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NOISE COMPARISONS OF SINGLE AND TWO STAGE DEMONSTRATOR FANS FOR ADVANCED TECHNOLOGY AIRCRAFT

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Abstract

A high-speed single-stage and a low-speed two-stage fan were designed, fabricated and tested under separate contracts to demonstrate their predicted low noise performance for an advanced 0.85-0.90 cruise Mach number aircraft requiring a 1.8-1.9 pressure ratio fan. Acoustic tests were made with both unsuppressed and suppressed configurations. The two-stage fan demonstrated that quiet fan technology developed for low-speed single-stage fan is applicable to two-stage designs. The unsuppressed two-stage fan was 3-5 dB quieter than the high-speed single-stage fan at the same pressure ratio. The unsuppressed high-speed single-stage fan demonstrated that significant reductions in inlet noise can be achieved from the sonic blockage caused by supersonic flow in the rotor blading. Both fans demonstrated suppressed inlet noise levels with treated sonic inlets that met advanced technology goals. Suppressed aft noise levels did not meet expectations for either fan. The aft noise problem is attributed to both excessive source noise and ineffective treatment performance. A need for technology advances in aft noise suppression or source noise reduction is indicated. At this time suppressed single-stage and two-stage fans remain acoustically competitive for advanced technology aircraft.

Introduction

NASA-Lewis sponsored an earlier study to define the optimum propulsion system for a long range advanced technology transport (ATT) aircraft with cruise Mach number between 0.85 and 0.9. The noise goal for this aircraft was 20 EPNdB below FAR-36 standards. Design concepts submitted by two contractors in 1972[1,2] specified an engine for this aircraft with a bypass ratio of about 6:1 and a fan pressure ratio of about 1.8 to 1.9. A significant difference in the two designs was the configuration of the fan. The General Electric Company specified a high-speed (1650 ft/sec tip speed) single-stage fan for this engine whereas Pratt and Whitney Aircraft specified a low-speed (1250 ft/sec tip speed) two-stage fan. Both configurations were predicted to give comparable noise, aerodynamic and economic performance for the aircraft. The predictions, however, depended on an extrapolation of current technology in aerodynamics, source noise and noise suppression for these fans.

For the high-speed single stage fan, a 1.8 to 1.9 pressure ratio at the specified levels of efficiency and specific flow was beyond the proven current technology. The predicted trends in source noise with increasing pressure ratio and tip speed also were questionable. Furthermore, although source noise was admittedly high at the required high tip speed, noise suppression was predicted to be more efficient for the characteristic combination-tone noise of high speed fans than it was for the noise of low speed fans. If the predicted performance could be met or exceeded, a single-stage fan does have advantages with regard to engine size, weight, and cost.

For the low-speed two-stage fan, a low source noise level was projected on the basis of quiet, low-speed, single stage fan technology. The reduction in source noise for two stage fans by eliminating inlet guide vanes and by increasing rotor and stator spacings while maintaining a high aerodynamic efficiency had not previously been fully explored. Efficient, high-level suppression of the characteristic noise of two-stage fans also had not been proven. If the predicted performance could be met or exceeded, a two-stage fan does have advantages with regard to high aerodynamic efficiencies.

Inasmuch as the competitive status of the one-stage and two-stage fans was based on extrapolated technology, NASA-Lewis sponsored additional studies with both contractors to demonstrate the predicted performance of these fans. Both fans were designed, fabricated and tested in half-scale models to minimize costs. The purpose of this paper is to review and summarize some of the acoustic results of these studies.

Both of the fan studies consisted of comprehensive programs in aerodynamic and acoustic design and testing during which detailed aerodynamic data were acquired and acoustic suppression with a variety of configurations was evaluated. This paper summarized only a portion of the overall effort. For more complete coverage the reader is referred to the reports on specific aspects of the studies (3-12) given in the reference list. A previous summarization of these studies[13], some of which is repeated herein, was prepared prior to the completion of the program.

The status of NASA-Lewis experience in fan source noise at the inception of the two fan contracts will first be summarized so that the results may be viewed from some perspective. The aero-acoustic design features of the single-stage and two-stage fans will then be reviewed together with the overall aerodynamic performance that was achieved by the designs. The acoustic performance of the baseline or unsuppressed configurations of the two fans will then be compared. Next, the suppressed noise performance obtained with treated sonic inlets and exhaust duct suppressors with splitters will be discussed. Finally, a summary of the acoustic performance is given.

Prior Status of Fan Noise

A NASA-Lewis view of the status of fan source noise at the inception of the one-stage and two-stage fan contracts is summarized in Fig. 1. Total sound power level and maximum perceived noise levels normalized by the fan thrust are shown as functions of fan total pressure rise (equal to pressure

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ratio minus one). Figure 1 is similar to displays previously presented by NASA-Lewis(13-15) to depict the status of fan noise. Of particular interest in the display are the correlations (shaded bands) for quiet, low speed, single-stage fans having large rotor-stator spacings and no inlet guide vanes. These correlations are based on NASA-Lewis tests of full scale fans for CTOL and STOL applications. The noise levels for these quiet fans were lower than that previously achieved. The low speed, single-stage correlations, therefore, provides a reference to gage the noise performance of other fan designs. The region of the correlations above about 0.4, pressure rise, however, represents an extrapolation of the trends developed at the low pressure rises of low speed fans.

The noise levels for low speed (1160 ft/sec tip speed) fans A, B and high speed (1550 ft/sec tip speed) fan C of the NASA-Lewis Quiet Engine Program(14) are also shown in Fig. 1. The data range from a low pressure rise at approach speed to the higher pressure rise at takeoff speed (generally 90% of design). Fans A and B were used to help establish the low speed noise correlation. When unsuppressed fan A was incorporated in an engine configuration it was projected to be 5 to 8 EPNdB lower than FAR-36 levels for a 707 or DC-8 class of aircraft. These projections were used to establish the approximate FAR-36 levels for PNL at a 200-foot sideline shown in Fig. 1 although, admittedly, an exact correspondence cannot be established.

Fan C, the high tip speed fan, is shown in Fig. 1 to have higher noise levels than the low tip speed fans. Of particular interest for the high speed single-stage fan contract was the trend developed by fan C at high pressure rise. The curve suggests that at a still higher pressure rise the noise level might continue to drop and approach that for low speed fans. The noise level at 0.8 to 0.9 fan pressure rise, therefore, was in doubt and was one of the objectives of the single-stage fan contract.

The approximate noise levels of conventional JT3D and JT8D class of two-stage fans is also shown by the shaded band in Fig. 1. These fans are substantially noisier than the low speed fans used to form the correlation band and exceed the FAR-36 levels. These conventional two-stage fans have inlet guide vanes and the blading for the stages is closely coupled. The quiet fan technology of low speed fans has shown that both of these features cause excess noise. An objective of the two-stage fan contract was to determine whether the noise levels of low-speed, two-stage fans approach that of single-stage fans when both incorporate the same quiet fan technology.

Aero-Acoustic Design and Aero Performance

Baseline Configuration

The basic configurations and overall aerodynamic design objectives of the half-scale one-stage and two-stage fans are shown in Fig. 2. The single-stage fan is a split flow configuration with a 6:1 flow rate ratio. Core flow was not simulated in the two-stage fan. The pressure ratio of the single-stage fan is somewhat lower than that for the two-stage fan but the design flow is higher. These scale model fans would deliver about the same design point thrust. Both fans, particularly the single-stage fan, have a design point specific flow that is higher than that in common usage.

The blade loading for the two fans compared to values for quiet fans tested by NASA-Lewis is shown by Fig. 3. Tip speed is shown as a function of total pressure rise and the lines of constant spanwise average work coefficient are utilized to indicate the degree of blade loading. The blade loading for the single stage fan is comparable to that of fan C discussed previously, whereas, the loading of the second stage of the two-stage fan is comparable to that of fans A and B. The first stage of the two-stage fan has the lightest loadings of all shown.

