Archimedes

Volume 3

Archimedes

NEW STUDIES IN THE HISTORY AND PHILOSOPHY OF SCIENCE AND TECHNOLOGY

VOLUME 3

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Volume 3
New Studies in the History and Philosophy of Science and Technology

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Atmospheric Flight in the Twentieth Century

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INTRODUCTION

All technologies differ from one another. They are as varied as humanity's interaction with the physical world. Even people attempting to do the same thing produce multiple technologies. For example, John H. White discovered more than 1000 patents in the 19th century for locomotive smokestacks.[1] Yet all technologies are processes by which humans seek to control their physical environment and bend nature to their purposes. All technologies are alike.

The tension between likeness and difference runs through this collection of papers. All focus on atmospheric flight, a twentieth-century phenomenon. But they approach the topic from different disciplinary perspectives. They ask disparate questions. And they work from distinct agendas. Collectively they help to explain what is different about aviation – how it differs from other technologies and how flight itself has varied from one time and place to another.

The importance of this topic is manifest. Flight is one of the defining technologies of the twentieth century. Jay David Bolter argues in *Turing's Man* that certain technologies in certain ages have had the power not only to transform society but also to shape the way in which people understand their relationship with the physical world. "A defining technology," says Bolter, "resembles a magnifying glass, which collects and focuses seemingly disparate ideas in a culture into one bright, sometimes piercing ray."[2] Flight has done that for the twentieth century.

Though the authors represented in this volume come from very different backgrounds, we share a concern to move beyond a fascination with origins and firsts. Instead, the essays of this book all attend to a technology forever in process, a technology modified all the way through its history. From its shifting relationship with the aerodynamic sciences to the shop-floor culture of bomber production; from the changing functions of patented mechanisms to the standards of pilot training, protocol, and disaster inquiries. Through and through, this is a book about the heterogeneous practices of aviation all the way down the line.

In some ways the technologies of flight seem remarkably stable: in looking at the earliest airplanes, the wings, ailerons, rudder and elevators seem remarkably congruent with the same features on a 747. Yet, over the course of the twentieth century, the technologies of flight have radically altered. Consider the perspective of Hugh Dryden, the former Director of the National Advisory Committee for Aeronautics and Associate Director of the National Aeronautics and Space Administration. He used to say the he grew up with the airplane. He wrote his first paper on flight in 1910, when he was 12 and the airplane was 7. In it he argued for

P. Galison and A. Roland (eds.), Atmospheric Flight in the Twentieth Century, vii–xvi

"The Advantages of an Airship over an Airplane," earning an F from a prescient if harsh teacher. At the time of his death in 1965, Dryden was helping to orchestrate humankind's first journey to an extraterrestrial body. Born before the airplane, Dryden lived to see humans fly into space.

Now, at the end of the twentieth century, humans are about to occupy an international space station. Its supporters believe that it will begin a permanent human presence in space. The Wright brothers could hardly have imagined that their primitive attempt to fly would lead within a century to a permanent presence off the Earth. The technology that they inaugurated transformed humans from gravity-bound creatures scurrying about the face of the Earth to spacefaring explorers looking back at the home planet as if it were an artifact of history. At the time of Apollo, historian Arthur Schlesinger, Jr., hazarded the guess that when future generations reflected on the twentieth century they would remember it most for the first moon landing.

Flight has defined the 20th century symbolically, spiritually, and spatially. Individual airplanes such as the workhorse DC-3, the democratic Piper Cub, the dreadful B-29, the rocket-like X-15, and the angular Stealth fighter have imprinted their shapes and their personalities on modern life. They represent our contemporary ability to deliver people, bombs, or disaster relief anywhere in the world in a matter of hours. Popular imagination has rendered the Wright brothers, Charles Lindbergh, and Chuck Yeager as quintessentially heroic individuals, icons of the human yearning to subdue nature, achieve freedom of movement, and conquer time and space. To the extent that the world has become Marshall McLuhan's global village, flight has made it so. Communications put us in touch with each other, but airplanes put us in place.

