77-833

Technology Status of Jet Noise Suppression Concepts for Advanced Supersonic Transports

W.T. Rowe,* E.S. Johnson,† and R.A. McKinnon‡
McDonnell Douglas Corporation, Long Beach, Calif.

In conducting technology studies for advanced supersonic transports, Douglas Aircraft Company of the McDonnell Douglas Corporation has found that the constraints of community noise dictate the engine cycle selection and nozzle design, and significantly affect the overall airplane configuration design. Since selection and development of an engine is probably the pacing item in any new program start, much activity is underway on definition of engine cycles, provisions for jet exhaust noise suppression, levels of suppression achievable, and the impact of each possible combination on overall airplane performance and technical risk. This paper presents one aircraft manufacturer's views on the technology status of three of the most promising exhaust nozzle designs meeting the noise constraints: the coannular, the coannular with plug, and the retractable mechanical suppressor. Each type is defined along with predicted operational characteristics. Theoretical and actual test performance, for both thrust loss and noise suppression, are summarized. Each of these three nozzles is combined with an appropriate engine, and is sized and integrated into a baseline Mach 2.2 supersonic transport to evaluate range performance. The current status of performance for the various suppression concepts is summarized.

Introduction

THIS paper includes the status of noise suppression concepts for advanced supersonic transports and recently completed propulsion airframe integration work at Douglas, based upon efforts sponsored by NASA-Langley, NASA-Lewis, and Company research.[1-3] The engine data for the turbojet are from a Douglas-defined cycle deck, based upon early General Electric (GE) data from the GE-4 engine. The engine data for the duct-heating turbofan and variable cycle engines are from Pratt & Whitney Aircraft (P&WA) and GE resulting from the NASA-Lewis study contracts.[2,3] The mechanical jet noise suppression data are based on estimates or small-scale testing sponsored by Douglas with support from Rolls-Royce. The coannular noise suppression data are from testing sponsored by NASA-Lewis.

Noise Suppression Background

During the last phase of the former U.S. SST program it was recognized that noise suppression would be required to provide an acceptable SST for operation at the major world airports. In 1969 the U.S. issued the initial regulation for noise certification of new subsonic aircraft designs, FAR Part 36. Later, in 1971, the International Civil Aviation Organization (ICAO) issued Annex 16. These regulations are recognized throughout the world as standards for noise requirements. Both define and employ the effective perceived noise level (EPNL), in EPNdB as the unit of measurement. Three discrete points are used. At each point a maximum permissible level of 108 EPNdB has been established for four-engined aircraft with maximum takeoff gross weights greater than 600,000 lb. Both regulations provide some tolerance whereby an overage at one point may be offset by an underrun at another point. The maximum deviation is set at 2 EPNdB by FAR Part 36 and ICAO Annex 16.

Presented as Paper 77-833 at the AIAA/SAE 13th Propulsion Conference, Orlando, Fla., July 11-13, 1977; submitted Aug. 26, 1977; revision received July 27, 1978.

Index categories: Noise; Airbreathing Propulsion; Environmental Effects.

*Technical Manager, Advanced Supersonic Transports. Member AIAA.
†Power Plant AST Technical Manager.
‡Acoustics AST Project Engineer. Member AIAA.

The engine source noises dominate the noise signature for the advanced supersonic transport (AST) designs studied, but at the approach flight condition nonpropulsive noise generated by an airframe with a wing of 10,000 ft^2 area could become a significant contributor to the overall noise level.[4] Turbojet engines, such as the GE-4 (former SST) and the Olympus 593 (Concorde), have noise signatures dominated by jet noise and produce unsuppressed noise characteristics such as shown in Fig. 1. It is apparent that for the higher jet exhaust velocities required for the takeoff operation, sideline noise levels above 108 EPNdB result unless suppression techniques are employed to reduce the jet noise. If the engines are simply throttled to obtain a low jet exhaust velocity as a way to reach 108 EPNdB at the sideline, the field length requirement becomes unacceptable or the engines must be oversized. This latter solution has been found to be very costly and inefficient as described in Ref. 5.

During the period from 1971 to 1975, DOT and NASA sponsored considerable research on jet noise suppression, most of which was on mechanical suppressors. The best results produced the suppression levels shown in Fig. 1. These mechanical suppressor designs penalized the aircraft from thrust loss in the nozzle and the weight of the hardware. Based on recent testing at GE and P&WA under the NASA Supersonic Cruise Aircraft Research (SCAR) program, designs have been identified which potentially can provide inherent suppression at no weight and with minimum performance penalties. These designs utilize coannular suppression and the levels estimated by the engine companies for the best of them are also shown in Fig. 1.

Noise Suppression Concepts

The two exhaust nozzle suppressor concepts noted above are currently under evaluation in combination with three basic engine cycles being studied for advanced supersonic transport applications. These combinations are summarized in the following paragraphs.

Nonaugmented Turbojet Engine / Mechanical Suppressor

The turbojet cycle is a candidate should a near-term advanced supersonic transport program be initiated, since the advanced technology engines studied could not be ready for initiation of design until the 1985 to 1990 time period.