Some additional design features of the two fans are given in Fig. 4. The hardwall bellmouth inlet was the configuration used to establish baseline aerodynamic and acoustic performance. Although both fans are indicated to have comparable diameters, these sizes do not represent exact half-scale models. The mating of the fans to existing hardware also affected the decision on actual size. Hub-to-tip ratio for both fans is relatively low as required for the high bypass ratio designs for advanced technology transport aircraft. The numbers of rotor and stator blades in each blade row indicated in Fig. 4 were determined from acoustic considerations. In general, there are more than twice as many stator blades than rotor blades because this ratio of blades should inhibit the propagation of the fundamental blade passage tones. The ratio is somewhat less than two, however, between the rotor and core stators for the single-stage fan and between the first stage stator and second rotor for the two-stage fan. The tones from these interactions may be expected to propagate. A large blade row axial spacing was also used for low noise. For the single-stage fan the spacing is two rotor chords for the bypass flow and 0.9 chord for the core flow. For the two-stage fan the rotor and stator spacing is two rotor chords for both stages but the stage spacing was only about one rotor chord. The two-stage fan was designed to permit variations in rotor and stator spacing although such variations were not tested due to funding limitation. This design feature, however, dictated a less than optimum flow contour for that part of the centerbody between the first rotor and last stator blade row.

The baseline aerodynamic performance of the single-stage fan is shown in Fig. 5. The performance map shows that at design speed, the flow was about 3% less than design although a relatively high specific flow of about 42.9 $lb/sec/ft^2$ was achieved. Stage efficiency was good with a peak value of about 82 percent while stall margin was about 9%. The exact reason for not achieving the design flow is not known, but flow rate for these high speed fans with shock waves is known to be very sensitive to the flow conditions within the rotor blade row. As shown in Fig. 6 the blade section near the tip are designed to capture the leading edge shock within the blade passage. The rotor blade throat area is designed larger than the aerodynamic optimum so that the capture process will occur over a range of fan speeds and particularly at takeoff speed. All this leads to flow patterns that restrict the maximum flow rate. Premature flow separations from the blade suction surface and/or secondary shocks at the trailing edge may develop as illustrated in Fig. 6.

However, those extremes may not have occurred in the case of the single-stage fan.

The overall aerodynamic performance of the single-stage fan was judged to be good and typical of this class of fan. The failure to reach design flow, however, required that the design point pressure ratio be accepted as about 1.75. Also, more stall margin would be desirable.

The performance map for the baseline configuration of the two-stage fan is shown in Fig. 7. The peak efficiency at design speed is very good with an adiabatic value of about 86.4 percent. Design flow, both total and specific, were also achieved. However, at peak efficiency, the fan had no stall margin, in fact, the stall line fell below the design point. The less-than-optimum centerbody contour between the first stage rotor and stator is one probable cause for the stall margin problem. As shown in Fig. 8, the centerbody was cylindrical in order to accommodate a change in rotor/stator spacing. Adverse pressure gradients were measured in this region of the centerbody and thus a thickened wall boundary layer could have precipitated the stall. Low performance in the hub region of the first stage rotor is another or related cause for the premature stall. In either event a more optimum design is possible to improve the stall margin.

The overall performance of the two-stage fan was also judged to be good and typical of this class of fan in the stall-free region. The fan was tested at operating conditions that avoided the stall region in subsequent acoustic tests.

Suppressed Configuration

The suppressed configurations of both the single-stage and two-stage fans consisted of sonic inlets with acoustic treatment and acoustically treated exhaust ducts with acoustic splitters. The sonic inlet configurations are shown in Fig. 9. A contracting cowl type of sonic inlet was simulated with changeable hardware in the case of the single-stage fan. An average throat Mach number of 0.79 was considered adequate for noise suppression in conjunction with the acoustic treatment at approach and takeoff power. The acoustic treatment consisted of four elements designed to suppress both low frequency combination tone noise and high frequency discrete tone noise. The treatment was limited to the cowl wall. No interstage treatment was used.

For the two-stage fan a translating centerbody type of sonic inlet was simulated by changeable hardware. An average throat Mach number from 0.9 to 1.0 was employed for noise suppression at approach and takeoff power. Acoustic treatment was used on both the cowl wall and the centerbody. The treatment was designed to suppress noise in the region of the blade passage tone. Acoustic treatment was also used on the inner and outer walls in the interstage region between the blade rows. This interstage treatment was also present in the baseline configuration.

The exhaust duct suppressors are shown in Fig. 10. Acoustic treatment was deployed in all exposed surfaces of the duct and splitter for both fans. The treatment was designed to minimize perceived noise levels by procedures previously developed by each contractor. The acoustic treatment for the core flow path of the single stage fan was active during all tests. Core flow was not simulated with the two stage fan. The shape of the exhaust duct flow path for both fans was dictated as much by the test facility hardware as by the optimum design for engine configurations.

A consideration in the use of sonic inlets for noise suppression involves the effect on aerodynamic and acoustic performances of inflow distortion that could result if inlet recovery were poor. Figures 11 and 12 compare the aerodynamic performance of the two fans with bellmouth and suppressor inlets at approach and takeoff speeds. No significant adverse effect on fan alone performance was noted. The loss in stall margin at approach speed for the single-stage fan did not restrict the normal operating range of this fan. Pressure recovery of the sonic inlets was generally good although the two stage fan inlet at an average throat Mach number of 1.0 exhibited a system efficiency loss of about 5 percentage points.

Acoustic Performance

Baseline Configuration

Characteristic narrow band spectra for the one-stage and two-stage fans are shown in Figs. 13 and 14. The single-stage fan spectra in Fig. 13 are typical for the inlet noise of high tip speed fans. The blade passage frequency (BPF) tone dominates the spectra at low speeds. Combination tone noise (sometimes called MPT's) increases with speed and at high speeds the combination tones prevail strongly throughout the spectra. Approach speed for this fan is about 65 percent of design speed and combination tone noise first appears at about this speed. The blade passage tone and the spectra level is shown to decrease at the highest speed - a probable result of shock capture and/or high specific flow. (Note that 1.09 N_D is not a noise critical operating condition.)

The two-stage fan spectra in Fig. 14 are characteristic of the inlet noise from two-stage fans. The blade passage tone and harmonics of the first stage (BPF_1,$2BPF_1$) and second stage (BPF_2,$2BPF_2$) are evident. Linear combination tones occurring at frequencies such as BPF_1 plus BPF_2 are also evident. A variety of linear combination tones can usually be identified in two-stage fan spectra. Figure 14 shows that the combination tone noise usually associated with high speeds does not dominate the spectra of the two-stage fan at its design speed.

Typical one-third-octave spectra of inlet and aft duct noise at approach speed are shown for the two fans in Fig. 15. The blade passage tone dominates both the inlet and aft spectra of the single-stage fan. The combination tones occurring at mid-frequencies are not readily identified in these spectra. The spectra for the two-stage fan show differences in the inlet and aft spectra. The inlet spectra is dominated by the first stage fundamental tone whereas the aft is dominated by harmonics of both the first and second stage tones. The low level of the fundamental tone in the aft spectra suggests that some benefits were obtained in aft noise by using stator to rotor blade number ratios of more than 2 to 1.

Excess noise caused by the test facility turbine drive system and by the fan jet scrubbing on facility walls was identified in the spectra for the two-stage fan by detailed analysis of narrow band spectra for fully suppressed configurations. The excess noise is identified by the region above the dotted line in Figs. 15 and 16. A correction for this excess noise was made in the suppressed noise data to be presented; however, baseline data are presented as measured.

The one-third-octave spectra for takeoff fan speed are shown in Fig. 16. The inlet spectrum for the single-stage fan is dominated by combination tone noise. Combination tones were also observed in narrow band spectra from aft in-duct measurements but they do not appear to dominate the one-third octave spectra of the aft noise shown in Fig. 16. The spectra for the two-stage fan has no strong tonal character for either the inlet or aft noise. In fact, excess facility noise may have been controlling much of the aft noise spectra.

The directivity of the noise is shown by the angular variation of overall sound pressure level of a 100 ft radius in Figs. 17 and 18. The single-stage fan was tested separately with inlet and aft drive systems that completely isolated the inlet and aft noise. In these and subsequent figures the inlet and aft noise will be shown separately for the single stage fan and shown combined for the two stage fan.

