4-13

p42

Crossed wings fly faster

Aerodynamics limits a helicopter's speed and prevents most aircraft from flying vertically. But suppose an aircraft could take off as a helicopter and then turn into a fixed-wing aeroplane?

George Marsh

BY THE end of the century machines will be flying that defy straightforward descriptions such as "helicopter" or "aeroplane". Bell, Boeing-Vertol and Sikorsky in the US are already flight testing "convertiplanes" that are hybrids of both. Flight tests on the lift and propulsion system for the latest of these hybrids, the "X-wing", are scheduled to begin in a few weeks.

At the root of this revolution are developments in aeronautics that make possible efficient machines that can take off and land vertically and fly forwards at high speed. The problem with a conventional helicopter is that aerodynamics prevents it from flying faster than about 200 knots, too slow to be ideal for commuter flights or for carrying troops or supplies over more than short ranges. It is impossible to fly faster because the blades of a helicopter's main rotor behave differently as they advance and retreat relative to the direction of flight. In a vertical flight on a windless day, each of the rotor's blades creates an equal amount of lift. As the vehicle begins to move forward, that movement creates a flow of air over the blades. An advancing blade on one side of the helicopter creates more lift than a blade on the other side which is retreating from the oncoming air. The faster the vehicle flies forward, the greater is the difference in lift created on the two sides of the vehicle.

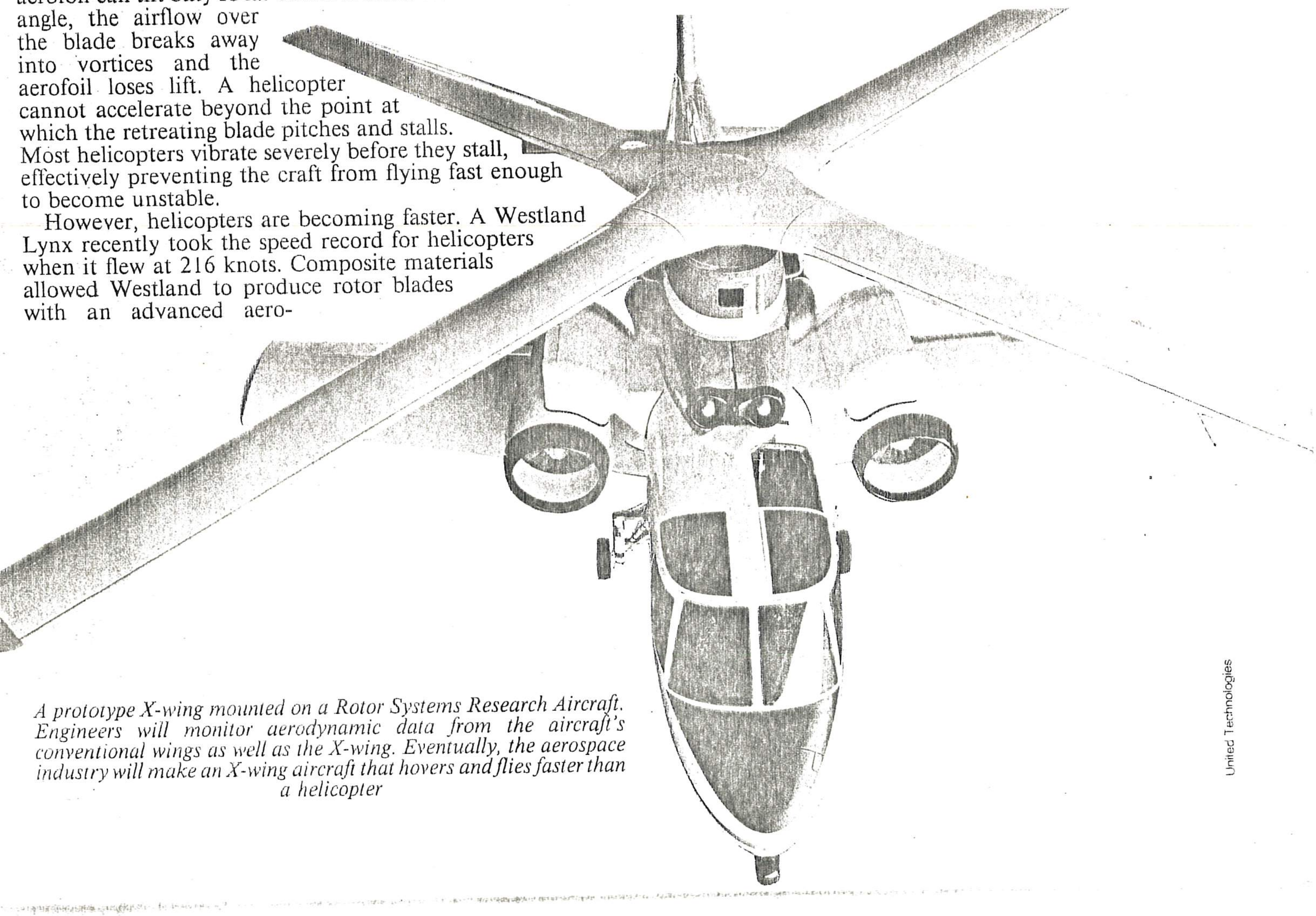
Helicopter designers counter this asymmetry by making each blade adjust its pitch as it rotates. As the blade retreats its forward edge pitches up to generate more lift. However, an aerofoil can tilt only so far before it stalls. At a certain critical angle, the airflow over the blade breaks away into vortices and the aerofoil loses lift. A helicopter cannot accelerate beyond the point at which the retreating blade pitches and stalls. Most helicopters vibrate severely before they stall, effectively preventing the craft from flying fast enough to become unstable.

