INTRODUCTORY REMARKS

Richard Whitcomb

NASA Langley Research Center

The principal point to be made in this report is that the designs of aircraft intended for flight at transonic speeds are probably less than optimum because of the lack of full-scale Reynolds number wind-tunnel data. Also, the need for sorting the effects of Reynolds number and aeroelasticity, which can be done in the NTF, will be addressed briefly.

Advanced transonic configurations, such as the supercritical wing, are inherently more sensitive to Reynolds number than earlier configurations because the pressure recovery gradients imposed on the boundary layer are generally steeper. The results of two-dimensional supercritical airfoil investigations and theoretical calculations have shown this effect. In recognition of this problem, a technique for approximately simulating full-scale Reynolds number characteristics at present wind-tunnel Reynolds numbers for near-cruise conditions is utilized at the Langley Research Center. The transition strip, which in the past has been located near the leading edge of the wing, is rearward so that the relative displacement thickness of the boundary layer at the trailing edge of the wing is the same as might be expected on a full-scale configuration with the transition near the leading edge. Two-dimensional wind-tunnel results indicate that the technique provides a very good simulation of airfoil characteristics at full-scale Reynolds number.

The variation of drag coefficient with lift coefficient is presented in figure 1 for an advanced supercritical wing designed for full-scale Reynolds numbers at a Mach number of 0.78 and a chord Reynolds number of approximately 2×10^6. Results are shown for conditions with the transition strip at 10 and 35 percent of the chord. Calculations indicate that with the transition at 35 percent of the chord, full-scale boundary-layer conditions are approximately simulated. This comparison shows that for the lift coefficient range near cruise (approximately 0.6), the drag with the rearward transition location is approximately 50 counts (0.0050) less than with the forward transition. This difference is far greater than the simple reduction in skin friction associated with the more rearward transition location. Surface oil-flow studies indicate that with the forward transition location on the supercritical wing, there are substantial areas of boundary-layer separation on the upper surface and on the lower surface in the rearward cusp. With the transition rearward, no significant separation is apparent.

It is the writer's strong belief that the results obtained with the rearward location are indicative of the drag characteristics which would be obtained at full-scale conditions. However, if this technique for simulating full-scale Reynolds number is not accepted as valid by an aircraft designer and the higher drags with transition forward are used, the supercritical wing configuration for which the results are shown would be completely unacceptable for a long-range cruise type aircraft. The designer would probably design a wing with a much more conservative supercritical airfoil (that is, one with reduced pressure recovery gradients). In particular, he would design his wing with lower thickness ratios and reduced aft camber. The resulting configuration would have substantially poorer overall performance than would one having a wing similar to that for which the data are shown. If the capability for testing at full-scale Reynolds number were available, the wind-tunnel results with the transition forward would, in the writer's opinion, be similar to those shown in the figure for the rearward transition location. With this data in hand, the aircraft designer would then be far more willing to design an airplane with a less conservative wing, such as that for which results are shown.

At higher lift coefficients, the characteristics of sweptback wings are significantly dependent not only on the Reynolds number but also on the aeroelastic deflections. In an attempt to separate these two effects, two models of the F-8 supercritical wing, one constructed of steel, the other of aluminum, were tested at several dynamic pressures in the Langley 8-foot transonic pressure tunnel. The variations of pitching-moment coefficients with lift coefficient obtained from this investigation for a Mach number of 0.99 are presented in figure 2. The results for the steel wing indicate that "pitch-up" is delayed and that the severity is reduced when the dynamic pressure is increased. This effect is due to both the increased Reynolds number and increased deflection of the model. For the aluminum model, which had one-third the stiffness of the steel model, the pitch-up is further improved compared with that for the steel model. This is a pure aeroelasticity effect. It is obvious from these results that in the determination of the higher lift characteristics of sweptback wings, the aeroelastic effects must be sorted from the Reynolds number effects. The NTF will allow such a sorting by its ability to hold dynamic pressure constant.

PANEL CONSIDERATIONS AND RECOMMENDATIONS

Laurence Loftin, Jr.

