# Zero-Length Inlets for Subsonic V/STOL Aircraft

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**Zero-length inlet performance and associated fan blade stresses were determined during model tests in the NASA LeRC 9×15 ft low-speed wind tunnel. The inlet models, which were installed on a 20 in. diam fan unit, had different inlet lip contraction ratios as well as unslotted, slotted, and double-slotted inlet lips. The inlet angle-of-attack boundaries for onset of flow separation were identified and compared to the operating requirements of several generically different subsonic V/STOL aircraft. The zero-length inlets, especially those with slotted lips, were able to satisfy these requirements without compromising the maximum cowl forebody radius. As an aid to the inlet design process, a unique relationship was established between the maximum surface Mach number associated with the separation boundary and the maximum-to-throat surface velocity ratio.**

## Nomenclature

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|---|---|
| $CR$ | = inlet lip area contraction ratio, $(R_{HL}/R_T)^2$ |
| $L_T$ | = inlet axial length from highlight to fan face |
| $M_F$ | = fan face Mach number |
| $M_{MAX}$ | = inlet maximum surface Mach number |
| $M_O$ | = flight or freestream Mach number |
| $M_S$ | = inlet surface Mach number |
| NDI | = fan flow distortion index |
| $P$ | = static pressure |
| $P_T$ | = total pressure |
| $P_{T_F}$ | = fan face total pressure |
| $P_{T_O}$ | = freestream total pressure |
| $R$ | = radius |
| $R_F$ | = fan tip radius, 20 in. |
| $R_{HL}$ | = inlet highlight radius |
| $R_{MAX}$ | = maximum cowl forebody radius |
| $R_T$ | = inlet throat radius |
| $V_{MAX}$ | = inlet maximum surface velocity |
| $V_O$ | = flight speed or freestream velocity, knots |
| $V_T$ | = inlet throat surface velocity |
| $X$ | = inlet axial coordinate |
| $\alpha$ | = angle of attack |

## Introduction

ENGINE air inlets for subsonic V/STOL aircraft must be designed for separation-free operation to achieve low cruise drag and to provide a steady supply of air to the engine at high total pressure recovery and low distortion. This is a more complex and significant task than for CTOL aircraft. The inlet must be capable of operating efficiently in high crosswinds during hover and very low forward speeds and at relatively high angles of attack during transition. Also the inlet must operate with large upwash from the forebody/wing flowfield during aircraft high-lift conditions and at low mass flow ratios during high-speed cruise.

Several V/STOL inlet models with and without boundary-layer control have been designed for separation-free operation and wind tunnel tested in recent years, primarily to determine low-speed performance and fan blade stress characteristics. Of all the models tested, only the slotted-lip inlet has provided any significant reduction in inlet length relative to that of a conventional axisymmetric inlet. In fact, the slotted-lip inlet has no diffuser and thus is identified as having "zero length." Decreasing the inlet length has the beneficial effect of reducing inlet weight, decreasing the moment arm associated with the inlet ram force during crosswind conditions, and improving pilot visibility in the side/aft directions for fixed-nacelle applications. These first two benefits are particularly significant for a V/STOL aircraft since they directly affect the size of the propulsion system. The operational feasibility of such an inlet has already been demonstrated, since zero-length, slotted-lip inlets have been used for many years on the Lockheed C-141.

The purpose of this paper is to present and compare with conventional inlet model data the experimental results obtained for a family of zero-length subsonic V/STOL inlets. All testing was conducted in the NASA LeRC 9×15-ft low-speed wind tunnel using a 20-in. diam fan unit. The inlet angle-of-attack limits for separation-free flow are identified and compared to the operating requirements of several generically different subsonic V/STOL aircraft. An empirical method for determining the separation boundaries is also presented to aid in the design of new inlet configurations. The effect of various configuration variables on the low-speed performance of the zero-length slotted-lip inlet is presented in Refs. 1-3.

## Concept Description and Design

The zero-length inlet concepts investigated during the program are illustrated in Fig. 1. Also shown for comparison is a schematic of a conventional axisymmetric inlet. All inlets shown in the figure have been designed to satisfy the operating requirements for a subsonic tilt-nacelle-type V/STOL aircraft. In general, the low-speed angle-of-attack capability of each inlet system is dependent upon the inlet lip profile, especially near the leading edge (i.e., highlight); the inlet lip area contraction ratio (highlight-to-throat area); diffuser area ratio (fan-face-to-throat area) and profile, if applicable; slot gap width, if applicable; and fan face Mach number or throttle setting.

For a conventional subsonic V/STOL inlet, a relatively long diffuser and large maximum forebody radius is required to satisfy the stringent low- and high-speed operating conditions. The length of the diffuser is a function of the diffuser area ratio and the maximum internal wall angle for which the flow will remain attached (with some margin). A relatively large inlet lip contraction ratio is required to provide separation-free flow during static crosswind and low-speed, high angle-of-attack conditions. Also, the forebody

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maximum-to-highlight-area ratio must be sufficient to provide a favorable lip suction force at cruise conditions. The resultant maximum forebody radius is often much greater than that required to encompass the engine envelope. Thus, the conventional subsonic V/STOL inlet tends to be long and heavy and to produce both high nacelle friction drag and aftbody boattail drag.

