideas presented in the wartime recruiting campaign. Of interest in the recruiting advertisement in *Popular Science* mentioned above is the direct reference to pressing "the button." It conveys the idea of the bombardier as a man of *action*, in control of the task of dropping the bombs. However, under normal circumstances, the Norden bombsight had no button for the bombardier to press. The bombardier set up the bombsight and, at the appropriate moment, the bombsight itself automatically released the bombs so that the limits of human reaction time did not cause the bombs to miss the target. The bombardier was not excluded from the process, as he still had to raise the release lever on the bombsight, but the bombsight itself effectively dropped the bombs.

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[77] U.S. Army Recruiting Service, "You'll be on the Greatest Team in the World!," *Popular Science*, December 1943, 19.

[78] Smallwood, *Tomlin's Crew*, 13.

The concept of pressing that button as the central purpose of the mission, though, did assign *priority* to the bombardier—nothing was accomplished until he pressed that button. It produced a simple visual image of a single action that was the culmination of the entire mission and concentrated the prestige of the bombing mission on the bombardier. Lt. Col. Charles "Combat" Hudson, a bombardier during the CBO, captured it thus:

> (the bombardier) had to fly the aircraft under the most harrowing conditions, straight and level over the target, for the pilot who flies the aircraft to and from the target never drops the bombs. The Norden bombsight was the most sophisticated bombsight in the world. This bombsight, through manipulations by the bombardier, takes into consideration several factors, including air density, wind force and direction, air and ground speed of the aircraft, drift, bomb configuration and other readings. Then it gradually centers two cross-hairs on the target, which might be miles ahead, telling the bombardier, who by now has taken charge and is actually *flying* the aircraft, how to get into the exact position and altitude and precisely when to drop the bombs (italics in original, underline added).[79]

Hudson's professional image is clear. He is the master of the bombsight, which tells *him* when to drop the bombs. Again, the importance of that single task is a reinforced as a defining element. However, if this study illustrates nothing else, it is obvious that the precision bombing system was far more than a single human or machine accomplishing one key function.

Also interesting is Hudson's statement that it is the bombardier, not the pilot, who is flying the aircraft at the crucial, most harrowing moment during the mission. As described above, however, many bombardiers were washouts from pilot training, having failed to learn to fly, and he makes no mention of the autopilot that allows him to "fly" the aircraft. While the action of dropping the bombs is built up as the culmination of the entire crew's efforts, which should be recognition enough of professional value, he finds it necessary to present that the bombardier, by flying the aircraft, assumed control of the mission from the pilot.

By implying that it was he, rather than the pilot, flying at the critical point in the mission, he is intentionally downplaying the pilot's role and skill, but it is a skill that he himself wished to possess. In fact, there was even an attitude among the bombardier community that regarded pilots as "glorified chauffeurs," whose only purpose was to deliver the bombardier to the point

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[79] Robin Neillands, *The Bomber War: The Allied Air Offensive Against Nazi Germany* (Woodstock, NY: Overlook Press, 2001), 169.

where he would assume control of the aircraft, and hence the mission, to accomplish their real purpose.[80] That image of the bombardier as the master of the bombsight and the single living purpose of the bombing mission is, however, misleading. The bombardier was, in fact, the product of an extensive training program that focused on creating a single, interdependent socio-technical bombardment *unit* that performed the task of precision bombing.

Combining the Socio and the Technical—Training and the Making of the Man-Machine

Just as early bombsight designers understood the technological and human shortcomings that contributed to bombing error, so to did they recognize the importance of experience and adequate bombardier training. After World War I, Henry Inglis summed up the relationship between experience and accuracy thus:

> The usual late war types of bombsights provide a considerable degree of accuracy, but only in the hands of trained teams because they allow too many personal errors of operation. Results are erratic because of varying degrees of experience.[81]

Experience could only be gained with time, but the bombardier training schools set up during World War II were structured to provide the repetitive training that would turn the bombardier recruit and his bombsight into a single, socio-technical man-machine.

The USAAF conducted bombardier training in two stages. The first stage, initial training, is the focus of this discussion, and during that time, the bombardier trained only with other bombardiers, learning the basics of bombardment. It was in initial training that the bombardier learned how his particular tools operated and how to use them, as its purpose was to produce an

> individually qualified specialist, whose experience in teamwork (was) limited almost entirely to that of pilot-bombardier cooperation and who…had little or no experience in bombing from tactical aircraft and at maximum altitudes.[82]

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[80] 1st. Lt. I. Brown, "Training Aids-Victorville," in *Trajectory* (The Army Air Forces Instructors School (Bombardier), 1943), 6.

[81] Quoted in Toole, *The Development of Bombing Equipment in the Army Air Forces*, 5.

[82] Baldwin, *Individual Training of Bombardiers*, 4.

The second stage, operational training, was conducted with the rest of the bomber crew, but focused on the more general conduct of a combat mission, and is beyond the scope of this study. During that stage, the crew learned how to operate as a complete team and employ their aircraft and weapon systems in a more combat representative manner, dropping bombs from maximum tactical altitudes using combat tactics.[83]

The length of the initial training stage varied throughout the war, as the need for bombardiers in the combat theaters fluctuated. Shortest prior to June 1943, when the operational need was the most pressing, it lasted 12 weeks. Graduates of this program were notably deficient in many areas, including basic performance and problem solving. As the war progressed, the program lengthened first to 18 weeks, and eventually to 24 weeks to incorporate more training and better prepare the graduates for combat.[84] Ground training comprised the majority of each program, during which, in addition to learning basic bombing theory, trainees focused on learning how to operate their bombing equipment, including the bombsight, bomb racks, and the AFCE or the C-1 Autopilot. The aerial portion of the training program focused on two primary areas: gaining enough proficiency with the bombing equipment to be able to drop consistently accurate bombs, thus achieving the qualifying score necessary for graduation, and developing smooth pilot-bombardier coordination.

Bombardier initial training revolved around the bombsight. It was during this time that the bombardier and the bombsight became a single system. Most bombardiers trained on the Norden M-Series bombsight, although through the middle of 1943, bombardiers destined to fly the B-24 trained with the Sperry S-1 sight. Troubles with reliability, accuracy, and availability limited that sight's usefulness, and eventually caused the USAAF to discontinued using it.[85] During training, recruits learned how to operate, repair, and calibrate these bombsights, while also learning the theoretical elements of the bombing problem. The bombsight was at the center of almost everything that they did, and they used specialized training devices, both on the ground and in the air, to increase their familiarity and proficiency operating it.

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[83] Ibid., 54.

[84] St. John, *Bombardier: A History, Volume II*, 13-14; Baldwin, *Individual Training of Bombardiers*, 49-52.

[85] The decision to discontinue the use of the Sperry S-1 bombsight has been debated several times. See Searle, "The Bombsight War: Norden vs. Sperry" for a good summary of the argument for continuing the use of the Sperry sight. The best sources for information on the acquisition and performance of both systems are *Case History of Norden Bombsight and C-1 Automatic Pilot, Parts I and II*; *Case History of S-1 and A-5 Automatic Pilot* (Wright Field, OH: Historical Office, Air Technical Service Command, June 1945), 202.2-14 V.1 and V.2, IRIS No. 142110 and 142111, US Air Force Historical Research Agency.

Procedure and Human Mechanization

On the ground, the bombardier first learned how to use the Norden in the skeletal A-2 bombsight trainer, a moving tricycle tower that held an operable bombsight and seats for the bombardier, an instructor, and a "pilot" (Figure 5.19). During a training run, the bombardier operated the bombsight just as he would in a bomber aircraft, attempting to "bomb" a target on the floor. The target, or "bug," was small metal box, propelled by an electric motor, and its movement simulated airborne drift. As the bombardier operated the bombsight, it passed steering commands to the pilot on a PDI, just like in the aircraft. When the A-2 reached the simulated bomb release point, an observer noted the bombsight position and recorded the "bombing" result.[86]
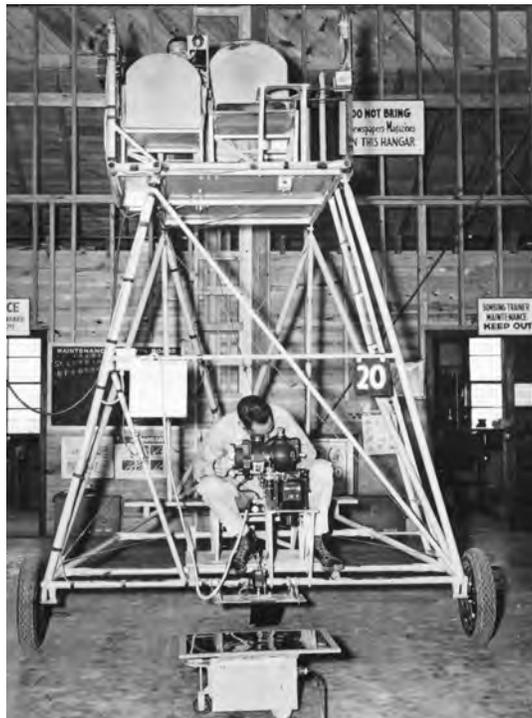
Figure 5.19
Norden bombsight A-2 ground trainer[87]

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[86] *The Norden Bombsight: Operation*.

[87] St. John, *Bombardier: A History, Volume I*, 18. This photograph shows the bombardier seated at the base of the trainer, looking through the bombsight, and the "pilot" peering out from behind the instructor's seat at the top of the structure. The light-colored box-like device on the ground in front of the trainer is the bug. For the run pictured, the bombardier is simulating a bombing attack from an altitude of 1,500 feet. For a higher altitude simulation, he would sit in the top right seat with the bombsight installed in front of his position.

In addition to providing training on the bombsight, the A-2 provided valuable crew-coordination training between the bombardier and the simulator pilot. The bombardier learned how his actions influenced the "aircraft" flight path. Later in the war, bombardiers trained in the more advanced A-6 trainer, which simulated the bombardier's ability to control the aircraft with the bombsight coupled to the autopilot (Figure 5.20). Trainees spent many hours in these simulators, as repetition was the key to learning the procedures for operating the bombsight.
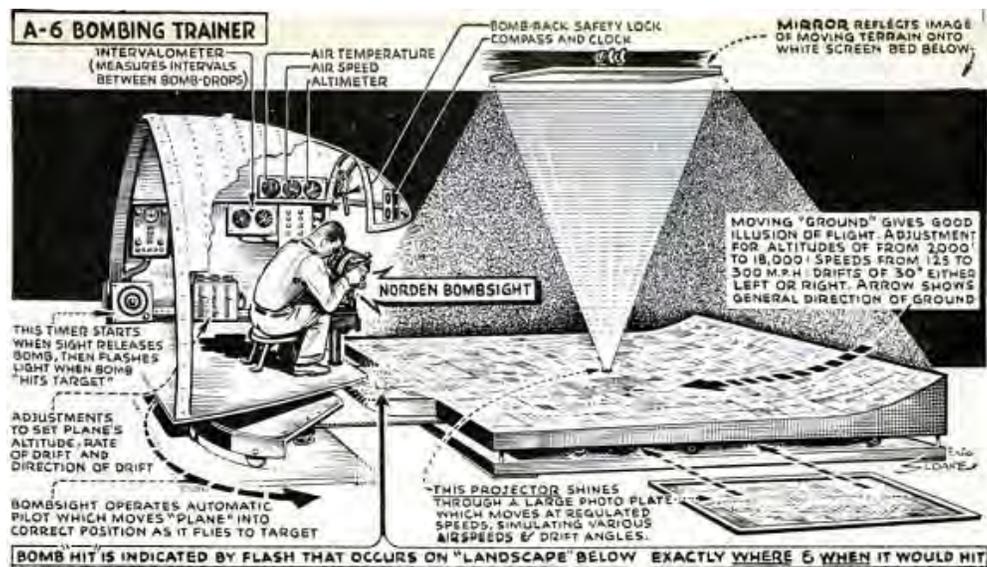
Figure 5.20
The A-6 Bombing Trainer, as depicted in the June 1945 issue of *Popular Science*.[88]

Airborne training built directly upon the ground simulator training, once again using a real bombsight in specially designed equipment. The trainees flew practice-bombing missions in a modified Beech AT-11 that had a Norden bombsight installed behind the Plexiglas nose of the aircraft, similar to those installed on combat bombers (Figure 5.21). Two trainees flew on each training mission with one instructor, taking turns dropping individual practice bombs on targets located on a bombing range. The aircraft provided a more realistic environment and presented more challenges for the trainee, from varying winds that changed the aircraft drift, to haze that obscured the target, and turbulent air that upset both bombing solutions and the trainees' stomachs. They dropped only one bomb at a time so that they could make multiple bombing attacks during each sortie. Again, repetition was the key to success.

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[88] Torrey, "The War's Most Closely Guarded Secret Revealed: How the Norden Bombsight Does Its Job," 73.

Coordination with the pilot received special emphasis in the air, as it did on the ground. Effective coordination between the bombardier and pilot was as critical to precision bombing as the ability to use the bombsight, both when using the PDI or, later, when using the C-1 Autopilot.[89] When the bombardier was controlling the aircraft flight path, the pilot still had a pivotal role, whether following the PDI or controlling the throttles while using the C-1, and was thus included as a part of the small socio-technical system with the bombardier and his bombsight. The success of the system depended upon all of the human and machine elements working together harmoniously.
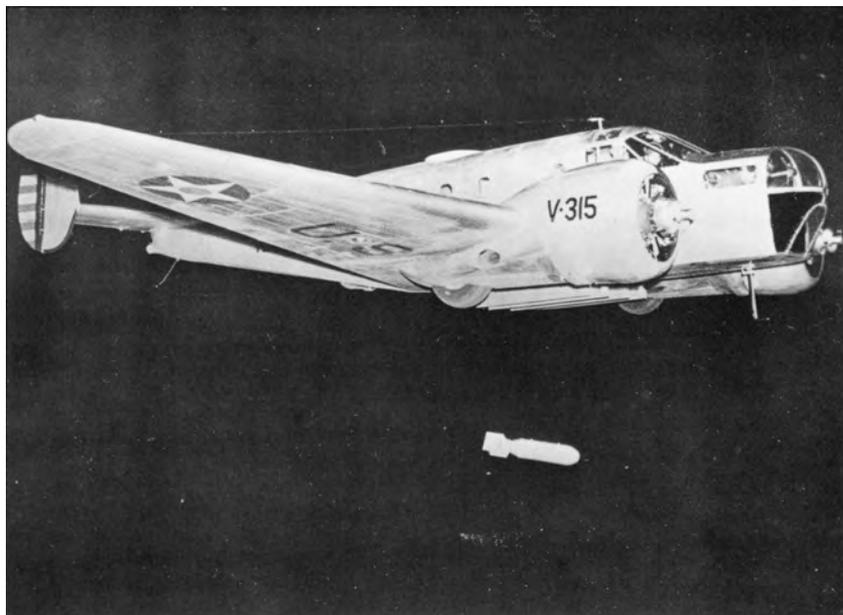
Figure 5.21
Beech Aircraft AT-11[90]

Both the A-2 and the AT-11 gave the trainees many opportunities to practice the tasks that they would perform on an actual combat mission. The ground and air training was structured around repetition. Throughout each training event, their instructors preached the mantra—"follow procedure, follow procedure."[91] Procedure was drummed into their heads in an

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[89] Baldwin, *Individual Training of Bombardiers*, 110.

[90] *Beech AT-11*, Photograph, n.d., National Museum of the United States Air Force, http://www.nationalmuseum.af.mil/shared/media/photodb/photos/050520-F-1234P-040.jpg (accessed 4 January 2011). Note that a censor has blacked out the lower portion of the nose in this picture to hide the Norden bombsight.

[91] Smallwood, *Tomlin's Crew*, 34.

effort to make their actions *automatic.* Unlike the navigator, who had his Flight Plan and Flight Log to guide actions, the bombardier had to learn his by rote and be prepared to execute them under the extreme pressure of the most stressful, dangerous portion of the mission—the bomb run. The Norden bombsight had automatic functions that reduced the opportunity for human error during bombing, and the bombardier training program did its best to mechanize the human to the maximum extent possible, as well.

Bombardier and Bombsight—Bonding the Socio-technical

Through the training program, the emphasis on procedure and repetition did bring the bombardier and bombsight together into a socio-technical unit, effectively thinking, acting, and perceived as one. Training films intentionally portrayed the bombsight as "part of (the bombardier's) brain," and its use even left a physical mark, fusing the bombardier's public image with the device.[92] The cover of the 18 May 1942 edition of *Life* magazine captures the iconic image of the World War II bombardier, a black ring around his right eye, left there by the rubber protective pad installed over the bombsight's optics to protect him injury during the turbulence of flight (Figure 5.22). That black eye was *the* mark of the bombardier—it made him instantly recognizable, as no other crewmember had one, or anything comparable for that matter.

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[92] *The S-1 Bombsight: Principles* (Army Air Forces Training Film Production Laboratory, 1943).

Figure 5.22
The bombardier with his blackened right eye[93]

The bombardier's bond with the bombsight extended, however, beyond a temporary tattoo or the stretched concept of a man and machine thinking as one. The bombardiers also made an emotional commitment to the bombsight. The Norden bombsight was a very expensive, secret device, and they swore an oath to protect the secrecy of its existence and its operation.[94]

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[93] William C. Shrout, *Bombardier*, May 18, 1942, Life Magazine.

[94] Although often referred to as America's worst-kept wartime secret, the Norden bombsight's existence was not officially acknowledged until 1944, when the New York Times revealed that the United States had provided them to Russia that spring. See McFarland, *America's Pursuit of Precision Bombing*, 206.

