DESIGN FEASIBILITY OF AN ADVANCED TECHNOLOGY SUPERSONIC CRUISE AIRCRAFT

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SUMMARY

Research and development programs by McDonnell Douglas, including both NASA contracted support and company-funded activities, provide confidence that technology is in-hand to design an economically attractive, environmentally sound supersonic cruise aircraft for mid-1980 world-wide commercial operations. The principal results of studies and tests are described including those which define the selection of significant design features. These typically include the results of (a) wind-tunnel tests, both subsonic and supersonic, (b) propulsion performance and acoustic tests on noise suppressors, including forward-flight effects, (c) studies of engine/airframe integration, which lead to the selection of engine cycles/sizes to meet future market, economic, and social requirements, and (d) structural testing.

INTRODUCTION

For four years, McDonnell Douglas (MDC), with both company funds and NASA contracted support, has been conducting advanced supersonic technology application studies, advanced supersonic technology engine integration studies, and development testing. This effort has been to substantiate that the design of an economically attractive, environmentally sound supersonic cruise aircraft for world-wide commercial operations is feasible for the mid-1980 time period.

Three years ago a conceptual baseline supersonic cruise aircraft was designed to evaluate technology problems. The conclusion is that it is now possible to design an advanced technology transport. The technology remaining to be validated consists of completing concentrated efforts to optimize configuration and to accomplish development testing in time for major program decisions.

MDC is continuing the necessary studies and testing to that extent possible with available funding. This paper summarizes some of the results of the advanced design studies which define significant configuration features, wind-tunnel test results, propulsion performance and acoustic testing of mechanical noise suppressors, structural tests, and engine/airframe integration studies.

SYMBOLS

Al	Aluminum
B	Body (Fuselage)
c.g.	Center of Gravity
C_D	Drag Coefficient
DOC	Direct Operating Costs
FAR Part 36	Federal Aviation Regulation for Noise
H	Horizontal Tail
L/D	Lift-Drag Ratio
$(L/D)_{max}$	Maximum Lift-Drag Ratio
M	Mach Number
SIC	Structural Influence Coefficient
Ti	Titanium
W	Wing
V	Vertical Tail

Technology Evaluation

Four years ago MDC conducted technology assessment studies to determine the feasibility of designing an improved supersonic cruise aircraft. An advanced design team involving the major disciplines (i.e., active controls, aerodynamics, propulsion, structures, materials, acoustics, airport compatibility, economics, etc.) was assigned this task. Analytical tools and experimental data have been used to parametrically derive candidate configurations.

Preliminary designs were completed for configurations at 2.2, 2.7, and 3.2 Mach numbers. These designs included sufficient detail analysis so that the direct operating cost (i.e., overall efficiency) of each design could be determined. The results (fig. 1) show that as the design Mach number increases, the direct operating cost increases rapidly. Also shown is that for an all metal airplane, a mix of titanium and aluminum materials provides the optimum design at the lower Mach numbers and that an all-titanium structure is required to survive the 2.7 M environment. The increase in the relative direct operating cost between the 2.2 and 2.7 Mach cases is 13 percent. The 2.2 Mach cruise region was selected for further technology evaluation and refinement studies. In 1975 the original study was repeated with greater design depth, including material allowables at each Mach number, thermal stresses, consistent aeroelastic constraints, and flutter fixes. Results again validate the 2.2 Mach speed selection as shown in figure 1.

Figure 2 summarizes the results of the advanced design study in terms of technology risk at each Mach number. In the 2.2 Mach region, the majority of the technologies are in the low risk area. This chart depicts the general variation in technology risk, by discipline, as Mach number increases. These relationships are developed from pertinent technical knowledge gained from over twenty-two years of continuous design, development, production and operation of supersonic fighters and test aircraft, including the D-558-II, X-3, F-101, F5D-1, F-4, and F-15. For a new commercial supersonic aircraft, McDonnell Douglas can see no advantages in departing from the low risk 2.2 Mach number type design.

Baseline Definition

To assess the technology, a 2.2 Mach advanced supersonic cruise point design (baseline) airplane has been defined. The target date for initiation of commercial operation was found to be feasible for the mid-1980's. The analysis and detail design integration is of sufficient depth to identify the geometric features, structural arrangement and concepts, materials, acoustic treatment, systems and sub-systems.

