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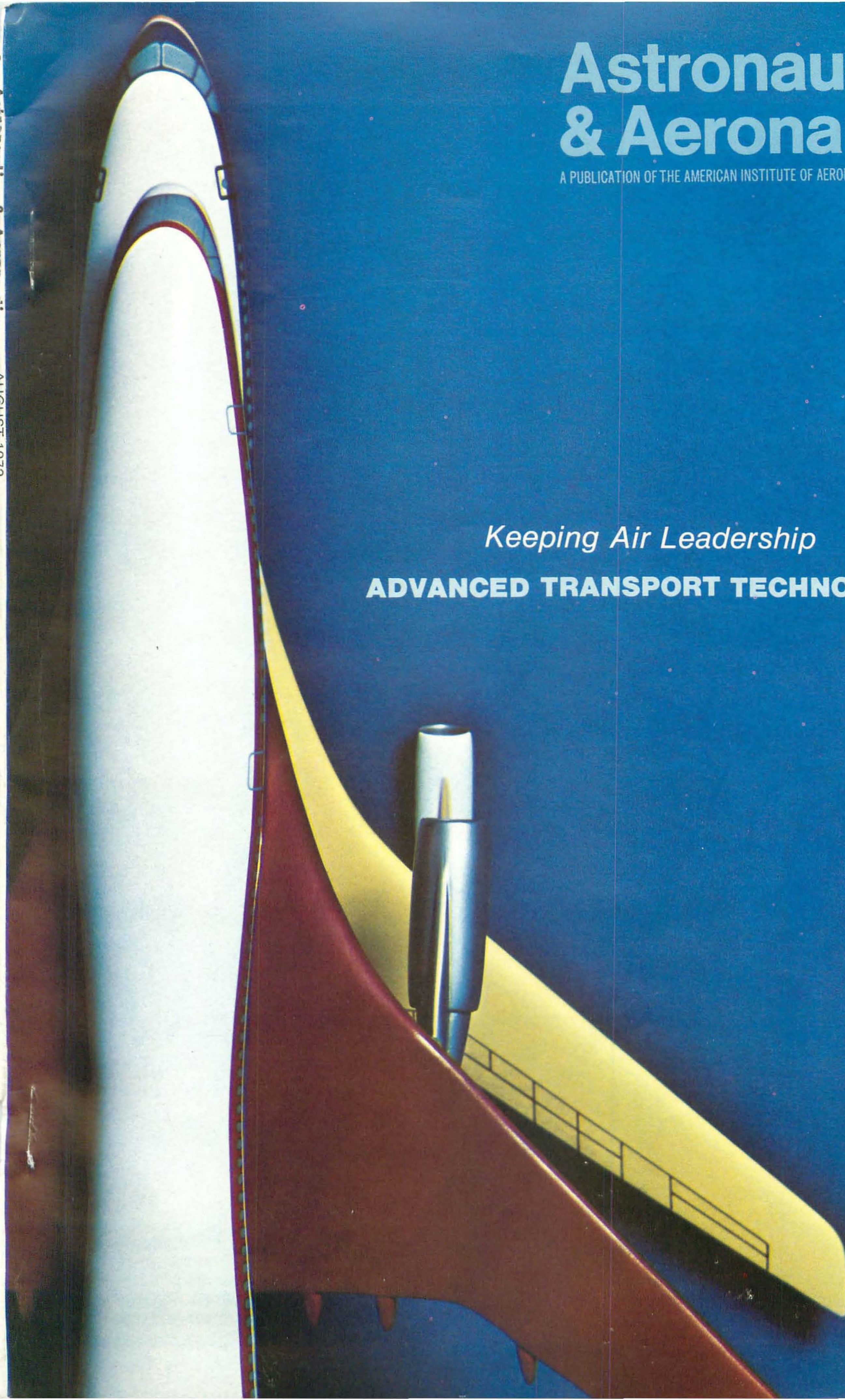