Cadet Oath

*In the presence of Almighty God, I do solemnly swear and affirm that I
will accept the precious trust placed in me by my Commander in Chief the
President of the United States of America by whose direction I have been
chosen for Bombardier Training.*
*I pledge myself to live and act according to the Code of Honor of the
Bombardiers of the Army Air Forces. I solemnly swear that I will keep
inviolate the secrecy of any and all confidential information revealed to
me, and in the full knowledge that I am a guardian of one of my country's
most priceless Military assets, do further swear to protect the secrecy of
the American Bombsight, if need be, with my life itself.*[95]

In addition to protecting their knowledge of the bombsight and its operation, bombardiers were
directed to attempt to destroy it at all costs if there was any possibility that it might fall into
enemy hands. The exact method of destruction was not prescribed, but shooting was mentioned
as an option, although it was unlikely that this would sufficiently disable it, as one bombardier
noted, "that would only lead to bullets bouncing around the cockpit—they were tough little
instruments."[96]

Figure 5.23
A bombardier cadet class taking the oath before seeing the Norden bombsight for the first time[97]

While some may question the true gravity of an oath in which a human swears to protect
a mechanical instrument with his life, some bombardiers took it very seriously. Lt. Bill

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[95] *Through the Crosshairs: Classbook for Bombardier Class 43-11* (Big Spring, TX: United States Army Air Forces
    Advanced Bombardier School, 1943). Some considered the oath "superfluous," as soldiers already took an
    oath to destroy equipment before it fell into enemy hands. See McFarland, *America's Pursuit of Precision
    Bombing*, 276, note 18.
[96] Neillands, *The Bomber War*, 169.
[97] *Taking the oath before seeing the secret Norden bombsight on the table*, Photograph, n.d.,
    http://www.nationalmuseum.af.mil/shared/media/photodb/photos/050520-F-1234P-038.jpg (accessed 7
    January 2011), National Museum of the United States Air Force.

Smallwood, a B-17 bombardier who was shot down and injured on 25 February 1944 during the massive Regensburg mission, actually crawled back into the nose compartment of his stricken bomber after helping other crew members escape, and shot his bombsight three times with a Colt .45 automatic pistol before bailing out himself. His rationale? At bombardier school, he had been trained "never to allow the enemy to get hold of the Norden sight."[98] Smallwood's actions, though likely ineffective, and willingness to risk his own life to protect the secrecy of the bombsight, demonstrated some measure of the attachment between the bombardier and the bombsight.

Through the repetition of the bombardier training program, with its specialized training devices and focus on procedure, the bombardier and bombsight became a single socio-technical unit. They were inseparable, with both defined by their shared function—precision bombing. Together, they were the result of over twenty years of effort to reduce the technological and human sources of error in bombing. The bombsight enabled the bombardier to perform functions that a human could not perform unassisted, such as calculating the location of the bomb release point in real time, directing the aircraft precisely to that point, and releasing the bombs upon the instant of arrival. The bombardier interpreted and created the environment that allowed the bombsight to perform those functions. Through technology and training, they were automated as much as was possible at the time to ensure that they, as a unit, could perform under the pressure of the most stressful portion of the bombing mission—the bomb run. The bombardier, as the human part of that unit, was the one gathered with the rest of the members of the bomber crew in the General Briefing room on the morning of their bombing mission.

The Purpose—Dropping Bombs and Hitting Targets

The Norden M-Series bombsight, with its ability to calculate the bomb release point, accurately direct the aircraft to that point, and release the bombs at the instant that the aircraft arrived, technologically eliminated most of the sources of bombing error. However, it was still dependent upon the bombardier for two critical functions: first, find, identify, and track the target, and second, interpret and enter the environmental data that the bombsight needed to perform its calculations. The bombardier accomplished these actions in the air, but, as with navigation, prepared for them extensively on the ground beforehand, beginning with mission

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[98] Smallwood, *Tomlin's Crew*, 152.

planning. It was during that time that he learned the details of the mission and acquired the essential data the enable him to construct a mental model of the mission that would guide his actions in the air.

The Bombardier's Briefing

During the General Briefing, attended by all of the crewmembers, the bombardiers learned the basics of the mission for the day, including details about the Initial Point (IP), axis, altitude, and airspeed of the bomb run, as well as operational data about the target and aiming point. The briefer also provided information on bomb loading, fuzing, fuel, ammunition, and any special tactics planned for the mission.[99] As with the rest of the crewmembers, it was the first time that most of them found out where they were going that day. It was in the separate Bombardier's Briefing afterward that they learned the essential details that would dictate their actions during the mission (Figure 5.24).

At the bombardier's briefing, the Group Bombardier concentrated on the specifics and mechanics of the bomb run. As with the Group Navigator, this bombardier rose to his position based upon demonstrated excellent performance and was responsible for the group's mission planning. Each bombardier received a flimsy containing bombing-specific information, including the forecast winds and weather coverage over the target and precomputed bombing data. This precomputed data included the planned altitude and airspeed for the bomb run, as well as values for the bombsight trail setting and the bomb dropping and sighting angles. The values were preliminary, as they were computed with forecast weather data, but served as initial planning factors and could function as a check on the bombardier's inflight calculations, where large deviations from the printed data could reveal errors made under the pressure of the bomb run.[100] After reviewing the data, the bombardiers' attention shifted to their primary function as the human element of the bombardment unit—preparing to find and identify the target.

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[99] *Bombardiers' Information File*, 8-2-1.

[100] Ibid., 8-2-1 - 8-2-2.

Figure 5.24
The Bombardier Brief[101]

Mechanizing the Human—Building the Visual Mental Model

Finding and identifying the target was the bombardiers' final necessary task before dropping his bombs. They spent the rest of the brief studying the planned flight route from the IP to the bomb release point, reviewing maps, photographs, and other visual aids that would enable them to construct a visual mental model of the upcoming mission so that they could recognize the target when they arrived. Target location and identification was a crucial skill, and in the words of one bombardier, "in many ways the bombardier that was able to locate and recognize the target the soonest was the one that was the most successful."[102] The maps and photographs were collected into two types of folders. The first, the *air objective folder*, contained an index of the targets in the area and provided a general description of the region and specific targets, with extensive maps and photographs covering the entire target area. It remained on the ground and the Group Bombardier and his staff used it for mission preparation only. The second, the *target folder*, the mission bombardiers carried with them for reference during the mission.

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[101] *Bombardier briefing*, Photograph, n.d., US Air Force Historical Research Agency,
    http://www.afhra.af.mil/shared/media/photodb/photos/080305-f-3927P-028.jpg.
[102] Myers, *Shot at and Missed*, 212.
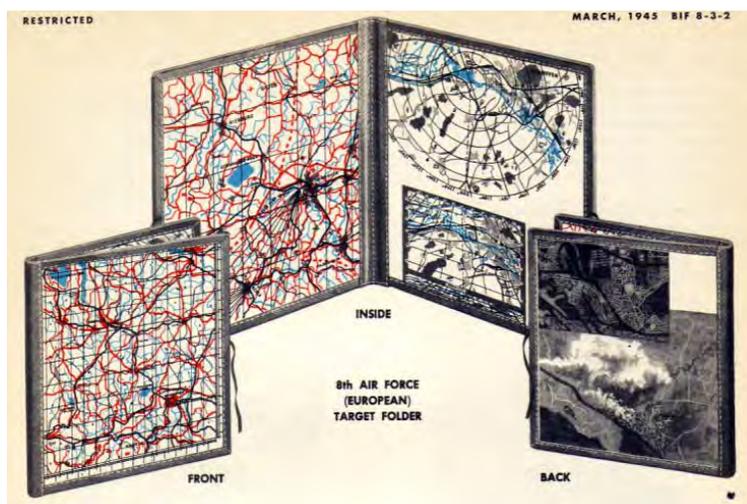
Figure 5.25
8th Air Force target folder[103]

The standard target folder used in the ETO was made from four sheets of 14-by-16-inch heavy acetate, stitched together on three sides to form a booklet. The top was open so that the bombardier could insert maps into the pockets, and the booklet was stiff so that he could stand it on end beside him in the aircraft for ready reference (Figure 5.25).[104] The contents of the folder varied, depending upon the amount of information available, but they generally contained essential maps, photographs, and charts, arranged in the order that they would be needed on the mission. Additionally, they might include regional or sectional aeronautical charts, scaled to show the route to and from the target area, but little detail (Figure 5.26). Charts covering the final phase of the target run, scaled at 1 inch to 4 nautical miles were included. These charts centered on the primary target and displayed prominent landmarks such as railroads, highways, water, and land elevations within a twelve-mile radius. They also showed the location of alternate targets within a four-mile radius, available for attack in the event weather or smoke obscured the primary target.[105]

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[103] *Bombardiers' Information File*, 8-3-2.

[104] Ibid., 8-3-1.

[105] Leroy W. Newby, *Target Ploesti: View from a Bombsight* (Novato, CA: Presidio, 1983), 222; *Bombardiers' Information File*, 8-3-2.
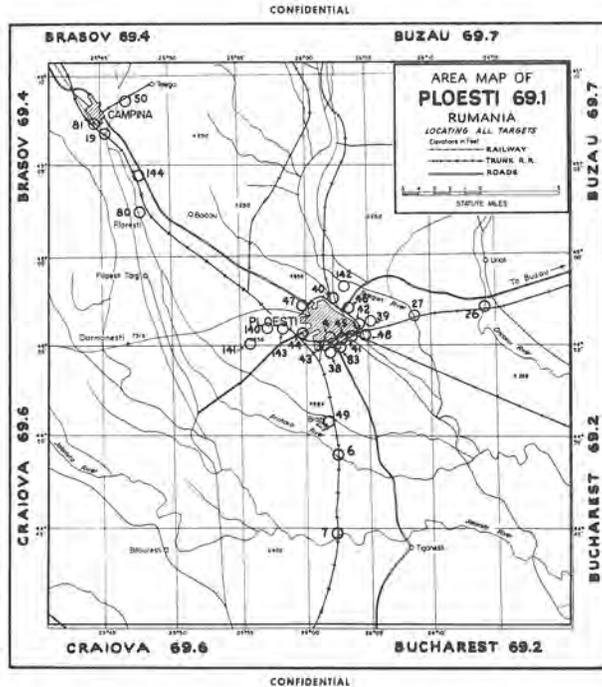
Figure 5.26
Regional chart of Ploesti, Rumania, from a target folder[106]

For rapid, final target identification, the bombardiers also carried specialized *target charts* and *perspectives* (Figure 5.27). The target charts were large scale, vertically oriented charts centered on the target area, but eliminated many of the usual details included on navigational charts, displaying only clear, geographical and cultural features that could assist in target location. For example, they displayed the general shape of the city, the dominant land and water patterns, railroads, and main highways, but did not show the entire street structure. The chart included five perspectives that displayed the target area from likely axes of approach, presenting a slant-view picture of the target area that showed how the terrain would look from the mission altitude.[107] The bombardiers used these and the other charts in the target folder to familiarize themselves thoroughly with the entire route from IP to the target so that they could quickly locate their position and, through pin-point pilotage navigation, direct the aircraft toward the target.

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[106] Newby, *Target Ploesti*, 222.
[107] *Bombardiers' Information File*, 8-3-2 - 8-3-4.
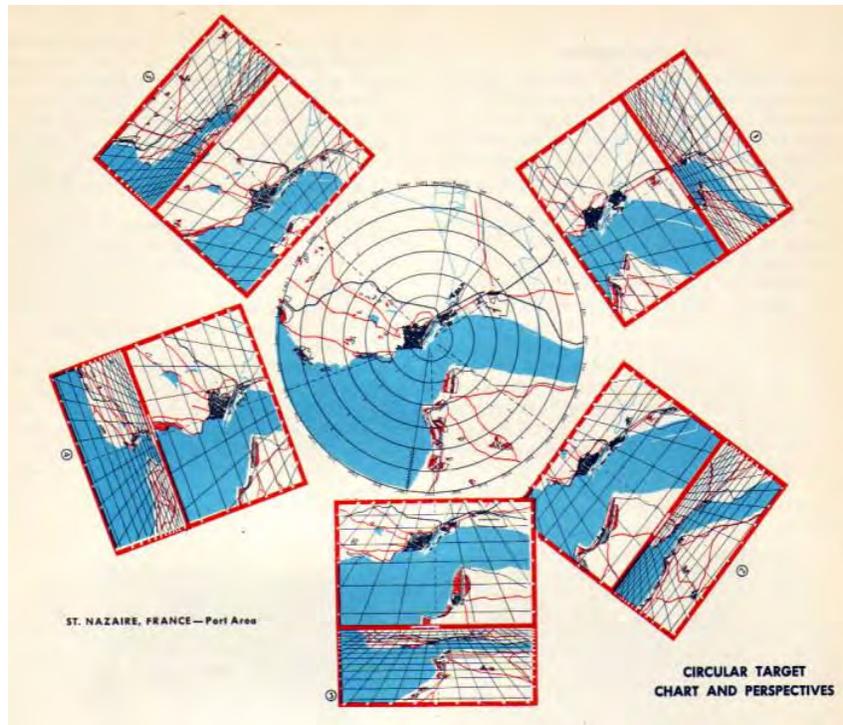
Figure 5.27
Circular Target Chart and Perspectives[108]

While the bombardier studied charts to learn the route to the target area, he also had to study the target itself, so that he could rapidly identify the specific aim point for his bombs among what might be a very large, complex industrial installation. When available, the Group Intelligence Officer projected target area photographs onto a large screen and pointed out the individual bombing aimpoints, as well as prominent physical features that would help the bombardiers locate them. The air objective folder also usually contained target area photographs for reference, taken from both vertical and oblique perspectives. The oblique photos were generally more useful for target recognition, as they represented the actual view that the bombardier would have during the target run. He would not see the target from the vertical perspective until the aircraft was flying over the target, after he had already released his bombs.[109] As the war progressed, target photographic coverage increased, as each bomber had a camera in the bomb bay that recorded the aircraft's bomb impact locations. The target area photographs were obviously very useful for target recognition, as they showed detail that was

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[108] Ibid., 8-3-4.
[109] Ibid., 8-3-5.

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absent from the charts in the target folder. If enough were available, bombardiers were authorized to carry them in their target folders on the mission.

In December 1943, the 1st Bombardment Wing (Heavy) discovered a method of making target study and recognition easier and more effective by constructing lifelike models, or "target tables," that reconstructed the target area in miniature. Based on a technique developed by the S-2 (Intelligence Officer) in a B-26 group, members of the wing planning staff built physical mock ups of individual target areas on linoleum-topped legless tables. To construct a model, they projected a target area photograph onto a tabletop with an epidiascope, and then sketched the target outlines with chalk.[110] They applied dyed sawdust to simulate fields, sealing it in place with shellac, built buildings of wood bits and plastic, and drew in roads, rivers, and lakes with colored chalk, creating a three-dimensional model that the bombardiers could examine from any angle. The models were very useful, and by February, the Wing had refined the process to the point that they could produce them overnight, between the initial receipt of the Field Order and the briefing time the next morning.[111]

The bombardiers used all of this information, from the charts, photographs, and models, to create a list of checkpoints along the route, identifiable features on the ground that they could use to guide the aircraft to the target. Suitable ground references included anything distinct that they could see and identify from the mission bombing altitude, both natural and manmade, including river bends, prominent mountain peaks, storage tanks, railroad crossings, stadiums, or any other contrasting objects. European targets, generally in or near cities, usually provided several cultural features suitable for use as checkpoints, whereas for targets in the Far East, which at the early stages of the war were on small Pacific islands, bombardiers had to rely upon geographic relief or distinct land and water combinations for recognition.[112]

Choosing appropriate checkpoints was a skill that bombardiers (and navigators) developed with experience. The bomb run altitude was a large factor in determining what types of ground features would be appropriate for selection. On high altitude missions, by far the most common in the ETO, the bombardier's perspective was much broader and more features were

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[110] An epidiascope is a device that can project opaque or transparent images onto a screen. It uses bright light to illuminate the image and then focuses and projects it through a series of prisms and mirrors.

[111] "1st Combat Bombardment Wing (H): Unit History 1 February, 1944 to 29 February, 1944", 1944, 4, Call WG-1-HI 1 Feb 44-29 Feb 1944, US Air Force Historical Research Agency.

[112] *Bombardiers' Information File*, 8-3-6 - 8-3-7.

visible, but they lacked detail. On these missions, the emphasis was on the use of combinations of large features or shapes, such as bridges crossing rivers or the shapes of city boundaries for checkpoints.

As navigating to the target by this technique was an entirely visual exercise, adverse weather could severely affect the bombardiers' ability to locate the target. A cloud layer beneath the aircraft could obscure those key checkpoints, and without any valid location reference, prevent the formation from accomplishing its mission. Poor weather in the ETO was a constant problem during the CBO, particularly in the winter months. Frequently, poor weather over England would prevent the bomber formations from taking off, and even when they could, weather over continental Europe would often cause them to either bomb alternate targets or return to England with their bombs. During January 1943, the 8th AF accomplished only four out of fourteen planned missions, and February was little better, with five effective missions. Although the weather improved in the spring, weather was still a major factor, allowing nine missions in March, four in April, and another nine in May.[113]

Weather was less a factor on the low altitude missions that 15th Air Force bombers occasionally flew against targets in Europe from their bomber bases in the Mediterranean Theater of Operations, but the bombardiers faced other navigation challenges. At low altitude, the perspective was much narrower and fewer prominent features were visible from the aircraft, although those that were appeared in more detail. While low altitude bomb runs could provide the valuable element of surprise, the apparent motion of the ground beneath the aircraft was much faster than at higher altitudes, and the bombardier had far less time to find and identify ground features, making navigation very difficult. Upon hearing that the final portion of the 15th Air Force B-24 raid against the Nazi oil facilities in Ploesti, Rumania, on 1 August 1943 was flown at an altitude of *thirty* feet, one exasperated 8th Air Force navigator was amazed, commenting that navigation at that altitude was impossible, as "the terrain went by too fast to locate it on the map. The mission was surely planned by the pilot."[114]

The bombardier's final step during the route and target study process was to distill all of the information gathered during the mission planning process into a single route map that

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[113] Arthur B. Ferguson, *The Early Operations of the Eighth Air Force and the Origins of the Combined Bomber Offensive 17 August 1942 to 10 June 1943*, U.S. Air Force Historical Study 118 (Washington, DC: U.S. Army Airforces Historical Office, October 1946), 215.

