Where aircraft FEAR TO GO

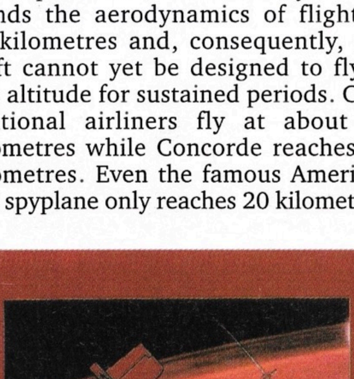
Just 30 kilometres above you is one of our planet's most inaccessible regions.

Ben Iannotta looks at the plans for exploring it

THE conditions are hostile. The air is so thin that anybody exposed to it would lose consciousness in seconds and yet the winds are smooth and swift. The sky is a deep velvet blue and the temperature a freezing – 65 °C. There is no moisture and nothing lives here.

This is not Mars but the region 30 kilometres above the Earth's surface. Few have visited and none have stayed for long—just a handful of rocket plane pilots and high-altitude balloonists.

The problem is that nobody understands the aerodynamics of flight at 30 kilometres and, consequently, aircraft cannot yet be designed to fly at this altitude for sustained periods. Conventional airliners fly at about 10 kilometres while Concorde reaches 15 kilometres. Even the famous American U-2 spyplane only reaches 20 kilometres.



True, a few supersonic and hypersonic aircraft have reached this altitude. In the 1960s, the American X-15 rocketplane forced its way to the edge of space at an altitude of 120 kilometres, albeit for only a few minutes. Modified versions of the Russian MiG-25 fighter plane have reached 30 kilometres for extremely short periods of time. But extended flight at this altitude has never been possible.

That is set to change. Researchers at NASA's Dryden Flight Research Facility in California are planning to hoist an uncrewed experimental aircraft to 30 kilometres using a balloon. They then plan to drop it nose first to see how it flies.

The $5-million project is called Apex and the results will be used to build research aircraft that can fly reliably for long periods at these altitudes. These aircraft will be hugely important for monitoring the atmosphere, remote sensing and surveillance. They may even be suitable for exploring other planets such as Mars, where the aerodynamic conditions are similar to those on Earth at 30 kilometres above the surface.

Naturally, though, the first step is to develop an aircraft that can fly in Earth's atmosphere. But because of the strange laws of aerodynamics that Apex will experience, the NASA team cannot rely on conventional methods of design. For example, models of Apex cannot be tested in a wind tunnel. Instead, the team is relying entirely on computer predictions of what will happen. Indeed, they hope the real flights will help improve their computer simulations.

"The worst case scenario is that it's a completely different flow regime and we have to go back to the drawing board," says Mark Drela, an aerodynamics expert at the Massachusetts Institute of Technology who designed the aircraft's wing. Even if the computer design is wrong, he insists that the aircraft cannot go out of control. "It'll just drop faster than we expect."

