How Two Bicycle Mechanics Achieved the World's First Powered Flight

Roddam Narasimha

The Background

On 17 December 1903, two bicycle mechanics from Dayton, Ohio in the United States helped a powered aircraft (they called it a 'Flyer') along a wooden rail in a desolate, wind-swept, sandy plain called Kitty Hawk in North Carolina, and flew the craft for almost a minute (*Figure* 1). By doing this the Wright brothers, Orville (1871-1948) and Wilbur (1867-1912) (*Figure* 2), had accomplished a feat that much of mankind, including some of its greatest minds, had considered impossible for thousands of years. Famous among the more recent of such skeptics had been Lord Kelvin, who had said as late as 1896, 'I do not have the smallest molecule of faith in aerial navigation other than ballooning'. There were many others who would have agreed with Kelvin, and indeed it was common to say at that time about anything considered impossible that it could not be done – 'man might as well try to fly'.

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How did the two bicycle mechanics accomplish what so many others could not? That is a natural question to ask, but as posed it is misleading, because although the Wright brothers ran a cycle shop in Dayton, it is clear that they were no ordinary mechanics. Indeed the striking thing about their aviation project was how extraordinarily systematic, analytical and ingenious they were. Although neither of the two brothers had even passed high school, they were both well educated in the true sense of the word. In particular the elder brother Wilbur was very well read, and had to drop out of high school just before he could have graduated only because his father decided at that very time to shift from Indiana to Dayton; Wilbur wanted to go to Yale but could not afford it and had obligations to the family which he felt he had to discharge. Father was a bishop of independent and

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Figure 1. One of the most famous photographs of history, showing the first flight of the Wright Flyer at Kitty Hawk on 17 December 1903. The person looking on at the right is Wilbur; Orville is piloting the plane, in a prone position. (This position was necessary because a sitting pilot would have added considerably to the drag of the vehicle; the prone position was also considered safer – in case of a crash the pilot got off with only minor bruises and mouthfuls of sand.)

Note the single rail which constitutes the runway. A sled fixed below the wings moved along the rail as the aircraft did its take-off run: there were no wheels or landing gear yet! Somebody (like Wilbur in the picture) had to hold up the wing-tip during the run to prevent the aircraft from tipping over.

The plane was driven by two counter-rotating propellers driven by a 12 hp gasoline engine, located on the lower wing to the right of the pilot. Both engine and propeller were specially designed for the plane – in fact Wilbur pioneered propeller technology; counter-rotation nulled out the torque that would otherwise act on the air frame. The two horizontal surfaces in front constitute the elevator in a 'canard' configuration – in current designs it would normally be part of the tail plane of an aircraft. The elevator gives control in pitch (nose up or down). The two vertical surfaces at the back constitute the rudder, used for turning the plane left or right. One of the major innovations in the Wright plane was the provision of control for rolling the plane during a turn; this was achieved by warping the wings (see Box 3).

The Wright Flyer was a biplane – i.e. had two wings. The low speed of flight demanded a large wing area, and the structural technology of the time did not permit the single large wings that we see in current monoplanes.

strongly held views; both father and mother were teachers. So the children grew up in a domestic atmosphere of learning and debate.

Before the Wright Brothers got started on the project (which was in 1896), there had indeed been human flyers of some kind. Such flight usually took the form of ballooning (i.e. lighter than air vehicles), most spectacularly in the work of the Montgolfier brothers in France, who demonstrated the first practical balloon in 1783. There had also been gliders, i.e. aircraft which were unpowered, and so had to rely on upcurrents in the atmosphere to sustain flight. Indeed some striking gliding feats had already been achieved, beginning with George Cayley's ideas in England (1773-1857) and going much further with Otto Lilienthal (1848-96) in Germany (whose work the Wrights closely followed). There was also a very visible American project run by Dr Samuel Pierpont Langley (after whom the NASA Langley Centre in Hampton, Virginia is now named); around 1900 Langley was Secretary of the Smithsonian Institution in Washington DC and had a generously funded project (worth $50000) for making what he called the 'Great Aerodrome' (a word he used for his powered flying vehicles – not for landing fields). Langley had earlier built scaled models, which had in fact shown very promising performance.