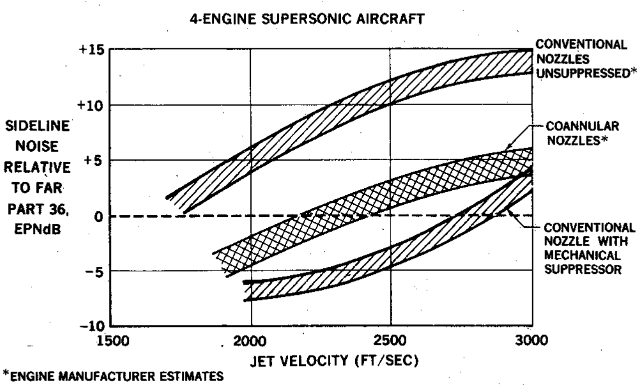

Fig. 1 Noise suppression comparisons.

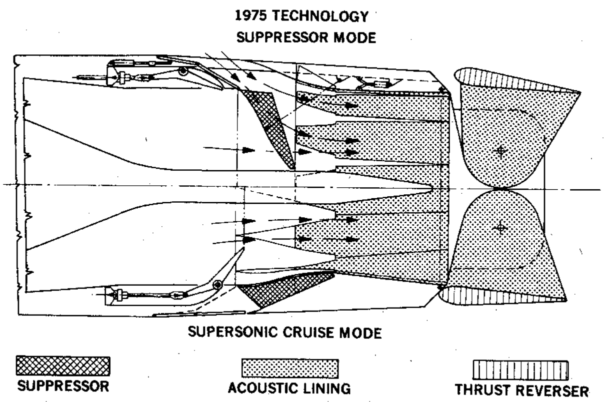

Fig. 2 MDC baseline turbojet/mechanical suppressor nozzle.

Douglas defined a nonaugmented turbojet based on the GE-4 engine of the last U.S. SST program but modified to optimize for a Mach 2.2 cruise speed. Weights and dimensions reflect a 1975 go-ahead level of technology. This engine has been used as a reference for evaluating potential improvements.

The convergent-divergent nozzle required for cruise for this reference engine is shown in the lower part of Fig. 2. The mechanical suppressor can be completely retracted within the ejector shroud. The takeoff configuration is depicted in the upper part of the figure. For jet noise suppression, the mechanical suppressor is deployed into the exhaust stream and ejector doors are opened to induce outside air into the mixer nozzle providing early mixing of the two flows. The inner walls aft of the ejector inlet are lined with acoustic material to suppress the high-frequency noise generated by the mixer nozzle. The suppressor reflects a design philosophy that emphasizes propulsive efficiency, while meeting all design installation requirements, and does not expand the basic nacelle envelope. The design accounts for all flight requirements for the nozzle and includes a thrust reverser, which is shown with a small deflection in the suppresor mode. This shapes the nozzle to produce additional noise suppression as demonstrated by the Concorde.

Double Bypass Variable Cycle Engine/Coannular Suppression

This engine is a low-bypass ratio (0.35) turbojet design which has been defined by GE under the NASA-sponsored Advanced Technology Engine Program. It is based upon materials and performance technologies that are projected to be available in 1985 go-ahead which implies initial operation of civil advanced supersonic transports about 1992. The basic engine nozzle as shown in Fig. 3 is a convergent-divergent plug-type design that incorporates a translating shroud, a translating plug, and a thrust reverser (not shown).

Suppression is obtained by ducting the lower velocity bypass air through struts to the inner stream and allowing the higher velocity core stream to flow through the outer stream.

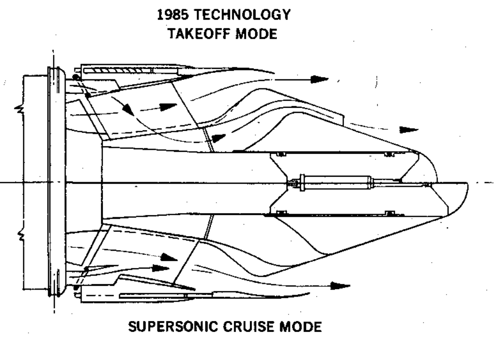

Fig. 3 GE double bypass/dual cycle nozzle.

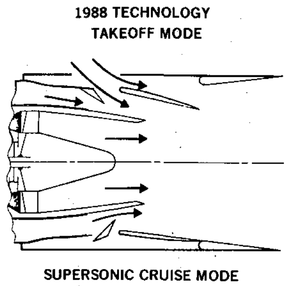

Fig. 4 P&WA variable stream control nozzle.

This provides the inverted velocity ratio required for coannular noise suppression. The design provides for an optional low-temperature augmentor which can be incorporated in the outer duct (not shown). If required, additional noise suppression could be provided by deploying a mechanical suppressor in the outer stream. The suppressor would be retracted into the plug when not in use. The variable-area bypass injector closes off the inner stream and mixes the bypass air with the core flow for efficient supersonic cruise operation.

Variable Stream Control Engine/Coannular Suppression

This engine is a duct-heating turbofan which has been defined by P&WA under the NASA-sponsored Advanced Technology Engine Program. It is based upon materials and performance technologies projected to be available in the 1988 time period which implies initial commercial operations in 1995. The design is a two-stream concept with duct burning for takeoff, climb, and supersonic cruise. The exhaust system as shown in Fig.4 is an ejector type which contains variable nozzles, ejector doors, and a thrust reverser (not shown). The inherent coannular noise suppression is obtained by increasing the velocity of the outer stream (by burning) and reducing the inner stream (by throttling) so that the inverted velocity ratio shown in Fig. 5 can be obtained.