The directivity of the noise at approach speed in Fig. 17 shows relatively uniform angular distribution of the noise for the two-stage fan. The aft noise for the single-stage fan shows a concentration near 130 degrees. The inlet noise is uniformly distributed up to an angle of about 50 degrees.

The noise directivity at takeoff is shown in Fig. 18. The two-stage fan again exhibits uniformity in sound propagation although aft noise levels are somewhat larger than inlet levels. The single-stage fan exhibits a noise concentration at about 45 degrees that did not occur at approach conditions. The aft noise is more uniformly distributed than it was at approach conditions. Although the peak noise level for the inlet and aft are nearly equal for the single-stage fan, the total aft noise exceeds that of the inlet.

Comparisons of the unsuppressed noise levels of the one-stage and two-stage fans with the reference levels established from NASA-Lewis quiet single-stage low speed fan studies are shown in Figs. 19 and 20. Figure 19 shows the total sound power level normalized by the fan thrust as a function of the fan total pressure rise. Data taken along operating lines with both an approach and takeoff nozzle area are shown.

The single stage fan with the spproach nozzle exhibits an aft noise level about 3-4 dB above the upper limit of the NASA-Lewis correlation and an inlet noise level near this upper limit. With the takeoff nozzle the aft noise is consistently about 2-3 dB above the upper limit of the correlation whereas the inlet noise exhibits a varied behavior. The inlet noise levels exceed the correlation in the mid-pressure rise region but decrease to less than the correlation at a very high pressure rise. These high pressure rise conditions were achieved by overspeeding the fan up to 110 percent of design speed in an attempt to explore the acoustic properties. Takeoff pressure rise occurs in the region of 0.6 to 0.7, the region where the inlet noise is near the upper limit of the NASA correlation.

The inlet noise levels for the single-stage fan shown in Fig. 19 demonstrate that noise reductions at the higher fan tip speeds do occur with proper aero-acoustic design. Noise reductions were expected from the capture of the inlet shock and from the reduced upstream propagation of fan noise with the high axial Mach numbers associated with high specific flows. The isolated inlet noise measurements imply that noise levels increased with the onset of inlet shocks but decreased as the capture process improved and as specific flow increased upon approaching design conditions. The low inlet noise at high speeds, however, is counteracted by the high aft noise levels that, as noted, were several dB above the upper limit of the NASA correlation at all pressure rise conditions. In summary, the single-stage fan exhibited total sound power levels (inlet plus aft) similar to that for fan C shown in Fig. 1.

The combined inlet and aft noise levels for the two stage fan are shown in Fig. 19 to fall within the NASA-Lewis correlation for low-speed single-stage fans and substantially below that for conventional two-stage fans shown in Fig. 1. The result demonstrates that noise levels for two stage fans are comparable to those for quiet single-stage fans when large axial blade spacings are used. The result also suggests that the noise penalty often attributed to combining stages is eliminated by adequate stage spacings. Figure 19 shows the two-stage noise levels with the approach nozzle to be somewhat higher than that for the takeoff nozzle. The use of the larger approach nozzle moved the fan operation to a less favorable aerodynamic efficiency and this may have contributed to an increase in noise.

Comparisons of perceived noise levels of the one-stage and two-stage fans with reference levels established by the NASA-Lewis correlation are shown in Fig. 20. The results are nearly identical to that observed for total sound power level in Fig. 19. The perceived noise levels presented in Fig. 20 are for the half-scale model data. Projecting the results to full-scale cause frequency shifts which affect perceived noise calculations. Such effects, however, are small and would not significantly change the overall observations presented on the noise characteristics of these single and two-stage fans.

Suppressed Configuration

A variety of configurations was tested during both the single-stage and two-stage fan studies in an attempt to fully evaluate the effectiveness of the suppressor designs. In this summary paper only results from fully suppressed configurations will be presented. An evaluation of these results and judgments about the effectiveness of the suppressors, however, depends on detailed studies of all the test data as well as the design procedures employed. Within this context, the fully suppressed results represent the demonstrated suppression on levels but do not necessarily reflect all the suppressor technology demonstrated by these studies.

It should also be noted that the suppressors for the single-stage fan were designed to minimize the perceived noise levels when the data are projected to full-scale engines whereas the two stage fan suppressors were designed to minimize scale model noise levels. The suppressed perceived noise levels to be presented for the single stage fan have been adjusted to reflect full scale behavior. The data to be presented for the two-stage fan, however, have also been adjusted by removing the tones from the drive turbine system that contaminated the data. These adjustments for both fans amounted to several dB at some far field locations.

A comparison of baseline and suppressed noise levels at approach speeds for the two fans is shown in Fig. 21. Perceived noise levels at a 200-foot sideline distance are shown as functions of angle from the inlet. The single-stage fan results show a reduction in peak noise of about 12 PNdB for inlet noise and about 14 PNdB for aft noise. The peak inlet and aft suppressed levels are about equal - a design objective that usually minimizes EPNdB noise levels. Suppressed noise levels with and without an aft noise shield are also shown for the two-stage fan in Fig. 21. Without the aft shield the peak level is reduced about 6 PNdB. The noise reduction is fairly uniform at all far field locations. The results with the aft shield, however, demonstrate that the sonic inlet suppressor was very effective giving about 20 PNdB suppression.

From detailed study of configuration comparisons (not shown here) acoustic treatment in the inlet caused a small amount of the noise reduction for the single-stage fan but its effect was probably insignificant as expected for the two-stage fan because of its near choke flow.

The effectiveness of the suppressors at takeoff speeds is shown in Fig. 22. Inlet noise suppression of the peak level for the single-stage fan approached 15 PNdB. Aft noise suppression of the peak level, however, was limited to about 7 PNdB. The suppressed aft noise radiating toward the inlet quadrant is shown to be higher than the suppressed inlet levels. The noise suppression for the two-stage fan at takeoff speed is similar to that for the same fan at approach speed. Without the aft noise shield the suppression of the peak inlet level is only about 5 PNdB even with a hard choked inlet. With the shield the inlet suppression is at least 20 PNdB as was the case at approach speed.

For both the single-stage and two-stage fans at takeoff speed and also for the two-stage fan at approach speed, the aft duct suppression was less than anticipated. Inadequate suppression in the core flow passage contributed to the low performance of the single stage fan. The exact reasons for the low performance of the two stage fan are not known. High level suppression has been demonstrated in other tests. The present results, therefore, indicate that additional emphasis on aft duct suppressor technology is needed.

Summary of Acoustic Performance

The acoustic performance of the high speed single-stage fan and the low speed two-stage fan designed and tested at half-scale for an advanced technology transport aircraft is summarized in Fig. 23. The maximum perceived noise level along a 200-foot sideline normalized by the fan thrust is shown as a function of fan total pressure rise for both fans. Shown on the figure for reference purposes is the NASA-Lewis correlation for quiet low speed single-stage fans. Also shown on the figure are the approximate 200-foot sideline levels that must be achieved to satisfy current FAR-36 standards for a 707 or DC-8 class of airplane. These levels, inferred from results of the NASA-Lewis Quiet Engine Program[14], served as an indicator of probable flight performance.

The baseline or unsuppressed noise levels for the single-stage fan are shown to be several PNdB above FAR-36 level at approach speed and at or about one PNdB below the FAR-36 level at takeoff speed. With regard to the NASA-Lewis correlation for low speed fans the single-stage fan exceeded the correlation by about 5 PNdB at approach speed, but was at the upper limit of the correlation at takeoff speed. The approach speed baseline noise was dominated by noise propagating from the aft duct. The baseline noise levels of the fan are comparable to previous quiet high speed fans. The suppressed noise levels for the single-stage fan were of the order of 10 PNdB below FAR-36 at both approach and takeoff speeds.

