For three decades, America's technological preeminence in aeronautics has enabled it to dominate the Free World aviation market. Nearly four out of every five civil air transports in service today are American-made.

In 1975, United States exports of civil aircraft, engines, and other aircraft parts totaled $6 billion, contributing significantly to America's more than $9 billion balance-of-trade surplus.

Foreign competitors, aided by financial support from their governments, are closing the margin of technological superiority held by the United States. As a result, America's share of the Free World aeronautical market faces a reduction.

Of the $6 billion total U.S. aeronautical exports in 1975, $2.7 billion consisted of civil air transports. The projected Free World market for civil air transports from 1976 through 1985 is about $50 billion. It is estimated that with a major effort to advance aeronautical technology, the United States can capture $40 billion of this market. If not, the U.S. share could drop as low as $25 billion. Advanced technology is, as in the past, a key to aircraft sales.

Fuel costs account for some 20 percent of the total operating expenses of airlines. As fuel prices climb, aircraft energy efficiency—fuel economy—takes on increasing importance.

NASA has identified technologies that in coming years can cut fuel consumption of civil air transports in half. The development and application of these technologies will not only aid airlines beset by rising fuel prices but also contribute to our nation's strength and assure employment for thousands of Americans.

Based on estimates of the size of the domestic commercial air fleet in 2005, the NASA-identified technologies would save about a million barrels of fuel daily, helping to conserve dwindling supplies of petroleum and to reduce reliance on foreign oil. Development of fuel-thrifty air transports is of equal importance to foreign airlines, a big market for American-built aircraft.

The aviation fuel-saving technologies spotlighted by NASA are as follows:

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**Engine Component Improvement**

- Fan blades get nicked...
- Compressor tips wear down...
- Ducts and bearing seals spring leaks...
- Turbine blades erode...
- Combustors warp.
- The gradual degradation of such engine components causes fuel waste. NASA proposes to conduct broad-scale engine tests to determine why engine components deteriorate and which impaired components waste the most fuel. Researchers will then focus efforts on lengthening the period of maximum effectiveness of components whose degradation causes the most fuel waste.

The objective of the program is to have improved components available by 1980 that could decrease engine specific fuel consumption by 5 percent.* Specific fuel consumption refers to the amount of fuel used by a jet engine to produce a pound of thrust. As specific fuel consumption drops, mileage climbs.

In this connection, NASA already has developed a seal for gas turbine engines that is effective under conditions so severe that conventional seals fail. The seal, referred to as the lift pad, can reduce not only fuel waste but also maintenance cost.

**Advanced Engines**

NASA is considering a number of advanced fuel-saving engine concepts. Engines employing this technology are expected to be available for new aircraft brought into service by 1990. A 10-percent decrease in specific fuel consumption is estimated as a result of such improved engines.

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*Projected fuel savings for the five technologies cannot be simply added up to get a grand total. Not all of them could apply to every type of aircraft. Also, one technology improvement may eliminate the need for another.
that a greater proportion of the fuel is converted into energy. The major technical problem is to develop engine structures and components that can tolerate the higher temperatures and pressures.

Another concept involves a regenerative system in which engine exhaust heat is recycled to produce additional thrust. The pacing problem here is to reduce the weight and complexity of the system.

A third approach involves use of a mixer, a mechanical device that combines the duct and core streams emitted by a fan-jet engine and discharges them through a common exhaust nozzle. The duct stream is the air that passes through and is compressed by the engine fan. It exits without being burned and generates thrust in the same way that air passing through a conventional propeller does. The core stream is the air that passes through the engine turbine. It is compressed and burned with the engine fuel before exiting. Improved mixing of the two streams, that the mixer would make possible, produces more uniform exit velocities and temperatures which both decrease specific fuel consumption and reduce engine noise.

Aerodynamic Design and Control Innovations

The application of NASA advanced aerodynamic design and electrical control systems to aircraft could reduce their fuel consumption by 15 to 20 percent. For example, flight tests of the NASA supercritical wing have indicated that it can increase the range of aircraft by some 15 percent. The wing's shape delays the build-up of air drag by moving the point of maximum drag to the wing's rear. The airfoil is slightly flattened on top and compensates for the resulting loss of lift by curving downward at the rear.

Substantial additional fuel savings are available through development of controls technology. NASA has made significant progress with its fast-acting computer-coordinated flight control system called digital fly-by-wire. The system is one of numerous practical benefits that evolved from the Apollo Moon exploration program.

Comparatively lightweight electrical wiring replaces the heavy network of metal rods, hinges, and hydraulic lines that normally convey the pilot's physical commands from his cockpit controls to the wing and tail surfaces. The rapid response of the system can significantly increase aircraft stability and damping which in turn reduce structural loads and aircraft weight.
Another aerodynamic innovation consists of nearly vertical airfoils, called winglets, at the wingtips. The winglets both act as lifting surfaces and reduce air drag.

### Laminar Flow Control

Laminar flow control provides the greatest potential for fuel conservation but would require a radical change in aircraft design. Estimates of fuel savings range from 20 to 40 percent, depending on the extent of application and the airplane design range. Air transports with laminar flow control could be in service by 1990.

Today's civil air transports typically cruise at about 800 kilometers (500 miles) per hour. One problem of traveling at such a speed occurs in the boundary layer, a thin sheet of flowing air that moves along the surfaces of the wing, fuselage, and tail of an airplane. At low speeds, this layer follows the aircraft contours and is smooth, a condition referred to as laminar. At high speeds, the boundary layer changes from laminar to turbulent, creating friction and drag that waste fuel.

The laminar flow control concept calls for removing the turbulent boundary layer by suction and thus maintaining laminar flow. Suction requires development of porous or slotted aircraft surfaces and lightweight pumping systems.

The practicality of the laminar flow control concept was demonstrated in the middle 1960's through U. S. Air Force flight tests of the X-21 aircraft. However, weights of materials and pumping systems at the time made its application uneconomical. Recent advances in lightweight composite materials (see below) and pumping systems may permit the design of practicable and reliable boundary layer suction systems.

### Composite Structures

Using composite materials rather than metal alone can decrease aircraft structural weight by about 25 percent, reducing fuel consumption by 10 to 15 percent. Composite materials are not only lighter but also stronger. NASA research activities will provide design and manufacturing data and will demonstrate the durability of composite materials in a flight evaluation program.

Composites are made up of filaments of boron or graphite arrayed in an epoxy, polyimide, or aluminum matrix. Composite structures are being extensively flight tested. Among such tests are those of a composite-reinforced wing midsection and a composite vertical fin.

A number of composite spoilers, panels, and rudders already are in airline service. These components, however, represent a tiny fraction of aircraft weight. Extensive use of composites would be possible on new aircraft introduced into service in the late 1980's.

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All NASA aircraft fuel-saving efforts are being conducted to assure the same or better levels of safety, service, and environmental protection as are present today. The new knowledge gained through development of energy efficient aircraft, like all new knowledge, may be expected to provide benefits beyond its immediate application.