Saving Fuel in Flight

By CHRISTOPHER VAUGHAN

Two slate-gray F-15s, gulping fuel, roar up out of the shimmering heat of a runway at Langley Air Force Base in Hampton, Va., then cut in the afterburners and belch fire as they initiate a perfectly coordinated, tandem turn up and to the right. Moments later, two other F-15s career down the glide path to land with their large, cigar-shaped fuel tanks now nearly empty.

In the middle of this martial activity, a slower, strange-looking civilian jet glides in for a landing. In contrast to the war planes, the Learjet flown by NASA's Langley Research Center has been modified with fuel savings rather than power in mind. The vertical "tipwing" fins at the end of its wings seem reminiscent of a 1948 Cadillac more than a jet plane, and a black band of air sensors circles one wing – an armband for airplanes.

Welcome to another war, the battlefield of aeronautical fuel efficiency. Here the campaign to make airplanes slice the air more efficiently has led engineers to machine tiny holes and grooves in airplane bodies and reintroduce propellers into the Jet Age. Here the front lines often occupy the first few thousandths of an inch above a plane's skin, and a wave of bugs that smash themselves against an ultrasmooth wing can vanquish the hopes of engineers.

At NASA centers and aircraft manufacturing plants across the United States, research born during past fuel shortages is paying off in exotic designs that are already changing the handling of some commercial airliners and should change the look of others in the early 1990s. The war on aviation-fuel consumption carries with it the promise of extended aircraft range and greater payload, because less fuel need be carried. It has therefore caught the eye of a U.S. military becoming more concerned with deploying rapidly to distant lands.

The prime way to get airplanes to sip instead of gulp fuel is to make them slip through the air more smoothly. Just as it is easier to push a sled over ice instead of sand, an airplane has to push less if the airflow over it is streamlined instead of turbulent. Though most jet planes appear the ultimate in streamlined shape, the airflow over their bodies is actually turbulent right where it matters most: at the very boundary between air and metal.

In flight, though air may stream over the plane at hundreds of miles per hour, the air molecules tumbling and bouncing across the molecules of metal move almost not at all in relation to the plane. The thin layer of air where the transition from slow- to fast-moving air is made is called the boundary layer.

The least drag occurs when this boundary region is smoothly layered, or "laminar," with the air molecules moving at successively faster speeds the farther away they are from the plane – like a well-ordered freeway where faster and faster cars stay left. But like a freeway where slow-moving cars jump into the fast lanes and vice-versa, the mixing of air molecules in a turbulent boundary layer can significantly impede their flow.

Decades of research since the 1930s seemed to indicate the boundary layer couldn't be kept laminar. "A myth developed that laminar flow was inherently unstable, and the boundary layer would always go turbulent," says NASA engineer Bruce Holmes.

Projects conceived in the oil-poor 1970s now bear fruit

The NASA Learjet has helped destroy that myth. The black band, or "glove," on its left wing is a supersmooth sheet of plastic outfitted with heat, pressure and noise sensors. Researchers at the Langley Research Center have shown that shaping the wing properly and eliminating airflow-disrupting bumps can coax the boundary layer into remaining laminar two-thirds of the way along the wing.

It turns out the problem was simply that wings could not be made smooth enough in the 1940s, 1950s and 1960s to get laminar flow. Researchers gave up on laminar flow just before production techniques and new materials got good enough to produce wings with the required smoothness. New polymers and composites can be produced without the slight imperfections that might create a turbulent wake along the wing.

Even with metal wings, the techniques used for making the airliners now flying are effective enough to conserve laminar flow further back on the wing "if we just shave the rivets a thousandth of an inch or so," says Richard Wagner, head of NASA Langley's laminar flow control project. NASA has been documenting progress in conserving laminar flow across the Learjet's metal tipwings by coating them with a special white paint that turns clear where there is turbulent flow, allowing researchers to "see" laminar flow in flight by looking out the jet's window.

Fabricating wings with perfect smoothness can make big differences in aircraft range. Burt Rutan's *Voyager* aircraft, in which brother Dick Rutan and Jeana Yeager completed the first nonstop circumnavigation of the globe in 1986, had laminar flow over most of its wing.

NASA Lewis Research Center in Cleveland and several industrial research teams recently completed development and testing of various designs, as in this NASA/Lockheed propfan test. For this, all were awarded the 1987 Robert J. Collier Trophy for the year's most significant achievement in aeronautics.

Lockheed Corp.

"We calculated what the range of the aircraft would be if [airflow] wasn't laminar, and found there would have been a 20 percent penalty," Holmes says. "They would have fallen 4,500 miles short, coming down off the coast of Venezuela somewhere."