Status of Suppression Development

A significant amount of testing and development has been completed on mechanical suppressor concepts in the years following the demise of the former U.S. SST. However, no specific design has been developed, integrated with an engine, and validated for forward flight effects. Current emphasis and testing by NASA and the major U.S. engine companies is on the promising developments of the coannular nozzles which provide inherent noise suppression, low-thrust losses, simplicity, and light weight. GE and P&WA have test programs underway to validate these concepts as applied to their specific advanced technology engine cycles. Douglas continues to analyze and refine airplane designs that utilize these concepts. Douglas also continues to stress the need for work on mechanical suppressors. The effort includes conducting scale model development tests for determination of propulsion and acoustic performance as a backup for coannular suppression for the following reasons.

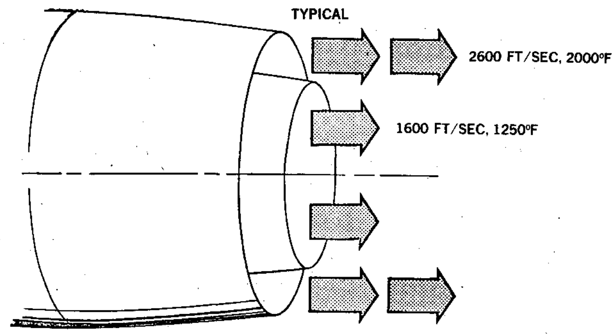

Fig. 5 Coannular nozzle exhaust conditions low-noise takeoff.

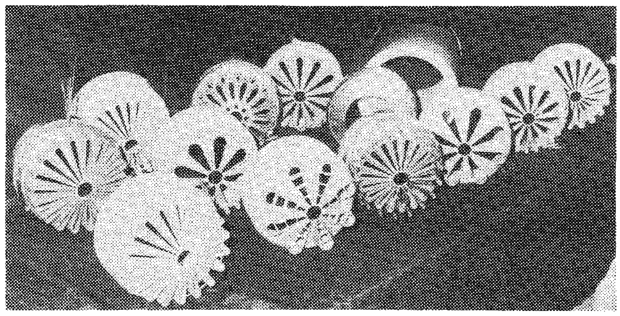

Fig. 6 MDC AST jet noise suppressor test nozzles.

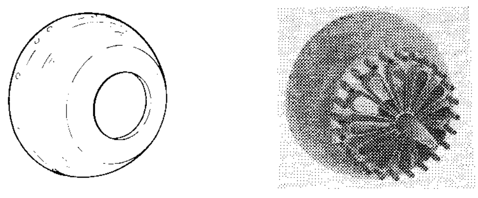

Fig. 7 Reference and mixer nozzles for nozzle/suppressor/reverser design of MDC baseline.

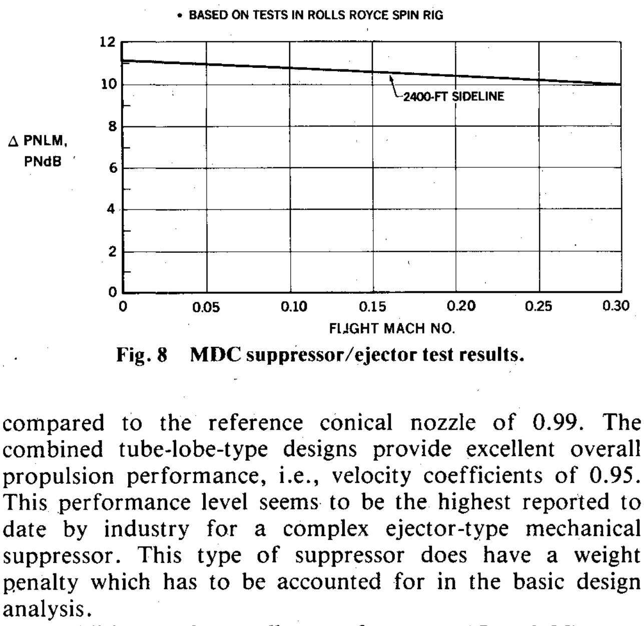

Fig. 8 MDC suppressor/ejector test results.

1) Mechanical suppressors, while heavier and difficult to design, offer less technical risk than do coannular designs. (For a near-term advanced supersonic transport this could be very important.)

2) Mechanical suppression jet noise signatures result in greater attenuation with distance offering improved far-field community noise levels for aircraft designed to just meet FAR Part 36 at the measuring points.[6]

3) Most advanced technology engines designed to utilize coannular jet noise suppression, because of increased exhaust velocities, seem to be marginal without some degree of mechanical jet noise suppression.

4) The inherent jet noise suppression of coannular nozzles, measured statically, has not been satisfactorily demonstrated at simulated or forward flight speeds.

The efforts of Douglas in developing a mechanical jet noise suppressor concept are described followed by a discussion of the coannular nozzles being developed by GE and P&WA.

