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INVESTIGATION OF NOISE FROM FULL-SCALE HIGH BYPASS ENGINE AND BLOWN FLAP SYSTEM

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ABSTRACT

A summary is presented of an acoustic test program for investigating engine noise suppression and jet/flap interaction noise associated with an EBF STOL powered lift system. A highly suppressed TF-34 engine and EBF wing were used in the investigation. The engine was suppressed 21 PndB to a level of 94 PndB. An UTW powered lift system was tested with conventional, mixer, and decayer-type nozzles. The configuration with velocity decayer nozzle and acoustically treated shroud had the lowest noise (98 PndB). An OTW configuration with non-decayer nozzle was about 10 dB quieter than the corresponding UTW system. UTW and OTW noise data are compared with scale model correlations.

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INTRODUCTION

Powered lift aircraft are currently under consideration for potential use in short-haul operations requiring runway lengths considerably shorter than those for conventional aircraft. Such short-haul systems are also likely to involve operation very close to populated areas. For this reason extremely quiet aircraft will be a necessity. NASA has selected a technology target of 95 EPndB on a 500 foot sideline for a 150 passenger size aircraft. This noise level is nearly 30 EPndB lower than the noise level of existing FAR-36 regulations when compared at 500 feet. A substantial effort is needed to achieve this noise technology goal because of the additional noise sources present in powered lift aircraft concepts.

As a part of an overall effort in STOL propulsion research and technology a full-scale externally blown flap (EBF) system acoustic test program was initiated in 1971. The TF-34 turbofan engine was used as the baseline engine because of its high bypass ratio (6:1) and relatively low fan and core exit velocities.

The objectives of the program were to (1) demonstrate the feasibility of reducing fan and core engine noise to the low levels of interest for the short-haul aircraft and (2) investigate jet/flap interaction noise with a quieted high bypass engine, for both under-the-wing and over-the-wing power-lift concepts.

The test equipment used in the program included both the unsuppressed and the fully suppressed engine, both velocity decayer and non-decayer exhaust nozzles, and a full-scale segment of an EBF wing and three-element flap system.

The design of an acoustically treated nacelle was accomplished jointly by the Lewis Research Center and the General Electric Company. Fabrication of the quiet nacelle, the various exhaust nozzles, and the EBF wing was accomplished by G.E. under Lewis Research Center contract. The tests were conducted both at the Edwards Air Force Base in California, in 1972, and at the Lewis Research Center in 1973 and 1974. Assistance in the conduct of the Edwards tests and in acoustic data recording was provided by Flight Research Center personnel. The tests included both suppressed and unsuppressed engine configurations. In addition an Externally Blown Flap wing section together with several engine exhaust nozzle configurations, including a velocity decayer nozzle, were used to investigate jet flap interaction noise.

Engine performance and acoustic data were taken for a range of engine powers. Both far field and internal duct acoustic measurements were taken.

The results of the first series of tests completed on both the suppressed and unsuppressed engine configurations are reported in reference 1. Initial tests of the suppressed engine with an EBF UTW system utilizing several engine exhaust nozzle configurations including a velocity decayer nozzle are reported in reference 2. The present paper summarizes the results of references 1 and 2 and introduces further results of current engine acoustic and EBF UTW and OTW tests. An evaluation of the significant results and accomplishments of the overall program is made and a discussion of the planned continuing technology program is given.

EBF SYSTEM

Engine

The engine selected for this program was the General Electric TF-34 which has a bypass ratio of 6.5:1 and a fan pressure ratio of 1.5:1. The baseline unsuppressed engine with inlet bellmouth is shown schematically in figure 1.

The relatively high bypass ratio and the corresponding low jet velocities of the fan and core exhaust of the TF-34 made this a desireable engine for EBF noise experiments. Also since the unsuppressed engine is highly noise dominated, the suppression of this noise to the low levels of interest for STOL aircraft serve to demonstrate the applicability of high noise suppression technology.

The engine was quieted by installing it in an acoustically treated nacelle and enlarging the core and fan exit areas. The enlarged core nozzle reduced the core jet velocity and noise while not significantly effecting the static thrust of the engine. Both the untreated and the treated engines were tested with the same inlet bellmouth. A detailed description of the design of the acoustically treated engine is given in reference 3. The fully suppressed engine configuration is shown in figure 2.

The fan inlet suppression consisted of three rings with treated surfaces on both sides and on the outer duct wall. All inlet treated surfaces were one-half inch thick perforated sheet aluminum honeycomb single-degree-of-freedom (SDOF) material designed for maximum suppression at the blade passing frequency of 3150 hertz.

The aft-fan treatment consisted of two treated rings plus treatment on both outer and inner walls. Three different backing depths were used to provide suppression for broadband, fan fundamental and harmonic noise sources.

The core exhaust treatment consisted of two treatment depths to provide for both high and low frequency suppression.

The maximum design suppression values in 1/3 octave SPL were 31 dB for the inlet, 37 dB for the aft fan, and 25 dB for the core exhaust. The overall noise reduction goal for the suppressed engine was 25 PndB.

Some of the performance characteristics of both the unsuppressed and the suppressed engine configurations are given in table I.

Wing

The EBF wing used for the tests is shown in figure 3. The swept tapered wing incorporates triple-slotted full span flaps, has a cord dimension at the engine centerline of 12.75 feet and a span of 10.75 feet. Further details of the wing and flap system are given in reference 2.

Exhaust Configurations

Several different exhaust nozzle configurations were tested in the program with the objective of reducing jet/flap interaction noise. The different exhaust nozzle configurations tested are shown in figure 4. Two basic types were tested, decayer and non-decayer nozzles. The decayer nozzle (fig. 5) was a 12-lobe design. The basis for the design is given in reference 4. The decayer was tested with the core flow discharged internally with a conic nozzle (fig. 4(d)) and with a daisy-type mixer (fig. 4(a)). A modification of the basic decayer to a separate fan flow and core flow co-planar decayer was also tested (fig. 4(e)). In addition this decayer was tested with a six-foot long acoustically treated shroud (fig. 4(f)). Other configurations tested included a convergent nozzle with core flow discharged internally using both the 12-lobe core mixer (fig. 4(b)) and a conic core nozzle. Exhaust pressure and temperature surveys were made at several axial locations behind the engine for each nozzle configuration.

System Installation

The initial tests of engine noise suppression and EBF noise were conducted at the Edwards facility (fig. 6). Follow-on tests are being conducted at a newly constructed facility at Lewis Research Center (fig. 7). Both facilities provide for mounting the engine at a centerline height 9 feet above the ground. Engine thrust is measured by calibrated load cells connected to a baseplate supported at ground level by flexure plates at the Edwards facility. In the Lewis Research Center facility, thrust is measured from above the engine on a flexible beam support. Both facilities provide a wing carriage system that allows the position of the engine with respect to the wing to be varied. Acoustic data are taken using 16 microphones located every 10 degrees on the arc of a 100-foot radius half circle. For tests with the EBF wing system, microphones were also located above the engine by use of a 60-foot boom crane. These microphones were used to obtain sound data for sideline calculations.

TEST PROGRAM

The main objectives of the test program were to demonstrate the feasibility of suppressing the noise of a high bypass turbofan engine and of the engine with EBF wing to the stringent noise goals of the short-haul powered lift aircraft.

The approach used was to provide sufficient sound treatment to the engine to suppress the fan and core engine noise to levels below the jet noise floor. The jet noise floor itself was reduced by operating the engine with enlarged fan and core exhaust areas. By thus providing a low-noise propulsive system, EBF noise as well as engine noise suppression technology could be investigated.

Elements

The main program elements are listed in table II. The tests consisted of engine alone and engine with EBF wing. Engine alone tests were performed with both the baseline unsuppressed configuration with co-annular nozzle and with the suppressed configuration with both velocity decayer nozzles and non-decayer nozzles. Exhaust jet velocity and temperature surveys were made of all exhaust nozzles tested. In addition to the full suppressed engine alone tests, runs were made with partially suppressed aft-fan duct and with both suppressed and unsuppressed core exhaust.

Engine with EBF wing acoustic tests were performed with both under-the-wing (UTW) and over-the-wing (OTW) configurations. UTW testing consisted of runs with seven different exhaust nozzle configurations including both velocity decayer and non-decayer types. Test variables included retracted (0°), take-off (40°), and approach (55°) flap settings and several spacings of the wing-flap system relative to the engine exhaust nozzle. Other UTW tests included dynamic pressure and temperature surveys of the flap surfaces for a dynamic loads program.

OTW testing consisted of testing one exhaust nozzle configuration (mixer-conic with deflector plate) with a smooth curved plate replacing the three element flap system used in the UTW testing. Only the take-off (simulated 40° flap) flap configuration was tested. Other OTW tests were also performed to determine the shielding effectiveness of the wing to both aft-fan machinery noise and jet exhaust noise. For these tests the engine was operated in the fully suppressed, the partially suppressed aft-fan duct, and the hardwall aft-fan duct configurations.