For the zero-length inlet concepts, the diffuser is eliminated and the inlet throat is located at the engine face. Since the throat radius for these inlets is greater than that for a conventional inlet, the maximum forebody radius will be larger if the inlet thickness remains unchanged. However, the required inlet lip area contraction ratio and, therefore, lip thickness depends upon the engine throttle setting (fan face Mach number) for which the inlet is designed and on the type of inlet employed (unslotted, slotted, or double slotted). At high throttle settings, the lower throat Mach number of the zero-length inlets relative to a conventional inlet allows a smaller contraction ratio to be employed, whereas the opposite effect occurs at low throttle settings, as will be discussed later in this paper. By adding one or more slats to the cowl lip, the inlet contraction ratios can be reduced provided the engine envelope can still be accommodated.

For a fixed contraction ratio inlet, the surface loading required to turn the flow into the engine is reduced by adding slats to the cowl lip as illustrated in Fig. 2. The reduction in loading and associated flow separation probability is due primarily to having increased cowl-lip surface area and multiple thin boundary layers rather than one relatively thick cowl-lip boundary layer. If the peak surface Mach number for the slotted-lip inlets is to be the same as that for the unslotted-lip inlets, then the contraction ratios for the slotted-lip inlets can be reduced.

The more slats that are added to the cowl lip the more complex the inlet design becomes. The unslotted-lip inlets (conventional and zero-length) consist of only a single cowl lip. The slotted-lip inlet consists of a single cowl lip, single slat which encompasses the entire circumference, slat support struts, and spring-loaded blow-in doors. The aerodynamic forces on the inlet are such that the blow-in doors, which are hinge mounted to the cowl forebody, open automatically at the static and low forward speeds to expose the slot and close automatically at high speeds to seal the slot, and form a part of the inlet forebody. The double slotted-lip inlet is identical to the slotted-lip inlet except that a 120 deg mechanically translating leading-edge slat is added to the lower portion of the 360 deg slat.

The selection of the inlet type and associated inlet lip contraction ratio is dependent upon the angle-of-attack requirements of the V/STOL aircraft. Because of the radically different V/STOL aircraft design approaches that have evolved, these requirements can vary by as much as 30-50 deg, as shown in Fig. 3. The lowest requirement is associated with those configurations which maintain the nacelle fixed relative to the aircraft while using a deflector nozzle to vector the exhaust flow to the desired angle. The highest requirement corresponds to configurations where the entire nacelle is tilted to achieve the desired thrust vector angle. An intermediate angle-of-attack requirement results when the nacelle is not only tilted, but also a vane is used to partially vector the exhaust flow. For each of the three generically different aircraft identified in the figure, the inlet flow must always remain attached within the range of angles of attack shown for each flight speed. For each of these conditions, the inlet/engine combination must also operate free of separation over a fan face Mach number range.

As an aid to the inlet design process, the flow properties at the inlet throat and at the maximum loading station on the cowl lip have been correlated for all configurations tested at operating conditions corresponding to the onset of flow separation. By identifying these parameters as measures of the likelihood of flow separation, an assessment can be made of any new inlet design by comparing the theoretically computed parameters with those associated with the separation boundary. A similar approach for designing conventional V/STOL inlets is described in Ref. 4. Potential flow methods, such as that described in Ref. 6, have been used successfully in computing the flow properties within subsonic inlets when operating at low-speed, high angle-of-attack conditions. When using potential flow methods for the slotted-lip inlets, a Kutta condition must be imposed at the trailing edge of the slats, as discussed in Ref. 3.

## Test Apparatus and Procedure

The zero-length inlet data discussed herein was obtained from model tests conducted in the NASA LeRC 9×15 ft low-speed wind tunnel. This facility operates at atmospheric total pressure and has a flight speed range of ~0-150 knots.

A 20 in. diam, turbine-driven, single-stage fan was used to provide the inlet mass flow. This fan represents roughly a 0.3-0.5 scale model depending on whether the full-scale aircraft has two cross-shafted engines or four independent high-bleed

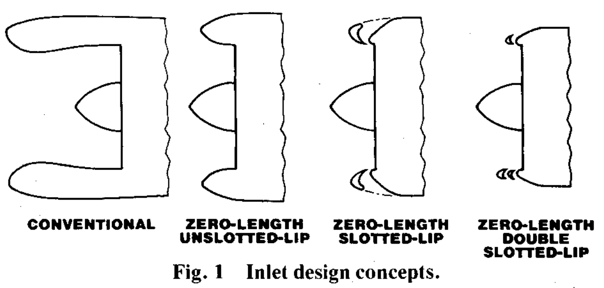


Fig. 1 Inlet design concepts.

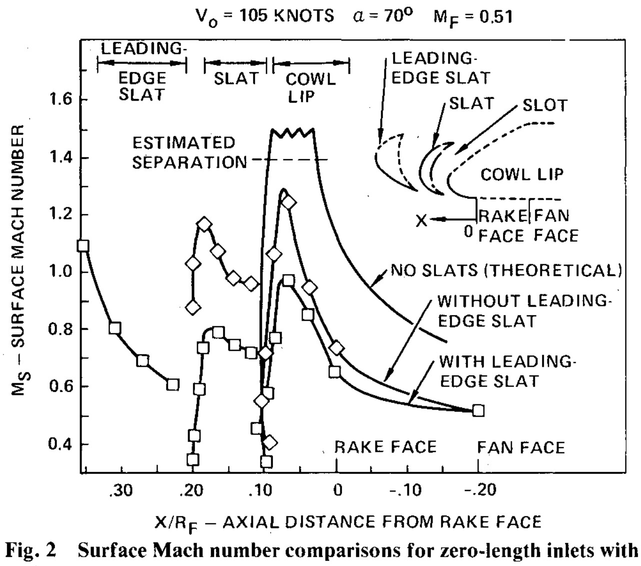


Fig. 2 Surface Mach number comparisons for zero-length inlets with and without slats.