The baseline noise levels for the two-stage fan are shown to be at or near the FAR-36 level at approach speed and several PNdB below at takeoff speeds. The levels at both approach and takeoff speeds are within the NASA-Lewis correlation and the results indicate that quiet single-stage fan technology is applicable to two-stage fans. The suppressed results for the two-stage fan are shown to be about 7 PNdB below FAR-36 at approach speed and about 10 PNdB below at takeoff speed. Analysis showed that both the approach and takeoff speed suppressed levels were limited by the performance of the aft suppressor.

These studies with the two half-scale demonstrator fans showed that unsuppressed noise levels of the one-stage fan are 3-5 PNdB higher than that for the two-stage fan. Suppressed noise levels for both fans were of the order of 10 PNdB below FAR-36. While not demonstrated in this paper, noise levels approaching 15 PNdB below FAR-36 appear possible with design refinements -- particularly with regard to the source and suppression of exhaust duct noise. Suppressed noise levels of the order of 15 PNdB below FAR-36 were achieved in the NASA-Lewis Quiet Engine Program[14] where lower pressure ratio bypass fans were utilized. Aft noise, however, also limits the overall suppressed noise levels for these fans. The current results imply that aft noise suppression becomes increasingly difficult with an increase in pressure ratio.

The achievement of 20 PNdB below FAR-36 with current technology for the ATT fans appears doubtful with exhaust duct noise suppression being the limiting technology area. At this time the single-stage and two-stage fans remain competitive for a quiet advanced technology transport aircraft engine on the basis of acoustic performance. The selection of the optimum engine, however, would not only depend on acoustic performance but would also be based upon trade-off studies involving engine weight and fuel consumption (fan efficiency) with due consideration of stall margin.

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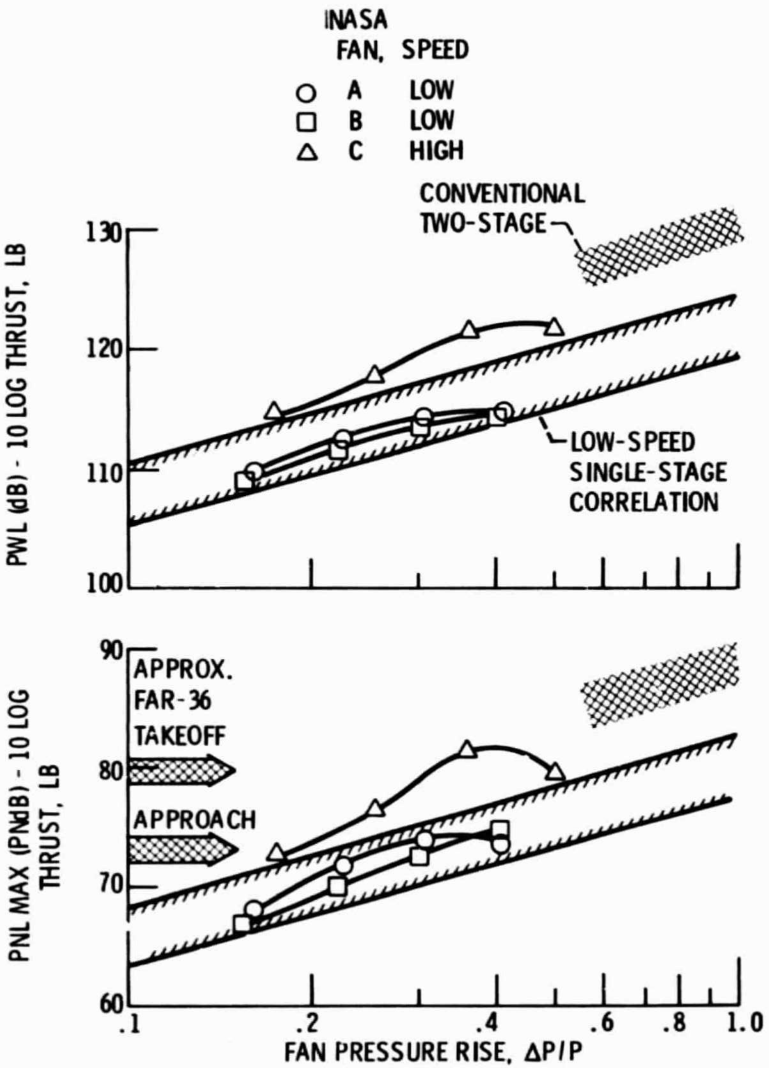

Figure 1. - Fan noise characterization, total sound power level (PWL) and 200 foot sideline perceived noise level (PNL).

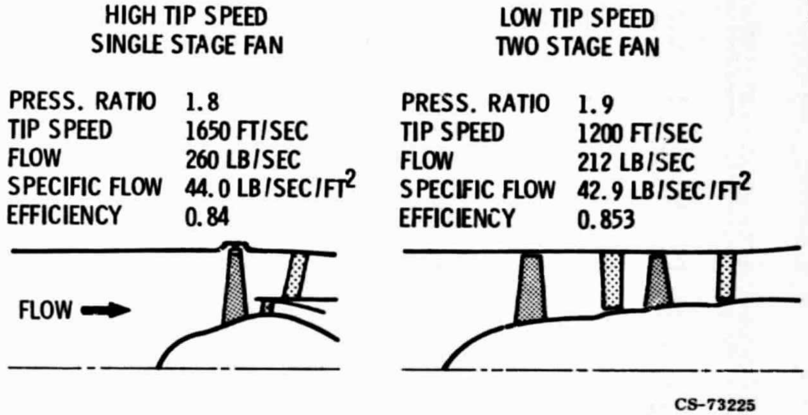

Figure 2. - Aerodynamic design properties.

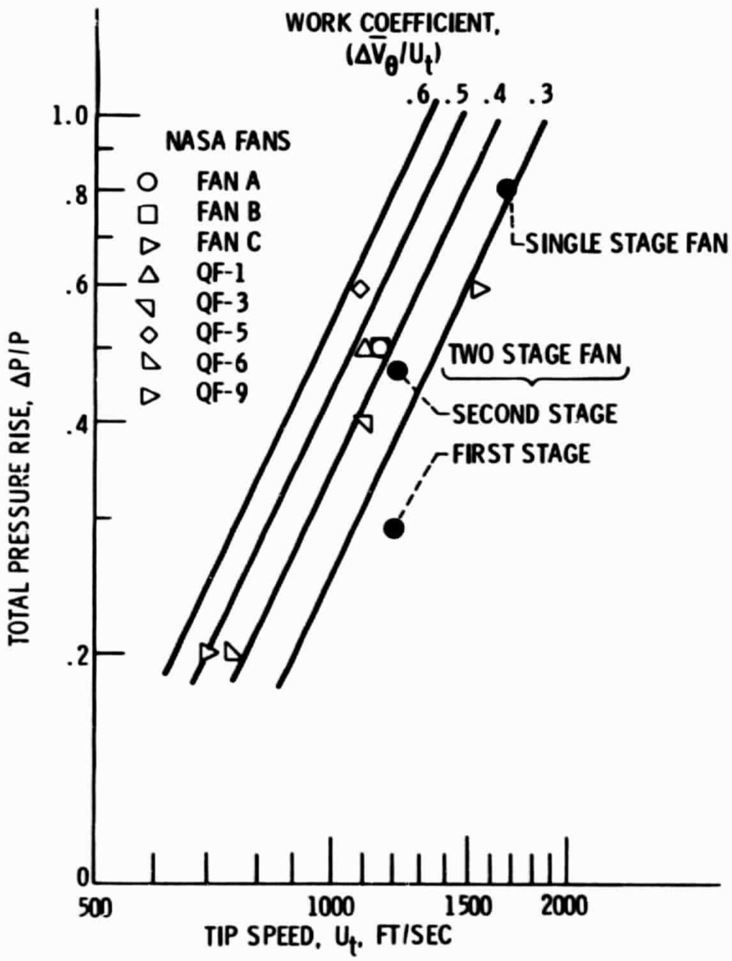

Figure 3. - Design comparison with NASA-Lewis fans.