Mechanical Suppressor

In the design studies initiated in 1973, Douglas defined an exhaust nozzle system for the reference dry turbojet engine. The exhaust nozzle system (Fig.2) is required to function as a variable-area nozzle, thrust reverser, and jet noise suppressor within the installation constraints of the selected nacelle. Optimum aerodynamic nozzle performance at cruise was established as a firm requirement and convergent-divergent elements required to meet this goal were defined prior to the definition of the noise suppressor. The final suppressor design selected consists of a deployable lobe-type mixer located at the primary throat and an acoustically treated shroud. The shroud is needed for satisfactory internal and external nozzle performance, and acoustic treatment is added for suppression of the high-frequency jet noise sources generated near the mixer exit.

A review and analysis of previous suppressor designs was conducted prior to initiation of a hardware development program. An analytical procedure to assess the ventilation capabilities of various suppressor designs was derived. Ventilation is defined as the induction of secondary air into the mixing zone of the suppressor to reduce the jet velocity of the primary gas flow. The analytical procedure determines the amount of secondary air flow blockage caused by the location and size of the mixing elements. The possibility of flow restriction or separation is estimated based on empirically determined limits. In this manner, each mixer concept can be assessed and rated.

The mechanical jet noise suppressor program was initiated with testing to screen several of the lobe-type mixers which showed promise from the design analysis. Twelve 15% scale nozzles including a reference 6-in. conical nozzle (Fig. 6) were designed, fabricated, and tested for propulsion performance. The 8-lobe and 12-lobe daisy nozzles were included to establish a base for reference to previous test results obtained in the DC-8 development program. Performance results for the nozzles at a simulated freestream Mach number of 0.3 show velocity coefficients from 0.92 to 0.95. These can be compared to the reference conical nozzle of 0.99. The combined tube-lobe-type designs provide excellent overall propulsion performance, i.e., velocity coefficients of 0.95. This performance level seems to be the highest reported to date by industry for a complex ejector-type mechanical suppressor. This type of suppressor does have a weight penalty which has to be accounted for in the basic design analysis.

In addition to the excellent performance ($C_V = 0.95$) some limited near-field acoustic data indicated that the 24-tube, 12-lobe (24T/12L) configuration also seemed to offer good acoustic performance. This configuration (Fig. 7) was selected, fabricated, and tested in a Company-funded program utilizing the Rolls-Royce spin rig. Rolls-Royce contributed the testing and data reduction. The nozzles tested were a 3-in. equivalent diameter scale model of the suppressor and a reference conical nozzle. Both nozzles were tested alone and in combination with hardwall and acoustically treated ejectors. Static and spinning tests were completed at free stream Mach numbers of 0.3, jet temperatures of 1500°F, and nozzle pressure ratios up to 4.0.

The model scale noise results have been converted to full scale and projected to distances of 1250 and 2400 ft, a typical flyover altitude and slant range sideline, respectively. Peak PNL values for the conical reference nozzle and the suppressor/ejector nozzle have been determined for equal thrust conditions at takeoff and cutback power levels. Spinning data at Mach 0.3 and static data are included. The peak-to-peak PNL suppression levels at takeoff power and the 2400-ft sideline for static and Mach 0.3 simulated flight speed conditions are shown in Fig. 8. The suppression levels attained

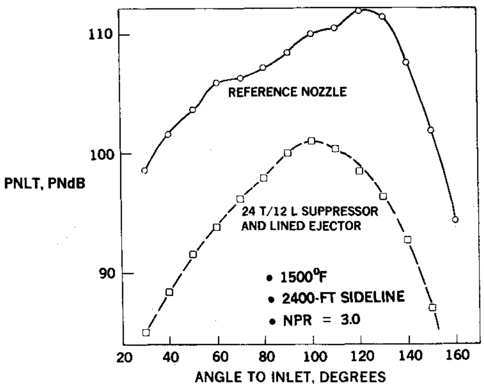

Fig. 9 MDC suppressor/ejector spinning rig test results.

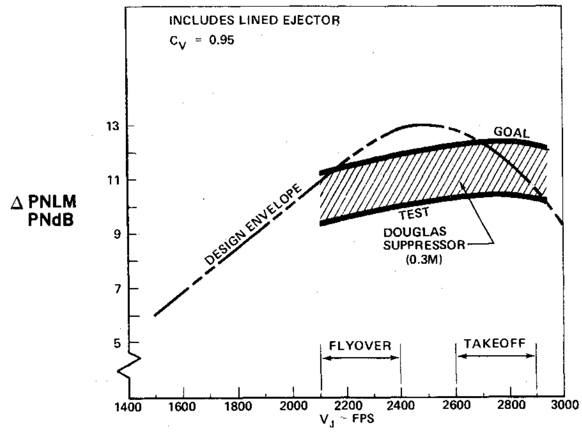

Fig. 10 MDC turbojet suppression data.

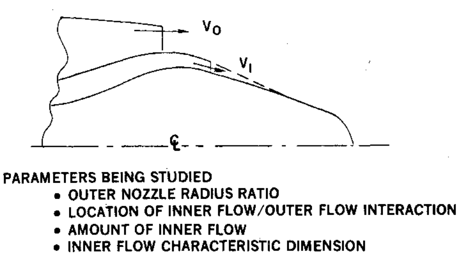

Fig. 11 GE annular nozzle.