Table I shows the characteristics summary for the baseline airplane. The fuselage is sized for 273 passengers with 15 percent first class and 85 percent economy class accommodations. Engines are mini-bypass turbojets with mechanical suppressors, sized for take-off at less than or equal to FAR Part 36 requirements, compatible with the near-term 1986 time period. Examples of advanced technology application are the incorporation of the arrow-type wing with geometry tailored to optimize performance and weight, use of area-ruled fuselage in combination with arrow wing and placement of engines to minimize wave drag, selection of optimum mix of metals and optimization of structural parameters (strength, fail-safe, aeroelastics, and flutter), and incorporation of acoustic treatment to meet environmental requirements. Single nacelles incorporating axisymmetric inlets were selected for this baseline after careful trade-off studies of options such as dual pods and two-dimensional inlets.

AERODYNAMICS

The advanced technology arrow wing is capable of producing significantly higher lift-drag ratios (L/D) than the delta planforms considered for the early supersonic transports (ref. 1). To validate this improved L/D in an integrated configuration, a MDC-NASA cooperative wind-tunnel test program was conducted. Figure 3 shows the model in the Ames test facility. The model was instrumented to obtain force and pressure data simulteneously. Some of the results were published in reference 2 and presented earlier in these proceedings (ref. 3). Figure 4 shows a summary of the test results at 2.2 Mach compared with the design point analysis. Also shown is the revised design goal based on possible improvements identified and the $(L/D)_{max}$ values used for the 2.2 Mach speed study validation. This correlation provides confidence that the analytical methods are sufficiently accurate for the necessary aerodynamic design of an improved supersonic cruise aircraft.

The wind-tunnel program also investigated both external compression and mixed compression inlets as defined in reference 4. Results of an integration study based on the tunnel data are shown in figure 5. The mixed compression inlet provides a 2 percent range improvement and is being adopted as part of the baseline configuration.

Wing-fuselage blending has been studied as applied to the baseline configuration for possible $(L/D)_{max}$ improvement. A blended configuration, which minimizes fuselage volume to the point where a minimally integratable configuration remained, is developed and analyzed. The 2.2 Mach number area-averaged-body area distributions are shown in figure 6 along with a summary of the aerodynamic analysis. The skin friction and wave drag are reduced; however, the larger wing to fuselage fillet results in an increase in the drag due to lift at the cruise lift coefficient. The resulting 1.2 percent improvement in $(L/D)_{max}$ is not as significant as has been reported from delta-wing-fuselage blending results. This occurs because a substantial reduction in peak cross-sectional area cannot be achieved with a carefully designed arrow-wing configuration. Because of the location of the wing main torque box the blending required to achieve integration of the wing spar to fuselage frame structure is aft of the maximum area peak.

In the low speed/high lift area MDC is providing the aerodynamic design for a NASA model as depicted in figure 7. This model is scheduled for testing during 1977 and is expected to provide much valuable aerodynamic data on leading edge devices and flaps.

STRUCTURES AND MATERIALS

To insure a reliable structure for commercial operation, an all-metal aluminum and titanium structure is considered for the near term (1980 go-ahead) design. The baseline materials, distribution of materials and possible construction methods are summarized in figure 8. This concept has recently been validated by another in-depth study. Study details are summarized in reference 5. The conclusion in the structural area is that large-scale technology development of manufacturing and long term testing of the titanium concepts must be initiated immediately in order that results may be available in time to support near-term program decisions.

Current company-funded efforts at MDC consist of fabrication and testing of panels of aluminum brazed titanium honeycomb representative of the wing design as shown in figure 9 and of a typical lower fuselage panel of weld-brazed titanium skin and stringers as shown in figure 10. Unfortunately, these programs are not of sufficient scope to identify the degree of risk such designs pose for selection on a near-term commercial supersonic aircraft.

EXHAUST NOZZLE SUPPRESSOR TESTING

Nozzle/suppressor/reverser configurations have been designed which integrate with the turbojet and mini-bypass turbojet engines. Since noise constraints are so critical to engine sizing and to final engine cycle selection, MDC has concluded that the mechanical suppressor development is a critical backup development item in the technology assessment program. It is recognized that coannular suppression is possible but its development and the applicable variable cycle engine to which it can be adapted is considered to be applicable only to a 1985 go-ahead program which may not be soon enough to match customer demand.