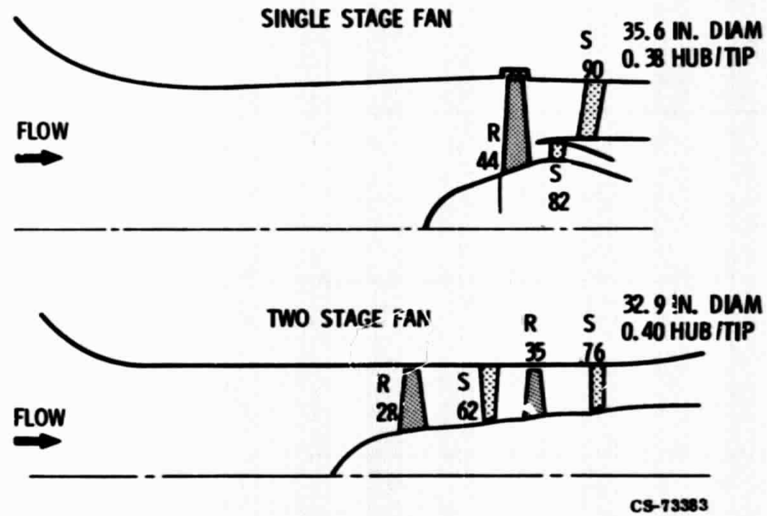

Figure 4. - Physical design properties. (Baseline bellmouth inlet configuration.)

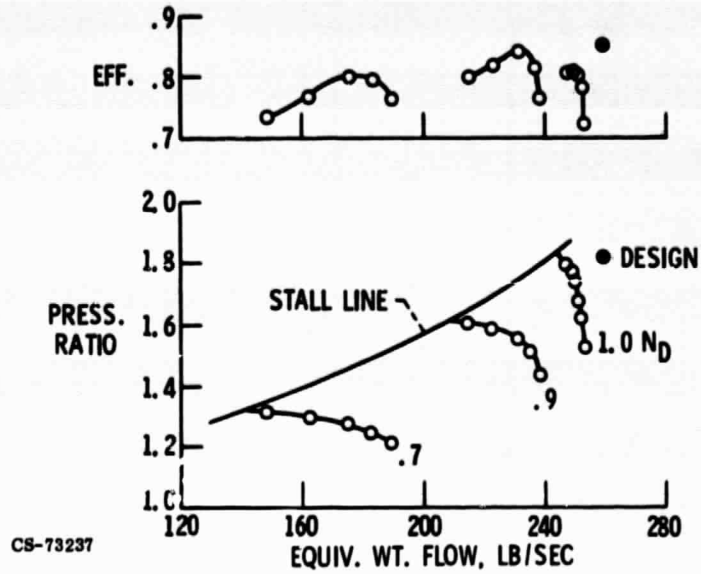

Figure 5. - Single stage fan performance. (Design tip speed, N_D, 1650 ft/sec.)

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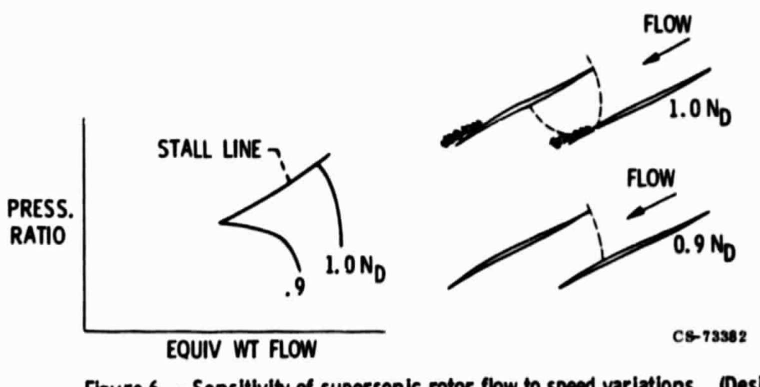
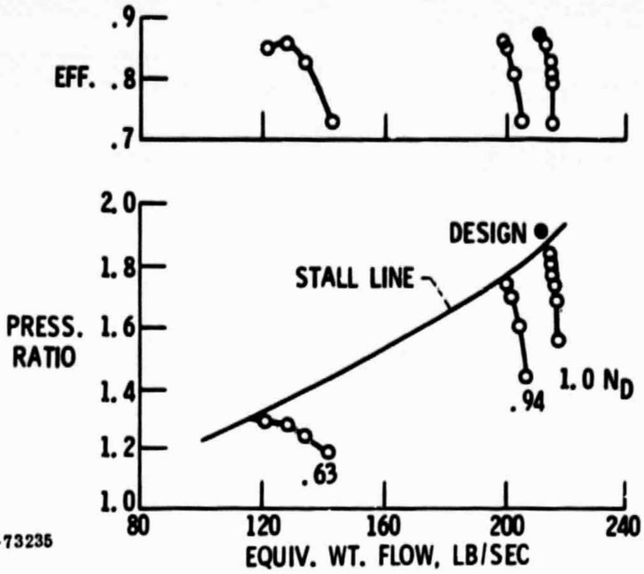


Figure 6. - Sensitivity of supersonic rotor flow to speed variations. (Design tip speed, N_D.)



CS-73235

Figure 7. - Two stage fan performance. (Design tip speed, N_D, 1200 ft/sec.)

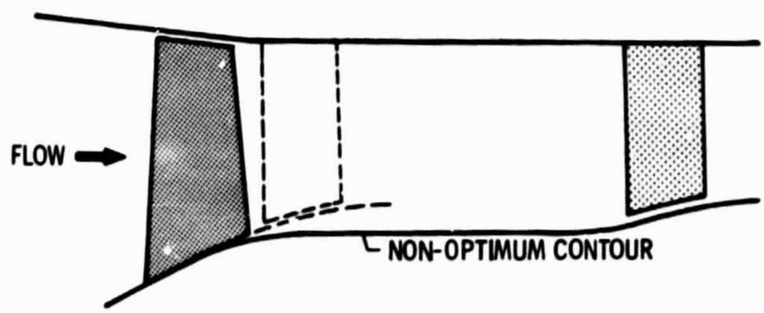


Figure 8. - Sensitivity of stall to flow path in variable rotor/stator spacing configuration of two-stage fan.

CS-73205

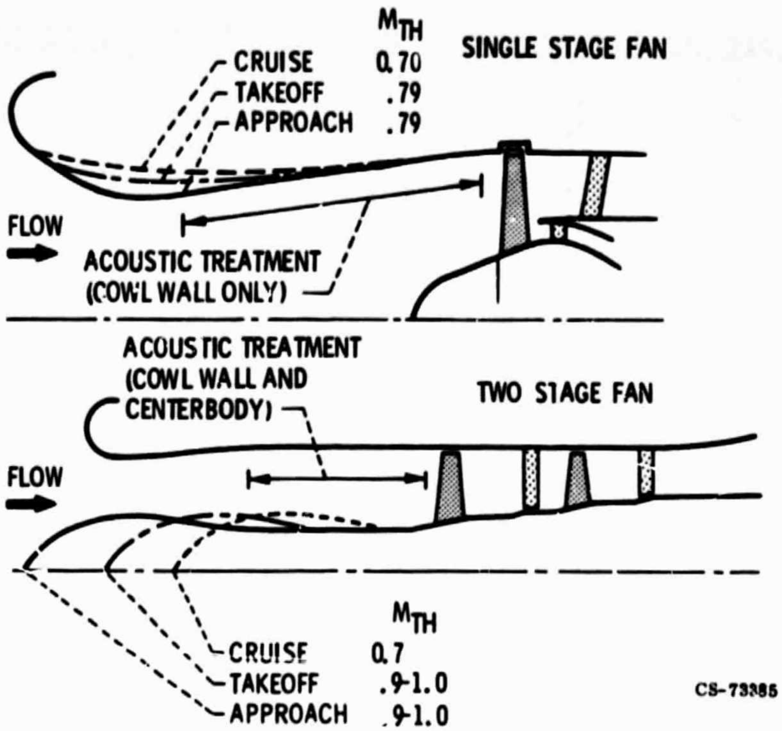


Figure 9. - Inlet noise suppressor.