[114] Crosby, *A Wing and a Prayer*, 108.

covered the portion of the mission from the IP to the target. He plotted the briefed bombing approach course and marked his checkpoints on the map, and then used a plotter to construct multiple axes of attack, providing references for numerous possible approaches to the target should they be needed if the formation diverge from the primary route for any reason. Placing these alternate routes on the map put them in relation to his chosen checkpoints, and increased his chance of finding the target (Figure 5.28). This final map simplified the bomb run, distilling it down to a single, handy reference that contained only that information absolutely necessary for flying the route and finding the target.[115] All of the hard work and preparation that went into creating it, in the words of one B-17 pilot, "paid off handsomely in allowing (the bombardier) to distinguish the target under most unfavorable conditions, like cringing from pink bursts of flak and uncontrolled aircraft."[116]
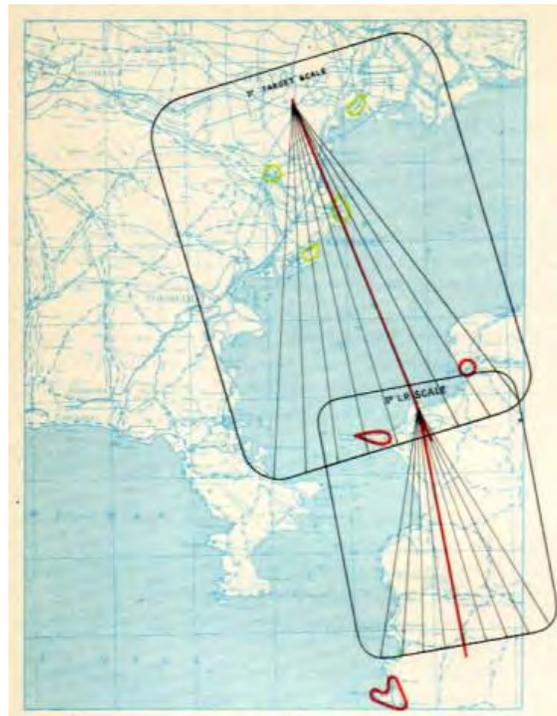
Figure 5.28
A sample IP to target run map[117]

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[115] *Bombardiers' Information File*, 8-3-9.
[116] Robert L. Hughes, "'Black Thursday' - 14 Oct 43", n.d.,
    http://www.100thbg.com/mainpages/history/history4/black_thursday.htm.
[117] *Bombardiers' Information File*, 8-3-9.

The bombardier's final target route map was, much like the navigator's Flight Plan and Mission Map, a sequential script for the bomb run. Each checkpoint marked another step toward the target. The process of preparing that map, the combination of the aeronautical chart study, photograph study and physical model study produced not only a physical guide to the target, but a visual mental model, as well. Through the integration of all of the visual data, the bombardier constructed an expectation of what he *should* see during the bomb run. That visual model became a part of the collective cognition that he would share with the Norden bombsight during the mission. The bombsight could calculate the bomb release point better than the human, but it did not know where the target was until told by the bombardier. It depended upon the bombardier to find and identify the target.

The Bombardier's Kit—Translation Tools and Interpreting the Environment

The bombsight was the bombardier's primary "tool," but he also used a variety of other specialized calculation and translation instruments that enabled him to "talk" to the bombsight— provide it the data that it needed to compute the bombing solution. Every student and graduate bombardier was issued a zippered, cloth case that contained those other tools, the items that the bombardier needed to set, operate, and adjust his bombsight. Enclosed were navigation tools, such as draftsman's dividers and parallel rule, a Weems plotter, pencils, erasers, and transparent triangles, as well as instruments for setting, using, and adjusting his bombsight. These included at least four manual bombing computers, bombing tables, dropping angle charts, a stopwatch, pliers, and a screwdriver.[118] He carried this case with him, in addition to his target folder, on every mission.

The navigation tools were critical, because they enabled the bombardier to make any necessary alterations to his charts or route plan if the mission changed once the formation got airborne. He also used them to perform one of his primary alternate tasks—navigation. The bombardier served as the backup navigator on the bomber crew, and his responsibility was to take over that task should the navigator become incapacitated or killed during the mission.[119] He was expected to be as adept with the E6-B as the navigator and have the ability to guide the

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[118] St. John, *Bombardier: A History, Volume I*, 31.

[119] *B-24: Pilot Training Manual for the Liberator* (Headquarters AAF, Office of Flying Safety, 1944), 239.

aircraft back home, if necessary, providing a welcome redundant capability for the aircraft level of the bombardment system.

Calculation and Interpretation—Quantifying the Environment

The most important items in the bombardier's kit were his manual computers, which enabled him to interpret the bomber's physical environment—altitude, airspeed, and drift—and "communicate" it to the bombsight. The computer used most often during the mission was the E6-B, as it provided the most capability to compute solutions to the general bombing and navigation problems that might arise.[120] Its capacity to solve multiple types of problems made it very useful calculations where accuracy was important, but did not require a great deal of precision. He used it just as did the navigator to compute the initial aircraft drift readings, which he used as a starting point when setting up the Automatic Bombing (AB) computer, which provided a much more precise value that was appropriate for the bombsight.

The three other manual computers in the bombardier's kit provided the capability to compute the more precise data required by the bombsight for precision bombing. The C-2, G-1, and J-1 computers were purpose-built, each for a specific calculation, and more accurate than the E6-B. They were larger and less complex than the E6-B, enabling greater accuracy, but were easier to manipulate and read in flight during the high-pressure, time-compression of the bomb run. The C-2 computer (Figure 5.29) was a circular slide rule, used to calculate the aircraft's bombing altitude, which was the aircraft height above the target at the time of bomb release. The bombardier calculated it using the target pressure altitude, obtained during the pre-mission briefing, aircraft pressure altitude above the target, calculated inflight with the E6-B, and the mean outside air temperature, which he read directly from the thermometer readout on his left-side instrument panel. Although the E6-B could perform the same calculation, the C-2 had a larger scale, enabling more precise calculations, and two clear plastic, swinging reference arms that made it easier to rapidly set up and read while wearing gloves in the extreme cold of high altitude flight.

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[120] St. John, *Bombardier: A History, Volume I*, 32.
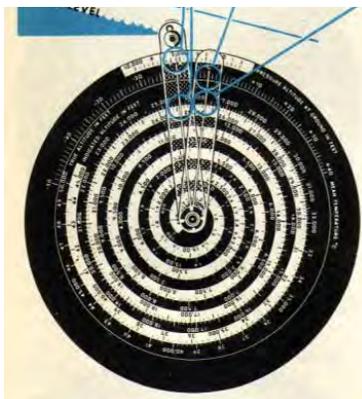
Figure 5.29
C-2 Bombing Altitude Computer[121]

The G-1 computer (Figure 5.30) calculated the aircraft true airspeed. Like the C-2, it was larger and easier to use than the E6-B, with a single plastic swinging reference arm. The bombardier used the J-1 computer (Figure 5.31) to calculate the initial sight angle setting for the bombsight telescope, and it was designed to rapidly produce sight angle solutions for bomb runs of 30 or 45 seconds, both typical values. All three of these computers produced bombing data that the bombardier set into the AB computer attached to the Norden bombsight.

Figure 5.30
G-1 True Airspeed Computer[122]

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[121] *Bombardiers' Information File*, 3-3-3.
[122] Ibid., 3-4-1.

Figure 5.31
J-1 Time of Run-Sighting Angle Computer[123]

The AB computer, discussed in the previous chapter, was another specialized manual computer, attached directly to the Norden bombsight (Figure 5.32). Although it remained in the aircraft and was not included in the bombardier's kit, it was a critical translation tool. Designed to calculate drift and vector triangles like the E6-B, the AB computer did so more rapidly, making it useful for calculating course corrections during the compressed period of the combat bomb run. The bombardier set the wind direction and speed on the computer, taken from the briefed weather forecast or measured as described in Chapter 4, and then attached a specific tangent scale to the computer, based upon the bombing altitude, true airspeed, and type of bomb loaded in the bomb bay. With those values set, the AB computer could display the correct drop angle, groundspeed, and drift angle for any aircraft heading.[124] The bombardier set up the AB computer before the bomb run so that he could obtain a correct aircraft heading to the bomb release point at any time during the run, which was particularly useful if the pilot had to perform any evasive maneuvers that took them off of the planned bomb run heading.

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[123] Ibid., 3-5-1.
[124] Ibid., 3-2-2 - 3-2-3.
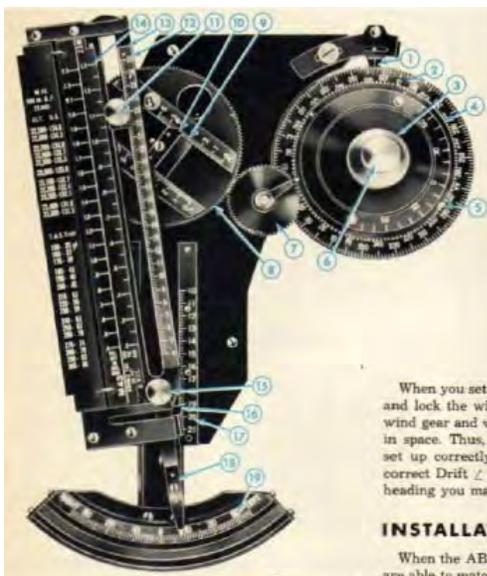
Figure 5.32
The Automatic Bombing (AB) Computer[125]

The final quantification tool in the bombardier's kit was a set of bombing tables that contained ballistic data for the various types of bombs used during World War II. Based upon the bombing altitude, the tables provided the bombardier the appropriate disk speed, actual time of fall, trail, drop angle, and sighting angle for setting up the bombsight. They also contained various conversion factors for altitudes or airspeeds not already quantified, that the bombardier could use to calculate in the air based upon actual environmental conditions.[126] This data was critical for the bombsight's initial setup, and it helped the bombardier verify the its operation, as well as set the initial sighting angle for the telescope, which put the crosshairs in the vicinity of the target, making it easier to locate and identify.

The bombardier's computers and bombing tables were purpose-built tools that enabled him to translate the bomber's physical environment into data usable by the bombsight to calculate the bomb release point. The bombsight was useless without that data, and he served as the socio-technical bombing element's "sensors" and interpreter, incorporating the physical context of the bomb run with the bombsight's ability to rapidly calculate a solution based on that context. This interdependent relationship defined the shared cognitive capability of that socio-

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[125] Ibid., 3-2-1.
[126] Ibid., 2-3-1 - 2-3-2.

technical element, with both the human and machine possessing unique cognitive capabilities that, when brought together, formed a more powerful whole.

The Bombing Mission and Bringing the Pieces Together

After the Bombardier's Brief, with the mission planning complete, the bombardier proceeded to his aircraft to rendezvous with the rest of the bomber crew. Enroute to the aircraft, he retrieved his Norden bombsight head from a special secure, steel-reinforced vault, where they were stored and kept under guard at all times, for which only the installation commander and the Armament Officer possessed the keys (Figure 5.33). Ordinarily, armament technicians issued the sight heads before each mission, although on occasion they were left in the aircraft, protected by armed guards and covered to keep them from sight. Once issued a sight head, a bombardier was required to arm himself with a service pistol at all times.[127] With the sight head in his possession, protected in a heavy canvas bag, the bombardier joined his crew at the aircraft (Figure 5.34).

Figure 5.33
Norden bombsight vault at RAF Halesworth, England[128]

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[127] Pardini, *The Legendary Secret Norden Bombsight*, 220-222.

[128] *Norden bombsight vault at RAF Halesworth*, Photograph, n.d.,
http://www.airfieldinformationexchange.org/community/showthread.php?996-Norden-Bomb-sight-store/page2 (accessed 19 March 2011).

Blue Ox

Figure 5.34
A bombardier stepping to a B-17[129]

The Bombardier's Compartment

Once at the aircraft, the bombardier checked the status of all of the armament, ensuring that the bombs and machine gun ammunition were loaded and ready for use. He then entered the compartment that he shared with the navigator in the nose of the aircraft. All of the his equipment was located between the Plexiglas nose of the aircraft and the bombardier's seat, which was riveted to the floor at the lip of the fuselage, in front of the navigator's instruments. At the center of the compartment, right in front of the bombardier's seat, was the pedestal for the Norden bombsight, wired to provide the 24-volt direct current power necessary to operate it. The low, armor-backed seat was adjustable both vertically and horizontally so that the bombardier could sit comfortably over his bombsight, which peered down through a flat portion of underside of the Plexiglas nose (Figure 5.35).

The nose was designed to "give the bombardier a perfect view so he (could) see the target," and the seat's location made that view "marvelous" and unequaled by any other crew position.[130] Early model B-17 noses had a metal frame that held the eleven Plexiglas windowpanes, as well as several gun ports that allowed the installation of .30-caliber machine

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[129] "Boeing Advertisement--Blue Ox," 77. In this picture, you can see the pistol strapped to the bombardier's right hip.

[130] *B-17F Pilot's Flight Operating Instructions, T. O. No. 01-20EF-1* (U.S. War Department, 1942), 103; Myers, *Shot at and Missed*, 218; John C. Minahan, "Bombardier," in *B-17 Fortress at War*, by Roger A. Freeman (London: Ian Allen Ltd, 1977), 121.

guns different locations. The B-17F replaced the metal-framed nose with a single-piece nose cone, retaining the gun ports, but the B-17G, the last generation of the bomber, eliminated the gun ports when Boeing installed a twin .50-caliber powered chin gun turret. While the nose was well-designed for bombing, it provided little physical protection, and was thick enough only to keep out "bird$4!7 and rain."[131]

Figure 5.35
A bombardier seated in the nose of a B-17G[132]

[131] Myers, *Shot at and Missed*, 50.

[132] *PhotoNordenBombardier.jpg*, Photograph, n.d.,
     http://www.twinbeech.com/images/bombsight/PhotoNordenBombardier.jpg (accessed 19 Mar 2011). We
     can see from the lack of gunports in the Plexiglas nose that this a B-17G. Also, above and to the right of
     the bombardier's head we can see the gunsight for the twin-.50-caliber gun turret under the nose of the
     aircraft.

To the bombardier's left, as he looked out the nose, were his bomb controls and instrument panel. Farthest forward were two control levers; one that opened the bomb bay doors and another that controlled whether the bombs were electrically released by the bombsight or mechanically "salvoed" and dropped all at once by the bombardier. Directly behind the levers, the instrument panel contained an airspeed indicator, thermometer, altimeter, and intervalometer. Also included were the C-1 Autopilot control panel and the controls for turning on the PDI. To the bombardier's right were his communication connection and controls, oxygen regulator, the electrical outlet for his heated flight suit, and the ventilation control for the heating duct that provided hot engine bleed air to defrost the nose and warm the bombsight.[133]

The Nose Gun—A Secondary Responsibility?

Aside from the bombsight, the most dominant item in the aircraft nose was the machine gun, and as he was the de facto nose gunner on the B-17, on most missions the bombardier would spend more time using it than the bombsight. While nominally responsible for all of the armament on the aircraft, including all of the defensive machine guns, in practice, the bombardier worried only about his gun, as each gunner on the crew was "an expert on his weapon and pretty self-sufficient."[134] Early models of the aircraft had several gun ports in the nose, but the bombardier's .30-caliber gun was usually installed on the right side, covering the front right sector of the aircraft, as the navigator's larger, .50-caliber machine gun protected the front left sector. This setup, however, was inadequate, because the small-caliber gun had a limited field of fire and left the nose of the aircraft poorly defended.

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[133] *B-17F Pilot's Flight Operating Instructions*, 103-105.
[134] Minahan, "Bombardier," 123.

Figure 5.36
A bombardier in the nose of a B-17G[135]

During the course of the war, the USAAF modified the B-17 several times to increase its defensive firepower, particularly in the nose. In the B-17F, a .50-caliber machine gun replaced the older, smaller weapon, somewhat improving defensive effectiveness, but it was the B-17G that gave the bomber a true frontal defense capability. Boeing installed a powered Bendix chin turret with twin .50-caliber machine guns below the nose of the aircraft (Figure 5.36). This chin turret provided much greater forward defensive coverage than a single gun, and incorporated an optical gunsight that increased accuracy over the basic "iron" gunsights on the older guns (Figure 5.37). The optical sight, which rotated with the chin turret while the bombardier's seat remained stationary, greatly increased the effectiveness of the aircraft's forward defensive firepower. One limitation, however, was that when it was in use, it blocked access to the bombsight. To gain

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[135] *Capt. Charles S. Hudson, Bombardier, In Nose Of A Plane At A Base In England.*, Photograph, n.d., 342-FH-3A49627-K2155, National Archives and Records Administration, http://www.footnote.com/image/#161286999 (accessed 19 March 2011).

access, the bombardier had to swing the gunsight and the turret control unit away and stow it to his right, and could not operate both systems at the same time.[136]
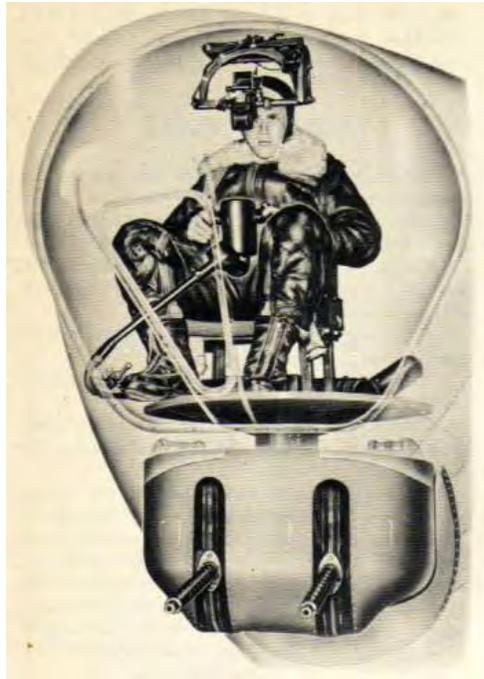
Figure 5.37
The optical gunsight and chin turret on the B-17G[137]

While the bombardier spent most of the mission manning his machine gun, he was poorly prepared to do so, particularly during the early stage of the CBO. Although bombardiers and navigators were supposed to receive flexible gunnery training as a part of their normal flight training in the United States, early in the war the pressing need for personnel in the ETO kept many from getting it before deploying for combat. They did receive additional gunnery training once they arrived in theater to better prepare them for the demands of maintaining the defensive power of the bomber formation, but it was generally inadequate and attacking German fighters soon discovered that the combination of the poor defensive coverage of the early-model B-17s and the lack of gunnery training made the aircraft very vulnerable to frontal attack.[138]

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[136] *Bombardiers' Information File*, 7-10-1.