Is a defining technology like other technologies? Or is it different? Does it obey the same rules, evince the same patterns, produce the same results? Or do defining technologies, by virtue of their powerful interaction with society, operate differently? The essays collected in this volume shed considerable light on these questions.

This volume – and the conference that launched it – began with a series of discussions between Alex Roland and Dibner Institute co-directors Jed Buchwald and Evelyn Simha. Would it not be original and fruitful, they wondered, to bring together historians of flight with a wider group of scholars and engineers from related fields – people who had not necessarily written on the history of flight? Peter Galison was recruited as a historian of science and private pilot – and together Roland and Galison began assembling the mix of historians of the technology of flight and the engineers, philosophers, sociologists, and historians who are represented here. Our great debt is to the Dibner Institute for their support of our conference from 3-5 April 1997, and the continuing interest they have had in seeing this volume come to fruition.

In addition to the individual merits of the papers gathered in this volume, we believe that collectively they shed light on the question of whether or not flight functions like other technologies. The simple answer is yes and no. The complete answer is more interesting and more provocative. Readers may find their own version of that answer in the papers that follow. Here we will attempt only to point out some of the ways in which the answer might be construed from these contributions.

First, flight may be seen as similar to other technologies. Patents represent one area in which this is true. These government charters to promote and reward innovation are often depicted as measures of inventive activity and stimulants to technological change. They might be expected to have played a significant role in the development of flight. Thomas Crouch and Alex Roland confirm this expectation, but find that it operated in unexpected ways. Crouch debunks the myth that the Wright patent choked U. S. aviation development in the period leading up to World War I. Though the Wright patent was surely unusual in its scope and impact, it did not retard development, as its opponents claimed, and it was not unique. Roland takes up the same issue where Crouch leaves it. Studying the impact of patents on airframe manufacture in the period from World War I to the present, he finds that patents were important at the outset, less so over time. This pattern is familiar in cumulative industries where foundational patents launch a new technological trajectory but then decline in relative importance.

National subsidy also shaped aviation in the same way that it has shaped other technologies, such as shipbuilding, armaments, microelectronics, and computers. Increasingly in the modern world, industrialized states have intervened in technological arenas deemed important to national security or prosperity. Aviation is no exception. Takehiko Hashimoto's paper demonstrates the strong role of government policy in the development of British aviation, a pattern repeated in other developed European nations. Walter Vincenti describes a research project within the National Advisory Committee for Aeronautics (NACA), one of the institutional mechanisms by which the United States government subsidized aviation development. The cross-licensing agreement at the heart of Roland's paper came into being at government behest and with the benefit of a $2 million government buy-out.

Dual-use is another characteristic that likens aviation to other technologies. It means that the technology has both military and civilian applications. From the very first, aviation has been dual-use; the Wright brothers built their plane as an end in itself, but first sought to sell it to the U.S. Army. George Lewis, the Director of Research of the National Advisory Committee for Aeronautics in the 1930s and 1940s, confessed that he could not think of any improvement in aviation that would not benefit military and civilian aviation alike. Thus the research conducted at the Army's McCook Field in the teens and twenties, examined here in Peter Jakab's paper, turned out to have important civilian applications. Likewise, the research that Walter Vincenti and his colleagues conducted at the NACA in the 1940s was equally applicable to the wings of military and commercial aircraft. And the production methods worked out in the mass assembly of B-17's and B-29's described by Robert Ferguson utterly transformed the practice of airplane assembly after 1945.

Ironically, dual-use has become less pervasive in modern aviation at just the time when the military services have focused more attention upon it. The reason is the increasingly specialized nature of modern, high-performance military aircraft. Many of them, for example, now feature skins that resist heating at high speeds, a characteristic unnecessary on commercial aircraft. Stealth technology, one of the marvels of recent research and development, has no utility for civilian aircraft. The special stability characteristics of fighter aircraft are unique. The avionics of high-speed, low-level flight have few applications on the commercial side, nor do electronic countermeasures, ejection seats, and the ultra-high flying technologies reserved almost exclusively to reconnaissance aircraft. Of course the period before World War II had its share of military technologies with no civilian analog, such as bombsights, armaments, and carrier-landing capability. But the irony remains that civilian applications of military aeronautical technology have become more elusive just when the military and the aerospace industry have taken the greatest interest in them.