Smoothness requirements and careful wing shaping are the "natural" methods for achieving laminar flow, but there are also some tricks to decrease turbulence artificially. For instance, if you don't like the boundary layer you're producing, vacuum it up and get rid of it.

This is the method that McDonnell Douglas Corp. and Lockheed Corp. have created for testing by NASA. McDonnell Douglas uses electron beams to drill thousands of pinpoint holes in the titanium skins of test wings. In flight, air is sucked out of the boundary layer through those holes to make the boundary layer thinner, stabilizing laminar flow. Lockheed uses slits along the wing instead of holes to do the same thing. Studies show that suction over the whole wing can provide up to 30 percent fuel savings, says Wagner.

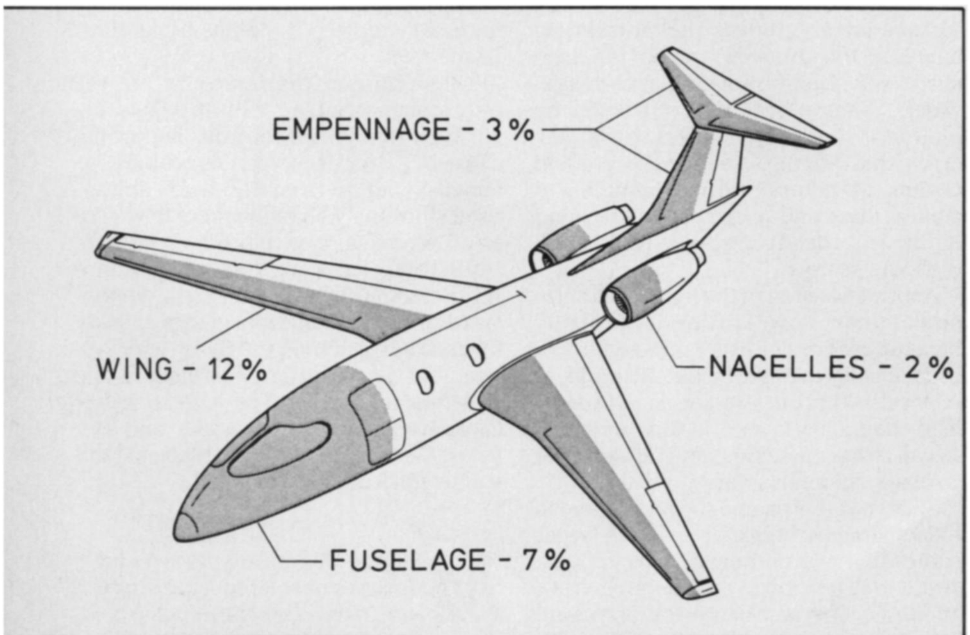
The brightest promise may lie in a hybrid system that combines smoothness, wing shaping and boundary layer suction, say NASA researchers. With hybrid laminar flow control (HLFC), the boundary layer is stabilized by suction only at the leading edge of the wing, and smooth, contoured surfaces on the rest of the wing conserve that laminar airflow. Such a system can provide the benefits of suction—and a 15 to 20 percent savings in fuel — without the problems of engineering and maintaining a wing completely riddled with vacuum lines.

NASA has also formulated a defense against bugs, whose carcasses can plug air holes and create turbulence. To win the battle of the bugs, an airplane can deploy a retractable "shield" at low altitudes — where most bugs are — that will take the brunt of the assault. The shield also has spray nozzles to keep the wing wet, because bugs don't stick to a wet wing, NASA engineers find.

Last year NASA completed two years of simulated airline service and flight testing of a plane using HLFC. After flying the craft through Southwestern summers and Northeastern winters—"all the worst of summer and winter conditions" — the NASA team found "everything worked very well," Wagner reports.

Airlines have worried about such a system's maintenance "skeletons in the closet," Wagner says. But since the test, airline representatives have become more supportive of HLFC. "It got everyone excited again about laminar flow," he says.