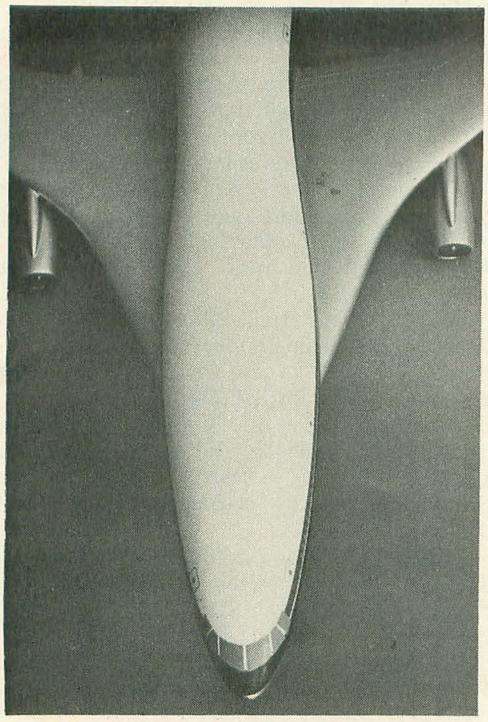
*Keeping Air Leadership*

**ADVANCED TRANSPORT TECHNOLOGY**

AUGUST 1972

ADVANCED SUBSONIC TRANSPORT TECHNOLOGY

# SUPERCRITICAL AERODYNAMICS WORTHWHILE OVER A RANGE OF SPEEDS



**By THEODORE G. AYERS**
Advanced Transport Technology Office

## The designer can choose speeds up to Mach 0.98 and more economy or present speeds and even greater economy and gain wider buffet margins either way

Supercritical aerodynamics will permit efficient flight at speeds approaching Mach 1.0 or improve aircraft structural and aerodynamic efficiency at lower speeds. Trades between speed and structural advantages can provide efficient aircraft designs over a broad subsonic speed range. Regardless of speed, supercritical technology can improve ROI more than enough to make up for the costs of reducing noise by 10 EPNdB. And supercritical aerodynamics can bring about substantial improvements in buffet onset and maneuver margins.

There is nothing new about supercritical flow. It exists whenever a high enough forward speed causes local flow over a lifting surface or body to exceed the sonic or critical value. Supercritical flow may occur at flight Mach numbers as low as 0.70 or 0.75 with a thick wing or body or may not occur until near sonic flight speed for a thin wing or body. For subsonic flight above the critical speed, regions of both subsonic and supersonic flow exist locally. Efficient aerodynamic design for this mixed-flow region requires developing new techniques different from those used for completely subsonic flow. This emerging technology has become known as supercritical aerodynamics.

The principal difference between conventional subsonic aerodynamic technology and supercritical technology lies in the cross-sectional profile of lifting surfaces (airfoils). At supercritical Mach numbers, a broad region of local supersonic flow extends vertically from both airfoils as indicated by the pressure coefficients above the sonic value and by the shaded areas of the flow fields in F-1. This region of supersonic flow usually terminates in a shock wave, which causes an energy loss and therefore a drag increase. In addition, the shock wave produces a positive pressure gradient at the airfoil surface which may cause separation of the boundary layer with an associated large increase in drag, severe airfoil buffeting, and stability and control problems. This shock-induced separation occurs initially on an airfoil because the low-momentum air of the boundary layer cannot traverse the pressure rise through the shock wave superimposed on the subcritical pressure recovery. The much flatter shape of the upper surface of the supercritical airfoil reduces both the extent and strength of the shock wave, as well as the adverse pressure rise behind the shock wave, with corresponding reductions in drag. To compensate for the reduced lift on the upper surface of the supercritical airfoil resulting from the reduced curvature, the airfoil has increased camber near the trailing edge.

The characteristics of the supercritical airfoil suggest three potential benefits from applications to civil aircraft. For those aircraft designed to operate at moderate subsonic speeds, Mach 0.70-

0.90, for example, the supercritical airfoil may permit reducing structural weight by using thicker wing sections or reduced sweep, or both, without penalizing aerodynamic performance. The weight reductions might permit increasing payload or increasing fuel volume for greater range or compansate for weight added to reduce engine noise and pollutant emissions or allow improving aerodynamic performance through increased aspect ratio.

Supercritical technology would have a second application in permitting efficient high subsonic speed cruise by delaying the transonic drag rise. Although this application may have the greatest appeal to users of business jet aircraft, it can also benefit commercial and military aircraft by saving en-route time on long-range missions. Wind-tunnel studies have shown that combining the supercritical airfoil with wing sweep and configuration area ruling makes possible efficient cruise very near the speed of sound.