The other side of dual-use, of course, is that research and development aimed at military products often differs from that supported by the commercial market. The military usually requires higher standards of performance and reliability. Perfecting such technology may require more research and development than market forces could support. But once the technology has been perfected, it may be transferred to the commercial marketplace fairly cheaply; the overhead has already been absorbed. The classic example of this is U.S. computer development during the Cold War,[3] but aviation provides a similar instance. The instrumentation developed by Frederick Suppe and his colleagues to test the performance of military aircraft could later be installed on commercial planes for a fraction of the cost. The turbofan engine development described by George Smith and David Mindell came free to the commercial manufacturers, fully paid for by the military. This phenomenon, a commonplace of United States development during the Cold War,[3] seeps into the issue of national subsidy. Roland's paper concludes that one reason for the success of commercial airframe manufacture in this country was the indirect subsidy of government research. Much of that subsidy took the form of military R&D.

Also, in its relation to science, aeronautics resembles other science-based technologies. John Anderson traces paths by which scientific knowledge has entered the realm of aeronautical engineering. Similar paths have marked the intercourse between thermodynamics and engine design, between solid-state physics and microelectronics, and between microbiology and genetic engineering. In aeronautics, as in all of these other realms, traffic moves along these paths in both directions. Just as science often provides theoretical models for better technology, so too does technological development often provide challenges to theory and new tools for scientific investigation. Walter Vincenti's paper offers a stunning example of the way in which cross fertilization of an experimental technique from one investigation allowed a breakthrough to conceptual understanding of physical phenomena in another. George Smith and David Mindell explain how advances in metallurgy yielded titanium fan blades for more efficient engines. By exploring the texture of shop-floor life in World War II aircraft production, Robert Ferguson shows how the design process was never restricted to the "top" of the assembly process – innovation, modification, re-design occurred all the way down from initial sketches to the final stages of production. These papers thoroughly rebut the naive picture in which design and knowledge enter only at the start of a massive project.

Equally revealing are the ways in which flight is different from other technologies. First, it is more dangerous than most. Peter Galison's paper wrests technological insight from two gripping commercial airline accidents; the imperative to identify the cause of an accident drives investigators toward a definition of agency that challenges our very understanding of technological systems and they ways in which they fail. Whether it is the test pilots in Frederick Suppe's account of flight instrumentation or the fatal crash of Otto Lilienthal, whom Roland represents as the inspiration for the Wright brothers, disaster accompanies the failure of this technology more swiftly and surely than almost any other.

Cost also separates flight from most technologies. Deborah Douglas explores the price of passenger accommodation in the early years of airport design and construction. If customers were going to pay for air transportation, they had to pass through a site that connected everyday life in two dimensions with a technology of three dimensions. The problems were enormous and costly. Frederick Suppe opens up the world of flight instrumentation, one of the auxiliary technologies without which flying would be riskier and less understood. Walter Vincenti reveals the painstaking detail required to understand – or begin to understand – the character of supersonic flow over an airfoil. George Smith and David Mindell track the evolving relationship among compressor, turbine, and airflow that characterized the incremental development of high-bypass jet engines. The wind tunnel in which these ideas were tested cost more to design, build, operate, and staff than did the complete research and development programs in many other technologies.