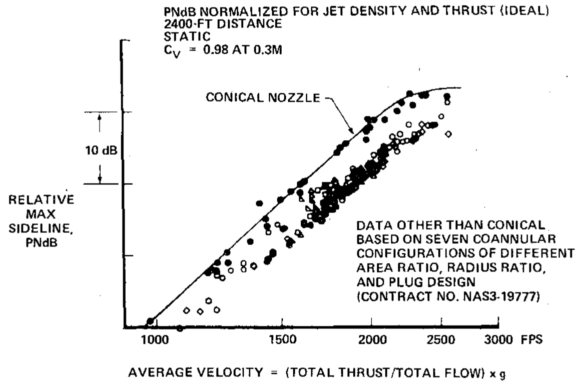

Fig. 12 GE results coannular nozzle maximum perceived noise level (PNdB) correlation.

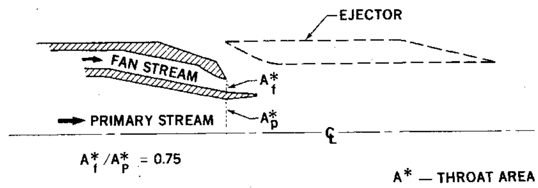

Fig. 13 P&WA coannular nozzle model.

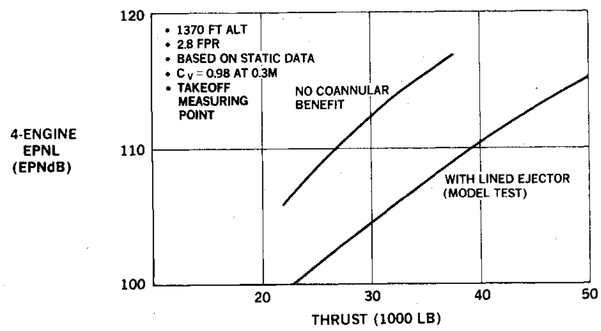

Fig. 14 P&WA suppression results.

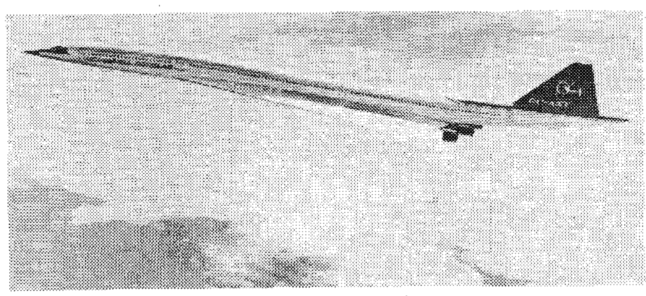

Fig. 15 Advanced supersonic transport.

for the 1250-ft flyover altitude at cutback power are within 0.2 PNdB of the sideline suppression levels.

Typical directivity patterns at the 2400-ft sideline for the circular reference nozzle and the suppressor/ejector nozzle operating at a nozzle pressure ratio of 3.0 and 1500°F gas temperature are shown in Fig. 9. Similar directivity patterns are achieved at all pressure ratios with the 1500°F gas temperature condition. In addition, static and spinning directivity patterns are very similar. The shift in the peak from 120 deg for the reference nozzle to 100 deg for the suppressor/ejector nozzle is consistent with previous industry test results.

To relate the test data to the airplane design, Fig. 10 is presented. The actual test data (corrected for scale factor) vs exhaust velocity (V_J) are shown. The +2 dB (labeled goal) is an estimate of the improvements possible due to scale effects and design refinements for a full-scale suppressor. Also shown in the figure is the suppressor design envelope which was originally utilized in the baseline engine sizing studies. It is noted that the test level is in excellent agreement with the predicted level and also does not decrease as rapidly at the lower velocities as the prediction.

Additional testing is underway in a cooperative test program with NASA. A 6-in. equivalent diameter suppressor (24T/12L) nozzle and a conical reference nozzle have been fabricated of Inconel and tested in an outdoor static test facility at the NASA-Ames Research Center at nozzle pressure ratios up to 2.7 and gas temperatures up to 1500°F. Tests in the NASA-Ames 40- by 80-ft wind tunnel are scheduled to begin in July 1977. The wind tunnel test results are intended to provide additional confirmation of the results from spin rig tests at Rolls-Royce and help provide information for future design evaluations of mechanical suppressors.

Coannular Plug Nozzle

The advanced technology engines defined by GE for the Douglas engine airframe studies utilize the type of design shown in Fig. 11. The parameters investigated under an FAA/DOT jet noise suppressor test program are shown.[7]

This concept utilizes a plug for supersonic cruise and is not designed to employ a shroud as part of the exhaust system.

Some noise results for various coannular plug nozzle designs are presented in Fig. 12.[7] These static data are from seven coannular configurations tested in the GE anechoic jet noise facility. Aeroperformance testing has also been completed on these models in the NASA 8- by 6-ft wind tunnel. Suppression levels of 5 to 6 PNdB are shown as compared to a mixed-flow circular nozzle. The average velocity coefficient at takeoff for the configuration is predicted to be 0.98 at Mach 0.3.