However, helicopters are becoming faster. A Westland Lynx recently took the speed record for helicopters when it flew at 216 knots. Composite materials allowed Westland to produce rotor blades with an advanced aerodynamic form. The work was done with the Royal Aircraft Establishment under the British Experimental Rotor Programme. Perhaps not surprisingly, the results are colloquially known as BERP blades. A BERP blade has an enlarged tip. Air flows more smoothly over this tip which means that a retreating blade can pitch to a greater angle before it stalls. But this is all that the new design has done. The aerodynamic constraint on a helicopter's forward speed remains fundamental. Enter the "transition aircraft" or "convertiplane".

The idea of a helicopter that can turn into an aeroplane as it flies, and vice versa, is not new. Only now, though, can technology deliver strong, light materials and control systems sophisticated enough to manage the transitions. Current developments, particularly in the US, suggest that transition aircraft are hovering over the horizon.

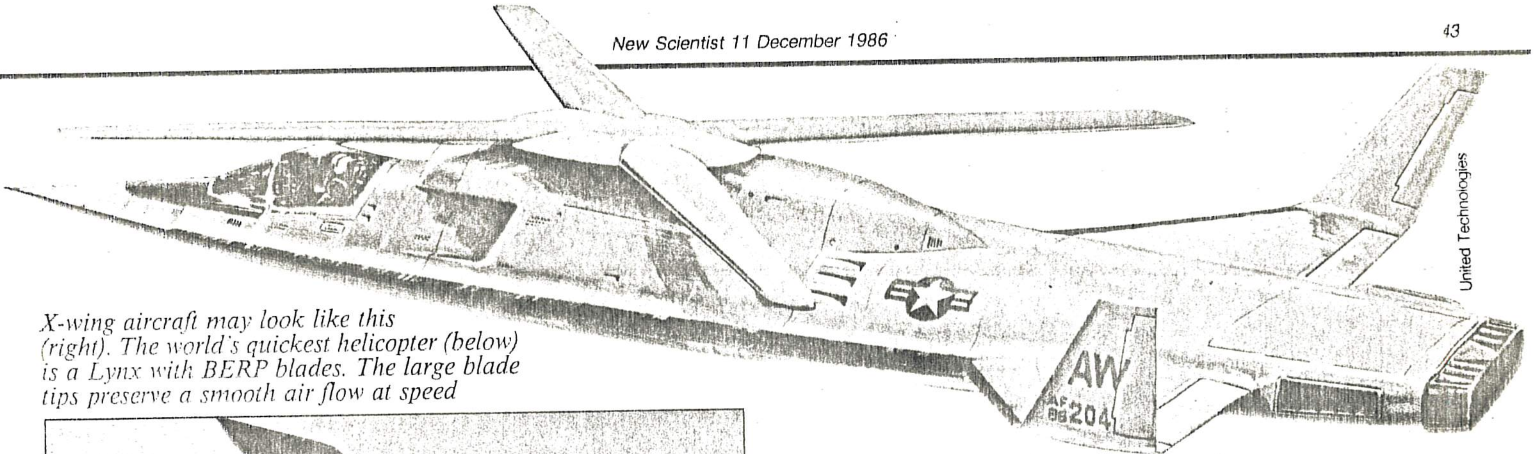
As long ago as 1977, Bell in the US flew a prototype aircraft with two vertical rotors on wings on the sides of the aircraft. The rotors took the aircraft aloft. After take-off, the rotors and their engines tilted forward so that the aircraft could accelerate. They gradually turned through 90 degrees to become propellers. As the aircraft built up speed, the wings began to support it and the vehicle could then fly forward as fast as its engine power and shape permitted.

