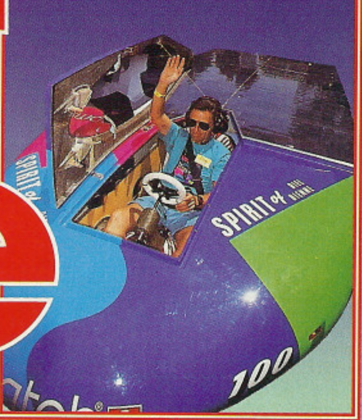
WHO *REALLY* INVENTED THE *MICRO*PROCESSOR?
IRAQ'S LETHAL WEAPONS • CONCRETE THAT BENDS

Popular Science

NEW SOLAR CELLS WIN IN AUSTRALIA



OBLIQUE WING: FUTURE SUPERSONIC AIRLINER?

SST

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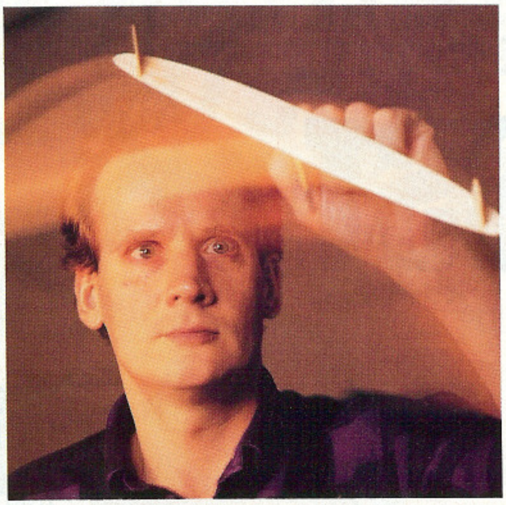
From The Editor


Associate Editor Stuart F. Brown: sky surfer?

Before joining this magazine, I envisioned the staff commuting to work with the aid of strap-on jet packs, keeping their coffee mugs warm with desk-top solar arrays, and otherwise engaged with the esoterica of their high-tech world. As it turns out, the editors of POPULAR SCIENCE are mostly occupied with the basic tools and techniques of modern journalism: making telephone calls, tape-recording interviews, and writing on personal computers. Most of the time, that is. Not too long ago, an odd-looking, surfboard-shaped model airplane floated gently into my office. Out in the corridor, where it had been launched by Associate Editor Stuart F. Brown, there was a lively discussion on aerodynamics. This month's cover story was taking shape.

Brown and his balsa-wood flyer had recently returned from an interview in California with Robert T. Jones, a world renowned aerodynamicist. Jones's idea for an oblique flying wing is not without a respectable body of support as the aerospace community once again takes up the challenge of designing the next generation of supersonic airliners.

Jones's design is a radical departure from the mainstream, where most designers call for a super-son of the Concorde: a bigger, faster, longer-range delta wing aircraft. In fact, the pivotal point in our ability to fly transoceanic distances in half the current time has little to do with wing or body design. Contributor J. T. Johnson reports that figuring a way to build an environmentally safe SST is the keystone problem, one which has plagued further development of SST aircraft for the last 20 years. The major obstacle is eliminating nitrogen oxide emissions from aircraft that would fly in the stratosphere, emissions that pose a threat to the ozone level. NASA scientists set a year-end deadline to at least find a theoretical answer.

Until last summer, the name Gil Hyatt meant virtually nothing in the computer world. Here was one more electronics engineer whose career seemed little more than a checkered string of unspectacular successes and insignificant failures. Now, thanks to the patent award that gives Hyatt claim to the invention of the microprocessor, Hyatt is center stage in a controversy that may rewrite electronics history. Who is this inventor, what was his role in the development of one of the most important technologies of our time—and where has he been all these years? Author Michael Antonoff reports that even if Hyatt is not a genius in electronics, he has been wielding a fast and potent copying machine. And now the world's electronics giants have no choice but to contend with him.

The massing of armies in the Middle East last fall got us wondering what kind of military technology Iraq possessed to counter the world-class armaments of the United States. We found, however, something more disturbing than a catalog of weapons comprised of chemical and biological poisons, a potent missile fleet, and a modern armored tank force. In fact, Iraq has been unusually skillful in parlaying to its advantage a burgeoning international market of weapons as commodities. Furthermore, over the last decade, Iraqi President Saddam Hussein has done more than simply buy modern military might. In "Iraq's Most Lethal Weapons," author Robert Windrem provides an inside look at a sophisticated military machine—and the frightening story of how it came to be.

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THE NEXT SST

It's been 22 years since the Concorde, the world's first commercial supersonic airliner, roared off into the stratosphere. But the rare and beautiful bird has come to be viewed as a fuel-guzzling, noisy, cramped financial boondoggle and an environmental hazard. What were only suspicions during its development are now certainties. Jet exhaust at high altitudes may prove every bit as damaging to the fragile ozone layer as chlorinated fluorocarbons (CFCs).

Against this backdrop, airplane builders and jet engine manufacturers around the world face the daunting challenge of developing the next generation of SST. This time there must be no compromise of fuel-efficiency or pollution control.

There are two schools of thought on what form the next SST

Radical as it seems, nothing's missing from the oblique flying wing (left), proponents say; it's got everything needed to be the most efficient SST possible. But it's the conventional-looking delta-winged concept plane (above) that represents mainstream thinking.

ILLUSTRATIONS BY KERRY LESLIE

ought to take: Several engineering teams are busy drafting delta-winged "paper airplanes" with cruising speeds ranging from Mach 1.6 to Mach 3.2. These would essentially be bigger, better versions of the Anglo-French Concorde. This is the mainstream effort and—not incidently—the primary funding beneficiary in the SST field.

"Wrong shape!" So says a small circle of researchers in California led by an eminent aerodynamicist who invented both the swept and delta wings in the 1940s. These renegades believe the next SST should have a radically different and more efficient form: the no-fuselage, no-tail, not-even-straight-ahead configuration known as the oblique flying wing.

This two-part report provides a status check on the aeronautical community's efforts.

DELTA WING SST

New engines, more passengers, and a tailored sonic boom are planned for the Concorde's likely successor.

