

Aeronautical Science 101:
The Development of Engineering Science
in Aeronautical Engineering Education at the University of Minnesota

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Introduction:

Engineering Science and Its Role in Aeronautical Engineering Education

In 1929, the University of Minnesota founded its Department of Aeronautical Engineering. John D. Akerman, the department head, developed the curriculum the previous year when aeronautical engineering was still an option for mechanical engineering students. Akerman envisioned the department's graduates finding positions as practical design engineers in industry. Therefore, he designed the curriculum with a practical perspective. However, with the rising complexity of aircraft through the 1930s, 40s, and 50s, engineering science grew more important to aeronautical engineering design practices than ever before. In 1948, the university closed a deal on an idle gunpowder plant. The aeronautical engineering department converted the site into a top-notch aeronautical research laboratory. A new dean for the engineering schools, Athelstan Spilhaus, arrived at the University of Minnesota in 1949. He brought a vision for science-based engineering. Akerman, who never felt completely comfortable with theoretical design methods, struggled with the integration of engineering science into his department's curriculum. Despite Akerman's resistance, engineering science eventually permeated the aeronautical engineering curriculum at Minnesota through this new lab and the dean's vision. In following this path, the University of Minnesota came to exemplify the significant place of engineering science in aeronautical engineering by the 1950s. This thesis hopes to decipher some of the major mechanisms pertinent to the develop-

ment of engineering science in aeronautical engineering education by looking at the University of Minnesota as a case study.

To consider the development of engineering science in aeronautical engineering education, one first needs to understand what the term means. The Oxford English Dictionary (OED) defines engineering science as “engineering regarded as a field of study, especially that part of it which can be treated according to the laws of mathematics and the physical sciences.”¹ The OED cites the following quotation from a 1901 issue of *Engineering* as the first appearance of the term: “The policy of the University [of Glasgow, in Scotland] is to offer to students a course of study in engineering science, and to leave them to acquire their experience and practice in the office or in the workshop.”² The 1907 Oxford University Gazette reported, “The above Statute proposes to establish a Professorship of Engineering Science. The Professor will give Laboratory--but not Workshop--Instruction.”³ By 1907 the term “engineering science” linked engineering to something more precisely scientific than a practical art.

It is not unimportant to the emergence of engineering science that engineers in Western societies began organizing themselves professionally around the turn of the century, largely in reaction to their subordinate social status to scientists. By identifying their work with scientific endeavors, engineers hoped to increase their prestige and raise their social standing. In a 1976 article, “American Ideologies of Science and Engineer-

¹ *Oxford English Dictionary on Compact Disc*, 2nd ed. (Oxford: Oxford University Press, 1992). Hereafter cited as *OED*.

² Quotation from *Engineering*, 6 September 1901, in *OED*.

³ Quotation from *Oxford University Gazette*, 15 October 1907, in *OED*.

ing,” historian Edwin Layton claimed that 19th-century American engineers such as Benjamin Isherwood and Robert Thurston “were pioneers in the development of a distinctive science for engineering.” Significantly, both men “found it necessary to reject the idea that engineering science could be reduced to the application of the laws of basic science to engineering.”⁴ By the 1930s aeronautical engineers recognized that their discipline commanded a distinct body of scientific knowledge that they preferred to call “aeronautical science.” This term appeared in the name of one of their leading societies, the Institute of the Aeronautical Sciences, founded in 1932. Following the Second World War, engineers came increasingly to use “engineering science” as the proper description of their approach to solving problems and generating new knowledge. Dr. Jerome C. Hunsaker, one of America's leading aeronautical engineers and the founder of MIT's aeronautical engineering department, described the fluid mechanics textbook that he co-authored with B. G. Rightmire in 1947 as an “introduction to a field of engineering science.”⁵ Essentially, what engineers were doing was constructing the concept of “engineering science” as an instrument that promoted who they were, what they did, and what they themselves most specifically could contribute to society.

Although engineers clearly identified their work as “engineering science” by the post-World War II period, historians of science and technology for the past four decades have been debating the proper meaning of the term. In 1974, Layton in another key

⁴ Edwin Layton, Jr., “American Ideologies of Science and Engineering,” *Technology and Culture* 17, no. 4 (October 1976), p. 691.

⁵ Quote obtained from William Trimble, *Engineering the Air: A Biography of Jerome C. Hunsaker* (forthcoming), p. 7. I extend a special thanks to Bill Trimble for making available to me several chapters of his Hunsaker manuscript.

article, "Technology as Knowledge," challenged the position of early historians of technology, notably Charles Singer, E. J. Holmyard, and A. R. Hall, who argued that technology was simply craft and that basic science was "the source of all new technical knowledge."⁶ Layton retorted:

Technique means detailed procedures and skill and their application. But complex procedures can only come into being through knowledge. Skill is the 'ability to use one's knowledge effectively.' A common synonym for technology is 'know-how.' But how can there be 'know-how' without knowledge?⁷

Clearly engineering straddled the line between science and technology. Engineering existed essentially indivisible from technology: engineers built things. But that did not preclude them from more scientific types of work. Engineers of the Institute of Aeronautical Sciences like Jerome Hunsaker understood that their discipline was built on technological precepts and rules. As Layton explained, the function of technological rules was "to provide a rational basis for design, not to enable man to understand the universe."⁸ Although the function of these rules was directed for the purpose of "doing" rather than just "knowing," the foundation of these rules can be very scientific. For Layton, Alexandre Koyre's concept of *technologie* equated to "engineering science," meaning the technological rules that "came ultimately to constitute a body of technology theory." Under the influence of science, this body of knowledge was then transformed in a fundamental way into something unique and distinguishable—not just from science but

⁶ Edwin Layton, Jr., "Technology as Knowledge," *Technology and Culture* 15, no. 1 (January 1974): p. 34.

⁷ *Ibid.*, pp. 33-4.

⁸ *Ibid.*, p. 40.

also from other forms of technological knowledge as well.⁹ Not only did “engineering science” possess different methods and ways of knowing and doing, as a distinct entity from science it also pursued very different goals.

Layton’s discussions of engineering science sparked a historiographical controversy that has now lasted for nearly thirty years. In a 1988 article “Transformations and the Myth of ‘Engineering Science’: Magic in a White Coat,” for example, Michael Fores adamantly disagreed with Layton’s ideas of engineering science as a distinct body of knowledge. For Fores,

Science is our species’ collected and tested knowledge of all aspects of what is taken to be a single universe. If some body of knowledge called ‘engineering science’ is taken to be identifiably separate (as Manx cats are from Persian cats), then it must be possible to throw a secure boundary of discrimination around it. But the use of ‘engineering science,’ like that of ‘applied science,’ is not discriminating; there is no boundary that can be drawn.¹⁰

Further, Fores asked, “How can ‘engineering science’ be a ‘new body of knowledge’ and a ‘technological activity’ concurrently?”¹¹ In his view, engineering science cannot be distinguished from science generally. Thus, engineers using scientific knowledge in design processes are simply practicing “applied science.”

Layton and his followers found Fores’s claims simplistic. To them, science is more than just a body of knowledge about the natural world—and in its own ways, so is engineering science. Fores is wrong to deny the existence of scientific “activity” in

⁹ Ibid., p. 40.

¹⁰ Michael Fores, "Transformations and the Myth of 'Engineering Science': Magic in a White Coat," *Technology and Culture* 29, no. 1 (January 1988): pp. 72-3.

¹¹ Ibid., p. 67.

different forms.¹² Both “science” and “engineering science” embody methodologies and research practices, not just a collection of information.

Generally speaking, this thesis sides with Layton in this debate. For purposes of analysis, “engineering science” will be defined in two ways. First, engineering science is a body of knowledge inherently indivisible from its context.¹³ This means, among other things, that engineers investigate and use engineering science to model the complex behavior of a technology mathematically as part of a design process. Scientists typically describe their work as a search for understanding. The purpose of engineering science, on the other hand, is much more goal (or object) directed. To achieve that goal, engineering science definitely uses theoretical approaches to knowledge but uses it for the purpose of *doing*. Aeronautical engineers immersed in engineering science will do such things as describe the behavior of a body, not just of a point, in a defined environment.

Secondly, engineering science involves distinct approaches to problem solving. A veteran research engineer who in retirement has produced very distinguished work in the history of technology, Walter Vincenti has best explained this difference in a series of essays published in 1990 as *What Engineers Know and How They Know It: Analytical Studies from Aeronautical History*. In one of his case studies, Vincenti argued that

¹² Edwin Layton, Jr., "Science as a Form of Action: The Role of the Engineering Sciences," *Technology and Culture* 29, no. 1 (January 1988): p. 83.

¹³ In her paper, “Repatriated Nature: Atomic Bomb Victim Body Parts and Post-War Japanese-American Relations,” given as part of the University of Minnesota History of Science and Technology Colloquium Series, 5 March 1999, M. Susan Lindee suggests that our understanding of radiation sickness and health conditions as a result of nuclear fallout is more meaningful when taken in the context of the whole body. She refers to this more complete knowledge as “natural knowledge” in the history of biology.

engineers used “control-volume analysis” to solve thermodynamics questions, while physicists use “control-mass analysis.” In control-volume analysis, a contrived boundary encloses a system, like a turbine engine. The placement of the boundary dictates which equations best represent the system. Then all the inputs and outputs—factors such as work, pressure, temperature, and velocity—that “cross” the boundary will be measured. All changes in those values represent the activity within the system and provide the necessary data used in solving a system’s equations. As Vincenti explained, control-mass analysis works best in closed systems where no fluid flow exists, that is, no matter enters or exits the system, only energy. For example, when a piston moves inside a cylinder, the conditions of the matter trapped inside change in temperature, pressure, and volume. Maybe a chemical reaction will be triggered, as in the case of a Diesel engine when combustion occurs. But most importantly, as Vincenti wrote, “almost all thermodynamic problems of interest to physicists (for example, the physical, chemical, and electrical properties of matter) do not involve fluid flow in any essential way and are thus amenable to control-mass analysis.”¹⁴

In contrast, engineering questions more often involve fluid flow. Engineers can use control-mass analysis for fluid flow problems, but the mathematical representations grow extremely complex when compared to control-volume analysis. Vincenti described the situation with a traffic metaphor. When accounting for vehicle movement, engineers prefer to record the frequency of cars passing through a predefined zone, instead of following a preselected group of cars. Essentially, engineers and scientists search for

¹⁴ Walter Vincenti, *What Engineers Know and How They Know It: Analytical Studies from Aeronautical History* (Baltimore: The Johns Hopkins University Press, 1990), p. 115.

different systems knowledge. In searching for this different knowledge, engineers have devised for their use scientific methods that are distinct from those implemented by scientists.

As a result, engineering science evolved into something more than just applied science. Theoretical studies in engineering remained unquestionably scientific in nature. But their subjects, methods, and purpose grew to be different. Those areas of engineering science with their foundations in more traditional science areas developed beyond purely scientific studies into unique systems knowledge for design. Engineers tailored scientific knowledge and methods to provide the kind of information that would make effective technological design more feasible.

From the term's inception (around the turn of the century) to the present day, the meaning of "engineering science" has remained very flexible—and never has been popularly understood or appreciated. For the early engineers who used the term, like Isherwood and Thurston, engineering science meant the application of Newtonian principles and simple conceptual theories to an engineering project. For example, aeronautical engineering theories in the early 1900s tried to explain phenomena such as "the effects of dihedral on lateral control."¹⁵ (The dihedral is the angle that the wings make with the horizontal plane of the aircraft. In flight when the plane rolls, if the dihedral is positive--the wings angle up--then lateral stability increases. The airplane tends to correct itself, or return itself to level flight.) But the explanations were purely

¹⁵ John Akerman, University of Minnesota General Extension Division Correspondence Study Department, Final Examination for Elementary Aeronautics, Akerman Correspondence, Miscellaneous, 1931-1941 file, box 2, Akerman Papers, University Archives, University of Minnesota (hereafter referred to as UA.)

qualitative in terms of explaining this aerodynamic behavior. But knowing that an airplane will behave in a given manner is not necessarily knowing *quantitatively* how significantly a dihedral will effect lateral stability. Such a limitation seriously handicapped the knowledge base that engineers incorporated into aircraft design.

Engineering science elevated engineering to more than a mechanical art. The more complex the design goals, the more important in-depth theoretical knowledge about the artifact and about its performance environment became. Engineers needed to create knowledge that not only *appeared* more mathematical and scientific; they needed to create knowledge that actually *was*.

With on-going advancement in aviation technology, the practical engineering methods of the early aeronautical engineers failed and grew obsolete. Aeronautical engineering faculty found that young engineers needed skills of the mind that previously were expected only of researchers. Some moved to broadening technical curricula to include engineering science that by its very nature was more theoretical. For educators, this meant more than exposing the students to a wind tunnel or some other piece of experimental equipment; it meant some advanced mathematics, deeper theory, and more systematic experimental methodologies (such as control-volume analysis and parameter variation), by which the design of something as complicated as a high-performance flying machine could be accomplished more successfully.

Wind tunnels, the basic tool of aeronautical research, offered a means by which to develop engineering science in that aerodynamic testing in this machine served both empirical and theoretical purposes. To achieve truly major results, a course of experiments needed to be guided by theory. But at the start of wind tunnel testing, such a

positive synergy was missing. The wind tunnel testing of model airfoils done by Wilbur and Orville Wright in their Dayton bicycle shop exemplified empirical testing. They collected lift and drag measurements for dozens of airfoil, then selected the most favorable design. They wanted a wing that performed better than what they had been achieving with their gliders at Kitty Hawk up to this time. They were not trying to contribute anything basic to airfoil theory. The next step, taken by others, was to use wind tunnels not just for data collection, but to explore basic aerodynamic phenomena. As this came to happen, engineers left empiricism behind and gave birth to a culture of engineering science within aeronautics.

Not until well after the turn of the century did the early forms of engineering science play a role in aircraft design. It was not that the early airplane builders were not conceptual enough in their thinking, but that their practices were largely empirical. Most of the pioneers were amateurs. Only Otto Lilienthal had received any formal training in what could be called aeronautical engineering. Consequently, any scientific knowledge they possessed about aerodynamics, structures, controls, and stability had been learned on one's own. It is questionable whether these early builders even possessed the technical background to understand the engineering science that did exist. Further, these individuals had one intention, i.e., to build an airplane, not to advance aeronautical engineering science. Without mutual involvement within a community devoted to using some form of engineering science in airplane design, the early airplane builders and the professional engineers interested in aeronautics revolved in separate orbits. Still, it is still important to consider the roles of early airplane builders in the development of aeronautical engineering and engineering science. After all, building successful airplanes

was the *raison d'être* not just of the pioneer aeronauts but of aeronautical engineering and engineering science as well.

Historians credit Sir George Cayley (1773-1857)¹⁶ with developing the early concepts of flight. In “On Aerial Navigation,” published in three parts in 1809 and 1810, Cayley described the cambered (curved) wing and its effects on lift. He explained the four forces on an aircraft: lift, weight, thrust, and drag. Cayley wrote, “The whole problem is confined within these limits—to make a surface support a given weight by the application of power to the resistance of air.”¹⁷ He intuited these concepts from his study of birds in flight and from whirling arm experiments. Cayley also constructed model gliders, including a “man-scale” model of 1853 dubbed “the Coachman Carrier.” Many historians suggest that his coachman did the test piloting, but it might have been one of his other employees; we know it was not Cayley himself.¹⁸ Nevertheless, after a short flight and a rather rough landing, the test pilot, whomever he was, promptly gave Sir George his notice.

The first American to pursue an interest systematically in aeronautics was Professor Samuel P. Langley (1834-1906)¹⁹, a distinguished astronomer and the Secretary

¹⁶ Biographical information from John Daintith et al., *Biographical Encyclopedia of Scientists*, 2nd ed. (Bristol: Institute of Physics Publishing, 1994), p. 151.

¹⁷ Quoted in Peter L. Jakab, *Visions of a Flying Machine* (Washington, D. C.: Smithsonian Institution Press), p. 22.

¹⁸ Charles H. Gibbs-Smith, *Sir George Cayley's Aeronautics 1796-1855* (London: Her Majesty's Stationery Office, 1962), pp. 177-9, 244.

¹⁹ Biographical information obtained from Don F. Moyer, "Samuel Piermont Langley" in Charles Coulston Gillespie, ed., *Dictionary of Scientific Biography*, (New York: Charles Scribner's Sons, 1973), VIII: 19-21.

of the Smithsonian Institution. In his article, "Story of Experiments in Mechanical Flight," published in the 1897 *Annual Report of the Board of Regents of the Smithsonian Institution*, Langley described the laboratory work he was performing as part of the design process of what would become his most infamous aeronautical endeavor, the full-scale "Aerodrome." Much about his experimental program was nothing more than trial-and-error testing. Langley wrote,

In order to learn under what conditions the aerodrome should be balanced for horizontal flight, I constructed over thirty modifications of the rubber [band]-driven model, and spent many months in endeavoring from these to ascertain the laws of "balancing;" that is, of stability leading to horizontal flight. Most of these models had two propellers, and it was extremely difficult to build them light and strong enough. Some of them had superposed wings; some of them curved and some plane wings; in some the propellers were side by side; in others one propeller was at the front and the other at the rear, and so every variety of treatment was employed, but all were at first too heavy, and only those flew successfully which had from 3 to 4 feet of sustaining surface to a pound of weight, a proportion which is far greater than Nature employs in the soaring bird, where in some cases less than half a foot of sustaining surface is used to a pound. It had been shown in the "Experiments in aerodynamics" that the center of pressure on an inclined plane advancing was not at the center of figure, but much in front of it, and this knowledge was at first nearly all I possessed in balancing these early aerodromes.²⁰

Langley used the same empirical approach to investigate steam engines as the motive power source for his aircraft. Langley admitted in his paper that after spending a considerable amount of time experimenting in the area of steam engineering, he came to realize that steam engines were too heavy to provide the amount of thrust needed.²¹ For his man-carrying *Aerodrome*, he used a gasoline-powered engine, a very good one that he

²⁰ Samuel P. Langley, "Story of Experiments in Mechanical Flight" in *Annual Report of the Board of Regents of the Smithsonian Institution*, (Washington, D.C: Government Printing Office, 1898,) 171-2.

²¹ *Ibid.*, 175.

and his mechanic Charles Manly had designed, with much higher thrust to weight ratio than his earlier steam engines.

Langley completed construction of his man-carrying aerodrome in 1903. On December 8 of that year, just nine days before the Wright brothers made aviation history at Kill Devil Hill, Manly twice test-flew the aerodrome from off the top of a houseboat in the Potomac River near Washington, and twice promptly found himself on a craft that fell like a sack of mortar into the water. Langley had decided to launch the aerodrome off a houseboat “because it was known that the aerodrome might have to be set off in the face of a wind, which might blow in any direction, and because it evidently was at first desirable that it should light in the water rather than on the land.”²²

While Langley considered the problems of balance, Otto Lilienthal (1848-1896)²³ in Germany had spent more time looking into the lift and drag effects of cambered airfoil design. Lilienthal trained in mechanical engineering at the Berlin Technical Academy, but aeronautics held his fascination. He believed that the dynamics of bird flight held most of the answers to effective airplane design and performance. He and his brother, Gustav, built their first set of wings in 1861. Over the next 30-plus years, they conducted whirling arm experiments and constructed numerous gliders. On August 9, 1896, while flying one of his gliders, a gust of wind caught the wings. Lilienthal used only his shifting body weight to control his gliders. Consequently, he could not overpower the force of the wind and crashed, breaking his back. He died the following day.

²² Ibid., 175.

²³ Jakab, p. 33.