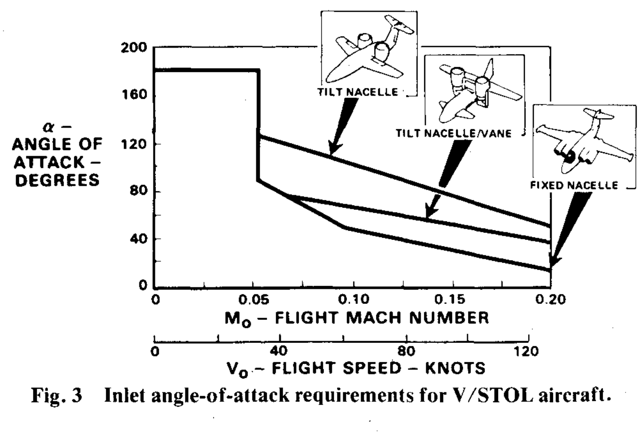


Fig. 3 Inlet angle-of-attack requirements for V/STOL aircraft.

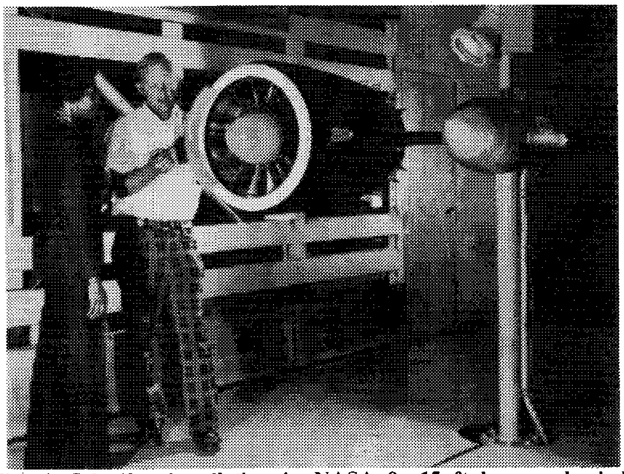

Fig. 4 Inlet/fan installation in NASA 9×15 ft low-speed wind tunnel.

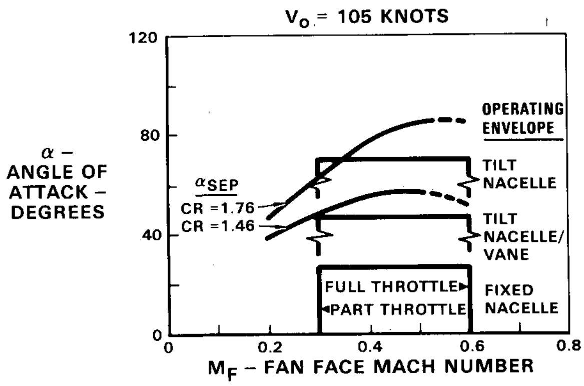


Fig. 5 Comparison of inlet angle-of-attack capability with aircraft operating requirements, conventional inlet.

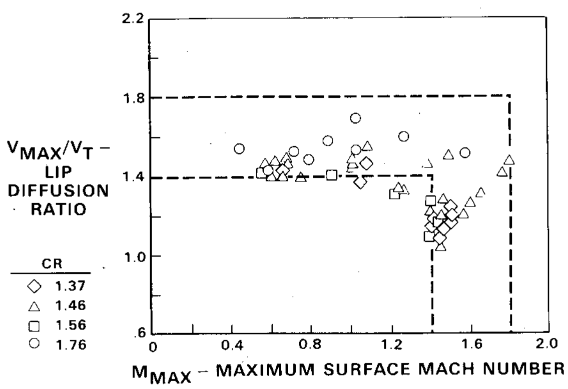


Fig. 6 Flow separation boundaries for conventional inlet.

engines (see Ref. 6), respectively. Detailed information regarding the aerodynamic characteristics of the fan can be found in Ref. 7. A photograph of the inlet/fan installation in the test section is shown in Fig. 4.

The basic wind-tunnel model was designed to represent a zero-length, slotted-lip inlet with the cowl blow-in doors in the open position. Two interchangeable 360 deg slats having highlight-to-trailing-edge area contraction ratios of 1.2 and 1.3 were provided along with a single cowl lip having a contraction ratio of 1.12. The struts used to attach the slats to the cowl lip were adjustable so that the desired slot gap widths could be easily and accurately set. Spacer rings were used to locate the cowl lip at various distances forward of the fan face. The zero-length, unslotted-lip inlet was simulated by installing filler blocks in the 0.51 in. wide slot gap passage. The zero-length, double slotted-lip inlet was simulated by attaching a 120 deg slat with a 1.3 contraction ratio to the bottom portion of the 360 deg slat having a 1.2 contraction ratio.