The Bell-Boeing Vertol V22 Osprey, developed from that prototype, promises to be first of the new aircraft to enter service. Osprey is being developed under the US Joint Services Advanced Vertical Lift Aircraft Programme. It will



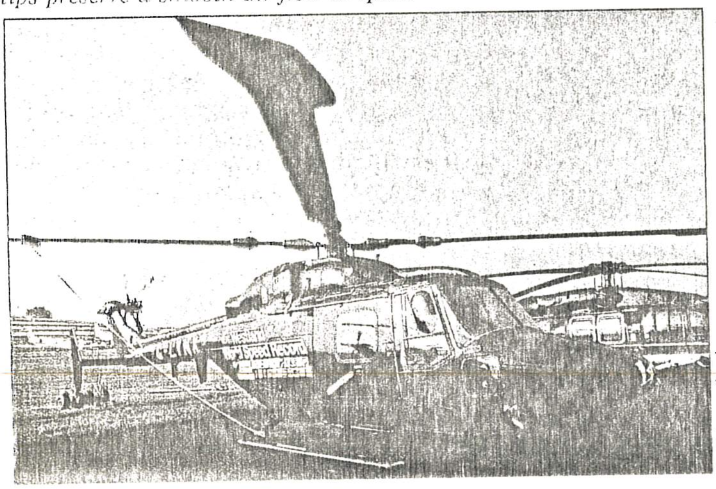
A prototype X-wing mounted on a Rotor Systems Research Aircraft. Engineers will monitor aerodynamic data from the aircraft's conventional wings as well as the X-wing. Eventually, the aerospace industry will make an X-wing aircraft that hovers and flies faster than a helicopter

United Technologies



United Technologies

X-wing aircraft may look like this (right). The world's quickest helicopter (below) is a Lynx with BERP blades. The large blade tips preserve a smooth air flow at speed



Flight International

carry 24 troops and a load of 4500-kilograms over 370 kilometres for the marines or the army. It will rescue four people up to 850 kilometres away and it will fly anywhere on special operations faster than 300 knots. This tilt-rotor vertiplane, as it is known, is due to enter service in 1991.

Another way to overcome the speed barrier faced by conventional helicopters is to mount two rotors, one above the other, on the same shaft. They rotate in opposite directions. An advancing blade on one side balances a retreating partner on the other side of the craft. As there is always an advancing blade on each side of the vehicle, the rotors maintain symmetrical lift. This deceptively simple arrangement is referred to as the advancing blade concept or ABC.