To initiate the validation testing for the nozzle/suppressor, MDC has fabricated 12 separate nozzle designs and has completed the propulsion performance testing. Excellent results have been obtained. One of the nozzles which produced a higher nozzle velocity coefficient than observed from previous test programs is shown in figure 11. Also shown in the figure is a smaller scale version of the same nozzle which is currently in test on the Rolls-Royce spin rig at Filton (fig. 12). This acoustic testing is to measure acoustic results on the spin rig to simulate forward flight effects. Also, additional tests are scheduled for the same design in the NASA Ames 40-foot by 80-foot tunnel during 1977.

ENGINE/AIRFRAME INTEGRATION

McDonnell Douglas has found it necessary to perform a rather detailed integration of the emerging advanced technology engine cycles for possible supersonic cruise vehicle application. Engine sizing for cruise must be carefully balanced with take-off noise constraints. Also, a comparison of uninstalled specific fuel consumption is not realistic as installation losses vary from engine to engine, and more importantly, not all engine cycles optimize cruise at $(L/D)_{max}$.

The procedure used by MDC for engine/airframe integration is outlined in figure 13. Initial sizing is established by FAR Part 36 noise requirements. After engine packaging is complete, a detailed configuration integration is accomplished where tail clearance, landing-gear length, flap clearances, pylon design, and structural and aerodynamic trades are made. The early engine integration work, including the dual valve and the early duct heating turbofan engines, has been reported in reference 6.

Figure 14 presents the detailed model which is used to complete the structural analysis. As shown in the example, for the new engine weight and c.g. location, the analysis calculates the size of each element for five loading conditions and then integrates to determine the wing and fuselage weight change. For those cases where significant changes are identified, a flutter check is included in the analysis.

Table II presents a summary of wave drags for typical configurations to illustrate the depth of detail involved in the aerodynamic analysis.

The final integration results where the candidate engine is evaluated in terms of range improvement are illustrated in figure 15. Range is plotted against engine airflow (engine size) so that the initial engine size can be modified if a larger engine than that sized for noise constraints is shown to provide maximum range. The advanced technology engines provide range improvements as high as 20 percent over the baseline airplane.

CONCLUSION

Design of an advanced supersonic cruise vehicle is now technically feasible. An expanded and accelerated development program to include the items listed in table III is needed to provide a 1980 go-ahead which could provide an operational airline transport by the mid-1980's.

REFERENCES

1. FitzSimmons, R. D.; and Roensch, R. L.: Advanced Supersonic Transport. SAE Paper No. 750617.

2. Radkey, R. L.; Welge, H. R.; and Roensch, R. L.: Aerodynamic Design of a Mach 2.2 Supersonic Cruise Aircraft. AIAA Paper No. 76-955.

3. Roensch, R. L.: Aerodynamic Validation of a SCAR Design. Proceedings of the SCAR Conference, NASA CP-001, 1977. (Paper 8 of this compilation.)

4. Welge, H. R.; and Henne, P. A.: Nacelle Aerodynamic Design and Integration Study on a Mach 2.2 Supersonic Cruise Aircraft. Douglas Paper No. 6461, presented to AIAA/SAE 12th Propulsion Conference, Palo Alto, California, July 1976.

5. Fischler, J. E.: Structural Design of a Supersonic Cruise Aircraft. Proceedings of the SCAR Conference, NASA CP-001, 1977. (Paper 43 of this compilation.)

6. FitzSimmons, R. D.; and Rowe, W. T.: AST Propulsion Comparisons. SAE Paper No. 750631.

TABLE I.- BASELINE CHARACTERISTICS SUMMARY

GROSS WEIGHT — kg (LB)	340,200 (750,000)
WING AREA — m^2 (FT^2)	929 (10,000)
PLANFORM	ARROW WING
PASSENGERS	273
CRUISE SPEED (MACH)	2.2
L/D AT CRUISE	9.6
RANGE — km (N MI)	8500 (4590)
ENGINES	4 MINI-BYPASS TURBOJET*
SFC AT CRUISE — kg/HR/N (LB/HR/LB)	0.138 (1.35) (INSTALLED)
THRUST/ENGINE MAX — N (LB)	332,300 (74,700)
NOISE	< FAR PART 36
STRUCTURAL MATERIAL	70 PERCENT TITANIUM 30 PERCENT ALUMINUM
TAKEOFF FIELD LENGTH — m (FT)	3260 (10,700)
LANDING FIELD LENGTH — m (FT)	1725 (5650)