Lilienthal seemed to understand the dynamics of flight in a way that other airplane builders of his time did not; he not only wanted to apply science for practical results, he aimed to pursue those practical results according to a systematic approach that modern engineers would instantly recognize as their own. His book, *Birdflight as the Basis of Aviation*, contained experimental analysis, mathematical representations, and empirical studies of birds in flight and wing models. He wrote, “An understanding of the most elementary conceptions of dynamics is all that we require in order to prove the correctness of these results, and it is fortunate that the most important features of flight are of a very simple dynamical character, embodying only the theory of the equilibrium-- and of the parallelogram of force.” Lilienthal entertained the hope “that not only the science of aviation but also that of dynamics, her indispensable handmaid, may gain new adherents, stimulating some of his readers to gain a closer insight into the teachings of theoretical mechanics, or least to refresh his college teaching.”²⁴ The German engineer grasped the concepts clearly, but also sensed the complexities of aeronautics. His most lasting contribution to the development of human flight was his tables of lift and drag data for various wing designs, later to be used by the Wright brothers.

The Wright brothers, through cleverness, study, and clarity of thought, were the first to achieve powered and controlled human flight successfully. As bicycle makers, they knew they had a lot to learn about designing and building a craft as complex as an airplane. In 1899 they wrote to the Smithsonian for all available literature on the subject. The package they received back included a copy of Octave Chanute's *Progress in Flying*

²⁴ Otto Lilienthal, *Birdflight as the Basis of Aviation*, trans. A. W. Isenthal (London: Longmans, Green, and Co., 1911), pp. 126-7.

Machines, published in 1894. This was the most complete compendium of aeronautical knowledge, equations, and data available at the time and included the works of Cayley and Lilienthal.

The Wrights gained valuable insight from their study. Historian Peter Jakab writes, “Their observance and analysis of the approaches taken by others greatly aided them in clearly and accurately defining the principle obstacles to human flight and how best to overcome them.”²⁵ Now knowing where they should begin, the Wrights used the existing lift and drag data and equations to design the wing for their 1900 glider.

They tested the glider as a kite that fall at Kill Devil Hill, near Kitty Hawk, North Carolina, on the Outer Banks. The results from these early tests suggested that the data used in the design were inaccurate. They returned to Dayton and constructed a small wind tunnel. The Wrights spent nearly two thousand hours testing numerous airfoil models.²⁶ Orville and Wilbur collected more accurate lift and drag data as well and corrected the value of “Smeaton's coefficient,” the constant of proportionality used in the lift and drag equations for an airfoil.²⁷ With the new data and corrected equations, the

²⁵ Jakab, p. 45.

²⁶ Theodore von Kármán with Lee Edson, *The Wind and Beyond: Theodore von Kármán, Pioneer in Aviation and Pathfinder in Space* (Boston: Little, Brown and Co., 1967), p. 129.

²⁷ Smeaton's coefficient was long believed to be 0.005. The Wrights recalculated the value to be 0.003. This may seem like a very small difference. But when it is applied to the lift equation, the results can be quite significant as can be seen in the following example of the 1903 Flyer.

The 1903 Flyer's longest flight on December 17 flew a distance of 852 ft in 59 seconds. The craft and pilot weighed just over 700 pounds. The wing surface area was 510 square feet. If we assume that the lift created under these conditions is equivalent to the weight of the flyer, then we can first solve for the coefficient of lift for the wing. Then replacing the corrected Smeaton coefficient with the original, we find that under the same conditions, the 1903 Wright flyer would have been able to lift 1175 pounds. This example

Wrights successfully redesigned the airfoils, leaving them with control, stability, motive power, structure, and piloting questions to address.

The final airfoil design of the 1903 Wright flyer followed wing shape patterns established by the previous airplane builders. The airfoil was very thin; the bottom surface was quite concave. At low speeds, this airfoil design performed well. However, with the design of newer gas-powered engines, an airplane was now capable of flying faster, if one ever got into the air. At higher speeds, the thin airfoils, like those used by the Wrights, lost some of their lift capabilities at higher angles of attack. Thicker airfoils with a shallower concave bottom curve performed much better under these conditions. But early airplane builders remained largely ignorant of these facts.

Part of the problem was that the early airplane builders like Lilienthal took too many of their ideas about aerodynamic design from birds. Comparing a bird's wing to the Wright flyer wing, one notices a striking similarity. The earliest aeronauts never experimented with thin airfoils at higher speeds and angles or with thick airfoils. And they could not find any information about this possibility in published works either. The German Wilhelm Kutta did not propose the first thin airfoil theory until 1902. Nikolai Joukowski, a Russian, improved upon it in 1910 and Max Munk, another German, perfected it in 1922. No thick airfoil theory existed until Theodore Theodorsen, a Norwegian, proposed one in 1931.²⁸ But even as this theory was developing, mostly in

indicates a benefit. But in the reserve case, an airplane designed to use 0.005 will only be able to lift sixty percent of the calculated weight. This could be disastrous!

²⁸ Information about these theories was obtained from John D. Anderson, Jr., *A History of Aerodynamics and Its Impact on Flying Machines*, Cambridge Aerospace Series, no. 8 (Cambridge: Cambridge University Press, 1997), p. 289-91.

Europe at first (both Munk and Theodorsen immigrated to the United States in the 1920s and went to work for the National Advisory Committee for Aeronautics), the builders of airplanes hardly relied at all on what would later come to be called engineering science. In part, this was because very little theory existed and what did exist was not terribly accessible. But it was also due in part to the fact that none of the pioneers, except for Lilienthal, had made much of an effort to further engineering science as part of their work. While not investing time in theoretical research did not prevent the Wright brothers from successfully inventing the airplane, knowledge of a thick airfoil's performance capabilities could have encouraged the Wrights to pursue a different and better wing design than was suggested by studying birds.²⁹

Early pioneers lacked developed aeronautical theories to work with not only because of their own neglect of research, but also because few scientists and engineers at that time were pursuing it either. The engineers investigating aerodynamics in this period did so largely in isolation. Flight seemed so impractical that few scientists were willing to invest their time in such a "hopeless" pursuit. Those that did were often scoffed at by their colleagues and by the public.³⁰

A few scientists and engineers earned a reputation for work in aeronautical science. The previously mentioned Joukowski (1847-1921)³¹, a mathematician, developed an interest in aeronautics at the same time Lilienthal was flying gliders in

²⁹ I wish to thank Bill Garrard for his comments about the historical development of airfoil theories.

³⁰ Jakab, p. 20.

³¹ Anderson, pp. 249, 251.

Germany. Joukowski even purchased one of Lilienthal's planes. His work on equations to calculate lift and his establishment of an aerodynamics laboratory in Moscow earned him recognition as "the father of Russian aviation."³² Ludwig Prandtl (1874-1953)³³, the premiere German academic in the field and the mentor of Max Munk (and Theodore von Kármán), proposed some of the earliest theories about the boundary layer, the very thin layer of air that "sticks" to the surface of a body in a fluid flow. Understanding boundary layers made calculating and, hopefully, reducing the effects of drag possible. Every aeronautical engineering student from the 1920s has heard these names and studied the contributions these men made to the field. But even their work diffused to airplane builders at an extremely slow rate.

Despite the Wright brothers' successful flight in 1903, aviation remained an unproven technology for some time to come. In fact, *Scientific American* did not publish any formal recognition of the Wrights' success until late 1906. The U.S. military, the first buyers of an aircraft, waited until February 1908 before entering into a contract with the Wrights.³⁴ Without much demand for aircraft, no industry grew. The Wrights spent their time improving their airplane and trying to market it. Until the market improved and an industry sprouted—largely the result of the airplane's role in World War I—little technological development in aviation could occur. The aircraft builders took no more interest in aeronautical science than did the Wrights in 1903.

³² Ibid., p. 250.

³³ Ibid., pp. 257, 260.

³⁴ Roger E. Bilstein, *Flight in America: From the Wrights to the Astronauts*, rev. ed. (Baltimore: The Johns Hopkins University Press, 1994), p. 15.

Aeronautical engineering science really did not begin to appear in the United States until 1913. MIT President Richard Maclaurin asked Jerome Hunsaker to develop an aeronautical engineering curriculum for the university in April 1913. Soon after, Hunsaker and Albert Zahm of Catholic University in Washington, D.C., one of the pioneering aeronautical engineers in America, left for a tour of European institutions and laboratories. Hunsaker had grasped the significance of mathematics and scientific principles to aeronautics and the design of aircraft by 1912, but this tour strengthened his convictions about the study of aeronautics. In a book soon to be published, historian William Trimble identifies Hunsaker's return from Europe with instruments and knowledge as "an intellectual transfer of major proportions, equivalent in some ways to that of the late eighteenth century, when Samuel Slater brought his knowledge of power textile machines to New England."³⁵ But many of the early American university programs teaching aeronautics in the 1910s and 20s still chose to approach the subject from an empirical perspective.

Many of these programs began as options or branches in mechanical engineering, one of the older engineering disciplines. Historian Bruce Seely has discussed in "Research, Engineering, and Science in American Engineering Colleges: 1900-1960" how societies for the promotion of engineering education were pushing for more science-based curriculum by 1900. Seely comments that "engineering schools moved slowly to adjust curricula, if at all" and suggests that the older disciplines, such as civil and mechanical engineering were the slowest departments to change.³⁶ Considering that

³⁵ Trimble, p. 87.

³⁶ Bruce Seely, "Research, Engineering, and Science in Engineering Colleges: 1900-

aeronautical engineering programs lived in the shadow of mechanical engineering, it is reasonable to think that some of those philosophies against change filtered down to the aeronautical engineers.

The aviation industry began to grow during World War I. Despite Hunsaker's intellectual transfer, the industry still functioned fairly empirically as it had under the early airplane builders. Industry's expectations for the new aeronautical engineers graduating from universities included little desire for theoretical research capacities.

In 1915, the National Advisory Committee for Aeronautics (NACA) was founded to provide research in the aeronautical sciences and guidance. The NACA published hundreds of research reports over the years. As support and interest grew for the scientific principles of aeronautics encouraged by Hunsaker, industry and academic engineers most often turned to the NACA as their source for the newest aeronautical knowledge. When aeronautical engineering departments gained their independence from mechanical engineering, the aeronautical engineers were free to adopt more engineering science courses. But those changes did not necessarily happen. As long as industry continued to rely on the NACA and other labs for its research, aeronautical engineering departments felt little pressure to overhaul their curricula. Except for schools like MIT and the California Institute of Technology, which founded their departments with the express purpose of stressing theory and scientific principles, schools like the University of Minnesota established practical design-oriented programs in aeronautical engineering.

In this thesis, the focus will be on the aeronautical engineering department at the University of Minnesota. The task is to see how and when a culture of engineering

science was incorporated into the Minnesota aeronautical engineering curriculum and to identify the institutional and intellectual mechanisms that were involved. Later in the thesis, I will consider how engineering science came to life at other schools outside Minnesota. I will compare both Guggenheim schools and non-Guggenheim schools to Minnesota in an effort to identify what might be called the necessary and sufficient conditions for engineering science to develop in an academic environment. Finally, in the conclusion, I intend to discuss why engineering science has proven so significant to aeronautical engineering and how the processes of change in universities such as the University of Minnesota reflected that significance.

The Foundations and Struggles of the Aeronautical Engineering Department at the University of Minnesota: The Legacy of John Akerman

The University of Minnesota first offered courses in aeronautical engineering to undergraduates in mechanical engineering in 1926. Professor Charles Boehnlein from the Department of Mathematics and Materials instructed all the early courses. The electives focused on aerodynamics, the study of air or gases in motion.

The early foundations of aeronautical engineering education as an option within mechanical engineering departments typified the situation at schools across the United States in the 1920s and 1930s. University faculty and administration often saw aeronautical engineering as little more than a highly specialized field of mechanical engineering. Many courses in mechanical and aeronautical engineering, such as engine design, structures, dynamics and controls, overlapped in this period. But the nature of aeronautical engineering eventually pushed in the direction of a separate discipline. Airplanes, after all, traveled in three-dimensional space with six degrees of freedom. Concern for the added motions of roll, pitch, and movement on the vertical axis distinguished the work of aeronautical engineers from that of other engineers; it was not just a specialized case of mechanical engineering. When university officials realized that aeronautical engineering required individualized treatment, they moved aeronautical engineering out from under the wing of mechanical engineering.

In early 1928, Ora M. Leland, Dean of the College of Engineering and Architecture, proposed to the Minnesota Board of Regents that an independent department of aeronautical engineering be established. He believed that “Minnesota is favorably lo-

cated to become a center for this field of engineering for the Northwest.”¹ Leland recommended that the new curriculum continue much as it had from within the mechanical engineering department:

A large part of the course in aeronautical engineering will be the same as mechanical engineering. Thus, by a combination of our existing courses in civil, electrical, mechanical, and chemical engineering, we shall be able to cover almost all of the proposed curriculum. Then, with our elective work in automotives, aviation, aerodynamics, and airplane and motor design, we shall be able to give a very creditable course and one which would fully justify itself. For advanced theoretical work, we have the advantage of a strong department of physics and another of mathematics.²

Leland envisioned a department firmly rooted in traditional, sound engineering methods, informed in aeronautical knowledge, and capable of providing young aeronautical engineers for the budding industry. Only his last comment about advanced theoretical work suggested any vision Leland may have had for the development of graduate studies and what by the 1940s would be called “engineering science.”

Leland named Professor Boehnlein and Professor Ronald Hazen, an assistant professor from Mechanical Engineering, as two of the department’s proposed faculty members. He valued their experience as former aviators. Leland wrote further, “I intend to obtain a third man, trained in aeronautical engineering but able to teach in one of our other departments, when a suitable vacancy occurs.”³ The third position turned into a special lectureship given to John D. Akerman. Akerman not only taught during the 1928-

¹ Ora. M. Leland to President L. D. Coffman, 4 February 1928, College of Engineering and Architecture, Department of Aeronautics, 1929-1940 file, President's Office Papers, 1911-1945, UA.

² Ibid.

³ Ibid.

1929 school year, but helped design the final form of the department. In the fall of 1929, the Department of Aeronautical Engineering at the University of Minnesota officially opened its doors to students. John Akerman, then an associate professor, served as its first department head. He would hold that position for nearly three decades.

The department's curriculum reflected the interests of industry, consistent with Akerman's background. Born in Latvia, Akerman began his aeronautical studies at the Imperial Technical Institute in Moscow under Nickolai Joukowski. When World War I started, Akerman served as a pilot for the Russian Imperial Air Service, then as a pilot in the French air campaign. He moved to the United States in 1918. Akerman's aeronautical interests led him to the University of Michigan. He earned a bachelor's degree in aeronautical engineering in 1925. Akerman stayed at Michigan until 1927, doing coursework for a master's degree and working on a subsonic wind tunnel endowed by the new Guggenheim Fund for the Promotion of Aeronautics. He designed the motors used to drive the tunnel airflow. He left Michigan for a position as chief design engineer at Hamilton Metal Plane Company in Milwaukee before finishing his master's degree. He never completed an advanced degree, a fact that later proved detrimental to the Minnesota program.

Mohawk Aircraft Corporation, located in Minneapolis, hired Akerman as the chief engineer for their new low wing monoplane in 1928. When Dean Leland went looking to fill the special lecturer position, he found Akerman working for Mohawk. Akerman fit Leland's expectations well. His training as an aeronautical engineer and his strong link to local industry made Akerman a logical choice.

Akerman's reputation for design work served him, and consequently the department, well during its early years. The Institute of Aeronautical Sciences and the Royal Aeronautical Society in London elected him a fellow in 1945 and 1948, respectively. He continued his work in industry as a consultant to Mohawk, Maderas Rotor Power Plant, Forter-field Aircraft and Engineering Corporation in Kansas City, and the Minneapolis Honeywell Regulator Company. The federal government even assigned Akerman along with Jean Piccard, another professor who joined the faculty in 1936, to study aeronautical research and technical developments in France and Germany during the summer of 1945 for the army.⁴ Through his connections, Akerman obtained discarded equipment and war surplus materials for department use. So Minnesota students' exposure to industrial methods, developments, and goals remained strong through Akerman. This orientation towards industry seems to have handcuffed the Minnesota program in some important ways, making it somewhat one-sided. One can look back at the course descriptions and titles from this period as a kind of litmus test. It is not surprising that they indicate a very practical orientation to the curriculum.

In his article "Research, Engineering and Science in American Engineering Colleges: 1900-1960," Bruce Seely measures the balance between engineering science and practical engineering in the civil engineering curriculum at Texas A&M. He does this by counting the hours spent by students studying theory versus hours spent in practice and laboratory courses. This methodology only works for the University of Minnesota until

⁴ I obtained all biographical information on John Akerman from the university-compiled biographical outline available in the Akerman Biographical File, UA; "Too Bad We Lost' Called Nazi Outlook," *Minnesota Daily*, 9 October 1945, Akerman Biographical File, UA; "Piccard, Akerman Will Return To U Monday," *Minnesota Daily*, 4 October 1945,

1951. After that year, the course bulletins no longer reported the time divided between recitation, lecture, and laboratory either by individual course or all-inclusively. This complicates efforts to make such comparisons over time.

A five-year curriculum replaced the standard four-year course of study in 1946. As intended, the five-year curriculum provided students with the opportunity to take more social sciences. Dean Lind wrote in his biennial report to the President for 1946-1948, "The general objective of the five-year program is to weave some of the threads of liberal education into the fabric of engineering education."⁵ Unfortunately for historical analysis of an engineering curriculum, the addition of liberal arts requirements somewhat skews the measurement.

In carrying the analysis beyond 1951, one relies on course names to indicate a course's make-up. For continuity, one can select all courses whose names include "design," "testing," "laboratory," or "practice" as practical courses. But even this way of measuring is problematic; it does not allow for changes within the class itself. New methods may be introduced into a class that would qualify it as "engineering science" and not "practice" without the course name ever changing. Further, the very heavily practice-oriented classes such as "Aircraft Installation" and "Forging" would not be counted. Therefore, only qualitative analysis of course names prove adequate.

The aeronautical engineering department at Minnesota offered eighteen courses its first year. Akerman taught the introductory courses in aviation and aircraft engines.

Akerman Biographical file, UA.

⁵ Samuel Lind, *The Biennial Report of the President of the University of Minnesota to the Board of Regents 1946-1948*, 31 December 1948, Vol. LI, no. 56, 81, UA.

These courses dealt primarily with hardware and pilot knowledge: structures, instruments, electrical systems, navigation, and communications. Charles Boehnlein continued as the professor for the more theoretical courses that dealt with aerodynamics. His three-course series introduced the concepts of aerodynamic forces, stability, propeller theory, and laboratory practices. Professor Joseph Wise from the civil engineering department taught two classes on structural stresses and forces as they applied to airframes and landing gear. Instructor Gustav Hoglund rounded out the faculty. Hoglund took responsibility for the laboratory courses, which covered airplane design, airplane parts and their construction, and airships.⁶

The practical nature of the coursework grew out of the department's foundation in mechanical engineering and the intentions of Dean Leland. But Akerman, as head of the department, commanded a lot of control over the direction of the department. Therefore, one should look at his courses in particular as an indication of what to expect from Minnesota's program.