In aircraft buffeting and maneuverability lies the third potential benefit of the supercritical aerodynamics. Careful integration of the supercritical airfoil into aircraft configurations significantly delays the Mach number for buffet onset at a given lift coefficient and increases the maximum lift coefficient for buffet onset at a given Mach number.

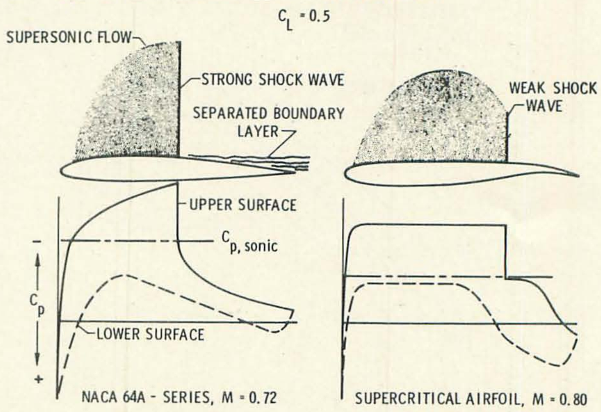
Results of several experimental programs support these conclusions. A wind-tunnel/flight program being conducted jointly by North American Rockwell, the U.S. Navy, and NASA uses a modified T-2C trainer airplane (F-2) in an effort to increase structural efficiency. A basic T-2C with a 12% thick conventional wing appears on the left, and a modified T-2C incorporating a 17% thick supercritical wing, designed by W. E. Palmer of North American Rockwell Corp., on the right. Bonding balsa to the original wing structure and overlaying it with fiber glass converted the wing to the modified form. This airplane does not represent an optimum design. It does, however, provide a reasonable test vehicle for flight evaluation of the aerodynamic characteristics of the thick supercritical wing.

Wind-tunnel data (F-3) show both the effects of airfoil section geometry and the well-known decrease in cruise Mach number with increasing thickness. Circles identify full-scale flight results obtained from the T-2C program. For a constant thickness of 12%, the wind-tunnel studies indicate that a well-designed supercritical airfoil could provide a 15% greater cruise Mach number than a conventional airfoil.

If the supercritical airfoil is used to increase the structural efficiency by increasing wing thickness, both the wind-tunnel studies and the flight results show an increase in thickness ratio of 42% (from $t/c$=0.12 to 0.17) will not degrade the aircraft cruise Mach number. The supercritical airfoil for the T-2C represents a somewhat conservative design approach because of a deliberate underestimate of the expected maximum permissible pressure recovery. Additional thick supercritical airfoil research may make possible total increase in thickness of about 58%.

Shaking of the wings by buffeting accelerates fatigue and makes passengers uncomfortable. The supercritical wing has significantly better buffet characteristics than the conventional wing throughout the operational flight envelope. It improves the maneuvering $g$-margin, the altitude increment between the design cruise altitude and the buffet boundary at a constant Mach number. It also improves the low-speed cruise margin, the Mach number increment between the design cruise