* ARBITRARY

TABLE II.- EFFECT OF ENGINE ON WAVE DRAG

ENGINE	ZERO LIFT WAVE DRAG ($C_{D_O} \times 10^4$)	CHANGE FROM BASELINE ($\Delta C_{D_O} \times 10^4$)
BASELINE DRY TURBOJET	26.80	—
GENERAL ELECTRIC MINI-BYPASS	23.88	—2.92
PRATT & WHITNEY 502 B	22.30	—4.50
GENERAL ELECTRIC DB/VCE	22.30	—4.50

TABLE III.- RECOMMENDED NASA TECHNOLOGY

TOP PRIORITY ITEMS
2.2 MACH

- INTEGRATED NOZZLE/SUPPRESSOR/REVERSER NOISE AND PROPULSION TESTS
- LARGE SCALE TITANIUM HONEYCOMB TESTS (WING)
- LARGE SCALE TITANIUM STIFFENED SKIN TESTS (FUSELAGE)
- COMPREHENSIVE TESTING OF ARROW WING AERODYNAMICS — CLEAN WING
- LOW SPEED VALIDATION TESTING
- INLET TESTS — PERFORMANCE AND CONTROLS
- ELEVATED TEMPERATURE — TIME TESTING ALUMINUM AND EPOXY COMPOSITES
- *FLUTTER MODEL TESTING*

PLUS
ENGINE TESTS

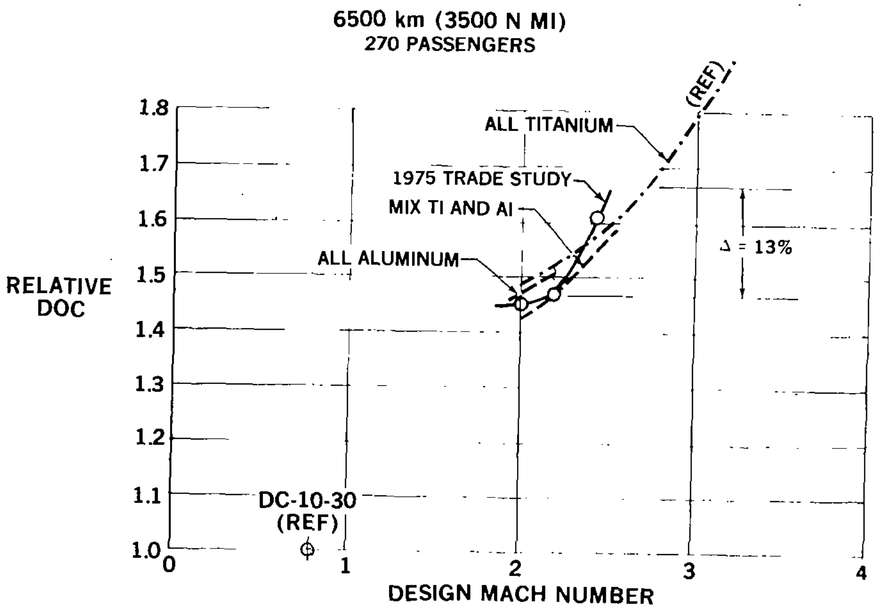


Figure 1.- Effect of design speed on DOC.

