VTOL AIRCRAFT

Go up, go forward, and go down

A large percentage of the population of the Western world has at least one experience of having flown inside a conventional (e.g. non-Vertical Take-Off and Landing) airplane, but only a small percentage of this population has ever been in a helicopter. And while airplanes dominate the aviation world, helicopters only fill small and often unseen niches. Other VTOL airplanes and machines are even less visible.

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Over a century ago Thomas Edison stated: 'The airplane won't amount to a damn thing until they get a machine that will act like a hummingbird - go straight up, go forward, go backward, come straight down and alight like a hummingbird' (Edison, 1905). It turns out he was quite wrong. Conventional aircraft like the Boeing 747 require relatively long runways, but have revolutionized air travel in a way few could ever imagine. Aircraft like the Jumbo Jet have made air travel available to the masses. Nonetheless, Vertical Take-Off and Landing (VTOL) aircraft could bring along advantages that could never be acquired with conventional aircraft.

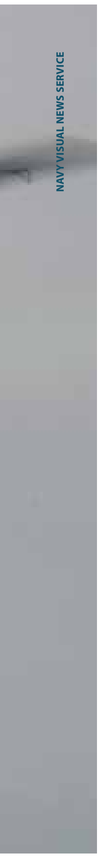
Even far before the Wright brothers performed the first powered flight in 1903, designing an aircraft that could hover was naturally one of the goals of Aeronautics. Leonardo Da Vinci was a pioneer in this field. He envisioned a platform that could be take-off vertically by means of an aerial screw spun by human-muscle power. Balloons surfaced in the time that followed, and dirigibles of the balloon were popular near the end of the 19th century. Still, heavier-than-air airplanes could only operate from long flat spaces such as runways, level fields or calm surfaces of water.

However, some wondered if the same force that pulls an airplane forward could be used to pull an aircraft straight up (i.e. take off vertically). These thoughts hint at why VTOL aircraft are not as practical as they perhaps sound. The thrust and drag forces are usually quite a bit smaller than the lift and weight forces. A conventional aircraft's thrust might only need to be 10% of its weight in order for the airplane to be pulled forward fast enough to generate enough lift to stay in the air. However, typically this ratio is close to 20%. This means an airplane that weighs 100tons might only need 20tons of thrust to stay in the air. Obviously, a VTOL aircraft that has a weight of 100tons needs 100tons of thrust to get off the ground. Since a conventional aircraft can only deliver a thrust of about 20% of its weight, a VTOL airplane needs five times the thrust of an equivalent non-VTOL aircraft.

This might not seem like a difficult issue. One could argue that larger engines will provide the plane with enough thrust to take of vertically. However, the engines carried by a VTOL airplane would weigh as much as five times or more as the engines carried by an equivalent airplane that does not take off vertically. It is important to know that the engine group is one of the heaviest component groups of an airplane. As a consequence, the useful payload is greatly reduced, and the added weight means the range of the VTOL aircraft will be small in comparison to the range of an equivalent non-VTOL aircraft.

Despite this major challenge, an aircraft that could use thrust for lift seemed like a goal worthwhile achieving. Helicopters were successfully flown for the first time in the early 1930s. Similar to today, their roles were limited to situations where the ability to land anywhere and hover were important. These roles include search and rescue missions, medical evacuations, military troop transports, construction aid, and journalism. But the helicopter's short range, relatively slow flying speed, extraordinary mechanical complexity, and extreme fuel demands designated that a regular winged airplane was used whenever possible.

While an aircraft that uses thrust to lift off vertically will evidently be heavier and more complex than a regular airplane, it