[137] Ibid.

[138] Richard H. Kohn and Joseph P. Harahan, eds., *Strategic Air Warfare: An Interview with Generals Curtis E. LeMay, Leon W. Johnson, David A. Burchinal, and Jack J. Catton* (Washington, DC: Office of Air Force History, U.S. Air Force, 1988), 26-27; Thomas Greer, "Individual Flying Training," in *The Army Air Forces in World War II, Vol. 6-Men and Planes*, ed. Wesley Frank Craven and James Lea Cate, vol. 6

Consequently, they developed and refined such tactics, and they proved very effective in the early stages of the CBO. Many B-17s were lost before the powered chin turret nullified some of the fighters' advantage.[139]

Takeoff and Preparation

After the bombardier checked the status of the aircraft's weapons, he settled in for the ride. After takeoff and during the formation rejoin, he provided the navigator visual position updates, if requested, and could help the pilot find other squadron and group aircraft as they tried to assemble. During that time, he confirmed with the pilot that the autopilot system was on and operating correctly, so that the gyros had ample time to reach their operating speed before they were needed. Sometime after passing 10,000 feet, and before there was a threat of enemy air attack, he left the nose compartment and walked to the bomb bay in the middle of the aircraft to arm the bombs. The B-17 was unpressurized, so above 10,000 feet the crew had to breathe supplemental oxygen to keep from dying of hypoxia, and while arming the bombs, the bombardier carried a portable oxygen bottle, connected to his oxygen mask so that he could survive.[140]

Bombers carried several types of bombs with different fuzes, but generally, arming them consisted of pulling a metal pin out of fuze on the nose or tail of the bomb, allowing an attached propeller to spin freely (Figure 5.38). After pulling the pin, the bombs were still safe to carry, as the fuze was not yet fully armed. The propeller had to turn several hundred rotations before it actuated a mechanism that enabled the bomb to explode on contact, which happened once the bomb got into the airstream when released from the aircraft. During arming, the bombardier could also manually set a detonation delay into the fuze, controlling how long it would wait after striking the target to detonate the bomb. Typical delays ranged from zero seconds to .10 seconds, and were dictated by target type. Some targets, such as those out in the open, required no delay and the bombs were effective upon immediate impact. Other targets, such as those contained in buildings hardened against attack, detonation was delayed so that the bomb could

(Washington, DC: 1983. Reprint, Office of Air Force History. Originally published Chicago: University of Chicago Press, 1955), 589-595.

[139] Baldwin, *Individual Training of Bombardiers*, 16, 33; Greer, "Individual Flying Training," 589-595.

[140] *Bombardiers' Information File*, 9-6-1 - 9-6-2.

penetrate the building before detonating, thereby delivering the greatest amount of explosive power to the correct location.[141]
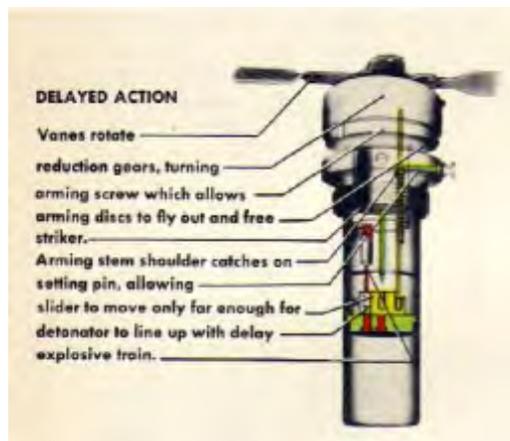
Figure 5.38
AN-M103 Delayed Action Arming Vane Nose Fuze[142]

After arming the bombs, the bombardier returned to the front of the bomber and took up his position behind the nose gun. Shortly after the formation completed its assembly and departed for the mission, he had the pilot trim the bomber for straight and level flight, set up the autopilot, and verify that it was working correctly, preparing it for use during the upcoming bomb run. Upon accomplishing that task, he fulfilled his function as the aircraft nose gunner for the time that it would take the formation to get to the IP for the bomb run, defending the formation from frontal attack, but taking the opportunity to compute the bombing altitude, airspeed, and drift during any lull in the action.[143]

Approaching the IP—Leading, Following, and Drop-on-Leader Bombing

As the formation approached the IP, the bombardier's attention shifted to the upcoming bomb run, but the HADPB doctrine and his place in the formation now dictated his actions. Every bombardier in the formation was trained to operate the Norden bombsight, but just as with the navigators, a professional and social strata existed among them. The adoption of the drop-on-leader formation bombing doctrine in early 1943 and the subsequent and creation of the lead

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[141] Ibid., Sections 7-1 and 7-2.
[142] Ibid., 7-2-2.
[143] Ibid., 8-1-2.

crew established lead, deputy lead, and wing bombardier positions. Each wing, group, and squadron had a lead bombardier in the lead aircraft for their element of the Combat Box formation, and the position held corresponding prestige. The lead bombardier flew in the lead aircraft, and he was responsible for finding, identifying, and tracking the target, and it was his bombsight that computed the bomb release point for the aircraft in his element of the formation. When his aircraft reached that point and his bombsight released its bombs, the rest of the formation released theirs, hence "drop-on-leader."

Lead bombardiers were selected based upon demonstrated superior performance. The man out front had to be good, as the success of the entire formation depended upon his skill, but while skill mattered greatly, it had to be accompanied by desire. Not every good bombardier wanted to lead, as selection guaranteed that they would stay overseas longer and fly some of the tougher missions. When selected, lead crews were assigned responsibility for a particular geographic area and set of targets. It became their job to learn everything that they could about those targets and the area surrounding them, thoroughly familiarizing themselves with the ground references so that they could lead the formation to the right point and strike the target on the first attempt. When headquarters scheduled a mission against one of the targets in their area of responsibility, they led the mission.[144] If the crew was assigned a particularly tough or well-defended set of targets, every one of their missions was guaranteed to be tough.

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[144] General Curtis E. LeMay, "Interview with General Curtis E. LeMay," interview by Col. Bill Peck, Oral History Transcript, March 1965, K239.0512-785 C.1, IRIS No. 1000342, US Air Force Historical Research Agency.
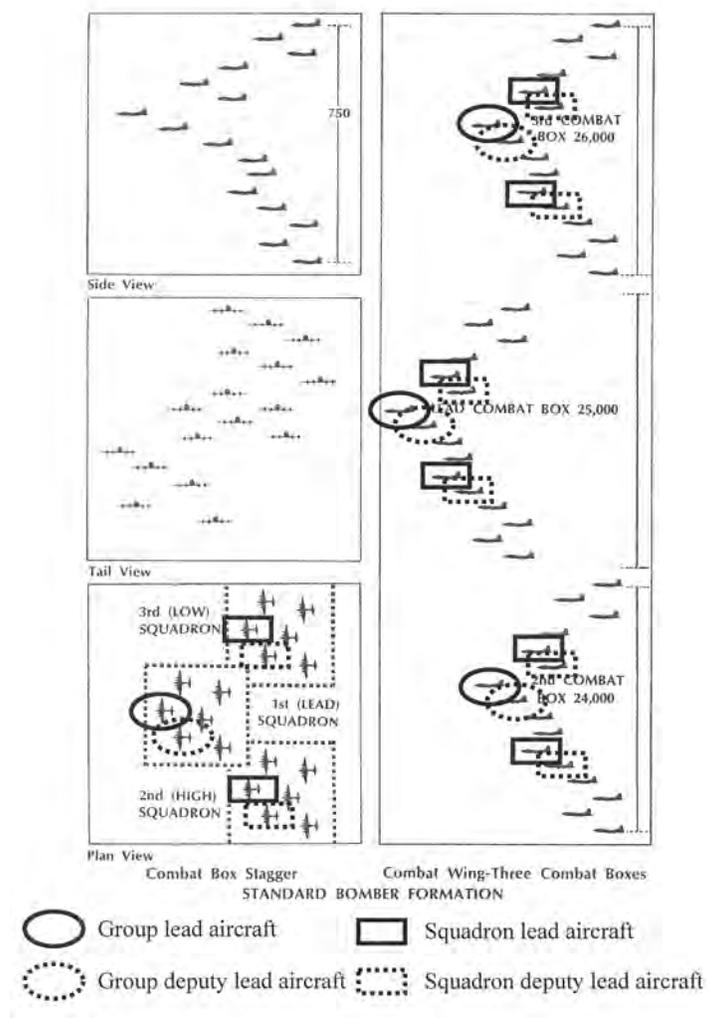
Figure 5.39
The Combat Box formation lead and deputy lead aircraft[145]

A Combat Wing formation of fifty-four bombers included three Combat Box formations, one of which was the lead group for the Wing, and each Combat Box comprised eighteen aircraft (Figure 5.39). The Combat Box was the primary bombing formation element in the bombardment system, and the lead crew in the lead Combat Box led the Combat Wing until the IP, whereupon it split into its three separate groups for the rest of the bomb run (Figure 5.40). Splitting into separate groups increased bombing effectiveness for two primary reasons. First, it was much easier to maneuver the smaller formation of eighteen aircraft, increasing the chance of successfully navigating to the target while still maintaining some mutual defensive capability.

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[145] Haywood S. Hansell, Jr., *The Air Plan That Defeated Hitler* (Atlanta, GA: Higgins-McArthur/Longino & Porter, Inc., 1972), 117. Shapes highlighting the formation positions added by author.

Second, it enabled the groups to create separate between themselves so that they did not interfere with each other in the target area and, by arriving at the target at slightly different times, it provided the opportunity for some of the smoke from the previous group's attack to clear away, reducing the chance of the target being obscured.[146] Thus, of the original fifty-four bombardiers in the formation, only three actually used the full capability of their bombsights.
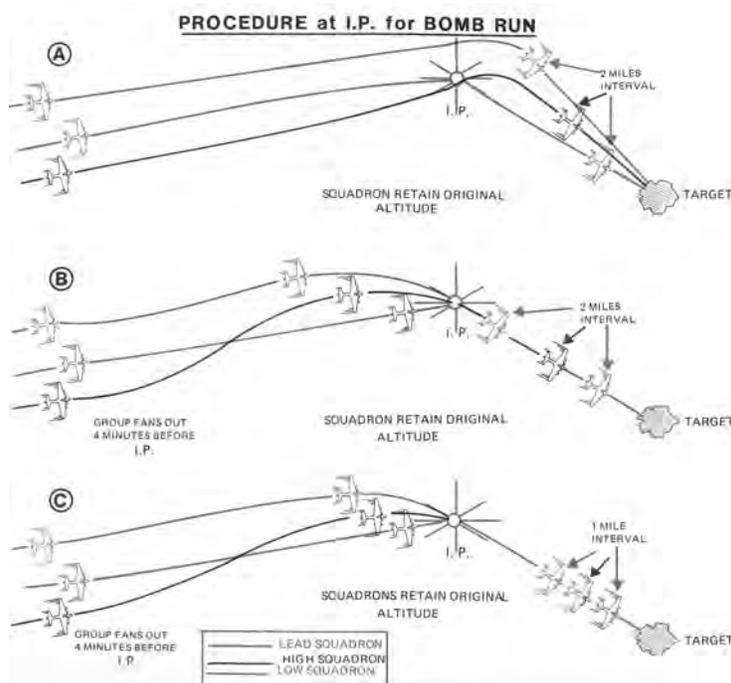
Figure 5.40
Combat Wing breakup and Combat Box spacing maneuvers[147]

Each Combat Box also had at least one designated deputy lead bombardier, whose job it was to take over the formation if the lead aircraft were disabled or shot down. The lead bombardiers for each of the three component squadrons of six aircraft that made up the group also served as deputy lead bombardiers. These bombardiers could not use the full capabilities of their bombsights because their pilots had to maintain full control of the aircraft to maintain their position in the formation. If the bombardier engaged the bombsight to the autopilot, it risked the aircraft falling out of position or, even worse, collision with another aircraft. While they could not synchronize their bombsights in course, thereby moving the aircraft to align directly with the

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[146] Ibid., 118.
[147] Kohn and Harahan, *Strategic Air Warfare*.

target, deputy lead bombardiers could synchronize in range, and still determine the correct instant to drop the bombs. The theory was that the lead bombardier would synchronize in course and range, and if his bombs should fail to release, the deputy lead bombardier would manually release the bombs when he reached the appropriate range from the target, followed by the rest of the formation. The aircraft formation was tight enough that the lateral displacement between aircraft was immaterial as far as the effect on the ground. If the lead bombardier had synchronized in course, the formation would pass over the correct bomb release point and the result was actually almost the same as if the lead aircraft itself had dropped its bombs, as the same bomb pattern would be laid on the target, delayed only by the deputy lead bombardier's reaction time.[148]

On a mission that proceeded as planned, the rest of the bombardiers in the formation did not use their bombsights at all. In fact, early in the war, there was a significant shortage of Norden bombsights, and many bombers set out on missions without one installed in the aircraft.[149] For those that did have one, their only opportunity to use it was if they fell out of formation and attacked a target on their own. While the drop-on-leader doctrine enabled those aircraft without bombsights to drop more accurate bombs, it was not without problems.

The drop-on-leader technique decreased the accuracy of the individual bombers that had bombsights in the formation, but increased the effectiveness of the formation itself by concentrating the bombs in the desired area of the target.[150] However, its dependence on the skill of the lead bombardier meant that the entire formation's success rested upon his ability to operate his bombsight skillfully. Indeed, there are many examples of entire formations dropping their bombs on the wrong target when the lead bombardier erred or his equipment malfunctioned. On 28 June 1943, during a planned attack on an airfield at the edge of Brussels, one bomb group unintentionally bombed the center of the city, which was off limits as a target,

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[148] "Bombsights-High Altitude Bombing Procedure with Automatic Bombing Computer-'M' Series, Technical Order (T.O.) 11-30-45" (War Department, Headquarters of the Army Air Forces, November 17, 1943), 2, Box 829 File:F5-G/1943/Bombsights (N.D.) High Altitude Bombing Procedure (1943) Photos, undated material, National Museum of the United States Air Force.

[149] *Case History of Norden Bombsight and C-1 Automatic Pilot, Parts I and II.*

[150] Hansell, Jr., *The Air Plan That Defeated Hitler*, 119.

when the lead bombardier accidentally released his bombs early. Fortunately, the bombs struck a German troop billeting area and killed only a few Belgian civilians.[151]

Likewise, to take advantage of the lead/deputy lead bombardier redundancy built into the Combat Box formation, the lead crew had to be willing transfer control of the formation to one of the deputy leads if they ran into trouble or had some sort of malfunction. However, this was not always the case. On 11 January 1944, equipment problems plagued a large-scale, long-range attack against an aircraft factory only fifty miles short of Berlin in Oschersleben, Germany. Enemy fighters harassed the formation the entire way, badly damaging the lead B-17 from the 91st Bomb Group when several 20mm cannon shells knocked out one engine and injured the pilot and copilot. The crew, however, maintained the lead position in the formation. Unfortunately, the damage to the aircraft extended to the mounting structure of the Norden bombsight, adversely affecting its operation, and the entire Group's bombs missed the target when they dropped on the lead bomber's errant signal.[152] The 1st Combat Bombardment Wing history which recorded the event makes no mention of why the formation leader did not surrender the lead for the bomb run to the deputy lead aircraft. Even with its limitations, the advantages of the drop-on-leader doctrine outweighed the disadvantage, and once adopted, the USAAF used it through the rest of the war.

Defining and Setting the Environment

Thirty to forty-five minutes before the IP, the lead and deputy leads prepared both their aircraft and bombsight for the upcoming bomb run. The lead bombardier had his aircraft commander engage the autopilot and check its operation, in so doing, began the process of controlling the bombsight's environment by establishing a stable altitude so that they could input an accurate altitude into the bombsight. Completing that, they verified their altitude, airspeed, and drift calculations, completed the process of setting up their AB computers, and input all of the data into their bombsights. With the altitude value set, these bombardiers verified the bombsight's operation by checking that the internal disk was spinning at the correct rate for that altitude. They plugged in specially designed hand-held tachometers that measured the speed of

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[151] Thomas Coffey, *Decision Over Schweinfurt: The U.S. 8th Air Force Battle for Daylight Bombing* (New York: D. Mckay Co., 1977), 232-233.

[152] "1st Combat Bombardment Wing (H): Unit History 1 January, 1944 to 31 January, 1944", 1944, 2-3, Call WG-1-HI 1 Jan 44-31 Jan 1944, US Air Force Historical Research Agency.

rotation, and adjusted the speed until they obtained at least three readings indicating that the disc speed was within ½ RPM of the required value (Figure 5.41).[153] Finally, they checked that all of the switches that operated the bomb racks and the bomb bay doors were in the on position.

Figure 5.41
Norden bombsight Jaeger tachometer[154]

IP Through the Bomb Run—"The most nerve-wracking twenty minutes of the mission"[155]

At the IP, usually 20 to 40 miles from the target, the individual Combat Boxes split out of the wing formation and began separate approaches toward their assigned targets (Figure 5.42). At this point, the lead bombardier in the Combat Box assumed "absolute command" of the entire formation, and began the process of following his navigation checkpoints to the target and preparing the bombsight for the final stage of the bomb run, maintaining that command until the bombs left the aircraft.[156] The entire run from the IP to the release point could last up to twenty minutes, depending on the length of the run and the effect of the wind at the formation's altitude. A headwind would increase the length of the run, while a tailwind would decrease it. Every bombardier performed his actions over those twenty minutes in a state of heightened danger. The flak invariably intensified as they approached the target, and although the aircraft could execute preplanned flak-avoidance maneuvers before the start of the bomb run, once the aircraft

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[153] "Handbook of Instructions for Bombsight Type M-9", June 5, 1945, Call 168.69-30, US Air Force Historical Research Agency.

[154] *Jaeger Tachometer*, Photograph, n.d., Armyairforces.com, http://forum.armyairforces.com/What-is-a-JAEGER-TACHOMETER-m129411.aspx (accessed 30 March 2011).

[155] Myers, *Shot at and Missed*, 9.