BY J. T. JOHNSON

Will a new generation of supersonic airliners be possible by the year 2010? NASA and an international consortium comprised of aircraft builders Boeing Co., McDonnell Douglas Corp., British Aerospace Ltd., Deutsche Airbus, and France's Aérospatiale think they could be. The U.S.S.R. and Japan may enter the race as well. But before the first dart-shaped successor to the Concorde can be built, designers will have to focus on curbing the release of exhaust containing oxides of nitrogen (NO_x), which can wreak chemical havoc on Earth's ozone layer. Without that milestone achievement, reigning in engine noise and sonic boom will remain moot points. Of course, both economic feasibility and environmental concerns will be examined during this proving stage.

In its time, the development of the Concorde by a government-subsidized British-French joint venture was proof of the aeronautical concept of a Mach-2 supersonic transport. But the Concorde was a huge business failure for several reasons. Its Rolls-Royce Olympus turbojets, while reasonably efficient at cruising altitude, are essentially early 1960s fighter-plane power plants. During takeoff and climb they make a tremendous amount of noise and gobble fuel, giving the plane poor range. Furthermore, to prevent disturbing and destructive sonic booms, the Concorde is restricted to subsonic speeds when flying over land. Originally conceived to carry about 120 passengers, the Concorde needed extra fuel tanks (which showed up during development). This reduced seating capacity, effectively cutting into per-flight revenues.

Drawing on the projections of a study that was commissioned by NASA showing increased passenger demand by the year 2000, Boeing and McDonnell Douglas posited that in order to be economically viable, the 21st-century SST will have to carry 250 to 300 passengers, at two to three times the speed of sound, and cover twice as many miles as the Concorde, but at one-seventh its cost per passenger mile.

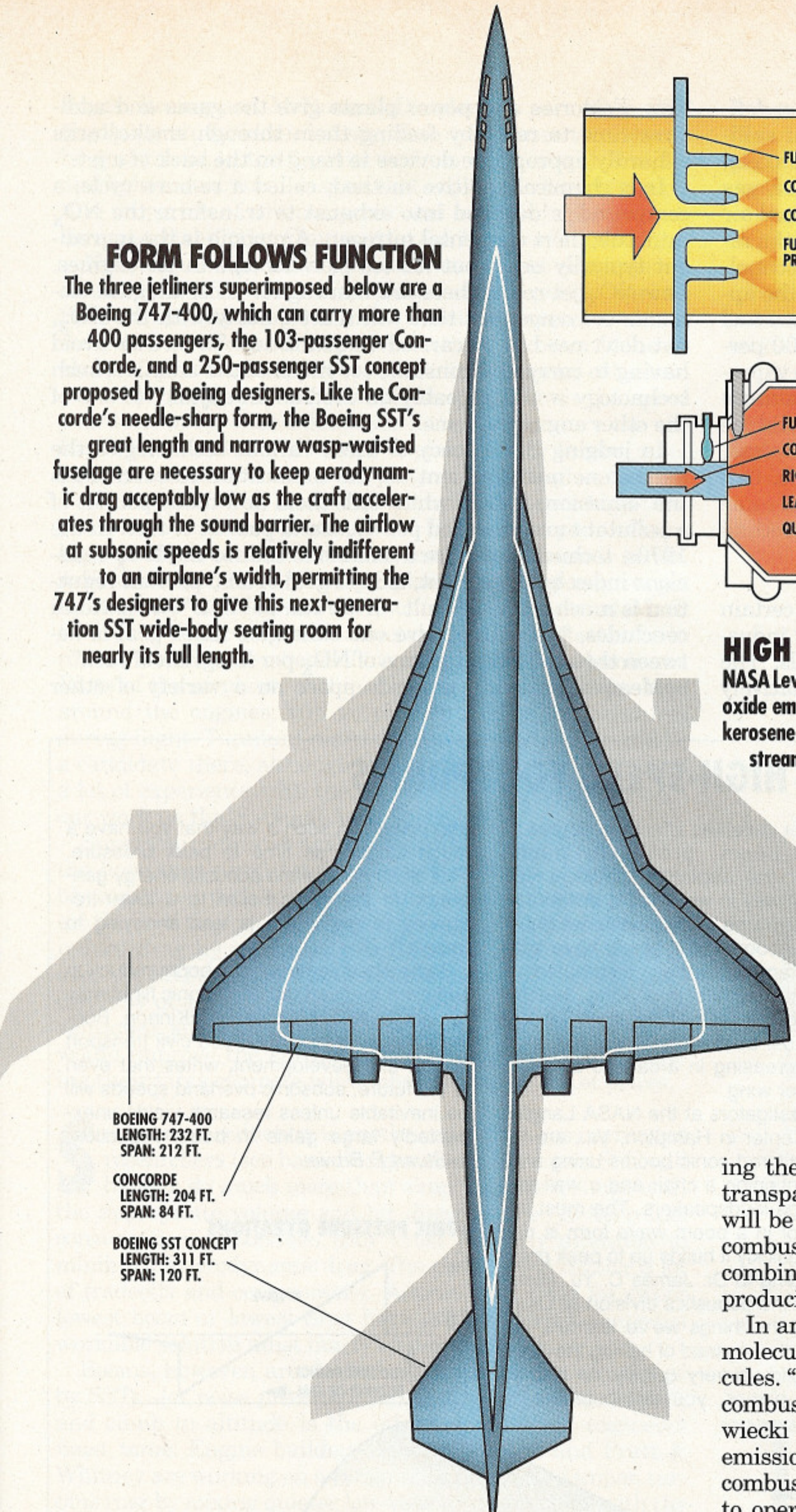
Ratcheting up the demands on the next SSTs in all categories—efficiency, profitability, and speed—will complicate the problem-solving process for researchers. For instance, to meet the economic and flight-performance goals expected from a new generation of SSTs, the engines operating 10 or 15 years from now will pump fuel and air through their combustion chambers at much higher temperatures for efficiency's sake. "Every 200 degree [F] increase in inlet temperature will probably double the NO_x," says Rich Niedzwiecki, chief of combustion technology at the NASA Lewis Research Center in Cleveland. Increased pressure in the engine's combustor section will also increase NO_x levels.

It's a prospect that has spurred researchers to examine what can be done to tweak the air-fuel mixture, the various engine temperatures, and the speed with which the gases pass through the combustor, with the goal of achieving efficiency gains as well as NO_x reductions.

