Flight on the Horizon: The Pivotal Year of 1896

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It has not been customary to include early aeronautical history in the AIAA Annual Meeting. However, the special importance of this 100th anniversary justified the session, in which three papers were delivered. This brief introduction is intended to provide background and a context for those lectures, which will appear in subsequent issues of this journal.

In the stunning rush of inventions at the end of the 19th century, the year 1896 held events remarkably significant for the development of the airplane and aeronautics in the early part of the 20th century. The three major figures responsible for those pioneering aeronautical events were the German mechanical engineer Otto Lilienthal (1848–1896) and two Americans: Samuel P. Langley (1834–1906), a self-educated physicist and Secretary of the Smithsonian Institution, and Octave Chanute (1832–1910) an eminent civil engineer best known for his participation in development of the railway system in the midwest United States but in 1896 voting his energies almost totally to invention of the flying machine. All three did much to solidify the foundations of early aeronautics by identifying, (occasionally unwittingly) and clarifying the problems to be solved. Their contributions were intimately tied to previous and contemporary activities in the quest to build a heavier-than-air flying machine. They learned from the past and their own progress helped make possible the later success of the Wright brothers.

So far as practical possibilities were concerned, in the mid-1890s prospects for building a piloted heavier-than-air powered aircraft were much better than were popularly perceived. Three major problems had essentially been solved: propulsion, structural design, and basic aerodynamics. Propulsion had not presented a serious obstacle since the invention of the internal combustion engine. By 1902, sufficiently light engines could be constructed (4 lbfhp) that the use of inefficient propellers could have been tolerated in a practical machine. It was the Wright brothers who achieved a remarkable advance in propeller design, increasing the efficiency by a factor of about 1.4 or more. That improvement was crucial to their success in 1903, for their engine weighed roughly 15 lbfhp.

Since the early 1800s, with the work of Sir George Cayley (1773–1857), correct practical ideas of structural design had been known. Simplified versions of kites, windmill blades, and boat designs were first used and were later improved by adapting some details of bridge designs. Lilienthal had extraordinary success with his wood, wire, and fabric construction of both monoplane and biplane gliders. Chanute improved upon Lilienthal’s basic biplane design by adapting the Pratt configuration of a bridge truss.

Surprisingly little basic aerodynamics was required to devise a scheme for designing a glider. Cayley did so in 1804–1809 essentially by attaching horizontal and vertical tails to a kite. In 1849, a scaled-up version of his crude glider is reputed to have flown carrying a boy on at least one occasion; in 1853 a larger craft (Cayley called it the governable parachute) may have carried his coachman on a glide in a small valley. The story is possibly apocryphal in some of its details—the important indisputable fact is that Cayley first proposed that, unlike birds, a mechanical flying machine should possess independent means of propulsion and generating lift. Moreover, he proposed the conventional aircraft configuration as it is now known: vertical and horizontal tails and a wing possessing dihedral and using a curved airfoil. He had made measurements and knew that a cambered profile gave a lift/drag ratio superior to that of a flat plate. With the two aft tails and dihedral, Cayley’s aircraft was, at least in principle, stable about all three axes, although there is no firm evidence—indeed, it is highly unlikely—that Cayley really understood stability in the sense that we do now.

Lilienthal, Chanute, and Langley all followed Cayley’s basic design and used the configuration of flying surfaces that is now conventional. Although they had an intuitive notion of stability, the three did not have an understanding of the true technical meaning of the term. Therefore, like all others attempting to build aircraft at the turn of the century, they could improve stability only by trial and error, and control necessarily became a crucial issue. The technical reason for general ignorance of the subject was that none of those trying to build aircraft wrote down an equation for moments and therefore had no theoretical framework for understanding stability.

Thus, the essential aeronautical problem that remained to be solved in the late 19th century was one of geometry: determine a configuration of surfaces, including controls, such that the known aerodynamic forces could be manipulated to provide equilibrium stability, and control. Cayley’s configuration possessed equilibrium and probably stability. Although he proposed the use of pilot-operated controls, they were not used in flight. In any case, because no lightweight engines were available until much later, he was forced to abandon his project to construct a powered aircraft capable of carrying a human.

In 1871 Alfonse Pénault (1850–1880) constructed and successfully flew a model with a wing span of 18 in. powered by twisted rubber bands driving a pusher propeller. The model had Cayley’s conventional configuration; its flight of 131 ft in the Tuileries Gardens in Paris on Aug. 18, 1871, was the first flight of a powered heavier-than-air machine. In a paper published in 1872, Pénault gave the first qualitative explanation of why the horizontal tail provides pitch stability in the face of small disturbances. Pénault’s success was well known by all who subsequently tried to build aircraft large enough to carry a person, and all adopted a horizontal aft tail for intrinsic stability except the Wright brothers, who concentrated on control exerted by the pilot. Their great achievement was realizing and demonstrating with a practical aircraft that a skilled pilot could control, stabilize, and fly a machine that was unstable alone.

During the years after Pénault’s death, there was considerable activity in developing flying machines in Europe and in the United States. Much of the effort, and faith, was devoted to lighter-than-air vehicles. Reflecting a common view of the situation in 1890, upon being invited to join the British Aeronautical Society, Lord Kelvin responded “I have not the smallest molecule of faith in aerial navigation other than ballooning, or of expectation of good results from any of the trials we hear of, so you will understand that I would not care to be a member of the Aeronautical Society.”