In the 1930s Akerman started teaching aeronautics courses as evening classes. Akerman saved copies of a quiz and the final exam from the basic aeronautics course. From today's perspective, it may be surprising to learn that Akerman gave essay exams. He asked questions such as "Define parasite resistance. How is it minimized?" and "Make a sketch of an airplane wood and wire wing construction showing drag and anti-

⁶ All curriculum information, including the required curriculum, course description and the instructor, was obtained from *The Bulletin of the University of Minnesota: College of Engineering and Architecture and School of Chemistry*, vol. XXXII, no. 48-vol. XXXVIII, no. 35, and *The Bulletin of the University of Minnesota: Institute of Technology*, vol. XXXIX, no. 38-vol. LXIV, no. 17 Minneapolis, Minn. (Hereafter cited as *IT Bulletin*.) In this instance, *IT Bulletin*, vol. XXXII, no. 48 (1929-1930), 55.

drag wires.”⁷ Unquestionably engineering students needed to understand basic concepts. In answering an essay question, a student could show that he or she understood the concepts but still not possess the skills to apply them. Aeronautical engineering students in the early 1990s (including myself) heard professor after professor say, “If you know the calculations are wrong, or the numbers are not working out, write a little story. Tell me how the numbers are wrong, and in what range they should lie. Show me that you understand the concepts.” But this tactic never earned a student more than partial credit because engineers work with more than just concepts. More importantly to the task of this paper, this practice shows that Akerman put little emphasis on mathematical rigor. It raises the question whether Akerman and the Minnesota program were typical of aeronautical engineering curricula of that era, or somewhat behind the times. The focus on what one really should call “theory” in aeronautical engineering was still quite limited in the 1930s, but aeronautical engineering science was growing steadily more mathematical, both in its demands as a discipline for aircraft design and institutionally in the form of the examples being set by such leading academic programs as Stanford’s, MIT’s, and Caltech’s. So one may wonder why a more positive correlation between the mathematization of aeronautical engineering as a discipline that was taking place nationally and internationally did not stimulate a stronger impetus to deepen the mathematical basis of the aeronautical engineering curriculum at Minnesota.

Course offerings expanded during the 1930s with the addition of new faculty and new interests in industry. However, a number of the changes still followed Akerman’s

⁷Akerman, University of Minnesota General Extension Division Correspondence Study Department, Final Exam for Elementary Aeronautics, Miscellaneous, 1931-1941 file, box 2,

orientation, if not his whims. In the mid-1930s Akerman began studying the effects of high altitudes on pilots. He believed the next advancement in aircraft technology would be stratospheric flight “where high speeds are possible and bad weather is not encountered,” a belief that one might generously call only slightly premature.⁸ On October 23, 1934 Dr. Jean Piccard, a Swiss chemical engineer, and his balloon-piloting wife, Jeanette Piccard, ascended in a cloth balloon to 57, 579 feet to record data on the stratosphere. The flight and the Piccards’ possible contribution to his own project attracted Akerman’s attention. Jean started experimenting with balloons in the early 1930s with his physicist brother, Auguste. While Auguste earned more fame for his scientific work than his brother, Jean readily commanded attention when discussing balloons and the stratosphere. With Dean Samuel Lind’s approval, Akerman invited both Piccards to Minnesota, but only Jean’s position—first as special lecturer, then as Professor in 1938—carried any status or pay.⁹ In addition to the stratospheric coursework, the faculty added courses on seaplanes in 1930 and dirigibles in 1931, both taught by Professor Wise.¹⁰ All this coursework, particularly Wise’s courses, reflected the industrial focus of the program.

The courses in aeronautical engineering available at Minnesota in the 1930s seem to indicate an industry-oriented outlook as dictated by departmental and university leadership. Further evidence supporting Akerman’s strong link to industry—and less to aca-

Akerman Papers, UA.

⁸ Akerman, lecture notes, file J, box 2, Akerman Papers, UA.

⁹ Patricia Hampl, "In Space--Dr. Jeanette Piccard," 7 November 1966, *Ivory Tower*, Jeanette Piccard biographical file, UA.

¹⁰ *IT Bulletin*, vol. XXXIII, no. 38, 57 and vol. XXXIV, no. 39, 60.

demia and laboratory research—survives in his papers. In August 1930, Akerman wrote a letter to Nicholas Beasley, President of Nicholas Beasley Aircraft Company in Marshall, Missouri. The letter declared Akerman's preference to return to industry. He wrote, "My brother-in-law, Stanley S. Lasha, informed me that you are looking for a competent engineer. May I submit my qualifications?"¹¹ Although Akerman never left the University of Minnesota for industry, he continued to consult. But his attraction to industry over other career paths surely influenced his vision for the department. He saw Minnesota as a training ground and service department for industry. Analysis of the department's curriculum confirms this.

But arguing that the department of aeronautical engineering at Minnesota focused mostly on supplying engineers for and services to industry was hardly a crime. In fact, Minnesota's department produced substantial numbers of talented engineers to the budding field, fulfilling industry's growing need for professional-rank employees with formal aeronautical knowledge. During the 1939-1940 school year, 3034 students enrolled in aeronautical engineering programs across the United States and Canada; 455 of those students studied at the University of Minnesota.¹² The question at hand asks whether the department showed signs of growth and development in accord with changing industrial and national academic trends. Those trends, particularly in the 1940s and 1950s, headed slowly but surely towards building a culture of engineering science.

¹¹ Akerman to Nicholas Beasley, 21 August 1930, Correspondence N, 1928-32 file, box 3, Akerman Papers, UA.

¹² Akerman to President Guy S. Ford, 2 May 1940, University of Minnesota (UMN), Aeronautical Flight Training, 1938-1939 file, box 35, President's Office Papers, 1911-1945, UA.

The aeronautical engineering curriculum at Minnesota showed little change towards incorporating engineering science in its first twenty years. Although only ten American universities offered aeronautical engineering degrees in 1939, and seven of them were Guggenheim schools. For those with Guggenheim status, we expect to find a strong emphasis on engineering science, as Daniel Guggenheim wished. Since Minnesota received no Guggenheim funding, one major impetus for moving toward engineering science was missing. Instead, the department remained more industry-oriented and less interested in focusing on the theoretical side of aeronautical engineering. Those courses that were added in the 1930s mostly fell into the category of practice, not engineering science. In some cases, the faculty even dropped some science-based engineering courses. One example of this occurred in 1935-1936 school when the second quarter of thermodynamics was removed from aeronautical engineering requirements. On the other hand, shop courses, such as Surveying and Forging, Welding, and Heat Treating, remained a part of the curriculum until 1946. Furthermore, until the fall of 1946, the curriculum required no mathematics beyond one quarter each of differential calculus and integral calculus. The Accreditation Board for Engineering and Technology (ABET) accredited the A.E. program at Minnesota in 1936. Apparently, no longer requiring a second thermodynamics class or the limited mathematics requisites did not effect the quality of education available at Minnesota, at least in the opinion of ABET. But from broader historical perspective, it does establish a pattern that Minnesota's aeronautical engineering program under Akerman demonstrated little evolution towards engineering science.

After ten years, the administration started showing concern over the direction of Akerman's department. It is not unusual, but expected, that the administration should

evaluate their departments regularly. The department's and the school's competitiveness with other universities depended on a state-of-the-art and progressive curriculum. Dean Lind had for some time been promoting reform of the curriculum. Lind's assertive attitude stemmed in part from his role in a newly organized "Institute of Technology" (IT).

In 1919 President Marion Burton had advocated the unification of the college of engineering, the school of chemistry, and the school of mines. At that time the Regents voted "to correlate the administration of the College of Engineering and Architecture and the School of Chemistry under one administrative head."¹³ The Regents readdressed the issue in 1935 when they believed the reasons for reorganization were more applicable. President L. D. Coffman wrote, "The interests of these three schools are similar; their work is becoming more and more inter-related; they all lie in the general field of technology; their curricula are based on mathematics and physical sciences."¹⁴ Further, the Regents felt that "the smaller the administrative unit, the more restricted the field of learning; the greater the isolation, the greater the intolerance and narrowness of those being trained in it."¹⁵ The administration believed that the reorganization of the three schools under one leadership would strengthen all the programs through greater and easier interaction between faculty and students. Samuel Lind received the appointment as Dean of IT in October 1935.

¹³ Memorandum by L. D. Coffman, 19 October 1935, 1, IT Administrative Board file, box 7, President's Supplemental Papers, UA.

¹⁴ Ibid, 1.

¹⁵ Ibid, 2.

In late 1935 President Coffman suggested to Lind a number of issues that IT should investigate. These included a common freshman year, a study of alumni job placement, a comparative study into relations between industry and universities, and an investigation into how IT could promote the economic development of the region. Coffman also suggested looking at the efficacy of establishing two levels of engineering education at Minnesota—one program for the rank-and-file engineers and another more intensive curriculum designed for future engineers in leadership positions.¹⁶ Ultimately, both the Regents and President Coffman saw the formation of IT as a step in the right direction to keep the University of Minnesota on the forefront of engineering education.

Consequently, Dean Lind felt obligated to evaluate his departments critically. He favored upgrading the curriculum, but by 1942 the emergencies of war dictated that universities contribute to the war effort by training the largest number of scientists and engineers possible, as well as providing helpful applied research. He thus postponed the upheaval of IT that would restructure the curriculum until the war was over. Lind wrote in his biennial report to the university president in 1942 that because of the emergency created by World War II, “further raising scholastic requirements have been temporarily suspended.”¹⁷

By 1946, the aeronautical engineering department received a lot of attention from Dean Lind and new president James L. Morrill. That year the university began negotiations with the U. S. Government to acquire the idle Gopher Ordnance Works and its ac-

¹⁶ All these suggestions come from a letter written by L. D. Coffman to Samuel Lind, 30 December 1935, IT, 1934-1935 file, box 35, President's Supplemental Papers, UA.

¹⁷ Samuel Lind, Report for President's Biennial Report for 1940-1942 [July 9, 1942], IT Papers, UA.

companying 8,000 acres of land. The university finally purchased the installation in March 1948 for \$1.¹⁸ On it was built the Rosemount Aeronautical Laboratory (RAL), which would serve as the aeronautical engineering department's primary research facility. Faculty members (Kenneth Anderson and Rudolf Hermann in particular) designed and installed a number of wind tunnels at Rosemount, including a hypersonic wind tunnel capable of producing speeds between Mach 7 and 11 and air temperatures of 3,000 degrees Fahrenheit.¹⁹ While the RAL would be the site of significant research for both industry and the military, the early years of Rosemount proved to be a time of considerable concern about the strength and direction of aeronautical engineering at Minnesota.

In the fall of 1946, John Akerman suffered a heart attack. Naturally the health of one of its department heads became a significant worry for the administration. President Morrill wrote to Dean Lind, "This leads me to raise with you the question as to whether we ought not, in conference with Professor Akerman, to proceed toward the strengthening of the Department of Aeronautical Engineering by the addition of a second well-trained and experienced man, competent both in teaching and research."²⁰ Malcolm Willey, Vice President of Academic Administration, addressed a further issue in a letter

¹⁸ University of Minnesota Department of Aeronautical Engineering, "Fifty Years of Aeronautical Engineering: University of Minnesota, 1929 to 1979" (Department of Aeronautical Engineering, University of Minnesota, Minneapolis.)

¹⁹ Akerman to Morrill, 2 April 1958, UMN, IT, Aeronautical Engineering Papers, 1958-1962, 1964-1969 file, UA. The Mach number, named after Ernst Mach, is a dimensionless term that signifies the proportion between a given velocity and the speed of sound. The speed of sound is referred to as Mach 1. A velocity three times the speed of sound would be Mach 3. This proportionality often simplifies calculations since the actual speed of sound varies with atmospheric pressure and temperature.

²⁰ Morrill to Lind, 24 January 1947, UMN, IT, Aeronautical Engineering Papers, 1946-1956 file, UA.

to President Morrill. He wrote, “The Rosemount situation is also involved since the main projects on which we are relying to carry forward the Rosemount development are in the field of aeronautical engineering. The contracts cover researches that Professor Akerman is responsible for.”²¹ As these three men discussed Akerman’s health, questions about his skill and *professional* ability to lead the department also arose.

Before the close of 1947 another incident came to the attention of President Morrill. The U. S. Navy requested the continuation of a balloon project that the navy, the General Mills Corporation, and the Piccards had been conducting privately. The navy wanted to expand the project participants to include the University of Minnesota aeronautical engineering department, which translated into financial support from the university. The written discussion that took place between President James Morrill, Malcolm Willey, and W. T. Middlebrook, Vice President of Business Administration in December 1947, concerned Akerman’s guidance and authority in the situation. Middlebrook wrote, “This balloon research is apparently getting a bit ‘off the beam’.”²² Morrill forwarded the letter to Willey with the query, “Is this getting out of hand? Where is Akerman in it, or is he—or anyone on our staff other than the Piccards?”²³ Morrill’s pointed comments about Akerman’s apparent disregard for the business of the department suggest a real concern that he was lax in other areas. One can see from the previous comments about

²¹ Willey to Morrill, 13 January 1947, UMN, IT, Aeronautical Engineering Papers, 1946-1956 file, UA.

²² Middlebrook to Morrill, 5 December 1947, UMN, IT, Aeronautical Engineering Papers, 1946-1956 file, UA.

²³ Memorandum from Morrill to Willey, 5 December 1947, UMN, IT, Aeronautical Engineering Papers, 1946-1956 file, UA.

Akerman's health that strengths in teaching and research were important to the faculty and administration. However, there was now evidence that Professor Akerman may no longer have been capable of successfully directing the department single-handedly in the manner desired by the administration.

In the midst of these troubles, Dean Lind retired in July 1947. After a year-long search, the Board of Regents approved Athelstan Spilhaus, a professor of meteorology and the director of research at New York University, as the new Dean of the Institute of Technology in September 1948. He officially took office in January 1949.²⁴ Spilhaus brought with him a vision of developing the scientific foundation of Minnesota's engineering programs. He advocated a focus on fundamentals and aspired for leadership in theoretical research. He believed that a science-based curriculum and research were the principal components of a strong engineering program.

Spilhaus had earned his bachelor's degree in mechanical engineering, then pursued a master's degree in aeronautical engineering at the Massachusetts Institute of Technology (MIT). He had studied engineering, but moved into the sciences of oceanography and meteorology. Surely, the time Spilhaus spent at both MIT in Hunsaker's program and NYU influenced his perspective on engineering education. The mission statement from the 1924 NYU bulletin for the College of Engineering suggests an early conceptual understanding of engineering science's possible contributions to aeronautical engineering. It read, "The spirit of the course at New York University is to train aeronautical engineers rather than aerodynamicists, men who can take part in the practical work of

²⁴ University News Service release, "Spilhaus named Technology Dean at U. of Minnesota," 28 September 1948, Athelstan Spilhaus biographical file, UA.

designing and constructing airplanes and dirigibles and their engines *on a scientific basis*”²⁵ (italics mine). One can see that as early as 1924 the aeronautical engineering faculty at NYU saw aircraft construction as scientific even though research was not necessarily a strong focus. In Spilhaus’s educational background, his professional activities, and his intellectual environment, one can appreciate some of the key ingredients inspiring his vision of science-based engineering at Minnesota.

Dean Spilhaus took over from much the same point where Dean Lind had left off. From the growing concern expressed by Dean Lind and the university administration, one surmises that Lind was again actively evaluating the conditions of the departments in IT, with retrenchment in mind. Dean Spilhaus naturally wanted to establish a sense of where the university stood in educational approaches, research, and technology. In 1950, Spilhaus reported that the “development of graduate instruction and research is emphasized.” At the same time, however, “continual efforts toward improving the regular undergraduate instruction” have been intensified, “this improvement too being stimulated by the increased research and graduate studies.”²⁶ He saw the country “in a state approaching total mobilization”²⁷ for the coming years. Spilhaus wrote further, “This places the heaviest demands on technology in all its phases. Clear recognition and acceptance of this

²⁵ NYU Bulletin excerpt quoted in Paul Hanle, *Bringing Aerodynamics to America* (Cambridge: The MIT Press, 1982), 7.

²⁶ Athelstan Spilhaus, *The Biennial Report of the President of the University of Minnesota approved and adopted by the Board of Regents 1948-1950*, [27 December 1950], Vol. LIII, no. 60, 89.

²⁷ *Ibid.*, 93.

situation should guide future planning.”²⁸ These ideas spanned across many scientific and technical disciplines; he referred to all parts of IT in his remarks.

But Spilhaus paid particular attention to the aeronautical engineering department. Undoubtedly, President Morrill would have shared with the incoming dean the concerns both he and Dean Lind felt about John Akerman. Further, in those first two years after Dean Spilhaus arrived, only one course—Airplane Design Laboratory for seniors—was added to the curriculum. Perhaps this was merely coincidence, as such a minor change should hardly draw Spilhaus’s attention. But as we shall see, Akerman and Spilhaus never saw eye-to-eye. Akerman showed no real effort to comply with Spilhaus’s vision in those first two years, and would show outward resistance to it later.

In his first biennial report the President in 1950, Spilhaus summarized his evaluation of the state of the aeronautical engineering department and his challenges for growth. He wrote,

In aeronautical engineering increased emphasis has been placed on graduate work and a number of students are assigned to the department by the Naval Postgraduate School at Annapolis. ... Three supersonic wind tunnels are in operation at Rosemount where a considerable volume of contract research work is being carried out. Because of the distance between Rosemount and the University, it is difficult to integrate the sponsored research work as fully as is desirable with the academic work of the institute. This physical separation has a tendency to inhibit the free interchange across departmental lines, which is one of the most valuable factors in the prosecution of research in a university.²⁹

While Dean Lind understood that the aeronautical engineering department would benefit from retrenchment, Dean Spilhaus had the drive, the determination, and the advantage of timing to improve IT and all the engineering programs at Minnesota. From his dogged-

²⁸ Ibid., 93.

²⁹ Ibid., 90.

ness to redirect the aeronautical engineering department in particular, Spilhaus obviously worked from an agenda for change. His motives were two-fold: to strengthen the aeronautical engineering department and keep it competitive nationally, and to remove Akerman as department head.

The turbulent relationship between John Akerman and Dean Spilhaus hindered the development of engineering science in the aeronautical engineering department. One is tempted to argue that the Spilhaus-Akerman relationship represented a conflict between supporters of engineering science integration and those content with practical design methods, but the specific actors in such a drama do not ever clearly arrive in costume on stage. Yet, faculty at other schools did engage this same issue with similar resistance to change. Many of these schools appear to have adopted engineering science methods with greater ease than did Minnesota. It seems clear that the events at Minnesota highlighted a clash of strong personalities, and only in part represented a larger trend. Still, the events did result in a slowdown in the full integration of engineering science in the University of Minnesota's aeronautical engineering department.

The spring of 1951 brought with it Dean Spilhaus's first major attempt to personally redesign the aeronautical engineering department. As a result of the common misconception that a surplus of engineers existed, coupled with the military need for college-aged soldiers to fight the war in Korea, enrollment reached its lowest point in the fall of 1951. The budget mirrored the drop in enrollment. Spilhaus pushed departments to streamline their costs as much as possible without risking their students' educations. Following his own advice, Spilhaus proposed making A.E. a division of Mechanical Engineering as it had been through 1929. He explained to President Morrill,

On a cost-per-student-hour basis, Aeronautical is our most expensive department in the Institute, and from an educational point of view I think we should get away from departments which deal with an end product. In this case, the airplane is a combination of fluid mechanics, structural mechanics, thermodynamics, and heat engines—all of which are taken up better in other departments of the Institution.³⁰

Fiscally the argument might have been sound, but it would have been unwise for the health of aeronautical engineering as a discipline. As mentioned earlier, many aeronautical engineering programs started as options within a mechanical engineering department, as happened at Minnesota. However, by 1951, the administrations at those universities—Iowa State and Purdue being two such cases—supported independent departments of aeronautical engineering. Mechanical engineering coursework no longer served the technological and theoretical interests of aeronautics effectively. This stemmed largely from the nature of aircraft and its working environment. As aeronautical engineers best knew, except for submarine crafts, aircraft (airships and balloons included) were the only vehicles that traveled in a third plane of motion.³¹ The complexity of motion alone increased the complexity of an aircraft over any vehicle traveling on land or the surface of the water. Further complexity arose when engineers considered the sensitive nature of the air to disturbance. The smoothness of an airplane's skin could change its performance dramatically. A very thin layer of ice on a wing, for example, affected the shape of an airfoil (the cross-sectional section of a wing) as well as the skin smoothness. Anyone who ever slid on a patch of black ice while driving an automobile knew just how dangerous an im-

³⁰ Spilhaus to Morrill, 16 April 1951, UMN, IT Papers, 1949-54 file, UA.