Coannular Ejector Nozzle

P&WA is developing this configuration (Fig. 13) in conjunction with advanced technology engines. The design does not contain a center plug, but is configured to take advantage of a lined ejector as shown in the sketch. A summary of noise results, based on coannular nozzle static model test data with lined ejector compared to the prediction for a nozzle without coannular benefit, is shown in Fig. 14. The suppression level shown is 8 PNdB. The average velocity coefficient at the takeoff condition is predicted to be 0.98 at Mach 0.3.

Summary Of Three Noise Suppression Designs

The current levels of jet noise suppression are based on estimates and small-scale model test data mostly at static conditions. Extensive development effort is required on all these noise suppression devices. It is important that demonstration at large scale of the effects of forward flight on jet noise suppression levels be accomplished as soon as possible. Engine selection cannot be accomplished until this is done as engine development is undoubtedly the pacing item for any improved and environmentally acceptable advanced supersonic transport.

Design Integration With Noise Constraints Considered

In determining the impact of a particular suppression device on the community noise level, it is necessary to involve the airplane characteristics such as thrust required, rate of climb, and flightpath for determining the position of the airplane during takeoff and landing. It is therefore necessary to incorporate the jet noise suppression device as a component of the engine and integrate the engine into an airplane. For this paper each of the three suppression devices is identified with a particular engine so that it is only necessary to define an airplane which can provide consistency for the other parameters. Douglas utilizes the baseline airplane design which has been the basis for technology refinement since 1973 (Fig. 15). Some of the important characteristics of the airplane are presented in Table 1. Rationale for the choices of some of the features is as follows:

1) Cruise speed of Mach 2.2 selected on the basis of extensive design and technology studies for point designs ranging in Mach number from 2.0 to 3.2.

Table 1 AST characteristics summary

Gross weight, lb	750,000
Wing area, sq ft	10,000
Planform	arrow wing
Passengers	273
Cruise speed, Mach	2.2
L/D at cruise	9.6
Range, n. m.	5240
Engines	double bypass VCE
SFC at cruise, lb/h/lb thrust	1.29 (installed)
Thrust/engine max, lb	66,700
Noise	FAR part 36
Structural material	70% titanium 30% aluminum
Takeoff field length, ft	10,700
Landing field length, ft	5650

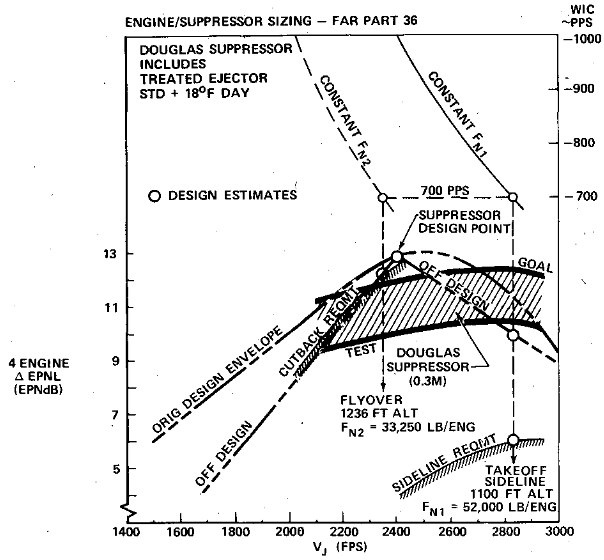

Fig. 16 MDC turbojet sizing.

2) Range of at least 4000 nautical miles to cover more than 80% of the world's overwater nonstop airline routes.

3) Noise constraint of FAR Part 36 or less and using today's airports.

4) An all-metal structural design consistent with initiating a near-term advanced supersonic transport program which can provide commercial service by the mid-1980's.

5) Payloads of 225 to 270 passengers.

Many sophisticated changes have been made to update the Douglas advanced supersonic transport baseline since 1973 as described in Ref. 8. For this paper the evaluation is for the three suppression/engine combinations. Each is integrated in the baseline by detailed analysis. Engine sizing and integration examples are given and performance for the various suppression concepts is summarized.

Initial engine sizing is accomplished as illustrated in Fig. 16. Thrust values at the sideline (F_{N1}) and flyover (F_{N2}) points are known. F_{N1} is 52,000 lb which is the thrust that gives the required field length and F_{N2} is 33,250 lb which is the cutback level to provide the specified climb gradient. These values correspond to specific values of exhaust velocities (V_J) for a given engine design. The size of the engine (defined in terms of airflow W1C) can now be increased and the same value of thrust obtained by throttling (which reduces V_J). This variation is shown by the two curves of constant F_{N1} and F_{N2} for sideline and flyover thrust levels, respectively. Noise levels are calculated at values of V_J corresponding to the constant F_{N1} and F_{N2} curves for the aircraft configuration. These values are converted to required suppression values by subtracting 108 EPNdB at each point and by application of estimated effects of shielding, ground attenuation, and exhaust shaping. The resulting curves are shown as the sideline requirement and cutback requirement curves and correspond to the constant F_{N1} and F_{N2} curves. The estimated suppression available with a mechanical suppressor is shown as a design curve (original design envelope) which encompasses the peak suppression values obtained from tests of many suppressor designs. A specific suppressor design (labeled design point) is selected on the original design envelope and the off-design operating line is established as shown. The design point is selected to best match the two suppression requirements (sideline and flyover) at V_J values corresponding to the different thrust values. The final step is the selection of the smallest engine which satisfies the required suppression values. For the turbojet, a 700-lb/s engine design provides the minimum size solution. The sideline noise is 4 EPNdB lower than the requirement and the flyover noise is the same as the requirement.