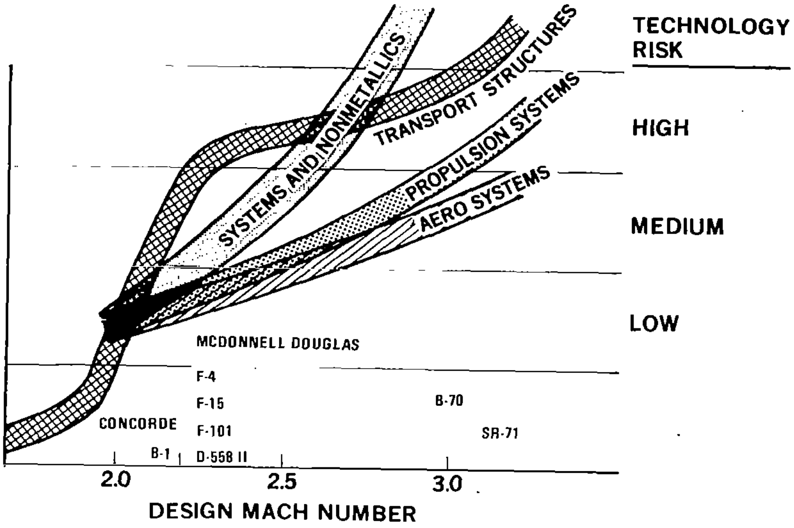


Figure 2.- Technology assessment.

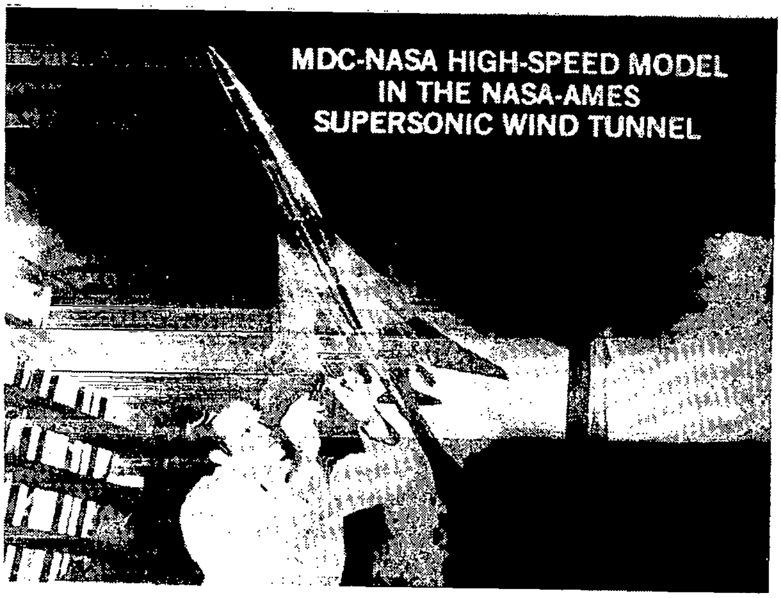


Figure 3.- MDC-NASA high-speed model in the NASA-Ames supersonic wind tunnel.

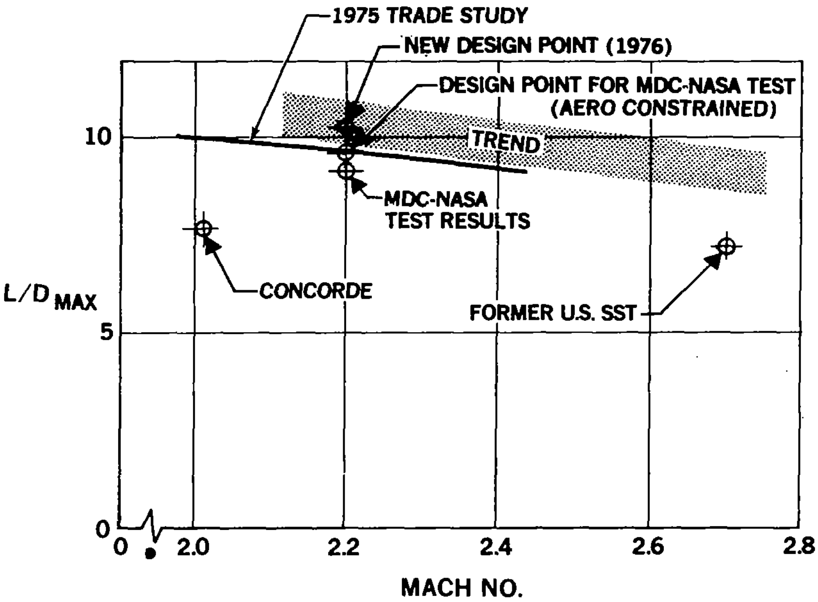


Figure 4.- Aerodynamic efficiency.