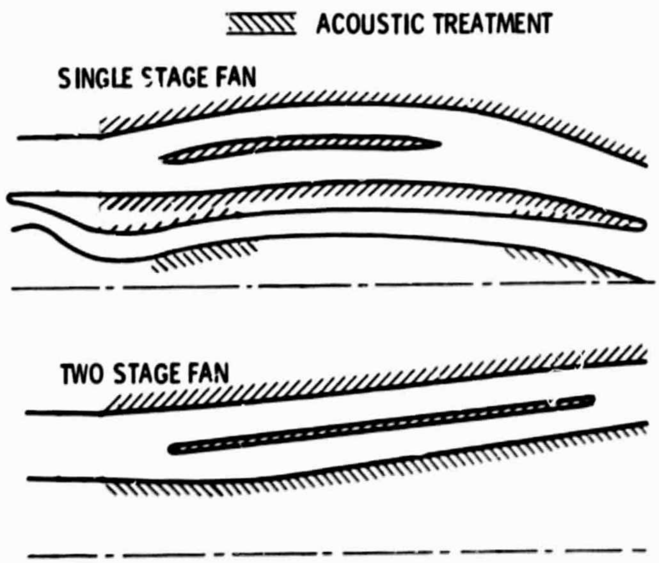
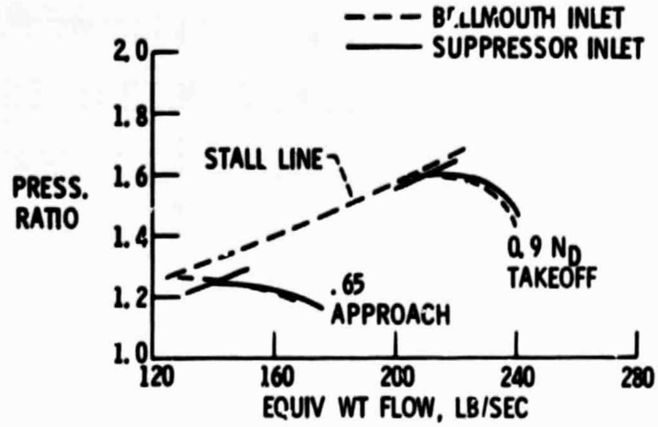


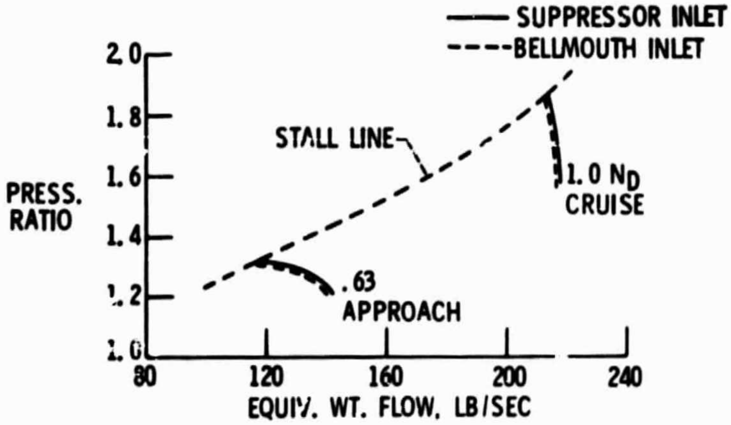
Figure 10. - Exhaust duct suppressor.

E-8688



CS-73211

Figure 11. - Effect of suppressor inlet on single stage fan performance. (Design tip speed, N_D, 1650 ft/sec.)



CS-73215

Figure 12. - Effect of suppressor inlet on two stage fan performance. (Design tip speed, N_D, 1200 ft/sec.)

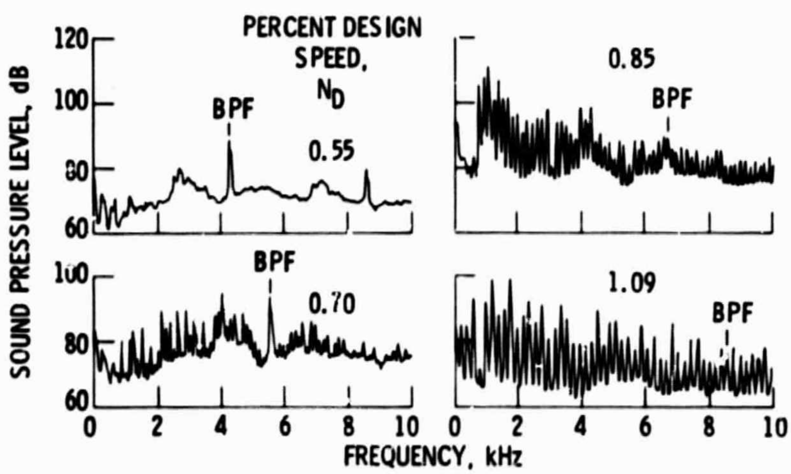


Figure 13. - Single stage fan (baseline) narrowband spectra, 50° angle. (Design tip speed, N_D, 1650 ft/sec.)

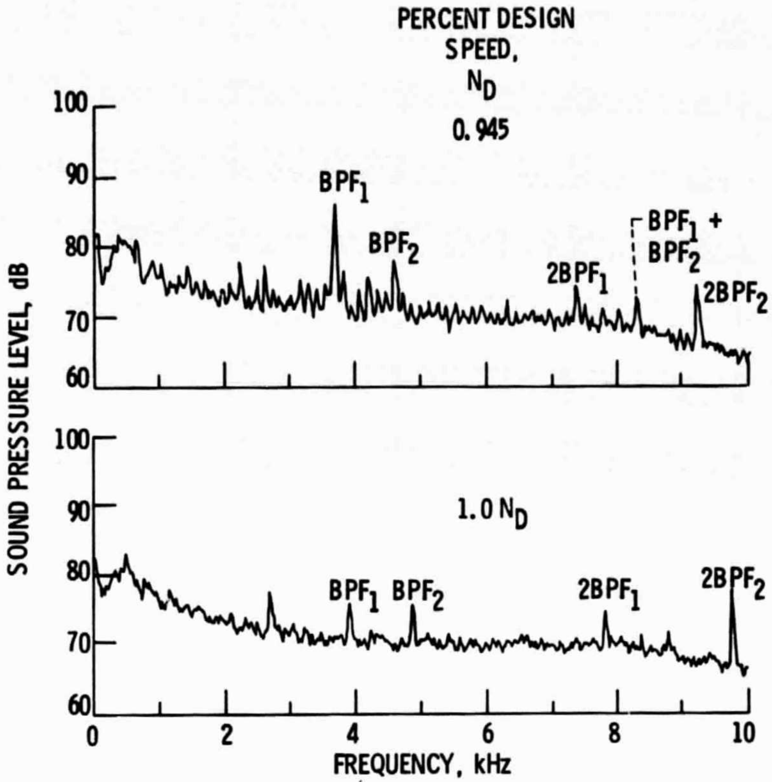


Figure 14. - Two stage fan (baseline) narrowband spectra, 60° angle. (Design tip speed, N_D, 1200 ft/sec.)

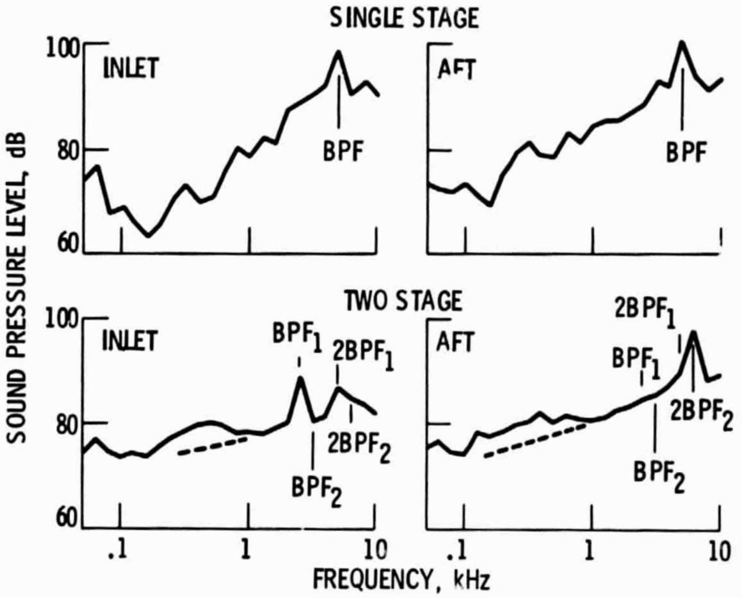


Figure 15. - Approach speed (baseline) 1/3 octave band spectra at 50° (inlet) and 120° (aft) angle from inlet and at 100 ft radius.