INTRODUCTION

The configuration aerodynamics panel discussed the future utilization of the National Transonic Facility (NTF) in the following areas:

(1) Basic tunnel calibration

(2) Establishment of confidence in the tunnel:

  (a) Wind-tunnel to wind-tunnel comparisons

  (b) Wind-tunnel to flight comparisons

(3) Exploitation of high Reynolds number capability:

  (a) Cruising aircraft

(b) Highly maneuverable aircraft

(c) Other

(4) Specialized experimental techniques

(5) New directions

The first three of these areas relate to experimental activities (listed in order of priority) which the panel thought should be considered for early implementation in the NTF. Areas four and five are of a somewhat different nature. The significant points made in the discussions in each area will be outlined in the following paragraphs.

BASIC TUNNEL CALIBRATION

Anomalies found in the comparison of data obtained from different wind tunnels have sometimes been traced to uncertainties in tunnel calibration. Accordingly, an accurate calibration of the NTF was considered to be of top priority. The calibration should include not only the usual pressure surveys but also measurements of the turbulence level. The use of the hot-wire technique at cryogenic temperatures was suggested as a subject for study in the time period before the NTF is brought into operation. The need for periodic checks on the tunnel calibration was also cited since the calibration of wind tunnels has been known to vary with time because of deterioration, minor alterations, etc. The measurement of certain critical aerodynamic characteristics on a "standard" model of some type was recommended as a possible means for obtaining a quick check on the tunnel. Such a technique was employed in the Langley two-dimensional low-turbulence pressure tunnel in the 1940's as a means for detecting any significant change in the tunnel turbulence.

ESTABLISHMENT OF CONFIDENCE IN TUNNEL

The conduct of investigations aimed at establishing confidence in the validity of results obtained in the NTF was considered as next in priority after the basic tunnel calibration was completed. These investigations were thought to be comprised of the following elements:

(1) Comparison of results from the NTF with data from other existing wind tunnels

(2) Comparison of results from the NTF with data obtained in flight.

The proposed comparative wind-tunnel investigations would involve tests of the same model in the NTF and in the various transonic facilities which are presently available. Measurements would first be made at the same values of the Reynolds number and Mach number in each facility, after which the investigation would be extended in the NTF to Reynolds numbers higher than those achievable in the other facilities. These comparative wind-tunnel investigations would serve to establish confidence in the NTF through comparisons of data obtained at comparable values of Reynolds number and Mach number in different wind tunnels. In addition, the methods and validity of extrapolating data obtained in present wind tunnels to Reynolds numbers beyond their capability will be better understood. Thus, the limitations and usefulness of these tunnels and the particular circumstances which require the unique capabilities of the NTF will be brought into clearer focus.

The following types of measurements should be made in each of the wind-tunnel investigations:

(1) Force coefficients

(2) Model surface pressure distributions

(3) Wake surveys

The detailed pressure measurements were thought to be particularly important as a means for identifying and understanding differences between data obtained in different wind tunnels. The type of "pathfinder" model to be used in the wind-tunnel investigations was discussed at some length. A configuration representative of 1980's state of the art which incorporates advanced aerodynamic design features (and thus is Reynolds number sensitive at some important combinations of Mach number and lift coefficient) was thought to be desirable. Both highly maneuverable aircraft and long-range cruising aircraft were thought to be possible candidates for the "pathfinder" model and should be given careful consideration. In fact, two different models representing the two basic configuration types might be desirable. Consideration should also be given to the availability of comparable flight data in the selection of the pathfinder configuration.

The following presently available wind tunnels were suggested for use in providing comparative data for validation of the NTF:

(1) Ames 11-foot transonic tunnel

(2) Langley 8-foot transonic pressure tunnel

(3) AEDC 16-foot transonic propulsion tunnel

(4) Marshall 32-inch Ludwieg Tube

Investigation of the pathfinder model in these facilities should take place on a schedule which is geared to provide the necessary data within the time frame that the NTF becomes operational. Selection of the model must therefore be made relatively soon.