To further complicate matters, future SSTs would climb beyond today's airliners to a cruising altitude in the stratosphere, where NO_x can be particularly damaging. Under certain conditions, one molecule of NO_x can act like a catalyst and initiate reactions that destroy hundreds of ozone molecules. Dr. Harold S. Johnston of the University of California at Berkeley and an adviser to NASA estimates that an SST fleet using conventional jet engines might reduce global ozone by about 15 percent. Dangerous levels of ultraviolet radiation could reach ground level from space—a catastrophe that nations have recently sought to avoid by banning ozone-attacking chemicals such as chlorinated fluorocarbons (CFCs) and bromide compounds. According to NASA reports, at these altitudes, NO_x emissions also have the potential of altering stratospheric circulation and climate.

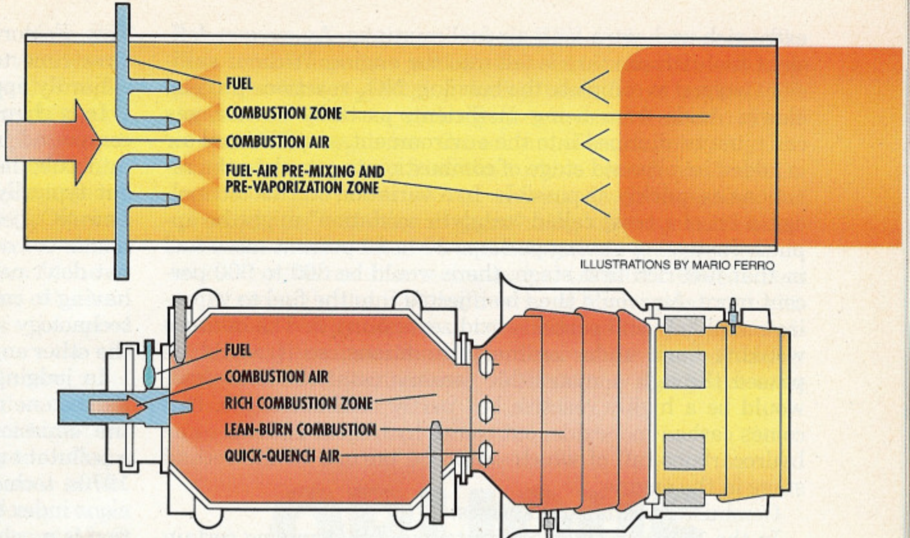
Cutting NO_x emissions five- to tenfold would reduce the ozone loss to a few percent, says Johnston. Another option, he suggests, may be to fly somewhat lower in the stratosphere, though the denser air at these altitudes would limit the aircraft to relatively lower supersonic speeds. "It is known through computer modeling that above twenty-one kilometers NO_x can produce strong ozone decreases in the stratosphere, and that below twelve kilometers no ozone decrease is likely."

In the face of these variables, NASA has launched a five-year $284 million High-Speed Research Program to deter-



FORM FOLLOWS FUNCTION

The three jetliners superimposed below are a Boeing 747-400, which can carry more than 400 passengers, the 103-passenger Concorde, and a 250-passenger SST concept proposed by Boeing designers. Like the Concorde's needle-sharp form, the Boeing SST's great length and narrow wasp-waisted fuselage are necessary to keep aerodynamic drag acceptably low as the craft accelerates through the sound barrier. The airflow at subsonic speeds is relatively indifferent to an airplane's width, permitting the 747's designers to give this next-generation SST wide-body seating room for nearly its full length.



ILLUSTRATIONS BY MARIO FERRO

HIGH TECH, LOW NO$_x$

NASA Lewis is exploring jet-engine combustors that may help reduce nitrogen oxide emissions. The lean pre-mixed, pre-vaporized method (top) mixes the kerosene fuel with large quantities of air before it is burned further downstream. The rich-burn/quick-quench/lean-burn design (above) burns fuel in two stages, first using little air, then an abundance of it.

mine if advanced SSTs could be environmentally feasible and, if so, at what price. Airplane builders will be closely watching the space agency's progress. The scientists and engineers at NASA Lewis and other research centers are a long way from building an ultra-low-NO$_X$ engine, to say nothing of flying it. But NASA does have a timetable for its SST research: The agency hopes that low-NO$_X$ combustion under the conditions required for supersonic cruise can be demonstrated in laboratory test hardware by the end of 1991. If the theoretical methods prove out, then the next goal is to build real-world combustor hardware by the end of 1995 and install it in test engines. "The environment," says Niedzwiecki, "is not a negotiable item."

But that target is based on a working assumption about environmentally acceptable levels for NO$_X$; other scientists are working on further defining what's safe for the atmosphere.

Tucked in a corner of a nondescript building on the far side of Cleveland's Hopkins International Airport is NASA's "high- pressure and temperature square-wave flame tube" designed to probe secrets of combustion. The heart of the rig— wired up to sensors and computers—is a chamber the size of a thick dictionary. During the next 18 months, video cameras will peer through transparent quartz windows, and lasers and spectrometers will be trained at the fiery cavity and its exhaust outlet as combustion and emissions experts strive to devise a way of combining kerosene and oxygen, as all jet engines do, while producing a minimum of NO$_X$ as a byproduct.

In an optimal oxidation process everything burns—every molecule of fuel combines with the right number of air molecules. "Lo and behold, when we have the perfect mixture for combustion, we have the highest amount of NO$_X$," Niedzwiecki laments. How can scientists hope to inhibit NO$_X$ emissions dramatically if they are the natural result of any combustion? "Essentially," Niedzwiecki concludes, "we want to operate as fuel-lean or as fuel-rich as possible." Niedzwiecki and his colleagues at NASA Lewis, and researchers around the nation, are focusing on three complex engine technologies that mix fuel with air at different stages and rates as they pass through the engine's combustors.

Lean pre-mixed/pre-vaporized combustion:

The challenge in this research is to optimize all the steps—air-to-fuel ratios, uniformity of the air-fuel mixture, speed of vaporization, and especially the speed at which the mixture flows through to the combustion zone—all of which occur in a few milliseconds. Standard jet-A kerosene is mixed with air upstream of the combustion zone, vaporizing it to a gas. Combustion takes place further downstream and is completed as quickly as possible.