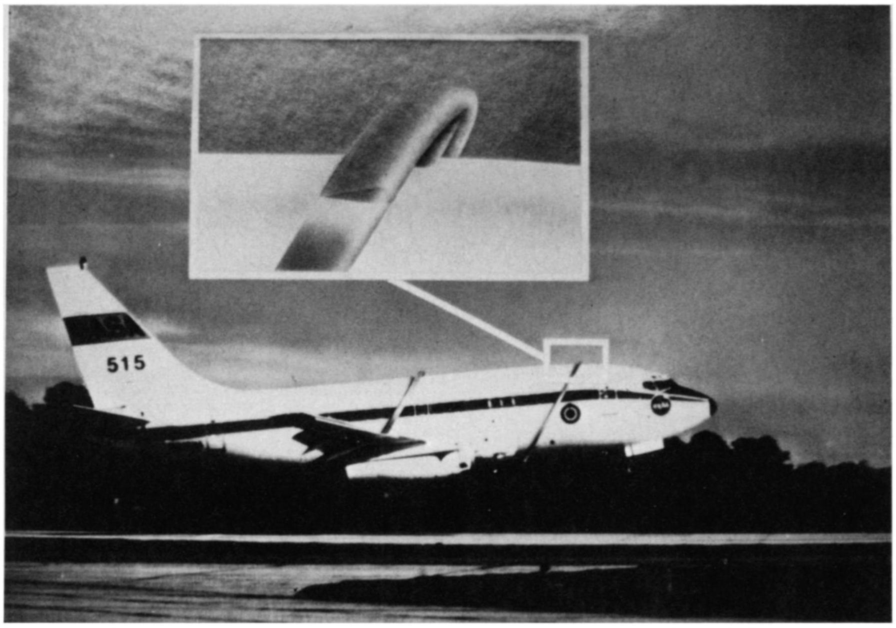
Even the military is interested in using HLFC to build a global military transport, according to Wagner. Such a plane would carry a 132,000-pound payload and "fly anywhere in the world, unload and come back without refueling," he says.



NASA

A NASA diagram shows the surfaces where laminar flow can be improved by smoothing and shaping airplane surfaces. Percentages indicate the amount of drag that can be reduced on each type of surface, yielding an overall drag reduction of 24 percent.

The number of surfaces on an airplane where engineers can tease out laminar flow is limited. Induc-



NASA

A drawing shows how large eddy breakup devices (LEBUs) might look on a NASA jet. Even though the foil-shaped surfaces are a source of drag themselves, they decrease overall drag by smoothing airflow over the aircraft.

ing laminar flow on the wing surfaces is not easy, but it is achievable. However, airflow on the fuselage and engines, which represents half an aircraft's drag, is nonlaminar for most of its course along these surfaces, and no good way exists to keep that from occurring.

Such airflow must be forced to assume some of the beneficial qualities of laminar flow. NASA researcher John B. Anders Jr. displays one of the weapons of coercion in his office at the Langley Research Center: an unassuming, clear sheet of plastic. The flexible, thin plastic, made by the 3M Co., seems smooth. But a squeaky pull of the fingers over the surface betrays the presence of what a microscope would reveal as long, V-shaped grooves.

The idea of putting grooves on the surface of an airplane came from the observation that it takes less force to push fluid through a triangular pipe than a circular one, even though a triangular pipe has more surface area and therefore should have more friction. "The reason triangular pipes have less friction is that the flow in the corners is forced to be laminar," Anders says. "The idea then was that we might be able to reduce friction further by putting a lot of those corners together."

NASA scientists then calculated the optimum shape and size for friction reducing, V-shaped grooves, and the 3M Co. machined the grooves, called riblets, into plastic. Like the triangular pipe, the grooves and ridges give the fuselage more surface area. In flight, half of each thousandths-of-an-inch-deep groove fills with low-friction laminar airflow. The result is a 14 percent reduction in drag over the fuselage. This translates into a 7 percent reduction in drag for the whole aircraft, and a potential $400 million savings in fuel per year for civilian aircraft, Anders says.

The really nice thing about the system is its simplicity. "You just slap it on and away you go," Anders says. The riblets covered the bottom of Dennis Connors' sailboat *Stars and Stripes* in the America's Cup race off Australia in 1987, and there is talk of lining long pipelines with the film for more efficient transport of liquids like oil.

One interesting epilogue: After the invention of the riblet film, researchers discovered tiny grooves on sharkskin. On analysis, the grooves proved the best shape and size for reducing drag in saltwater. "Nature beat us to [riblets] by millions of years," Anders observes. Since that finding, Anders has studied dozens of natural forms, including a stuffed duck and a cactus, in the wind tunnel in order to discover their drag-reducing secrets.

Another weapon in the fight to stabilize nonlaminar flow is the large eddy breakup device (LEBU) — a 1- to 6-inch-wide airfoil that rings the fuselage at intervals along the airplane. Small eddies in the boundary layer can cause drag, but so can larger eddies as they roll along the fuselage, Anders explains.