Additional tests include further modifications with the engine alone and with the engine and EBF wing. Engine-alone tests include a redesigned aft-fan duct with a single splitter. The objective of this effort is to investigate an optimized aero/acoustic design based on data obtained from the earlier two-splitter tests and utilizing current advanced aero/acoustic design techniques. Other engine-alone tests will investigate engine inlet noise suppression. Far field and internal duct acoustic data will be obtained for hard and soft duct walls with and without splitter rings.

Engine with EBF wing tests for the UTW case will be performed with a redesigned wing and flap system incorporating "quiet flap" configurations including porous flap trailing edges. OTW tests will include tests with a redesigned straight wing and a 4:1 aspect ratio OTW exhaust nozzle. A wing force measuring system will be utilized to evaluate static turning effectiveness of the various wing and flap configurations.

Aerodynamic performance and far field acoustic data are obtained for all tests. In addition near field and internal duct acoustic measurements are made on the suppressed engine configurations.

Near field measurements were made using a row of 10 microphones spaced at intervals of about 4 feet and located 8 feet from the engine. An acoustic array device was also used to measure individual noise sources.

Status

The elements of the test program already completed from table II are: A.1, B.1-4, C.1 & 2, D.1 & 4. An engine inlet noise investigation (B.6) is presently underway. Tests B.5, C.3 and D.2 are planned for the future.

Summaries of the engine and EBF test results are reported in references 1 and 2. Results of near field, acoustic array, and internal duct acoustic probe measurements are described in reference 5. The results of more recent engine and EBF tests are included herein.

ENGINE NOISE

Fully Suppressed Configuration

The fully suppressed engine, shown in figure 2, was tested over a range of engine power with the baseline co-annular nozzle. The baseline unsuppressed engine shown in figure 1 was tested to provide reference performance and acoustic conditions. The results of these tests are given in figures 8 through 10 and are described in more detail in reference 1. Maximum perceived noise on a 500-foot sideline for both the unsuppressed and suppressed engine plotted against corrected fan speed is shown in figure 8. A total system noise of 94 PndB or just over 21 PndB noise reduction was obtained at rated fan speed.

One-third octave band spectra for both the suppressed and unsuppressed engines are shown in figure 9. The spectra are compared at 50° (fig. 9(a)) and 130° (fig. 9(b)) microphone locations. These spectra show a total elimination of the peaks due to the fan tones in the suppressed engine. Suppression values for the inlet (50° microphone) for frequencies corresponding to the first, second, and third BPF amounted to 29, 19.5, and 20 dB, respectively. Values of suppression for the 130° microphone were somewhat less probably due to the presence of jet noise.

The perceived noise directivity in PndB on a 500-foot sideline is shown in figure 10. The directivity for 7 100 rpm fan speed case is shown in figure 10(a). The maximum PnL for the suppressed engine occurs at 120° from the inlet. This directivity pattern is probably due to the dominance of either broadband aft-duct noise or jet noise in the suppressed engine. Figure 10(b) shows the same directivity pattern for a lower fan speed. These data again show a maximum PndB at 110° - 120°.

The results of the fully suppressed engine tests indicate that the goal of achieving low levels of noise (92 - 94 PndB) at rated speed for realistic EBF system noise experiments was met in the static ground tests. These levels would be expected to decrease for the in-flight forward speed condition.

Fan Aft-Duct Suppression

Two additional suppressed engine configurations were tested in which the aft fan splitters were removed. These configurations were for the suppressed (soft) duct wall and for the unsuppressed (hard) duct wall. The engine exhaust configuration for these tests was the mixer-conic (fig. 4(b)). The results of these tests are shown in figures 11 and 12. Figure 11(a) presents maximum PnL on a 500-foot flyover against fan speed. The unsuppressed and fully suppressed data are essentially the same as that used in figure 8. The hard duct with splitters removed, but with suppressed inlet and core exhaust gave a noise reduction of about 9 - 10 dB at 6600 rpm. The soft wall case without splitters gave a noise reduction of about 17 dB, while the fully suppressed duct with two splitters resulted in only about another 4 dB reduction for a total of 21 dB.

Figure 11(b) presents the soft wall, no-splitter and two-splitter data and the hard wall, no-splitter data plotted against mass-averaged jet velocity. On the basis of a constant value of jet velocity, the no-splitter case has the same noise as the two-splitter case. This is an indication that the jet noise floor is at a high enough level to prevent any additional suppression beyond the soft wall no-splitter case from being heard.

Figure 12 presents the 1/3 octave spectra for the two-splitter and no-splitter case. The solid line in the figure represents pure jet noise and was obtained using the correlation from reference 6. This correlation was derived using scale model ambient temperature data. A modification to the correlation was made to account for the jet temperatures of the full-scale engine. The engine data agree well with the scale model data for pure jet noise indicating the dominance of jet noise in the engine case. At the BPF of 3150 hertz there is evidence of some fan tones in the no-splitter data. The two-splitter data show no BPF tones are present, but the data at lower frequencies are at a higher level than the no-splitter data. This higher noise level could be caused by the effects of flow over the splitters. (The flow Mach number in the splitter passage was about 0:45).

The foregoing aft-duct suppression discussion has indicated that the original suppressor design provided suppression to levels below the jet noise floor. Although the true levels of this suppression cannot be determined from far field measurements, internal acoustic probe data (ref. 5) indicated that approximately 26 PndB of fan noise suppression was obtained. These levels of suppression are in the range required for the short-haul aircraft. The data from these tests has provided better understanding of suppressor design and has provided the basis for a new aft-fan suppressor design. The new design provides for optimization of the aero/acoustic design by incorporating a single splitter and a recontoured duct wall. The splitter passage Mach number will be reduced from approximately 0.45 to 0.30 in the new design. Tests of the new configuration will provide additional data for assessing the effects of duct Mach number, flow generated noise and define true suppression levels.

Suppression Thrust Losses

The tests performed on both the unsuppressed and suppressed engine configurations allowed evaluation of both the pressure losses and the thrust losses due to the acoustic suppression. Figure 13 presents the thrust of both the baseline unsuppressed and the fully suppressed engine both with co-annular exhaust nozzle. At 100 percent rated fan speed (corresponds to value of thrust for rated turbine gas temperature, $T_{5.4}$, of 1955° R) the suppressed engine (fig. 13(a)) had a thrust loss of 14.1 percent.

Figure 13(b) presents the results of tests with aft-fan duct splitters removed. (The engine used for these tests had a different serial number and was tested at a different facility than that presented in figure 13(a).) Data are shown for the baseline unsuppressed engine, the suppressed engine with the no-aft splitter configuration, and the fully suppressed (2-splitter) configuration. Both the no-splitter and two-splitter data were obtained with the mixer-conic exhaust nozzle. At 100 percent rated fan speed the thrust loss in percent was 9.8 for the suppressed engine with no-splitters and 14.8 percent for the fully suppressed engine with two-splitters. The losses for the no-splitter engine were made up of the inlet, added aft-fan duct and core exhaust duct.

A breakdown of the thrust losses obtained for the fully suppressed engine of figure 13(a) is shown in figure 14. The losses were calculated from measured total pressure losses using influence coefficients derived from an engine performance deck. It is obvious from the figure that the aft-fan duct accounts for about twice the combined losses of both the inlet duct and core exhaust duct. As indicated in figure 13(b) removal of the aft-fan splitters cuts the aft-fan duct losses approximately in half or to about 5 percent.

An estimate was made of the overall thrust losses for an optimized aerodynamic/acoustic design in which the acoustic suppression would be the same as the measured value. An improved inlet splitter aerodynamic design, a single aft-fan duct splitter with improved aerodynamic contouring, and a shortened core exhaust duct (by combining both high-frequency and low-frequency treatment) were assumed. It was estimated that these changes could reduce thrust losses by approximately 50 percent.

The new design single splitter aft-fan duct when tested will allow verification of the major thrust loss suppressor component in the system.

Tests are also being performed to investigate the effects of removal of the engine inlet splitter rings on both the aerodynamic and acoustic performance of the engine. These tests are identified as B.6 in table II. The inlet duct will be tested with both hard and soft wall duct both with and without splitter rings.

EXHAUST CONFIGURATION RESULTS

Two types of exhaust nozzles were tested, the velocity decayer and the non-velocity decayer. The specific nozzle configurations tested are illustrated in figure 4. Detailed results of these tests are given in reference 2.

Aerodynamic

In general, the non-velocity decayer nozzles exhibited very little decay as compared to the decayer nozzles. This is illustrated in figure 15. The non-decayer mixer-conic did, however, have a fairly rapid decay rate for the first 40 inches with little decay after that. The decayer nozzles were designed to reduce the exhaust velocity 38 percent in 115 inches (three equivalent nozzle diameters). The data indicate that considerably greater velocity reductions than design were attained (approximately 50 percent reduction based on average velocity, and around 65 percent for peak velocity). The data also indicate (plume surveys) that considerable divergent flow and jet spreading occurred downstream from the nozzle exit. This jet spreading has the effect of increasing the flap impingment noise (ref. 6).

A comparison of the effective exhaust velocities based on corrected thrust is shown in figure 16. The velocity decayer nozzles had the highest effective exhaust velocities while the non-decayer mixer-conic had the lowest. The higher exhaust velocities resulted from the smaller effective flow area due to flow separation and higher internal flow losses.