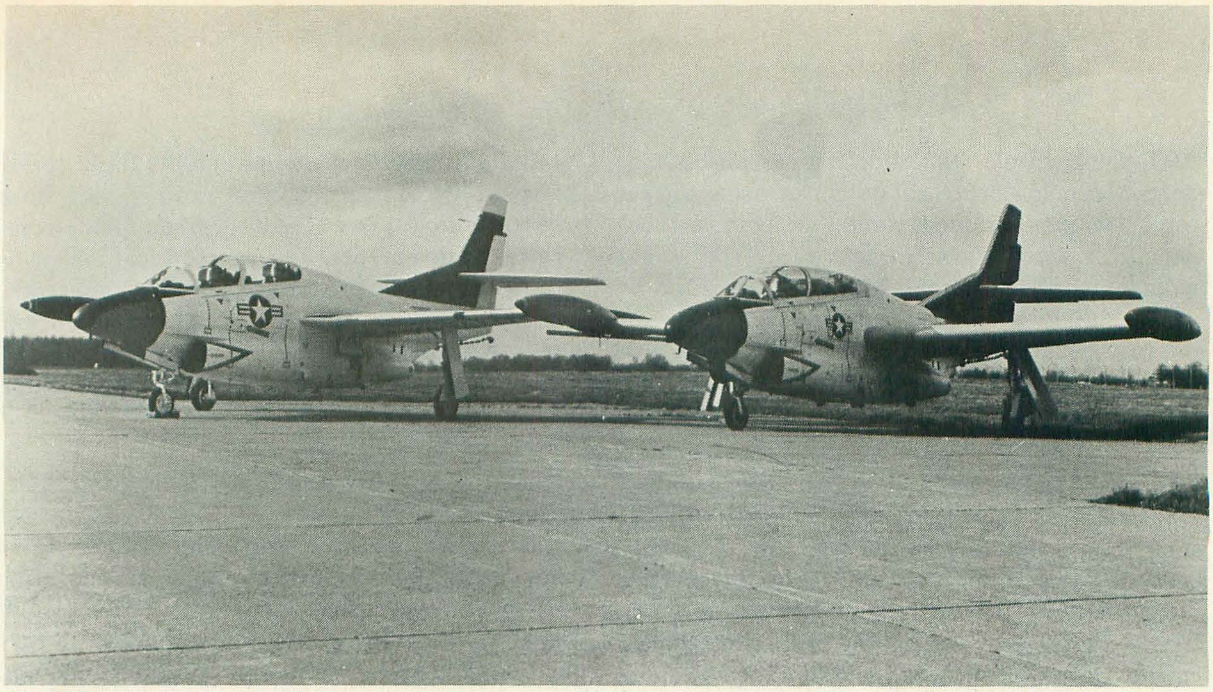
**F-1 SUPERCRITICAL FLOW PHENOMENA**




Mach number and low-speed buffet boundary at a constant altitude. But it slightly reduces the overspeed buffet margin, the Mach number increment between the design cruise Mach number and the high-speed buffet boundary at constant altitude. However, the same increase in thickness for a conventional wing would reduce the high-speed boundary much more, as indicated by the reduction in drag-rise Mach number.

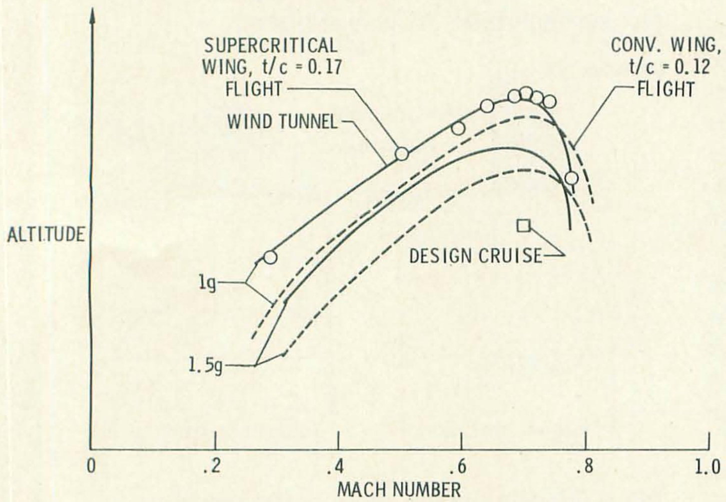
Another advantage of the thick supercritical wing shows up at low speeds. Because of the much larger leading-edge radius of the thick supercritical wing, the modified wing of the T-2C proved a higher maximum lift without flaps than the original wing with the flaps down (F-5).

There has been concern expressed about the possible sensitivity of the supercritical wing to local contour variations, such as waves, or steps. The modified wing on the T-2C is not ideal. Although special care was exercised to maintain a fair leading edge, many waves exist aft of this region.

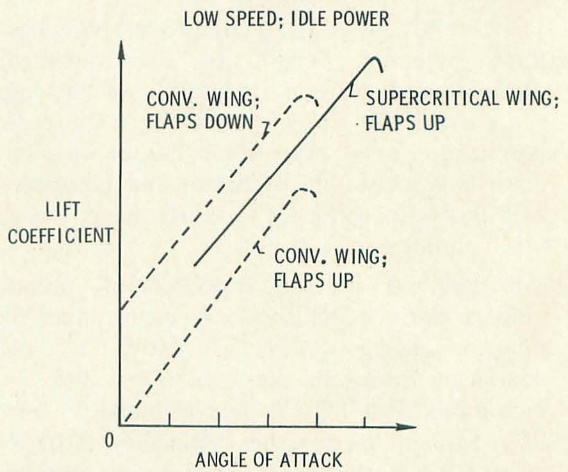


F-2 **T-2C aircraft with supercritical wing** appears at right, one with a conventional wing at left. Balsa and fiber glass were used for the conversion.