[156] *Pilot Training Manual for the B-17*, 18.

entered the final phase, evasive maneuvers were prohibited, as they decreased bombing accuracy. Enemy fighters, however, usually ceased their attacks during the bomb run so that they avoided getting accidentally shot down by their own forces, which was fortunate, as the bombardiers in the front of the formation were busy with their bombsights and unable to operate their guns.
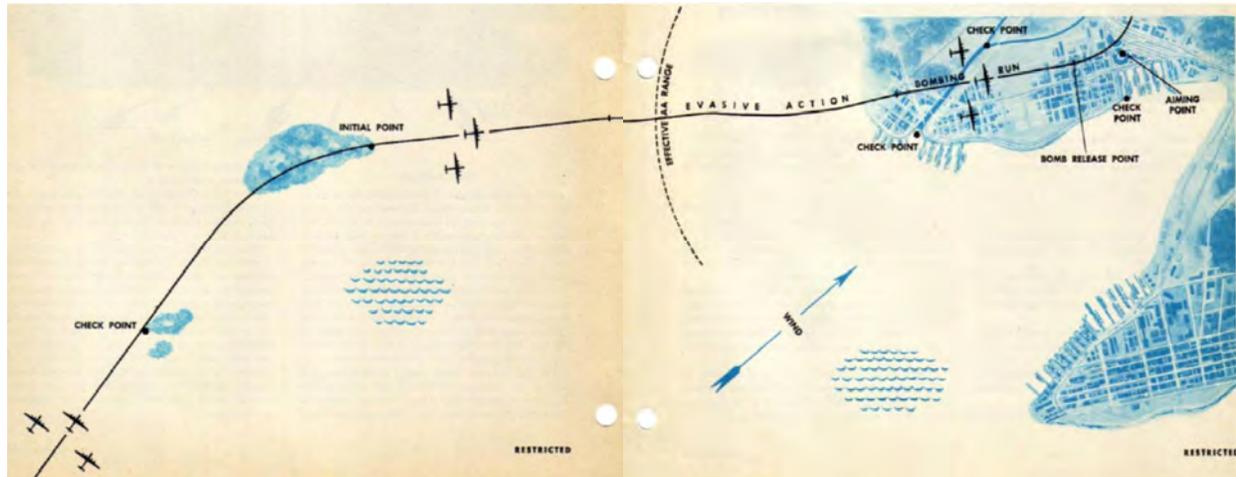
Figure 5.42
The IP to Target run[157]

This phase of the mission was, without question, the most intense physically and emotionally. In the words of one veteran bombardier:

> Usually as you start the bomb run, no matter how cool you try to appear to your crew, your blood pressure if taken would probably register off the scale. Your pulse sounds like a trip hammer as it pounds away at about twice its normal rate. Something is caught in your throat that is slowly choking you and you finally realize it is your own heart trying to come out your mouth. Your bladder feels like it is going to empty all over you and your rectum is chewing a hole in your leather seat.[158]

The danger during the bomb run placed an enormous strain on all of the crewmembers, but the bombardier had the added burden of knowing that if he did not accomplish his job and drop his bombs, they would have faced the danger for naught.

Passing the IP, the pilot or the bombardier in the lead aircraft electrically opened the bomb bay doors, and the rest of the crews in the formation followed suit when they saw the

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[157] *Bombardiers' Information File*, 8-5-3 - 8-5-4.
[158] Myers, *Shot at and Missed*, 212.

doors swing open. A light illuminated on both the pilot and bombardier's control panels when the doors opened, but in the event that the electrical door motors failed, they could be opened manually from within the bomb bay.[159] The procedure was extremely risky, and required that the bombardier climb onto the narrow catwalk suspended between the bomb racks and crank the doors open with a crank handle. He had to remove his parachute in order to fit on the catwalk, and take an oxygen bottle so that he could breathe. Opening the doors in this fashion was always exciting, and provided, in the understated words of one bombardier, a "real sensation" as the doors opened and "a terrific view of the ground below."[160]

With the doors opened, the pilot adjusted the autopilot, if necessary, as the flight characteristics of the aircraft changed with the large doors hanging in the airstream, and added power to compensate for the additional drag. Once adjusted, the lead and deputy lead bombardiers leveled the bombsight stabilizer, taking one more step toward controlling the bombsight's environment by establishing the initial vertical reference. After rechecking the correct setting of the bomb rack switches, they then shifted their attention to finding and identifying the target.

The lead and the deputy lead bombardiers started the process of target acquisition after the initial turn over the IP, using the route map and target folder to identify the ground checkpoints that would lead them to the target. The navigators in these aircraft, having temporarily given up the duties of directing the aircraft flight path, moved forward to assist with the process. Each knelt beside the bombardier and placed one hand on his shoulder, signaling that he was in position.[161] In clear meteorological conditions, they usually acquired the target fairly rapidly because of all of the preflight study and effort put into creating the target folders and route maps. With the target in sight, these bombardiers then absorbed themselves in the operation of his bombsight, while the rest of the bombardiers in the formation kept their eyes glued to the lead aircraft, awaiting the signal to drop their bombs.

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[159] *Bombardiers' Information File*, 7-4-2.

[160] Robert W. Reichard, "Bomb Bay Doors Jammed," in *Bombardier: A History, Volume II*, by Philip A. St. John (Paducah, KY: Turner Publishing Company, 1998), 43.

[161] Elson Bernard Spangler, "Elson Bernard Spangler," interview by Lisa A. Korzetz and Jerry Luther, Audio, March 1, 2008, Elson Spangler Collection (AFC/2001/001/62899), Veterans History Project, American Folklife Center, Library of Congress, http://lcweb2.loc.gov/diglib/vhp/story/loc.natlib.afc2001001.62899/ (accessed 16 December 2010).

The lead bombardier made the final adjustment to the AB computer to establish the drift angle, uncaged and leveled the vertical gyroscope to stabilize the optics, pressed his eye to the black rubber cup of the telescope, synchronized the bombsight on the target, and steered the bomber toward the bomb release point. As he raised the release lever on the bombsight, enabling the automatic release mechanism, he had as much control over the entire bombardment system in that moment as it was possible for him to have. He controlled the direction of eighteen aircraft, as well as when they would release their weapons. Every other socio-technical element in the system responded to his will—right up to the point that his aircraft reached the bomb release point and the Norden bombsight electrically released the bombs from the bomb bay, when it would all vanish.

The rest of the bombardiers in the formation kept their eyes glued to their leader, waiting for the bombs fall from the aircraft so that they could release their own. This, of course, required that the first see the bombs. At times, environmental conditions, such as haze or smoke, made the bombs difficult to detect, particularly for bombardiers farther away from the lead aircraft at the outer edges of the formation. Early in the war, the 1st Bomb Wing experimented with painting the lead aircraft's bombs bright colors to make them easier to see, and even tied colored cloth streamers to the bomb fins to make them more visible. After achieving limited success with smoke flares attached to the bombs, powerful Skymarker bombs with highly visible smoke trails were adopted in the autumn of 1943 for use in all lead aircraft, making them much easier to visually detect.[162] Since only the lead bombardier's bombs released automatically, all of the other bombardiers had to manually release theirs, which reintroduced the potential for range errors due to the limits of human reaction time. To account for this, lead bombardiers began aiming and releasing their bombs just short of the target, and the rest of the bombardier's slight delay in releasing their own bombs actually moved the formation's mean point of impact nearer the target.[163]

As the lead bomber reached the computed bomb release point, several thousand pounds of bombs fell from the bomb racks and the aircraft jumped noticeably.[164] The lead bombardier, after checking the indicator light on his bomb rack panel to ensure all of the bombs had been

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[162] Roger A. Freeman, *The Mighty Eighth War Manual* (London: Jane's Publishing Company, Ltd, 1984), 46.
[163] Ibid.
[164] Reichard, "Bomb Bay Doors Jammed," 43.

released, made the classic call "Bombs Away!" over the bomber's internal communication system, and immediately returned control of the aircraft back to the aircraft commander, who turned the aircraft toward a Combat Wing rejoin point so that the Combat Boxes could reform for the journey back to England.

Actions and Identity—Drop-on-Leader and the Dismantling of the Engineered Human

The twenty minutes from the IP through bomb release was the pinnacle of the lead bombardier's mission. During that time, the months of training in the United States, the extensive and repetitive practice on the ground and in the air, the hours of target study and preparation, and the iron will to persevere through the terrifying defenses all came together. The bombardier and the bombsight were a single, unified socio-technical system and the bombardier was *the bombardier*. However, when the bombs left the aircraft, it severed his immediate connection to the bombsight, and he became once again, as did the rest of the bombardiers in the formation, the aircraft nose gunner. While the bombardier and the bombsight together made a single socio-technical unit, it took the bombsight to make the bombardier. Without it, he was a gunner—vitally important, but no longer "the ultimate purpose of (the) entire airplane and crew."[165] If the bombsight was so central to the identity of the *lead* bombardier, what of the identity of the rest of the bombardiers in the formation? Their immediate connection to the bombsight was far more tenuous and, in some cases, non existent.

Other than the three lead and perhaps fifteen deputy lead bombardiers, the rest of the wing bombardiers in the formation did not even need their bombsights. Their job was to watch the lead bomber and "toggle" their bombs on cue. Many flew without bombsights, and it was not uncommon for a bombardier to fly numerous missions, sometimes over fifteen, before he actually even used one.[166] The construct of the formation and the drop-on-leader employment doctrine made having a bombsight in every aircraft an expensive, unnecessary redundancy, and by the middle of 1944, realizing how they were actually being used in the theater, the AAF cancelled production orders for 2,375 bombsight heads. Interestingly, at the same time they

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[165] *Pilot Training Manual for the B-17*, 18.

[166] Frank A. Wiswall, "Frank A. Wiswall, WWII & Korean War Veteran, US Army Air Forces, US Eighth Air Force," interview by Sandra Stewart Holyoak and Roger Zepeda, Transcript, April 25, 2008, Rutgers Oral History Archives of World War II, http://oralhistory.rutgers.edu/Interviews/wiswall_frank.html (accessed 21 December 2010).

increased the requirements for bombsight stabilizers and C-1 autopilot systems in an effort to get fully functional autopilots into all of their heavy bombers.[167]

The widespread, institutional use of this toggling method of bombing gave rise to a new term for the wing bombardier—"togglier." The term togglier conveyed a distinct image. Whereas the *bombardier* was a highly trained individual, master of a complex, secret machine, the *togglier* was merely a switch flipper. It completely recharacterized the bombardier's role and how others perceived him on the crew, reflected in one copilot's comment that "all he (the bombardier) had to do was toggle the bombs when the leader let his go. Soft life."[168] Indeed, recalling his decision to choose navigator training over bombardier training, one 8th AF navigator plainly stated

> Well, I didn't want to be a bombardier. I'd just sit up there and toggle switches [laughter].[169]

Even though bombardiering was never the most popular choice among recruits, this type of attitude represents a long fall from the fellow who took charge and delivered the "knockout punch."[170]

The switch from bombardier to togglier even changed the structure of the crew. Since the bombardier actually spent most of the mission acting as the aircraft nose gunner and most did not use their bombsights, a trained gunner could realistically accomplish the job. This change in task, which coincided with a shortage of trained bombardiers in theater, caused bomb unit commanders to look elsewhere for personnel to drop bombs early in the war.[171] Consequently, select enlisted gunners and armament technicians, already trained in aerial gunnery, were chosen to train as toggliers. Those selected received some training on how to operate the bomb racks release systems, but many learned the job through real-mission experience, learning what they

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[167] Toole, *The Development of Bombing Equipment in the Army Air Forces*, 94.

[168] Bert Stiles, *Serenade to the Big Bird* (New York: W.W. Norton, 1952), 20.

[169] Donald E. Lundberg, "Donald E. Lundberg, World War II Army Air Forces Veteran, 468th Bomb Group," interview by Sandra Stewart Holyoak and David Fulvio, Transcript, April 23, 2008, Rutgers Oral History Archives of World War II, http://oralhistory.rutgers.edu/Interviews/lundberg_donald.html (accessed 21 December 2010).

[170] U.S. Army Recruiting Service, "You'll be on the Greatest Team in the World!," 19.

[171] Baldwin, *Individual Training of Bombardiers*, 137.

needed to know on the job by adapting quickly to their new role.[172] This decision to use enlisted crewmembers to act as toggliers, perhaps, illustrates the prominent role that the Norden bombsight played in the bombardier's professional identity, as it occurred less than one year after the USAAF made the decision to not train enlisted recruits in 1942. Once the role transitioned from a specific, learned skill with an expensive, complex machine to flipping a switch, the task of dropping bombs no longer maintained the status necessary to require an officer to complete it.

While learning how to operate the systems was not difficult, effectively filling even the reduced role of the bombardier was not always easy. The selection and training of these enlisted toggliers ignored the bombardier-crew integration training that the bombardment doctrine writers had deemed so important in the development of the bombardier, particularly the importance of effective cooperation between the bombardier and the bomber pilot. One waist gunner thrust into the role with no training, based only on the fact that he had washed out of bombardier training, committed several errors on his first two missions due to inadequate training on the equipment and a lack of understanding of how he interfaced with the rest of the crew.[173] The human-machine link was critical at the bombardment element level (human-bombing technology), but just as important was the human-human link in the larger, aircraft level of the bombardment system. The mastery of the bombsight may have professionally defined the bombardier, but it was integration with the rest of the socio-technical elements in the aircraft made him successful. Absent that integration, the system performance suffered.

With adequate training, however, the togglier effectively ceased to exist as an integral element of the individual bombardment team—the human and machine elements that made up the individual bomber crew and its aircraft—and became instead an element in the larger bombardment system, an extension of the lead bombardier and his Norden bombsight. The drop-on-leader doctrine harnessed the togglier's capabilities together into a larger, centrally controlled network, much as the control of the overall formation resided with the command pilot in the lead aircraft. Drop-on-leader took control, autonomy, and professional status from most of the

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[172] Frank Yarmoski, "Interview with Sgt. Frank Yarmoski, 398th Bomb Group Togglier 601st Squadron, Eighth Air Force," interview by Marilyn Gibb-Rice, Video, November 2007, http://www.398th.org/History/Veterans/Voices/Interviews/Interview_Yarmoski_Frank.html (accessed 24 November 2010).

[173] Gerald Astor, *The Mighty Eighth* (Dutton Adult, 1997), 329-330.

individuals in the bombardier position, but conveyed all that was lost onto the one in the lead. While the doctrine maintained the importance of the task, the method by which it accomplished that task largely dismantled the engineered human bombardier by separating most of them from the very machine that not only defined them, but made the overall doctrine of HADPB possible.

Conclusion

Automation, Mechanization, and the Bonds of the Socio-technical

The bombardier, the Norden, bombsight, and the HADPB doctrine illustrate, perhaps better than any other example, the interdependent nature of the parts of the socio-technical bombardment system. Bombing emerged very early as a doctrinal mission, and the human inability to perform that mission drove the development of a specialized machine that compensated for those human inabilities by automating as much of the bombing process as possible. The complicated nature of operating the bombsight and its need for accurate data and a precisely interpreted and defined environment led to the creation of a specialized human, defined by his mastery of the bombsight, as well as the doctrine that guided their use as an independent socio-technical element. That doctrine, however, also largely destroyed that human as a professional entity, when the drop-on-leader formation bombing tactics greatly diminished the need for him as a technical specialist.

The Norden bombsight was the result of a bombing system development process that focused on eliminating accuracy errors caused by both humans and machines. Gyrostabilization compensated for the human inability to provide the bombsight a stable environment from which to operate, and synchronization enabled the real time integration of bombing data, providing a calculating capability unavailable in earlier bombsights. It also reduced human error by automating as much of the bombing process as possible. Coupling the bombsight to the SBAE or M-H C-1 Autopilot eliminated communication errors between the bombardier and pilot and gave the bombardier the ability to fly the aircraft to the bomb release point more precisely than the human pilot alone. Automating the bomb release process eliminated the significant error due to the limits of human reaction time. The bombsight, however, was not autonomous. It required a skilled human to define its environment and operate its calculating mechanism.

The bombardier was a single-task specialist, much like the navigator, defined by his ability to operate the bombsight. He did not exist as a dominant professional entity within the

Air Corps until bombsights became too complex for a pilot to operate while still flying his aircraft, and his actions were largely mechanized during training so that he could master that complexity. The bombardier's primary function was to provide the bombsight the data that it required, but could not obtain on its own. Like the navigator, he interpreted the bombsight's physical environment through flight instruments, calculating the airspeed and altitude values necessary for a precision bombing solution. Unlike the navigator, he did not integrate that data and turn it into something new. The bombsight itself accomplished that with the mechanical calculator contained within the sight head.

The bombardier, however, did share the bombing system's cognitive function with the bombsight. His unique ability to find, identify, and track the target enabled the bombsight to perform all of its functions. He accomplished this through a process of visual and mental model building during the mission planning process, effectively building himself a visual script of what he should see during the mission through the intense study of maps, charts, photographs, and models. During the mission, he set up the bombsight, establishing and defining its environment, giving it the ability to do its job, training it on the target. The bombsight, in return, with its connection to the autopilot, gave the bombardier the key capability that he used to define his own identity—the ability to fly the aircraft. He served the bombsight, but he was rewarded with a measure of control over the whole bombardment system.

However, what technology giveth, doctrine taketh away. Where the bombardier derived his own identity from his control of the bombardment system, however fleeting, a capability supplied by automation, it was a form of automation that led to his loss of professional status. The doctrinal shift from individual bombing to drop-on-leader formation bombing, with its use of a single key bombardier at the front of the formation, reduced the role of all others to that of automaton. See the bombs...toggle the switch. Once the majority of the bombardiers were reduce to toggliers, their unique skill with a machine that was no longer installed on the aircraft became unnecessary for the success of the mission, and they all but disappeared from the B-17 crew.

The bombardier, the bombsight, and the HADPB doctrine *were* all interrelated. Each influenced the shape, existence, and use of the other. The basic functions designed into Riley Scott's bomb dropper in 1911, defined by the desire to drop precision bombs, were the same functions included in the Norden bombsight, and in all subsequent precision targeting systems.

The machine performed those functions for which it was better suited—real time, dynamic calculation and near-instantaneous, precision action. The human performed those functions that, at the time, were uniquely human—sensing the physical environment, defining that environment, and visually finding, identifying, and tracking the target. Neither was perfect at their task, and moving forward, each function would become the focus of further technological development, as weapon system designers sought to create ever more precise systems.