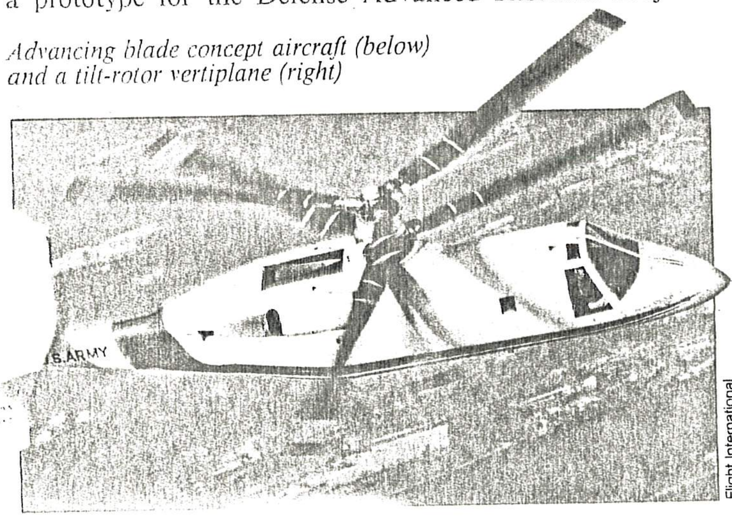
The ABC requires stiff blades that cannot collide with each other in the course of the tortured motions typical of a rotor in flight. Only modern composite materials are light and rigid enough to prevent such collisions. Sikorsky chose graphite and glass fibre composite blades for its experimental ABC helicopter, the XH.59, which exceeded 250 knots in 1981.

The latest thing in hybrids is the X-wing. The X-wing has four stiff blades which form a rotor for vertical flight. They lock into a fixed "X" position, with each blade at 45° to the fuselage, to act as wings for cruising. Sikorsky has developed a prototype for the Defense Advanced Research Projects Agency and NASA. Enthusiasts claim that X-wing could leapfrog both the ABC and the tilt-rotor. Sikorsky "rolled out" an X-wing mounted on a Rotor Systems Research Aircraft (RSRA) in August. The RSRA is a "flying wind tunnel" designed to test advanced rotors. Two jet engines and a 15-metre wing guarantee that the RSRA stays aloft while it tests the X-wing which is driven by two turboshaft engines. Engineers can monitor data from the RSRA's wing and the X-wing separately. They will stop and start the X-wing while in flight.

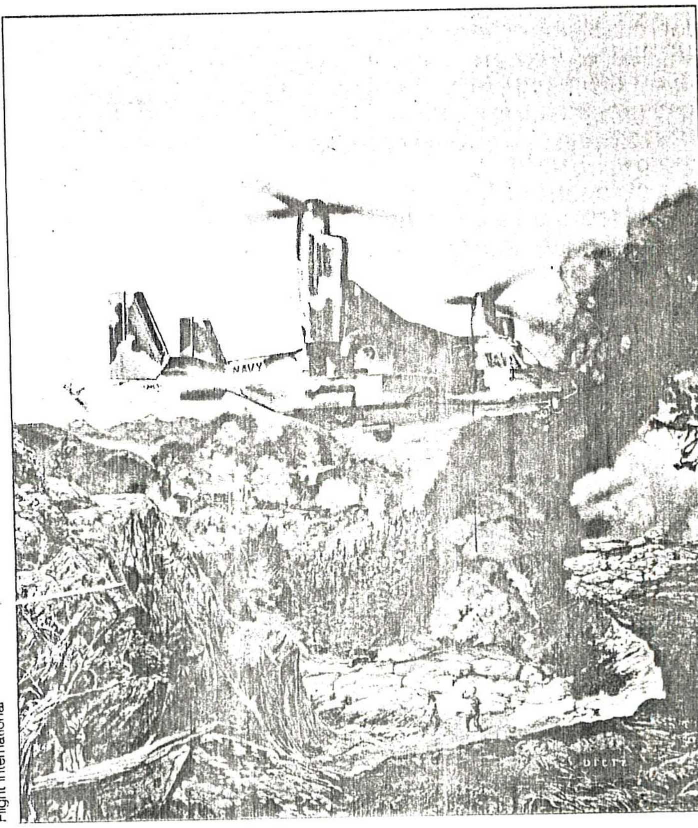
Tests on a scale model of a prototype X-wing aircraft suggest that it could fly at up to 400 knots—ideal for commuter flights says the company. Much of the excitement of the concept lies in the advanced technology required to overcome formidable engineering problems. Imagine, for example, how to maintain lift during the transition from vertical to horizontal flight. The rotor has to slow to a standstill, lock and then become wings—all within 30 seconds. The X-wing must be able to change configuration safely while flying slowly near the ground.

Work by a British scientist at the University of Southampton in the early 1960s will make the X-wing's transitions possible. Aerodynamicists had long speculated on the possibilities of creating lift by blowing or sucking air over a wing when an aircraft flies too slowly to keep airborne. Such a mechanism could, theoretically, keep a helicopter aloft as its rotor slows to a stop.