E-8688

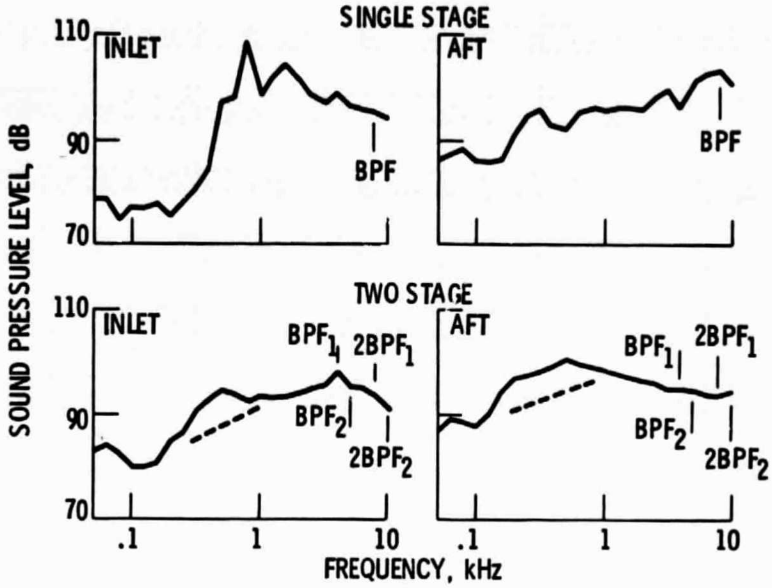


Figure 16. - Takeoff speed (baseline) 1/3 octave band spectra at 50^o (inlet) and 120^o (aft) angles from inlet and at 100 ft radius.

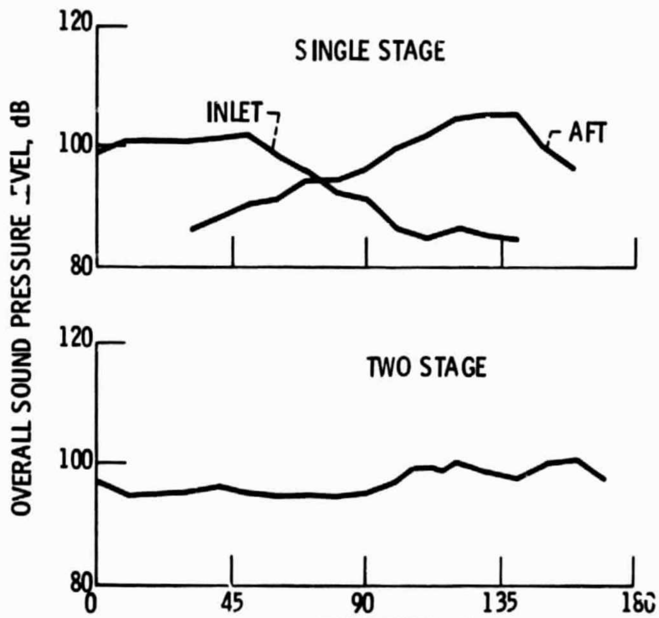


Figure 17. - Approach speed (baseline) directivity. Overall SPL at 100 ft radius.

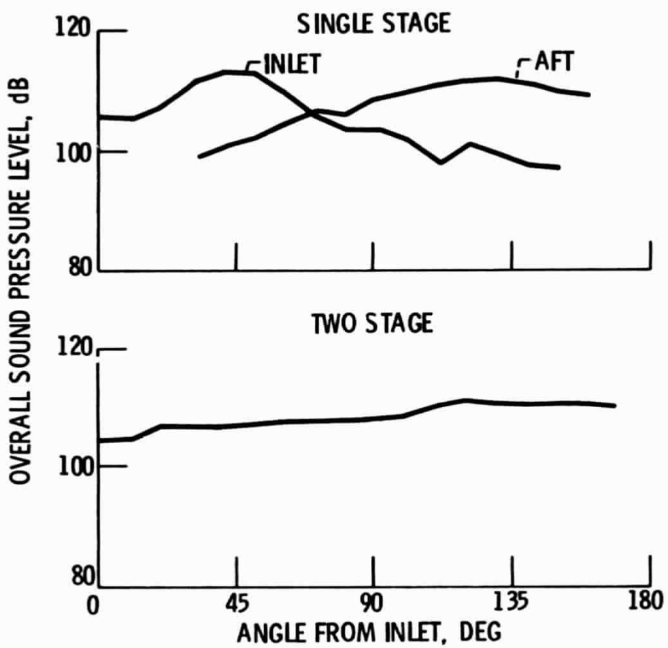


Figure 18. - Takeoff speed (baseline) directivity. Overall SPL at 100 ft radius.

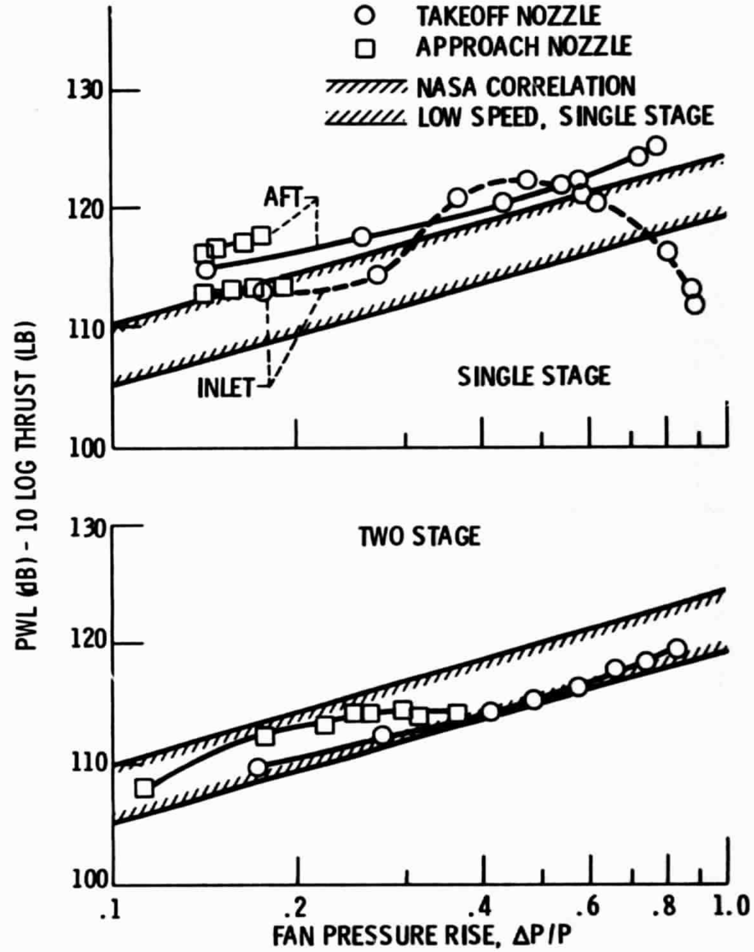


Figure 19. - Correlation of total sound power for baseline configurations.