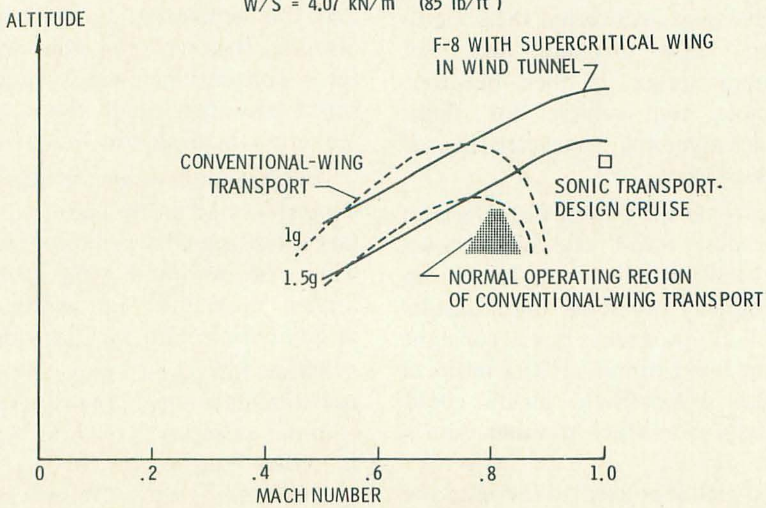
**F-4 BUFFET BOUNDARIES FOR THE T-2C**




**F-5 LIFT CHARACTERISTICS OF T-2C**




**F-8 BUFFET BOUNDARIES OF CONVENTIONAL AND SUPERCRITICAL WINGS**



The favorable lift, drag, and buffet characteristics obtained despite these waves is very encouraging and should dispel much of the concern about the sensitivity of the supercritical wing to contour variations.

The basic flight program for determining the aerodynamic characteristics and flying qualities of this modified straight-wing airplane has been completed. Additional flight studies underway seek detailed boundary-layer measurements to assist in understanding boundary-layer characteristics in the presence of local shocks and in extreme pressure gradients.

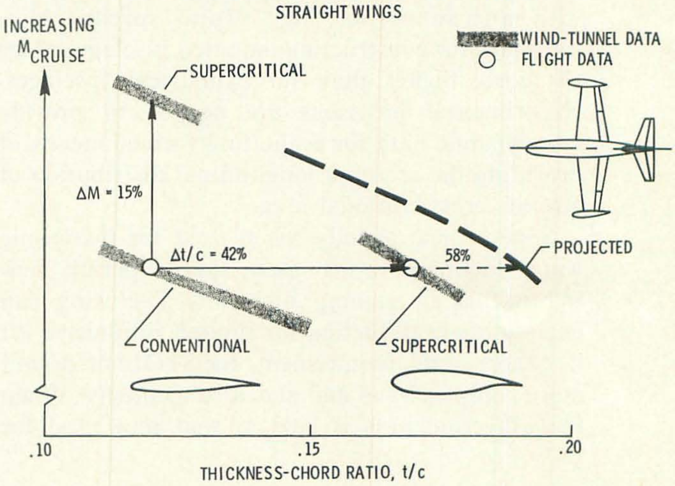
The swept wing encompasses a higher speed range. Wind-tunnel studies have indicated that combining the supercritical airfoil, the area rule, and wing sweep can push the cruising speed of subsonic aircraft very near Mach 1.0. Careful integration of all aircraft components is important for maximizing aerodynamic efficiency at these high cruising speeds. Richard T. Whitcomb of NASA Langley has developed one candidate—a three-engine advanced-transport configuration for near-sonic cruise (F-6). The forebody shape, the area ruling of the fuselage in the region of the wing, the wing root-chord extension, the contouring of the fuselage in the vicinity of the nacelles, the extension of the nacelle pylons, and the supercritical airfoils all contribute importantly toward obtaining the combination of good over-all area distribution with local contours that avoid adverse shock/boundary-layer interactions.