Sufficient instrumentation was installed on the model to evaluate the total pressure recovery and distortion, flow properties along the inlet surfaces, and fan blade stresses. Six equally spaced rakes, each containing 19 total pressure probes and 2 static pressure taps, were located at the fan face. Three removable five-tube total pressure rakes were located at the slot exit. Approximately 180 static pressure taps were located along axial rows at 5 circumferential angles on the inlet slats, cowl lip, and spacers. The fan blade vibratory stresses were measured using strain gages located at the root of the suction side and the tip of the pressure side of three chosen blades.

To detect the onset of internal flow separation within the inlet, the fan blade stresses, two fan face total pressure probes (referenced to duct static pressure), and one slat surface static pressure were continuously recorded and visually monitored during the test. For each test point (flight speed and model angle of attack), the fan speed was increased from idle to the maximum allowable rpm (approximately 2000-7800) and then returned to idle. Static conditions were examined first. Then, an angle-of-attack sweep from low to high was made for each progressively higher flight speed.

Only incipient separation is considered herein. This is defined to occur when going from an unseparated flow condition to one where the total and static pressures just become equal at any fan face probe location. Generally, the incipient separation point could be established equally well by either varying the fan speed for a fixed angle of attack or increasing the angle of attack for a fixed fan speed. However, the incipient separation and flow reattachment points generally occurred at slightly different conditions.

## Results and Discussion

### Conventional Inlet

Conventional subsonic inlets can provide a steady supply of air to the engine at high total pressure recovery and low distortion if the inlet flow remains attached. However, once flow separation has been initiated, the inlet performance deteriorates rapidly with small changes in operating conditions. Inlet operating limits (flight speed/angle of attack/fan face Mach number) are generally established based upon the onset of flow separation rather than fan blade stress levels. This results in a conservative approach and provides some margin to insure satisfactory operation at the required design point.

The separation angle-of-attack boundaries for two conventional inlet models having contraction ratios of 1.46 and 1.76 are shown in Fig. 5 for a flight speed of approximately 105 knots. These inlets were tested in the NASA LeRC 9×15 ft low-speed wind tunnel using the same 20 in. diam fan unit employed for the zero-length inlet models. Separation-free flow will exist for each inlet if the angle of attack/fan face Mach number conditions fall below the appropriate separation boundary curve. Conversely, separated flow will exist within each inlet if the operating conditions fall above the appropriate curve.

Figure 5 also compares the separation angle-of-attack boundaries for the 1.46 and 1.76 contraction ratio inlets with the operating requirements for a fixed-nacelle, tilt-nacelle-with-vane, and tilt-nacelle types of V/STOL aircraft at a flight speed of 105 knots. The upper boundary of the aircraft operating region is determined from the inlet-angle-of-attack requirements identified in Fig. 3. The side boundaries of the operating region are determined by the required operating range of the turbofan engine, that is, from full to part throttle. At a flight speed of 105 knots, the 1.46 contraction ratio inlet just satisfies the operating requirements for a tilt-nacelle/vane type of V/STOL aircraft, and the 1.76 contraction ratio inlet almost satisfies the operating requirements for a tilt-nacelle aircraft. For these particular inlets, the part-throttle side of the operating region is most critical. During the design process, a similar examination would need to be conducted at other flight speeds to determine if more critical conditions exist.

As an aid to the design of new inlet configurations, the separation boundary has been expressed in terms of two potential flow parameters, the lip diffusion ratio (maximum-to-throat surface velocity ratio) and the peak surface Mach number on the inlet lip. At low fan speeds, a large amount of flow deceleration must occur on the inlet surface between the maximum velocity location and the diffuser exit. Since most of this deceleration occurs on the inlet lip and not in the diffuser, the lip diffusion ratio, which is based on the local throat surface velocity, is used as the correlating parameter. This is in contrast to the diffusion ratio used in Ref. 4, which is based on the diffuser exit surface velocity. The lip diffusion ratio closely approximates the maximum velocity gradient on the inlet since the surface distance over which the lip diffusion occurs is very nearly the same for all inlets. At high fan speeds, shock/boundary-layer interactions may strongly influence the boundary-layer separation process. As a result, the peak Mach number is also used as a correlating parameter. By determining the value of these local flow parameters for conditions along the separation boundary, an assessment can be made of inlet geometric design parameters for separation-free operation.

Experimental separation data are presented in Fig. 6 as a function of the lip diffusion ratio and peak surface Mach number. These data were obtained from model tests conducted in the NASA LeRC 9×15 ft low-speed wind tunnel using both a 20 in. diam fan unit and a 12 in. diam vacuum system. The models installed on the fan unit had inlet lip contraction ratios/diffuser area ratios (fan face flow area to throat area) of 1.46/1.214, 1.46/1.068, and 1.76/1.068. The models installed on the vacuum system had inlet lip contraction ratios of 1.37, 1.46, and 1.56 and a common diffuser having an area ratio of 1.214.

