

SCIENCE and ENGINEERING

In the History of Aviation

(Reprinted From *Technology and Culture*, Vol. II, No. 4, Fall, 1961.)

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An attempt to evaluate the roles of science and engineering in the history of aviation must of necessity begin by making it clear what is meant by "science" and "engineering." Clarity requires that a definition be simple rather than complex. Consequently, at the risk of oversimplification, we will define science as the accumulation of knowledge about the physical world, both through the gathering and classification of factual data and the formulation of basic laws and principles, and engineering as the application of this knowledge to purposes deemed useful to man. In other words, the scientist wants to know chiefly for the sake of knowing; the engineer wants to know for the sake of using.

This is a distinction more likely to be blurred than not. Scientific research has often been undertaken in order to elicit information which is needed for a specific purpose, or with the idea that the results will have an eventual applicability. It is in fact a fair guess that more scientific knowledge has come from this source than from strictly "pure" research. On their side, engineers have frequently taken on the functions of the scientist because they have had to fill gaps in the theoretical background or the body of data available for what they wanted to do. Nevertheless, the distinction has to be made if we are to evaluate accurately the importance of contributions to science and technology. The two are related, but neither synonymous nor identical.

The history of aviation offers a number of useful tests of these propositions. Man dreamed of flight for many centuries before he could transform the dream into reality, so that there is a long record of speculation on the subject and occasional experimentation, none of it of any real value in solving the problem until late in the eighteenth century. Leonardo da Vinci, it is true, had some shrewd insights, but his ideas were lost for too long to influence the pioneers of aviation, and his own efforts were hopelessly blocked by the inadequate technology of his time. To compound his difficulties, his concepts of flying machines ran to the helicopter, whose problems were not solved until the 1930's, and the ornithopter, or flapping-wing device which is still unsolved. ⁽¹⁾

The effective beginning of aviation dates from 1783, when successful balloon ascensions were achieved in France. ⁽²⁾ The Mongolfier brothers, who were first in the field, used heated air in their balloons: in fact, they believed at first that the lifting effect came from the smoke and they did not really know why their ideas worked. There was, however, an obvious disadvantage to carrying and open fire into the air, and Professor J.A.C. Charles, a physicist, found a more promising gas in hydrogen, isolated by Henry Cavendish in 1766.

The balloon naturally suggested the airship, but the gap between concept and execution was a broad one. Except for a moderately successful experiment by a French engineer, Henri Giffard, with a steam-powered dirigible in 1852, ⁽³⁾ the airship had to wait until the twentieth century, not only for the internal combustion engine but for the patient efforts of men like

Alberto Santos-Dumont and Count Zeppelin in working out the problems of structural design and control mechanisms.

Systematic and useful study of heavier-than-air flight began at about the same time as the balloon experiments. As early as 1810 Sir George Cayley, who has as good a claim as anyone to be considered the first real aeronautical scientist, put his finger on the fundamental problem; namely, "to make a surface support a given weight by the application of power to the resistance of air." ⁽⁴⁾ He rejected the ornithopter idea for the fixed wing and even suggested some sort of internal combustion engine as the probable power plant. His followers made enough progress so that in 1876 a twenty-seven year old Frenchman, Alphonse Penaud, was able to publish a patent for a flying machine with double surfaced planes set at a slight dihedral angle, a large aspect ratio, and cambered wings. ⁽⁵⁾ In short, by 1876 the theory of powered flight was quite well understood; the stumbling block was the engineering problem of designing an engine which would be light enough to get off the ground and at the same time powerful enough to drive the machine through the air. There were some experiments with steam. John Stringfellow succeeded in flying steam-propelled models in England in the 1840's, and Samuel P. Langley did the same thing in the United States fifty years later, ⁽⁶⁾ but the results did not encourage further development in this direction.

Power, of course, was not the only problem. Striking as had been the nineteenth century advances in the study of the problems of flight, there was still need for testing of theories and for the accumulation of a body of data by actual flying experience with some man-carrying device rather than with models. This was the contribution of the great gliding pioneers like Lilienthal, Pilcher, Montgomery, and Chanute. They tried, by rule of thumb added to the small body of existing knowledge, various wing and body designs and control mechanisms in actual flight. They compiled some useful information about the behavior of flying machines, and they made the inevitable mistakes, fatally in the case of Lilienthal and Pilcher, which constituted invaluable guideposts for their successors.