Orville Wright

Wilbur Wright

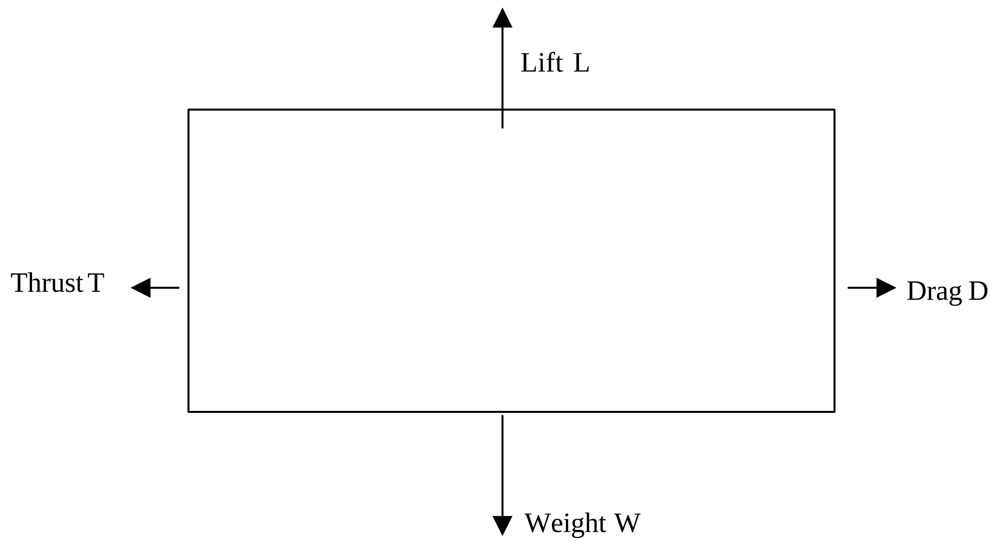
Figure 2.

However, sustained powered flight had proved beyond human reach. Both distinguished scientists like Kelvin and Langley as well as outstanding engineers like Lilienthal had found it difficult or impossible. There was of course the old Greek legend about Icarus, who stuck wings on his shoulders (using wax) and tried to fly; his failure (because in part the wax was supposed to have melted as he approached the sun) has been part of Western myth for a long time. Many cultures have been fascinated by the idea and vision and dream of human flight; we have had our own myths of *pushpaka vimanas*, for example.

One legitimate question that arises therefore is why the Wright brothers were so rash as many thought at the time to take on their project, and what led them to it. Wilbur appears not to have been impressed by the kind of opinion that Kelvin and others had expressed because he saw that flight was common in the animal world: his own optimism was based on the idea that 'while thousands of most dissimilar body structures, such as insects, fish, reptiles, birds and mammals are flying with pleasure, it was reasonable to suppose that man might also fly.' That

Box 1. The Balance of Forces on an Aairplane

In steady horizontal flight the weight (W) of the plane is balanced by the vertical component of the aerodynamic force, called the lift (L). The resistance offered by air to the motion of the plane, called the drag, acts horizontally, and has to be overcome by the thrust generated by the power unit, through a propeller or a jet or a combination of both.



The lift is largely generated by the wings, but the drag comes from all parts of the aircraft. These forces as they would act on the Wright Flyer, are shown in the accompanying figure.

More generally when the aircraft is not flying horizontally lift is the aerodynamic force acting normal to the direction of flight in the plane of symmetry of the aircraft, and drag is that acting in the direction opposing flight. In unsymmetrical flight there can be a side force as well.

still leaves open the question whether flapping is necessary for flight, but after all not all birds flap vigorously, and George Cayley had already identified the basic technological problem of human flight as one involving the presence of wings to generate enough lift, a power unit to generate the thrust required to overcome the resistance to flight (or the drag of the vehicle), and a system that provided ability to control the flight of the vehicle. (See *Box* 1.)

There was a more mundane reason as well. The Wright brothers had begun to look for something beyond their bicycle business, which they had set up during a boom in the early 1890s, but the market had since declined. Although the Wrights had acquired a considerable reputation for the bicycles they made, including their own 'Wright Special', and had even made a fair bit of money out of their enterprise, their income was dwindling so they had to look for new business. Finally, in the year 1896 two of Langley's unmanned model aerodromes had made successful flights. The famous inventor of the telephone, Alexander Graham Bell, had been very optimistic about the possibility of human flight and had supported Langley's projects. Lilienthal, who had made some very interesting flights on his glider, died in an accident the same year. Strangely this accident seemed to have been the turning point in the Wrights' thinking, Wilbur decided to go ahead to look at aviation very seriously. He had some money of his own, made from the cycle business, and his father agreed to part with a sum of one thousand dollars to each of the two sons to support their venture. So the brothers started off.