The current generation of jets attained increase in cruise speed primarily through the use of increased sweep and new airfoil shapes. A comparison of drag coefficient at design cruise lift coefficient (F-7) for early and current jet transports with wind-tunnel data for this advanced trijet indicates that supercritical aerodynamics may make possible a further increase in cruise speed.

An exploration of the buffet boundaries for a near-sonic cruise-transport wing has come from wind-tunnel tests of an F-8 airplane model incorporating a representative transport-type wing very similar to that used for the three-engine near-sonic configuration. A comparison of the results with buffet boundaries for a conventional-wing transport (F-8) assumes the same wing loading for both airplanes. The maneuvering *g*-margin and the low-speed cruise margin for the near-sonic transport-type wing appear about equal to the conventional transport margins. The increased speed of a near-sonic transport might permit flight at higher altitudes than for conventional transports because of the increase in the high-speed, buffet-free lift coefficient. The actual cruise altitude will depend on many other factors such as cruise wing loading and the availability of suitable engines.

The very promising results obtained for the F-8 model in the wind tunnel provided the data base for large-scale flight tests of an F-8 airplane incorporating a representative transport-type supercritical wing (F-9). This flight program sought

**F-3 TWO WAYS OF USING SUPERCRITICAL AIRFOIL**




to demonstrate the near-sonic performance in actual flight, to extend and refine supercritical aerodynamic-design technology, to evaluate the maneuver and speed margins for the wing, and to determine the off-design performance nearer full-scale operating conditions than possible in the wind tunnel. These flight tests will also help determine the surface smoothness required to exploit the full aerodynamic potential of the supercritical wing.

The first flight of the modified F-8 took place on March 9, 1971, at the NASA Flight Research Center. The data obtained since have verified the predicted performance in most respects. Like the T-2C, the F-8 is not wholly representative of a transport configuration, but it does provide a good test bed for the wing. At present it carries a rather stiff wing designed for simplicity, which therefore does not simulate the aeroelastic characteristics of a transport wing. In addition, the wing does not incorporate high-lift devices of the type used on transport aircraft. The F-8 flight program is

**THEODORE G. AYERS** served as technical manager, aerodynamics, for two years in the program office. He has now returned to the 8-Foot Tunnels Branch, where he has responsibility for supercritical aerodynamics research for advanced military aircraft. Earlier he had spent nine years there working on military aircraft performance at transonic speeds and on supercritical aerodynamics. He joined Langley in 1961 after receiving a B.S. in aeronautical engineering from Northrop Institute of Technology.

continuing. Future plans may include determining the effects of a realistically flexible wing with high-lift devices.

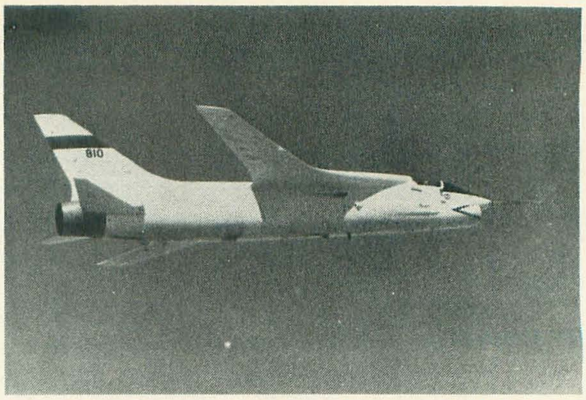
The systems studies undertaken as a part of the Advanced Transport Technology Program have indicated a number of areas in aerodynamics needing additional technical effort, either to solve problems or to develop further potential.

For example, high bypass ratio engines for reducing noise decrease the nacell fineness ratio because of their increased diameter. Low fineness ratio lowers the drag-rise Mach number and has brought on a need for work on nacelle aerodynamics for aircraft designed to cruise at high subsonic speeds.

The fuselage cross-sectional area needed for storing landing gear and aircraft subsystems and for accommodating passenger seating with desired seat widths and number abreast, aisle widths and number, and head room in some instances conflicts with area-ruling for high cruise speeds. Also, estimates for constructing indented fuselages place the costs higher than for cylindrical fuselages. Experimental programs are needed to provide aerodynamic data for evaluating various means of providing the required longitudinal distribution of aircraft cross-sectional area.