When the twentieth century arrived the maximum essentials for powered flight had come into existence: some fundamentals of aerodynamics, a body of experimental data, and the internal combustion engine as a power plant with a potentially low enough weight-power ratio. So we come to Samuel P. Langley and the Wright brothers.

Langley was preeminently a scientist - self-taught astronomer and physicist, with a brief experience at the beginning of his career as a practicing civil en-

⁽⁴⁾ Ibid., p. 251.

⁽⁵⁾ E.C. Vivian and W.L. Marsh, *A History of Aeronautics* (New York, 1921), pp. 16-17.

⁽⁶⁾ Langley Memoir on Mechanical Flight (Washington, D.C., 1911), pp. 3-5. The partisans of steam have not been as vocal in aviation as in automobile history, but they exist. We can grant that if enough effort and ingenuity had been expended on it, the steam engine might have been adapted to the needs of aviation. Once the lightweight internal combustion engine became available, however, no one thought it worthwhile to continue with steam.

⁽¹⁾ F.A. Magoun and Eric Hodgins, *A History of Air-Craft* (New York, 1931), p.8.

⁽²⁾ A contemporary account of early balloon experiments: H. Garnerin, *Aeronautica* (London, 1802).

⁽³⁾ Magoun and Hodgins, op. cit., p. 123.

gineer. The story of his experiments in flight from 1887 to 1903 is one of endless patience and determination in the face of constant disappointment from unforeseeable mishaps and inferior workmanship. He almost succeeded because his assistant, Charles M. Manly, a mechanical engineer, designed and built for him a five-cylinder radial engine developing 52 horsepower and weighing 125 pounds. (7) It would be pointless now to revive the bitter controversy between the partisans of Langley and the Wrights. We do not know, for instance, if Langley had solved the problem of lateral stability, which he like the Wrights regarded as more difficult than the matter of propulsion, although we do know that Glenn Curtiss rebuilt and flew Langley's machine in 1914. The best indication is that Langley's "aerodrome" would have flown in 1903 if it had not fouled its launching gear on both occasions when Manly tried to get it into the air.

On the other hand, suppose Langley had spent less time in calculation and in experimenting with models and more in actual gliding flights as the Wrights did. Might he not then have realized that he did not really need his elaborate catapult contrivance, perched on top of a houseboat in the Potomac? It is an engineering truism that the more complicated a mechanism is, the greater the likelihood of something going wrong.

The Wright brothers are difficult to classify as either engineers or scientists, because they were educated as neither but functioned on various occasions as both. Their story is too well known to require repetition here. For our purpose what is required is to point out that their basic approach was that of the engineer: accumulating all the available information, designing and testing their own models and gliders, like Manly building their own engine because no manufacturer was willing to undertake to construct so light a motor.

(8) They became scientists of necessity because information they needed was either inaccurate or non-existent. In 1901, Wilbur Wright concluded that existing tables of figures on lift surfaces were in error, and the brothers then compiled their own by constructing a wind tunnel and testing some 200 wing surfaces in it.

(9) Then, when they came to the consideration of power, the brothers discovered to their astonishment that although propellers had been used in ships for over half a century, no body of propeller theory existed, and they had to work it out mathematically for themselves.

In other words, it would be a grave error to write off the Kitty Hawk achievement as a triumph of cut-and-try by a couple of tinkers. The Wrights prepared themselves not only by flying gliders but also by mastering the existing body of aeronautical science and adding to it on their own.

At this point, we have got man into the air on the strength of a little science, somewhat more engineering, and a long hard process of trial and error. Since it is clearly out of the question to deal in a single paper with all that has happened since, we can select those features in the subsequent history of aviation which bear most directly on the influence of and relationship between science and engineering.

First, conspicuously, is the striking growth of aeronautical science after the possibility of flight

(7) Ibid., p. 250. The gross weight of the power plant, including fly wheels, battery, gas and water tanks was 187-1/2 lbs. See also H. Lippincott "The Navy Gets an Engine", JOURNAL A.A.H.S., Vol. 6, No. 4, p. 248.

(8) Fred C. Kelly, The Wright Brothers (New York, 1943), p. 87.