The First Experiments

It is remarkable how, once these thoughts crystallized in Wilbur's mind, he set about his project in what may be called a very scientific way. In 1896 when he was contemplating the project the objective had primarily been *research*, 'to help the future worker who will attain final success'. So he first collected all the information that was available in published form. He wrote to Langley, and to the civil engineer Octave Chanute who had a deep and scholarly interest in flying. He studied in detail the work of Lilienthal and of the pioneering British engineer John Smeaton, who in the 1750s had made tests to help design better windmills. He made a thorough and critical analysis of this international literature, and regretfully concluded that 90% of it was false! It seems astonishing now that the earlier data had never received such careful scrutiny before. Nevertheless by 1899 Wilbur came to the conclusion that achieving human flight was only 'a question of energy and skill', and so decided to go ahead. He first calculated everything he could, checking other

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workers' results for consistency. In 1901 the brothers made gliding tests with models at Kitty Hawk, and realized that better scientific data was needed. Kitty Hawk is located some 60 miles north of Cape Hatteras in a few-mile strip of North Carolina land stretching south into the Atlantic Ocean. The site was selected by the Wright Brothers after a careful survey of many alternatives, its advantages being the weather and the sandy terrain that enabled test vehicles to make a soft landing. Wilbur's negative assessment of previous data was discouraging, and on the way back home from Kitty Hawk after the 1901 tests he told his brother, "Not within a thousand years would man ever fly".

The brothers' experiments however had already caught the attention of perspicacious observers, among whom Chanute was one. Chanute played an interesting role in the Wright brothers' projects: often a helpful and encouraging scholar and curious spectator, sometimes a self-appointed mentor, sometimes a condescending patron (spurned firmly by the Wrights), and occasionally announcing himself as a 'collaborator' with his capable 'pupils'. Those announcements caused consternation and outrage in the Wright brothers, who promptly, firmly but politely declined all his offers of material support and ideas for projects. Chanute however frequently invited the Wright brothers to write and lecture about their work, and in 1901 Wilbur let himself be persuaded to speak to the Western Society of Engineers at Chicago about his work. Wilbur started once again by noting that the flying machine required wings for lift, a power unit to move it forward and adequate control to sustain flight. His assessment was that the first two problems had been solved, and that it was the third that was the main obstacle. He realized that it was necessary to control an aircraft in three dimensions, in particular around all three axes. (See *Box* 2.) That was not the standard view at the time (although it appears obvious to us now); before the Wrights it was considered that pitching and yawing (or turning) were all that was required, a view that was held for example by Langley. This view was inspired by an analogy with ships; if a ship could turn by the use of only a

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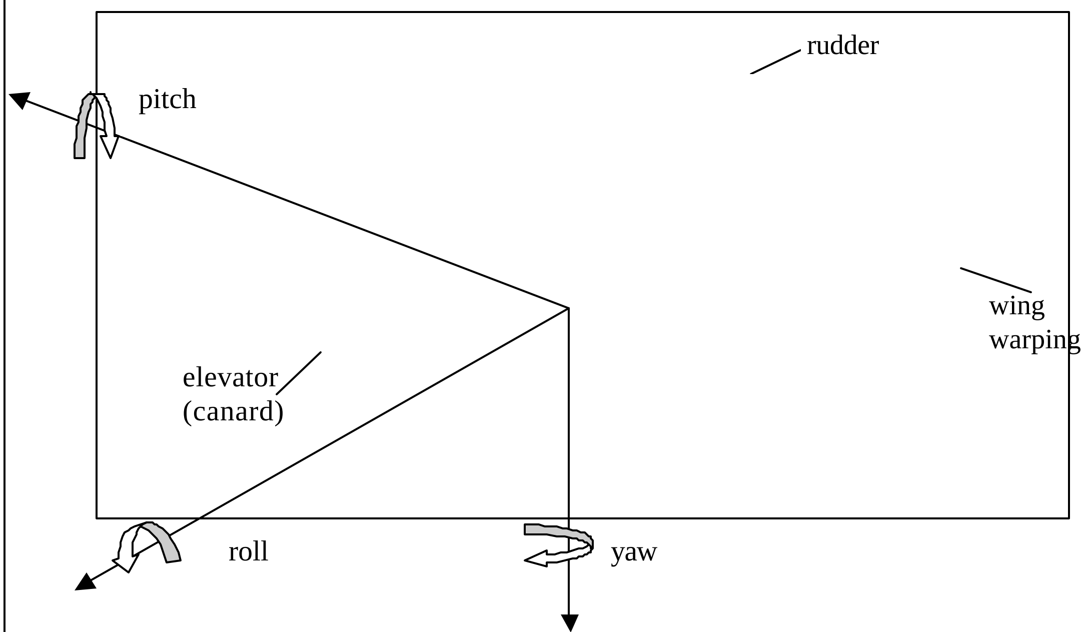
Box 2. The Six Degrees of Freedom of an Aircraft in Flight