Idealistically, comparison of wind-tunnel and flight data should provide the final answer on the validity of the wind-tunnel data. Unfortunately, such comparisons frequently raise more questions than they answer. In order to minimize the possibility of unexplainable anomalies, the panel suggested that direct comparisons of drag measurements made in flight and in the wind tunnel should be deemphasized because of the difficulties in obtaining the measurement of engine thrust in flight. Instead, wake surveys, boundary-layer measurements, and pressure distributions were thought to provide the best bases for comparing wind-tunnel and flight data. The aircraft chosen for comparative tests should be of modern design and be properly instrumented. A precise air-data system for measurement of Mach number and dynamic and static pressure is required, as is an accurate means for measuring angle of attack and angle of sideslip. Detailed measurements of structural deformation are mandatory.

Selection of the aircraft for the comparative tests is directly related to the configuration of the pathfinder model which has been discussed previously. The flight data should be available on a timely basis for comparison with wind-tunnel test results. Early implementation of the flight investigation is accordingly indicated.

Two aircraft were discussed as possible candidates for consideration. These were the F-111 transonic aircraft technology (TACT) and one of the advanced military STOL aircraft (AMST). The TACT aircraft employs a supercritical wing, is highly instrumented, and will provide detailed data within the required time period. It has the possible disadvantage of operating at a relatively low transonic Reynolds number (40×10^6 maximum). Both candidate AMST aircraft employ straight, supercritical wings but are relatively slow. The selection of the aircraft and the associated pathfinder model requires detailed study and should be resolved in a timely manner.

EXPLOITATION OF HIGH REYNOLDS NUMBER CAPABILITY

Exploitation of the high Reynolds number capability of NTF was considered in relation to long-range cruising aircraft, highly maneuverable aircraft, and certain other types of vehicles. There was considerable discussion as to the relative priority of experimental studies of long-range cruising aircraft and highly maneuverable aircraft. An unanimous conclusion was not reached; however, the consensus was that studies of long-range cruising aircraft should rank next in priority after the experimental investigations needed to establish confidence in the validity of data obtained in the facility.

Long-range cruising aircraft comprise civil passenger and freight transports, military logistics aircraft, bombers, and long endurance aircraft. Future investigations of this class of aircraft in the NTF should be focused on an advanced technology aircraft intended for operation in the 1990 time period. Some of the important aerodynamic phenomena which might be characteristic of such an aircraft and which would probably require the high Reynolds number capability of the NTF are:

(1) Shock — boundary-layer interaction and flow separation together with their associated effects on the load distribution and the force and moment characteristics of the aircraft

(2) High-speed buffet together with the pitching and rolling characteristics at high speed

(3) Interference drag at high speed

(4) Control-surface effectiveness and hinge moments at high speed

In addition to these items, much work was thought to be needed in the development of improved high-speed airfoils, and the formulation of criteria and methods for the design of these airfoils. The presently available Langley 0.3-m transonic cryogenic tunnel was considered suitable for much of the experimental airfoil work. This work could begin in the very near future. Low-speed problems involving stall, buffet, and development of high-lift devices might also be undertaken on a two-dimensional basis in the 0.3-m transonic cryogenic tunnel. At a later date, three-dimensional studies might be desirable in the NTF.

The Reynolds number sensitive features discussed for long-range cruising aircraft are also inherent in highly maneuverable aircraft. The requirement for simultaneous operation at high subsonic speeds and high-lift coefficients, however, suggests Reynolds number sensitive design features in future highly maneuverable aircraft which are not found in long-range cruising aircraft. Advanced maneuvering aircraft, for example, might incorporate one or more of the following design features:

(1) Variable geometry for increased maneuverability. Concepts such as variable leading- and trailing-edge shapes and flaps, as well as thrust vectoring, integrated in the aerodynamic design of the aircraft might be considered

(2) Vortex-lift concepts which might involve fixed strakes or close-coupled canards might also be considered

Models involving combinations of these design features, as well as others which may evolve, should be studied in the NTF. In addition to measurement of the usual pressures, forces, and moments, attention must be given to buffet onset and intensity at various combinations of high lift and Mach number. The effect of various design features on buffet and high-speed stall is considered to be particularly important.