Figure 6 shows that for separation-free flow, the inlet must be designed to have both lip diffusion ratios and peak surface Mach numbers below $1.6 \pm 0.2$. The bandwidths associated with the separation boundaries are relatively small, especially when one considers that the correlated data consist of different flight speeds, model scales, diffuser area ratios, and inlet lip contraction ratios. A conservative design approach would result if the inner limit of the separation boundary were to be used. An attractive feature of the correlation is that the theoretical curve corresponding to various fan face Mach numbers at constant inlet angle of attack and flight speed intersects the inner limit of the separation boundary at almost a perpendicular angle. As a result, the fan speed at which separation occurs can be clearly defined.

#### Zero-Length, Unslotted-Lip Inlet

Decreasing the throat Mach number of unslotted-lip inlets by increasing the throat area until the diffuser area ratio becomes unity results in lower surface Mach numbers for a given fan speed. At low fan speeds, however, the lip diffusion ratio becomes larger because the throat velocity decreases faster than the maximum surface Mach number. As a result, a zero-length inlet having the same lip contraction ratio as a conventional inlet will have a higher separation angle of attack at the high fan speeds and a lower value at the low speeds. In essence, the separation angle-of-attack curves, such as those shown in Fig. 5 for conventional inlets, are shifted to the right for zero-length inlets. This is a favorable effect for low contraction ratio inlets where the most critical inlet design condition tends to occur at high fan speeds or full throttle. For high contraction ratio inlets, however, this effect is unfavorable since the critical design condition tends to occur at part throttle.

Figure 7 compares the separation angle-of-attack boundaries for the 1.2 and 1.3 contraction ratio inlets with the operating requirements for the three generically different V/STOL aircraft at a flight speed of 105 knots. As indicated in the figure, the 1.3 contraction ratio inlet exceeds the operating requirements for a fixed-nacelle-type V/STOL aircraft at full throttle. (For this particular aircraft, the crosswind conditions during hover are more difficult to satisfy than those at a flight speed of 105 knots.) The rate of performance degradation beyond the separation boundaries, however, is less for the zero-length inlets than for the conventional inlets since there is no diffuser along which the separation region can grow. For the zero-length inlets, the separated flow region is limited to only the fan tip.

Experimental separation data for the zero-length, unslotted-lip inlets are presented in Fig. 8 as a function of the lip diffusion ratio and peak surface Mach number. Since these data fall within the bandwidths established for the conventional inlets in Fig. 6, the separation phenomena must be primarily related to the flowfield properties on the inlet lip and essentially independent of diffuser area ratio if the diffuser is well designed. The correlated data consist of different

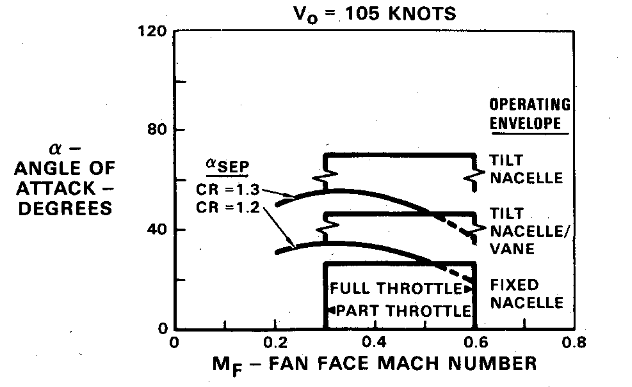


**Fig. 7 Comparison of inlet angle-of-attack capability with aircraft operating requirements, zero-length unslotted-lip inlet.**

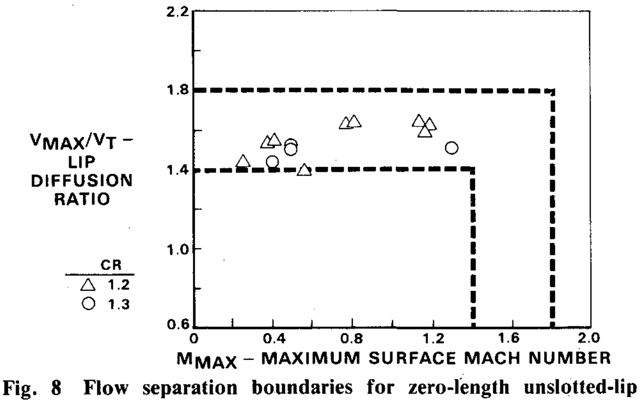


**Fig. 8 Flow separation boundaries for zero-length unslotted-lip inlet.**

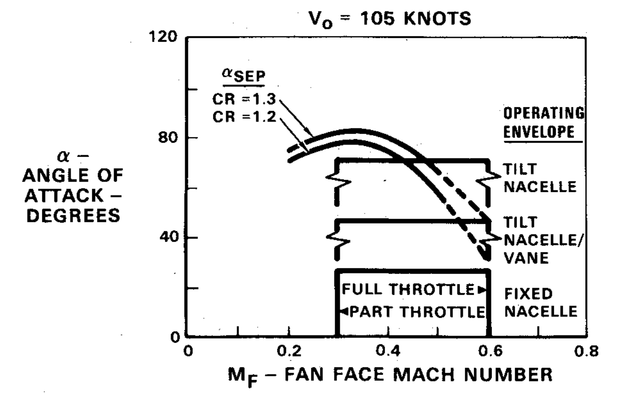


**Fig. 9 Comparison of inlet angle-of-attack capability with aircraft operating requirements, zero-length slotted-lip inlet.**

flight speeds and inlet lip contraction ratios. With the throat and fan face Mach numbers being equal, the peak surface Mach number limit was not achieved even at the high fan speeds.