Chapter 6

Conclusion

This study began with a single question:

How has the physical dislocation of the operator, enabled by automation technology, changed what the RPA operator does as compared to what a manned-aircraft operator does?

It did not seek to answer that question, but rather proposed that as a single element of a larger *socio-technical system*—a system comprised of interdependent humans, machines, and the doctrine that guides their creation and use—we cannot understand what an aircraft operator does without opening the system's "black box" and considering those actions in the context of its entirety. It also advanced that we cannot understand to what extent automation has changed what the aircraft operator does, or indeed if it has, without understanding how humans have used automated machines in aerial combat systems in the past. The study thus set out to take the first step toward building that understanding through the examination of the precision bombardment system employed by the United States Army Air Forces (USAAF) during the opening phase of the Combined Bomber Offensive (CBO) in World War II, in an effort to establish a conceptual mutual relationship between humans, machines, and doctrine in aerial combat systems that can provide an intellectual framework to better frame the fundamental issues surrounding the original question.

This project's major contribution to the study of complex systems, particularly aerial combat systems, and the human-machine relationship within them, is the clear characterization of those systems as socio-technical, extending beyond the confines of bipolar human-machine relationships to include military doctrine as an integral element. It advances that military doctrine, the set of fundamental beliefs that guide the construct and use of the socio-technical systems nations use to employ military power, is as much a part of these human-machine systems as the physical components because it, through intentional or preconceived interaction, affects the behavior or output of the system as a whole. The study established the relationship between humans, machines, and the high-altitude daylight precision bombing doctrine (HADPB) by first examining the structure of the USAAF bombardment system, presenting it as a three-level socio-technical system, describing the socio-technical elements at each level, including the

primary automated machines involved, and how it was actually used in practice. Then, it examined the actions and tasks performed by the three principal humans on the heavy bomber crew—the pilot, the navigator, and the bombardier—describing and analyzing their professional construct and creation, the machines that helped shape their professional identities, how those humans and machines together accomplished the necessary tasks associated with the precision bombing mission—flying, navigating, and bombing—and how the HADPB doctrine affected their creation and use.

This concluding chapter first briefly reviews the major points of the study and then uses them to characterize the general relationships between doctrine, machines, and humans in the USAAF's precision bombardment system, providing a foundational conceptual structure that will enable us to better understand the interdependent relationship between these elements in other aerial combat systems, including how and why the elements are designed and used as they are, and, most significantly for the original question that generated the study, how changes in an element may affect another. Following that, defines the roles that each element in the bombardment system played, paying particular attention to automated technology, and identifies the unique contribution made by each. Finally, it considers the impact of this study on further research into the human-machine-doctrine relationship in aerial combat systems, very briefly applying the ideas to the F-111 and F-117 weapon systems.

The Colossal Network of Humans, Machines, and Ideas

The precision bombing system used by the USAAF during the CBO was the first true aerial combat system, easily identified as such by the interdependent humans and machines that worked together to perform the precision bombing mission. However, the system was more than a simple collection of humans and machines. It also included the HADPB doctrine that influenced the behavior of the system by shaping its purpose, design, and operation. The doctrine created a clear purpose for the system, defined the tasks necessary to realize it, established roles for humans to accomplish those tasks, guided technology development to produce machines that enabled the humans to perform those tasks, and combined them for use in a three-level structure that facilitated system control at each level.

At the lowest level of the bombardment system, the HADPB doctrine bound humans and machines together into individual socio-technical elements, each focused on performing one of

the specific tasks necessary for precision bombing. When combined at the intermediate level, these individual human-machine teams formed the bomber crew that operated the bomber aircraft, the system's primary machine that embodied the HADPB doctrine. Although functional as individual precision bombing units, these aircraft did not become truly effective until combined at the system's highest level into purpose-built formations of multiple aircraft, working together as a single-entity to execute the doctrine.

The bomber formations were the execution element of the HADPB doctrine, and although the doctrine defined their initial design and operation, their performance as a system caused a change in the doctrine itself. When the realities of combat bombing at the outset of the CBO proved that the original design actually prevented bombardiers from dropping precision bombs with their Norden bombsights, experience trumped theory and USAAF leaders altered their construction and employment method to increase system effectiveness. The adoption of the drop-on-leader doctrine and Combat Box formation improved bombing effectiveness by imposing greater control, but forced a significant doctrinal change that emphasized system performance over individual performance and that redefined accuracy. The concurrent creation of the lead crew concentrated system control in a select few individuals at the highest level of the system, further enhancing system effectiveness but altering the behavior of the individuals at the lower levels, fully establishing the interdependent relationship between doctrine, humans, and machines by showing how doctrine shaped the professional construction, identity, and actions of the human operators.

Command and Shared Control

The humans at the lowest level of the bombardment system, the pilot, the navigator, and the bombardier, were distinctly socio-technical in construct. Each possessed a specific skill that provided mastery of a particular machine associated with a singular task, a skill that defined them professionally as a member of both the bomber crew and the larger system. The leader of the bomber crew, the pilot is the most identifiable and the only one to transcend the strict association with a particular task or machine. Initially valued for the technical skill that provided control of the aircraft, the pilot's role in the system evolved into that of system controller as aircraft and aerial combat missions became more complex. The need to control a group of humans and machines working toward a common goal transformed his role into that of the

aircraft commander, a generalist capable of making those diverse elements operate as a single socio-technical unit at all levels of the bombardment system, but whose central skill—flying—remained relevant.

Doctrinally, the aircraft commander was responsible for the performance of all of the functions on the aircraft, but did not possess the technical expertise to do so directly. He thus commanded the aircraft system by sharing control with the other crewmembers, allowing each to perform their own tasks. This process of shared control enabled a single pilot to effectively control the bombardment system at the aircraft level, but also enabled designated command pilots to assume greater control over the squadrons, groups, and wings that comprised the system at the formation level. Through shared control, but unified command, these command pilots controlled their groups of aircraft as single elements, depending upon the pilot-commanders at lower levels to do the same with their own elements, making the massive bomber formations into manageable systems focused on accomplishing the precision bombing mission.

While command became the defining characteristic or skill for the bomber pilot, it was firmly rooted in his original skill—flying—as effective functioning of the system at all levels required a capable pilot. Command and flying grew inseparable as the characteristics that enabled control, and when the mandated use of the autopilot gave the bombardier the ability to "fly" the aircraft during the most critical phase of the mission, pilots resisted the adoption and use of the automation, as it threatened their professional identity and ability to control. Not only did it give another crewmember, quite likely one who had failed to complete pilot training, the capability to perform what had previously been an exclusive skill, it directly implied that the autopilot was a better, more precise flyer than the human pilot. However, attitudes changed when it became apparent that the autopilot, in addition to enabling the bombardier to more precisely drop bombs, enhanced the pilot's ability to command the aircraft through shared control, and it became accepted as an integral, necessary part of the system. Effective use of the autopilot actually became a new measure of piloting ability, as understanding how the machine worked, how to set it up, and how to adjust it for precision flight evolved into a new flying skill. The human pilot and automatic pilot developed into an integral socio-technical team that, *together*, flew the aircraft.

Sharing control with humans and machines enabled the pilot to perform more effectively his roles as both pilot and commander, and this shaped a fundamental relationship with

automation that has existed to the present day. Growing beyond his initial definition as a technical specialist, the pilot's professional identity escaped the single machine-task constraint, unlike the other key members of the bomber crew, who were more limited by singular tasks and association with a single skill or machine.

Integration, Calculation, and Translation

The navigator, although not constrained by a single machine, was narrowly defined by a single technical task, aerial navigation, which he accomplished with specialized instruments and calculators through a process of shared cognition, acting primarily as a data integrator. Navigation was a task initially accomplished by reluctant pilots, and non-pilot aerial navigators did not exist until the increased complexity of the long range flights necessary to execute the HADPB doctrine and the personnel pressures of the Air Corps expansion programs required their creation as a separate individual, schooled in the use, care, and calibration of highly specialized navigation instruments and mathematics.

The navigator performed his job in specialized "centres of calculation," unique locations that enabled him to use the unique cognitive and calculation capabilities resident in maps, charts, and mechanical calculators to integrate and transform disparate sets of data into new, useful models for navigation. These idealized textual, temporal, and spatial models served as execution level instructions that he used during the bomber mission to guide the aircraft to and from the target, providing a constant reference that enabled him to translate the aircraft's physical position into an idealized position and locate it in time, space, and relative to the mission flow.

Responsible for getting the bomber to and from the target and knowing where it was at all times, the navigator possessed no direct control over its operation. Relying entirely on the pilot to follow his instructions, he gathered data from his extended "senses," the aircraft flight instruments and other members of the bomber crew, and combined it to locate the aircraft position relative to the models created on the ground. He constantly transformed data in an iterative process, repetitively estimating instrument readings, quantifying environmental conditions, and calculating movement through the air, ofttimes with no sight of the ground, but always transitioning between the physical world and the idealized world of the navigation models. The persistent demand for constant calculation, position plotting, and record keeping largely mechanized the navigator's actions, taxing his cognitive abilities to the point that he was

often unable to accomplish other tasks and almost isolating him from the physical realities of aerial combat.

Doctrine influenced the navigator's action, as the implementation of drop-on-leader bombing and the lead crew dictated his specific role during the mission based upon his aircraft's position in the formation. Only the lead navigator performed all of the functions of aerial navigation—calculating his aircraft position and providing direction to the pilot, while the rest performed a lesser task, "follow the pilot" navigation, where they carried out the same calculations, but possessed no capability to control the aircraft heading or airspeed. This complicated their task, as they had to continually estimate the aircraft direction and speed so that they could calculate their aircraft position and track it within their navigational models.

The navigator was a technical specialist who performed a single task—he navigated—unconcerned with the operation of the aircraft other than how it affected its position in time and space within the bombing mission. As a professional member of the bomber crew and as an individual, his skill at that task and the tools that he used to accomplish it wholly defined him. Although aerial navigation used no automated machines at the beginning of the war, the USAAF attempted to increase navigation precision by imposing control over the navigator through rigid procedure, mechanizing his actions and making him as much a human-machine as possible. Automation and task mechanization were paired in the pursuit of greater precision, however, in the final socio-technical pair on the bomber crew—the bombardier and the Norden bombsight.

Interpretation, Definition, and Redefinition

Precision bombing was the sole mission of the bombardment system, and the bombardier and the Norden bombsight were the socio-technical element at its center. With an unambiguous task—dropping precision bombs with the Norden bombsight—both a task *and* skill with a particular machine defined the bombardier most clearly of all of the crewmembers. Bombing began as a socio-technical task, as humans used progressively more complex machines to perform the complex, dynamic calculation, precision flying, and instantaneous bomb release necessary for precision bombing. As with navigation, pilots initially dropped bombs, but the Air Corps recognized the importance of the task sufficiently that it defined it clearly within its bombardment doctrine, formalizing the position and duties that established the bombardier, with the pilot, as a key member of the bombing team.

While the bombardier was a key member of the bombing team, the bombsight made him so. Bombsights aided the bombardier with the real-time integration, calculation, and precision flying necessary to compute, locate, and fly to the bomb release point, and were the key to the ability to bomb accurately. The Norden bombsight, the product of a long search for a single machine capable of performing all of these functions, was the most accurate bomb-dropping computer of its era. With the bombardier's assistance, it determined the correct point at which to release the bombs and greatly reduced the source of human bombing error by automating both the necessary real-time calculation and the task of actually dropping the bombs. When coupled to the Minneapolis-Honeywell C-1 Autopilot, it also helped the bombardier fly precisely to that point, all of which improved accuracy significantly. Although the Air Corps recognized the importance of training aviators to use this complex device, for the same reasons as the navigator, the bombardier did not emerge until World War II as a non-pilot technical specialist.

In creating that specialist, the Air Corps constructed an individual completely entwined with the bombsight, defined both by his ability to accurately interpret its physical environment and find, identify, and track the target. Although the Norden bombsight automated much of the bombing task, the Air Corps sought to reduce the remaining opportunity for human error by mechanizing the bombardier's actions through repetitive training, much like the navigator, effectively fusing him with the bombsight into a single auto-mechanical element. The ability to use the bombsight put the bombardier at the center of the bombing mission, and when paired with the capability to steer the bomber during the bomb run, provided by the autopilot to an individual who had likely washed out of pilot training, it gave him significant control over the aircraft during the most critical portion of the mission.

Control at that critical point became a central identifying characteristic for the bombardier, but the alteration of the very HADPB doctrine that created his privileged position in the bombardment system destroyed that identity. The adoption of the drop-on-leader doctrine made the lead bombardier in the Combat Box the sole controlling element during the bomb run, as only he operated the bombsight, steered the formation, and dictated when the bombardment system, as a whole, dropped its bombs. All other bombardiers were relegated to the lesser duty of "toggling" off their bombs on the leader's signal, using virtually none of the training that had turned them into professional members of the bomber crew. Consequently, in the clearest display of the connection between doctrine, individual action, and professional identity, they all

but disappeared, replaced by lesser-trained toggliers whose only qualification was the ability to arm the bombs and flip a switch. What technology and skill had granted, doctrine took away.

As the first complete aerial combat system constructed from interdependent humans, machines, and doctrine, the bombardment system used during the CBO set the stage for all such systems that followed. Examining the process of its design and use at all levels from a socio-technical perspective illustrates a number of key characteristics that enable us to see how and why subsequent systems developed as they did, as well as understand the evolving relationship between humans and machines within them.

The Characteristics of the Bombardment System
Complexity

The first notable characteristic of the bombardment system is its sheer complexity, comprised of an incredible number of moving parts from top to bottom, all synchronized in pursuit of a common purpose. At the highest level, assembling and employing the multitudes of bombers that made up each formation was both complicated and deadly. Forming and maneuvering them required extended orchestration and thinking well beyond the simple act of turning left or right, and a small misstep in speed, direction, or altitude could have significant consequences, as losses to collision or enemy action decreased their offensive and defensive effectiveness. Navigation errors could cause lead bombers, and hence entire formations, to miss their target or bomb the wrong one. Worse still, sometimes these missteps were beyond human control, as environmental factors such as poor weather enroute or over the target could further complicate the process and prevent them from accomplishing the individual or collective tasks necessary to perform the overall mission.

The machines used in the system were highly complex, as well, and some, like the Norden bombsight, represented the cutting edge of technical development. Successful operation required extensive training, and producing bombsights that met the exacting mechanical specifications necessary for precision bombing from high altitude was a challenge that stretched the limits of manufacturing capability. Throughout the war, Norden and other bombsight producers continually struggled with the production process, and even as late as late 1944, the USAAF was reporting that 75 to 80 percent of the bombsights it received were unsuitable for

combat use.[1] Even simple machines such as the E6-B computer, used by the navigator and bombardier, stretched the limits of complexity, brought together with maps, charts, and flight instruments to form a shared calculating capability that extended far beyond their individual capacities.

The humans in the system were equally complex as individuals and as a group, defined by the job they performed and the machine that they used to perform it. Some, such as the navigator and bombardier, performed single, well-defined tasks requiring specific skills that established their professional identity. Others, like the pilot, performed a similarly well-defined task, flying, but derived professional identity and position from another, less well-defined but more powerful task, command. All, however, were incapable of fulfilling their function without a technological partner that not only enabled them to perform that function, but formed an integral part of their professional identity, bringing to light perhaps the most important characteristic of the bombardment system—there is no instance where a human or machine performed a task as a single entity. Interdependent humans and machines acted as individual socio-technical elements, each forming an extension of the other, but even those elements existed as part of greater whole, and we cannot understand the function of any one of them without considering all of the others.

Additionally, the humans existed in a complex professional and social structure with a distinct pecking order defined by the doctrine that brought them together as a team, the organizationally held belief in pilots as leaders, and the superior-subordinate relationships that were a product of the military rank system. Those structures could conflict with informal structures, such as the meritocracy produced by the creation of the lead crew positions, which bestowed control upon those who demonstrated technical excellence regardless of rank, or a humans' own individual assessment of their value based on the role played on the crew, founded on the particular skill and machine that defined them, such as with the bombardier. These social relationships, between the humans and machines and the humans and humans, created a complicated, messy environment that served only to complicate another key characteristic of the bombardment system—control.

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[1] Stephen L. McFarland, *America's Pursuit of Precision Bombing, 1910-1945* (Washington, DC: Smithsonian Institution Press, 1995), 145.

Control—Machines and Command

All systems need control. The complexity of the bombardment system drove its design and evolution as a three-level system to enable control, but two primary factors directly affected how that control was exercised: machines and command. Machines played a key role in defining which human in the system had the authority to exert control. The pilot, by virtue of his ability to *fly* the aircraft, the lowest level at which all of the pieces of the system came together as a cohesive element, was the de facto system controller. When the autopilot and bombsight provided the bombardier the ability to "fly" the aircraft more precisely than the pilot during the most critical phase of the mission, they directly challenged the pilot's right and ability to control the system. However, because the autopilot and bombsight provided only a limited ability to *steer* the aircraft, not fully control it, the bombardier did not become the overall system controller. They merely gave the bombardier the ability to perform a part-task better than the pilot could. In fact, the autopilot, by helping the pilot fly the aircraft during the non-bomb run portions of the mission, improved the pilot's ability to exert the control that he already possessed.

The second dominant factor that affected how humans controlled the bombardment system was the function of command, and it more clearly explains why the bombardier did not become the system controller. Machines could provide only limited control over specific parts or functions of the overall system, but all of the system functions needed to be controlled and, significantly, harmonized. Command, a function doctrinally vested in the pilot, provided the ability to exert that control. It gave the pilot organizationally derived responsibility that trumped the simple ability to fly the aircraft as the source of the authority to control the system. He alone was responsible for its correct operation, and while the pilot shared control to manage system complexity, he did not share command. The concept of command as a broader force that supercedes but includes system control is a key consideration as we examine the development of subsequent aerial combat systems.