(9) Wilbur Wright "Some Aeronautical Experiments", Address to the Western Society of Engineers, Sept. 18, 1901, in Papers of Orville and Wilbur Wright, M. W. McFarland, ed., vol. I (New York, 1953), pp. 99-118.

had been demonstrated. The determination of the aeronautical pioneers from Cayley to the Wrights becomes all the more impressive when we realize that they had to contend not only with the derision of the uninformed but with an impressive body of scientific theory indicating that they were actually attempting the impossible. Yet no less a figure than Sir Isaac Newton had made calculations of air flow on wings showing much less lift than was actually obtained, while the existing body of theory in fluid mechanics gave no evidence of lift or drag in perfect fluid flow. Not until the work of Kutta in Germany, Jukowski in Russia, and Lanchester in England between 1902 and 1907, was the existence of lift firmly established in aerodynamic theory.

Once the break was made, research in aeronautics expanded rapidly, for some time considerably more so in Europe than in the United States. American opinion rather astonishingly ignored the achievement of the Wright brothers and watched apathetically while Europe forged ahead in aviation. There were some exceptions. Glenn Curtiss, introduced in 1907 to heavier-than-air flight through Alexander Graham Bell's Aerial Experiment Association, unquestionably led the field in the development of flying boats, an engineering rather than a research operation, (10) and in 1913 M. I. T. installed an aerodynamics laboratory with a four-foot wind tunnel. (11) Large-scale aeronautical research in the United States got its effective start when the shadow of the First World War stimulated Congress to create the National Advisory Committee on Aeronautics in 1915, with instructions to "supervise and direct the scientific study of the problems of flight, with a view to their practical solution." (12) In executing these instructions, the NACA covered the entire spectrum of aeronautical science and engineering: it engaged in basic research, and it studied specific technical problems submitted to it by the government and the aviation industry.

Much of this research has provided the basis for practical developments in the design and construction of aircraft. The advance of aerodynamics, for example, has made possible improvements in airfoil and airframe design which have approximately doubled lift per square foot, and reduced drag by a factor of three-fourths since the first decade of this century. (13) For the layman whose memory goes back far enough, aeronautical science here represents the difference between the sleek-lined monoplane of the present and the elaborate structure of struts and wires which characterized the airplanes of forty years ago.

This story can be repeated throughout the whole field of aeronautics. Research in problems of stability and control, stresses, the chemical composition of fuels, and so forth, has been an indispensable component of progress in aviation. It would be easy, indeed, to conclude that the course of development has fallen into a definite pattern of establishment of basic principles and data followed by specific application; in other words, that after the cut-and-try pioneering days ended, aeronautical engineering became dependent on aeronautical science.

But did it? With due respect to advances in other

(10) Aircraft Yearbook, 1921, p. 140, Curtiss, a manufacturer of motorcycles, first entered aviation by making engines for small airships. See also G.A. Hardie, Jr. - "The Birth of Naval Aviation", JOURNAL A.A.H.S., Vol. 6, No. 1, pp 3-13.

(11) "The Airplane Problem", Aviation, vol. IV (1918), p. 778.

(12) George W. Gray, Frontiers of Flight (New York, 1948), p. 13.

(13) John K. Northrop, Aviation History, address given in Library of Congress, Nov. 3, 1948, p. 8.

areas, the outstanding factor in improving aircraft performance has been the spectacular development of the power plant, and this has been predominantly an engineering achievement. To illustrate from American experience the 12 h.p. engine used at Kitty Hawk grew into the 12-cylinder, 400 h.p. "Liberty" of the First World War with no significant change in design. The radial engine which came into use during the 1920's was a new departure in practice but not in principle; the basic idea was incorporated in the engine Manly built for Langley in 1903. By the end of the Second World War, propeller-type engines had attained 3000 h.p. by a steady process of refinement. (14) The engine was capable of further improvement, but by this time speeds and altitudes had reached the effective limit of the propeller.

The next step was the jet, easily the major breakthrough in propulsion in the history of aviation. In popular terminology it is no doubt considered one of the miracles of modern science. The basic principle, however, has been recognized for centuries. Hero of Alexandria used a jet of steam in his "aeropile" in the first century A.D. (15) Admittedly, this gadget was nothing but an interesting toy; the rocket, however, is a form of jet propulsion, and rockets have been in use for military and other purposes since the thirteenth century. (16) How many Americans realize when they sing of the "rockets' red glare" that it was something more than a poet's imagination or a display of fireworks put on by the British to entertain Francis Scott Key?