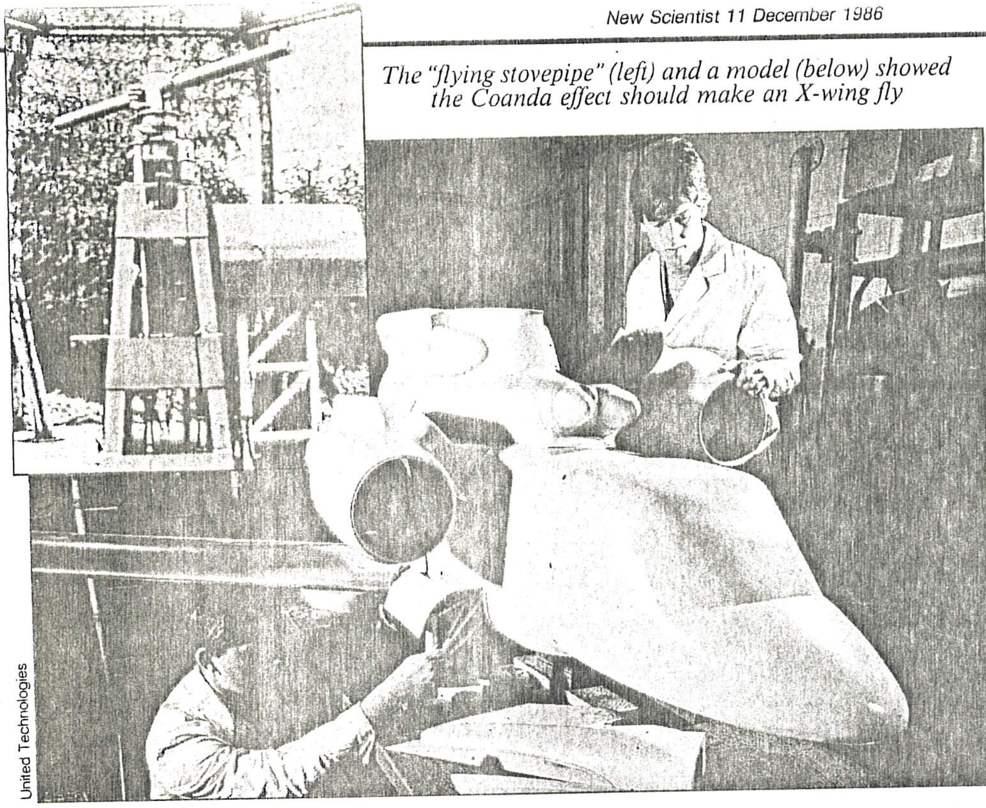
Advancing blade concept aircraft (below) and a tilt-rotor vertiplane (right)



Flight International



Flight International



The "flying stovepipe" (left) and a model (below) showed the Coanda effect should make an X-wing fly

Ian Cheeseman at Southampton realised that the Coanda effect—named after the Romanian Henri Coanda who discovered it in 1910—is the key to the mechanism. Essentially, Coanda recognised that air forced over a curved surface tends to follow the curve. The stream entrains the surrounding air and accelerates it over the curve to create lift, just like the air flowing over the top surface of a conventional wing. A curved surface can thus become an aerofoil. Cheeseman built a blown cylindrical rotor—which was usually called the "flying stovepipe"—to demonstrate lift and proposed a rotor system that could maintain lift even when stopped, a feature essential to the X-wing.

An X-wing has symmetrical blades. The blades have curves of similar shape on their top and bottom faces so they can "fly" both forwards and backwards. When the blades are locked, all four contribute lift derived from air drawn over their top faces by compressed air from their trailing edges, and the airflow created by the vehicle's forward speed. The blades are all wings. It does not matter which two blades are leading and which two are retreating. The blades rotate like a traditional helicopter's rotor when the X-wing flies slower than its transition speed. Unlike a conventional rotor, however, X-wing does not adjust the pitch of its blades. Rather, it relies on the Coanda effect to preserve symmetry of lift as air flows out of slots in the trailing edge of each blade.