**Zero-Length, Slotted-Lip Inlet**

The separation angle-of-attack boundaries for the zero-length slotted lip inlets having contraction ratios of 1.2 and 1.3 just satisfy the full-throttle operating requirements of a fixed-nacelle and tilt-nacelle/vane types of V/STOL aircraft, respectively, at a flight speed of 105 knots, as shown in Fig. 9. The relationship of these boundaries to the aircraft operating requirements at different flight speeds is presented in Fig. 10 at the critical full throttle conditions. As the figure indicates, a flight speed of approximately 105 knots is the most critical design condition.

At the inlet design point, flow separation on the 1.12 contraction ratio cowl lip was much more predominant than that on either of the two slats. This cowl-lip flow-separation effect, however, is quite dependent upon the slat design. If a slat with a high rather than low contraction ratio is employed, the surface Mach numbers on the slat will be low. This will produce a relatively high back pressure on the slot flow which, in turn, will result in low surface Mach numbers on the cowl lip. The effect of the 1.2 and 1.3 contraction ratio slats on the cowl-lip separation characteristics is illustrated by the fan face total pressure profiles shown in Fig. 11. It is evident from the figure that the flow on the cowl lip is almost separated for the smaller slat and attached for the larger slat. The slat wake effect on the total pressure profiles is shown in Fig. 11 to be relatively small.

Figure 12 presents the experimental cowl-lip separation data for the zero-length, slotted-lip inlets. Again the separation data fall within the bandwidths established for the unslotted-lip inlets. The correlated data consist of different flight speeds, inlet slat contraction ratios, slot gap widths, and inlet throat/fan face spacer lengths.

Although desired, a correlation similar to that of Fig. 12 could not be developed for the slat because the flow on the cowl lip always separated before any significant amount of flow separation developed on the slat. To be meaningful as a design tool, the correlation must identify the separation boundaries on one surface when the flow that is to be computed on all other surfaces is attached. Such was the case with the cowl lip but not for the slat. Since the correlations provided in Figs. 6, 8, and 12 are essentially the same, it is reasonable to assume that these same correlations would also apply to the inlet slat. A conservative design may result, however, if a certain amount of flow separation on the slat can be tolerated without exceeding the engine distortion limits. This situation is addressed in greater detail in the next section.

**Zero-Length, Double Slotted-Lip Inlet**

A significant improvement in angle-of-attack capability was obtained by adding a 1.3 contraction ratio leading-edge slat having a 120 deg circumferential extent to the existing zero-length slotted-lip inlet with the 1.2 contraction slat installed. As shown in Fig. 13, this inlet more than satisfies the operating requirements of a tilt-nacelle-type V/STOL aircraft.

Flow separation for this inlet is most likely to occur on the leading-edge slat, probably because the surface has a rather sharp contour at the highlight. Even so, the separated slat flow does not necessarily cause the fan face total and static pressures to be equal, as they were for those inlets where flow separation initially occurred on the cowl lip. As a result, leading-edge slat separation may occur at different operating conditions than those identified from fan face rake data and used to determine the inlet angle-of-attack capability. The total pressure profiles shown in Fig. 14, for example, indicate that slat separation does not occur until achieving a 100 deg