Rich-burn/quick-quench/lean-burn combustion:

This would be a two-stage engine that controls NO$_X$ by taking advantage of the low rate at which it forms in both extra-rich and extra-lean air-fuel mixtures. An oxygen-deficient fuel-rich mixture is fed into the engine. Without sufficient oxygen to complete the burning, NO_x reactions proceed slowly. Aside from being inefficient, partially burned gas can't just be dumped into the environment, so additional air is added in a second stage of combustion to complete the reactions as quickly as possible. In a variation on this technology, a bit of a twist called "catalytic oxidation" might be applied. Instead of having perhaps 20 to 80 percent more fuel in that fuel-rich first stage, there would be 300 to 900 percent more. Air would then be injected into the fuel to vaporize completely and partially oxidize, or burn, it. The mixture wouldn't burn under ordinary conditions, so it would be passed through a monolithic ceramic catalyst. The result would be a highly reactive but partly combusted gas. Out comes carbon monoxide, out comes hydrogen, and out come hydrocarbons, all of which would be burned in the second stage in the engine.

Combustion exhaust additives:

In the 1970s and '80s scientists found that mixing certain elements or compounds with the exhaust emitted by industrial furnaces could dramatically reduce NO_x levels. The problem is that the additive-driven reactions are relatively slow. Factories and power plants give the gases and additives time to react by feeding them through smokestacks —hardly appropriate devices to hang on the back of a jet.

In a chemical-additive method, called a re-burn cycle, a compound is dumped into exhaust to transform the NO_x into safe, inert elemental nitrogen. Ammonia is the ingredient typically used, but it's too slow for use in jet engines. Low-NO_x jet researchers are hunting for those magical elements or compounds that will react quickly with the NO_x, but don't need to be carried in quantities. To further avoid having to carry and consume too much of the additive, such technology would probably be used as an adjunct to one of the other engine systems.

In judging the efficacy of these various technologies the touchstone measurement for the combustion researchers is the "emissions index," which tells them how many pounds of a pollutant are produced per thousand pounds of fuel. In the 1970s, technologies were available to reduce the NO_x emissions index by 30 percent; today's goal of a 90 percent reduction is much more difficult. "If we can do that," Niedzwiecki concludes, "we will achieve our emissions index goal of between three and eight grams of NO_x per kilogram of fuel."

Meanwhile, study proceeds apace on a variety of other

SONIC BOOM: HIGH-SPEED FOOTPRINTS

Anyone who has heard an aircraft flying faster than the speed of sound will remember its nerve-shattering ba-boom and the accompanying rattling—sometimes shattering—of windows.

The big bang is caused by a cone-shaped shock wave (below) that trails continuously behind an aircraft traveling supersonically. Actually, a pair of closely spaced shock waves are generated at the airplane's nose and tail. They cause a sudden and brief rise in air pressure, followed by a quick decompression below atmospheric pressure, then a return to normal pressure. Represented on a graph, these pressure gyrations trace a pattern resembling the letter "N" and deliver a chest-thumping double boom that is felt as well as heard by people on the ground as the sonic "footprint" passes over them.

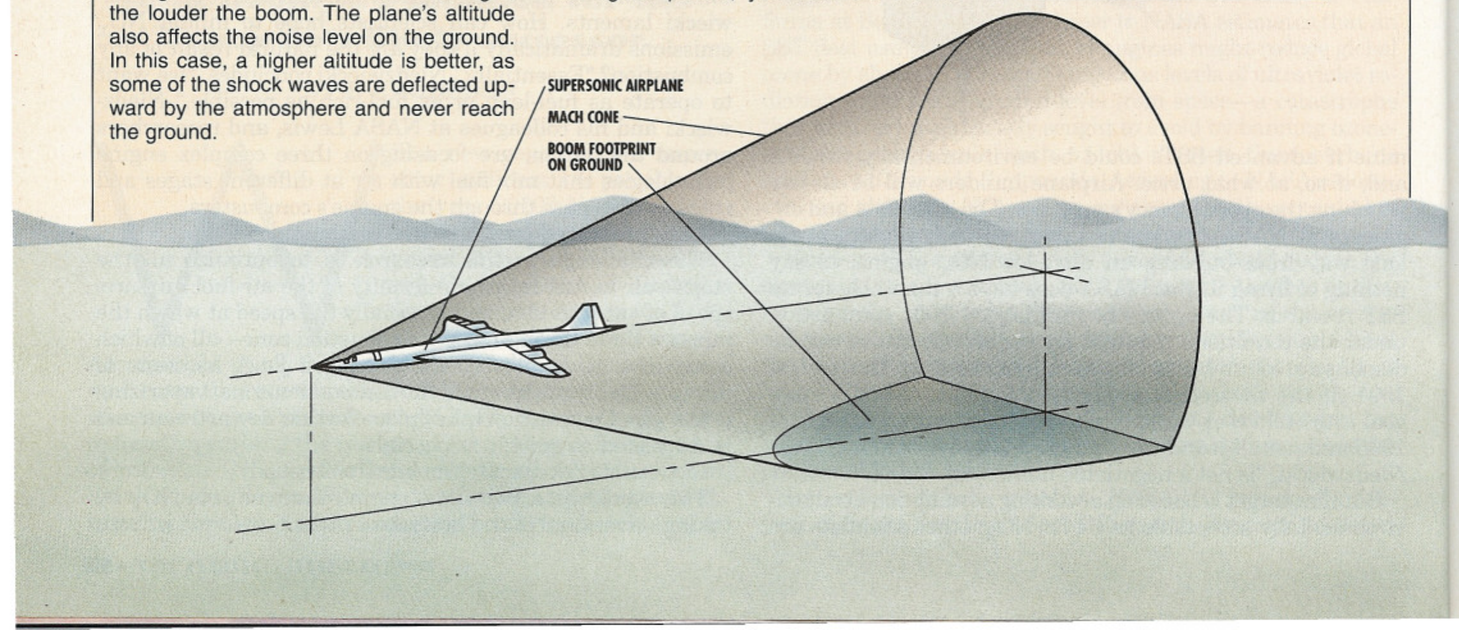
The amount of sheer racket in a sonic boom is mostly dictated by the speed of the aircraft. In the Mach 2.5 to Mach 3.2 range that some designers project for a next-generation SST, the faster the flight, the louder the boom. The plane's altitude also affects the noise level on the ground. In this case, a higher altitude is better, as some of the shock waves are deflected upward by the atmosphere and never reach the ground.

Two subtler variables affect the degree to which a boom provokes public aggravation: the airplane's physical volume and the way in which lift is distributed across the airframe to support its weight in flight. A "low-boom" SST would have both its volume and lift widely distributed, a mandate that results in a long needle-shaped fuselage with lifting surfaces beginning almost at the aircraft's nose, then gradually increasing in area and blending into the major wing.

