finite core size and use of artificial viscosity are currently being investigated.

Conclusions

A surface singularity method has been developed for the "exact" calculation of unsteady three-dimensional lifting potential flows including the effects of wake roll-up. Numerical calculations of the early stages of the flowfield for a rotor impulsively started revealed that the indicial thrust and circulation overshoot shortly after motion starts and then approach asymptotically from above their steady-state values. Additionally, the modeling of the distorted rotor wake geometry was partially successful with initial tip roll-up and contraction being present. However, more work is required before an accurate description of the complete wake geometry can be obtained.

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Inlets for High Angles of Attack

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Nomenclature

A_e = flow area at diffuser exit
A_t = flow area at throat (minimum area)
$\mathfrak{D}_{max}$ = inlet total pressure distortion [(maximum total pressure)-(minimum total pressure)] / (average total pressure)
M_e = Mach number at diffuser exit
p = surface static pressure
P_0 = freestream total pressure
V_0 = freestream velocity
x = axial distance from highlight
α_{sep} = angle of attack (measured between freestream velocity and inlet centerline) resulting in inlet flow separation, deg.

Introduction

INLETS capable of operating successfully to high angles of attack are required for STOL and some VTOL aircraft concepts. In the STOL application, high angles of attack result from the large upwash generated by high wing lift coefficients.[1] With VTOL aircraft, large angles of attack may be generated during the transition maneuver. Analytical and experimental studies[2-6] indicate that increasing lip thickness, or contraction ratio, can substantially improve the ability of the inlet to tolerate large flow angles. However, this approach generally results in inlet lip designs that are in conflict with the lip shape desired for most efficient cruise operation. In this

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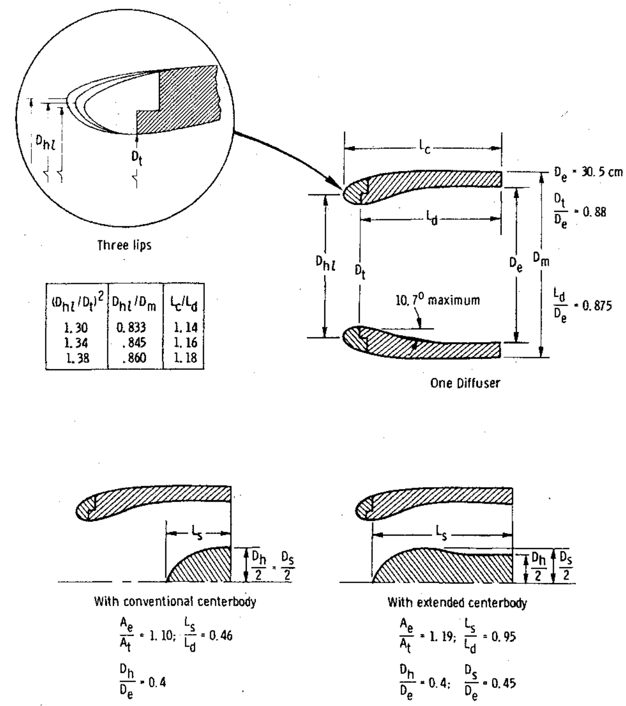

Fig. 1 Inlet geometry and nomenclature.

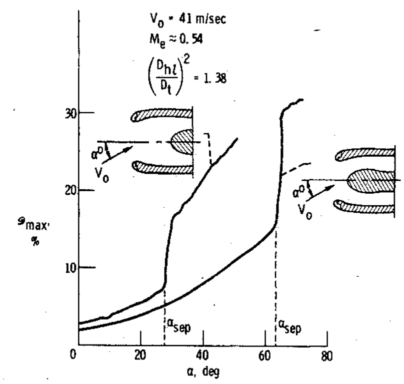

Fig. 2 Increase in distortion with increasing angle of attack and flow separation.

Note the results of low-speed wind tunnel tests are presented that suggest another approach in designing for high angles of attack.

Apparatus and Results

An inlet design for high-speed subsonic flight was tested in the Lewis Research Center's 2.75 by 4.58 meter (9×15 ft) V/STOL wind tunnel at a forward velocity of 41 meters per sec (80 knots). This velocity is representative of STOL takeoff and landing conditions and VTOL transition.

The geometry and nomenclature used to describe the inlet lips and diffuser tested are shown in the top sketch of Fig. 1. Three removable entry lips, having contraction ratios, $(D_{hl}/D_t)^2$, of 1.30, 1.34, and 1.38 were tested with a single diffuser. The internal contour of each entry lip was an ellipse with a major to minor axis ratio of 2.0. The NACA-1 cowl shape was used for the entry lip external forebody. As indicated by the table of Fig. 1, the ratio of inlet cowl length to diffuser length, L_c/L_d, increased slightly with increasing lip contraction ratio. This was due to the increase in internal lip axial length that resulted from maintaining a constant major to minor axis ratio.