Shared and Distributed Cognition

As a complex socio-technical entity that reacted to a dynamic environment to perform a specific mission, the bombardment system demonstrated another key characteristic—shared cognition. Every task was dependent upon the sharing of unique cognitive capabilities distributed throughout the system in both humans and machines. The navigator combined his

abilities to interpret the physical environment and integrate data with the calculation and translation capabilities resident in his charts, maps, and E6-B computer to navigate. Likewise, the bombardier combined his ability to interpret the bomber's physical status and the data in the bombing tables and translate it for use by the Norden bombsight, which, as an advanced mechanical calculator, had the ability to compute the solution to the bomb dropping point problem rapidly in a dynamic environment. In each case, the separate cognitive capabilities of the humans and machines came together, complementing each other, to enable the solution of complex problems beyond the capacity of either alone.

While humans and machines shared cognition, so too did the humans on the bomber crew. The pilot depended upon each specialist crewmember to acquire and maintain the knowledge and expertise necessary to perform their tasks, and as a whole, they formed a larger, more capable cognitive element. Similarly, the navigator depended upon the other crewmembers to provide him usable navigation information that they gathered from sources to which he lacked access, such as the view of the ground from their crew position. As the set of central beliefs shared by all of the crewmembers, doctrine played a role in shared cognition, as it provided a common base of knowledge that shaped their thought processes and perceptions, enabling them to work together toward a common goal.

While doctrine enabled shared cognition within the individual socio-technical element and aircraft-levels of the bombardment system, it is interesting to note that it also inhibited that sharing at the larger, formation level of the system. The USAAF policy of radio silence during bombing missions prevented navigation and targeting information from being shared between aircraft, and in several instances this lack of communication led to missed navigation turn points, attacks on the wrong target, or the loss of aircraft and aircrews.[2] This policy clearly inhibited sharing data or information outside the aircraft, but another area of potential investigation for the phenomenon is rooted in the bombardment system's the social realm—the influence of the command structure. With so much doctrinal emphasis placed on the significance of command as the final arbiter of control in the system, was there an institutional barrier that prevented subordinate elements from questioning the actions and decisions of the command pilot and lead

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[2] The question of sharing information between elements in aerial combat systems remains a challenge in the USAF to this day, and the institutional resistance to the implementation of effective datalink systems is an area ripe for investigation. For a perspective on the advantages of information sharing in aerial combat, see Barry D. Watts, *Clausewitzian Friction and Future War, Revised Edition*, McNair papers: No. 68 (Washington, DC: Institute for National Strategic Studies, National Defense University, 2004).

crew to the detriment of the overall mission? If so, this merely reinforces the interdependent nature of the bombardment system, the assertion that doctrine is an integral element, and that social structures and relations can have system-wide effects.

The Aerial Combat System—The Elements, Their Roles, and "What They Do"

The processes of shared control and shared cognition reveal a pattern in the roles played by the humans, machines, and doctrine in the bombardment system, with each performing distinct functions based upon their individual expertise or purpose. While not all are specific, well-defined singular tasks, these functions capture what each did, providing the foundation for the examination of the design and use of subsequent aerial combat systems and, most significantly for the current debate surrounding the roles of humans and automation in remotely piloted aircraft (RPA), the evolving relationship between these elements within the systems.

Doctrine—Purpose, Design, and Direction

The sharing of control and cognition between the humans and machines in the bombardment system did not evolve spontaneously. It happened because the system elements were bound by a common purpose, assembled to enable controlled pursuit of that purpose, comprised of complementary humans and machines focused on well defined tasks, and operated in a way that took advantage of the system's designed capabilities. Doctrine's role in the system was to ensure that all of that occurred by clearly defining the system purpose, defining the human and machine elements around the functions necessary to achieve it, and defining how they, as a socio-technical unit, would perform those functions. In this manner, by intentionally affecting its behavior, the doctrine itself became the key contextual factor and an integral part of the bombardment system.

Humans—Complex Cognition

The human role in the bombardment system involved employing a unique set of cognitive skills to perform the complex tasks associated with the inherent complexity and uncertainty of a dynamic socio-technical system. The bomber crewmembers applied these skills at every level of the system in an effort to impose control and make it work as unified network focused on achieving a single objective or purpose. They accomplished this through three

primary functions: interpreting and translating the environment, integrating disparate sets of data, and system management and judgment.

Interpreting and Translating the Environment

The bomber crewmembers interpreted the bombardment system environment at the individual human-machine element level, acting as "sensors" for a particular machine. The pilot interpreted the aircraft attitude for the autopilot, using his eyes to combine what he could see out of the cockpit window and on the aircraft instruments to create a single reference that the autopilot, by design, accepted as truth. Without that level truth, the autopilot could not sense deviations from it and make corrections. The navigator interpreted the bomber's physical state through the flight instruments, radio, and visual sources, often having to interpret imprecise readings or indications to gather useful data. In the process, he often converted analog and position data to digital data that his calculators and charts could use to compute the aircraft position.

The bombardier's role as interpreter was perhaps the most instructive regarding the human role in the bombardment system, as it involved many complex, core functions that are still performed in current aerial combat systems. The Norden bombsight performed almost all of the dynamic calculations necessary for precision bombing, but had no capacity to collect the necessary data. The bombardier provided that data, some of it digital, gathered from flight instruments and bombing tables, but also critical analog data that involved finding, identifying, and tracking the target. The bombardier found the target visually and identified it based upon the information gathered during the extensive pre-mission route study and mission planning process. When he did this, he transformed a geographic point on the ground into an *objective*—the reference point upon which the bombsight based all of its calculations—orienting it in the physical world and establishing the critical relationship between the bombsight and the target.

When the bombardier pointed the bombsight at the target, he translated its position into direction data, and then managed the relationship between the target and the bombsight by continuing to visually track the target and synchronize the bombsight's optical tracking mechanism. Through this process, he translated the target position data into tracking rate data, ultimately enabling the bombsight to create the miniature analog of that physical relationship between the bombsight and the target that analog enabled the it to calculate the bomb release point. While the bombsight ultimately performed the calculation, it was the bombardier's ability

to identify a point on the ground as a target and manage the relationship between it and the bombsight that enabled the system to work.

Integrating Disparate Sets of Data

The crewmembers also managed complexity in the bombardment system by exercising the unique cognitive ability to integrate disparate sets of data and transform them into data usable by the machines in the system. The pilot integrated two very different sets of data—his visual perception of the aircraft attitude relative to the horizon and the digital and rate information that obtained from his flight instruments—into a single representation as he defined the level reference for the autopilot. The navigator managed more complex problems in his "centres of calculation," integrating visual, analog, textual, and position data and continually translated it into data usable by his E6-B computer, his Flight Record, or his air plot. The bombardier's function as an integrator was perhaps the most challenging of all, as he combined digital data from bomb tables and drift calculations, visual data on his target photos and perspective charts, and direction and motion data derived from his operation of the bombsight into a coherent whole that enabled the bombsight to perform its function.

System Management and Judgment

The final human role in the bombardment system, managing the system and exercising judgment, combined both interpreting the environment and integrating data within the context of the mission—making sure that the system was doing what it *needed to do* and operating within the parameters of the context of the mission itself. The navigator and bombardier operated primarily at the individual machine level, caring for their machines and ensuring that they were operable and properly calibrated. They also exercised judgment when using those machines, often having to interpret imprecise instrument readings from fluctuating gauges or displays to determine a value for the airspeed, heading, or altitude needed for their calculations. The navigator served as a "sanity check" on his own work, continually evaluating his calculated position relative to his pre-mission plan as well as his inflight records, ensuring that his solution was reasonable and within an acceptable range of error, functioning much like a modern Kalmann filter. The bombardier was the final decision authority on whether to allow the bombsight to drop the bombs. Making that decision, either way, required understanding the mission and its purpose, and integrating its real-time context to evaluate whether anything

differed enough from what was anticipated to warrant not completing the defining task at the center of the bombardment system.

The pilot managed the system at both the individual machine and larger system levels. He managed the autopilot while it was in use, monitoring its performance, adjusting it when necessary, and ensuring that it kept the aircraft moving in the right direction. Likewise, he managed the crew to ensure that they were performing their jobs. At the system level, the pilot ensured that his particular element was performing in compliance with the overall mission plan, whether as an individual aircraft or a larger portion of the formation, fulfilling its role as defined by the HADPB doctrine and functioning correctly within the context of the mission *overall*. This was perhaps the most complex cognitive function of all, and an inherent responsibility of command, as it required a complete understanding of the mission, its purpose, and how his particular element fit into it.

Ultimately, system management and judgment were intertwined as one function, boiling down to an assessment of whether something was *right*. Did the navigation calculation place the aircraft in the right position on the Flight Plan and mission map? Was the building or bridge under the crosshairs in the bombsight the right target? Was the aircraft or formation going where it needed to in order to accomplish the mission objective? The answers to these questions could be difficult and they were always subjective, as they required an interpretation and understanding of some particular context surrounding the question, whether it was a fluctuating compass or deciding to continue in the face of deteriorating weather over the target. Only the humans in the bombardment system possessed the unique cognitive ability to capture the complexity of that context, integrate with the greater mission and doctrinal context, and play the role of decision maker to arrive at an answer.

The humans in the bombardment system performed shared cognitive tasks with specific machines, but their uniquely human cognitive ability to constructively manage the complexity within the system defined their role. While some of the particular functions, like navigation or bombing, were strictly defined and even mechanized to an extent, and others, like flying and command, were much more flexible, each one required interpretation, integration, and management within some not-easily quantifiable context. The ability to handle this complexity, however, was not matched by a similar ability to perform some of the specific tasks with the precision necessary for the bombing mission. That role fell to the machines in the system.

Machines—Simplification

Just as the processes of shared control and shared cognition reveal a distinct pattern in the roles played by humans, so too do they for the machines used in the bombardment system. While the bomber aircraft played a prominent role in the system, the roles played by the individual machines provide the foundation for understanding the human-machine relationship in aerial combat systems. Machines performed very specific cognitive tasks, and in the case of the automated machines physio-cognitive tasks that involved some form of sensing and action or reaction, that simplified the complex and varied human cognitive tasks necessary to operate the bombing system. They accomplished this through two principal functions: performing complex calculations in a dynamic environment and executing precision physical and cognitive tasks.

Calculation, Precision Action, and the Single Task

The machines in the system were designed to support a specific task with a specific capability. Aerial navigation required a great deal of repeated calculation, and accuracy and speed were essential for precision. Rapidly solving the complex geometric, vector, and trigonometric problems necessary to calculate the aircraft position was beyond the unaided cognitive capacity of most navigators. Specially designed mechanical calculators, flight planning and recording forms, and navigational charts with embedded cognitive capabilities enabled the navigator to perform these calculations and navigate effectively. While extremely powerful, however, these devices were limited in their application, useful only for the specific function of navigation calculation. The bombardier was also involved in complex calculation, but he used a machine with much greater precision to simplify the problem of locating the single point in space from which he could drop his bombs and hit the desired target, the Norden bombsight.

Arguably the most advanced airborne mechanical calculator of its era, the Norden bombsight was more powerful than the navigator's computers and solved complex, dynamic mathematical calculations far more quickly than is conceivable for a human alone. When used with the other computers and bombing tables, it enabled the level of rapid calculation necessary for precision bombing. As a calculator, however, the Norden bombsight was even more limited than the navigator's were, intended for a more narrowly defined task—to locate the precise position of the bomb dropping point. It could perform no function other than those related to the

task of bombing.[3] The single task orientation that characterizes the calculating machines is reflected in the bombardment system's automated machines, as well.

The bombardment system relied on two primary automated machines, the Norden bombsight and the Minneapolis-Honeywell C-1 Autopilot, both designed to perform the precise, timely actions necessary for precision bombing. Other than calculation, the bombsight performed two automatic functions: it gyroscopically kept the optical system oriented to the true vertical after the bombardier leveled it, and it automatically released the bombs from the aircraft precisely at the calculated bomb dropping point, both of which increased bombing accuracy. While separate physical functions, their common purpose was dropping precision bombs. The autopilot performed one automated function—it automatically maintained the flight attitude commanded by the system operator, whether the pilot or bombardier. It was very precise, able to counter the normal oscillations of an aircraft in flight much faster and more accurately than a human pilot could. While it served to relieve pilot fatigue on long duration flights and provided the bombardier the ability to precisely control the aircraft flight path, it performed only a single function—it maintained the flight attitude commanded by the human operator. Nothing more.

The machines in the bombardment system were all single-task focused. They performed tightly defined, single functions that accomplished very specific cognitive and physio-cognitive tasks. Where the human role was to manage the complexity in the system, the machine's role was to *simplify* specific aspects of that complexity for the human by making certain tasks easier to accomplish rapidly and more precisely. While they helped the crewmembers perform rapid, complex calculations in a dynamic environment and execute the precise physical tasks necessary for precision bombing, none of the machines, even the automated ones with rudimentary capability to sense their environment and react to it, was able to deal with the uncertainty or complexity inherent in the bombing mission. They performed their task regardless of the mission purpose or the context surrounding it, and were likewise unable to adapt their behavior in response to a change in that context. They executed only that which the human operator directed. It is this inability to adapt to the context that is the most interesting, and possibly most important, aspect about the machine's role in the system, and sheds light on how we may

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[3] As discussed in Chapter 4, the Norden bombsight could compute the aircraft drift for the navigator, much like a drift meter, but this function was integral to bombing, as well.

understand if and how automation has changed what the human operator really does in aerial combat systems.

Automation, Concentration, and Control

One of the principal issues in the debate surrounding the present-day increased use of RPAs is the effect of the increased use of automation in aerial combat systems. As such, it is useful to examine the effect of the use of automation in the first aerial combat system—which predated current RPA systems by over half a century. All of the automated machines in the bombardment system performed single, well-defined, cognitive tasks that began with human operator input, remained under operator supervision during operation, and could be terminated by the operator at any time during execution. They were *automated*, but not *autonomous*. Additionally, while the task that they accomplished could be individually quite complex, within the larger system, it was cognitively quite simple. At no point were the technologies called upon to understand why they were performing that task or how it fit into the larger system's operation and purpose. That role fell to the human operator. They acted independent of any context other than the tightly defined parameters that controlled their operation. This is the area where we must look for change in the human-machine relationship. If, as we examine subsequent aerial combat systems, we see automated machines shouldering more of the complex cognition burden, we can then look for change in the human operator's actions as they push more tasks to machines, freeing up cognitive capacity.

While the conclusion that machines accomplished easily-defined tasks and humans more complex ones is neither new nor surprising, it provides insight into the rationale used to determine which functions might be chosen for automation in aerial combat systems and why. Handing off time consuming cognitive tasks to automated machines freed up more of the human's limited cognitive capacity so that it could be dedicated to the higher-level task of *controlling* the system. The greater the number of tasks that can be automated, the greater the amount of control a single human can exert over the larger system. This concept clearly guided the use of automation in the system, but its influence is far wider and not limited just to automation, indicating a more generalized phenomena that we can clearly see through the development of the bombardment system as just that—a socio-technical system.

As we examine the bombardment system, we see clear indications of the process of defining tasks, designing an element to perform that task effectively in a fashion that is controllable, and suborning it to a controlling authority. Initially, the pilot performed all of the tasks on an aircraft associated with bombing. However, as the task of dropping bombs became more complex and beyond the capacity of the single human pilot, the Air Corps developed both a specialized machine *and* a specialized human to perform that single task, and likewise with navigation. These socio-technical elements became controllable entities focused on a single task, and the pilot evolved to become the controller of those elements. The socio-technical elements were not automated, but the actions of the humans themselves were *mechanized* through training and procedure to try to gain some of the benefits of automation by reducing their complexity, limiting their role, and making them more predictable. Through this process, the pilot gained more ability to control the system at the aircraft level.

The process of concentrating tasks at a central location in the system in order to reduce complexity and exert more control over them extended into the formation level as well, as observed in with the adoption of the drop-on-leader doctrine and the creation of the lead crew. Creating a single lead navigator and lead bombardier decreased the number of socio-technical "cognitive units" in the formation, making control easier for the command pilot, but it had an added benefit. By limiting the number of participants in the bombing and navigating process, but increasing their span of control within the system, it made it possible to improve system performance with a smaller investment in training.[4] As demonstrated by the great reduction in the number of bombardiers and the creation of togglier, only the lead bombardier and his

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[4] Before the war, the Air Corps had planned to combine bombardier and navigator training and put a single bombardier-navigator on each crew. Combining the two tasks was viewed as a solution to the pressing demand for trained personnel in both areas, as well as an opportunity to reduce the number of crewmembers on bomber aircraft, saving weight and enabling them to carry more bombs. The constant shortage of qualified personnel and the difficulty of finding recruits capable of being trained in both specialties prevented the Air Corps from fully implementing the program at the beginning of the war. They did, however, begin training a significant number of dual-qualified bombardier-navigators on the use of the less-complex D-8 bombsight and in dead reckoning navigation for use on the smaller crews of medium bombers, such as the B-25. By late 1943, they had developed several different training programs that trained bombardiers more thoroughly in some areas of navigation, and trained navigators in the basics of bombing and how to use the bombsight. The particular program that a recruit completed depended upon which bomber he would fly in combat. For example, recruits destined for assignment to a B-29 unit were "completely dually trained" as celestial navigators and bombardiers, whereas those destined for B-17s or B-24s received only bombardier and dead reckoning training. See Ben R. Baldwin, *Individual Training of Bombardiers*, Army Air Forces Historical Study 5 (Washington, DC: U.S. Army Air Forces Assistant Chief of Staff, Intelligence Historical Division, May 1944), 58-70.

deputies needed to know how to operate the Norden bombsight. In that case, a few well trained individuals were all that was required, greatly reducing the amount of expensive training necessary to make the bombardment system effective. Of course, once the single task of bombing was concentrated in a single point, it became a logical candidate for more automation.

In 1944, the USAAF developed and fielded the Radio Bomb Release (RBR) automated bombing system, codenamed "Crawfish," which used radio signals to trigger the simultaneous release of all of the bombs in an entire bomber formation. A radio in the lead bomber transmitted a signal when the lead bombardier's bombsight dropped its bombs, triggering receivers in the rest of the formation to do the same. Only used in a limited capacity, as the system was subject to malfunction and jamming, RBR produced very tight bomb patterns when it worked, further demonstrating how a single control technology could improve system performance.[5] As single tasks, both navigation and bombing were appropriate candidates for further the further application of technology, automated and otherwise.