³¹ Submarines do have control over their vertical motion. However, the design of a submarine is not critical for its success like it is for an airplane. Submarines maintain their vertical position in the ocean through buoyancy. An airplane's airfoil design makes or breaks this aspect of its performance. In this way, a submarine is much more similar to a ship than to an aircraft.

perceptibly thin layer of ice could be. On an airplane wing, that same amount of ice could cause a substantial loss of lift, leading to a crash. In analyzing the special requirements of aircraft engineering, historian James R. Hansen has commented that aeronautical engineering “became a field of engineering where ‘almost’ was not good enough.”³² In sum, placement as an option within a larger mechanical engineering department just was not “good enough” for aeronautical engineering education.

On the surface, Spilhaus’s move on the aeronautical engineering department can be seen as assault on the importance of the discipline. Although that may have been part of it, several facts suggest otherwise. First, Spilhaus earned his master’s degree in aeronautical engineering from MIT. Spilhaus would have at least respected the field after completing a degree in that discipline, especially at MIT. Secondly, he declared his motives openly both in the proposal to President Morrill and in his report to the Board of Regents. He wrote in the 1952-1954 biennial report, “An effort was made, also, to eliminate highly specialized curricula with very limited enrollment, not solely because such curricula are expensive to maintain but also in the belief that such a degree of specialization in undergraduate work is not warranted in engineering today.”³³ His motives were less about removing A.E.’s distinction than it was about providing solid education using limited resources. Of course, his decision to target aeronautical engineering over any other department suggests that some personal stake may also have been involved.

³² James R. Hansen, “Demystifying the History of Aeronautics,” in *A Spacefaring Nation: Perspectives on American Space History and Policy*, ed. Martin J. Collins and Sylvia D. Fries (Washington, D. C., Smithsonian Institution Press, 1991), 158.

³³ Athelstan Spilhaus, *Biennial Report of the President and the Board of Regents 1952-1954*, [30 June 1954], 134, UA.

Thirdly, Spilhaus never demanded that aeronautical engineering alone change. Spilhaus's interest in improving curricula spanned all of IT. By the fall of 1952, IT had completely integrated a five-year program for all the engineering departments. For the first two years, all engineering students followed a standard curriculum that emphasized the "basics," particularly mathematics and physics.

Lastly, the success of Spilhaus's proposal meant a restriction in Akerman's capacity to direct the department. Akerman and Spilhaus worked against each other at almost every turn. Akerman saw the department as his child. Spilhaus, flexing his administrative muscle, gave Akerman reason to believe that his autonomy was threatened. He had openly voiced his dislike of Spilhaus after his arrival to Minnesota.³⁴ Conversely, Akerman infuriated Spilhaus through his resistance to accept change and foster growth of a more scientific approach within the aeronautical engineering department. Both men had the best interest of the department in mind, and their views on how to achieve it were very different. In a report on the university's aeronautical research facilities, Akerman expressed his perspective on American aeronautics and how the University of Minnesota could provide for the field:

The recent recognition by the public, industry and government of the necessity of extensive research in technological fields, in order to maintain American leadership in the modern world, is of chief importance.... These facilities [at Rosemount] supplement the new facilities now available on the main campus and are valuable both as instruments for student instruction and as necessary tools for research. An opportunity to secure the services of specialists in research and teaching fields, who want to combine their research activities with academic work, was also provided.³⁵

³⁴ Robert A. Hoel, personal notes of IT Alumni Association meeting, 6 June 1958, UMN, IT, Aeronautical Engineering Papers, 1958-62, 1964-9 file, UA.

³⁵ Akerman, "Aeronautical Research Facilities," University of Minnesota Department of Aeronautical Engineering Research Report 74 (Minneapolis: 1971), Forward.

Unfortunately, the strained relationship between Akerman and his dean ultimately created “drag” on the advancement of aeronautical engineering education at Minnesota. The proposition to move aeronautical engineering back into the mechanical engineering department failed. The hostility between Akerman and Spilhaus grew worse.

Spilhaus refused to give up his quest to see Minnesota’s engineering curriculum develop its strength in basic science, engineering science, and its “underlying principles,” by which he meant mathematics. Again, in his 1956 biennial report to President Morrill, this aim was evident. He wrote that curriculum revision should be directed “toward a commonness of interest in basic subjects with emphasis on engineering science and its underlying principles throughout.” He went on:

In speculating how to best use limited resources for education the rapidly expanding fields of physical science and technology, the conclusion may be reached that there are two priority areas: first, as has been emphasized, priority support for the basic sciences and, secondly, priority support for the development of the newest applications, potential outgrowths and results of cross-fertilization of the established sciences.³⁶

Despite his efforts through 1955, however, the Engineering Council of Professional Development (ECPD) expressed the following criticism after its evaluation of IT: “the tendency in certain areas towards ‘practice’ courses in the fifth year with relatively little use of fundamentals and theory, and the desirability of greater use of mathematics and engineering science in these courses.”³⁷ Spilhaus knew early on in his time at Minnesota that

³⁶ Spilhaus, *Biennial Report of the President and the Board of Regents 1954-1956*, [30 June 1956,] 127-8, UA.

³⁷ College of Engineering, Report of the Engineer's Council of Professional Development, [10 November 1955], Minutes and related documents of meeting of the faculty, 1953-7 file, UA. The Engineer's Council of Professional Development was established in 1932. In 1980, the council changed its name to the Accreditation Board for Engineering and

the curriculum in the aeronautical engineering department was especially practice-oriented and an overhaul of the aeronautical course requirements should be a priority.

Spilhaus's second attempt to gain control of the sluggishness he saw in the aeronautical engineering department came in May 1957. He proposed a radical modification to the department—a merger with the Department of Mechanics and Materials and the subsequent removal of John Akerman as its head. Mechanics and Material was a service department; it granted only graduate-level degrees, but taught undergraduate courses. In this way, other departments did not need to develop expertise in additional areas. Aeronautical engineering was a professional department, one that granted undergraduate degrees.

Spilhaus intended the merger to combine the strengths of both departments and hopefully improve upon the weaknesses he saw in the aeronautical engineering program.

In his proposal he wrote,

Those weak departments which are to be retained are permitted to strengthen themselves in the best possible way by acquiring staff competent in an engineering science area. Such a course of action avoids perpetuation of a current engineering practice orientation which becomes obsolete in the practicing life of the future engineer and encourages a sound reorientation on lasting *engineering science* fundamentals³⁸ (*italics mine*).

Spilhaus easily could have directed this comment directly at the aeronautical engineering department. In not doing so, Spilhaus made clear that this aim applied to all of IT. To Spilhaus, strengthening IT meant more than just adding basic science courses; it meant

Technology or ABET.

³⁸ Spilhaus, "Recommendations for Administrative Action for Upgrading Aeronautical Engineering," [29 May 1957], 4, UMN, IT, Aeronautical Engineering Papers, 1957 file, UA.

fostering engineering science. But despite the broad, sweeping changes that he had made to IT, Spilhaus believed that those changes would do little to solve the ingrained problems in aeronautical engineering.

Spilhaus identified the general incompetence of the staff and leadership as the deep-rooted problems holding back the aeronautical engineering department. Staff members competent in engineering science were “essential to provide the internal guidance necessary for strengthening its undergraduate curriculum and its graduate and research programs.” What was more, “the presence of staff in a department competent in two or more engineering science areas” would aid greatly both in “redirecting a curriculum along broad and basic lines” and “replacing descriptive courses which emphasize the ‘how’ of current practice by analytical courses directed towards understanding the ‘whys’ so essential to creative engineering of the future.”³⁹ Spilhaus suggested that the new department formed by merging Aeronautical Engineering with Materials and Mechanics would be stronger in more engineering science areas, thereby making the department more competitive.

Spilhaus identified Dr. Chieh-Chien Chang and Dr. Rudolf Hermann, both professors of aerodynamics and fluid mechanics, as the only two professors on staff competent in an engineering science area. Spilhaus emphasized, “Obviously Aeronautical Engineering must be strengthened by the addition of engineering science competence.”⁴⁰ But he directed his most candid criticism of the department pointedly at John Akerman:

³⁹ Ibid., 3-5.

⁴⁰ Ibid., 1.

Even though Aeronautical can draw on the rest of the University for course work and consultation, a reasonable number of competent staff must be located administratively within the Aeronautics Department, otherwise such important matters as educational policy and curricular development are left to second-rate people. Merely having competent staff is not sufficient; they must be located where they can be most effective in policy and curricular matters.⁴¹

Unquestionably, Spilhaus believed that Akerman was holding the department back and ultimately weighing it down because of his narrow views and his inability to attract new, competent faculty.

Naturally, Akerman took offense at Spilhaus's implications and at the overall proposal. In fact, no records survived to suggest that Spilhaus and Akerman even communicated directly with each other about the proposal during the year in which the merger was on the table. President Morrill acted as the mediator between the dean and the department head.

At Morrill's request, Akerman wrote a 111-page report countering the criticisms made by Spilhaus. Akerman argued that from 1949 to 1956, it was Spilhaus who held back the department. He wrote, "The restraint was definite in the form of instructions from the Dean not to expand, but to concentrate in one line."⁴² Akerman claimed that Spilhaus had "restrained" the aeronautical engineering department in the following ways: "meteorology was reduced to one course...and the professor was removed from the Aeronautical Engineering staff and attached to the Mechanical Engineering Department;" "flight activities and facilities...were thrown out of the Department by the Dean;" and

⁴¹ Ibid., 1.

⁴² Akerman, "Report on the Present Status of and Proposed Changes in the Department of Aeronautical Engineering at the University of Minnesota," 7, UMN, IT, Aeronautical Engineering Papers, 1957 file, UA.

“controls and servo mechanisms were classified as Mechanical and Electrical Engineering fields.”⁴³ Akerman further wrote that schools like Princeton, Purdue, and Illinois had extended their own flight activities, and MIT and Michigan had recently included controls and servomechanisms in their fields of study. By drawing attention to other schools’ activities, Akerman hoped to show how detrimental Spilhaus’s own “narrow” vision was to the aeronautical engineering department at Minnesota.

Akerman tried further to bolster the reputation of his department in a section of the report entitled, “Efforts to Present the Status of Aeronautical Engineering in a Very Poor Light.” Spilhaus created a chart comparing the two departments in question and comparing mechanical and civil engineering with respect to the strength of a number of engineering science areas. This chart can be found in the appendix as Chart 1.⁴⁴ Spilhaus examined each department for research activities and faculty competent in a given engineering science area, such as fluid mechanics. In this way, Spilhaus attempted to illustrate the significant weaknesses of the aeronautical engineering department. Akerman added a “corrected column” to Spilhaus’s chart. He complained that Spilhaus arranged the engineering science areas so “as to favor” Mechanics and Materials, and to give Aeronautical Engineering an appearance that it lacked competence. Akerman’s additional column included his own evaluation of the department’s research activities and the staff and faculty. This modified chart can also be found in the Appendix as Chart 2.⁴⁵

⁴³ Ibid., 7-9.

⁴⁴ Ibid., p. 112.

⁴⁵ Ibid., p. 113.

Akerman reacted strongly to Spilhaus's selection of Drs. Chang and Hermann as the only truly competent members of his staff. He wrote, "No mention is given to other fields or other staff members, although under other departments of the Institute his chart lists persons and activities of lesser stature as 'Fields of Strength'."⁴⁶ He defended the abilities of Eugene Stolarik as "an outstanding teacher, engineer and scientist [who qualifies] to be listed in a 'Field of Strength'."⁴⁷ Although Spilhaus did not include Stolarik in the chart, the wording of the proposal indicated that he in truth respected Stolarik's teaching ability. His concern lay in the lack of *permanent* faculty. He wrote, "Beyond [Chang, Hermann, and Stolarik] the department depends primarily on temporary assistance in the form of Rosemount lecturers. The number of competent staff in the Aeronautical Department is thus well below critical size and this is one reason why it has been unable to attract new competent staff."⁴⁸ But Akerman viewed this apparent affront to Stolarik as Spilhaus's way of snubbing Stolarik for not pursuing a doctorate.

As noted earlier, Akerman never even finished his master's degree. Spilhaus filled his eight-page proposal with references to the aeronautical engineering department's competency level, many of which were directed at Akerman's leadership. Akerman's defense of Stolarik's ability to teach without holding a Ph.D. hints at the tension between him and Spilhaus about his own background. He defended his competency in one section of his response outlining his own aeronautical expertise and history. In this and other ways, Akerman attempted to counter every claim Spilhaus made about the

⁴⁶ Ibid., 14.

⁴⁷ Ibid., 14.

⁴⁸ Ibid., 5.

sorry state of the aeronautical engineering department. But he showed even less tact and control over his feelings than Spilhaus did. He wrote:

Such action can only be explained one of two ways: (1) deliberate purposeful degradation of the work done in the Department of Aeronautical Engineering, or (2) complete ignorance and misunderstanding of the Aeronautical Sciences. Both of these explanations have been encountered in the history of aeronautical education when outsiders have dealt with aeronautical fields.⁴⁹

It seems likely that Akerman knew that Spilhaus himself had earned a master's degree in aeronautical engineering. Clearly, Akerman viewed Spilhaus's proposal as a "deliberate" attack, not a "misunderstanding." Akerman aimed further shots at Spilhaus when he wrote, "Is this the beginning of a 'planned allocation' of our young men to various fields of technological study by 'super authorities' wielding hidden power through excessive influence on the subordinated group of aeronautical students? Why not do it by arbitrary assignment as exercised in Russia?"⁵⁰ Further, he viewed as one of the consequences of accepting the merger proposal "the apparent acceptance of questionable ethics in the promotion of personal projects to the detriment of loyal and capable personnel with long service and achievement records."⁵¹

Akerman wished to be free of Spilhaus just as much as Spilhaus wanted to be free of Akerman. His long report to Morrill included a counter-proposal for the separation of the aeronautical engineering department from IT and the establishment of an independent School of Aeronautical Sciences.⁵² He wrote:

⁴⁹ Ibid., 13.

⁵⁰ Ibid., 31.

⁵¹ Ibid., 42.

⁵² Ibid., 44.

This plan would have the main advantage of free selection of humanistic, basic scientific and specialized aeronautical courses as determined by the faculty of the Aeronautical School to meet the needs of a proper aeronautical education without the adjustments, generalities, compromises, influences and dominations of other departments to suit their interpretations as to what is proper in aeronautical science and industry.⁵³

Clearly, Akerman never appreciated Spilhaus's vision for Minnesota. Actually, Akerman, a very close-minded man, never seemed open to many new ideas from anybody.

This closed-mindedness transferred into his dealings with others, both professional and privately. Richard Deleo, a former staff scientist at Rosemount Aeronautical Laboratory called Akerman “a tough mule.”⁵⁴ In a letter to Fisk Teachers Agency, Akerman announced a one-year vacancy for an instructor in the department. He wrote, “The candidate should be American, Caucasian, and have a Bachelor or Master’s Degree in Aeronautical Engineering.” He further added that it was preferred if the applicant was not a Jew.⁵⁵

Akerman also took a dim view of the abilities of women as aeronautical engineers. In a reply to a young woman requesting the freshman requirements for entrance in the department, Akerman recommended that in addition to mathematics courses she should consider taking typing and shorthand. He forwarded her the bulletin listing the requirements. But he also suggested that her advisor look through it for her to confirm that she met all the requirements, intimating that she would not be able to appraise the

⁵³ Ibid., 45.

⁵⁴ Richard Deleo, telephone conversation with author, 7 June 1999.

⁵⁵ Akerman to Fisk Teachers Agency, 5 September 1936, Correspondence file F, box 1, Akerman Papers, UA.

situation herself.⁵⁶ Throughout Akerman's reports, he referred to students as "our men" or "our boys" even after the department had graduated female aeronautical engineers.⁵⁷

When President Morrill read Akerman's report, he noted that Akerman seemed to argue more effectively for the organization and strength of the aeronautical department than Spilhaus did for its weaknesses. But he also recognized that the "problem is essentially one of personality conflict [and] distrust of Akerman's scientific competence."⁵⁸ He questioned privately whether Spilhaus would have ever proposed the merger if Akerman was not the department head. Had Spilhaus been the only person to voice his concern about Akerman's ability to lead, Morrill may have been more inclined to search for other solutions to the conflict than the two proposals already on the table. But Spilhaus was not alone. From Morrill's personal notes of a private meeting with Dr. C. C. Chang in the fall of 1957, it is clear that Spilhaus was not the only one who felt Akerman was a difficult man with whom to work. Morrill himself began to think that Akerman's term as head of the department should end.

Dean Spilhaus recruited Dr. Chang from Caltech to upgrade the staff and curriculum. Spilhaus promised to support Chang in all his efforts. Chang reported to Mor-

⁵⁶Akerman to Gladys Hanson, 20 February 1935, Correspondence file H, box 2, Akerman Papers, UA.

⁵⁷ These references can be found in Akerman, "Report on the Present Status of and Proposed Changes in the Department of Aeronautical Engineering at the University of Minnesota," 7, UMN, IT, Aeronautical Engineering Papers, 1957 file, and a memorandum from Akerman, 6 May 1940, Dept. of Aeronautics file, box 35, President's Office Papers, UA. I am unaware of the graduation date of the department's first woman, but know that Ms. Margaret Stickles graduated in 1944.

⁵⁸ Morrill, personal notes, 6 September 1957, UMN, IT, Aeronautical Engineering Papers, 1957 file, UA.

rill that the undergraduate curriculum at Minnesota was “seriously out of date” and that “efforts by both Dean Spilhaus and himself to change and improve it” were “consistently blocked by Prof. Akerman.”⁵⁹ He described Akerman as “entirely resistant to change and improvement generally” and his administration as “arbitrary.”⁶⁰ Chang also believed that the graduate curriculum and staff were not competitive and that “competent staff could not be retained because of (a) common knowledge and consensus in the aero[nautical] eng[ineering] field that Prof. Akerman is dictatorial and arbitrary in his administration and (b) no oppor[tunity] for participation in an improved and soundly developing program [existed].”⁶¹ He further supported Spilhaus in the conclusion that Akerman lacked the “scientific and administrative competence to manage, single-handed, two such important enterprises as the Aero. Eng. Dept. and Rosemount.”⁶² Chang reported that even students had filed complaints about Akerman with Sigma Gamma Tau, the honorary aeronautical engineering fraternity.

On April 11, 1958, after almost a year of debate, meetings, letters (none between Spilhaus and Akerman), and acrimony, the Board of Regents accepted the recommendation to merge the Department of Aeronautical Engineering with Mechanics and Materials. Akerman retained his status as Professor, but would serve only as head of the Rosemount Aeronautical Laboratory, which became an independent agency within IT, no longer a

⁵⁹ Morrill, personal notes from a private meeting with Dr. C. C. Chang, 21 August 1957, UMN, IT, Aeronautical Engineering Papers, 1957 file, UA.

⁶⁰ Ibid.

⁶¹ Ibid.

⁶² Ibid.

subsidiary of the aeronautical engineering department. Dr. Benjamin Lazan, Associate Dean of IT and head of Mechanics and Materials, took over as head of the combined departments.