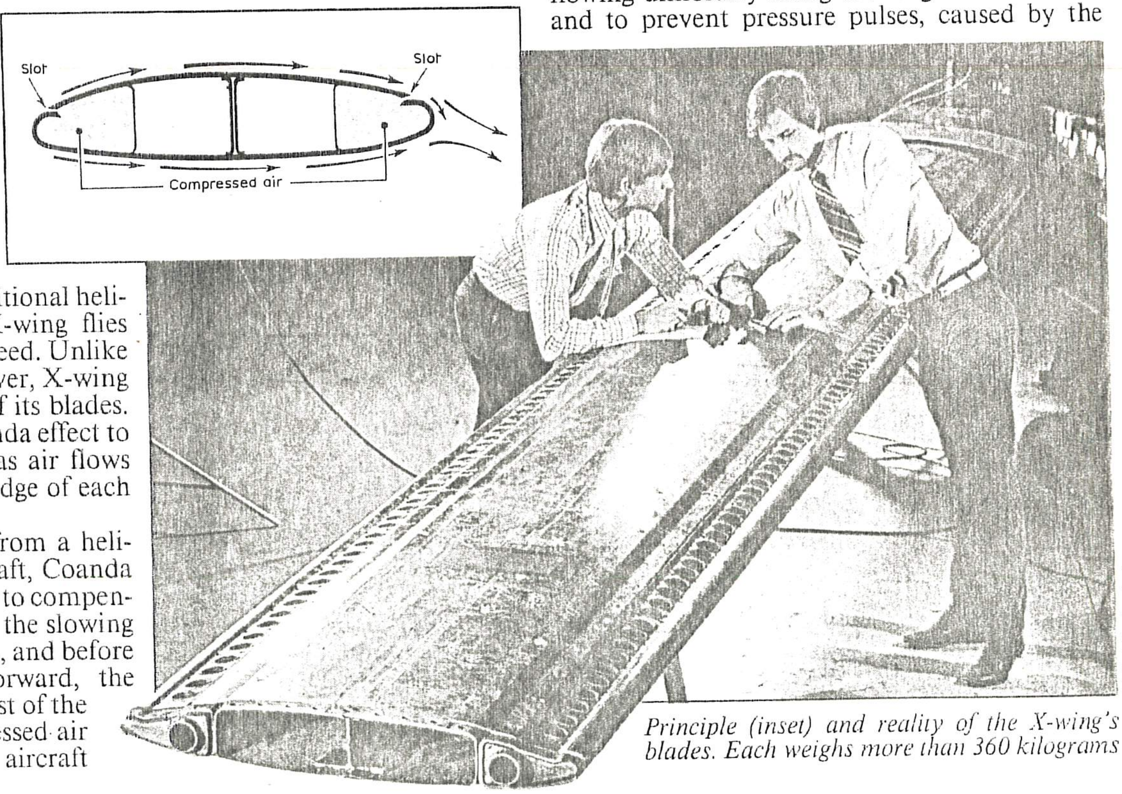
As the vehicle changes from a helicopter into a fixed-wing craft, Coanda lift over all blades increases to compensate for the loss of lift from the slowing rotor. When the rotor locks, and before the vehicle accelerates forward, the Coanda effect provides most of the lift. The current of compressed air gradually reduces as the aircraft accelerates and creates lift from the fixed aerofoil.

If the principle of an X-wing is fairly simply stated, the engineering needed to bring it about is another matter. It was impossible to build an X-wing until three technologies had matured sufficiently: the control of air circulation (or pneumodynamics), digital electronic control and advanced composite materials.

Aerofoils normally manoeuvre an aircraft in the air as well as supply lift. X-wing will be able to manoeuvre because compressed air passes to the slots in its blades through a series of ports around the rotor's hub. The ports vary the mass, flow and velocity of the air that they deliver to each blade. This generates differential lift in each aerofoil which rolls (turns) and pitches (raises or lowers) the aircraft.

A plenum, shaped like a doughnut, surrounds the rotor shaft. The plenum contains 48 air valves, in two layers of 24, spaced every 15 degrees. The top layer feeds compressed air to the slots in leading edges of the blades. The bottom layer of valves feeds the trailing edges. As each blade moves past a pair of valves, air passes, via ducts in the blade, to the slots. When the pilot wants to roll the aircraft, the valves on one side of the plenum open more than those on the other. This increases the lift on each blade as it passes the open valves. Similar adjustments produce pitching moments. To move up or down, the pilot opens or closes all the valves together.