LEBUs, as their name suggests, seem to reduce drag by breaking up those larger eddies. But exactly how they can reduce drag 8 to 10 percent even though each is a hunk of metal stuck into the airstream baffles researchers. "Even though we've been studying them five years, we still don't know the physics of why they work," Anders says. Another puzzle is why they work better when placed in pairs, one directly behind the other.

The best setup seems to be a combination of riblets and three pairs of LEBUs on a fuselage. The combination has an additive effect, Anders says. "When you combine these systems you can get drag reductions of 15 percent, which begins to get people's attention."

A method that already allows airliners to slip more efficiently through the air is called "flying by the wire." Military aircraft have long used a fly-by-wire system, in which the connection between the pilot and the control surfaces of the aircraft is made not mechanically, by cables or hydraulic lines, but by electrical signals along wires strung through the aircraft.

Flying by the wire saves fuel in two ways. On a commercial airliner, replacing heavy cables with thin wires can trim 700 or 800 pounds off the weight of the aircraft, according to a spokesman for Airbus Industrie, the European aircraft consortium. Lighter aircraft use less fuel.

The electrically mediated commands in a fly-by-wire system also lend themselves to easy modification by computer. In Airbus' new A320 aircraft, computers can fly the aircraft so that it "slices" through the air always "teetering on the edge" of making a turn, says Norris Krone, an official of the American Institute of Aeronautics and Astronautics in Greenbelt, Md. This not only makes the plane more maneuverable, but also saves fuel by allowing the plane to balance itself in a configuration that offers least resistance to the air. Such a balance point is unstable and too difficult for a human to achieve for long, but the computer can make the constant minute corrections necessary to keep the plane flying thus, Krone says.

The A320 and the Concorde are the only commercial aircraft that use exclusively fly-by-wire controls, in part because U.S. aircraft companies are dubious about giving up tried-and-true cables — used since the Wright brothers flew — for an all-electrical system pretty much controlled by a computer. When an Air France A320 crashed in June during a demonstration flight, some observers quickly focused suspicion on the fly-by-wire system, but an investigation blamed the crash on pilot error. The A320 also has cable backups for the rudder and elevators that would allow the plane to land if all electrical systems failed.

Many aeronautical engineers have focused not on reducing drag but on increasing the efficiency of the gas-guzzling beast itself: the engine. Jet engines race through the skies by sucking vast quantities of air through rotary teeth, then compressing that air and mixing it with fuel in a combustion chamber. The exhaust from the continuous explosion in the combustion chamber drives turbine blades, which power the spinning blades at the front to suck in more air.

In modern turbofan jet engines, much of the air sucked in at the front "bypasses" the combustion chamber and is forced out the back of the engine, pushing the plane along much as the air coming off a propeller would. If this air had to pass through the combustion chamber, as it did in early jet engines, all that extra air would have to be combined with enough fuel to make it combust. This wastes a great deal of fuel without giving the plane much extra push.

Jet airliners now use "high bypass" engines that force one part of air through the combustion chamber for every six parts pushed straight out the back. As engineers designed jet engines with higher and higher bypass ratios, the question became: Why not make an engine where almost all the air bypasses not just the combustion chamber but the engine itself?

Thus was invented the propfan, an "ultra-high" bypass engine that is a throwback in two ways. The fan blades are on the outside of the engine like a propeller, and all the air that passes inside the engine goes through the combustion chamber as in the earliest jets.

The result, though, is anything but a throwback. With 20 to 40 times as much air bypassing the combustion chamber as goes through it, the engine becomes very fuel efficient. The propfan engine offers about a 40 percent increase in efficiency over engines now on airliners, according to Don Hanson, a spokesman for the Long Beach, Calif.-based aircraft division of McDonnell Douglas Corp.

Many new turbofan engine designs just coming into production also use very high bypass ratios for increased fuel efficiency, but the propfan is still about 25 percent more efficient than these, Hanson says.

Yet fuel efficiency may not be enough. With the price of fuel low and no sign it will rise anytime soon, aviation fuel costs rate low in the priorities of many airlines at the moment, according to industry sources.

"Fuel is not a major concern for airlines right now," says Jack Gamble, a spokesman for the civil aviation division of the Boeing Co. in Renton, Wash. "The executive of an airline will be looking at the cost of labor, the cost of [loans], the cost of ground operations. After all that, the cost of fuel becomes rather insignificant."

New technologies must prove themselves, must "earn themselves onto an airplane," Gamble says. Others cite the time-consuming testing and Federal Aviation Administration (FAA) clearances for devices such as LEBUs and HLFC when explaining why fuel-efficient devices may not reach airplanes for many years.