Spilhaus believed, as did Chang, that the department's curriculum was out of date and its objectives were obsolete. In the last ten of his twenty-nine years as head of the department, Akerman had shown little initiative to maintain the highest level of performance and competitiveness in the department. With the large number of students enrolled in aeronautical engineering at Minnesota, it is reasonable that Akerman would never even question the competitive nature of the department nationally. But both Spilhaus and Akerman saw the university's limited resources in research as a hindrance to the department. Rosemount Aeronautical Laboratory filled the void in Minnesota's research capabilities. With that improvement, Minnesota's aeronautical engineering department could attract the kind of faculty members capable of advancing the department as a research entity.

This chapter should not conclude without a brief review of the history of the Rosemount Aeronautical Laboratory, which came to serve as the aeronautical engineering department's primary wind tunnel facility. By 1960, RAL housed a continuous-flow transonic tunnel, continuous-flow and blow-down supersonic tunnels, and a high-temperature hypersonic wind tunnel.⁶³ Limited space in the Aeronautical Engineering building on campus and the destruction by fire of the Engineering Experiment Station in

⁶³ Akerman, "Aeronautical Research Facilities," 12. The hypersonic tunnel was installed in 1958, while the other tunnels mentioned were operational in 1951 when Akerman compiled this report.

February 1953 meant that the majority of the departmental research took place away from campus.

The University of Minnesota officially acquired the buildings and equipment for RAL on over 8,000 acres of land of Gopher Ordnance Works, an idle powder-manufacturing site, from the War Assets Administration for \$1 in 1948. The stipulations of the agreement required the university to use the facility for 25 years on projects of public interest. The W.A.A. also reserved the right to take back the facility should a war emergency arise. Conditions aside, this exchange stood as the largest transfer to an educational institution by the W.A.A.⁶⁴ Rosemount housed a number of different facilities. But university negotiators, including Akerman, expected the aeronautical laboratory to be one of the most significant contributors at Rosemount. He wrote in his proposal to the War Assets Administration regarding the Gopher Ordnance Works that RAL “would provide not only a new research center but also a training place for new scientists studying supersonic velocities in aerodynamics.”⁶⁵ President Morrill confirmed this perspective in his statement recorded by the W.A.A. in its news release. Morrill’s quotation reads, “Present research being undertaken at the former war plant include basic and developmental research in the aeronautical and ordnance fields of jet propulsion, electronics, guided missiles, subsonics, transonics, supersonics, air velocities, polio, cancer, and agriculture.”⁶⁶

⁶⁴ Information on the transfer of the Gopher Ordnance Works to Minnesota was obtained from an undated news release made by the War Assets Administration, copy of news release, Akerman Papers, box 1, UA.

⁶⁵ John Akerman, “Proposal from the University of Minnesota regarding the Gopher Ordnance Works Rosemount, Minnesota,” 43, Akerman Papers, box 1, UA.

⁶⁶ W.A.A. news release.

In the original proposal, Akerman relied on the 1946 Meade War Investigating Committee Report to the Congress on aircraft research, development and production as evidence of the pressing need in the United States to establish a facility like RAL. Akerman wrote, “[The report] said the United States now finds itself inadequately equipped with research facilities for new radical, high-speed aircraft and the NACA and armed forces are ‘primarily responsible.’ ... The committee said the Army and the Air Forces and NACA now plan ‘unprecedented expansion of basic and applied research’. It said these plans should be expedited and needed facilities constructed post haste.”⁶⁷ For these reasons, Akerman argued that the establishment of Rosemount Aeronautical Laboratory “would be a great educational asset to the State and the Nation.”⁶⁸ As an educational tool, Rosemount offered Minnesota students the opportunity to get involved with real engineering projects as part of a class assignment or as a student employee. For the aeronautical engineering department at Minnesota, RAL meant not only access to vast research opportunities, but it also attracted some of the top research engineers to the faculty. In helping to acquire Rosemount, Akerman certainly did help his department move towards engineering science, but unfortunately his own personality, leadership, and private research agenda did not bring that evolution to total fruition.

The significance of a laboratory like RAL to the strength of engineering science in an aeronautical engineering department should not be underestimated, though. In the university’s new laboratory environment, professors and students together investigated

⁶⁷ John Akerman, “Proposal from the University of Minnesota regarding the Gopher Ordnance Works Rosemount, Minnesota,” 46, Akerman Papers, box 1, UA.

⁶⁸ *Ibid.*, 43.

real-world engineering problems. But as tremendously important as having a lab like RAL was, it was not the only necessary precondition for departmental strength in engineering science. What the development, practice, and teaching of engineering science required more than anything else was talent of mind, ingenuity, and leadership with a broader vision and deeper commitment to fundamental research. Wind tunnel testing and experimentation took place along a continuum between empiricism and theory. Although Akerman strongly supported having wind tunnels for research at Minnesota, he lacked the ability to contribute the qualities of mind and leadership necessary to nurture a culture of fruitful engineering science on campus.

Analysis of Akerman's weaknesses underpin this thesis's argument that Akerman was just not the kind of individual who could successfully establish an engineering science approach within Minnesota's aeronautical engineering program. To wit, during the period that RAL was in operation, Akerman conducted no aeronautical research of his own. Rather, he turned his attention to aviation medicine and the development of flight suits, a field better suited to Akerman's personal interests than to the research agenda of the RAL. Furthermore, as we have seen, C. C. Chang mentioned to President Morrill that Akerman's reputation in the field limited Minnesota's ability to attract new and outstanding job candidates. But even Spilhaus admitted that the department already had two invaluable faculty members in Chang and Rudolf Hermann. With capable engineers like Chang and Hermann serving in both the classroom and the lab, the aeronautical engineering department at Minnesota could teach its students valuable engineering science methods even without the benefit of a model department head. In the next chapter, we will see how that in fact occurred.

Rudolf Hermann and the Transfer of Engineering Science to Minnesota

To understand how engineering science could find its way into the curriculum at Minnesota before Akerman's removal as department head, we must examine the teaching and research practices of the faculty. Rudolf Hermann serves as the best excellent example of how this could be done. But before examining Hermann's contributions to Minnesota's history, one should consider his personal background to understand how it shaped his own ideas about engineering science.

Rudolf Hermann came to the University of Minnesota in December 1950. By this time, Hermann had already established himself as a highly competent scientist and engineer both in Germany and the United States. He earned his Ph.D. in physics from the University of Leipzig in 1929. He moved on to the Technische Hochschule at Aachen to study aerodynamics. In 1935, he completed his *Doktor habilitation* (Dr. habil.), the second doctorate required of all professorial candidates in Germany.

Hermann's first engineering position was as an assistant in the Department of Applied Mechanics and Thermodynamics at the University of Leipzig from 1929 to 1933. The German lab environment gave even the lowest level assistants hands-on experience not only performing experiments, but with evaluating and interpreting data. Experience working in the university lab, not to mention his educational background, served Hermann well. But what was even more important to the growth of his involvement in engineering science than simply this experience in the lab were the science-based, theory-oriented questions being asked about aeronautics by his

contemporary German scientists and engineers. He became intimately familiar with many of these questions, especially after 1934 when he took over as head of the supersonic wind tunnel division at Aachen, a position he kept until 1937.

Adolf Hitler became Chancellor of Germany in 1933. By early 1935, Nazi leadership unveiled the Luftwaffe, defying the Versailles Treaty that ended World War I. Although this was part of a general push forward in aeronautics, one special build-up involved rockets, a new technology not specifically prohibited for development in Germany by the Versailles Treaty. In the mid-1930s, the German army created a major rocket development center on the Baltic coast at Peenemünde. From this installation would rise what might arguably be called the most awesome and futuristic aeronautical technology of the war soon to come, the guided missile.¹

In 1935, the Luftwaffe Technical Office introduced Wernher von Braun, the German rocket pioneer, to Rudolf Hermann who was still working at Aachen as an assistant professor in addition to holding his position in the wind tunnel center. The Peenemünde group was troubled by the aerodynamic design of missile fins and turned to Hermann and his facilities at Aachen to provide the preliminary study of the drag component.²

Because of the significant role supersonic aerodynamics played in rocket design and the distance of the Aachen lab from Peenemünde, von Braun felt that the rocket camp needed its own supersonic wind tunnel and its own supersonic specialist. Hermann

¹ Michael J. Neufeld, *The Rocket and the Reich: Peenemünde and the Coming of the Ballistic Missile Era* (Cambridge: Harvard University Press, 1995), p. 41.

² *Ibid.*, 68.

joined the Peenemünde group in April 1937 as Director of the Supersonic Wind Tunnel Laboratory of the Army Rocket Experimental Station. The construction of two supersonic tunnels was Hermann's priority. The first tunnel was a 20-second, blow down tunnel with a 40-centimeter-wide test section and a maximum running speed of Mach 4.4; and the second, an 18 x 18 centimeter continuous-flow tunnel with a maximum speed of Mach 3.1. The theoretical design of the De Laval nozzles used to accelerate the tunnel flows to supersonic velocities proved to be an extraordinarily complex task.

Nevertheless, Hermann and his team perfected the designs for the testing facilities while providing novel methods for acquiring transonic and supersonic data, such as drop tests from an altitude of 7000 feet. Through these tests, Hermann and his staff gathered supersonic flight data on the aerodynamic design of the A-5, a redesigned A-3 rocket used to test guidance systems.³ The lessons learned from the study and testing of the A-5 were later incorporated into the design of the notorious V-2 ("Vengeance Weapon") rocket, which was launched against London late in the war. This experience gave Hermann the status of chief aerodynamicist for the V-2 rocket.

On August 18, 1943, the British air forces bombed the Peenemünde camp. Army Ordnance decided to move the Supersonics group to an underground site at Kochel in the Bavarian Alps.⁴ Preparation of the new facility was slow. Hermann's team did not report to Kochel until 1944. Until his arrival date in the Alps, Hermann lectured on supersonic

³ Ibid., 87-9. The guidance system was intimately linked to the aerodynamics of the rockets. The Peenemünde group found in previous tests with the A-3 that at supersonic conditions, the design of the rocket made it so aerodynamically stable that guidance corrections were difficult at best.

⁴ Ibid., 197, 205.

aerodynamics and ballistics at Aachen and in Berlin, a tribute to his expertise in the field. In fact, Hermann's position as lecturer for Aachen and Berlin began in 1935 and did not end until 1945.

With the end of World War II, the Allied Powers sent representatives to occupied Germany with the intentions of claiming the top scientists in a variety of fields for the benefit of science and weapons making at home. The operation came to be known as Project Paperclip. By the end of 1952, 544 German specialists were living and working in the United States because of Project Paperclip. Five hundred and sixteen of these specialists and 1063 of their dependents obtained U. S. citizenship, Rudolf Hermann included.⁵

As these scientists and engineers arrived in America, they were usually housed and put to work on military installations under guard. Hermann found himself in 1945 employed as a consultant with the Air Engineering Development Division at Wright Patterson Air Force Base in Dayton, Ohio. The American public was not told of the presence of German scientists and engineers working in the United States until early December 1946. *Newsweek* magazine described the work of the scientists from Kochel: "As the war ended, [Dr. Rudolf Hermann] was building a 7,000-mile-an-hour wind tunnel in the Bavarian Alps. With six associates brought from Germany, Hermann is working on supersonic wind tunnels for the United States Army."⁶

⁵ Clarence G. Lasby, *Project Paperclip: German Scientists and the Cold War* (New York: Atheneum Press, 1971), 244-5.

⁶ "Secrets of Hitler," *Newsweek*, 9 December 1946, 64-69.

Even before World War II ended questions had been asked about how the situation with the German scientists should be handled. Some people in the U. S. military and government, like Under Secretary of War Robert Patterson, felt that only the Germans “whose work required their presence” should be imported and “that [the War Department] keep them under strict surveillance; and that it return them to Germany as soon as possible.”⁷ General Gladeon Barnes, Chief of Ordnance, hoped that all the scientists imported, but particularly the rocket scientists, be permitted to “come work with ‘long-term’ intentions.”⁸ By 1948, however, some of the incoming Germans were being approved for work in American industry, and with that approval came essentially full freedom of choice.⁹ Scientists already in the United States were also being released for industry work. In 1950, Hermann left his Paperclip position at Wright Air Force Base, and joined the faculty in the Department of Aeronautical Engineering at Minnesota.

The environment at Minnesota in 1950 was not conducive to much change when Hermann arrived. But he brought to the university more than just a new way of working. He brought knowledge and expertise of supersonic and hypersonic flight, subjects that were new to the curriculum. In addition to this new expertise, Hermann also taught mostly graduate level courses, which was a weak area in the aeronautical engineering department.

During the twelve years Hermann served on the faculty at Minnesota, he taught a three-quarter series on supersonic aerodynamics. In the fall, he taught Aerodynamics of

⁷ Lasby, 71.

⁸ Ibid., 73.

⁹ Ibid., 233.

Supersonic Inlet Diffusers; during the winter quarter, Aerodynamics and Flight Performance of Supersonic Missiles; and in the spring, the continuation of the winter quarter course. The only given description, which was for the fall course, read:

Diffuser types and pressure recovery. The one-dimensional normal shock diffuser. Various definitions of diffuser efficiency. Compression by one, two, or more oblique shocks. Two-dimensional diffuser for ramjets. Spike diffusers and pulsations.¹⁰

At first glance, this looked like a course that simply introduced students to the important equipment of supersonic research, and was thus comparable to the customary, less theoretically oriented graduate courses offered at Minnesota. But when the details of this description were compared to that of Akerman's graduate level course, Advanced Aircraft Engines, one saw significant differences. The description of Akerman's Advanced Aircraft Engines course was as follows:

An advanced study of aircraft engines and auxiliary equipment, analysis of current developments in aircraft engines, new engine accessories and installations. Theoretical analysis of their effect upon the performance of modern aircraft.¹¹

Akerman clearly focused on the hardware: what equipment existed, what state-of-the-art design was on the horizon, and how well the device worked. In Hermann's course description, the devices were actually named. Also mentioned were the characteristics of sonic and supersonic environments, such as "pressure recovery," "compression by oblique shocks," "definitions of diffuser efficiency," and "pulsations." Researching supersonic aerodynamics required an understanding of the equipment and instrumentation, which Hermann's course carefully introduced. Hermann also sought to

¹⁰ *IT Bulletin*, vol. LIV, no. 23, 70.

¹¹ *IT Bulletin*, vol. XLI, no. 32, 74.

teach the science of supersonics, that was, the conditions that existed in supersonic environments and how to understand, predict, and work within them. Without course syllabi or lecture notes, it is difficult to fully grasp the actual content of the course. However, one detects real distinctions between pedagogical methods from the wording of course descriptions.

Hermann served the University of Minnesota both as a teaching professor and researcher, much as he had in Germany. He and his family lived in one of the 25 staff houses on the grounds of RAL, where he acted as Technical Director of the Hypersonic Facilities. At RAL, Hermann conducted theoretical research on supersonic and hypersonic flow characteristics, rocket sleds, and ramjets, with much support and funding from the U. S. Air Force and U.S. Navy.

Hermann was consistently productive during his years at RAL. By February 1958, when the University Archives compiled the Hermann biographical file, he had published over 45 papers on supersonic aerodynamics and diffusers. Between July 1959 and July 1961, he wrote or co-authored an additional 30 reports.

Hermann was one of the top researchers, if not the top, in supersonic and hypersonic aerodynamics in the United States in the 1950s and 1960s. His reports ranged in topic from the basic questions and issues that arose in the development and construction of wind tunnels to the advanced theory of high-speed flows. Hermann wrote papers such as “Starting and Operation of the 12 Inch by 12 Inch Supersonic Blow Down Wind Tunnel”; “The decay of weak oblique shock waves in two-dimensional supersonic

flow”; and “Theory of ground interference on rocket sleds.”¹² Many of Hermann’s articles were published as RAL research reports, but others were published in the *Journal of the Aeronautical Sciences* or presented at conferences on wind tunnels, supersonics, and space technology.

Between his teaching, research and paper commitments, Hermann found time to write a text published in 1956, *Supersonic Inlet Diffusers and Introduction to Internal Aerodynamics*. His preface stated: “With the growing emphasis on obtaining higher and higher Mach numbers in supersonic flight of turbojet and ramjet powered aircraft, the necessity of maximizing the inlet diffuser pressure recovery of the propulsion system has become increasingly evident.” Hermann intended that his book provide “a systematic and comprehensive treatment of the flow characteristics of diffusers in general and inlet diffusers in particular.”¹³ Hermann envisioned his audience to be scientists and engineers in government, industry, and academic research laboratories as well as graduate students.

As already seen, his course descriptions indicated Hermann’s focus on engineering science and theory. Dick Deleo has spoken highly about Hermann’s course, *Supersonic Inlet Diffusers*, which Hermann generously offered in the afternoons to the staff of RAL in addition to his students on campus. Deleo has commented: “His lectures ... were very complete. He really didn’t need the text at all. They were exceptionally good. And that [subject] was all new at that time. That was probably the best course at

¹² University of Minnesota, *Publications of the Faculties*, (Minneapolis: 1952), 34, (1953), 32, and copy of Publication of the Faculties for July 1, 1959-June 30, 1960 President Form 1.

¹³ Rudolf Hermann, *Supersonic Inlet Diffusers and Introduction to Internal Aerodynamics*, (Minneapolis: Minneapolis-Honeywell Regulator Company, Aeronautical Division, 1956), vii.

that time in the country.”¹⁴ To the great benefit of the students, Deleo recalled, “He used that [course] in the design of wind tunnel diffusers. We got a program with [the air force’s Arnold Engineering Development Center] to develop supersonic diffusers for their big wind tunnels down in Tullahoma [Tennessee] and used a lot of his theory there to help out. It was a very good course.”¹⁵

In the classroom and in the lab, Hermann brought theoretical knowledge and his understanding of engineering science to the students and put it into their hands. The students benefited greatly from Hermann’s teaching methods and his personal style. Deleo has commented, “[Hermann] was more personable [than Akerman.] He would try to guide you.”¹⁶ When working with Hermann, students faced real engineering problems like the design of the Tullahoma diffusers. Also, they studied with a world-class theoretician and interacted professionally with experienced co-workers and supervisors. With Hermann at RAL, Minnesota students had one of their best opportunities to develop skills in engineering science.

After June 1958, Akerman no longer served as head of the Department of Aeronautical Engineering and, with this change, resistance to change generally evaporated in that department. The new A.E. head, Ben Lazan, immediately took the wheel and set a course for the coming decade. The Report of the Curriculum Committee presented to the College of Engineering in December 1958 included four typed pages of renamed courses, redesigned courses, reorganized courses, and brand new courses that

¹⁴ Deleo, telephone conversation, 7 June 1999.

¹⁵ Ibid.

¹⁶ Ibid.

were intended to better prepare students for the complexity of the field in 1958. The need to update such a significant portion of the coursework reinforces Spilhaus's argument that Akerman had long before lost touch on the pulse of industry and could no longer serve the students' best interests. The changes even included abandoning the old three-quarter sequence of courses, Aerodynamics (Aero 100-101-102), a series whose description had been only slightly modified twice since 1931, and replacing it with the three-quarter series, Theoretical Aerodynamics.¹⁷

It is difficult to know how much of a contribution Rudolf Hermann made to these changes towards a more theoretically minded program. But there are some curriculum recommendations that suggest the high regard by the faculty and the administration for Hermann's work and teaching style. In a memorandum by the secretary of the Board of Regents, L. R. Lunden wrote:

The President [of the University, O. Meredith Wilson,] discussed with the Board the need for an organizational change in the Rosemount Aeronautical Laboratories to provide more emphasis in the area of hypersonic research and a more direct relationship of the Laboratory to the Institute of Technology and the Graduate program.¹⁸

¹⁷ College of Engineering, Report of the Curriculum Committee to the College of Engineering [5 December 1958], Minutes and related documents of meetings of the faculty, 1958, 1964-5, UA. The course description for Aero 100-101-102 in IT Bulletin, vol. XXXIV, no. 39 (1931-1932) is "Atmospheric properties. Fluid mechanics. Stream functions and velocity potential. Motion of body in liquids in three dimensions. Prandtl's wing theory. Dynamic loads, stability, maneuverability, controllability." In 1950, the year the description was first rewritten, it read, "Atmospheric properties; fluid mechanics; Prandtl's wing theory. Dimensional analysis. Performance stability, propeller theory. Motion of body in fluids in three dimensions." In 1951, "Atmospheric properties" and "Dimensional analysis" were dropped.