Each lip and diffuser assembly was tested to determine its tolerance to angle of attack, with first a conventional cen-

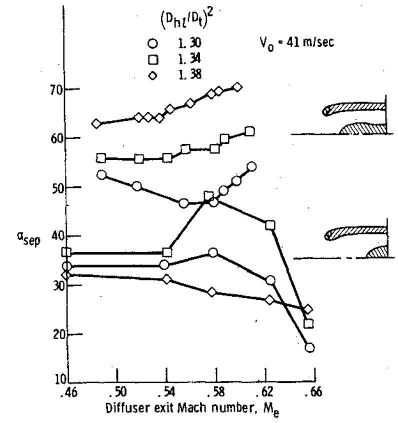

Fig. 3 Effect of centerbody on separation angle of attack.

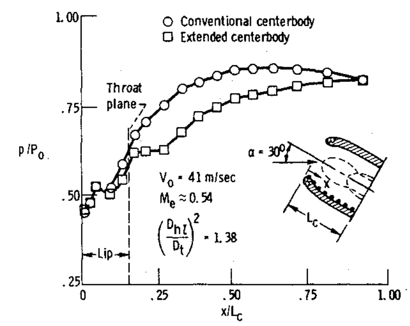

Fig. 4 Effect of centerbody on lip and diffuser axial static pressure distribution with attached flow.

terbody, and then with an extended centerbody (bottom of Fig. 1). Reynolds number of the internal flow, based on throat diameter, D_t, was approximately 5×10^6.

Inlet flow separation resulting from high angle of attack is readily identified by the traces of total pressure distortion shown in Fig. 2. With both the conventional and extended spinners, an abrupt increase in distortion indicates the onset of inlet flow separation. The traces indicate that the design of the centerbody has a surprisingly large effect on the separation angle, α_{sep}.

The effect of the centerbody on the separation angle is shown in Fig. 3 as a function of lip contraction ratio and inlet flow. This figure shows that a large improvement in the separation angle was obtained with the extended centerbody for all contraction ratios. Note that with the extended centerbody, an increase in the separation angle was obtained with increasing lip thickness. However, with the conventional centerbody an "optimum " contraction ratio appears to exist. (A contraction ratio of 1.34 is better than both 1.30 and 1.38 at most values of M_e.) A possible explanation for this behavior may be deduced by examining the axial distribution of surface static pressure measured within the inlet from the highlight to the diffuser exit.

Figure 4 shows the axial static pressure distribution measured at 30° angle of attack with both the conventional and extended centerbodies. The inlet lip contraction ratio is 1.38 with both inlets, and both have attached flow. As indicated by Fig.3, the inlet with the conventional centerbody is on the verge of flow separation at a 30° angle with $M_e = .54$. However, with the extended centerbody separation did not occur until the angle of attack was more than doubled to approximately 65°. Figure 4 indicates that the presence of the extended centerbody greatly reduced the diffusion rate just downstream of the throat. However, the pressure distribution on the lip was only slightly affected. The conclusion is that with the conventional centerbody, the critical element in determining tolerance to angle of attack may have been the diffuser. An "optimum" lip may result because large values of contraction ratio can result in a thicker initial boundary layer at the diffuser entrance thereby increasing the likelihood of diffuser separation. Alternatively, the high surface velocity encountered with a thin lip may lead to weak shocks which interact with the boundary layer to cause premature separation on either the lip or within the diffuser.

The reduced adverse pressure gradient obtained in the diffuser with the extended centerbody caused the inlet lip to become the critical element, thereby resulting in the observed increase in separation angle.

Conclusions

Model test results indicate that an extended centerbody may be very effective in improving inlet tolerance to angle of attack. The improved performance was obtained by reducing the adverse pressure gradient just downstream of the throat. The benefit of this effect could possibly be obtained with a short conventional centerbody by recontouring the diffuser or by using an extended throat to reduce the adverse pressure gradient.

Results suggest that with a given diffuser and conventional centerbody, increasing contraction ratio will improve angle-of-attack performance to the point where the diffuser becomes the critical element. A further increase in contraction ratio may then actually result in poorer inlet performance.

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Errata

Influence of Rainfall Intensity on Erosion of Materials at Supersonic Velocities

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On page 761, column 2, paragraph 3, the last sentence should read: The mass encountered is calculated from the water concentration and the swept volume a particular specimen encompasses as it travels down the track.

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Index categories: Materials, Properties of; Hypervelocity Impact; Research Facilities and Instrumentation.