Controls on the slots' apertures supplement valve control. The slots remain closed until the air pressure inside each blade exceeds the pressure outside by at least 20 kilopascals (or about one fifth of normal atmospheric pressure). None opens fully until the pressure difference reaches 40 kilopascals. Maximum pressure in the plenum is about 120 kilopascals. Springs in the slots are adjusted to keep the air flowing uniformly along the length of the blade and to prevent pressure pulses, caused by the

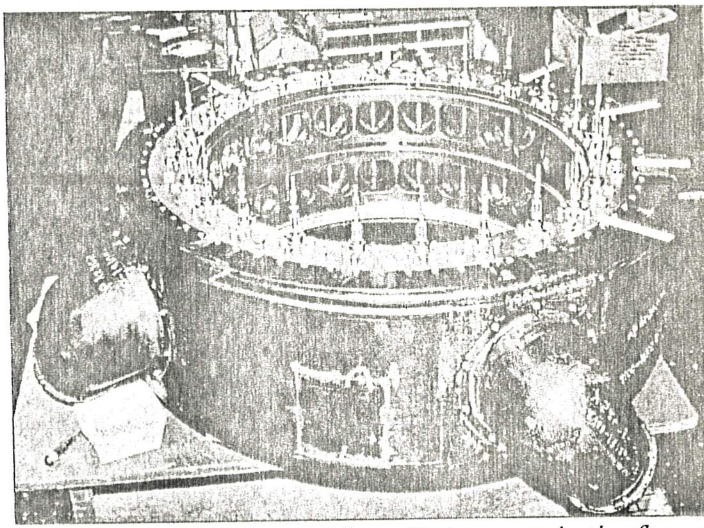


Principle (inset) and reality of the X-wing's blades. Each weighs more than 360 kilograms plenum's valves, reaching supersonic speeds on their journey down the inside of the blade. A supersonic air flow inside a blade would set up a shock wave and cause potentially dangerous vibrations.

The X-wing on the RSRA is 19 metres in diameter and it requires a substantial flow of air. Two 1120-kilowatt turbojets turn the rotor and drive a compressor that draws air from scoops outside the fuselage and forces it into the plenum. These engines also drive electrical generators and hydraulic pumps.

Conventional helicopter blades are flexible, as you can see by looking at how they droop when an aircraft is parked. The blades stiffen enough to lift a vehicle only under the influence of centrifugal force. However, no centrifugal force acts on X-wing blades when they are locked. They must rely on their own inherent stiffness. In fact, X-wing blades must be stiffer than any conventional rotor because the two forward blades project into the airstream at an angle, which places large aerodynamic loads on their tips.

A few years ago it would have been impossible to produce a blade stiff enough for X-wing. The current X-wing blade consists of a symmetrical, composite plastics envelope, formed over a graphite I-beam for support. The beam is attached to a lightweight titanium hub. The blades are nearly 1 metre across at the root and more than 0·7 metre across at the tip. Each blade weighs more than 360 kilograms.


United Technologies

The plenum at the centre of an X-wing controls the flow of compressed air to each blade. The top layer of valves feed the slots on the leading edges of the rotating blades