¹⁸ L. R. Lunden, "Memorandum to the files," IT Dean's Papers, Aero Engr. Gen. Correspondence, 1954-72 file, UA.

This “closer integration of that activity with the related graduate programs in I.T.” was enacted in 1961, confirming the positive influence that Dr. Hermann’s teaching had on the department’s curriculum.¹⁹

In June 1962, Rudolf Hermann left the University of Minnesota to accept the position of Director of the newly founded aeronautical research laboratory at the University of Alabama in Huntsville, a neighboring facility to Marshall Spaceflight Center where Hermann’s former collaborator from Peenemünde, Wernher von Braun, was in charge. But during his time at Minnesota, he contributed to the Aeronautical Engineering program his knowledge and understanding of supersonic and hypersonic theory and an approach to engineering science at a time when the Institute of Technology was ready for change.

¹⁹ Frank Verbrugge, *Biennial Report, 1960-1962*, [June 30, 1962], 124, UA.

Engineering Science Outside the State in Comparison to the University of Minnesota

Three mechanisms existed at Minnesota that encouraged the incorporation of engineering science into the aeronautical engineering department: Athelstan Spilhaus's vision of a strong science-based engineering curriculum; Rosemount Aeronautical Laboratory with its research professors; and the transfer of elements of engineering science culture from the German rocket team's experience at Peenemünde in the person of Rudolf Hermann.

More than any other single factor it was the Spilhaus-Akerman affair that set the University of Minnesota apart from other universities. Not every university trying to update its curriculum in this period faced a conflict as heated. In the chapter at hand, other schools with aeronautical engineering programs will be examined to see how they encouraged the development of engineering science. In comparing these schools to the University of Minnesota, the intention is to identify the institutional and intellectual forces fostering the growth of engineering science in American universities teaching aeronautical engineering during this era.

Aeronautical engineering departments after 1927 fell into two major categories; Guggenheim schools and non-Guggenheim schools. Representatives from both promoted engineering science in their departments, and one can learn something by comparing the Minnesota program with representatives from each. The Guggenheim schools established aeronautical engineering departments in the late 1920s, the same time Minnesota's

department broke away from mechanical engineering. Therefore, we will look at these schools first.

Daniel Guggenheim organized the Daniel Guggenheim Fund for the Promotion of Aeronautics in January 1926. Guggenheim intended the fund “to promote aeronautical education throughout the country; to assist in the extension of aeronautical science; and to further the development of commercial aircraft, particularly in its use as a regular means of transportation of both goods and people.”¹ The fund endowed seven schools for aeronautics programs and laboratories, dedicated to teaching the fundamentals. The California Institute of Technology received one of these grants in 1927.

Dr. Robert Millikan, Caltech’s president, spearheaded the university’s initiative to establish a program in aeronautics. As a physicist, he insisted that the aeronautics curriculum be built on a strong foundation in science, particularly mathematical physics. Millikan recruited one of Ludwig Prandtl’s prize students, Dr. Theodore von Kármán from the Aerodynamics Institute at Aachen in Germany, to head the new department.

Von Kármán brought a particular strength in engineering science to Caltech. In *Millikan’s School*, historian Judith Goodstein writes, “Von Kármán was an aerodynamicist, trained in physics and mathematics, and he believed strongly that engineers should be taught to use mathematics to solve physics problems. Without question, von Kármán had his feet planted in both worlds.”² Von Kármán wrote about

¹ Harry F. Guggenheim, *Report of the Daniel Guggenheim Fund for the Promotion of Aeronautics, 1926 and 1927* (New York: The Daniel Guggenheim Fund for the Promotion of Aeronautics, Inc., 1928), copyright page.

² Judith R. Goodstein, *Millikan’s School: A History of The California Institute of Technology* (New York: W. W. Norton & Company, 1991), p. 163.

the early attempts at flight, “For advances in any real sense it was necessary for science to catch up with the dreams and experimenters and set a basis for further developments in a rational manner.”³ Von Kármán had a strong sense of the indispensable nature of science and theory in aviation, even though his motives were to achieve practical applications. Von Kármán’s philosophy could well have been read directly from the mission statement of the Report of the Daniel Guggenheim Fund for the Promotion of Aeronautics.

Von Kármán understood that engineering was a hybrid of technology and science, making it something more. He insisted, “An engineer is not a scientist. In addition to basic technical knowledge he must have the creative capacity to design new hardware. Engineering schools that fail to recognize and encourage this dual role are remiss in their duty to the profession.”⁴ Von Kármán was concerned about the trend of technological development in which scientists played the key roles and not engineers. What was important, he thought, was “to repair the imbalance in the scientific world and turn out people who not only understand fundamental phenomena but can use this knowledge for developing new devices.” In his view, “this in turn will not only bring some glory to the engineer, but I think it will contribute substantially to the pace of progress.”⁵

For Caltech students, this meant that the core curriculum would require significant numbers of courses in mathematics, engineering design and laboratory courses, some

³ Theodore von Kármán, *The Wind and Beyond: Theodore von Kármán, Pioneer in Aviation and Pathfinder in Space* (Boston: Little, Brown and Company, 1967), p. 58.

⁴ Ibid., p. 157.

⁵ Ibid., p. 159.

physics, and less of other sciences, since engineers, not scientists, were the sought-after product. Von Kármán believed that engineering curriculum should be distinct from science curriculum.

The aeronautical laboratory at Caltech, financed by the Guggenheim Fund, served a dual purpose. The Guggenheim Aeronautical Laboratory at the California Institute of Technology (GALCIT) provided industry as well as the faculty and students with research facilities. As would happen with Rosemount in later years, faculty members used the laboratory facilities for their own research and as a classroom for aeronautical engineering students. But GALCIT's Pasadena location placed it in one of the nation's centers of aviation industry. Since industrialists, like Donald Douglas, had not established research capabilities with their own funds, GALCIT served as the primary research center for southern California aviation. When Douglas Aircraft, for example, wanted a particular subject investigated, it would sponsor and help pay for the work to be carried out at the lab. Von Kármán and his staff would conduct the research requested, thus helping to advance the American aviation industry.

Goodstein notes that through this service relationship with industry, other engineering problems and questions arose that von Kármán and his team then addressed, such as the aerodynamic consequences of propellers on overall performance and the effects of turbulence on lift.⁶ GALCIT workers were breaking new ground in aerodynamic research. GALCIT benefited particularly from the types of aircraft companies in the vicinity: Douglas Aircraft, Consolidated Aircraft, North American, Lockheed and Martin Companies all settled in southern California. These companies were some of the

leaders of the industry technologically. This gave GALCIT faculty and students the opportunity to participate in the development of cutting edge industrial technologies. Because of GALCIT, Caltech students, both those enrolled in classes taught by the research professors and those working in the lab under their direction, learned the strengths of theory and practical application.

Another Guggenheim program grew up at the University of Michigan, where the country's very first aeronautics program started in 1914. Michigan received its Guggenheim grant in 1927. Since the program was well established by 1927, the Guggenheim Fund marked the endowment for the construction of an aerodynamics laboratory and the salary for a Professorship of Applied Aeronautics.⁷

The A.E. department at Michigan benefited from its early faculty's broad backgrounds and strengths. Felix Pawlowski, a Pole, had worked in Russia with Igor Sikorsky, had spent time experimenting with Gustave Eiffel's wind tunnel in Paris, and had studied aerodynamics at the University of Paris.⁸ Professor Edward Stalker, who wrote a textbook on basic aerodynamics, was "an outstanding mathematician."⁹ Stepan Petrovich Timoshenko taught courses in structures, but made it his pedagogical mission

⁶ Goodstein, p. 174.

⁷ Guggenheim, p. 10.

⁸ Clarence L. "Kelly" Johnson with Maggie Smith, *Kelly: More Than My Share of It All* (Washington, D. C.: Smithsonian Institution Press, 1985), p. 14; University of Michigan Aerospace Engineering Web Administrators, "History of the Aero Dept.," [website]; available at <http://www.engin.umich.edu/dept/aero/general/history.html>; INTERNET.

⁹ Johnson, p. 15.

to encourage stronger foundations in mathematics for American engineering students.¹⁰ As already noted, mathematics played a key role in understanding the complexities of aeronautical engineering. By the 1930s the faculty at Michigan had established a solid program in aeronautical engineering knowledge through coursework and lab work heavily rooted in mathematics.

Like GALCIT, the Michigan labs served as a resource for industry. The department's most well known graduate, Clarence "Kelly" Johnson, the engineer behind Lockheed's Skunk Works and its famous U-2 and SR-71 aircraft, wrote in his autobiography about his experiences as a master's student working in the Guggenheim lab at Michigan. He remembered Lockheed shipping a model of its innovative all-metal twin-engine aircraft, the Electra, for stability testing in 1933. Kelly emphasized his discovery of the aircraft's significant longitudinal stability problems and directional control problems.¹¹ Johnson's involvement in this type of research clearly indicates the strength of a university laboratory-industry relationship in aeronautical engineering. Further, considering Johnson's description of the rich laboratory environment at Michigan, one can see how beneficial that industry relationship proved to be to engineering students. The large industries coming to the Guggenheim labs for research worked on the cutting edge of aircraft technology and expected the most up-to-date

¹⁰ Mark Levinson, "Encounters Between Engineering Science and American Engineering Education: The Postwar Textbook Revolution" (paper presented at the annual meeting of the Society for the History of Technology, Pasadena, Cal., October 1997), pp. 3-4. I wish to thank Mark Levinson for his permission to cite this paper.

¹¹ Johnson, pp. 20-21.

knowledge. Students with a chance to work with them on real engineering problems benefited immensely.

All the Guggenheim schools were established within three years of Minnesota's aeronautical engineering department becoming independent. But the Guggenheim schools were responsible, as expected by the trustees of the Guggenheim Fund, to serve as leaders in aeronautical engineering education and to provide research and encouragement to the aviation industry in ways other schools were not nearly as capable. In trying to track the growth of engineering science in aeronautical engineering education, one can establish the Guggenheim schools as a benchmark. As promoters of aeronautical education, these schools trained future professors. As assistants in the extension of aeronautical science, they trained world-class researchers. As developers of commercial aviation, these schools endeavored to maintain the highest level of competency in aeronautical science so they could provide industry with effective information.

In this early period, the Department of Aeronautical Engineering at Minnesota, just branching out of mechanical engineering, was catering more to industry's desire for employees than it was for any ambition for world-class research information. Akerman designed the curriculum for entry-level engineers less rigorously trained in the more complex engineering science methods put to use in the Guggenheim institutes and the NACA's research facilities. This is not to say that the Minnesota and other non-Guggenheim alumni who went on to be employed as industry engineers simply "crunched numbers" or never produced creative work.

Walter Vincenti describes how different kinds of creative work can be done by engineers, in his discussion of the development of flush riveting. The development of

flush riveting methods from the 1930s to the early 1950s relied upon unique approaches to production that dealt with the special aerodynamic problems of thin sheet thickness, strength and fatigue, and aerodynamic smoothness.¹² But industry of this era spent little of its own time or money developing the more mathematically complex theories that by the 1950s would come dominate the process of design. Industry was content with the NACA and the Guggenheim labs filling the research role. Further, airplane designers were still performing well by using knowledge gained from experience.

In addition, the University of Minnesota aeronautical engineering department never established relations with large aviation companies like those the Guggenheim labs attracted. Except for some homebuilt aircraft companies, such as Pietenpol, all aircraft production companies in the state of Minnesota folded by 1931 because of financial failure or their inability to built a working aircraft.¹³ This left regional, independent inventors to ask the University of Minnesota laboratories for help and consultation in aircraft design. One of these independent inventors was J. W. Johnson from La Crosse, Wisconsin. He designed an airfoil with a small rotating rod positioned on the top of the airfoil extending the length of the wing. The aeronautical engineering department invited Johnson to test his model in its wind tunnels.¹⁴ Unfortunately, Minnesota's faculty and students enjoyed only such limited relations with industry as private consultants and summer interns. Dean Leland's hope from 1928 that the University of Minnesota would

¹² Vincenti, pp. 170-199.

¹³ Noel E. Allard and Gerald N. Sandvick, *Minnesota Aviation History: 1857-1945* (Chaska, MN: Mahb Publishing, Inc., 1993), pp. 108-116.

¹⁴ Akerman to J. W. Johnson, 10 January 1935, Correspondence file J, box 2, Akerman Papers, UA.

grow to serve as the center of aeronautical engineering for the Northwest never came to fruition.

The Guggenheim schools led in engineering science education because those schools provided the detailed research for industry. Without this intimacy with the aviation industry, the University of Minnesota aeronautical engineering department's role as a research provider floundered. Minnesota's primary mission to provide industry with aeronautical engineers, who would then turned to Guggenheim and NACA labs for research, remained. The A.E. curriculum's limited growth in the realm of engineering science reflected this circumstance.

The non-Guggenheim schools represented the next step in the incorporation of engineering science into aeronautical engineering education. Aeronautical engineering departments typically began as options or branches within mechanical engineering. The University of Minnesota fit this category well. But Minnesota's aeronautical engineering program broke away from mechanical engineering remarkably early. Usually these programs remained that way for years. Iowa State University and Purdue University both established aeronautical engineering options in mechanical engineering, but neither program obtained independence until the 1940s. Both serve as illuminating case studies to compare with Minnesota.

Iowa State first offered courses in aeronautical engineering to graduate students in mechanical engineering in 1929, then to undergraduates in 1930. William Beven, a graduate and former instructor of mechanical engineering at Purdue University, taught these early courses. Beven's courses followed an approach to aeronautical engineering similar to Akerman's courses: they introduced the fundamentals of aircraft, but ignored

theoretical analysis of aircraft dynamics. Topics included elementary laws of aerodynamics, general theories of design, and the study of stability and control surfaces.¹⁵

Considering the year, the status of the program as an option in mechanical engineering, and the lack of a major endowment, the circumstances of the program at Iowa State typified what was normally the case at non-Guggenheim schools. Until 1943 when aeronautical engineering broke away to form an independent department, few changes occurred in the curriculum. But, in fact, those changes that did occur suggested a positive attitude towards engineering science, or at least a broader perspective on the importance of advanced engineering methodology by the administration and faculty from a very early date.

The description for the Division of Engineering found in the 1929-1930 announcements underscored the importance of science to engineering education while emphasizing core skills such as English. It read: “The fundamental studies come mainly in the freshman and sophomore years, and include Mathematics, Chemistry, Physics, English, and Economic Science. Their importance to the engineer can hardly be exaggerated, for they make the foundation for the whole superstructure of his technical

¹⁵ All course information for Iowa State University was obtained from *Iowa State College of Agriculture and Mechanic Arts Official Publication: Announcements* for the years between 1922 and 1938, *The Iowa State College Bulletin: Announcements* for 1938 to 1959, and *Iowa State University of Science and Technology General Catalog: Announcements* for 1959 to 1963. These publications will be cited hereafter as *ISC Announcements*, *ISC Bulletin*, and *ISU Catalog*, respectively. Information about the first aeronautics courses taught at Iowa State was obtained from *ISC Announcements*, vol. XXVII, no. 41, pp. 232-236.

education.”¹⁶ The faculty backed up their claim by providing a strong foundation in the sciences with appropriate coursework.

In the 1932-1933 school year, the faculty required three courses on statics, materials, and dynamics, which were offered in the Department of Theoretical and Applied Mechanics as prerequisites for the aeronautics courses.¹⁷ The courses in mechanics were “intermediate between those in physics and mathematics on the one hand and the professional and design courses of the several engineering curricula on the others.” It was the function of these courses “to familiarize students with physical laws and to supply rigorous training in the application of these laws to problems in the fields of engineering materials and hydraulics.”¹⁸

Admittedly, these courses qualified as applied science courses more than as engineering science courses. But one must remember that aeronautical engineering science was (and still is) similar in appearance to theoretical physics, but with specialized technological methods and purposes. Therefore, in introducing an engineer to the physical laws and theories and their relevance to practical design, these courses taught students about engineering science.

The first course taught at Iowa State that may be called an aeronautical engineering science course appeared in the university’s 1930-1931 bulletin. The Department of Mathematics introduced a graduate level course titled “Hydrodynamics and Mathemat-

¹⁶ *Ibid.*, p. 77.

¹⁷ *ISC Announcements*, vol. XXX, no. 39, pp. 230, 233-234, 252.

¹⁸ *Ibid.*, p. 251.

ical Theory of Airfoils.”¹⁹ By 1937, the instructor, Dr. Ernest Anderson, renamed the course “Theoretical Aerodynamics.”²⁰ Although the mechanical engineering faculty did not require their aeronautics option students to take this course, a number of them likely enrolled in it as an elective since it catered most to their interests and discipline.

Ultimately, Professor Anderson’s calling came from aeronautical engineering, as he officially moved his association to the aeronautical engineering department in 1953 and took over as department head in 1956.²¹

Not all of the new courses added to the aeronautical engineering curriculum fulfilled the engineering science interests of the discipline like Theoretical Aerodynamics did. But the new courses often kept pace with the developments in the field. One course on aircraft propellers and airships dropped the airship component in 1933.²² In 1935, Professor Beven and Professor Neil Bailey introduced a graduate level course on the circulation and vortex theories of airfoils, airfoil characteristics, and propeller theory.²³ The airplane propellers course was discontinued and a supersonic flight course appeared for the first time in the 1948-9 catalogue.²⁴ The next year, the faculty upgraded this course to a three-quarter series on shock waves and compressible flow theory.²⁵ By 1950,

¹⁹ *ISC Announcements*, vol. XXVIII, no. 41, p. 235.

²⁰ *ISC Announcements*, vol. XXXV, no. 41, p. 296.

²¹ *ISC Bulletin*, vol. LI, no. 33, p. 162; *ISC Bulletin*, vol. LIV, no. 32, p. 117.

²² *ISC Announcements*, vol. XXXI, no. 39, p. 243.

²³ *ISC Announcements*, vol. XXXIII, no. 38, p. 290.

²⁴ *ISC Bulletin*, vol. XLVI, no. 45, p. 109.

²⁵ *ISC Bulletin*, vol. XLVII, no. 51, p. 157.

Iowa State aeronautical engineers were studying turbo-jets, turbo-props, ramjets, pulse jets and rocket propulsion systems for aircraft. The faculty added a second quarter of this reactive propulsions course in 1957 and a third quarter in 1961.²⁶ The 1961-1962 school year also saw the introduction of two courses on missile and space theory.²⁷ The regularity with which courses were evaluated at Iowa State also indicates the presence of a faculty acting with their department's competitiveness in mind.

Two weeks before the bombing of Pearl Harbor on December 7, 1941, the State of Iowa had approved the curriculum for an independent department of aeronautical engineering. In the fall of 1943, Wilbur C. Nelson took over the leadership of the new aeronautical engineering department. During World War II, Iowa State's aeronautical engineering department participated in the U. S. Navy's V-7 and V-12 training programs, which provided flight training and engineering coursework to naval officers. For schools without large research facilities during the war, federal military training programs served as the school's primary means of attracting government acknowledgement and funding. When the Cold War started heating up in the 1950s, positive impressions left on the military and U. S. government by the universities through wartime training turned into federal research grants.