Unlike surface vehicles, an aircraft flies in three dimensions; it can therefore have translational velocities in each of three directions, and rotational (angular) velocities around each of the corresponding three axes.



The translational components correspond in general to forward (flight) speed, and rising/sinking or sideslip motions. The angular motions (see figure) can be pitch, roll and yaw. In a coordinated turn an aircraft turns left (or right) as it banks or rolls with the left (or right) wing going down.

rudder, it was assumed that an aircraft should be able to do the same. Wilbur was the first to understand that this cannot be, because by and large a ship moves in two dimensions whereas an aircraft flies in three. Wilbur reasoned from his experience with cycling and by watching birds, and came to the immediate conclusion that control was required for pitch and yaw as well as for roll. It turned out that this fundamental insight was what set the Wright brothers apart from all the other enthusiasts of the time, and was eventually what was responsible for their success.

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Success

The realization that the available data were so unreliable led the Wright brothers to make their own tests, and this they proceeded to do with meticulous care and ingenuity. They made some tests by mounting small wing surfaces on a horizontal cycle rim and comparing differential forces between the surfaces. (The rig they set up for the purpose was very clever. A flat plate and a short wing were mounted vertically on the horizontal rim in such a way that if the forces on them were equal the rim should not rotate in wind – or when it was ridden on a bicycle. The observed rotation thus provided an indication of force differentials between the surfaces.) They then went on to build their own wind tunnel, testing wings for the pressures and forces acting on them. They made such careful analysis of their data that they could pin-point the precise errors in previous work. The brothers then built new gliders in 1902 using their own aerodynamic data, and found that they worked extremely well; in fact during their campaign that year they broke all previous records on gliding. Using the new numbers that he had generated and could now trust, Wilbur calculated the parameters required for successful powered flight and wrote the 'specifications' for their Flyer, as shown in *Box* 3. As they were doing this Wilbur's estimate of the time required to achieve powered flight underwent a dramatic reduction from thousand years to fifty!

As Wilbur began to think powered flight was feasible, the brothers collaborated with a friend to design a special light engine of their own – of the new internal combustion type (running on gasoline, not steam as Langley's aerodromes did).

Box 3. Wilbur's specifications

	1902 estimates	1903 Flyer values
Wing area	520 sq. ft.	510 sq. ft
Weight of machine	625 lb	605 lb
Engine power	8-9 hp	12 hp
Weight of engine, propeller transmission	~200 lb	-

As they gained experience with the new engine their optimism soared, and they began to wonder whether powered human flight would be feasible within two years!

After return from the successful 1902 glider tests in Kitty Hawk, the Wright brothers built a new wind tunnel and made more tests; and their confidence in their estimates was now vastly enhanced. Indeed Wilbur Wright had now become – unknown to the rest of the world – the most knowledgeable applied aerodynamicist. (By the way there was no useful theoretical aerodynamics at all at the time, but it was born in the following decades. [5]) He used this knowledge also to design his propellers, which significantly out-performed earlier designs. On 23 March 1903 the brothers decided to make the first application for a patent (they had held back till that point of time in spite of the repeated injunctions of their friend Chanute), and as they did so the brothers knew that they should now be able to fly. In June Orville wrote to a friend, "Isn't it wonderful that all these secrets have been preserved for so many years just so that we could discover them?" The Wrights then made their craft and took it to Kitty Hawk as usual. Just before they started their tests in December reports arrived of the spectacular failure of Langley's machine; his Great Aerodrome took off from a platform on the river Potomac, and plunged immediately into the water, virtually ending the project and throwing great doubts in the public mind about the possibility of powered flight. But the Wright brothers were unfazed, for they had already known (based on their own data) that Langley could not possibly have succeeded, and so were neither surprised nor disturbed by his failures. Indeed, after tests on 14 December, which were technically not successful but technologically very encouraging, Wilbur realized that there could no longer be any question about final success. On the 17th Orville made the first attempt (the brothers usually tossed a coin to decide who would go up first) and flew for 12 seconds. This may not mean much, but for the Wright brothers it was decisive; for they knew now for certain that their design parameters were almost right. The last flight of the day,