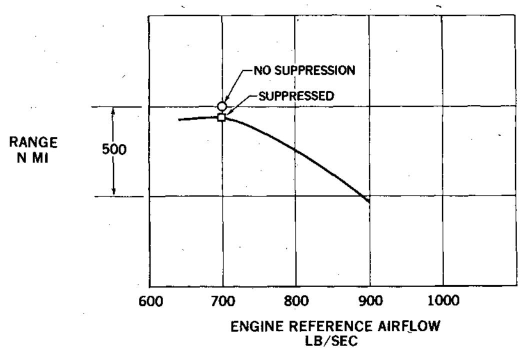

Fig. 17 Turbojet engine/mechanical suppressor.

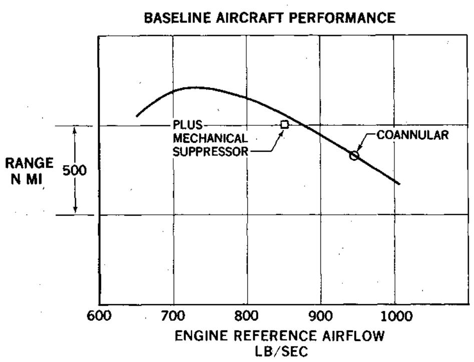

Fig. 18 GE DB/VCE sizing.

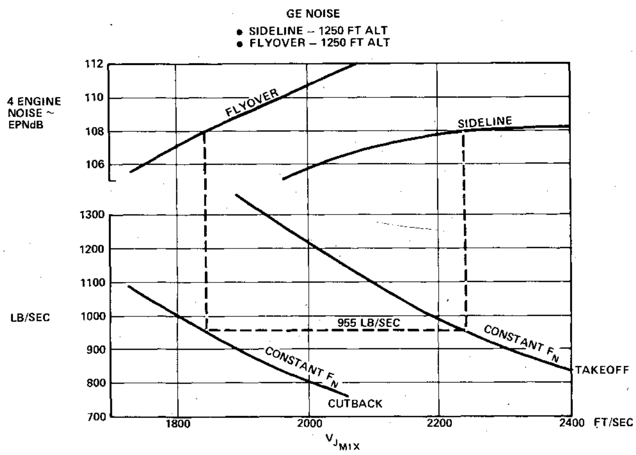

Fig. 19 Double bypass VCE/coannular suppression.

The data from the Rolls-Royce spin rig tests from Fig. 10 are also shown in Fig. 16. The engine size of 700-lb/s is again shown to be a minimum acceptable size. The resulting flyover noise level is the same as the prediction and the sideline is shown to be slightly lower.

This is the engine cycle which has been integrated and refined in the baseline airplane design. Therefore, it is sufficient to state that rigorous structural, aerodynamic, and detail configuration analyses have been completed. The resulting range variation vs engine size is shown in Fig. 17. The 700-lb/s noise constrained engine design also matches maximum range. As pointed out earlier the weight of the suppressor has to be accounted for in the detail design. For this case the suppressor weight reduces the range by 40 nautical miles.

Double Bypass VCE/Coannular-Integration

Initial engine sizing, due to consistent field length requirements, is as shown in Fig. 18 for the same takeoff and cutback thrust levels used for the baseline turbojet con-

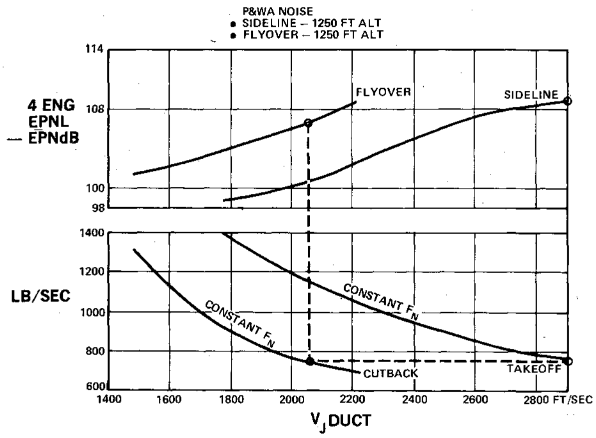

Fig. 20 P&WA VSCE sizing.

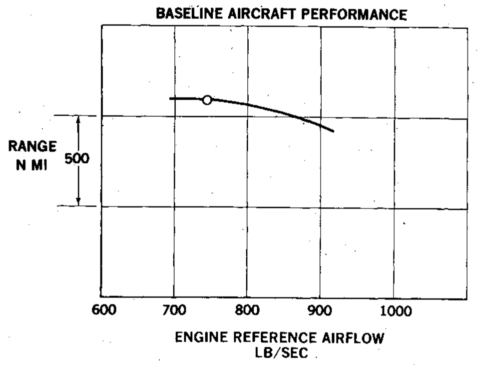

Fig. 21 Variable stream control engine/coannular suppression.

figuration. The total suppressed noise values (including installation effects) are plotted as a function of the mixed exhaust gas velocity ($V_{J\mathrm{mix}}$). The engine size is selected to be the minimum to provide FAR Part 36 or lower noise levels. For this design, however, an engine size of 955 lb/s results.