The romance of flight permeates all these papers, and sets this technology apart from most others. Frederick Suppe captures it in his account of daring test flights in the desert. Even Deborah Douglas' account of early airport design resonates with the adventure and excitement that airport designers were trying to exploit. The heroic airmanship of pilot Al Haynes and his crew in nursing United Airlines Flight 232 to a controlled crash ennobles an otherwise tragic technological failure. A technology that allows humans to "slip the surly bonds of earth" cannot help but appear romantic in comparison to the mundane tasks to which most technology is committed. Indeed, in recent years scholars have begun to historicize the romance of aviation, using the airplane as a means of exploring larger issues of twentieth century cultural history.[4]

Few technologies generate the infrastructure that has grown up around atmospheric flight. The Wrights achieved flight with the materials that they could haul by rail and boat from Ohio to North Carolina, supplemented by food and shelter purchased locally. Today aviation needs research and development of the kind described by Smith and Mindell, Hashimoto, Eric Schatzberg, and Vincenti; testing and instrumentation like that explored in Suppe's paper; institutional guarantees of rights to innovation as laid out by Crouch, Roland, and Roger Bilstein; operating infrastructure such as airports (Douglas) and accident investigation (Galison); and much more. Some of the infrastructure is private, some public; most of it now has to be coordinated internationally, so that flight can cross national borders without loss of system integrity.

Finally, atmospheric flight requires higher standards than most other technologies, in part because of the danger involved, in part because of the cost. When a single airliner can cost more than $100 million and an airport costs billions, the incentive to ensure their faultless operation is high. When a single accident can kill hundreds of people, the incentive is incalculable. Hashimoto, Schatzberg and Ferguson show the ways in which standardization entered aircraft design and testing early in the century. Suppe's paper demonstrates how the price of standardization has risen, with ever more expensive and accurate instrumentation and ever more data points required to get the information necessary for confident operations. Galison's inquiry into accident investigations reveals the lengths to which the government will go to root out system weakness and replace it with the standardized practice linked to higher levels of safety.

These papers also demonstrate the ways in which flight has varied from time to time and place to place. The historical literature of flight is notoriously parochial and nationalistic; indeed, it proved difficult to break that pattern in assembling the participants in this volume. But even when flight is studied comparatively and from various perspectives, it is difficult to discern international patterns over time. Rather the principal artifacts of this technology, the airplanes themselves, along with their support equipment and infrastructure, reflect the national styles and the periods in which they were generated. The reasons for this are not hard to find.

The main reason is institutional. In consonance with recent scholarship on the shaping influence of the research environment, several papers explore the ways in which differing research styles produced differing artifacts. Hashimoto takes sociologist of science Bruno Latour's notion of inside/outside research behavior as his explicit model for understanding the impact of Leonard Bairstow on the development of British aviation in the years between the world wars. The concentration of the British on stability research and wind-tunnel modeling, and their tardiness in adopting boundary layer theory and corrections for wall interference effects, were a direct result of Bairstow's determination to defend his research base in empirical, wind-tunnel studies. It took an international, comparative research project in the 1930s to reveal the extent to which this concentration had retarded British development. Robert Ferguson explores the specificity of engineering cultures even when the companies are producing the identical airplane. Or perhaps, as Ferguson shows, "identical" needs to be put between quotation marks: it seems that no amount of drawing, personnel exchange, or even exchange of airplanes could surmount the myriad of details that separated production at Boeing from that at Vega or Douglas.

Like Hashimoto, our commentator, David Bloor, has stressed the potential fruitfulness of a sociological reading of institutional identity, though Bloor invokes the sociologist Mary Douglas. Douglas's idea is that rather than dichotomizing institutions, we might invoke a two-by-two matrix, so to speak: institutions are either egalitarian or hierarchical, and they are either boundary-policing or boundary-permeable. Using this four-way typology, Bloor queries our various authors as to where on such a chart they might find their "engineering cultures," e.g., General Electric versus Pratt and Whitney or Goettingen versus Cambridge. That is, Bloor wants to know whether the various ways that engineers treat objects reflect basic sociological features of the way they treat the people with whom they work.

Also attentive to engineering culture is Walter Vincenti, who attributes the success of his research team to the creative, unstructured, eclectic laboratory environment they enjoyed at the Ames Aeronautical Laboratory of the U.S. National Advisory Committee for Aeronautics. He pictures a free association between theory and empiricism, in which individual researchers were able to bring new ideas and proposals from any source. They were measured by their efficacy in solving the problems at hand, as opposed to the doctrinaire constraints imposed by Bairstow in the British environment.