Nevertheless, McDonnell Douglas is pushing ahead with the propfan engine. In September the company flew an MD-80 jetliner with a General Electric propfan engine at the famous Farnborough Air Show in England, and McDonnell Douglas plans to begin making propfan-powered planes in the early 1990s. Riblets, being a simple technology, should begin showing up on airplanes in the next two or three years, NASA's Anders says. And the military's need for long-distance flight without refueling will keep that sector interested in drag-reduction technologies, HLFC researcher Wagner says.

Then again, depending on the occult dynamics of OPEC and the vagaries of oil exploration, fuel prices may skyrocket once more. If they do, the campaign to scrimp on precious petrol will begin again. Airlines will demand fuel-efficient planes from manufacturers, the FAA will push through approval on fuel-efficient designs and more money will be spent on research. In the end, of course, money and economics are what determines whether fuel-efficient designs take off or languish. □

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The Ages of Gaia: A Biography of Our Living Earth — James Lovelock. This book expands on the theory of Gaia — the Earth as a single living organism with all living species as components of that organism. The author first sketched the theory in 1979, and here he explains the ages of Gaia: the Archean, when the only life was bacteria; Middle Age, when many-celled plants and animals emerged; and Modern Times. Closing chapters explore the possibility of establishing a geophysical system on Mars and the meaning of Gaia in the context of religious faith. Norton, 1988, 252 p., illus., $16.95.

Annual Reviews of Phytopathology, Vol. 26 — R. James Cook, Ed. Includes reviews in the fields of abiotic stress and disease, molecular genetics and breeding for resistance. Annual Reviews, 1988, 493 p., charts & graphs, $36.00.

Creation: The Story of the Origin and Evolution of the Universe — Barry Parker. This physicist and award-winning science writer traces the universe from the Big Bang and its initial dramatic expansion to the first nuclei and atoms and the formation of galaxies and their distribution in space. The text goes on to explain how elements formed in stars and life emerged in the universe. Woven throughout the book is an interesting look at the scientists who made these discoveries. A glossary of technical terms is included. Plenum Pubs 1988, 297 p., illus., $22.95.

Kourion: The Search for a Lost Roman City — David Soren and Jamie James. Archaeologist Soren and journalist James here chronicle the excavation and reconstruction of this ancient Roman city on the southern coast of Cyprus, which was destroyed by a great earthquake in A.D. 365. Details Soren's discovery of the world's earliest preserved Christian community. Doubleday, 1988, 222 p., color/b&w illus., $21.95.

The Mind — Richard M. Restak. Provides the general reader with a beautifully illustrated overview of the thinking of many varied authorities on the nature of the mind. As a companion guide to a nine-part PBS television series "The Mind," it focuses on nine aspects of the mind: philosophy, development, aging, addiction, pain and healing, depression and mood, thinking, language and violence. Bantam, 1988, 328 p., color/b&w illus., $29.95.

The New Dinosaurs: An Alternative Evolution — Dougal Dixon, foreword by Desmond Morris. The author, by mixing geologic and paleontologic fact with fantasy, creates a unique vision of how dinosaurs would look and act today if they had not become extinct. Stunning color illustrations introduce fantastic animals, such as the glub of the woodland swamp, the nectar-sucking gimp of the Neotropical realm and a flock of whiffles in the Palaearctic tundra. Discusses current extinction theories and the fundamentals of dinosaur evolution and classification. Salem Hse, 1988, 120 p., color/b&w illus., $19.95.

Roadside Geology of Alaska — Cathy Connor and Daniel O'Haire. Following the main highways and roads of Alaska, this book explores the varied geological formations of the landscape, from Devil's Desk to Snowslide Gulch. Maps and photographs enhance the text in this roadside reference. Mountain Pr, 1988, 250 p., illus., paper, $12.95.

Seasons of the Seal — Fred Bruemmer and Brian Davies. Follows the life of one harp seal as she mates, migrates and gives birth to her pup in subzero cold. More than 135 spectacular photographs dominate this story, which includes some natural history of the harp seal and describes how the Inuit people have depended on the seal for survival. Northword, 1988, 159 p., color illus., $29.95.

Worse Than the Disease: Pitfalls of Medical Progress — Diana B. Dutton. Explores the social, ethical and economic dilemmas modern society faces as a result of medical innovation. The author presents for the general reader case studies of innovation with adverse side effects — DES, the artificial heart and the swine flu immunization program. She also discusses the possible future problems of unmonitored genetic engineering research. Concluding chapters are devoted to the policy issues arising from the cases, such as risks and rights of participants in medical studies, compensation for injury caused by medical innovation and the role of the public in forming future public health policy. Cambridge Univ. Press, 1988, 528 p., $29.95.