Boom investigators at the NASA Langley Research Center in Hampton, Va., are reproducing tailored sonic booms using a little room containing a chair and a wall that is full of large loudspeakers. The most important factor in a boom wave form is rise time—how quickly it builds up to peak pressure, according to Dr. James C. Yu, assistant chief of the acoustics division at Langley. "One of the things we've learned," he explains, "is that instead of having the overpressure build up very quickly, as it does with fighter planes, you distribute the lift and volume in such a way that you have a much longer rise time to peak pressure. This shifts most of the acoustic energy generated in the sonic boom to a lower-frequency range, which is less annoying to people."

Some observers feel that boom reduction sufficient for overland supersonic flight may remain elusive. Malcolm MacKinnon, Boeing's manager of high-speed civil transport design and development, writes that even in the future, subsonic overland speeds will be inevitable unless research yields unexpectedly large gains in boom reduction. —*Stuart F. Brown*

SONIC PRESSURE GYRATIONS



fronts. Boeing and McDonnell Douglas, as part of an SST feasibility study, identified significant advances that should be possible in 10 to 15 years, such as engines with simpler and lighter structural designs that exploit the high-temperature properties of new composite and metallic high-temperature materials ["21st Century Hot Jet Engines," June '90].

New high-temperature-resistant low-weight materials also enter the SST arena as airplane builders ponder various SST configurations. As a rule of thumb, extensive use of composite materials can trim the weight of a new plane by about 20 percent compared with traditional metal-alloy construction. "Airframe material choices depend on the speed you want to fly, which determines the temperature the airframe reaches due to friction," explains Bruce Bunin, manager for advanced commercial programs at Douglas Aircraft.

"The spectrum of likely materials runs from a high-temperature aluminum to composites being developed that use high-strength carbon fibers in a matrix of polyimide or bismaleimides polymers," Bunin explains. "As temperatures get up into the 600-degree-Farenheit range you see at Mach three, the choice might be a metal-matrix composite of silicon-carbide fibers embedded in rapidly solidified aluminum. Parts of the airplane, such as the wing's leading edges and around the engines, will go to even higher temperatures during flight. Titanium-matrix composite material would be a candidate there, although it gets expensive. We've gained a lot of experience with these titanium composites through our work on the National Aero-Space Plane."

Supersonic laminar airflow control is being studied with the hope that careful refinements in aircraft shape, possibly combined with a powered suction system that pulls in air through tiny pinholes in the plane's skin, can be used to reduce drag by minimizing turbulence in the air passing over the SST's surface. NASA recently conducted tests successfully of a suction system installed in the wing of a conventional jet airliner. These technological developments would improve the efficiency of supersonic airliners, helping their fares compete with subsonic airline ticket prices.

Sonic boom reduction is another area that has captivated researchers (see box). Designers of a low-boom SST will have to do much more than simply create a shape with the appropriate volume and lift distributions. To keep fuel consumption reasonable, they must also pay attention to minimizing aerodynamic drag. The process will involve a lot of tradeoffs and compromises. Aircraft optimized for either lowest boom or lowest drag have fairly different shapes; a workable solution must marry elements of both.

Booms, however, aren't the only aural offense committed by SSTs. Jet noise produced during airport taxiing, takeoff, and climb to altitude is the other sonic demon engineers must tame. Engine builders General Electric and Pratt & Whitney are working on a range of designs that dampen turbine roar by mixing quieter low-velocity ambient air with the high-velocity gases roaring out of the turbine. The trick for designers is to achieve the maximum noise reduction while paying a minimum penalty in lost thrust from the engine.

In the late 1960s American SST researchers paid a one-percent lost-thrust penalty for every decibel of sound reduction. Current technology has doubled noise reduction for each percent of thrust forgone, but NASA's goal is to double that again to four decibels less noise for a one-percent thrust sacrifice, says Dr. James C. Yu, assistant chief of acoustics division at the NASA Langley Research Center in Hampton, Va.

The variable-cycle engine design General Electric developed for the ongoing Air Force Advanced Tactical Fighter program could lend itself to quiet operation on and near the ground. These engines operate both as relatively quiet low-altitude turbofans and as turbojets that permit efficient supersonic cruise at high altitudes, where engine noise dissipates before it can offend the public ear. GE's engine uses variable-area bypass injectors and a retractable exhaust-noise suppressor, which is extended during takeoff and landing. The doorlike mechanisms work together to insert a stream of cooler engine-bypass air into the column of much hotter high-velocity exhaust exiting from the turbine core. Turbulent mixing of the two flows occurs, slowing down the gases and inhibiting the formation of aggravating low-frequency noise.

Work on this successor to the Concorde will proceed, attended by the need for technological tradeoffs. Researchers must reconcile the SST hallmarks of high speed and altitude with reality. Reality, in the form of the public's environmental awareness and its demand for fuel efficiency and reasonable transoceanic airfares, may just prove to be too much for this project.