The high internal losses are illustrated by the thrust coefficient, C_T, defined as the measured thrust divided by the ideal thrust calculated from total pressure measurements upstream from the exhaust nozzle. The thrust coefficient is shown plotted against fan pressure ratio in figure 17. The decayer nozzles had thrust coefficients from 0.90 to 0.94, while the non-decayer nozzles had coefficients from 0.96 to 0.99.

The conclusions reached from the results of these tests were that the decayer nozzle designs produced velocity decay higher than necessary, had high internal pressure losses, and increased effective jet velocities. An optimized design utilizing the results of these tests could conceivably result in a configuration with less velocity decay but with greatly improved thrust performance and effective exhaust jet velocity.

Acoustic

A comparison of the noise from each of the exhaust nozzle configurations is shown in figure 18. Maximum PnL at 500-foot flyover is shown plotted against corrected thrust. In general, the mixed flow decayer nozzles were noisier than the non-decayer nozzles. The quietest configuration, the mixer-conic (non-decayer) was about 12 PndB below the noisiest decayer nozzle. The higher effective exhaust velocity for the decayer nozzles and the lobed design which results in higher frequency spectrum both contribute to the higher perceived noise levels for these nozzles. One decayer configuration, the co-plannar with acoustically treated shroud was, however, only about 3 PndB louder than the quietest mixer-decayer nozzle.

An optimized acoustic design for the decayer nozzle would result in fewer lobes with a lower aspect ratio and reduced effective jet velocity and less jet spreading. A design with fewer lobes with lower aspect ratio would lower the frequency spectrum and thus reduce PNL These modifications are also consistent with improved aerodynamic performance.

FLAP SYSTEM NOISE

A series of acoustic tests were performed with the suppressed engine and the EBF wing described previously herein. A more extensive description of these tests is given in reference 2. The wing was mounted vertically on a movable table which allowed testing of various engine-to-wing positions. Microphones for recording flyover data were located on a 100-foot radius half-circle centered on the engine exhaust nozzle. Microphones were also located 50 feet directly above the engine exhaust to provide sideline noise data.

Under-The-Wing Configurations

The general orientation of the engine exhaust and EBF wing are shown in figure 19. Nominal test positions of the wing and flap system and the six exhaust nozzle configurations tested are listed on the figure.

A comparison of the maximum perceived flyover noise levels for the various exhaust nozzles and flap configurations tested is shown as a function of thrust in figure 20. These figures allow a detailed examination of the perceived noise characteristics of the individual configurations over the range of variables covered.

A summary of pertinent data from all the configurations tested is tabulated in table III. Data are given in the table for the 40° take-off flap position and rated thrust, and for the 55° approach flap setting and 80 percent rated thrust conditions. Engine alone and engine with wing and flap noise values are given. The difference column represents the wing system noise increment for each of the configurations. In general, the wing noise increment is greatest for the nozzle configurations with little velocity decay (around 10 to 13 PndB). The difference between engine alone and total with the flap for the co-annular baseline configuration was 11 PndB. This noise difference is primarily due to flap impingment noise due to the high impingment velocity (approximately 850 ft/sec).

The decayer nozzles, as a result of their lower values of impingment velocity, showed much smaller noise increments when the wing system was introduced (around 4 to 6 PndB).

The quietest configuration tested was the co-plannar decayer with treated shroud which gave a maximum flyover noise of 98 PndB for take-off thrust and take-off flap position. This configuration was only 4 PndB louder than the engine-alone case. This noise over the engine-alone noise is probably due to flow scrubbing the lower surface of the wing from the jet exhaust and from redirected jet noise. The impingment velocities for the decayer nozzles were less than 400 ft/sec so that relatively little added noise is generated from the flap.

It should be noted that, as indicated earlier, the particular decayer nozzle configurations used resulted in increases in engine-alone noise (table III). This increase influenced the overall noise with the wing system. It is believed, therefore, on the basis of these tests, that it should be feasible to obtain UTW systems with minimum noise (approaching 3 PndB above engine-alone level) with properly designed velocity decayer nozzles that do not increase the engine-alone noise.

Optimum-design decayer nozzles, however, might still have some objectionable features for overall system performance because of such factors as increased nozzle weight and diameter and some measure of internal and external (cruise) drag. Also for advanced short-haul propulsion systems with low-velocity exhaust, achieving velocity decay becomes more difficult. Accordingly, planned follow-on tests for the UTW concept will concentrate on an evaluation of a concept to reduce flap source generated noise in conjunction with a conventional nozzle (item C.3, table II). The source reduction concept involves the use of porous flap trailing edges.

Over-The-Wing Configurations

The OTW exhaust nozzle and wing orientation is shown in figure 21. All OTW tests were performed with the mixer-conic exhaust nozzle and deflector plate. For these tests the three-element flap system was replaced with a curved steel plate representing the 40° take-off flap position. A photograph of the OTW test setup is shown in figure 22.

Maximum 500-foot flyover PNL plotted against corrected engine thrust is shown in figure 23 for both engine alone and the OTW system. Data are shown for the soft-wall fan duct with no splitters in figure 23(a). At the rated thrust condition the total OTW system noise was about 99 PndB. The noise added between the engine alone and the OTW system was only 2.5 PndB. This added noise results from unshielded deflector noise and low-frequency trailing edge flap noise.

Figure 23(b) presents data for the engine configuration with hard aft-fan duct walls and no splitters. A comparison is given for the engine-alone case and for the OTW system. Also included on the figure for reference is the OTW system, soft-wall aft-fan duct without splitters from figure 23(a). The hard-wall aft-duct configuration was obtained by taping over the acoustically treated surfaces. The engine-alone hard-wall noise level at rated thrust was about 7 dB higher than the engine-alone soft-wall case (engine-alone noise in fig. 23(a)), due to the emergence of aft-fan noise.

The introduction of the OTW wing system reduced the hard-wall engine noise by around 3 PndB, as shown in figure 23(b). This noise reduction was the net result of wing shielding of the fan, jet and deflector plate noises, together with the added low frequency noise from the wing-flap system. The interesting question raised by these data is whether it would be possible to obtain an OTW system noise level comparable to the soft-wall case (dashed line) with some level of aft-duct suppression less than that in the soft-wall configuration.

A comparison of SPL 100-foot 1/3 octave spectra for engine-alone, UTW and OTW configurations with non-decayer nozzles, is shown in figure 24. The data show that the UTW configuration has a higher noise level across the entire frequency range except at 50 hertz. The OTW system noise has a peak at 50 hertz and is approximately the same as engine-alone noise in the mid-frequency range. The engine-alone no-splitter data is slightly higher than the engine-alone two-splitter data from 2 000 to 20 000 hertz. The reason for this higher noise is probably due to unsuppressed fan noise for the no-splitter case.

A noise level comparison for engine-alone and for both UTW and OTW configurations with non-decayer nozzles is shown as a PNL 500-foot flyover directivity plot in figure 25. The noise comparisons were made with the mixer-conic exhaust nozzle at a jet velocity of 635 ft/sec. Flap angle for the wing configuration was 40°. Engine-alone and OTW system noise peaked at angles of 110° to 120°, while the UTW noise peaked at 90° for the 40° flap angle. For the exhaust velocity shown, the UTW configuration had a peak noise level of 96.5 PndB while the OTW configuration had a peak of 87.5 PndB, or about 9 PndB lower than the UTW configuration. The peak value of noise for the OTW system was only about 2 PndB higher than for the fully suppressed engine-alone noise.

In view of these results with the OTW configuration with the attached nozzle deflector plate (fig. 21), it was decided to pursue the OTW approach further with a specially designed nozzle that would be more representative of a real installation. The nozzle design, based on results of model tests is basically a 4:1 aspect ratio nozzle with the flow directed onto the wing upper surface. This nozzle will be tested with both the original swept wing section (fig. 22) and a new straight wing section (item D.3, table II). Provision will also be made at that time for wing force measurements in the lift and drag directions.

Inasmuch as the jet flap interaction noise may be the most dominate noise source of an EBF short-haul powered lift system, the full-scale acoustic results described herein, are of major importance in the design of the engine for such a system. Accordingly both the UTW and OTW acoustic test results are being used in design of the QCSEE (Quiet Clean Short Haul Experimental Engine) program. These results are used in the cycle selection involving fan pressure ratio and fan and core exhaust velocities.

Correlations

The full-scale engine system data have generally been in fairly good agreement with small-scale model data (e.g. refs. 7 through 10). A further example comparison of measured and predicted flap noise for both the UTW and OTW configurations is shown in figure 26. The data are presented as OASPL at 90° and 100-feet plotted against effective jet velocity for mixer-conic exhaust nozzle and 40° flaps. The prediction curves, derived primarily from cold-flow scale model data, are from reference 6 for the UTW configuration and from reference 7 for the OTW configuration. The prediction curve is in excellent agreement with the full-scale data for the UTW case, but the OTW data is about 2 dB below the prediction curve. The OTW prediction curve from reference 7 was adjusted downward 2 dB to free-field conditions to account for ground reflections by the method of reference 11.