A number of other classes of vehicles, for example, missiles and spacecraft, were discussed as possible candidates for exploiting the unique capabilities of the NTF; however, no recommendations were made for specific programs in these areas.

SPECIALIZED EXPERIMENTAL TECHNIQUES

The need for development of a number of specialized experimental techniques for use in the NTF was discussed and several recommendations were made. The development of techniques for measuring turbulence at cryogenic temperatures has already been mentioned in the discussion of tunnel calibration, but it is introduced again at this point. Development of methods of flow visualization at cryogenic temperatures was thought to be very important and should be the subject of study in the Langley 0.3-m transonic cryogenic tunnel in the near future.

The NTF, as now being designed, is equipped with a sting-support system. The panel recommended that consideration should also be given to the development of several additional types of support system. One of these was the "plate" support. In this type of support, the model is mounted on a vertical plate (alined with the airstream) which extends from the bottom of the fuselage to the tunnel floor. The forces and moments are measured at the juncture of the model and the plate. This system avoids the need for distorting the rear of the fuselage to accept the sting. The plate support is considered as complementary to and not a replacement for the sting-support system. Other support systems thought to be in need of design and development for NTF are

(1) Semispan support

(2) Systems for measuring dynamic stability derivatives

(3) Two-dimensional support

(4) Support for flight-path trajectory simulation. This type of support involves two stings which can position one model in relation to another. For example, the forces and moments on a store following separation from an aircraft can be measured and the resulting motion of the store computed to provide the next point on the trajectory.

NEW DIRECTIONS

Investigations at high Reynolds numbers in the NTF will no doubt suggest opportunities for improved aircraft performance which are not now anticipated. The experimental studies of long-range cruising aircraft and highly maneuverable aircraft which have already been discussed may suggest new means for cruise and maneuver enhancement. Various types of boundary-layer control may provide new opportunities, and the ability to achieve large leading-edge Reynolds numbers on three-dimensional wings may yield unanticipated improvements.

The large independent variation of dynamic pressure for a given Mach number provides an important means of aeroelastic tailoring which has not been available before. These are only a few examples of ways in which the capabilities of the NTF may reveal new possibilities for improvement. Many others no doubt exist and will be explored and exploited as new programs are undertaken in the tunnel.

ROUND-TABLE DISCUSSION

A question was raised during the round-table discussion subsequent to the panel meeting as to why flight and wind-tunnel comparisons were necessary on advanced technology aircraft. It was pointed out that the supercritical wing and other advanced design features pose most of the Reynolds number sensitive questions. It was further pointed out, however, that the advanced state of the art pathfinder model involves an inconsistency. The problem is how to select, in the near future, an advanced configuration for which substantiating flight data will be available by 1981.

Another commenter cautioned against placing too great an emphasis on early wind-tunnel and flight correlation. Correlation between wind tunnel and flight is extremely difficult at present and will improve only as the state of the art of both wind-tunnel and flight measurements improve. Furthermore, NTF is a unique facility which should not be bogged down on comparisons of data for old aircraft, which may not have the Reynolds number problems characteristics of more advanced configurations.

Another commenter suggested that a most useful program would involve the design of configurations optimized for operation in the chord Reynolds number range from 50×10^6 to 60×10^6. Performance of such configurations when tested at a Reynolds number of 5×10^6 to 10×10^6 might be very poor but be outstanding at the higher Reynolds number. The importance of analytical techniques in such high Reynolds number designs was emphasized.