OBLIQUE WING SST

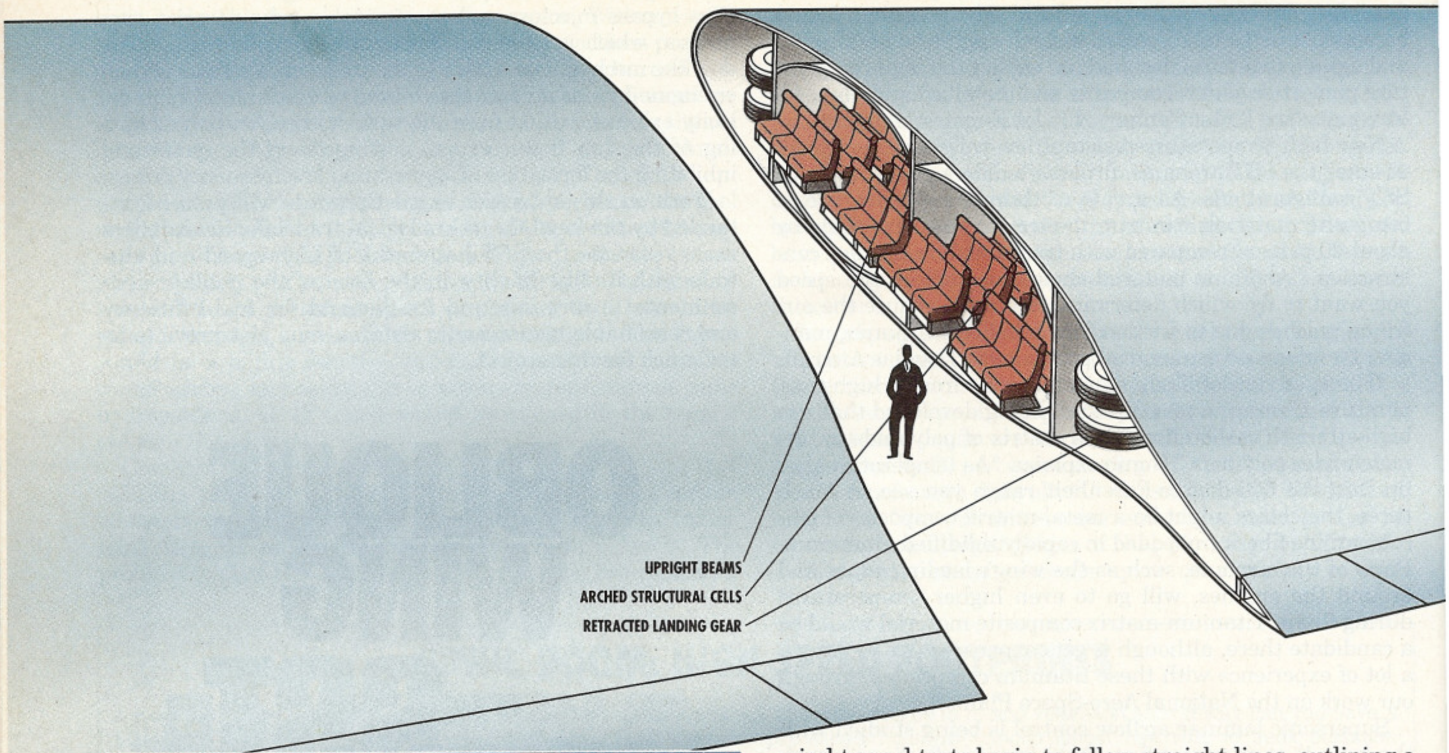
Forget the familiar fuselage and tail—just fill a wing with people and angle it into the airflow.

BY STUART F. BROWN

The dream of an airplane that's a wing and little more has tantalized aeronautical engineers for many decades. Pioneering designer John K. Northrop began researching flying wings in 1928, and from 1940 to 1950 he built a series of them that gripped public imagination. The concept is alive and well; the company bearing Northrop's name builds the controversial B-2 stealth bomber, a flying wing designed for minimal detectability by radar.

But what about an *oblique* flying wing—a flying machine that not only lacks a fuselage, but doesn't even travel straight ahead? According to its developer, Robert T. Jones, "People aren't trained how to think about an airplane like this. Engineers immediately conjure up all sorts of problems—which is what I did at first. It took me a long time to think it through, but after working on the idea for forty years, the problems have gone away for me."

The eminent aerodynamicist, recipient of many distinguished awards, including the Smithsonian Institution's



At his California home, aerodynamicist Robert T. Jones demonstrates the flight-worthiness of the oblique flying wing with a balsa-wood model.

Langley Medal for extensive contributions to theoretical aerodynamics, only began garnering the attention of people in the aeronautical world at the close of World War II, when it was discovered that the Germans had been testing theories on sweeping aircraft wings aft to achieve supersonic flight. Jones's presentation of similar calculations and wind tunnel test results in 1945, while working at the Langley Memorial Aeronautical Laboratory, were initially ignored. Nevertheless, his discoveries would revolutionize the configuration of aircraft.

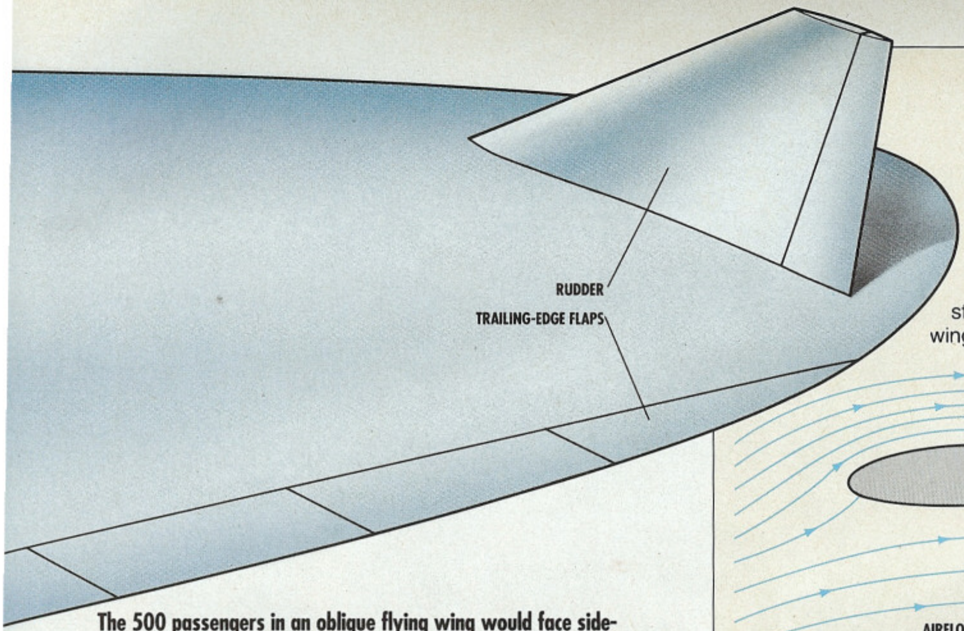
In essence, he found that a dramatic change occurs in the airflow around a high-speed airplane as it thunders past the speed of sound. The streamlines seen in supersonic wind tunnel tests begin to follow straight lines, outlining a cone-shaped shock wave that has its tip at the plane's nose. If the Mach cone trailing back from the nose of an airplane flying supersonically cuts across its wing tips (see diagram opposite page), shock waves can batter the wings severely enough to cause them to disintegrate. The faster an airplane flies, the narrower its Mach cone, therefore the further back its wings ought to be swept, Jones concluded.