CONCLUDING REMARKS

The full-scale EBF system test program described herein has provided significant information on noise level characteristics of real UTW and OTW powered lift systems.

Specific performance data and design implications have been provided in the areas of engine noise suppression and thrust losses, exhaust nozzle performance for mixer- and decayer-types, and system noise for UTW and OTW configurations with various nozzle designs. The results, in general, tend to indicate a favorable prognoses for the attainment of the low noise levels required for STOL operations. Much of the information generated in this program has been utilized in design activities such as the QCSEE (Quiet Clean Short Haul Experimental Engine) program. In particular the QCSEE program has utilized the full-scale UTW and OTW acoustic test results in the engine cycle selection involving fan pressure ratio and fan and core exhaust velocities.

The total test program described herein should provide a valuable technology data base for application to short-haul aircraft design.

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TABLE I. - TF-34 ENGINE PERFORMANCE AT MAXIMUM POWER CORRECTED TO SEA-LEVEL-STATIC, STANDARD DAY.

	UNSUPPRESSED ENGINE	SUPPRESSED ENGINE
THRUST, F_n (LB)	9 400	8 080
FAN SPEED, N_f (RPM)	6 800	7 040
CORE SPEED (RPM)	17 050	17 150
H. P. TURB. DIST. TEMP. $T_{5.4}$ (^{o}R)	1 955	1 955
TOTAL AIRFLOW (LB/SEC)	329	340
CORE FLOW (LB/SEC)	44.0	44.1
BYPASS RATIO	6.48	6.70
FAN PRESSURE RATIO	1.468	1.504
FAN JET VELOCITY (FT/SEC)	850	773
CORE JET VELOCITY (FT/SEC)	1 250	905
FAN EXIT AREA (IN.^{2})	656.7	790
CORE EXIT AREA (IN.^{2})	208.8	281

TABLE II. - EBF SYSTEM ACOUSTIC TEST PROGRAM

ELEMENTS	MEASUREMENT	YEAR
A. UNSUPRESSED ENGINE		
1. BASELINE, CO-ANNULAR NOZZLE	PERF, ACOUSTIC	1972(E), 1973(L)
B. SUPRESSED ENGINE		
1. BASELINE, CO-ANNULAR NOZZLE	AERO., ACOUSTIC	1972(E), 1973(L)
2. EXHAUST NOZZLE CONFIGURATIONS, 7 NOZZLE TYPES	AERO., ACOUSTIC PLUME SURVEYS	1972(E), 1973(L)
3. CORE EXHAUST NOISE, SOFT AND HARD WALL DUCT	AERO., ACOUSTIC	1972(E), 1974(L)
4. AFT FAN NOISE, SPLITTERS REMOVED, HARD AND SOFT WALL DUCT	AERO., ACOUSTIC	1973(L)
5. AFT FAN NOISE, REDESIGNED DUCT, SINGLE SPLITTER, HARD AND SOFT DUCT	AERO., ACOUSTIC	1974, 1975(L)
6. ENGINE INLET NOISE, SPLITTERS REMOVED, HARD AND SOFT DUCT	AERO., ACOUSTIC	1974(L)
C. FLAP SYSTEM NOISE - UTW		
1. EXHAUST NOZZLE CONFIGURATIONS, EBF WING, 7 NOZZLES, FLAP ANGLE AND WING PLACEMENT VARIED	ACOUSTIC	1972(E), 1973(L)
2. FLAP DYNAMIC LOADS, MIXER-CONIC NOZZLE	DYNAMIC P, T	1973(L)
3. QUIET FLAP CONFIGURATIONS, POROUS FLAP TRAILING EDGES	ACOUSTIC	1975(L)
D. FLAP SYSTEM NOISE - OTW		
1. FLAP NOISE, EBF WING WITH FAIRED UPPER SURFACE, MIXER-CONIC NOZZLE WITH DEFLECTOR PLATE	ACOUSTIC	1972(E), 1973(L)
2. FLAP NOISE, 4:1 ASPECT RATIO NOZZLE, EXISTING SWEPT EBF WING AND NEW STRAIGHT WING	ACOUSTIC, L/D-FORCE SYSTEM	1974(L)
3. NOISE SHIELDING, AFT FAN SPLITTERS REMOVED, HARD AND SOFT DUCT	ACOUSTIC	1973(L)

(E) EDWARDS
(L) LEWIS

TABLE III. - EBF UTW NOISE RESULTS

NOZZLE CONFIGURATIONS	ENGINE ALONE	TOTAL WITH FLAP	DIFFERENCE
	MAX FLYOVER PNL, PNdB		
A. 40° FLAP; RATED THRUST (TAKEOFF)			
1. CO-ANNULAR (BASELINE)	93	104	11
2. MIXER-CONIC	92	102	10
3. CONIC-CONIC	92	103	11
4. MIXER-DECAYER	100	106	6
5. CO-PLANNAR DECAYER	98	102	4
6. CO-PLANNAR DECAYER W/SHROUD	94	98	4
B. 55° FLAP; 80 PERCENT RATED THRUST (APPROACH)			
1. CO-ANNULAR (BASELINE)	89	102	13
2. MIXER-CONIC	88	99	11
3. MIXER-DECAYER	97	---	---
4. CO-PLANNAR DECAYER	92	97	5
5. CO-PLANNAR DECAYER W SHROUD	89	95	6

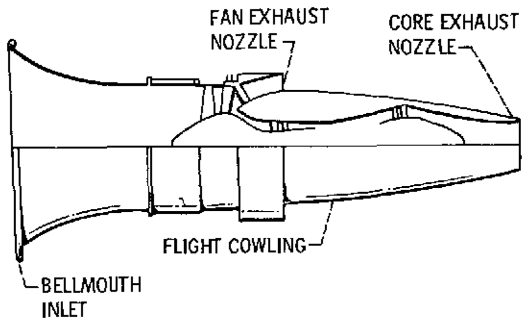


Figure 1. - Schematic diagram of baseline unsuppressed TF-34 engine.

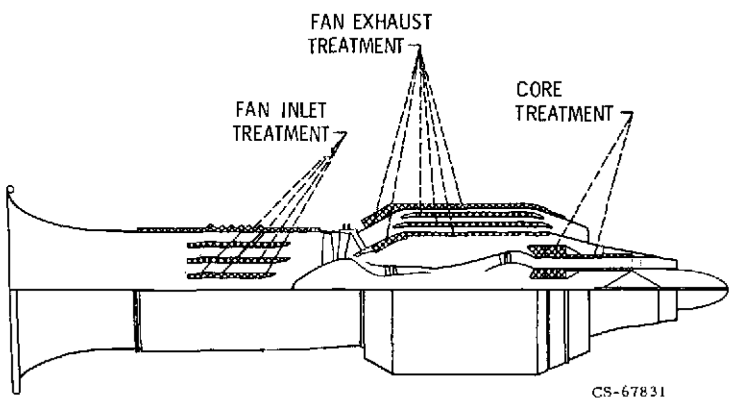
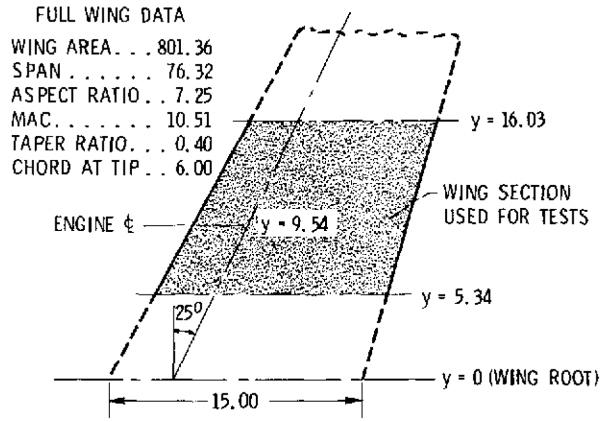
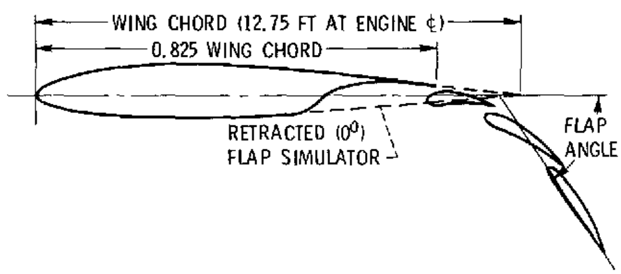


Figure 2. - Acoustically treated TF34 engine with separate flow exhaust.



(a) SCHEMATIC OF WING SECTION.



(b) TYPICAL CHORDWISE PROFILE THROUGH WING AND FLAPS.