Suppe presents an entirely different research environment, instrumentation of flight testing. The principal dynamic at work here is the relationship between improving instrument technology and the ever increasing demand for more data. Instrumentation offers more and better data, but it can hardly keep pace with the demands for more data points and more precision as aircraft speed and performance improve. The research imperative is therefore not to figure out the design of better aircraft but to develop and field equipment that will keep up.

Research and development in aerodynamics took a fascinating, counterintuitive turn in the account Smith and Mindell provide of the high-bypass jet engine. While one might expect that a radical new design by one company would stimulate equally radical changes in the competition, these authors show quite the reverse took place. In a highly secretive program, General Electric stunned the aviation world with their novel 1957 single-stage, aft-mounted fan. Pratt and Whitney responded, but their counter was a similarly efficient but completely incremental two-stage fan with vastly simpler aerodynamics. In part because of novelty-related start-up problems for GE, P&W triumphed in the marketplace.

Peter Galison describes an entirely different institutional imperative. The National Transportation Safety Board (NTSB) is required by law to investigate technological failure in a particular way. Torn between seeking to understand an accident in all its complexity of contributing causes and the institutional demand to locate a more localized "probable cause," accident investigation is a vexed enterprise. Under these constraints, the investigating team is often driven to identify point failures, especially point failures that are subject to remedy. Thus an institution that is poised at the very nexus of technological understanding, i.e., at the point where technology fails, is bound by law to view that failure narrowly and instrumentally. This can lead to great technical virtuosity and poor contextual understanding. And so, while trying to preserve a "condensed" notion of causality, the investigators time and again sought to embed the causal account in the wider spheres aimed at by psychological, organizational, and sociological approaches.

Peter Jakab captures the excitement of McCook Field in its early years. Before the U.S. Army knew what it was going to do with aviation, and before its institutional research arrangements settled into routinized patterns, McCook Field was a hothouse of innovative ideas and experiments. Distinguished researchers accepted appointment there and brought their creative energies to a field rich with promise and interest. If anything, there was too much innovation and experimentation at McCook Field in these years, with the research program seemingly running off in many different directions at once. The result was that McCook Field did not itself come to be credited with any great technological breakthroughs, but the people who worked there honed their research skills and gained invaluable experience. As an institution, it turned out to be a better training ground than a proving ground.

Even Deborah Douglas's account of airport development in the United States suggests the powerful ways in which institutions shape technological development. Commercial passenger travel achieved market viability in the United States in the 1930s. The so-called "airframe revolution" that produced the DC-3 is most often credited. But Douglas reveals that airport design also played a role. Only when the airport came to be envisioned as a user-friendly, comfortable, safe, and aesthetically pleasing nexus between air and land travel could airlines hope to attract the passengers who would make their enterprise profitable. The American decision to make airports local institutions prodded the market toward competitive design and production that pitted cities against one another in their claims to be most progressive and advanced. The results were airports like LaGuardia in New York, which lent a unique stamp to American aviation and helped to foster development of the entire commercial enterprise.

John Anderson attests to the importance of institutions in transferring knowledge and understanding back and forth between scientists and technologists of flight. Nikolay Joukowski, the head of the Department of Mechanics at Moscow University, was the first scientist to take Otto Lilienthal's work with gliders as a fit subject for scientific investigation. The resulting Kutta-Joukowski theorem, which revolutionized theoretical aerodynamics, gained purchase in part because of the weight of Joukowski's reputation and his institutional setting. So too did Ludwig Prandtl's position at Goettingen University lend credibility to his research on the boundary layer. He took up a practical problem, theorized it in a revolutionary scientific concept that transformed modern fluid dynamics, and then gave it back to practical application in his own work and his students' on the flow of air over wings and fuselage.