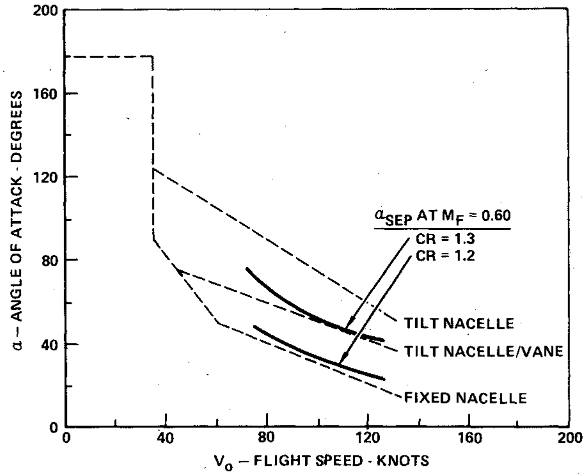


**Fig. 10 Effect of flight speed on inlet angle-of-attack capability, zero-length slotted-lip inlet.**

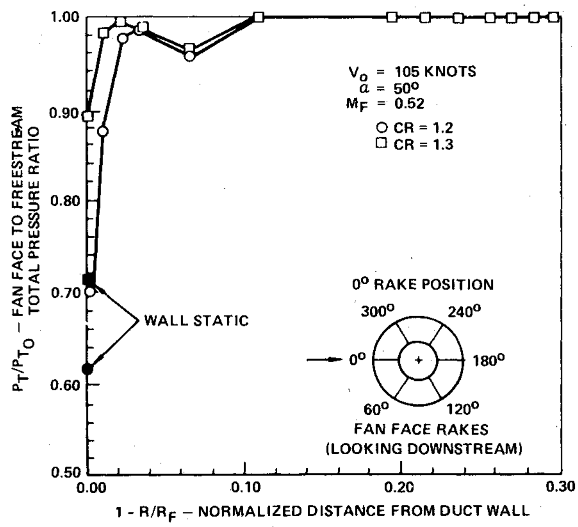


**Fig. 11 Fan face total pressure profiles for zero-length slotted-lip inlet.**

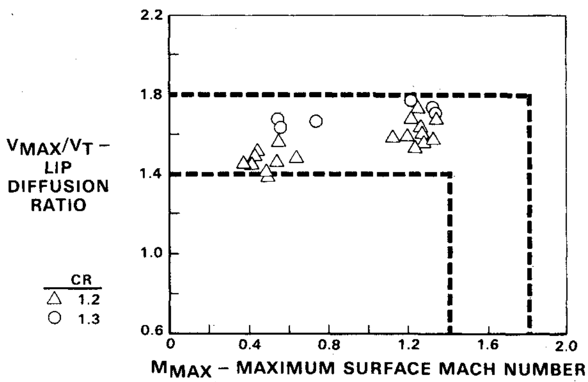


**Fig. 12 Flow separation boundaries for zero-length slotted-lip inlet.**

angle of attack. The static pressure distributions shown in Fig. 15 indicate that the slat diffusion ratio corresponding to the separation boundary occurs above an angle of attack of 100 deg for the slat and cowl lip and at 60 deg for the leading-edge slat. Nevertheless, at a 100 deg angle of attack, the fan face total pressure recovery and distortion, as shown in Fig. 16, are acceptable for a typical turbofan engine.

Sufficient data were not available for correlating the separation boundary data for the zero-length, double slotted-lip inlet. Most of the data were acquired at conditions where the fan face rakes indicated that flow separation had occurred. Since the flow on the leading-edge slat is already

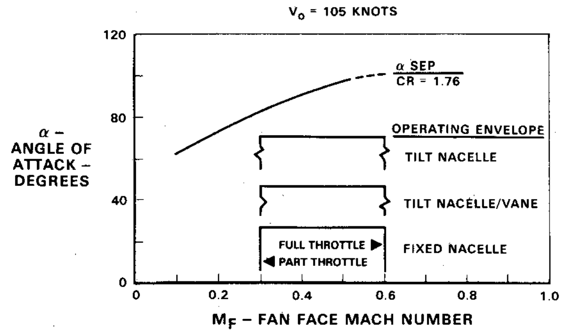


**Fig. 13 Comparison of inlet angle-of-attack capability with aircraft operating requirements, zero-length double slotted-lip inlet.**