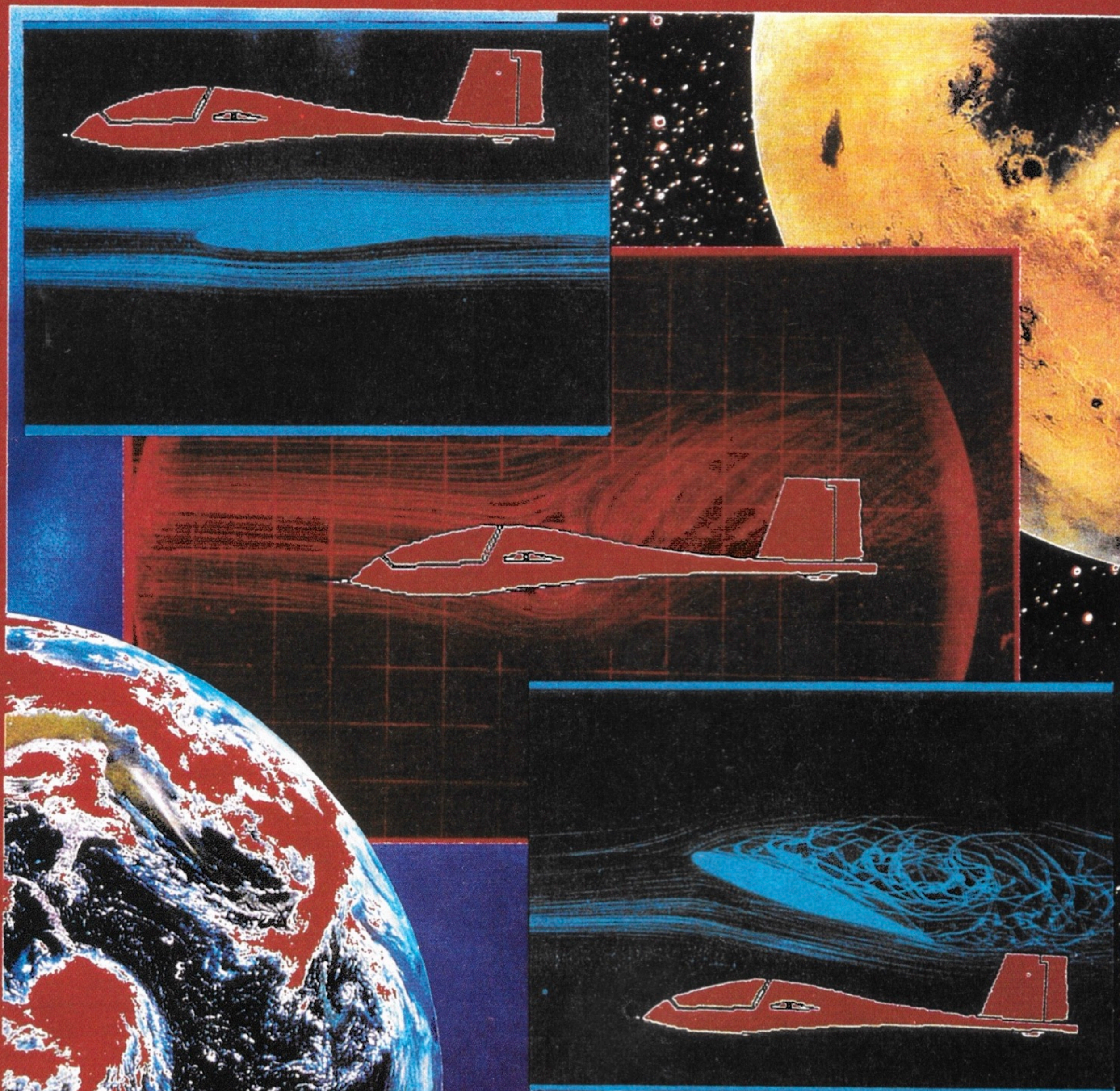
The lack of wind-tunnel testing may seem like an oversight. Wind-tunnel tests are extremely useful because they allow researchers to test small-scale models so that the design can be modified before expensive full-scale aircraft are built. But even if Drela had wanted to test his design in a wind tunnel, he could not. Peculiar as it may sound, the aerodynamics of flight at 30 kilometres cannot be recreated in this way.

Wind-tunnel tests work because the flow of fluid over a scale model can be made to mimic the flow on a larger scale by manipulating factors such as the speed of the flow, its density and viscosity. Together these determine a factor known as the Reynolds number and it is this that characterises the flow.

Reynolds numbers vary over many orders of magnitude. The flow around a dirigible can have a Reynolds number in the billions, around a jet aircraft in the tens of millions, while insects cope with Reynolds numbers in the thousands. In simple terms, the number tells engineers how "sticky" the air is within the layer flowing across a wing. All that a wind tunnel must do is reproduce over a scale model the "stickiness" that an aircraft experiences in real flight.

Of course, there are limits to how successfully this can be done, especially because the fluid of choice for most wind tunnels is air at atmospheric temperature and density. Without changing the

Illustrations: Chris Draper



density or viscosity of the fluid, engineers are limited to altering the size of their models and the speed of the airflow. Because of these limits, most wind tunnels are good at reproducing airflows in the range of millions to tens of millions.

But the flow over Apex's wings will have a Reynolds number of 300 000, about the same as a hawk's. To mimic this, a wind tunnel model would need to have a wing span of just 2·5 centimetres and measuring the flow around such a small model would be well-nigh impossible. "You just can't put instruments on such an itsy-bitsy little model," says Drela.

Low Reynolds numbers cause other problems. In these conditions, the viscous properties of air make it much more difficult for turbulence to form. Since turbulence plays an extremely important role in reducing the amount of drag that aircraft experience, without it an aircraft must overcome huge forces to move through the atmosphere.

"The flow around Apex is rather like the flow around a golf ball," says Drela. "In fact, they have similar Reynolds numbers." Purely spherical golf balls are notoriously poor fliers. When hit, they do not travel far because the flow around them is smooth. So to create drag, golf balls are dimpled. "It's dramatic. Turbulence can reduce drag by a factor of 2," says Drela.

This is one of the reasons why wind tunnel tests are futile. Small amounts of turbulence form in the flow as the air passes through fans and veins inside a tunnel. "This kind of small-scale turbulence never occurs in the atmosphere," says Drela.