In addition, Jones's work showed that a swept wing had only one-tenth the drag of a straight wing at Mach 1. He went on to prescribe the delta wing for aircraft flying closer to Mach 2. Current swing-wing aircraft such as the F-14 fighter exploit these principles to obtain good lift from straight wings at takeoff and low drag from increasingly swept wings as the aircraft accelerates through the sound barrier.

Jones became interested in looking beyond delta wings after the 1947 discovery by aerodynamicists Wallace D. Hayes and Theodore von Karman at the California Institute of Technology that swept wings theoretically should have the same drag regardless of whether they are going forward or backward. This model, called the reversed-flow theorem, says Jones, meant that an arrow-shaped wing, traveling point foremost, couldn't be the single-best configuration because the same triangular shape traveling broad-base forward, according to the theorem, would have equal drag performance.

As a result, he approached the problem of discovering the *true* optimum wing configuration from the premise that the most efficient wing would look the same coming or going. His calculations led him to conclude that a single shape—the long, narrow ellipse—delivered the best lift-to-drag ratios from subsonic speeds all the way to Mach 2. The only modification necessary was to have it assume an oblique direction during flight above Mach 0.8. This would keep its leading edge behind the Mach wave trailing from its forward tip. Thus the oblique wing concept was born. Jones soon went on to discard the fuselage and tail altogether and concentrate on oblique flying wings.

Jones first tossed oblique flying wing models into a room full of people at the 1958 International Congress of Aero-



The 500 passengers in an oblique flying wing would face sideways to the airliner's direction of flight in rows of seats running from front to back of the craft. Lightweight arch-shaped structural cells with upright beams form the principal load-bearing members. Landing gear, baggage holds, fuel tanks, and various componentry are in the areas surrounding the passenger cabin.

nautical Sciences in Madrid. "I flew them at a cocktail party. The Russians were there, the head of NASA was there... .Oh, it was fun," he recalls. "I gave a talk on supersonic wing design, and I explained the theory of the oblique ellipse, which I had developed in 1952."

At the next congress in 1962, Dietrich Kuchemann, the Concorde's chief designer, presented a paper on plans for the new airliner. Its narrow delta wing wouldn't have enough span to fly efficiently at low speeds, so the plane required a noisy afterburner assist to get off the ground. Hence, about 40 percent of its fuel load would be needed for takeoff, climb, and reserve. Godfrey Lee, a well-known engineer associated with the British Handley-Page Aircraft Co. who had been enthusiastic about the oblique wing models in 1952, pointed out that an oblique flying wing design might save enough fuel to double the Concorde's payload. "But at that time no experimental confirmation of the theory was available, so it's not surprising that such a concept was rejected," Jones recalls.

Funding for oblique wing research has had its ups and downs over the years, as will any project that challenges the current definition of how a good design should look. By conducting tests over the past 20 years, and by funding projects at Stanford University in Stanford, Calif., the NASA Ames Research Center in Mountain View, Calif., has played a central role in the oblique wing's history. Jones retired from NASA Ames in 1981 as principal engineer after a long and distinguished career.

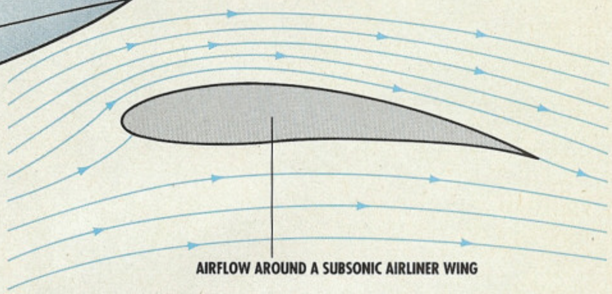
The most visible outcome of the work at Ames is the AD-1 research aircraft, a low-speed lightweight jet designed by Burt Rutan under a NASA contract to explore the flight behavior and controllability of a pivoting oblique wing mounted atop a conventional fuselage. Testing proved the AD-1 to be a well-behaved and fuel-efficient plane. NASA pilot Tom McMurtry made demonstration passes at a recent Oshkosh air show with the wing yawed at its maximum angle of 60 degrees.

Real-world oblique-winged airplanes with conventional fuselages have also been the subject of two major studies, one of them conducted for NASA by Boeing in the 1970s. It

[Continued on page 90]

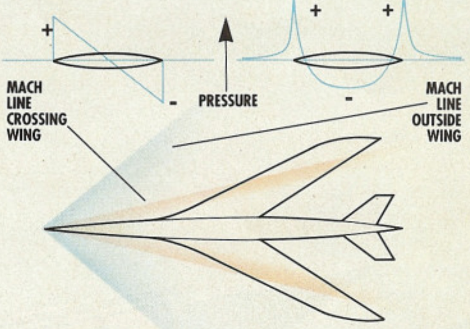
CHEATING THE SOUND BARRIER

When a subsonic airliner, such as the Boeing 747, flies at its cruising speed, the flow of air over its wings is smooth. Viewed in a wind tunnel, the streamlines surrounding a model of its wing trace soft, almost unperturbed curves.

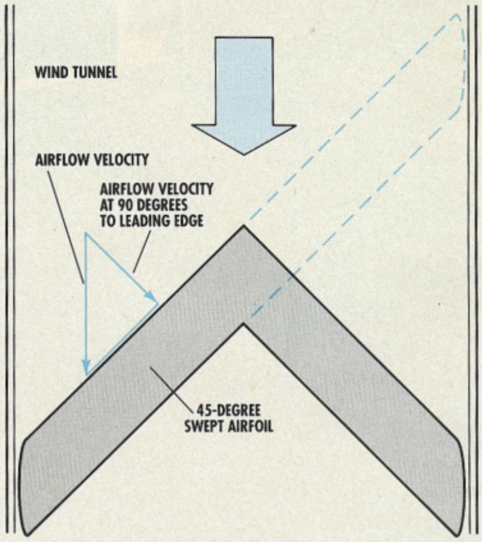


AIRFLOW AROUND A SUBSONIC AIRLINER WING

At supersonic speeds, Mach lines, or straight shock waves (below), angle back from an aircraft's nose. If the Mach line crosses the wing, an abrupt pressure rise occurs at the wing's leading edge, followed by a sharp pressure drop ending suddenly at the trailing edge. The result is a sonic boom and a roughly tenfold increase in drag. When the airplane's wing is swept behind the Mach line, however, positive pressures at the leading and trailing edges are balanced by negative pressure underneath it, minimizing drag.