Iowa State's attentiveness to then-current areas of study and its timely inclusion of more theoretical, mathematics, and science courses was likely associated with the department's regularly changing faculty. A significant percentage of the aeronautical engineering faculty advanced through the ranks from undergraduate and graduate student

²⁶ *ISC Bulletin*, vol. LVI, no. 15, p. 113; *ISU Catalog*, vol. LX, no. 16, p. 210.

²⁷ *Ibid*, pp. 210-211.

to instructor, and occasionally to professor. Along with professional advancement, one finds more mature interests in the latest technological advances. Between 1943 and 1963, no department head remained in the position longer than seven years (Dr. Ernest Anderson took the position in 1956 and still held the position in 1963.)²⁸

The backgrounds of these department heads provide insights into the nature of their administrative and intellectual leadership. Professor Wilbur Nelson (1943-1947) had studied aeronautical engineering at Michigan. Professor Carl Sanford (1947-1953) held a bachelor's degree from Oregon State University and a master's degree from North Carolina State College in mechanical engineering. Dr. Glenn Murphy (1953-1957) had pursued an education at the University of Colorado (BS), University of Illinois (MS), and Iowa State (Ph.D.) in civil engineering. Dr. Murphy also held a joint appointment in the theoretical and applied mechanics department at Iowa State during this time. Finally, Dr. Ernest Anderson had earned his doctorate in civil engineering from Iowa State, but came to aeronautical engineering from the mathematics department. The heads of the aeronautical engineering department pursued a variety of technical interests, some involving higher mathematics and advanced theory. This engendered broader perspectives into the faculty and students consistent with the development of engineering science.

Unlike Minnesota, Iowa State did not build its first wind tunnel until 1941. Consequently, the students' education in laboratory research methods was strictly limited. To maintain the highest level of competence and educational standards, the faculty focused on their strengths in the lecture room. Iowa State's development of a science-based curriculum depended on the staff and their willingness to grow.

Purdue University's School of Aeronautics served as a second case study. Its history follows a very similar path to that of Iowa State's aeronautical engineering

²⁸ All faculty information was obtained from the course bulletins for these years.

program. The mechanical engineering department first offered four courses in aeronautical engineering as a senior option in 1921. The department name changed to the School of Mechanical and Aeronautical Engineering in 1942. Aeronautical engineering had its own curriculum at this time, but the head of mechanical engineering, Professor Harry L. Solberg, still controlled the leadership of the department. The Board of Trustees finally approved the formation of a separate School of Aeronautics for the fall of 1945 and named Professor Elmer Bruhn, a professor of structures at Purdue since 1941, as the acting department head.²⁹

During World War II, Purdue participated in the navy V-12 engineering program and the Curtiss-Wright Cadette program. Sponsored by Curtiss Aircraft Company, this program hired young women to study basic aeronautical engineering at one of the seven selected schools before filling positions at Curtiss Aircraft left empty by the male engineers who went to war. Minnesota also received training contracts for the V-12 and Curtiss-Wright Cadette programs, in addition to the V-7 program. John Akerman noted that only ten schools in the United States and Canada total were granting degrees in aeronautical engineering in 1939.³⁰ A survey conducted by the American Council on Education for the Civil Aeronautics Administration in 1944 found that still only eighteen

²⁹ All historical information about Purdue University's history in aeronautics was obtained from A. F. Grandt, Jr., W. A. Gustafson, and L. T. Cargnino, *One Small Step: The History of Aerospace Engineering at Purdue University* (West Lafayette, IN: School of Aeronautics and Astronautics, 1995). I wish to thank Skip Grandt for his efforts in providing me with further curriculum information.

³⁰ Akerman to President Guy S. Ford, 2 May 1940, Dept of Aeronautics, 1940-1945 file, box 35, President's Office Papers, 1911-1945, UA.

schools in the United States offered courses towards a bachelor's degree.³¹ Consequently, the chances of a school with an aeronautical engineering curriculum getting a wartime training contract were good.

One reason why all three of these non-Guggenheim schools earned training contracts instead of research contracts was their lack of research facilities. Purdue was only moderately equipped for research at the start of the war. In 1937, the university owned only one small continuous flow wind tunnel and a collection of small engine parts.³² In 1934, however, Purdue had constructed the first university-owned airport in the nation and installed some structural testing equipment before the end of World War II. While limited resources made arrangements for traditional laboratory courses a real juggling act, the airport offered a new and different opportunity: for flight testing. This course allowed students to compare the results of theoretical calculations and actual flight performance. It also gave students their first real exposure to design. Because of the complexities of representing a body operating in air, theory could provide only ideal solutions. In studying an actual situation against the ideal, students and experienced engineers began to understand more of the complexities. In this way, Purdue made remarkably good use of its limited resources.

Compared to Minnesota, where aeronautical engineering separated early from mechanical engineering, it took much longer for "aero" to become independent at Purdue. Perhaps Purdue's faculty and administration did not understand aeronautical engineering as so complex and unique a discipline. However, in most other respects its curriculum

³¹ Grandt, Gustafson, and Cargino, p. 47.

³² *Ibid.*, p. 12.

was well ahead of Minnesota's. In the summer of 1942, Purdue added Differential Equations to the list of required courses, whereas it took until the 1946-1949 bulletin for this course to emerge at Minnesota.³³ Purdue offered a course in gas turbines and jet propulsion in 1947, two years before Minnesota.³⁴

In 1938, three members of the Purdue aeronautics faculty submitted a proposal for an aeronautical engineering laboratory. Its authors wrote: "In our opinion fundamental theory should continue as a basic point of emphasis," an emphasis that suggested researchers had more in mind than developmental testing or cut-and-try experimentation.³⁵ The proposal for a new aeronautics laboratory failed at that time, but the desire to emphasize fundamentals persisted. In 1945, when the department officially separated from mechanical engineering, the faculty designed a new curriculum knowing that most students would finish their bachelor's degree and seek employment in industry. However, they included an option that would encourage the top ten to twenty percent of the junior class to enroll in additional mathematics courses, advanced fluid flow and elasticity courses, and other advanced theoretical courses. This option prepared students for both research positions at NACA facilities as well as graduate studies.³⁶ Minnesota offered no advanced training like this for undergraduates.

While the postwar curriculum previewed the significance of engineering science, a new track offered in 1954 did more to stimulate that trend at Purdue. In 1950, Dr.

³³ *Ibid.*, p. 25; *IT Bulletin*, vol. XLIX, no. 46, p. 19.

³⁴ Grandt, Gustafson, and Cargnino, p. 73; *IT Bulletin*, vol. LII, no. 23, p. 21.

³⁵ Grandt, Gustafson, and Cargnino, p. 22.

³⁶ *Ibid.*, pp. 61-2.

Milton Clauser took over as head of the aeronautics department. He quickly proposed a new curriculum with more theoretical, and fewer laboratory, courses. Clauser believed the 1950 curriculum “was not rigorous enough and that it was slanted toward a terminal degree program for those going directly into industry.”³⁷ The irony of his statement, which other members of the faculty quickly identified, was that Clauser came to Purdue from a position as head of mechanical design at Douglas Aircraft. Why would an industry man insist on more theoretical work in the curriculum? His assertion suggested that by 1950 engineers in industry had begun to perform their own theoretical studies instead of relying so much on outside sources for research. Clauser understood how important it was becoming for bachelor level design engineers in industry to feel comfortable working in a laboratory in which engineering science flourished.

The new Theoretical Aeronautics option premiered in the fall of 1954. As Clauser desired, this option required eight semester courses in mathematics, including Vector Analysis and Numerical Methods in Analysis. Another significant feature of this curriculum was the requirement of four Engineering Mechanics courses. Similar to the Department of Theoretical and Applied Mechanics at Iowa State, the Division of Engineering Sciences in the School of Civil Engineering aimed “to provide a scientific basis to emerging engineering disciplines at both the undergraduate and graduate levels, and to enable graduates of the program to be able to interpret and to apply basic science to engineering.”³⁸ Originally this option was restricted to all but the top students.

³⁷ Ibid., p. 121.

³⁸ Ibid., p. 145. The Division of Engineering Mechanics changed its name to the Division of Engineering Sciences in 1954. The course designation (EM) for 1954 does not reflect this change yet.

However, in 1960, the School of Aeronautics officially merged with the Division of Engineering Sciences. All aeronautical engineers who graduated from Purdue from that time on received an education emphasizing mathematics and engineering science.

Purdue's selection of faculty members also reflected this focus on theory and research. When the trustees voted to make aeronautical engineering a separate department, the faculty produced a list of desirable qualities for applicants. This list included possession of a degree in aeronautical engineering, several years of experience in industry or research, a Ph.D. for full professor status, and "a record of published papers".³⁹ The faculty itself did not change much over the department's first two decades, but it was quite competent in aeronautical engineering sciences. The department head only changed hands twice from 1945 to 1963. The second and third department heads, Milton Clauser (1950-1955) and Harold DeGroff (1955-1963), both completed their doctorates at Caltech. A number of other professors held Ph.Ds. These included Merrill Shanks, who held dual appointments in Aeronautics and Mathematics and spent time as a NACA engineer, and Hyman Serbin, who held a Ph.D. in Mathematics, Physics, and Mechanics from the University of Pittsburgh. It also included Hsu Lo, who graduated from Michigan before being hired by the NACA, and Bruce Reese, a Purdue Ph.D. who served as the school's director of the Jet Propulsion Center.⁴⁰

Like Iowa State, Purdue took advantage of the limited resources available. Purdue could not offer the most attractive salaries, housing, or opportunities for outside consulting work to its faculty. The research facilities were small but growing. The

³⁹ Ibid., p. 62.

⁴⁰ Ibid., pp. 65, 66, and 68.

School of Aeronautics committed itself to that goal. The curricula at both schools, Iowa State and Purdue, demonstrated strong commitments to providing excellent education for engineering students. The reputation and prestige resulting from this commitment helped to attract top-notch applicants to the faculty and to the student body.

What do these examples tell us about what might be called the “necessary and sufficient conditions” for the development of a culture of engineering science in U.S. aeronautical engineering education? Without question, the history of the Guggenheim institutes served as a benchmark for how theoretical and practical engineering co-existed constructively within an individual school. Their talented faculty possessed backgrounds and skills vital to the ways and means of engineering science—and, not coincidentally, their research facilities were some of the most advanced laboratories of their time anywhere in the world. The Guggenheim institutes received extraordinary financial support to hire the best faculty members and to build premier facilities that could not be afforded at non-Guggenheim schools. Much of the equipment that Minnesota, Iowa State, and Purdue came to have for research and teaching purposes, they obtained from industry’s scrap piles and from war surplus. The aeronautical engineering departments at the Guggenheim schools did not have to develop their strength in engineering science at some point *after* their establishment; they built it in from the start. Daniel Guggenheim expected the schools benefiting from his family’s generosity to build programs capable of producing engineers with a strong enough command of aeronautics to spread their knowledge to other schools and to industry at large. And in that goal, the Guggenheim schools largely succeeded.

But if a world-class faculty and state-of-the-art research facilities were an absolute requirement for the development of a culture of engineering science, no other aeronautical departments in the United States other than those with Guggenheim status could have developed aeronautical engineering programs strong in engineering science. This was not the case.

In this chapter, we have looked at two schools, Iowa State and Purdue, which developed aeronautical engineering programs strong in engineering science without the benefit of grand endowments or world-class research facilities. Therefore, it is hard to argue that the factors promoting engineering science in the Guggenheim schools were the only ones at work in American aeronautical engineering education.

Other triggering mechanisms for engineering science came to exist at the non-Guggenheim schools. At both Iowa State and Purdue, faculty established a foundation of engineering science and science-based courses. By the 1950s, both schools required undergraduate aeronautical engineering students to take courses in Theoretical and Applied Mechanics and Engineering Sciences, as well as advanced mathematics. Both schools achieved this state of development and understanding about the nature of aeronautical engineering education without the advantage of extensive research facilities like GALCIT or the Guggenheim lab at Michigan, or even Rosemount.

The founders of all three of these labs (as well as the other Guggenheim-supported labs) intended them to support industry through research. While Minnesota's industry base was comparatively small to those calling on the Guggenheim labs for help, the Minnesota faculty and administration hoped that Rosemount with the aeronautical engineering department would fuel growth. Even the small industrial presence in

Minnesota may have contributed to the relatively early separation of aeronautical engineering from mechanical engineering. Iowa State, located in tiny Ames, and Purdue in West Lafayette, Indiana, possessed no local aviation industry. Without major federal funding or private grants, these schools and others like them found the development of large laboratory facilities a daunting challenge. Minnesota took advantage of the War Assets Association's distribution of war surplus in getting the Gopher Ordnance Works and its existing equipment for their lab site. Although any school could apply for war surplus, facilities like the Gopher Works were not plentiful or easily accessible to universities with aeronautical engineering programs.

Unquestionably, the Rosemount Aeronautical Laboratory made much of Minnesota's early education in engineering science possible. Rosemount attracted some highly qualified professors to the university, who taught their students the engineering sciences important to aeronautics. After Akerman's removal as head of the department, the faculty quickly brought more engineering science into the curriculum. So for Minnesota, Rosemount was a vital force promoting a culture of engineering science. But it was not the only force. On its own, it was hardly enough. What was also required was the right kind of faculty, under effective departmental leadership with a vision.

The two non-Guggenheim examples discussed here show how two faculties, otherwise deficient in resources, effectively integrated engineering science into their curricula. The process involved progressive thinking about the state of the discipline and subsequent changes in approaches to teaching engineering from "heavy in practice" to "weighted in theory." The department heads at Iowa State and Purdue understood those requirements; Spilhaus, Chang, and Hermann understood them; Akerman did not.

Minnesota showed little outward change until 1959, while Iowa State and Purdue, younger programs, displayed the new philosophy by the early 1950s.

In a recent paper on how college textbooks contributed to the growth of engineering science in U.S. aeronautical engineering education, engineer *cum* historian Mark Levinson has argued that new engineering textbooks published in the late 1950s and early 1960s “became the tools for both the more progressive older engineering faculty and the ‘young Turks’ to remake American engineering education into one largely based on engineering science.”⁴¹ Levinson noted that the earliest of these texts that were more oriented towards scientific and mathematical methods were written by Caltech professors in 1949 and 1950, but that few of these seminal texts got into the hands of engineering students until later.

Based on the conclusions of this thesis, which has found some substantive moves in the direction of engineering science at non-Guggenheim schools prior to 1960, Levinson’s argument seems too limiting. In his view, engineering science played no significant role in aeronautical engineering prior to the “textbook revolution” he has identified, a conclusion the research of this thesis belies.⁴² The testimony of Dick Deleo of Minnesota’s RAL supports this thesis’s contention. He has noted that Dr. Hermann’s students never really needed the required textbook for Hermann’s course on supersonic inlet diffusers. According to Deleo, Hermann presented the material with such detail and clarity that the text offered little further information.

⁴¹ Levinson, p. 12.

⁴² Levinson is a trained mechanical engineer who was educated in the 1950s. Levinson, telephone conversation with author, 20 August 1999.

Levinson's textbook argument may relate more to newer departments whose development trailed behind the Guggenheim and older non-Guggenheim schools considered here. One might also suggest that it takes faculty members already open to engineering science to adopt the types of revolutionary textbooks discussed by Levinson.

It was not one single factor, like a textbook revolution, that engendered engineering science in aeronautical engineering programs in the United States. As seen in this thesis, it was a matrix of trends and factors, many of them local and particular to an institutional setting and the personalities within it, that determined how quickly and how successfully a culture of engineering science came to distinguish an aeronautical engineering education program in America.

Conclusion: Engineering Science in the Larger Picture

Aircraft, from gliders to Boeing 777s, from helicopters to military fighters, are among the most complex technologies in existence today. From the Greek myth of Icarus forward through time, human flight has been an aspiration of many. But despite centuries of effort, it was still not until December 1903 that the Wright brothers achieved that dream. The complexity of each aircraft system and the successful combination of all its individual systems make the process of designing and building an aircraft that has even a chance of getting off the ground a difficult challenge. Unquestionably, designing and building an aircraft without a developed understanding of theory is possible. But it is highly risky and becomes riskier the more complex the design and performance requirements become.

The fundamental questions raised by this thesis have been: What forces first defined the character of the aeronautical engineering program at the University of Minnesota? Why was not a culture of engineering science a defining characteristic of that program from the start? What forces retarded it? And what trends and forces eventually stimulated its growth? Finally, why was it important for such a culture to develop anyway? Could not Minnesota have continued to contribute to the education of aeronautical engineers in America without moving in this direction? The answer to this final, and ultimate, question lies in appreciating why the culture of engineering science has proved so vitally important to advanced work in aeronautical engineering.

Engineering science has proven especially significant to the progress of aeronautical engineering in two ways—one involving cost, and the other, a desire to push the envelope. For decades now, the complexity of aircraft has made development by purely empirical methods prohibitive. Recall that it took the Wrights three years and four airplanes to achieve flight, and another six years to improve the design before the military purchased a single machine. Homebuilt airplanes, like the Minnesota-based Pietenpol airplanes, still exist today, and kits are still being sold to private pilots interested in owning their own plane. These little aircraft serve as fine examples of how simple methods of design and construction that require only limited theoretical knowledge can be successful. But nothing can be farther from the case when it comes to the large commercial and military aircraft that have been dominating the airways since at least the 1930s. When one considers the performance expectations put on the design and manufacturing of these planes, then it is easy to understand how engineers *must* benefit from the adoption of theoretical methods—or rather, experimental methods deeply informed by theory. Lesser methods of trial and error or cut and try simply would not work.

For decades, aircraft have been pushed to fly faster, farther, and higher. Aerodynamically, structurally, and propulsion-wise, the challenges have been monumental. Propellers could not provide enough thrust to accelerate airplane to supersonic speeds. Well before an aircraft reached Mach 1, shock waves formed on propeller blades, reducing the engine efficiency. Flight at supersonic speeds required a host of new technologies, not just a jet engine, and with them, formidable new knowledge. Prior to the turbojet and supersonic design revolutions, engineers basically

reached the limits of the paradigm established by Cayley. In his book on the turbojet revolution, historian Edward Constant II borrowed the term “presumptive anomaly” from Thomas S. Kuhn to describe the predicament aeronautical engineers faced in the 1930s. For Constant (and Kuhn), a presumptive anomaly occurred when “scientific insight or assumptions derived from science indicate either that under some future conditions the conventional system will fail (or function badly) or that a radically different paradigm will do a much better job or will do something entirely novel.”¹ In the case of propeller-driven aircraft, classical aerodynamics prevented supersonic flight. Engineers had to find a new paradigm if they ever wanted planes to fly at supersonic velocities. The invention of jet engines served as the revolutionary new concept from which a new paradigm of aeronautical engineering was born, one in which engineering science was more essential than ever.

Even if a technology could be successfully designed and constructed with a limited amount of theory and scientific knowledge, further technological development would be extremely limited without it. Constant held that ‘all technology is intrinsically imperfect.’ Every technical process and device “can presumably become better, faster, safer, and more efficient.”² But unless engineers understand scientifically and theoretically why that process is not 100 percent efficient, then their efforts to mechanically improve the performance are greatly hampered. Engineering science helps to clarify what is happening in the physical world, even if it cannot perfectly represent it.

¹ Edward W. Constant II, “A Model for Technological Change Applied to the Turbojet Revolution,” *Technology and Culture*, vol. 14 (1973), 555.

² *Ibid.*, 554.