The basic law of jet propulsion is simply Newton's third law of motion, that every action has an equal and opposite reaction. Here we have an illustration of both the propositions advanced at the beginning of this essay. Rockets were in practical use for 400 years before anyone explained why they worked; and the fundamental principle underlying jet propulsion was understood for another 250 years before it became possible to master the technical details required to convert Newton's law into a functioning jet engine.

The creation of a jet engine which would outperform the piston engine was an engineering problem, or rather a series of engineering problems. The idea which opened the way for a solution, the use of a gas turbine to provide a high-pressure jet, originated in the mind of a twenty-two year old Royal Air Force cadet in 1929. The principle of the gas turbine was not new either; the idea can be traced back to 1791. (17) However, when young Frank (now Sir Frank) Whittle conceived of applying the gas turbine to jet propulsion, he still had a dozen years of frustrating effort ahead of him before he had an engine operating in actual flight. (18) His difficulties were not matters of fundamental principle, but technical points like the proper setting of turbine blades or the control of air turbulence in the compressor.

The last phase of this story can be appropriately introduced by quoting from an entry in the weekly reports of the Engineering Department of Convair for April, 1945.

(14) Ibid., pp. 20-21.

(15) R. S. Kirby, et al., Engineering in History (New York, 1956), p. 34.

(16) Willy Ley, Rockets, Missiles, and Space Travel (New York, 1951), p. 51.

(17) Sir Frank Whittle, Jet (London, 1953), p. 307.

(18) The Germans were the first to fly jet aircraft. Whittle believes that they used his basic ideas, which had appeared in technical journals before the war, and that they sacrificed quality in order to rush production. See Ibid., pp. 289-290.

"Work has just started on possible airplanes for supersonic speed... A turbo-rocket power plant seems to be the most promising at the present time. Practically no aerodynamic data are available in this speed range, and what there is isn't consistent." (19)

In other words, the high-pressure development of jet propulsion which the Second World War started had put into our hands a power plant which provided both new problems and new opportunities for aeronautical science. Quoting again, this time from J.H. Kindelberger of North American Aviation: (20)

"In air-frame design, which had been refined nearly to the ultimate of low-drag for the 400 m.p.h. region, new trends were started involving radical changes in shape, control systems, equipment, and structures. But each solution brought new problems as near-sonic and transonic phenomena were explored in wind-tunnel and flight trials.

"For example, the instability experienced with swept wings at near stalling speeds resulted in experiments with various solutions. . . As is always the case, the problems seem relatively simple when the solutions have been found, but in the frantic period of exploration it often appears that the laws of physics are capriciously defying our best efforts."

It may be, indeed, that aviation, especially as it moves into the realm of missiles and space flight, has become so radically changed as to invalidate generalizations which were applicable up to about 1950. Certainly the aeronautical engineer of today has to be much more of a scientist than his predecessor of fifty years ago. The history of aviation, nevertheless, shows a constant pattern of what John L. Atwood, President of North American Aviation, defines as "nibbling at the edge of the unknown." (21) At some times aeronautical science has opened the way for further engineering achievements; at others technological advance has made it possible to go beyond the existing limits of scientific knowledge.

Is there accordingly a meaningful distinction between science and engineering in aviation? For the historian there is, if history is to be an accurate evaluation and interpretation of past experience. An intelligent differentiation will clarify the significant steps in the development of aviation, and it ought to illuminate the fact that aeronautical science and aeronautical engineering have been complementary rather than competitive. Man is not quite in the position of the bumblebee, which we have been told is constructed in violation of the laws of aerodynamics but goes ahead and flies anyway. Man has the privilege of thinking about what he is doing. Still, we would never have got off the ground if some of our number had not been willing to try something without having to know the answers in advance.

(19) Ms. History of Convair, A Division of General Dynamics Corporation, p. x-1.

(20) J. H. Kindelberger, "Design of Military Aircraft", Aeronautical Engineering Review, vol. 12, no. 12 (Dec., 1953), p. 6.

(21) John L. Atwood, Some Aspects and Problems of the Aircraft Industry, address at Eighth Stanford Business Conference, Stanford University, July 28, 1949, p.7.

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