Computer-controlled flight

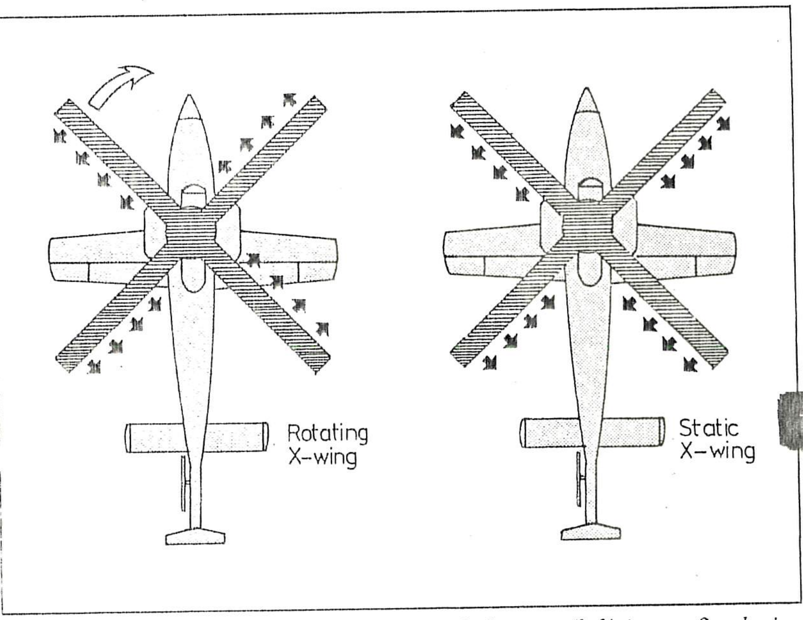
One complication faced by the designers of the X-wing is that compressed air can heat the surfaces of the blades to around 170°C. They maintain the material's integrity by using a graphite fibre in a matrix of a resin called bizmaleimide, together with adhesives that resist high temperatures. One benefit of hot blades is that they prevent ice building up.

The complexities of controlling engines, the speed of the rotor, the pitch or lift of each blade at any moment, rotor locking, air flow and velocity are well beyond the capabilities of any human pilot. The designers of X-wings have therefore introduced a computer between the pilot and the machine's actuators. The computer controls the vehicle in response to the pilot's commands.

The flight control computer (FCC) is at the heart of a digital system that controls the machine's complex pneumodynamics. The digital system carries out a far more comprehensive role than a conventional flight control system. The computer, which has 20 microprocessors sends signals to the X-wing's actuators electrically rather than mechanically. To guard against failure, this "fly-by-wire" system is in fact four systems in one. Only one needs to work for an X-wing craft to fly, so the whole system is said to have four levels of redundancy. Sikorsky describes it as "one of the most powerful flight control computer systems ever built".

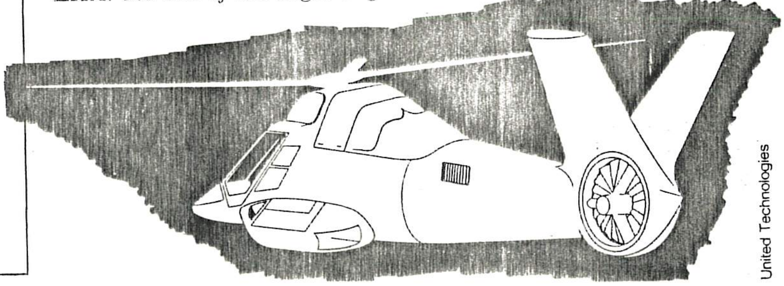
The FCC monitors signals from a sensor in the craft and controls the aircraft in every axis. The FCC switches the 48 actuators controlling the flow of air from the plenum to the blade slots. Other actuators control the compressor, the collective pitch of the blades and stop and start the rotor. Accelerometers monitor how the vehicle rolls and pitches in response to the pilot's control movements. The FCC will also smooth the ride of passengers in an X-wing. To dampen vibrations, the computer sends up to five pulses of air into the blades every time the rotor revolves once. The system also controls the rotor brake, clutch, and a motor that moves the X-wing to its correct position should the "smart" brake fail. Each blade must sit accurately at 45° to the fuselage when the aircraft turns from a helicopter into an aeroplane.

Not all future vertical take-off aircraft will be rotary-winged or transition aircraft. The vectored thrust aircraft is already familiar as the Harrier and the American AV8B "jump jet". The Phalanx organisation in California has proposed a modern vectored thrust aircraft, based on a small, light airframe fitted with a powerful turbofan. Phalanx's calculations show that its design should achieve an astounding performance by employing the latest composite, aerodynamic and engine technologies. Meanwhile, work continues on the "light helicopter experimental", or LHX, which will develop the traditional helicopter about as far as it can go. But, as they say at Sikorsky, only the X-wing is the shape of wings to come. □



When an X-wing changes from a helicopter (left) into a fixed-wing aircraft (right), Coanda blowing on two blades must shift from one edge to another. The rotor halts in 30 seconds

LHX: the end of the beginning?


United Technologies

George Marsh is a technology journalist.