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made by Wilbur, covered a distance of 852 feet and lasted 59 seconds. Wilbur knew that the problem of human powered flight had been solved – if with one minute's flying training he could make a minute's flight, a little more flying experience and some improvements in design were all that were required for the conquest of air to be a reality. Orville sent a telegram to his father:

> Success four flights thursday morning all against twenty one mile wind started from level with engine power alone average speed through air thirty one miles longest 57 seconds inform Press home Christmas.

(There is a curious and unexplained discrepancy of 2 seconds in the reported duration of flight.) Shown that message by the father, an Associated Press reporter said,

> "Fifty-seven seconds, hey? If it had been fifty-seven minutes then it might have been a news item."

In retrospect it is surprising how long the world took to notice properly the significance of the extraordinary feat of 17 December. As far as the Wright brothers themselves were concerned they were now so supremely confident that they immediately and quietly set about their future projects, absolutely certain that they had already achieved success where all others had failed.

The Flyer that had been used on 17 December was also incidentally responsible for the first aircraft accident in history, as at the end of the day the machine was overturned by a violent gust and severely damaged; John Daniels, a local volunteer who took the historic photograph of the first flight, was injured in the process. The machine was never flown again.

The Wright Approach

At this point it is interesting to ask what the key factors were in the Wright brothers' extraordinary success. First and foremost, it appears to me, was Wilbur's attitudes, which were those of a superb engineer: He was systematic in everything he did, read critically all published material, made his own tests wherever he had doubts, designed and built the equipment necessary for conducting those tests, always made preliminary estimates and calculations before embarking on design, modified the design soon after testing the vehicle, and analysed the flight data in real time (as we would say today – he could do this because he had the numbers at his finger tips and could right away interpret observed performance in terms of design parameters). And the brothers together were ingenious in mechanical design and fabrication, and in fixing the problems as they were encountered. Between the two Wilbur was perhaps more the thinker, and Orville more the tinker – and the two covered the spectrum from research through design and development. Indeed one can say that the Wright brothers set the style and method of aircraft design that is followed to this day; only our tools are now vastly more powerful.

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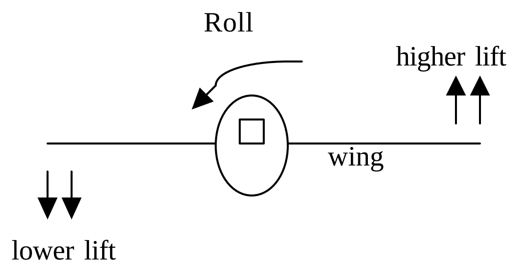
But, apart from the methodology they followed, the major technological contribution they made was to realize the importance of achieving control in all three dimensions, in particular lateral control. (See *Box* 4.) This was a crucial departure from all previous work on flight. To the Wrights, so familiar with bicycles, it was obvious that if the aircraft had to turn it would have to bank as well, just as if you want to veer left on your bicycle you will tilt left as well. So they set about designing a mechanism by which, as rudder was applied to yaw the aircraft left, a rolling moment would be applied as well on the aircraft to bank it in the appropriate sense. This they did by warping the wing, i.e. by applying a torque at the wing tips, through cable and pulley, inducing them to twist in such a way that the lift on the right wing was higher than on the left and the aircraft would roll in the right direction. It took considerable effort on their part to get the warping right (recall that their wings were light and flexible), but once they had done it they could easily make the aircraft go around in circles or even in figures of eight.

Box 4. How Active Lateral Control Works by Wing Warping

To see how an aircraft rolls, consider a simple monoplane.



To roll as shown, the right wing has to generate more lift than the left. This was done in the Wright Flyer by twisting the two wings: the trailing edge of the right wing is twisted down, increasing the lift on it, and that of the left wing twisted up, decreasing the lift on it. This provides the torque required for rolling the aircraft. An alternative (commonly used in modern designs) is to use small control surfaces called ailerons, mounted near the trailing edge of the wing outboard (i.e. towards the tips). The right aileron deflected down increases the lift on the right wing, and, with the left aileron deflected up, produces the required torque.