Figure 3. - Wing and flap details. (All dimensions in ft)

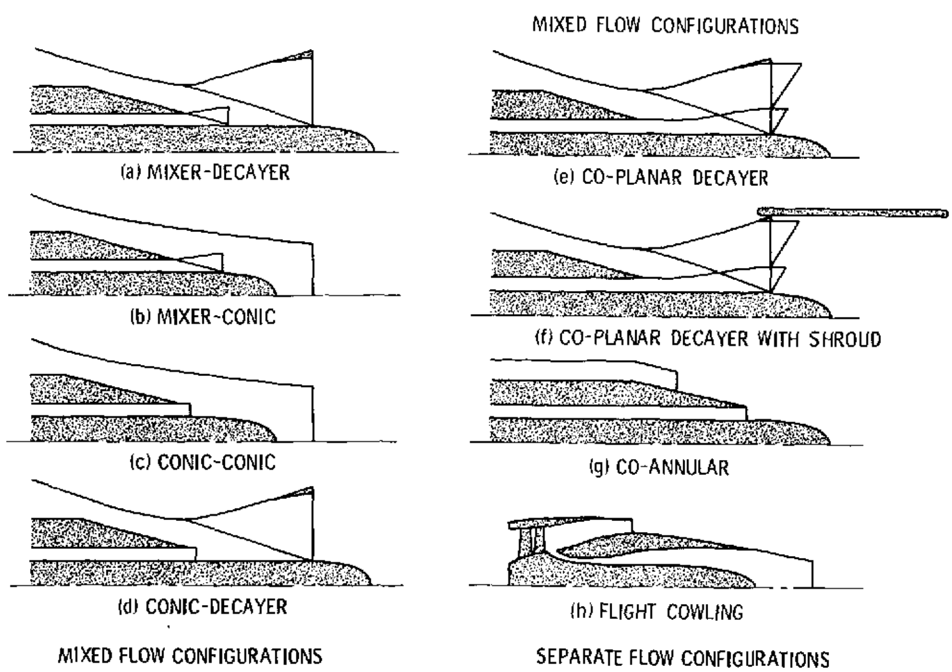


Figure 4. - Engine exhaust nozzle configurations.

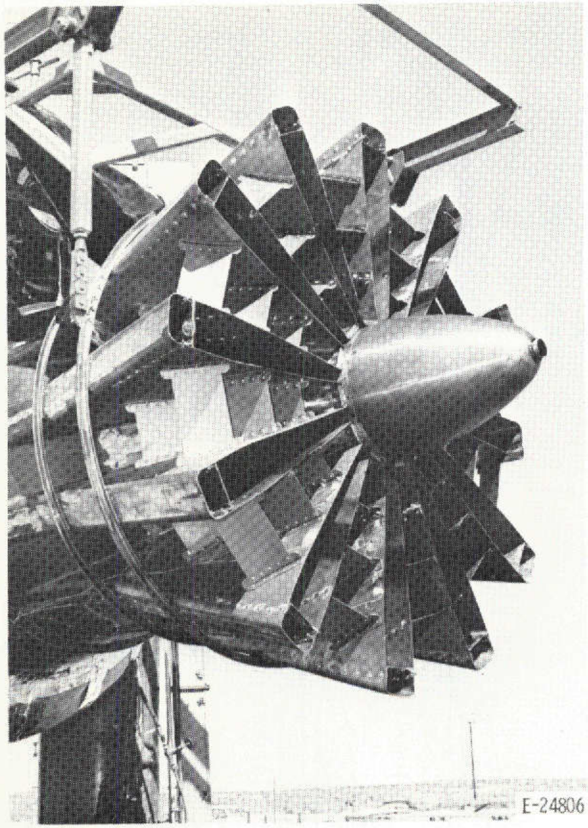


Figure 5. - Twelve-lobed velocity decayer nozzle.

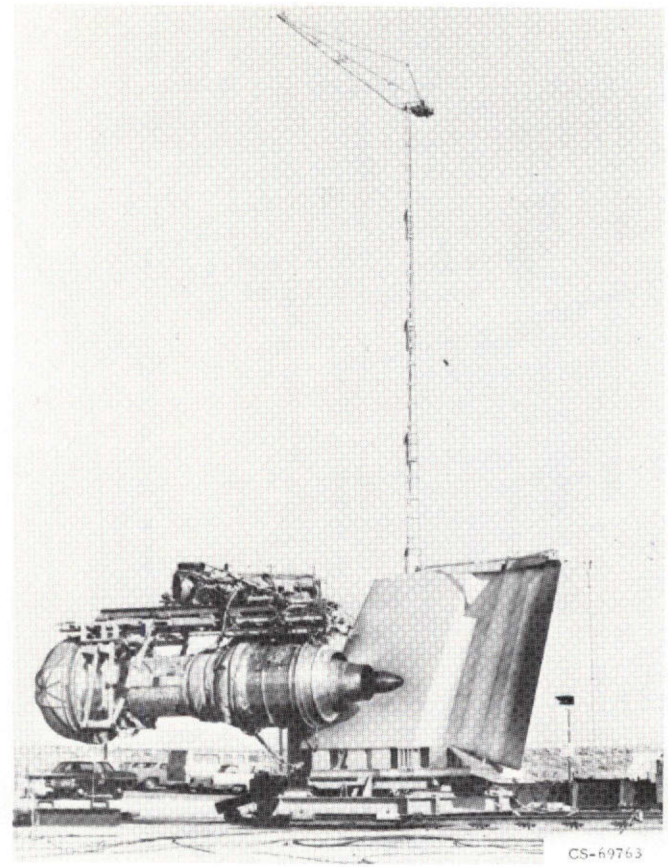


Figure 6. - Test installation at Edwards Air Force Base.

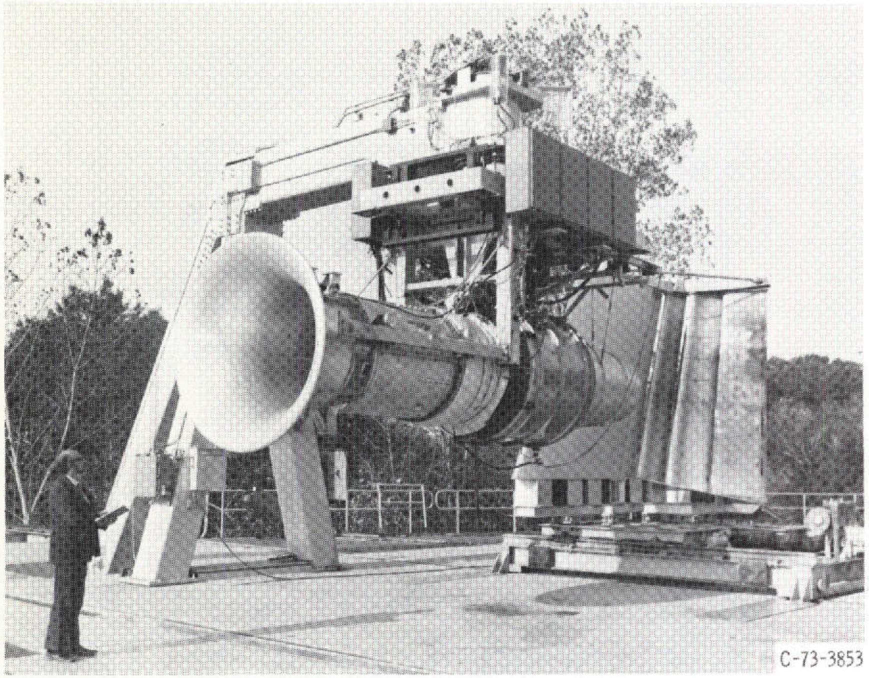


Figure 7. - Test installation of TF-34 at Lewis Research Center.

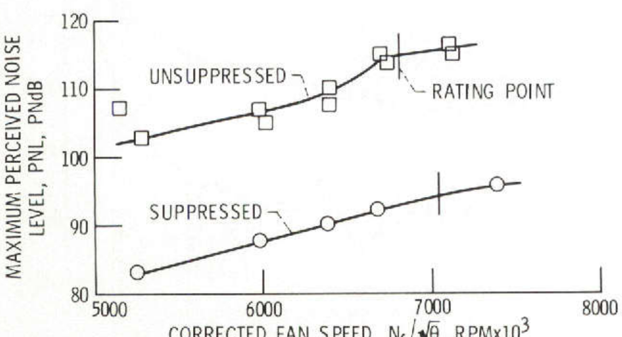


Figure 8. - Maximum perceived noise on a 500 foot sideline as a function of fan speed (co-annular exhaust nozzle).