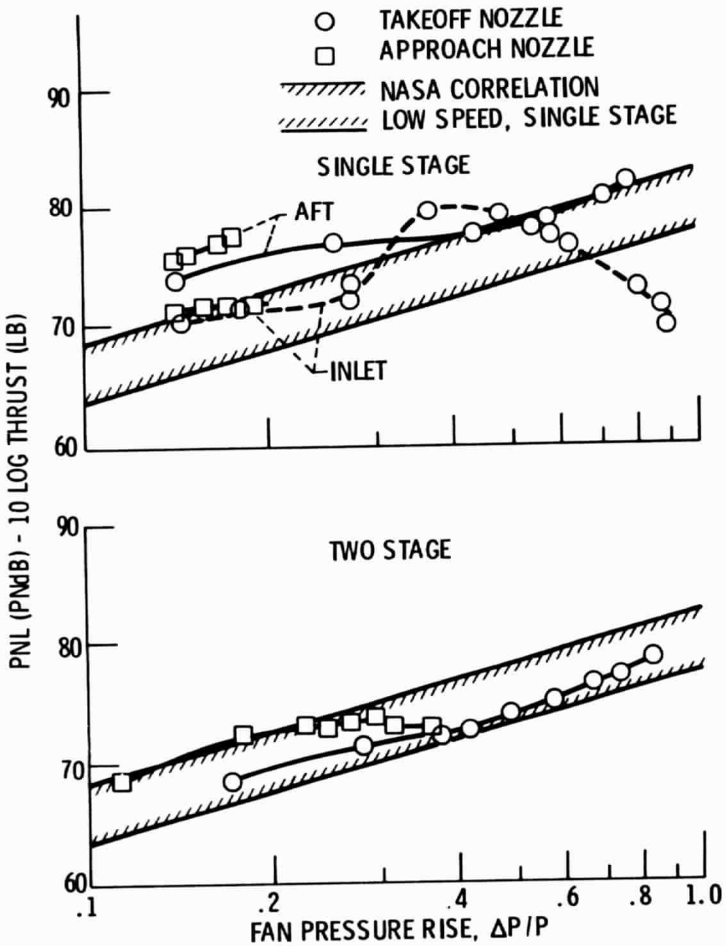


Figure 20. - Correlation of maximum perceived noise levels (PNL) at 200 ft sideline for baseline configuration.

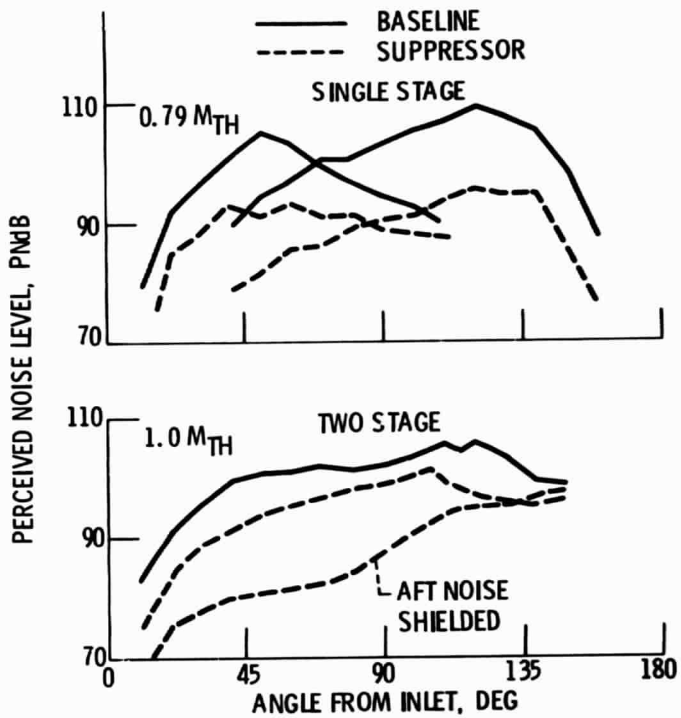


Figure 21. - Approach speed noise suppression. (Perceived noise levels at 200 ft sideline.)

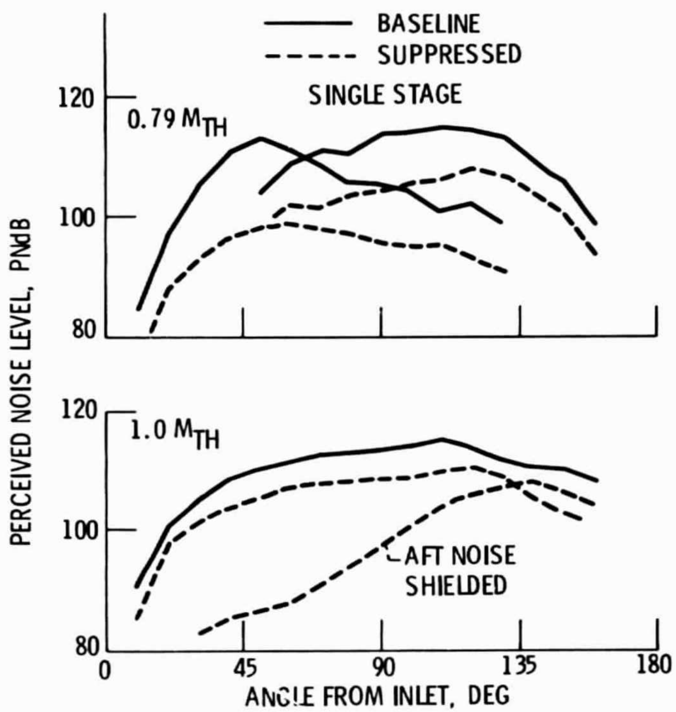


Figure 22. - Takeoff speed noise suppression. (Perceived noise levels at 200 ft sideline.)

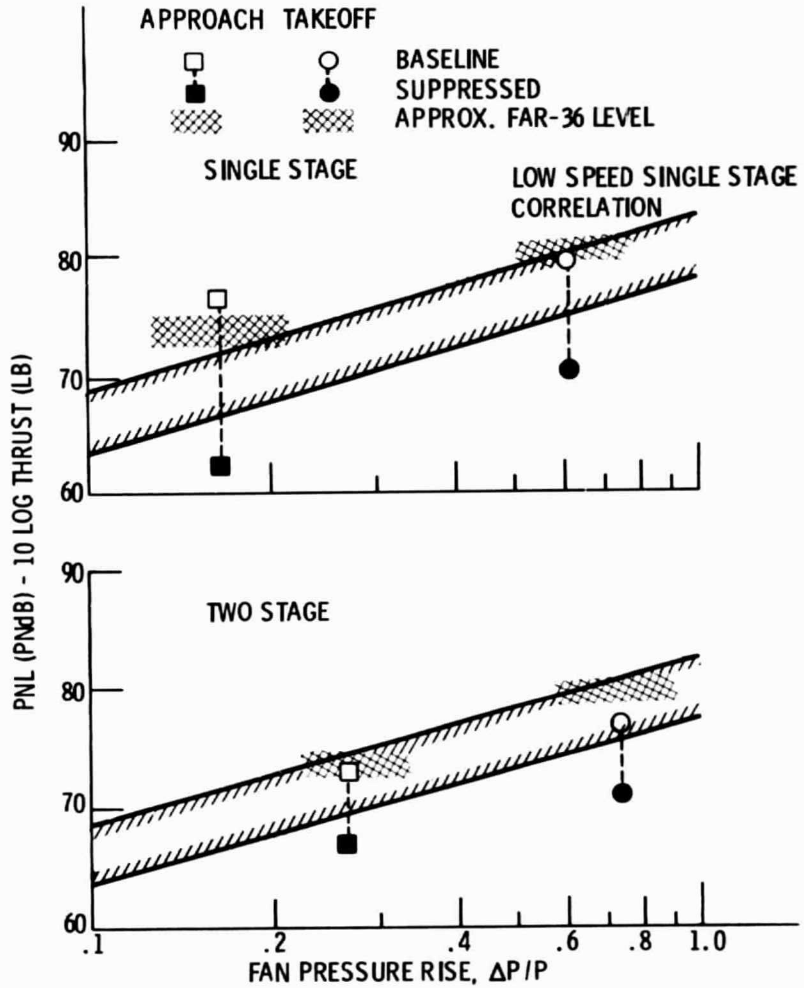


Figure 23. - Comparison of baseline and suppressed perceived noise levels (PNL) at 200 ft sideline.