SUPERCritical aerodynamics

A very promising opportunity for improving aerodynamic performance of civil aircraft in the 1970's and beyond is that afforded by the supercritical aerodynamic concepts developed by Dr. Whitcomb and his Langley Research Center colleagues. The basic element of this technology is the two-dimensional supercritical airfoil concept which provided the major breakthrough by materially increasing the drag rise Mach number. The basic principle is illustrated in figure 1 by comparison with a conventional airfoil.

For the conventional airfoil, approximately 12-percent thick, operating at a Mach number of 0.7, the flow accelerates over the upper surface and a rather extensive supersonic flow region develops that is terminated by a strong shock wave. A large increase in drag occurs due to the energy loss associated with the shock and, more importantly, to the boundary layer separation induced by the pressure rise through the strong shock.

In the supercritical airfoil concept the upper surface curvature is markedly reduced except near the trailing edge. This reduced curvature reduces the velocities and delays the formation of the supersonic flow region to a higher flight velocity. The example shown is for a Mach number of 0.8 and even for this relatively large increase in Mach number over that for the conventional airfoil, the velocities in the supersonic region are diminished and the vertical extent of the region reduced. This reduces the energy loss in the wave but, more importantly, it eliminates the shock-induced boundary layer separation. The lift lost by the reduced velocities is then recovered the high trailing-edge camber in the subcritical flow aft of the shock. The
concept can also be utilized to provide increased airfoil thickness while maintaining the same drag rise Mach number as a thinner conventional airfoil.

Application to straight wings. - The application of the two-dimensional supercritical concepts to improve the characteristics of a straight wing aircraft is illustrated in figure 2. Here the cruise Mach number is presented as a function of wing thickness-to-chord ratio for both conventional and supercritical airfoils as applied to the T-2C aircraft. Two sources of data are presented. The shaded lines represent estimates based on wind-tunnel data and illustrate both the effect of airfoil section and the well-known decrease in cruise Mach number with increasing thickness. The circular symbols represent full-scale flight data obtained from a joint NASA/Navy/North American program utilizing the T-2C. Looking first at the case where the thickness is held constant at 12-percent, wind-tunnel studies have indicated that a well designed supercritical airfoil could provide a 15-percent increase in cruise Mach number relative to the conventional T-2C airfoil. It should be kept in mind that the particular percentage improvement quoted applies to the 12-percent thick airfoil case.

If cruise Mach number is held constant and the supercritical airfoil used to allow an increase in thickness both the flight results and the wind-tunnel results indicate that the cruise Mach number can be maintained while providing a 42-percent increase in thickness ratio. Because of the rather extreme thickness, a somewhat conservative approach was taken in the design of this particular supercritical airfoil. It is believed that by additional research on thick airfoils the cruise Mach number curve could be raised as indicated by the "projected" curve which would result in a total increase in thickness of 58 percent. These large increases in wing thickness can be used to either reduce wing weight or for the same weight allow an increase in wing aspect ratio and in
either case provide increased wing volume for housing such items as powered-lift systems or increased fuel tankage. There should be many opportunities to apply this concept to future civil aircraft and discussions relative to general aviation and STOL aircraft are presented in papers 17 and 20 of this volume.

Application to swept wings. - With regard to swept wings the supercritical airfoil, the area rule and wing sweep concepts can be combined such that the drag rise of a subsonic type transport can be delayed to near-sonic speed. This concept is illustrated in figure 3. Here the upper bound for drag rise Mach number of a lifting wing having a supercritical airfoil is presented as a function of wing sweep according to the well-known cosine rule. Also shown is the drag rise Mach number of a good equivalent body of revolution developed at Langley with the aid of the supercritical technology, which represents the drag rise Mach number associated with volume and sets the upper limit for the complete aircraft configuration. The optimum wing sweep and the good equivalent body are matched at the intersection. The match is accomplished by providing the complete configuration with the good equivalent body area progression by means of fuselage indentation and the wing glove, and providing the full sweep benefit by use of the wing glove to reduce the unfavorable wing-fuselage interference. The symbol represents the experimental results of such a design approach and demonstrates the near-sonic capability.

Application of these concepts to increase both the aerodynamic cruise efficiency and speed of a swept wing transport type aircraft is shown in figure 4, where the variation of the aerodynamic efficiency term in the range equation is presented as a function of Mach number for a conventional design and a supercritical design based on wind-tunnel development tests. The
design incorporates supercritical airfoil, improved planform, and good area
progression discussed above and it will be noted that the optimum cruise
is very near-sonic speed and that sizable increases in both cruise speed
and efficiency are indicated relative to the conventional configuration.
Also shown is an ideal upper bound and a wave drag cutoff and it can be seen
that the supercritical concepts are pushing close to the upper right corner.
The upper bound is based on the span and wetted area of the supercritical
configuration and assuming full leading-edge suction, an elliptical span
loading, skin friction 10 percent above the flat plate turbulent value, 25
counts of compressibility drag and no trim drag.

It should be pointed out that for certain classes of aircraft the aft
engines result in a serious balance problem. In this regard Langley is
currently supporting both in-house and contract research directed towards
optimizing wing-mounted engine configurations. The impact of the supercritical
technology on various transport aircraft applications are discussed in paper
21 of this volume.

Beyond Mach 1.0 increases in wave drag and sonic boom are encountered
which will require additional configuration approaches. An approach to a
possible low supersonic transport is presented in paper 22 of this volume.