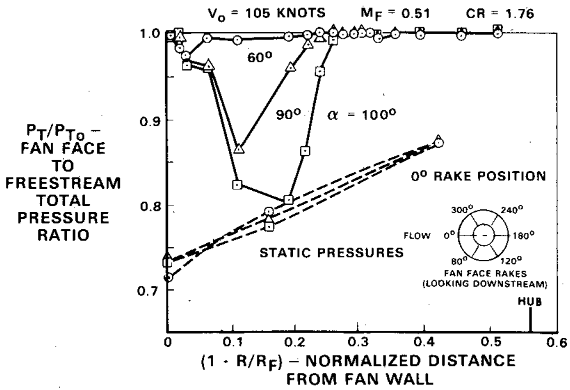


**Fig. 14 Fan face total pressure profiles for zero-length double slotted-lip inlet.**

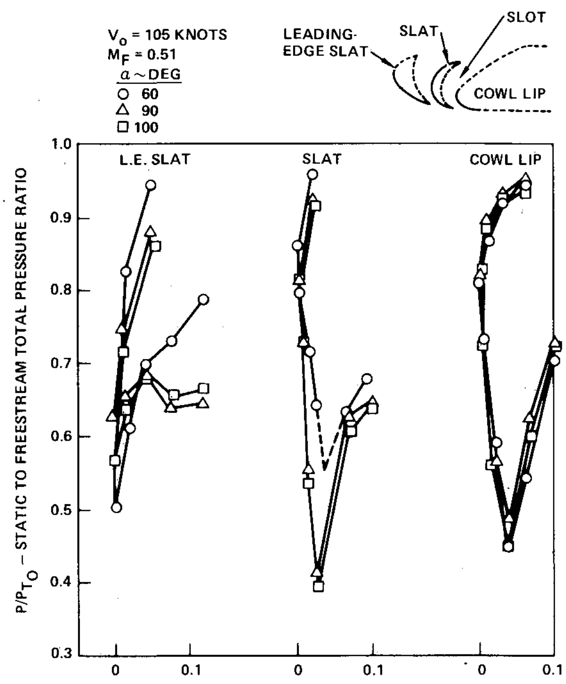


**Fig. 15 Slat/cowl lip surface static pressure distributions for zero-length double slotted-lip inlet.**

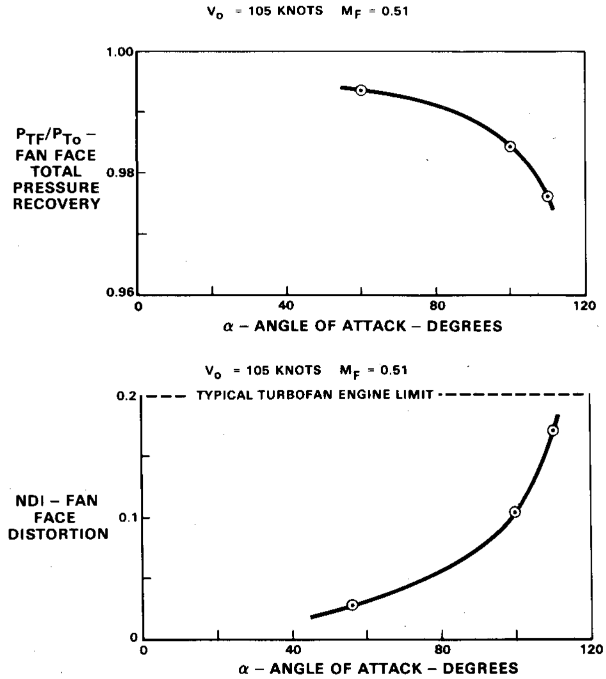


**Fig. 16 Fan face total pressure recovery and distortion for zero-length double slotted-lip inlet.**

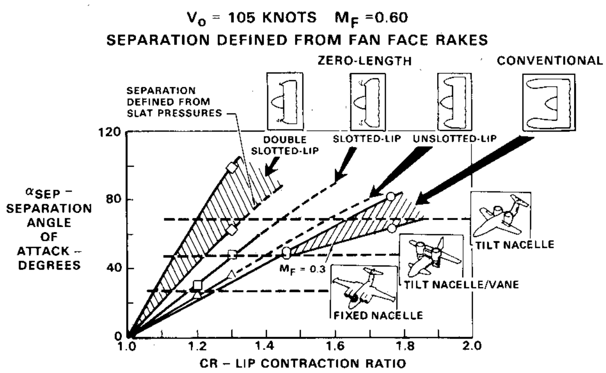


**Fig. 17 Summary of inlet angle-of-attack capability.**

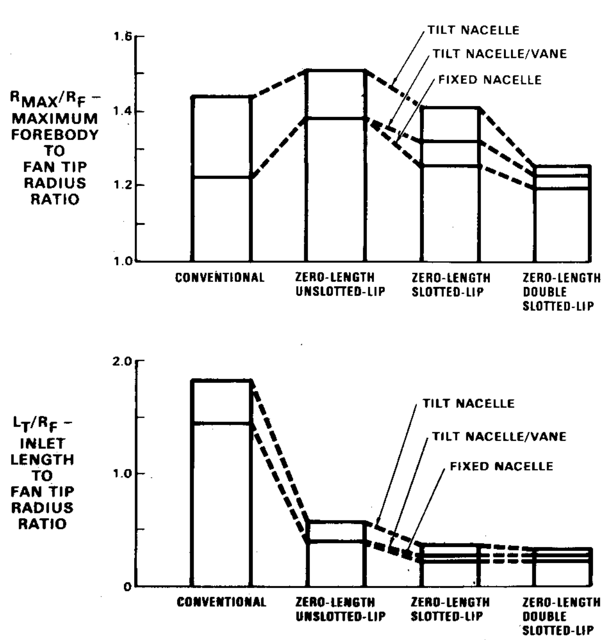


**Fig. 18 Maximum forebody radius and inlet length comparisons.**

separated at these conditions, a correlation of these data would not be consistent with the previous correlations nor be meaningful unless the actual flow properties along the slat could be theoretically determined. The conditions corresponding to the onset of flow separation on the leading-edge slat were difficult to identify during the test and, therefore, were not closely examined. As with the slat for the zero-length slotted-lip inlets, it is reasonable to assume that the previous correlations would apply as well to the leading-edge slat.

## Conclusions

Various combinations of inlet lip contraction ratios and inlet types can be employed to satisfy the operating requirements of different V/STOL aircraft. This is illustrated in Fig. 17 where the effect of inlet lip contraction ratio on the maximum angle of attack for separation-free flow is shown for the conventional inlet and for the family of zero-length inlets at a flight speed of 105 knots. In general, the separation angle of attack can be increased by increasing the inlet lip contraction ratio, inlet throat area, and number of slats. Further increases can be obtained by allowing the flow on the slat to separate provided the cowl-lip flow remains attached and the fan face distortion limits are not exceeded. The greater the aircraft angle-of-attack requirement, the more significant the percentage reduction in inlet lip contraction ratio becomes for the zero-length inlets relative to the conventional inlet. Full-throttle conditions tend to be the most critical for designing the low-contraction-ratio zero-length inlets, whereas part-throttle conditions tend to be the most critical for designing the high-contraction-ratio conventional inlets.

The suitability of the zero-length inlets over a more conventional inlet depends to a large extent on the differential in maximum cowl forebody radius and inlet length. This is illustrated in Fig. 18 for inlets which have been designed at high speed for a drag divergence Mach number of 0.7 and an inlet actual-to-critical mass flow ratio of 0.692 and at low speed for either hover or at 105 knots, whichever is the most critical. For the zero-length unslotted-lip inlet, the present reduction in contraction ratio relative to that for a conventional inlet is not sufficient to compensate for the required increase in throat area. As a result, a penalty in maximum cowl forebody radius exists which must be weighted against the benefit in length reduction. For the zero-length, slotted-lip inlet, a sizable reduction in inlet length can be achieved without adversely affecting the maximum radius, even for the fixed-nacelle-type V/STOL aircraft. For the zero-length double slotted-lip inlet, significant benefits in both maximum cowl radius and inlet length are obtained, especially for the tilt-nacelle-type V/STOL aircraft.

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