The cases of Joukowski and Prandtl serve not only to illustrate the ways in which institutions have shaped the development of flight technology but also to introduce a final way in which these appear to address differences in flight. University research in Russia and Germany influenced aeronautical development long before American and British universities achieved such an impact. In fact the German style of university-based, theoretical research in aerodynamics was spread to the United States by two of Prandtl's students. As Roger Bilstein makes clear, Max Munk went to the National Advisory Committee for Aeronautics in 1929 and developed there the innovative variable density wind tunnel for which the NACA won its first

Collier Trophy. Even more significantly, Theodore von Kármán accepted the invitation of Nobel laureate Robert Millikan to join the faculty at the California Institute of Technology and direct its Guggenheim Aeronautical Laboratory. From that institutional base von Kármán went on to exert a formative influence on aeronautical research and development and on the policies of the United States Air Force. American aeronautical development took on a more theoretical turn because of the immigration of this European, especially German, style of research.

National variations in research styles are evident in other papers as well. Eric Schatzberg reveals the impact of national tastes for materials in his discussion of the wooden airplane in the 1930 and 1940s. The United States' preference for metal as an aircraft building material flowed from preconceptions about the modernity of aluminum, not from a judicious evaluation of the merits of wood. For equally nationalistic reasons, Canadians preferred wooden aircraft and developed them with great success during World War II. And the Americans, under the pressure of World War II developed modes of exchange between competing airframe manufacture that fundamentally altered the character of the industry.

Hashimoto uses the International Trials of the early 1920s to demonstrate the differences in national research styles and practices and the difficulties involved in standardization. The Trials also revealed the parochialism of the British and contributed to their movement toward continental practice. Roland demonstrates the ways in which specific national experience in the United States differentiated the impact of patent practice from that in other countries. The introduction of a patent pool in 1917 was driven by the legal logjam surrounding the Wright patent. The government intervened to buy out the Wright interests and the interests of their leading competitor, Glenn Curtiss. The resulting patents pool lasted for 58 years and distinguished United States patent experience from that of any other nation. This history cries out for a comparative study of aircraft patenting experience in other nations to see what conclusions might be drawn about the impact of patents in general and the comparative efficacy of the American model.

Bilstein's paper is the most self-consciously international and comparative. It both reinforces and challenges the general perception of aviation as a parochial and nationalistic technology. Bilstein notes, for example, that American aeronautical development really was different from that in other countries, a fact that no doubt helps to account for America's remarkable domination of this industry for so many years. But Bilstein also notes that ideas and innovations from other countries were constantly finding their way to America, undermining the stereotypes of native American genius that have plagued the field since the remarkable achievement of the Wright brothers.

But Bilstein's paper also helps to point up one of the great generalizations that may be applied to this quintessential twentieth-century technology. As the century has proceeded, the technology has become more universal and homogeneous, less parochial and nationalistic. Japan is licensed to produce a version of the American F-16. American airlines fly European-manufactured Airbuses. American aircraft manufacturers mount Rolls Royce engines on their planes. Virtually every large airplane in the world uses fundamentally the same landing gear. Airports, navigation, and ground support equipment the world over are becoming increasingly standardized. The differences between aircraft remain stark and obvious, and the variations from country to country continue to reflect idiosyncrasies of national style and infrastructure. But all this diversity persists in the midst of a general trend toward uniform and standardized technology. This, too, is a mark of the twentieth century.

Alex Roland
Peter Galison

NOTES

[1] John H. White, *American Locomotives* (Baltimore: Johns Hopkins University Press, 1968), p. 115.

[2] J. David Bolter, *Turing's Man: Western Culture in the Computer Age* (Chapel Hill: University of North Carolina Press, 1984), p. 11.

[3] Paul Edwards, *The Closed World: Computers and the Politics of Discourse in Cold War America* (Cambridge, MA: MIT Press, 1996).

[4] Peter Fritzsche, *A Nation of Fliers: German Aviation and the Popular Imagination* (Cambridge, MA: Harvard University Press, 1992); Joseph J. Corn, *The Winged Gospel: America's Romance with Aviation, 1900-1950* (New York; (Oxford University Press, 1983).