In the Wright Flyer the wing was warped by applying appropriate forces on the wing tips through cable and pulley. The cable was pulled from a cradle which the pilot (who was resting on it) swung with his hips, but as he moved the rudder was swung as well through other cables, giving the aircraft a gracefully banked turn.

As explained in the text, the Wright Flyer's control system was active. The principle of active control is easily illustrated. A stick hanging down from a pivot is stable, for after a small lateral deflection it eventually returns to the equilibrium position (vertically down). The same stick swung up by 180 degrees (with pivot at the bottom) can be in equilibrium, but this position is so unstable that the stick quickly falls over. However a pole resting on the palm of one's hand can be kept vertically up by juggling its base by moving the hand appropriately – i.e. by moving the palm in such a way that the overturning motion of the pole is counteracted by translating its base. The pole is thus given 'artificial' stability by 'active' control. The Wright Flyer had artificial lateral stability through the active control provided by the pilot as he swung the cradle he was resting on.

For active control to be effective the time constants of the control system must match the dynamics of the vehicle. The Wright machine was slow and light, so human agility was fast enough and human forces large enough to control the 'fractious horse' that the aircraft behaved like. With the very much bigger and faster aircraft of today the technological parameters attainable by modern control systems determine the bound for the acceptable stability characteristics of the aircraft.

Spectators of their later flights were invariably stunned by the graceful way in which the Wright flyers could circle over the airfield. Today's aircraft induce a bank by allowing the pilot to deflect ailerons, which are relatively small flaps located towards the wing tips: what the Wright brothers achieved by continuous warping of the wing, rather like what birds do, is now done by deflecting a discrete part of a much more rigid wing. Incidentally the idea of the aileron itself was also something that the Wrights had thought of – indeed it was part of the patent they took out in 1903.

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By the way this control was what we would today call 'active', i.e. it was achieved by exerting appropriate forces and moments on the craft to correct or counter whatever deviant motion it was developing at the time (see *Box* 2). Active control is to be distinguished from passive control, where the system is basically stable, and any small perturbation automatically decays returning the system to equilibrium – no human or other intervention is required. Most modern aircraft today, especially the military ones (including for example the LCA), are basically unstable, and require a complex flight control system consisting of sensors, actuators and computers to keep them flying safely. (Active controls are preferred especially on a combat aircraft as they make it lighter and more agile.)

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The Aftermath

The character of the story changes dramatically after the 1903 achievement . The brothers went ahead to make several planes during the following years, sought money from the US Army (which at first rejected their offer), negotiated with various bankers, entrepreneurs and industrialists – from whom they never obtained terms that satisfied them, started fighting legal battles with others who infringed their patents, and generally had a hard time protecting their intellectual property (as we would put it now) against a variety of smart poachers. The story of these years is often bitter. Eventually the Wrights sold their inventions in France, and in 1908 Wilbur travelled there with

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his machine to demonstrate its abilities to the skeptical and sophisticated aeronautical community of that country. (The French thought that they were the pioneers of human flight, and did not always take kindly to the Wright brothers' claims.) As Wilbur waited for good weather, Paris newspapers screamed that the Wright brothers were bluffing, and that their demonstration would be a flop. But Wilbur kept his cool, and when the weather cleared made a flight that took away the breath of the spectators and instantly converted them. The President of the Aeronautical Society of Britain, Maj Gen Baden-Powell (brother of the founder of the Boy Scout movement) immediately understood the significance of that flight in Paris, and said: 'That Wilbur Wright is in possession of a power which controls the fate of nations is beyond dispute'.

In succeeding years the world heaped praise and honours on the Wright brothers; they became wealthy as well, making shrewd business deals both in the US and in Europe. Interestingly however Wilbur was not happy as a businessman, and said he looked forward to the time when they could retire to devote themselves again to scientific research. In 1912 he died after an attack of typhoid, and control of the business now vested solely in his brother. Orville was basically an ingenious tinker, happy making and fixing anything – from printing presses to aircraft to gadgets at home, but he did not see himself as one who would devote a life time to making better aircraft. In any case, once the Wright brothers had shown that powered flight was possible, the number of people attempting to surpass their performance went up enormously, and in a matter of years all those spectacular records that the Wright brothers had established were shattered by inventors and engineers in both Europe and the United States. The Wright patents expired in 1917, and Orville sold his interests at the right time to make a fortune, and virtually retired from the aircraft business. He continued to be honoured widely by the world, and served as an adviser to NACA, the US National Advisory Committee for Aeronautics (the predecessor of today's NASA).