Most of the time it can be ignored. When an airliner's wing is tested, for example, the "free stream" turbulence is insignificant compared with the turbulence created by the wing. But for low Reynolds numbers, the free-stream turbulence is large compared with that created by the wing. It can even trigger more turbulence, an effect known as "tripping", and this can dramatically reduce the drag. "But you'd never know whether the drag was being reduced by the wing design or the free stream turbulence," says Drela. This problem lies at the heart of Apex's wing design—which must be carefully shaped to encourage the formation of turbulence.

At the same time, the design must tackle another problem caused by the air's viscosity. "The thick, sluggish boundary layer is prone to separate from the upper surface of the wing," says Al Bowers, another aerodynamics expert at NASA. When this happens, the aircraft suffers the catastrophic loss of lift known as a stall.

Engineers accept that there is little they can do to prevent the boundary layer bubbling away from the front of the wing. But there is a neat way out of the problem: the trick is to taper the aerofoil so that the boundary layer reattaches several centimetres down the wing. To pull this off, Apex must fly at about two-thirds the speed of sound, just fast enough to accelerate the air flowing over the top of the wing beyond the speed of sound.

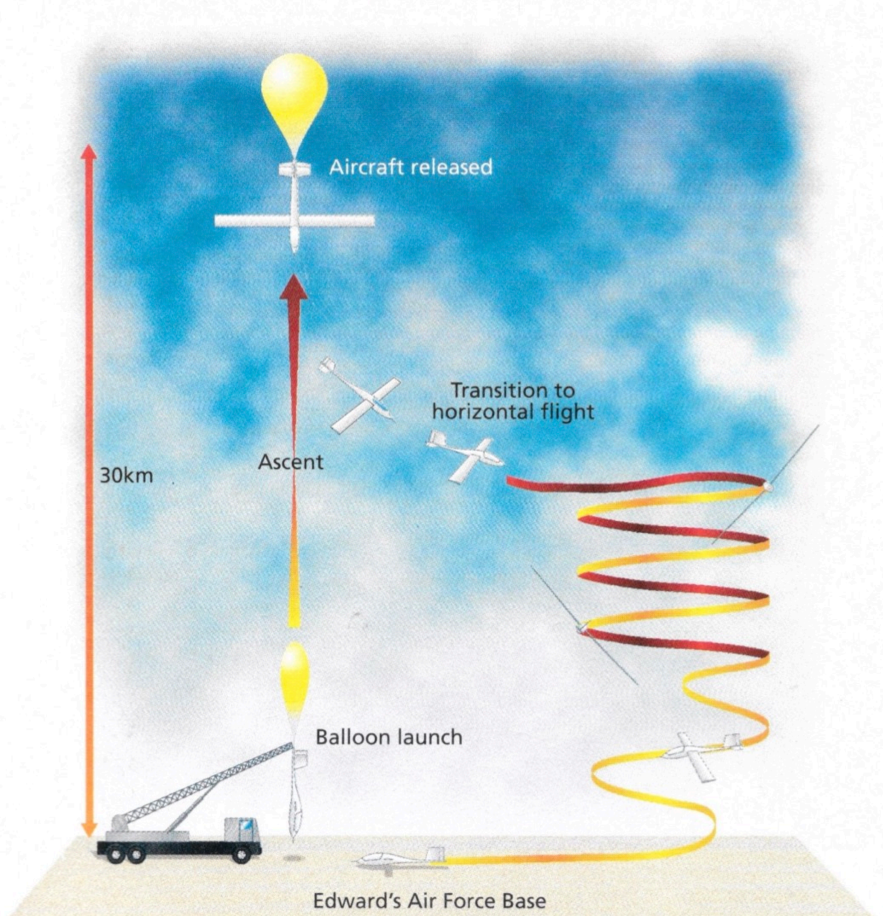
This creates a shock wave that sends ripples of turbulence through the boundary layer. This has the double benefit of reattaching the boundary layer and creating the turbulence necessary to reduce drag. Meanwhile, the rest of the airflow is subsonic. "You are between a stall where there is not enough lift and the region where you get shock waves," says Jeff Bauer, chief engineer on the project. "You're flying up there on a knife edge."

Drela can only hope that his design will do the trick. The aircraft has the appearance of an ungainly glider with a wingspan that is nearly twice the length of its 6·7-metre fuselage. Nevertheless, the design has been fine-tuned using computer models with low Reynolds number airflows, a technique known as computer fluid dynamics or CFD. "CFD modelling is common," he explains. "But usually the models are calibrated using wind-tunnel tests," an option that is not possible with Apex.

Instead, NASA will use the results from the real flights of Apex to calibrate the CFD simulations. A section of the aircraft's wing will be riddled with holes connected to sensors that will measure the distribution of pressure over the wing. At the same time, an array of metal tubes called a "wake rake" will protrude behind the trailing edge of each wing to measure the amount of turbulence as it flies.