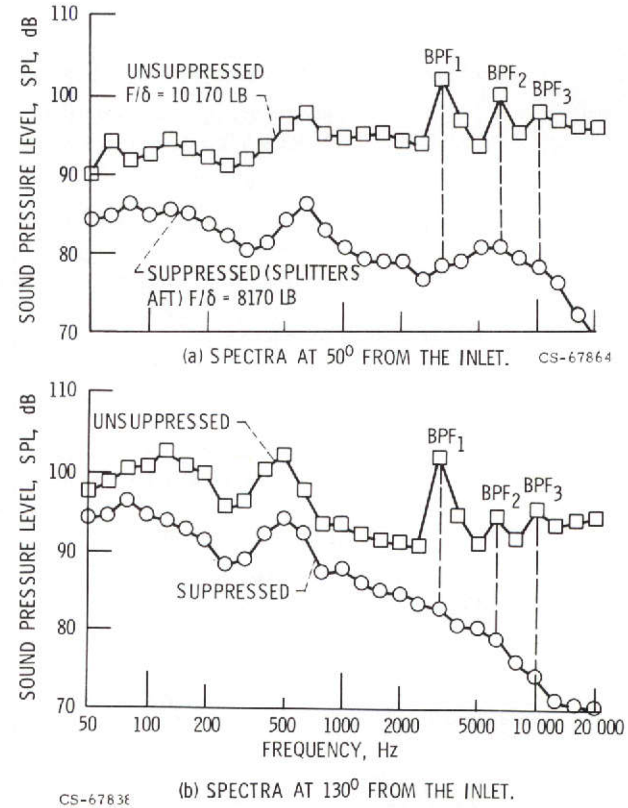


Figure 9. - Comparison of 100 foot 1/3 octave band spectra for the suppressed and unsuppressed engines at $N_f/\sqrt{\theta}$ = 7100 RPM (co-annular exhaust nozzle).

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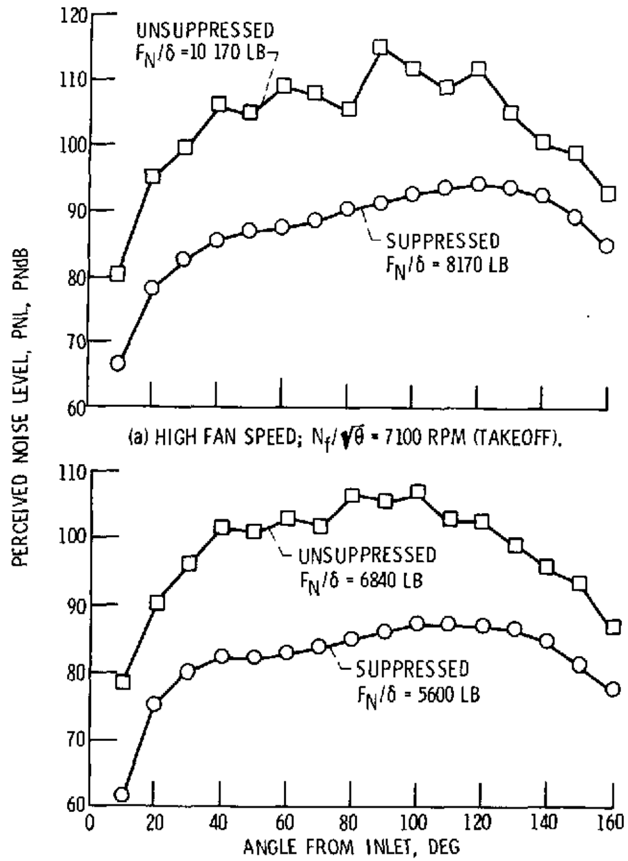
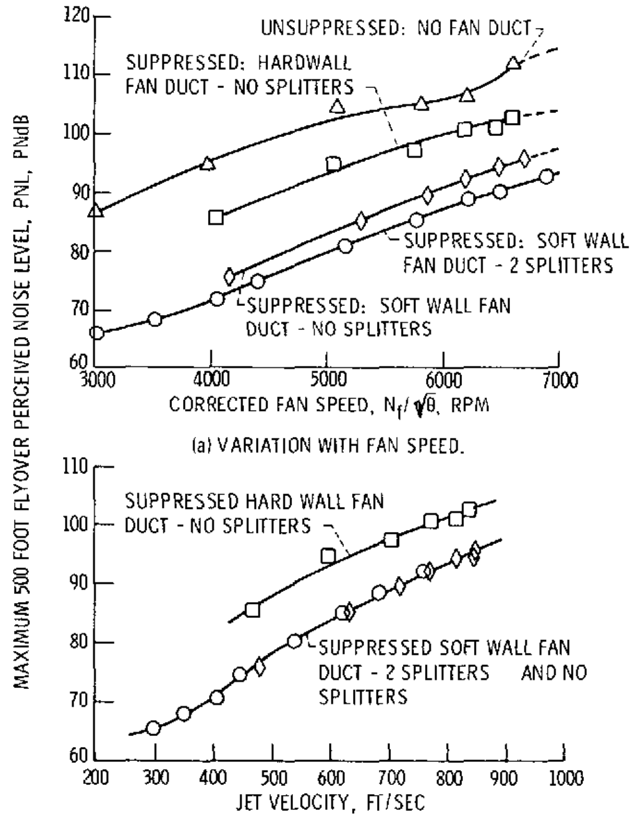


(a) HIGH FAN SPEED; $N_f/\sqrt{\theta}$ = 7100 RPM (TAKEOFF).

(b) 85% RATED FAN SPEED, $N_f/\sqrt{\theta}$ = 5980 RPM (APPROACH).

Figure 10. - Perceived noise level directivity, 500 foot sideline (co-annular exhaust nozzle).



(a) VARIATION WITH FAN SPEED.

(b) VARIATION WITH MASS AVERAGED JET VELOCITY. DATA FOR CONSTANT NOZZLE AREA.

Figure 11. - The effect of aft fan acoustic treatment on engine perceived noise.

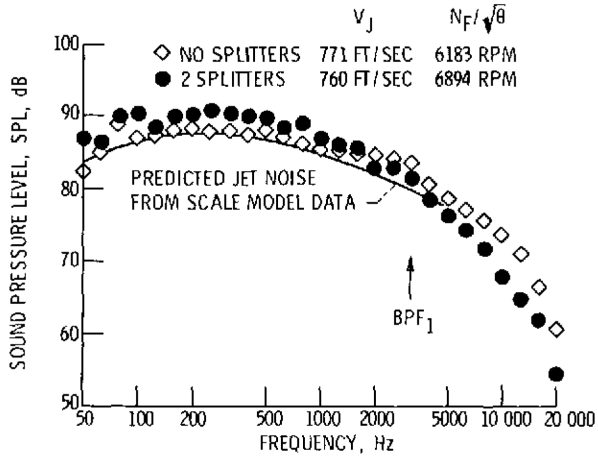


Figure 12. - Comparison of 100 foot 1/3 octave band spectra for suppressed engine with and without aft fan duct splitters.

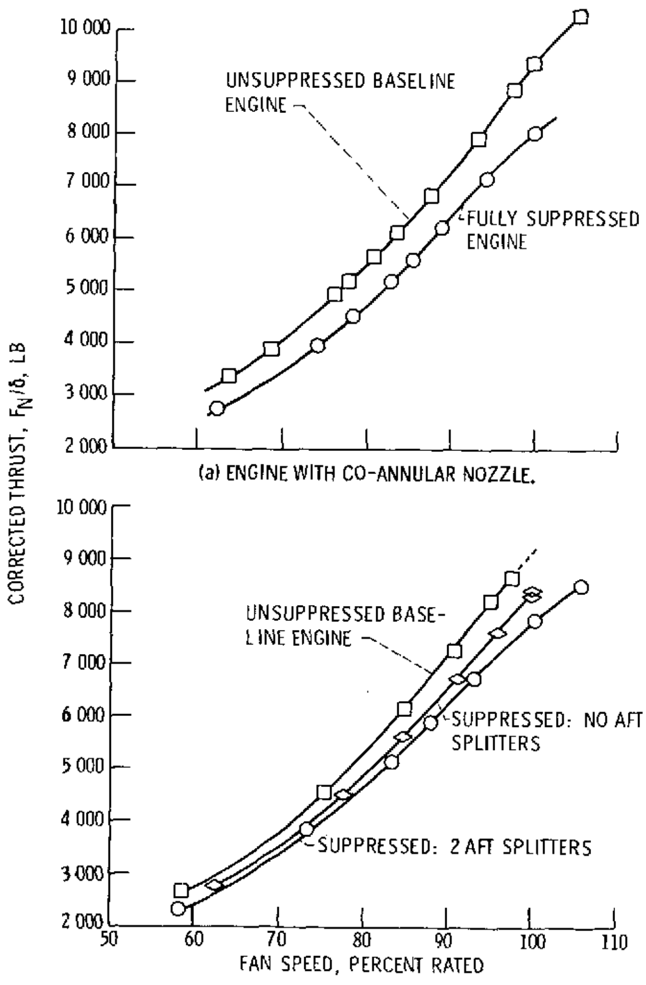


Figure 13. - Engine thrust loss due to suppressed nacelle.

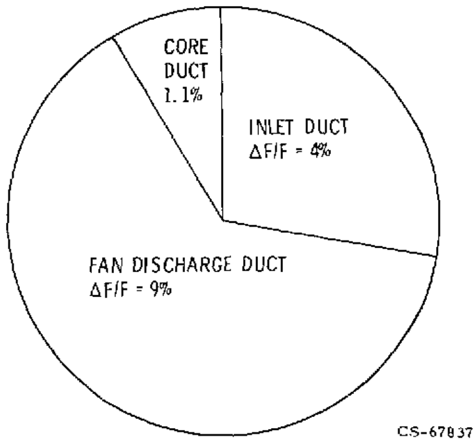


Figure 14. - Estimated thrust loss breakdown obtained from measured pressure losses in treated engine ducts. Total thrust loss, 14.1 (co-annular exhaust nozzle).