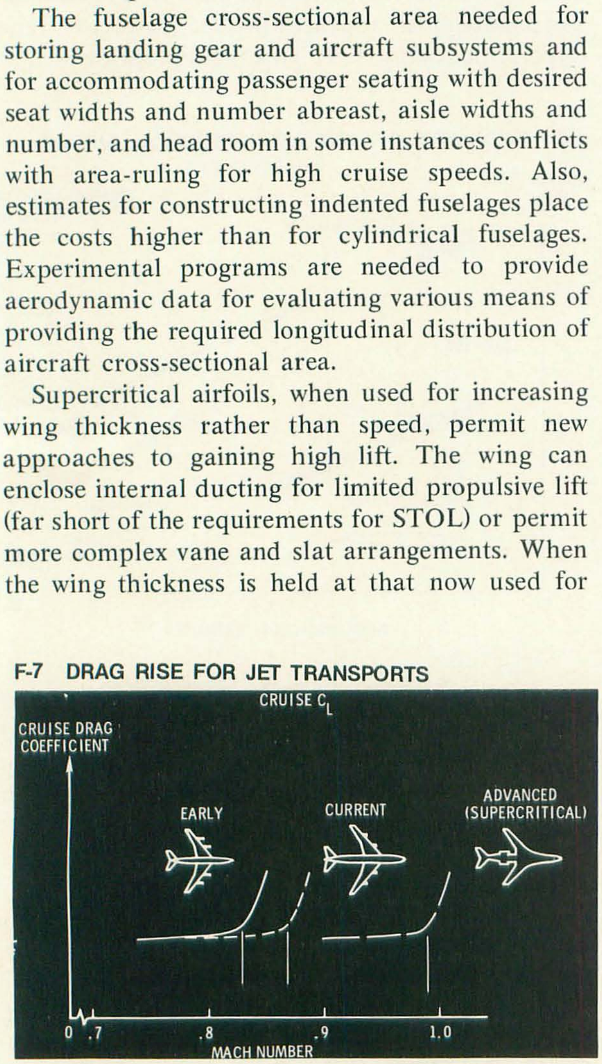
Supercritical airfoils, when used for increasing wing thickness rather than speed, permit new approaches to gaining high lift. The wing can enclose internal ducting for limited propulsive lift (far short of the requirements for STOL) or permit more complex vane and slat arrangements. When the wing thickness is held at that now used for conventional airfoils, the new shape of the supercritical sections introduces new constraints and opportunities in the design of flaps and controls. Both experimental and theoretical approaches to these problems are needed.

The airframe systems studies concluded that active controls for gust- and maneuver-load alleviation and possibly for flutter suppression would allow a lighter structure. Experimental programs must be begun to define the active-control aerodynamic surfaces and determine their impact on the configuration cruise aerodynamics. They should also investigate possible new methods for providing flight-path control for the new operational procedures anticipated for the terminal area, as well as for high-speed cruise. Flight programs currently underway will provide much needed design and validation data for supercritical aerodynamics. However, further vigorous research and technology programs are needed to fully exploit the potential of supercritical aerodynamics by the time the airframe industry and the airlines are ready for the next generation subsonic long-haul CTOL transport.

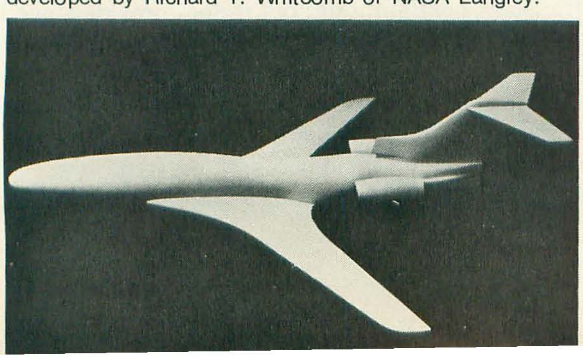


**F-9 F-8 with a more transport-like supercritical wing** than the T-2C has verified most wind-tunnel predictions of near-sonic performance and other characteristics. Future flight-testing programs should include a more flexible wing with high lift devices.

**F-7 DRAG RISE FOR JET TRANSPORTS**




**F-6 Near-sonic trijet candidate configuration** has been developed by Richard T. Whitcomb of NASA Langley.



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