World War II saw a great swelling of American technological development, and by the middle of 1943, a revolutionary new technology was slowly taking its place at the head of the giant bomber formations flying over Europe—radar.[6] Specially trained Pathfinder crews flew radar-equipped bombers in the lead position, using the new technology to assist with both navigation and bombing when weather obscured the ground, adding a tremendous new offensive capability while simultaneously creating a new crew position, the radar operator, which required an entirely new skill set.[7] Interestingly automation brought bombing and flying even closer together during the war in PROJECT APHRODITE, where worn out B-17s were converted to remotely piloted aircraft, loaded with 20,000 pounds of explosives, and then flown remotely into high-value ground targets.[8] The guided missiles and RPAs in use today can count these "Weary Willie" bombers in their lineage.

Automation technologies played a large role in the bombardment system, as they performed single, well-defined, time consuming cognitive tasks that required speed and

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[5] Roger A. Freeman, *The Mighty Eighth War Manual* (London: Jane's Publishing Company, Ltd, 1984), 46.

[6] For an excellent account of the United States' tremendous scientific and technological advances during the war, see James Phinney Baxter, *Scientists Against Time* (Cambridge, MA: MIT Press, 1968).

[7] For a perspective on the use of radar and the role of the Pathfinders in the British effort during the CBO, see Gordon Musgrove, *Pathfinder Force: A History of 8 Group* (London: Macdonald and Jane's, 1976).

[8] Dik A. Daso, *Hap Arnold and the Evolution of American Airpower* (Washington, DC: Smithsonian Institution Press, 2000), 186-188.

precision, freeing up the humans in the system to perform the more complex cognitive tasks associated with operating the system within the context of the mission. Although automated, these technologies were not autonomous and required human operators to apply their capabilities to the particular needs of the mission. The automation of these tasks reflected a larger socio-technical trend of concentrating human and machine capability in a central location in the system, enabling greater control over them and over the larger system itself. Technical development focused on improving performance in these areas, and the bombardment system began changing as new capabilities were developed and implemented. New technologies brought new crewmembers and new procedures to operate them, but they were bound together by the same element of the system that defined the initial components, defined their form, and guided their operation—doctrine.

All of the elements in the bombing system had distinct roles. The humans performed complex cognitive tasks that required interpreting and translating the system environment, integrating disparate sets of data, and exercising judgment, managing the system to ensure that all of the elements performed within the particular context of the mission. The technologies aided the humans by performing single tasks that required rapid complex calculation or precision action that was beyond human capability, freeing up their uniquely human cognitive capacity so that the system could function at all levels. Doctrine was the key contextual element in the bombardment system—the "why" that bound together the humans, machines, and ideas. Its role was to provide the purpose, the design, and the direction for the system's use. In this role, it affected the makeup of the socio-technical elements, both physically and socially, but was itself affected by their actions. Acting as the glue that held the system together, it is not possible to understand how the system's physical and social elements operated, at any level, without considering it a full and equal part of the system.

Looking Beyond the First Step—The Socio-Technical View of Aerial Combat

Three decades after Riley Scott first demonstrated his bomb dropper, the United States took the first aerial combat system to war. From August 1942 to the end of December 1943, USAAF bomber formations visually bombed 2,766 targets out of 2,872 struck, dropping over

109,000 short tons of bombs and losing 1,567 aircraft in the process.[9] While it was the first use of a bombardment system on a large scale, that period of the CBO effectively marked the end of an era. In the years following, inventions such as radar and other automated machines produced new methods of flying aircraft and dropping bombs, and while large bombers remained a viable aerial combat alternative, many new systems emerged that employed smaller aircraft with different capabilities. Rather than viewing that change as a continuing, monochromatic procession of new aircraft that could drive inaccurate, context independent conclusions about the roles of humans and machines in these systems, the socio-technical perspective developed in this study provides an alternative way to interpret aerial combat system development, using doctrinal change as a common thread that enables us to reveal the evolving human-machine relationship, particularly with regard to how automated machines affected what the human operators did and who they were.

The first major, non-nuclear, doctrinal change after World War II occurred in the early 1960s, when improved enemy air defenses and the need to drop bombs at night or in any weather condition made high-altitude, daylight bombing a poor option for the precision strike mission. The need for a high speed, low-altitude, all-weather bomber drove the development and fielding of the General Dynamics F-111. The F-111 was a fighter-bomber aircraft operated by two crewmembers, a pilot in the left seat and a weapons system officer (WSO) in the right, and although smaller than the B-17, it carried more bombs and could fly much farther. Highly complex, it incorporated many automated flying, navigating, and bombing systems, reflecting a distinct trend toward the increased use of automation in aerial combat.

One of the most significant automated systems was the terrain following radar (TFR), a forward-looking radar that, when coupled to the aircraft autopilot, provided the capability to fly at the extremely low altitudes and high speeds necessary to avoid the enemy air defenses without hitting the ground. The TFR automatically maintained a set altitude, and could fly the aircraft at altitudes and speeds far beyond the human pilot's capability, particularly at night when he could not see the ground. In high threat combat areas, it was not uncommon for the pilot to set the TFR to maintain 200 feet while the aircraft traveled at airspeeds up to 600 miles per hour. With the system engaged, the pilot did not touch the flight controls, and although he monitored its

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[9] Data taken from spreadsheet 1942-45.xls in Richard G. Davis, *Bombing the European Axis Powers: A Historical Digest of the Combined Bomber Offensive, 1939-1945* (Maxwell Air Force Base, AL: Air University Press, 2006).

performance, there was little or no time to override an errant flight control input, and he had to develop a clear trust relationship with the system in order to get comfortable using it. The TFR's outstanding low-altitude flying capability had an interesting role in the trust relationship between the crewmembers, as well. On crews where the pilot and WSO were unfamiliar with each other, the WSO was often more comfortable when the autopilot was flying the aircraft at low altitude than when the human pilot was flying, as he knew what to expect from the autopilot.[10]

The TFR and autopilot also integrated with the F-111's navigation system, itself a highly automated inertial navigation system (INS) that kept track of the aircraft position by tracking its movement with a series of internal gyroscopes. Together, they largely automated the function of flying to the target, able to fly the aircraft on a preplanned mission flight route, avoiding obstacles and integrating a great deal of the physical mission context in a way that was not possible during World War II. Both the TFR and INS also integrated with the aircraft's weapon system computer and bomb targeting radar, creating a coupled bombing system that was conceptually a direct descendant of the Norden bombsight. After the WSO "designated" a target on the radar scope, the weapon system computer flew the aircraft to the correct release point, from which it could drop the bomb automatically, if desired.[11] This integrated system also gave the WSO the ability to "fly" the aircraft through the computer and autopilot, as well, by simply moving his target designator on the radar scope and changing the target location and thus the steering point for the computer.

The F-111 used many automated machines to help the aircrew perform its mission, with the TFR and weapon system computer further refining the ability to perform tasks accomplished on the B-17, like flying and bombing, and the INS performing new ones, like navigation. All of these systems required that the humans, as well, refine some of their existing skills or develop other new ones to operate them. The pilot had to improve as a system manager, as both the TFR and the complexity of the entire aircraft system placed new demands on his cognitive skills. The WSO, who was in fact part navigator and part bombardier, had to improve as a system manager as well, as he was responsible for several automated navigation and bombing systems, and had to

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[10] Terrance McCaffrey, "Interview with Terrance McCaffrey, Col, USAF," interview by Raymond P. O'Mara, August 13, 2010; Raymund E. O'Mara, "Interview with Raymund E. O'Mara, Maj. Gen., USAF (Retired)," interview by Raymond P. O'Mara, June 13, 2010.

[11] The system had a consent-to-release function operated by the pilot, much like the release lever that the bombardier used on the Norden bombsight.

learn how to visually interpret the radar display and determine how to locate and identify his target on a monochrome green screen, as well. Studying radar "pictures" of targets replaced studying photographs during mission planning on missions where radar bombing was planned, and interpreting them evolved into a skill in itself.[12] As the navigator, the WSO had to learn how to manage the computer's internal navigation model, which involved understanding and monitoring a task—inertial navigation—that he himself could not even perform. The most important thing that the humans had to develop, however, was the ability to trust their machines as they took on more and more mission critical functions, the correct performance of which was essential for the survival of the aircrew itself. This essential trust bound the humans and machines together more tightly as a socio-technical unit.

While each of the automated machines used on the F-111 still essentially performed a single task, when integrated as a weapon system they performed much more complex cognitive tasks than the machines on the B-17 by concentrating more functions into fewer locations in the system. This concentration enabled the size of the crew to be reduced, as it gave individual humans the ability to manage more tasks, but automation's ability to provide system control to different individuals reinforced some of the machine-induced social phenomena observed in the B-17. The WSO, who operated the weapons system computer and navigation system, gained much more physical control of the aircraft, including the mission critical functions of navigating and bombing, while the pilot surrendered even more of his flying responsibility to the same computer and the TFR and autopilot. In fact, the job involved enough system control that there was initial discussion regarding replacing WSOs with inexperienced pilots to provide them the opportunity to become seasoned before moving to the left seat as the aircraft commander, much like the copilot in the B-17.[13]

The USAF investigated this possibility in 1967 during COMBAT LANCER, the first combat deployment to Vietnam, when they put pilots in the right seat instead of the navigators who had trained for the position. The experiment proved fruitless, however, serving only to annoy both parties, denying the navigators the opportunity to perform their jobs and causing resentment among the pilots denied the opportunity to fly the aircraft. Ultimately, pilot manning

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[12] See "COMBAT LANCER Preliminary Report (Secret/NOFORN) (Information extracted declassified 14 July 2010)", December 20, 1968, K168.03-262, IRIS No. 113011, US Air Force Historical Research Agency.

[13] See *Aircrew Composition Study for F-4 and F-111 Aircraft (Combat Eternal)* (United States Air Force, 1968), M-U 38264-77, Muir S. Fairchild Research and Information Center, Maxwell AFB, AL.

shortages prevented any further use of pilots in the right seat, and the basic crew functions went unchanged. The pilot occupied the left seat as the aircraft commander, responsible for the overall management and successful operation of the system, and the WSO occupied the right seat, a technical navigation and bombing specialist. The case provides an opportunity to explore more deeply the phenomena witnessed with the adoption of the C-1 autopilot in the B-17 regarding a machine's ability to grant control in a system where control is defined, at least in part, by a specific physio-cognitive task that is central to the professional identity of one of the human operators.[14]

The F-111 case is an opportunity to see how automated machines can change the human operators' physical actions in aerial combat systems, but also raises questions that provide insight into the evolution of human and machine functions in these systems. As automated machines gained more ability to physically fly the aircraft, how did the pilot's role evolve? What additional functions and responsibilities did the pilot assume? If giving a machine or another operator the physical ability to fly did not change the fundamental control structure in the system, what is the role of flying in system control? Perhaps, what does it really mean to "fly," and most importantly, what are the key skills necessary to perform that function? The increased use of automation spurred by doctrinal change prompted these questions, and within twenty years, another significant doctrinal change produced a new system in which the use of automation raised even more questions about the pilot's role in manned aerial combat systems.

Where the doctrinal change to low-altitude, all-weather strike brought humans and machines closer together in the F-111 socio-technical system by further blurring the lines between human and machine roles, the fielding of the F-117 Nighthawk stealth fighter in the 1980s did so to an even greater extent. The F-117 emerged in response to the very poor performance of US-built aircraft against Soviet-built air defense systems during the 1973 Arab-Israeli War. Created as a single-seat, medium altitude, night, precision strike platform, the F-117 was a technological marvel, and the unique nature of its design directly influenced the human pilot's actions while employing it.[15]

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[14] See Major Norman L. Rice, *Effects of Right Seat Manning and Radar Strike Preparation on the F-111 "Combat Lancer" Project*, Corona Harvest, Project CORONA HARVEST (Maxwell AFB, AL: Aerospace Studies Institute, Air University, January 1971), K239.032-21, IRIS No. 917632, US Air Force Historical Research Agency.

[15] See Martin L. Van Creveld, *Military Lessons of the Yom Kippur War: Historical Perspectives* (Beverly Hills, CA: Sage Publications, 1975). The F-117 is actually an interesting case where the doctrine emerged from the

The need to achieve and maintain stealthy characteristics drove the F-117's design, and the unique shape necessary to minimize radar detection produced an aircraft that looked more like a science fiction-inspired spacecraft than a strike platform. The aggressively swept wings made the aircraft inherently unstable in pitch, thus uncontrollable by a human pilot without the use of a digital fly-by-wire flight control system. That flight control system was part of a complex digital autopilot that could rapidly and accurately sense the aircraft attitude and perform the complex calculations necessary to keep the aircraft in flight. While the pilot still controlled the aircraft direction and orientation with a conventional flight control stick, the autopilot modified his control inputs with its own before moving the flight control surfaces, making flying the aircraft a true team effort.

The autopilot also played a major role in the aircraft's combat employment. During a mission, the aircraft had to remain correctly oriented to the known threats to maintain its stealthy profile. This meant flying precise headings for extended periods based on the threat, turning only when necessary. Rather than tax the pilot with this task, the autopilot flew the mission profile, controlled by an electronic flight program created on the ground before the mission, consisting of a set of executable instructions, much like the flight plan created by the B-17 navigator in World War II. The autopilot flew the aircraft for the majority of the mission, with the pilot "hand flying" it only during takeoff, transit periods, aerial refueling, and landing. This significantly decreased role as a flyer raises some interesting questions when we examine the system socio-technically, especially when we then examine the human role in RPA systems.

Who, or what, was flying the aircraft? Certainly, the pilot is one answer, as he sat in the cockpit with direct access to the flight controls, necessary for takeoff and landing, and able to override the automatic system at any point. The autopilot is another possible answer, as it maintained direct control over the flight control surfaces, and even integrated the mission context with its knowledge of the necessary headings and turn points, a function performed only by the human pilot in the B-17. But how did it know that contextual information? Actually, it was a set of specialized mission planners who programmed it before the mission, many of who were not even pilots. Since the autopilot was executing *their* instructions, are they not a possible answer

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successful development of stealth technology, rather than the technology developing in response to a doctrinal need. This serves to reinforce the interdependent nature of all of the elements in aerial combat systems. See Paul G. Kaminski, "Low Observables: the Air Force and Stealth," in *Technology and the Air Force: A Retrospective Assessment*, ed. Jacob Neufeld, George M. Watson, Jr., and David Chenoweth (Washington, DC: Air Force History and Museums Program, 1997), 299-309.

to the question? Of course, there is no single, clear answer. As seen with the F-111, the concept of flying evolved as the aerial combat systems themselves evolved and incorporated more automation into every operation.

The autopilot actually controlled the aircraft for the majority of the mission for another reason, as well. Since the F-117 was a single-seat aircraft, the pilot was responsible for dropping the bombs on the target. The aircraft had a very advanced infrared targeting system, and the pilot spent the majority of the time during the mission using it to find, identify, and track the intended target. He did this by watching a single, monochromatic screen located in front of his control stick, controlling where the targeting system looked so that he could visually acquire the target. Once acquired and identified, he pointed a laser at the target, which the seeker on the laser-guided bomb (LGB) carried by the aircraft tracked as it fell. During that fall, the seeker steered to the laser spot, as the pilot essentially remotely flew the bomb to the target through the bomb's flight control system, attaining a level of precision bombing that was only dreamed of during the CBO. In a very odd twist to the story of the World War II bombardier using the C-1 Autopilot and Norden bombsight to perform the pilot's job of flying the aircraft, the autopilot in the F-117 actually gave the pilot the ability to do the bombardier's job.

Obviously, the pilot's physical role in the F-117 was different in several ways from the B-17 or F-111 pilot, but they were evolutionary changes largely driven by the use and dependence upon automated systems. The F-117 brought system management to a new level, as the pilot had to monitor the autopilot, the aircraft engine and performance instruments, and the operation and employment of the targeting system, but he still remained the aircraft commander, the individual responsible for the entire system. The targeting system introduced the need for the pilot to develop a new skill, however. Understanding and interpreting the infrared display was part art, part science, and took much practice to master and it developed into a new measure of "piloting" ability among F-117 operators. Rather than the ones who could turn the hardest or shoot the fastest, excellence in the F-117 was measured by how well and how fast a pilot could identify his target on the targeting system display.[16]

As a highly automated system, the F-117 graphically illustrates the effect of the use of increased automation on the physical actions of the aircraft operator. As machines took on

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[16] Mike Merritt, "Interview with Mike Merritt, Lt Col, USAF (Retired)," interview by Raymond P. O'Mara, August 12, 2010.

progressively more of the cognitive load associated with individual technical tasks, concentrating them into fewer and fewer automated systems, it enabled the pilot to perform more of the higher-level management tasks necessary to keep the entire system operating. From that perspective, automation changed the pilot's fundamental role in the system very little. That fact alone is the conceptual bridge that links the human, machine, and doctrinal roles developed in this thesis to the debate surrounding the effect of the increased use of automation in today's RPA systems. In the F-117, a weapon system fielded in the 1980s and already retired from the active flying inventory, an automated machine accomplished almost all of the mission-related flying functions. It was far more automated than most of the RPA systems in use today, particularly those that employ weapons. If we wish to evaluate the effect of the increasing use of automation in unmanned systems, we need merely to look back at those other manned systems that we have so recently used, very successfully, in combat.

This brief glance at the F-111 and the F-117 within the context of the entire study only scratches the surface of what we can learn about the human-machine relationship in aerial combat systems by examining them from a socio-technical perspective, but it shows the value of that frame of reference for better understanding the social, technological, and doctrinal issues surrounding the increased use of RPAs in today's militaries. Although remotely piloted, broadly conceived, the RPAs of the twenty first century are colossal networks of specially trained humans and purpose built machines and automation technologies, including pilots, sensor operators, aircraft, satellites, computers, datalink systems, and weapons, guided by a new, developing set of doctrinal ideas and beliefs, that together bring a new set of airpower capabilities to the battlefield—essentially grown up versions of the bombardment system that the United States took to war against Germany in 1942. Understanding them requires the same holistic approach used in this study, focusing on the central roles played by *all* of the elements in the system, rather than focusing on a single human-machine physical relationship. Only then can we conquer the real challenge of identifying change in the relationship between the elements, because the change reveals itself in what each element *does*, which is not necessarily dependent upon where it *is*.

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