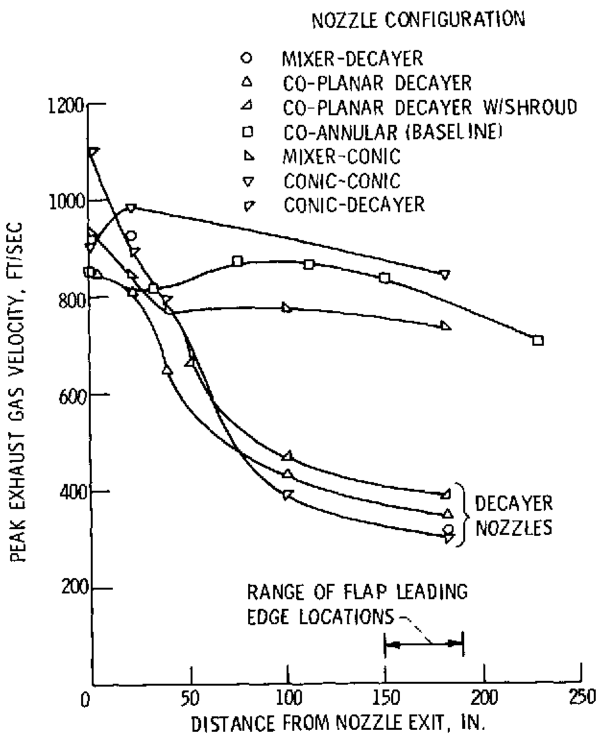


Figure 15. - Velocity decay characteristics of exhaust nozzle configurations for fully suppressed engine at rated power.

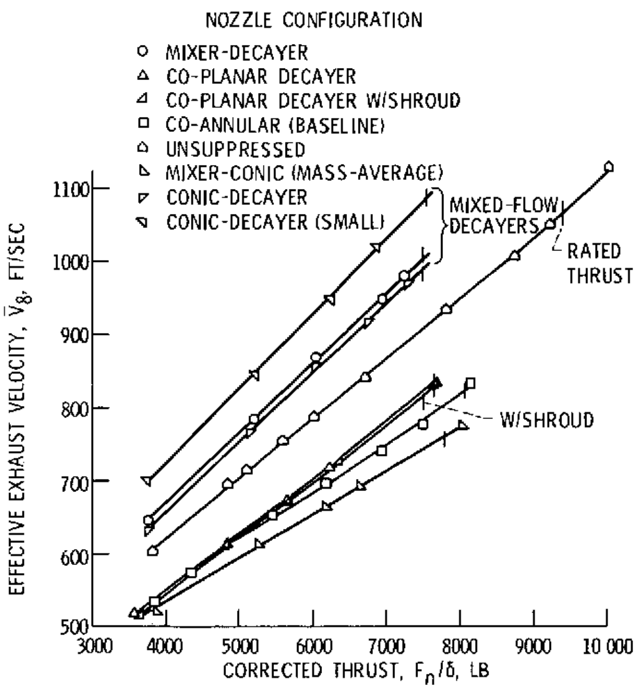


Figure 16. - Exhaust nozzle velocity comparisons.

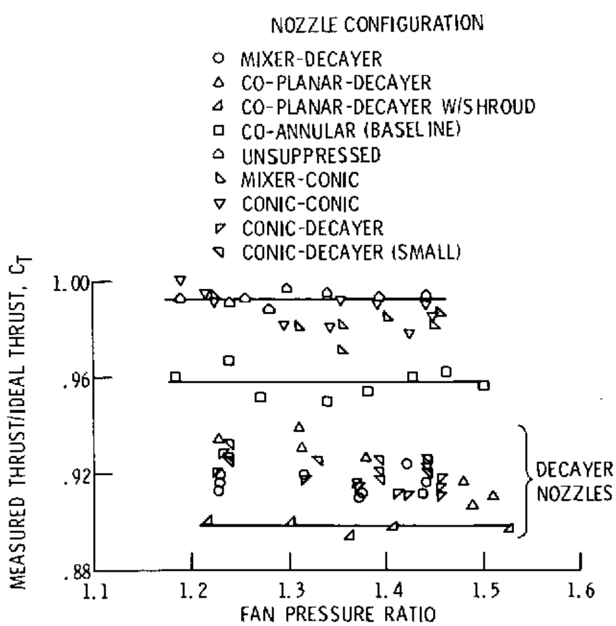


Figure 17. - Exhaust nozzle efficiency.

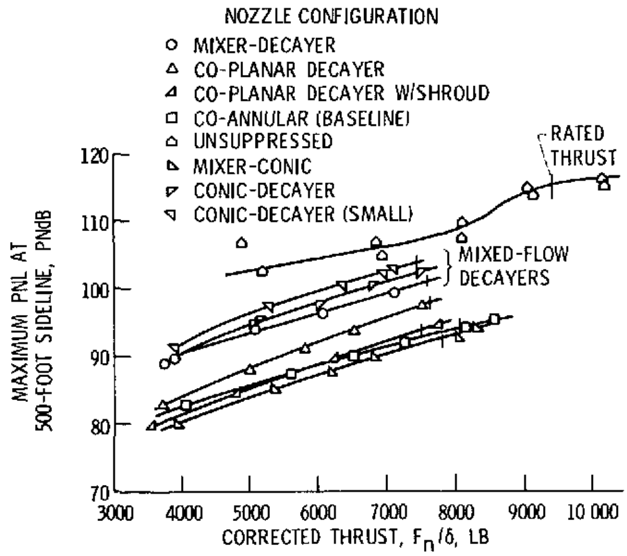


Figure 18. - TF34 noise comparison, engine alone.

CONFIGURATION	x, IN.	y, IN.	z, IN. 0-20-40° FLAPS	z, IN. 15-35-55° FLAPS
MIXER-DECAYER	0	-45	183	165
CO-PLANAR DECAYER	0	-45	183	165
CO-PLANAR DECAYER W/SHROUD	0	-57	192	172
CO-ANNULAR (BASELINE)	-12	-41	168	150
MIXER-CONIC	-12	-41	168	150