Walter Vincenti has elaborated this point: “Functional failure, presumptive anomaly, and the need to reduce uncertainty in design thus appear as three distinct, if often concurrent, driving forces (or sources) for the growth of engineering knowledge.”³ Further, Vincenti has demonstrated how the method of “parameter variation,” which engineers have used very successfully in any number of significant experimental programs, may produce the data needed “*to bypass the absence of a useful quantitative theory*—that is, to get on with the engineering job when no accurate or convenient theoretical knowledge is available.”⁴ Those in tune with engineering science may at times employ parameter variation in another way, by thoughtfully using theory to pinpoint the parameters that are most important to vary. According to Vincenti’s line of thinking, engineering science has provided the basis for most advanced aeronautical engineering for many decades now. Lesser empirical methods have proved secondary.

As Vincenti understood, trying to understand why engineering science has been so crucial to aeronautical engineering raises epistemological questions. What does it mean to know how a plane flies? Any high school physics student should know what makes a plane fly: a plane will fly if it can create enough lift and thrust to overcome its weight and drag. But knowing how a plane flies involves more complex variables. As discussed previously, the very thin airfoils used by the early airplane builders proved less effective than thick airfoils, particularly at higher Reynolds numbers.⁵ Engineers who

³ Walter Vincenti, *What Engineers Know and How They Know It: Analytical Studies from Aeronautical History*, (Baltimore: The Johns Hopkins University Press, 1990), 47.

⁴ *Ibid.*, 162.

⁵ Reynolds number is a dimensionless number representing the ratio of inertial forces to viscous forces in a flow. The number is calculated from the density, velocity, and the

understood the theoretical concepts of aerodynamics “knew” how both an airplane with thick wings and one with thin wings flew. An experienced airplane builder, in his way, came to learn this, but from a different knowledge arena not so in tune with theory.

In the Seventeenth Wright Brothers Lecture before the Institute of Aeronautical Sciences in 1954, Glenn Martin, an early aircraft builder, spoke about the contributions to aerodynamics made by Germany’s Ludwig Prandtl and by England’s Frederick Lanchester. Martin explained:

Succeeding papers by Prandtl and Lanchester between 1907 and 1919 developed the theory of the finite wing, the thing we were all interested in, and explained scientifically what we all had known from experience--that the best lift-drag characteristics are obtained from a high aspect ratio wing. The Lanchester-Prandtl theory, as some call it, provided the first rational basis for the aerodynamic design of wings and also gave loading information needed for structural design. It also clarified the aerodynamics of biplanes and explained the existence of interference between the two wings, which we had begun to suspect and which led, eventually, to the monoplane. One of the important results of this theory was the fact that it broke wing design down into two separate parts: the effect of air foil section and the separate effect of wing geometry.⁶

In his lecture Martin identified key concepts in aircraft design that engineering science either clarified or provided with new insights. Even Martin as a practical airplane builder appreciated engineering science for the lessons it taught about how planes fly.

University of Maryland aerospace engineering professor and aeronautics historian John Anderson has offered another telling example of the significance of engineering science to design, one based on James R. Hansen’s larger study of research activities at

viscosity coefficient of the fluid flow and the chord length of the airfoil in the test stream. The number is as a scaling factor from models to full-size aircraft.

⁶ Glenn L. Martin, “The First Half-Century of Flight in America,” *Journal of the Aeronautical Sciences*, vol. 21, no. 2 (New York: Institute of the Aeronautical Sciences, Inc., 1954), p. 78.

NACA Langley. Following Hansen's version, Anderson relates how in 1935, in an effort to design a laminar-flow airfoil, aeronautical engineer Eastman Jacobs proposed using knowledge of pressure gradients across an for purposes of design.⁷ Jacobs's more theoretically oriented colleague at Langley, Norwegian Dr. Theodore Theodorsen, contrived an airfoil theory that could be used to determine the pressure gradient. By reversing the theory, Jacobs calculated the outline of an airfoil with a favorable pressure gradient (that is, decreasing) over a longer length of the airfoil. This marked the first time an engineer designed an airfoil to meet data point expectations, instead of meeting performance desires.

The irony of Jacobs's application of engineering science to design came when the airfoils were put to actual use. Because of the difficulty in constructing aircraft skin as smooth as a wind tunnel model, the airfoils in practice failed miserably at low speeds; the flow was turbulent over much of the airfoil. However, with the introduction of high-speed aircraft in the 1940s and 1950s, Jacobs's laminar-flow airfoils proved quite successful.⁸ In terms of this thesis, this case study shows how engineers can use their

⁷ Laminar flow means the flow is smooth and steady over the entire surface of the airfoil, not turbulent. At no point, does the flow "separate" from the airfoil; it stays attached to the surface. Separation is the formation of a circulating region of fluid, a small eddy, sitting on the surface of the airfoil. These areas of circulation form near the trailing edge of the airfoil. As the area of separation grows larger, it affects more of the trailing surface of the top of the airfoil, destroying lift capacities.

The pressure gradient is the difference between the pressure measures at the surface of the airfoil and the pressure of the undisturbed flow. If this gradient is negative, then the flow is attached to the airfoil. If it is positive, the flow has separated. Jacobs proposed to design an airfoil by first selecting the desired pressure gradient across the wing. Theoretical calculations would determine the shape of the airfoil, which should maintain laminar flow.

⁸ An abbreviated account of Jacobs's experiments can be found in Anderson, pp. 348-52. The full story is in Hansen, *Engineer in Charge: A History of the Langley Aeronautical Laboratory, 1917-1958* (Washington, DC: NASA SP-4305, 1985).

knowledge of engineering science to improve how planes fly, but also that a gap in that knowledge may lead to failure.

Furthermore, new technologies sometimes challenge what engineers consider to be proven knowledge. James Hansen has considered how supersonic aircraft with their sleek delta wing configuration and the “flying wing” design of the B-2 Bomber completely negate the principles of airplane design inaugurated by Sir George Cayley. Cayley wrote in the early 1800s that an airplane needed engines, control surfaces, and separate wings and fuselage, and designers adhered to that paradigm for the next 150 years. But the supersonic design revolution of post-World War II changed things fundamentally. Hansen recalls the words of aerodynamicist, Dr. Dietrich Küchemann, one of the fathers of the supersonic airliner the Concorde, who wrote that it was “a dangerous fallacy to pretend that our knowledge of the design of aircraft is nearing its peak and reaching the ‘ultimate,’ that nearly everything worth knowing is already known, and that there is not much more to come.”⁹ In this sense, even engineering science cannot answer all the questions.

In concluding this thesis one should return to how the processes of change at a university reflect the growing significance of engineering science in aeronautical engineering. At the University of Minnesota, visions of change and new research facilities eventually attracted professors highly competent and open to the development of engineering science. Rosemount Aeronautical Laboratory also played a vital role. It gave faculty members such as Chang and Hermann the opportunity to pursue their

⁹ Quoted in James R. Hansen, “Aviation History in the Wider View,” *Technology and Culture*, vol. 30, no. 4, p. 653.

interests in aeronautical engineering science as well as the nurturing environment to pass their knowledge and methods on to students. But the presence of a research laboratory could alone build a strong foundation for engineering science education. Students had to understand mathematics, science, and theoretical concepts as well as analytical research methods.

John Akerman understood the importance of research, but he lacked the background, experience, personality, and administrative character to foster a culture of engineering science at Minnesota. As sociologist Joseph Ben-David, author of *The Scientist's Role in Society: A Comparative Study*, has noted, scientists in the established disciplines have had “many misgivings about the danger of blurring the borderlines between disciplinary science and problem-oriented research which often lacked theoretical significance.”¹⁰ Something like this seems to apply to engineer Akerman. When an engineer is personally not capable of working from theory, or synergizing experiment with theory, his or her program of teaching and research of a subject as complex as aeronautical engineering will be seriously flawed. As related previously in a discussion of wind tunnel testing, it was emphasized that research methods in wind tunnel range from empirical to theoretical, and that the most fruitful approach does not fall between the two but combines both. Akerman’s background, his performance at Minnesota, and his behavior all suggest that his talents in research fell between the two, and in fact were more empirical than theoretical. He rarely combined the two. Dick Deleo remembers, “A lot of [students] resented [Akerman] because he couldn’t guide them to a

¹⁰ Joseph Ben-David, *The Scientist's Role in Society: A Comparative Study*, Foundations of Modern Sociology Series (Englewood Cliffs, NJ: Prentice-Hall, Inc., 1971), 145.

master's degree or a Ph.D.”¹¹ Unquestionably by the 1950s, other professors in the department surpassed Akerman in his abilities to teach the most current engineering knowledge. His difficulties in the department stemmed from his lack of basis in the culture of engineering science as much as it did from his conflicts with Dean Spilhaus.

The shift in aeronautical engineering education towards engineering science occurred no doubt in part due to the introduction of a new generation of engineering professors. Unquestionably, the new younger professors at Minnesota, Iowa State, and Purdue benefited from broader trends moving in this direction, many of them sparked by the turbojet and supersonic design revolutions. They enjoyed the advantage of more engineering science in their own educations than Minnesota's faculty had under Akerman. But one can find examples from across the country of professors close in age to Akerman (born in 1897) who embraced engineering science. These men included Theodore von Kármán (1881), Jerome Hunsaker (1886), Max Munk (1890), Rudolf Hermann (1904), and Eastman Jacobs (1904). Von Kármán, Munk, and Hermann all studied aeronautics in Germany. Even Akerman admitted his admiration for the training students received in Germany. He wrote in his 1957 reaction to Spilhaus's proposal, that “the independent chairs of aeronautics in Aachen and Goetingen [sic] were the Meccas of the aeronautical world.” He admitted that they are “still leading schools of aeronautical sciences and, as after World War I, are still sources for outstanding scientists in aeronautics.”¹² Although Hunsaker did not study in Germany, he possessed a natural affinity for engineering science and toured German facilities in the 1910s. And these

¹¹ Deleo, interview.

¹² Akerman, “Counterproposal”, pp. 3-4.

noteworthy individuals were not the only contemporaries of Akerman who embodied the advantages of engineering science; James Hansen in his study of NACA Langley shows how an entire laboratory from the mid-1920s on came to be characterized by an engineering science approach to aerodynamic research. Thus, the development of engineering science cannot be explained simply by a generational shift accompanying the turbojet and supersonic design revolutions. Somehow Akerman just did not have the background and mindset necessary for immersion in engineering science culture. The fact that he earned only a bachelor's degree no doubt was a factor, but the same was true for many others (such as Eastman Jacobs), who did engage engineering science in their research programs. Obviously, there were many personal factors at work in both scenarios. Perhaps it will take careful biographical analysis to sort most of them out.

External developments obviously played a role in the story as well. Because of World War II, the Korean War, and the Cold War, the United States found itself in a near-constant state of war or readiness from the late 1930s on. In an age of "Big Science" and "Big Technology," the Federal government and U.S. military needed to expand laboratory facilities greatly. The Meade report following World War II, which Akerman had cited in his proposal for acquiring the Gopher Ordnance Works, encouraged the growth of aeronautical R&D facilities nation-wide. New installations such as the AEDC in Tullahoma, Tennessee were built from scratch. The NACA received major funding for new wind tunnels. And existing laboratories, such as GALCIT and RAL, expanded under additional government sponsorship. Expanding its research agenda, the U.S. military-industrial complex became more and more enamored of engi-

neering science, which was proving increasingly important in the design of high-performance aircraft and eventually spacecraft as well.

By looking at the funding sources for the aeronautical engineering research projects at Minnesota, one sees how Federal government became more and more vested in work done at RAL. In the 1952-1954 Biennial Report, Dean Spilhaus quoted \$2.25 million as the amount given to the Institute of Technology from sponsors outside the state in the spring of 1954, up from \$1.3 million in 1952.¹³ In 1956, Spilhaus noted that “more than 95 per cent of the funds designated for research in the Institute come from sources outside of the state support.” He wrote, “It is our belief that sponsored research, properly governed by such policies [of complete integration of teaching and research], supported by the federal government and by industry has become a continuing and permanent part of national planning and that a university does not take a risk in budgeting and planning ahead for it.”¹⁴ As if to confirm Spilhaus’s intuition, the financial support for research from outside of Minnesota doubled from \$3 million in 1957 to \$6 million in 1962.¹⁵

As indicated by Spilhaus in the above quotation, by the 1950s industry became a significant financial contributor to research initiatives in academe. In fact, Hermann wrote his book, *Supersonic Inlet Diffusers and Introduction to Internal Aerodynamics*, while under contract to Minneapolis-Honeywell Regulator Company, Aeronautical

¹³ Spilhaus, *Biennial Report of the President and of the Board of Regents, 1952-1954* [June 30, 1954], 135, UA.

¹⁴ Spilhaus, *Biennial Report of the President and of the Board of Regents, 1954-1956* [June 30, 1956], 129, UA.

¹⁵ Frank Verbrugge, *Biennial Report, 1960-1962*, [June 30, 1962], 123, UA.

Division to investigate variable spike inlet diffusers and the related control problems.¹⁶

Industry took the same stand as the federal government, i.e., that allotting funds to academic research was a financially, scientifically, and militarily sound investment.

Historian Judith Goodstein comments,

Well into the 1940s, very few such companies had research groups comparable to those maintained by the electrical industry, for example. Advanced research was done in government laboratories, under the auspices of the National Advisory Committee on Aeronautics and at some graduate schools.¹⁷

From the number of contracts being signed, both federal and industrial, and the amount of money being funneled into university-based research facilities, a significant amount of the advanced research to which Goodstein is referring was taking place in an academic environment by the 1960s. Even schools like Purdue and Iowa State found enough funds to establish research labs. Furthermore, by investing so heavily in academic research in aeronautics, industry and the U.S. government justified the existence of academic labs and perpetuated the work that advanced engineering science culture.

One might ask, “If the research that helped stimulate engineering science was mostly being produced in academia, and engineers with only a bachelor’s degree were those typically found in industry, then why was incorporating engineering science into the undergraduate engineering curriculum so important?” Part of the answer involves the fact that industry engineers actively participate in the design process. They do not simply turn over the performance specifications to academic researchers and ask for a blueprint. If this were the case, industry would only hire craftspeople and assembly workers. Con-

¹⁶ Hermann, viii.

¹⁷ Goodstein, 175.

sumers or in-house developers compile “wish lists” of performance specifications. Those wish lists change because of competition. Industry engineers use the principles of engineering science to construct a working model. On occasion, achieving those specifications pushes the limits of a design engineer’s knowledge. By calling on researchers, the design engineers have the resources available to investigate the larger questions that cannot be solved in-house. But engineering science is not limited to obscure formulas and abstract concepts. An industry engineer must know how to think about and use those formulas and abstract concepts if any of the research being done is to help advance the state of aeronautics. Otherwise, as Dean Spilhaus argued in his 1957 proposal, the engineer’s knowledge becomes obsolete.

Unlike what was happening at the turn of the century, aircraft design engineers and research engineers today do not act independently of each other; they interact, in part because they *must*. They need to be able to communicate with each other, and that means speak the language of engineering science. As demands grew in the 1930s for airplanes that flew faster, farther, higher, and with greater maneuverability, all within acceptable safety limits, engineers required more and more knowledge. Aeronautical engineering departments in universities around the country adapted their curricula to further develop their students’ understanding of engineering science. Those skills proved important in their careers in industry and created research opportunities in industry and academics, as well as in the military. Even in the Department of Aeronautical Engineering at the University of Minnesota, where the department head mounted significant resistance to change, engineering science strongly infiltrated the curriculum. Through vision, a rise in research activity, but most importantly, the conscious efforts of an insightful faculty,

engineering science finally secured a vital role in aeronautical engineering education at Minnesota and, through its students, into the broader aeronautical community as well.

THE ROLE OF VARIOUS ENGINEERING SCIENCE AREAS IN THREE PROFESSIONAL ENGINEERING DEPARTMENTS*

Engineering Science Area	Professional (degree-granting) Departments or Branch of Engineering			
	Mechanical	Civil	Aeronautical	
Fluid Mechanics	Heat trans. & fluid mech. Eckert, Hartnett, Ibele, Irwin.	Hydraulics & fluid mech. Straub + St. Anthony Staff	Aerodynamics & fluid mech. Chang, Hermann.	Semi-fluid & pseudo-solids, <u>Rheology & viscoelasticity</u> <u>Aeroelasticity</u> Solid Mechanics of part. rigid and deformable bodies.
Solid Mechanics		Structures & Solid Mech. Anderson, Graves Soil Mechanics Kersten		Elasticity, plasticity, dynamics, stability.
Materials				Elastic, flow, & fracture properties, their deter-mination & design sign. Behavior analysis
Materials Processing	Matls. Proc. & Shop Holtby, Crowder			Forming as appl. Plasticity Cutting as flow & fracture
Thermo-dynamics & Power	Thermo. & heat engines. Murphy, Lee, Ibele, Hartin.			
Instruments & Control	Instruments & Control LaJoy	Surveying Fant		
Areas of Special Interest	Heating, Air Cond., Ref. Jordan, Algren, Lund.	Highway Eng'g & Soils Thomas & Kersten		
	Industrial Engineering McElrath.	Sanitary Eng'g Schroepfer		
	Creative design ("imagineering," synthesis followed by analysis, concept of engineering compromise)			

* The three departments are those whose major interest lie in the "Mechanical" area.
Excluded are electrical, chemical, metallurgical, and mineral engineering.

THE ROLE OF VARIOUS ENGINEERING SCIENCE AREAS IN THREE PROFESSIONAL ENGINEERING DEPARTMENTS*

Engineering Science Area	Professional (degree-granting) Departments or Branch of Engineering			Department of Mechanics and Materials	Corrected Column for Aeronautical Engineering
	Mechanical	Civil	Aeronautical		
Fluid Mechanics	Heat trans. & fluid mech. Eckert, Hartnett, Ibele, Irwin.	Hydraulics & fluid mech. Straub + St. Anthony Staff	Aerodynamics & fluid mech. Chang, Hermann.	Semi-fluid & pseudo-solids. <u>Rheology & viscoelasticity</u> <u>Aeroelasticity</u> Solid Mechanics of part. rigid and deformable bodies.	Aerodynamics & Fluid Mechanics (Gas Dynamics) Chang, Hanson, DeCoursin
Solid Mechanics		Structures & Solid Mech. Anderson, Graves Soil Mechanics Kersten		Elasticity, plasticity, dynamics, stability.	Aircraft Design and Structural Analysis. Stolarik (Also Graves)
Materials				Elastic, flow, & fracture properties, their deter-mination & design sign. Behavior analysis	Thermal Stresses in Aircraft Structures Scipio, Voltin, Riabokin
Materials Processing	Matls. Proc. & Shop Holtby, Crowder			Forming as appl. Plasticity Cutting as flow & fracture	
Thermo- dynamics & Power	Thermo. & heat engines. Murphy, Lee, Ibele, Hartin.				Hypersonics Aerodynamics and Space Propulsion Hermann, DeLeo
Instruments & Control	Instruments & Control LaJoy	Surveying Fant			Aircraft Stability and Control. Heinrich, VanMeter
Areas of Special Interest	Heating, Air Cond., Ref. Jordan, Algren, Lund.	Highway Eng'g & Soils Thomas & Kersten			Human Engineering Akerman Retardation & Re-Entry Heinrich & Staff
	Industrial Engineering McElrath.	Sanitary Eng'g Schroepfer			Aeronautical Research-Sub, Super, and Hypersonic RAL Staff
	Creative design ("imagineering," synthesis followed by analysis, concept of engineering compromise)				

* The three departments are those whose major interest lie in the "Mechanical" area. Excluded are electrical, chemical, metallurgical, and mineral engineering.

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