In a matter of years all those spectacular records that the Wright brothers had established were shattered by inventors and engineers in both Europe and the United States.

But there was one dispute with the Smithsonian Institution that took a long time to settle. They refused to recognize that the first powered flight had been made by the Wright brothers, claiming that Langley had shown the *capability* of flight (although he had not achieved it) even before the Wrights. A long and bitter dispute erupted between the two parties, and in 1928 Orville sent the original Wright Flyer to the Science Museum in Kensington, London, as apparently nobody in his own country seemed to want it. This led to a public furore in the US, and shocked many Americans into realizing that justice had still not been done to the Wrights. It was only in 1942 that the new leaders of the Smithsonian made appropriate settlements with Orville, who eventually asked for the return of the Flyer that he had loaned to Kensington. When Orville died in 1948 the original Wright Flyer made its way home, and is now preserved at the National Air and Space Museum in Washington.

The Smithsonian Institution refused to recognize that the first powered flight had been made by the Wright brothers

Thus ended the story of the invention of one of the greatest technological marvels in human history.

Suggested Reading

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Sage Bharadvaja's Vimana Prakarana

Sage Bharadvaja of Rgvedic period is endowed with the authorship of a chapter on airplanes – Vimana Prakarana – in his work *Yantra Sarvasva.* The book *Yantra Sarvasva* is not available to scholars in its complete form; it is supposed to have 40 chapters on various technology related subjects. However, the chapter on Airplanes is available through a manuscript at the Baroda Oriental Library.

A commentary and explanation on this chapter has been provided by Bhodanada of 8th century BC. This scholar refers to many earlier experts on the aviation technology and quotes their statements. The book contains eight chapters with 500 sutras written by Bharadvaja. These chapters are further divided into an average of eight subject chapters.

The work starts with a quote on *Vimana*, the Airplane – '*Vegasamnad Vimanondajanamiti*.' It means a mechanical vehicle flying in the sky at the speed of a bird. But commentators like *Lalla*, *Narayana*, *Vishvambhara* have expanded the term to mean ultimately a vehicle which can travel in all the three spaces – sky, land and water.

The text begins with a list of secrets, which a pilot should know for operating an airplane. They can be classified into three groups – learning the technology of airplanes, learning the secrets of flying and operating them to safeguard the aircraft from enemy attacks. The majority of these secrets, astonishingly, refer to presence of the enemy and avoiding detection by the enemy. The work instructs the pilot to use *Rohini Vidyut* (like radar) for detecting the presence of another aircraft. By using *Saudamini Vidyut*, it says, you can hear a conversation taking place in another aircraft. The *Vidyut* referred here cannot be loosely translated as electricity, as it is done now. It is in effect the whole spectrum of electromagnetic radiation. Through step by step instructions it asks the pilot to use appropriate mirrors (*darpana*) to create an illusion of another aircraft in the sky (*drshya rahasya*) or to 'make the aircraft vanish as if to create *Amavasya* in the brightness of the noon Sun.' (*Adrshya rahasya*)

The text has many chapters on manufacturing of the alloys that are to be used in fabricating an aircraft, the food that should be consumed during the flight, the clothing to be worn during travel, manufacturing techniques of the mirrors that are used in an aircraft, the fuel that has to be used, the wind forces (*vata shakti*) that are to be understood, the power of darkness (*tamo shakti*) which is to be shackled for creating illusions, the placement of various controls and switches (*kili*) in the cockpit, etc. The text correctly identifies the three main forces – lift, drag and yaw – due to wind experienced by the airplane as *yasa*, *viyasa* and *prayasa* respectively.

Techniques propounded for manufacturing the alloys and mirrors, seem to be copied from *Amshubodhini*, another work of Saint Bharadvaja. A study of various materials described in *Amshubodhini* of Maharshi Bharadvaja was carried out by the National Metallurgical Laboratory of Hyderabad and Jamshedpur under the instruction from Indian National Science Academy, New Delhi. This project was completed in 1991 and a report was submitted. Prototypes of the alloys as explained in the text were manufactured and they were found to have, largely, the characteristics as explained in the text. Many of these were not available in the Handbook of Metals and they were subsequently patented.

The work of Bharadvaja throws up interesting possibilities, which have not been hitherto considered.

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