Lilienthal was the first aeronautical scientists/engineering having a technical education and experience. Equally important to his accomplishments, he recognized a crucial matter of style: to build a successful aircraft, he had simultaneously to learn how to fly. With that decision, Lilienthal was first to combine accepted notions of equilibrium and stability in flight with his new idea of control to maintain equilibrium in the face of disturbances. He became the first pilot, of hang gliders, and although killed while practicing his philosophy, he inspired others by his example. He set the Wrights on their path to success and also motivated the rebirth of aviation in France in 1899 with the primitive gliding tests of Ferdinand Ferber (1847–1909).
Less well known is the fact that Lilienthal also inspired a crucial step in the initial theory of airfoils. In his 1889 book, Lilienthal sketched his impression of streamlines for flow past a profile showing clearly his conclusion that for best performance (lift/drag) the flow departs the trailing edge smoothly. W. M. Kutta knew that result, believed it explicitly, and in 1902 introduced it as the theoretical constraint now known as the Kutta condition. Thus, Lilienthal contributed fundamentally to both the practice and theory of aircraft design.

Chanute recognized Lilienthal as the contemporary leader in aerodynamics. Whereas he vigorously pursued collecting all available information about flight, he also designed and constructed his own man-carrying gliders. Owing to his maturity in the 1890s, Chanute was aided by others who actually flew the aircraft, with some limited success. Probably Chanute is most widely known for his encouragement of the Wrights from the beginning of their work and for their voluminous and detailed correspondence. His sole truly significant technical contribution was his adaptation of the Pratt truss bridge design as the basis for his biplane structure. That configuration was adopted by the Wright brothers and remained as the usual structural design of biplanes until cantilevered structures became known. Chanute’s 1896 glider was his practical realization of contemporary understanding about constructing an aircraft.

Despite his extensive efforts to invent a successful airplane, Chanute was hampered by the notion that the machine must be intrinsically or automatically stable. He worked to progress beyond the hang glider, in which the pilot exercises control by shifting his center of mass, but always tried to reduce the operating responsibilities of the pilot. He did not investigate problems of control by deflecting surfaces and missed the hints given him by the Wright brothers concerning their use of wing warping to achieve control in roll. Chanute’s eternal monument is his wonderful book Progress in Flying Machines, a collection of earlier articles, published in 1894. That volume summarizes essentially all of aeronautics and the practice of building aircraft.

Samuel P. Langley was already a highly respected internationally known astronomer in 1886 when his attention was drawn to the problems of flight by a lecture at the Buffalo meeting of the American Association for the Advancement of Science. As a physical scientist, Langley was impelled to investigate and solve what he perceived to be the fundamental problem of flight and aeronautics. He had considerable influence and financial resources, first as Director of the Allegheny Observatory in Pittsburgh and later (1887 until his death in 1906) as Director of the Smithsonian Institution.

As his object of fundamental aerodynamical research, Langley settled on the thin flat plate—possibly the worst choice from the point of view of obtaining useful information for designing an airplane. His work, begun in 1887, was published in a large historically interesting volume Experiments in Aerodynamics, published by the Smithsonian in 1891. Although uniquely extensive, the work had no apparent impact on practical or theoretical aerodynamics.

Fortunately, quite distinct from his aerodynamic researches, Langley began designing and building a long series of models in 1887. In that program, he began directly with Penaud’s success. His relatively small, rubber-powered models were largely unsuccessful and he was never able to match Penaud’s flights of 1871.

Believing that his chief difficulty lay in the weak thrust available with his twisted rubber, Langley took an enormous leap and determined to build large models powered by a light steam engine. At last, after 5 years of work, he had no such powerplant that would work to the stream. Interpreted as Smeaton’s coefficient, \( k \) in the formula \( \text{drag} = k \times \text{speed}^2 \), this quantity had become the reference example for drag data in the 19th century. Wells obtained values around 0.0045, fairly close to the value of 0.0050 accepted at that time (drag is in pounds and speed is in miles per hour). In contrast, Langley found \( k \) to be approximately 0.0030, very close to the value known now for the same range of Reynolds number. This matter is interpreted as Smeaton’s coefficient to convert Lilienthal’s data to the form they used in their design work. The incorrect value of \( k \), approximately 0.0050, recommended by Lilienthal led them seriously astray, the chief reason that they began their own work on powerplants.

Wells constructed his tunnel, which may have been the first since Phillips’s tunnel, by directing the flow in a ventilated duct. His intense interest was to perform experiments for designing an airplane. His work, begun in 1887, was published in a large historically interesting volume Experiments in Aerodynamics, published by the Smithsonian in 1891. Although uniquely extensive, the work had no apparent impact on practical or theoretical aerodynamics.

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Even this brief historical perspective yielded 1896 as a pivotal year: Lilienthal died; Chanute reached the pinnacle of his success in constructing unpowered gliders; and Langley’s extended flights of the first powered models gave him the confidence to scale up his tandem wing design and attempt piloted flights of a powered heavier-than-air machine. Only Lilienthal’s technical accomplishments were fundamental to the successful invention of the airplane, but all three are significant figures in the evolution of aeronautics.