Integration of this configuration results in a slight improvement in cruise efficiency ($\Delta L/D$ max of 0.25) and a weight saving of 7700 lb as compared to the turbojet. The resulting range variation vs engine size is shown in Fig. 19. Since the 955 lb/s engine size does not represent a thrust-limited engine, it is advantageous to add a mechanical suppressor. The result is that a thrust-limited engine size of 850 lb/s becomes the minimum size engine. Increased range results from this engine concept as compared to the reference turbojet.

Variable Control Engine Coannular-Integration

Initial engine sizing is as shown in Fig. 20 for the same takeoff and cutback thrust levels used for the turbojet configuration. The total suppressed noise values (including installation effects) are plotted as a function of the mixed exhaust gas velocity ($V_{J\mathrm{mix}}$). Engine size is selected to be the minimum to provide FAR Part 36 or lower noise levels. An engine size of 755 lb/s results, which is the minimum size to meet takeoff thrust and noise requirements.

Integration of this configuration also results in a slight improvement in cruise efficiency ($\Delta L/D$ max of 0.25) and a significant weight saving of 19,000 lb as compared to the turbojet. The resulting range variation vs engine size is shown in Fig. 21. Increased range also results from this engine concept as compared to the reference turbojet.

Summary

Based on detail design evaluations and model testing, the current status for engine suppression concepts is summarized

Table 2 Engine suppression concepts summary

	MDC turbojet	P&WA VSCE	GE DB/VCE
Type of suppression	mechanical	coannular	annular
Suppression capability (4-eng.)			
sideline, EPNdB	15	8	6
flyover, EPNdB	12	8	6
Takeoff C_V (0.3M)	0.95	0.98	0.98
Cruise ΔC_V	0	0	0
Weight increase of mechanical suppressor	4-5% of eng. wt.	0	0

in Table 2. The suppression of the mechanical suppressor is 15 EPNdB which includes a 3.0 EPNdB value for exhaust shaping (as demonstrated by the Concorde, see Ref. 9).

Conclusions

The following conclusions are based on data included herein and on previous studies and are presented as the authors' opinions:

1) Validation of suppression levels for all concepts at large scale and forward flight velocities is required.

2) The engine cycle selection will dictate the suppression technique to be used.

3) Mechanical suppressors have earlier availability.

4) Mechanical suppressors offer the least management risk and are more flexible for variations in demonstrated noise and changes in noise criteria.

5) Coannular suppression seems applicable only to variable cycle engines which are therefore longer term, offer greater range but may be noisier to the community.

6) The timing of the need for a satisfactory advanced supersonic transport will dictate the engine cycle selection. For a go-ahead between now and 1980, a turbojet or a low-bypass Olympus derivative engine would be selected and both would require mechanical suppressors. For a 1985 go-ahead, variable-cycle engines and coannular noise suppression with some degree of mechanical suppression seems optimum. Between 1980 and 1985, the answers are less obvious.

Acknowledgements

The authors wish to acknowledge the contributions of R.D. FitzSimmons, Director of Advanced Supersonic-Transports, McDonnell Douglas, for his valuable suggestions and consultations provided during the preparation of this paper.

References

[1] "Engine/Airframe Compatability Studies for Supersonic Cruise Aircraft," Douglas Aircraft Company, Long Beach Calif., NASA CR-132610, Jan. 1975.

[2] Howlett, R.A. and Streicher, F.D. "Advanced Supersonic Propulsion Study Phase IV Final Report," NASA CR-135273, Sept. 1977.

[3] Allen, R.D. and Joy, W. "Advanced Supersonic Propulsion Study, Phases III and IV—Final Report", NASA CR-135236, Nov. 1977.

[4] Morgan, H.G. and Hardin, J.C. "Airframe Noise—The Next Aircraft Noise Barrier," *Journal of Aircraft*, Vol. 12, July 1975, pp. 622-624.

[5] FitzSimmons, R.D. and Hoover, W.C., "AST—A Fifth Engine for Environmental Consideration," SAE Paper 730899, National Aerospace Engineering and Manufacturing Meeting, Los Angeles, Calif., Oct. 16-18, 1973.

[6] "Aircraft Community Noise Impact Studies," Douglas Aircraft Company, Long Beach Calif., NASA CR-145152, Jan. 1977.

[7] Lee, R., "Coannular Plug Nozzle Noise Reduction and Impact on Exhaust System Designs," NASA CP-001, Proceedings of the SCAR Conference, Langley Research Center, Hampton, Va., Nov. 9-12, 1976.

[8] Rowe, W.T., "Design Feasibility of an Advanced Technology Supersonic Cruise Aircraft," NASA CP-001, Proceedings of the SCAR Conference, Langley Research Center, Hampton, Va., Nov. 9-12, 1976.

[9] "Concorde Noise, a Submission to the Environmental Protection Agency and Federal Aviation Administration," Report No. C636, May 1974.