So after the flight, this data will help physicists to reconstruct the airflow to

Down to Earth: Apex will make its first flight at 30 kilometres without ever having been tested in a wind tunnel. NASA can only hope its computer predictions are correct



find out where the boundary layer has separated and the amount of turbulence that has formed. It will also calibrate the team's CFD models, anchoring the data. Hence the nickname NASA engineers have given to Apex of the "wind-tunnel in the sky".

And if the problems with aerodynamics weren't bad enough, building a machine that can function at 30 kilometres is equally tough. With the temperature at – 65 °C, it might seem that the challenge would be to keep Apex warm. In fact, it is just the opposite. The mechanical actuators that move Apex's ailerons and flaps generate heat, but the air is so thin

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at this altitude that there aren't enough molecules to draw this heat away.

The solution the Apex engineers have come up with is to place small metal plates near the actuators to conduct heat away and radiate it out into the atmosphere. The technique has been used before but never at this altitude, says Bauer. The plates will be installed on the underside of each wing so they are out of the sunlight. "We'd also hate to disturb the flow on the top surface," he adds.

Then there are the aircraft's electronic systems, such as the flight-control computer and the electronics associated with the experiments—which also generate heat. "We're especially concerned about the balloon ride up," Bauer says. Over the first 10 kilometres, the instruments have to be kept warm as the temperature plummets, then at higher altitudes the problem becomes one of cooling. Just how this will be solved isn't yet clear.

Nevertheless, engineers began constructing the outer shells of two Apex aircraft in February. For this job, NASA has turned to a small company near Los Angeles called Advanced Soaring Concepts, which builds everything from gliders to components for Formula 1 racing cars and amusement park rides.

Settling on a final design has not been easy. The aircraft must be extremely light—only 270 kilograms, about the weight of three men—and yet cope with forces five times greater than gravity. "We're fighting weight like crazy to fly at that altitude," says John Del Frate, who oversees the Apex project. At the same time, the wings must remain rigid because any twisting will influence the pressure measurements. A twist of more than half a degree could ruin the results. "We're at the edge of what is doable," adds Del Frate.

Initially, the structure was built from carbon composite. But engineers at Advanced Soaring Concepts had their doubts when experiments showed that the carbon composite wings would twist by as much as 4 degrees. The only way to make them stronger would be to use more material, but that would exceed the weight limit. "We had to inform NASA it wouldn't work. Boron composites are the only materials that can maintain that stiffness at that

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weight," says engineer Tor Jensen, president of Advanced Soaring Concepts.

The boron material is formed by running tungsten filaments through a boron trichloride gas and then weaving them into a lightweight blanket that is hardened with resin. The process is expensive—Advanced Soaring Concepts buys the material for $1000 per kilo. The entire wing, including the internal spar, will be made from the material as well as the tail.

Ironically, this new breed of aircraft could leave NASA with a painful choice about high-altitude flight. The US hopes to build a fleet of supersonic aircraft known as High Speed Civil Transports, that will travel faster and higher than Concorde. Some environmentalists fear these planes will pollute the stratosphere and, in particular, damage the ozone layer.

But because few measurements have been made in the middle stratosphere, nobody knows what effect aircraft will have on the atmosphere at this height. Scientists can make isolated measurements using balloons, but these take samples only in one place.

What scientists want is a way to fly around in the middle stratosphere taking large numbers of measurements in different places and even bringing samples back to Earth. Apex and its successors will help to determine what chemistry occurs in the upper stratosphere and what the risks will be.

Even further in the future, the Apex data could help build a plane to fly above Mars where the density of the atmosphere is similar to that at 30 kilometres above Earth. An uncrewed Martian plane could be armed with infrared and optical cameras to survey more territory than a surface rover and take higher-resolution photos than an orbiting probe.

"You could see sand dunes and ripple patterns. You could look for dry lake beds that might have accommodated life," says NASA scientist Larry Lemke, who dreamt up the Mars application. You could even land at the most promising site, he adds. Once on the ground, a robot arm could grab a soil sample and analyse it using microscopes or spectrometers.

Lemke and a team of engineers at Ames Research Center in Palo Alto, California, are trying to convince NASA managers to launch just such a mission when Mars comes within reach next in 2001. They have pitched the $200-million project as part of NASA's interplanetary Discovery series.

If it is accepted, the plane could provide a short cut for scientists studying the history of life on Mars. "In one mission you would be able to do discovery and exploration," he says.

The first flight tests for Apex are planned for next year. Only then will Lemke discover how good a Martian flyer it could be. □

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