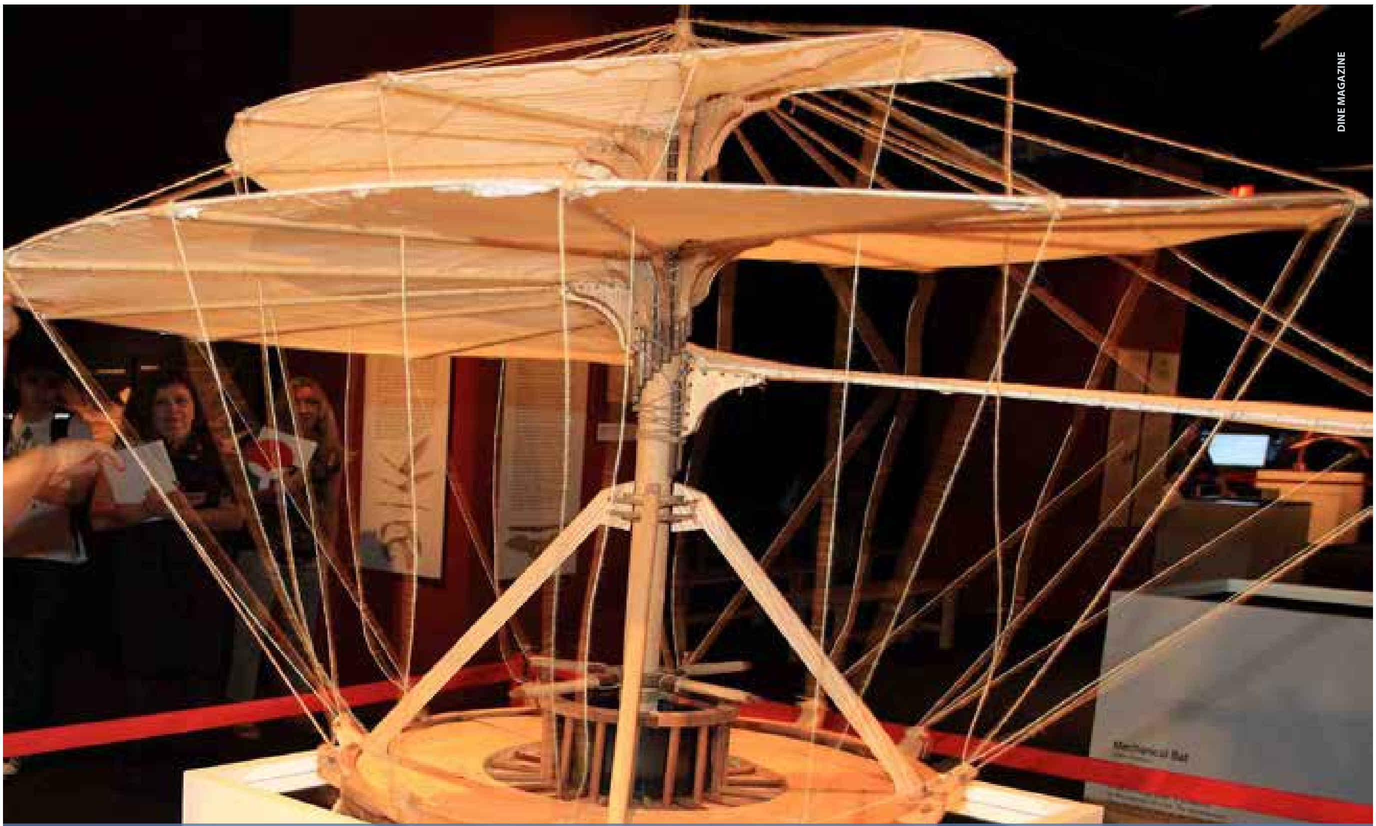


Figure 1. Leonardo Da Vinci devised plans to make a VTOL device using an aerial screw

does not have to be as bad as a helicopter. Helicopters hover all the time. If the aircraft is only required to hover during take-off and landing, while during cruise the thrust can be directed forwards for conventional flight, the aircraft can fly faster, further, and longer, without the need for much more fuel. If this kind of dual-mode VTOL technology could be developed, most of the disadvantages of the helicopter would be abolished.

When turboprops were first being introduced right after World War 2, some people noticed that these engines could provide more thrust than the total weight of a conventional airplane. Some airplanes could climb vertically for a certain period of time. Hence, their weight was completely cancelled out by the thrust of the engines. Theoretically, such an airplane can be put on its tail like a rocket, and take off straight up like a rocket. These airplanes are called 'tail-sitters'. In the end, the reason why the tail-sitter concept was abandoned was that any commercial application is obviously non-viable. Just try and imagine how passengers would get in and out of a vertical tube in which they are laying flat down. Furthermore, military pilots stated it would be very difficult to land such an airplane on an aircraft carrier.

Now that the thrust issues were solved, engineers focussed their attention on control. But how is a VTOL aircraft controlled? In order to control any given airplane, the aircraft needs airflow over the control surfaces on the wing and tail, something a VTOL aircraft does not experience during vertical take-off and landing. All VTOL airplanes face this problem and there are a handful of standard solutions.

One could place control surfaces in the downwash airflow of the propeller, eject high-pressure air from little holes in the wingtips, nose and tail or change the angles of the blades on the propeller so that it pulls the airplane in different directions.

A solution found often is to turn the orientation of the engines instead of turning the orientation of the whole aircraft. In a so-called tilt-engine design the engines are tilted forward to enable forward flight and control. This was not possible for a long time since the engines were not powerful enough to keep the plane in the air and accelerate it forwards at the same time. The tilt-engine approach was tried in many variations, including some aircraft where the wings turn upwards along with the engines. Eventually, after many accidents and failures spread over several decades, this concept became operational in 1989 in the form of the V-22 Osprey (See cover visual).

Instead of moving the orientation of the entire engine, one could also direct the airflow. This was tried in propeller airplanes where the propellers were tilted up into a helicopter configuration and in jets where the engine nozzles could similarly be turned downwards instead of backwards. This thrust-vectoring approach became operational in the infamous Harrier jump jet.

Instead of turning the airflow at all, one could also deflect the air downward after the engines have expelled it. This involves placing bucket flaps behind the engines. While some experimental VTOL aircraft could take-off and land vertically with this system, the system was found most useful in short take-off and landing (STOL) aircraft like the C-17.

A fan mounted inside a duct can be made much more efficient than a prop, since there are fewer blade-tip losses, and since the duct itself can act like a diffuser and nozzle, sucking air in the front and accelerating it out the back. Many VTOL airplanes use ducted fans. However, the only successful design up until this day is the Joint Strike Fighter produced by Lockheed Martin.

One last approach involves having dedicated engines to produce lift. These engines turn off while flying forwards during cruise. Instead of having one massive engine and a mechanism to rotate it, the aircraft could also have one big engine or a few small ones directed vertically and a small engine mounted horizontally. This may sound like a good idea, but in practice this concept has been proven to be unsuccessful.

References

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