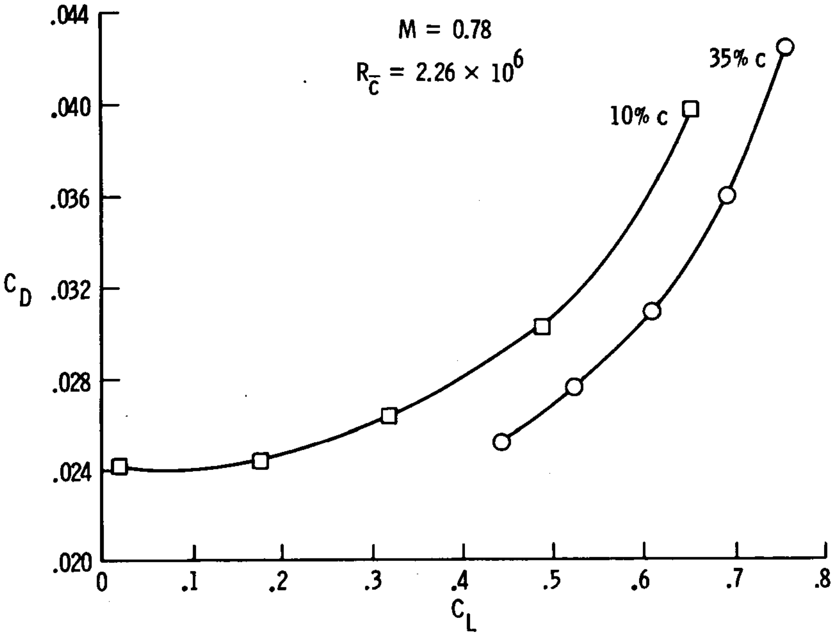

Figure 1.- Effect of wing transition location on drag for an advanced supercritical wing.

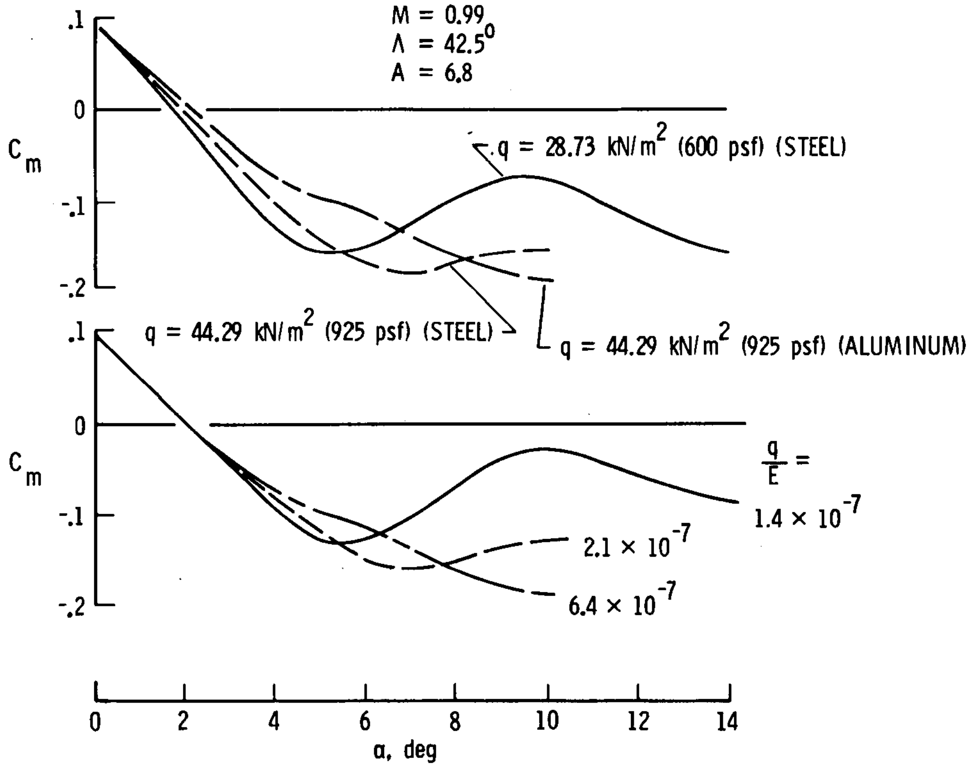

Figure 2.- Pitch characteristics for the F-8 supercritical wing model.