Robert T. Jones explained this phenomenon in the 1940s when he showed through wind tunnel tests that a swept wing (below) actually responds to the lower velocity of the airflow that it experiences at right angles to its leading edge. Even though the wing's speed is supersonic, it behaves as if it were flying subsonically.



Oblique wing

[Continued from page 63]

focused on a commercial airliner designed to fly at Mach 1.2. Boeing's design was judged to be "promising," and it inspired the AD-1's shape, but nothing further came of it.

Tom Gregory, assistant to the director for advanced systems design at NASA Ames, says, "I've been working on this thing for fifteen years, and I'm sold on it." The 22-foot radio-controlled oblique wing he and his colleagues rigged up in 1976 is in the Smithsonian Institution's collection. "It was outfitted with a symmetric tail to give it stability, but it was a handful to fly without any electronics. Eventually we were going to add automatic stability control, but some people were down on the project."

NASA plans further wind tunnel tests of a refined oblique airfoil at angles up to 70 degrees and speeds as high as Mach 2. Computational fluid dynamics simulations of airflow over oblique flying wings are planned, as are studies of the wing's sonic boom characteristics.

Funding provided by NASA Ames during the past four years has also supported oblique flying wing work at Stanford University by Dr. Ilan Kroo, an aeronautical engineering professor, and two of his students. Kroo, in the mid-1980s, worked on a program funded by the Navy to study aircraft carrier-based oblique wing fighters that could patrol efficiently for long periods, then accelerate to Mach 1.6 to intercept attacking aircraft. "You could sweep the wings almost ninety degrees to store a lot of them on a carrier deck," says Kroo.

Kroo is looking ahead to the next major step, which will be flying an instrumented, remotely-piloted oblique wing with a 20- to 30-foot wingspan. It would rely on either rocket power or small jet engines to gather data on flight performance at supersonic speeds.

Post-doctoral student Steve Morris has worked on controlling smaller, unstable radio-guided aircraft.

"Our research job," says Kroo, "is to identify some of the potential problems and show whether the oblique wing makes sense from a performance standpoint. No airplane company in its right mind is going to risk twenty billion dollars to build it unless it is pretty sure the concept can work."

In his collaboration with Stanford researchers, Jones proposes an oblique supersonic airliner with sideways-facing passenger seats arranged in short rows running from front to back inside the wing (see diagram, page 62). Windows are set into the wing's rounded leading edge, while the thin trailing edge is occupied by computer-directed flaps that control the airplane's pitch and roll motions. This automatic stability control permits the wing to be loaded from front to rear (with fuel, gear, avionics, and passengers) while achieving minimum drag. A pair of vertical rudders near the wing tips provides the craft's yaw, or steering control.

They envision it as having a wingspan of about 500 feet and the capacity to transport 500 passengers. The wing's principal selling feature, they say, is its ability to fly at Mach 1.6—twice the speed of a Boeing 747—while consuming no more fuel than the subsonic jetliner.

Propulsion is furnished by two large high-thrust turbofans with a variable-bypass design—like the one developed by General Electric for the Air Force Advanced Tactical Fighter program —which makes the engines efficient over a wide range of speeds and altitudes. The jets themselves would swivel from side to side on their pylons, allowing the flying wing to change its angle of obliqueness. This would maintain aerodynamic efficiency while accelerating past the speed of sound and beyond.

Jones and the other oblique wing researchers believe that a flying wing configuration could overcome the stumbling blocks facing any new supersonic transport: airport noise, sonic boom, and ozone damage caused by oxides of nitrogen (NO_X) contained in jet exhaust.

They cite wind tunnel tests performed at Ames showing that an oblique flying wing can have a lift-to-drag ratio as high as 30:1 at takeoff. (The efficient 747, which doesn't fly supersonically, boasts drag at one-twentieth of its weight, or 20:1, at cruising altitude. This translates into a highly respectable 60 flight miles per passenger per gallon of fuel. The Concorde's poor lift-to-drag ratio of 7:5 is brought about by wave drag during transatlantic cruising at Mach 2.)

NASA Ames's Gregory says: "There's basically no load in the structure of a flying wing most of the time because the gravity load is offset at every point on the airplane by the lift." Conventional airplanes are the opposite: Their wings act as long levers that require massive internal structures to withstand the huge bending loads generated by supporting a heavy central fuselage. The flying wing's aerodynamic efficiency, combined with the low weight inherent in an all-wing design, means that only modest engine thrust is required to take off and climb away. Roaring afterburners aren't needed at all, meaning quieter getaways.

As for sonic boom, at a sweep angle of 45 degrees, the oblique flying wing will be able to reach a maximum of 750 mph without creating any boom, Jones predicts. Beyond this speed, he feels that sonic boom is more or less irreducible, obliging supersonic airliners to follow an Arctic route for overland flight.

Mach 2 money barrier

Jones, in fact, is disdainful of current studies focusing on SSTs that would fly at Mach 2 or 3. "Mach two is kind of a money barrier. By the time you get to this speed, the lift-to-drag ratio is so bad you can hardly tell the difference in efficiency between an oblique wing, a delta wing, or a swept wing. That's one area where the aeronautical community doesn't agree with me. They all want to go to at least Mach two, but I think it's just a glamorous macho thing."

Alex Van Der Velden of the Netherlands, one of the graduate students working on the wing at Stanford, sees avoiding damage to the atmosphere's protective ozone layer as another reason to abandon the idea of flying at Mach 2 or faster. By limiting its speed to Mach 1.6, an aircraft can fly efficiently below the altitude where NO_x emissions harm the ozone layer. "In the end, this airplane will never fly unless it's environmentally acceptable," he argues. "The criterion I propose we follow is one in which we cause no more ozone depletion than do subsonic jets."

At age 80, teaching "Wing Theory and Classical Aerodynamics" to graduate students at Stanford and working some of the time from the tool-strewn study of his hilltop home, Jones still likes to teach visitors how to fly simple balsa-wood models of the wing that has occupied his thinking for much of his professional life. Lately he has been calculating the different control surface angles needed to make an oblique flying wing turn left or right.

Even if airplane manufacturers someday convince themselves to build an oblique flying wing airliner, how can they be sure travelers will be willing to ride on it? Jones believes the answer is simple: "People will watch the stewards and stewardesses—who are more or less ordinary folks like themselves—board the plane. Then they'll get on after them."