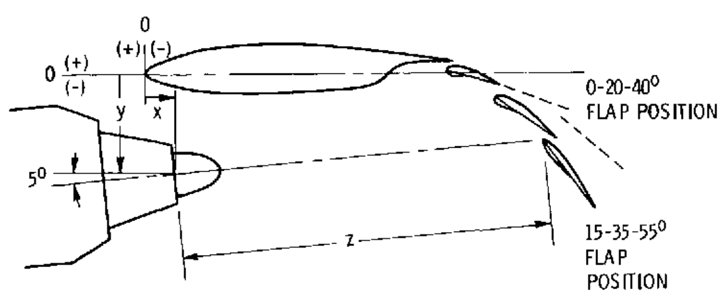


Figure 19. - Exhaust nozzle - wing orientation

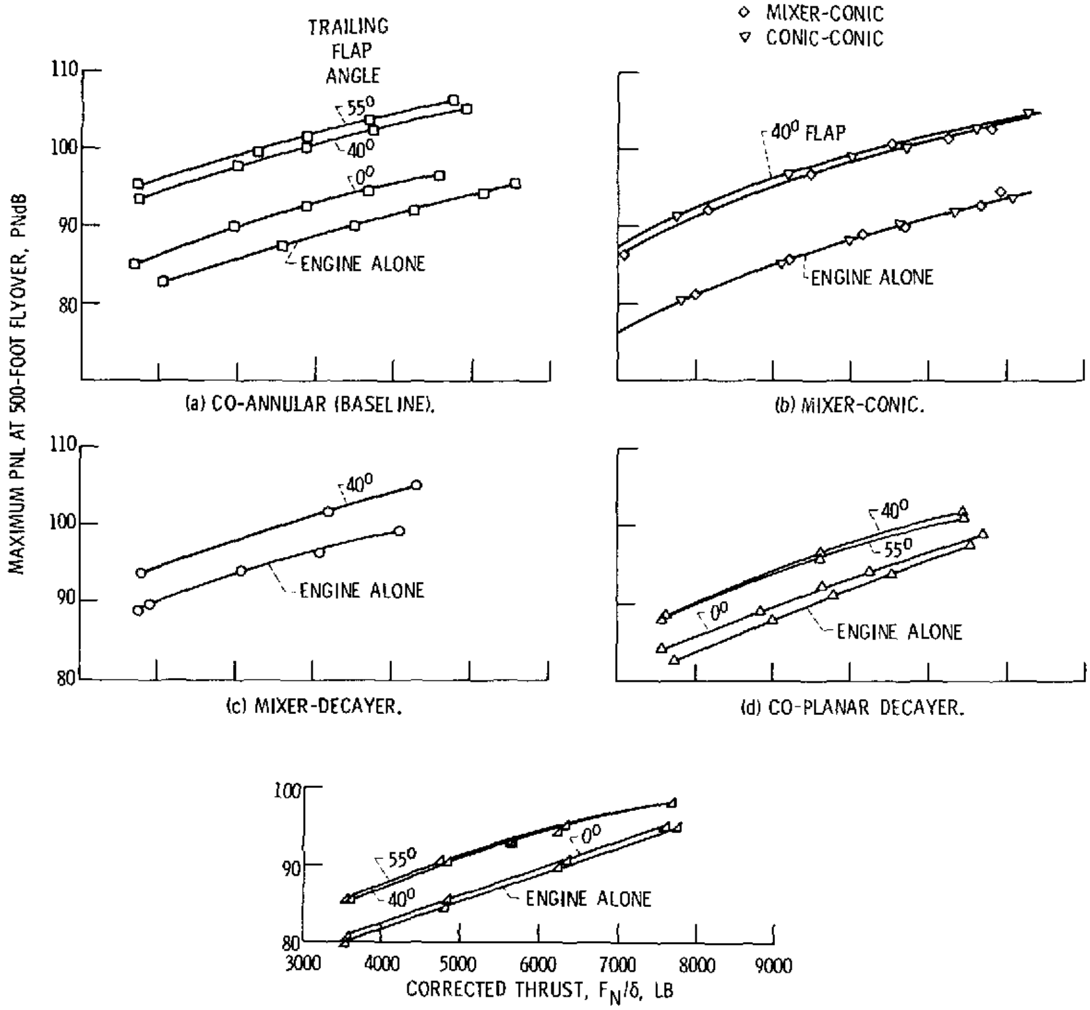


Figure 20. - Maximum perceived noise for EBF-UTW configurations (nozzle configurations of fig. 4; orientation of fig. 19).

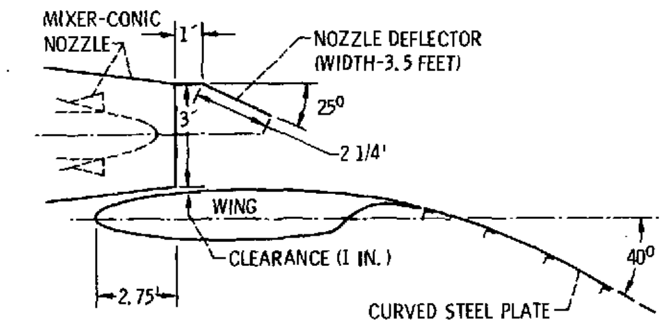


Figure 21. - OTW exhaust nozzle and wing orientation.

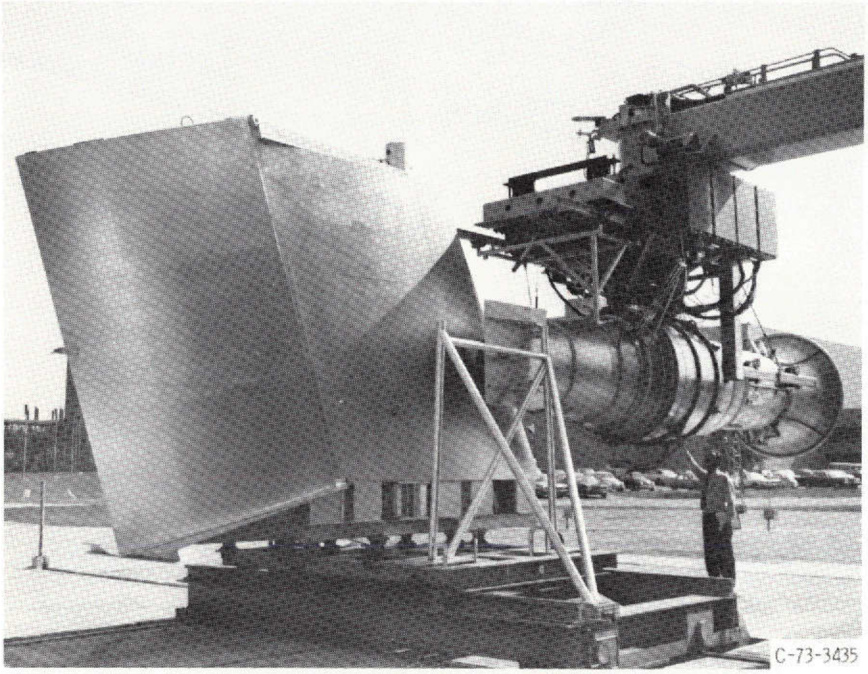


Figure 22. - Setup for engine EBF OTW test.

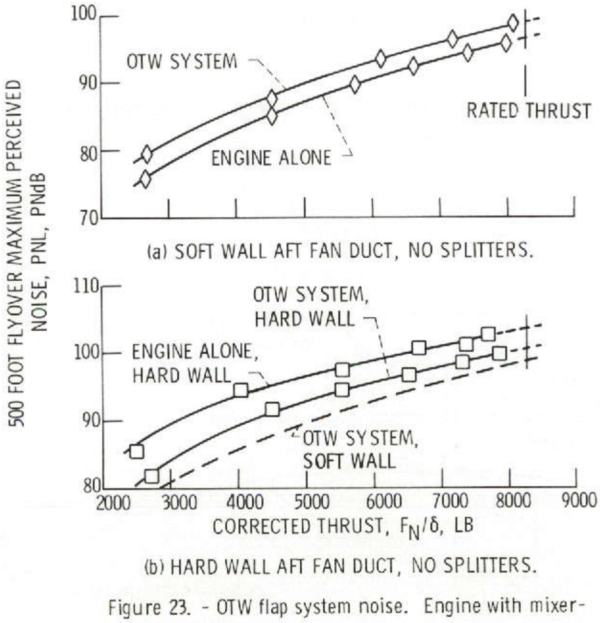


Figure 23. - OTW flap system noise. Engine with mixer-conic nozzle.

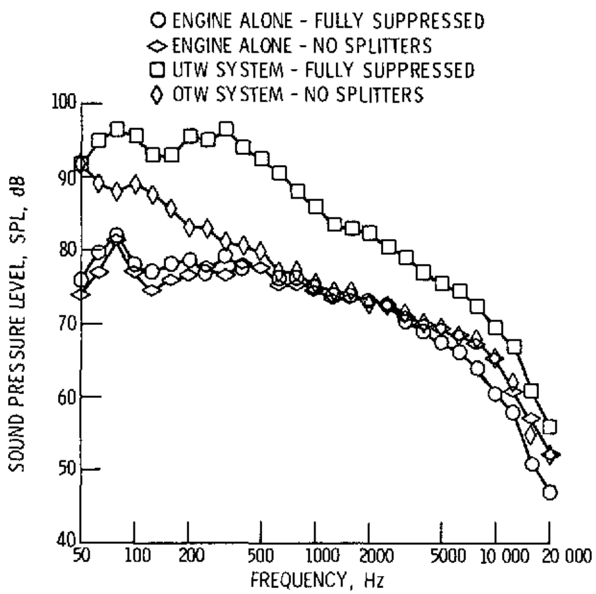


Figure 24. - Comparison of 100 foot 1/3 octave spectra for engine alone and EBF configurations (90° from inlet).

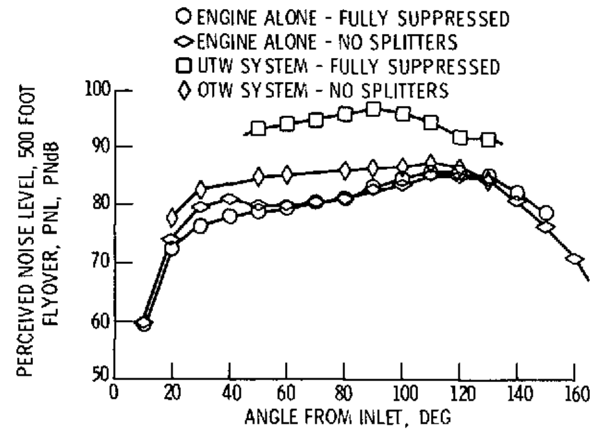


Figure 25. - Noise directivity comparison, engine alone and engine with EBF configurations, V_j = 635 ft/sec.

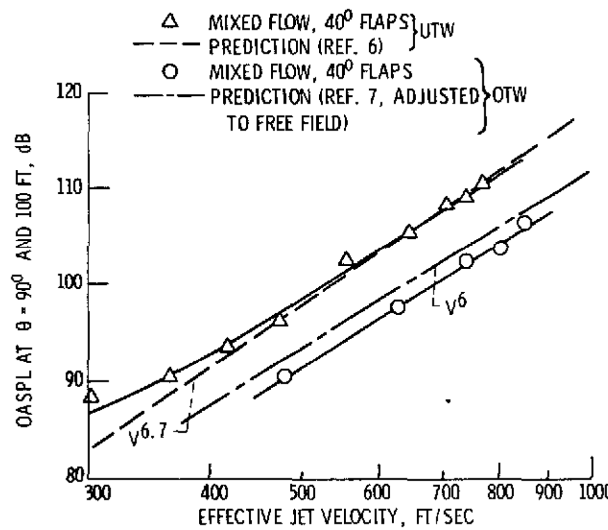


Figure 26. - Comparison of measured and predicted flap noise.