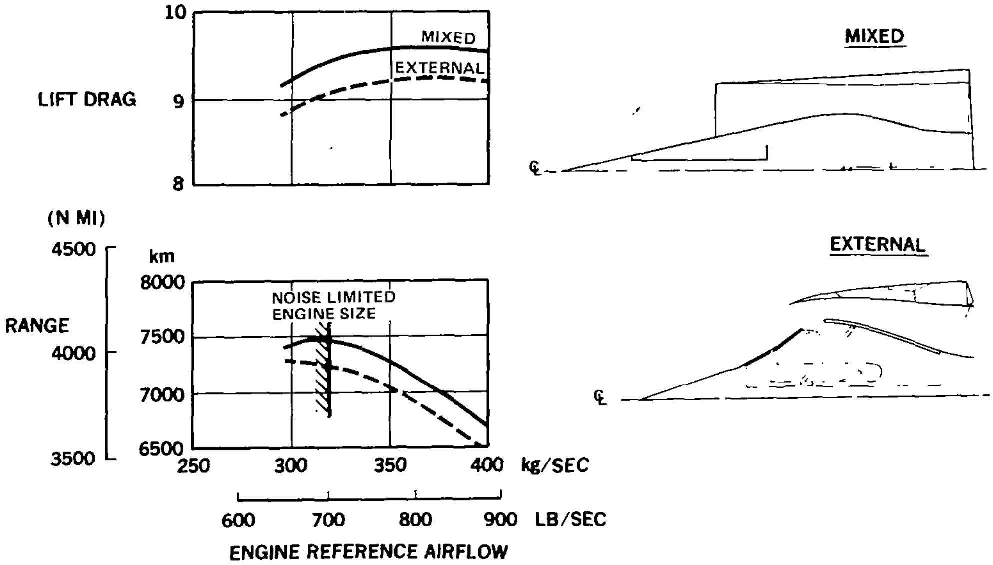
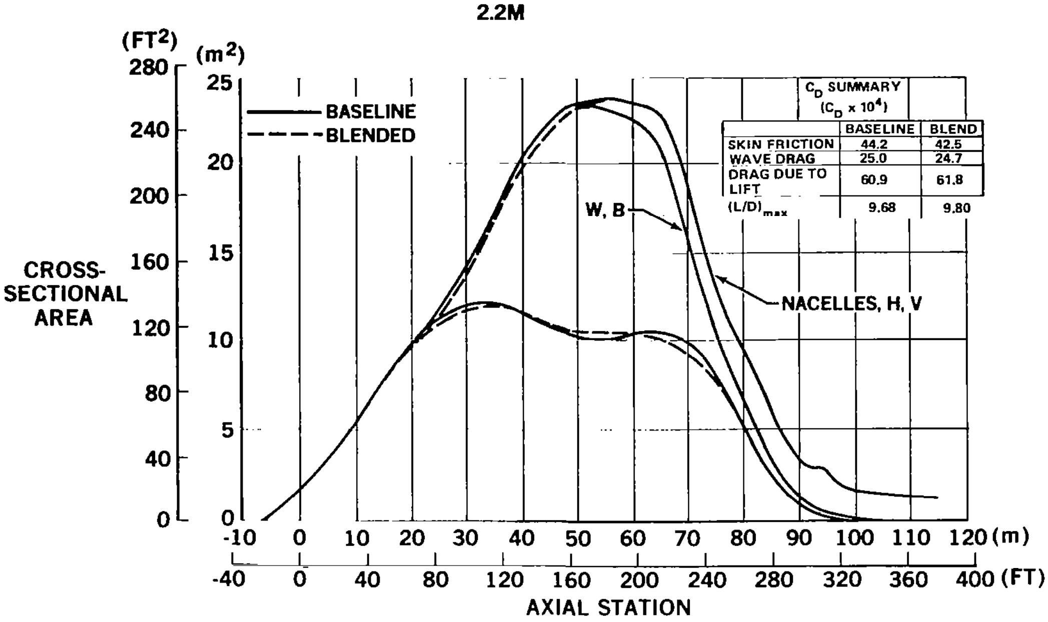


Figure 5.- Effect of mixed and external compression inlets on performance.



C_D SUMMARY
(C_D x 10^4)

	BASELINE	BLEND
SKIN FRICTION	44.2	42.5
WAVE DRAG	25.0	24.7
DRAG DUE TO LIFT	60.9	61.8
$(L/D)_{max}$	9.68	9.80

Figure 6.- Area-averaged-body area distributions.

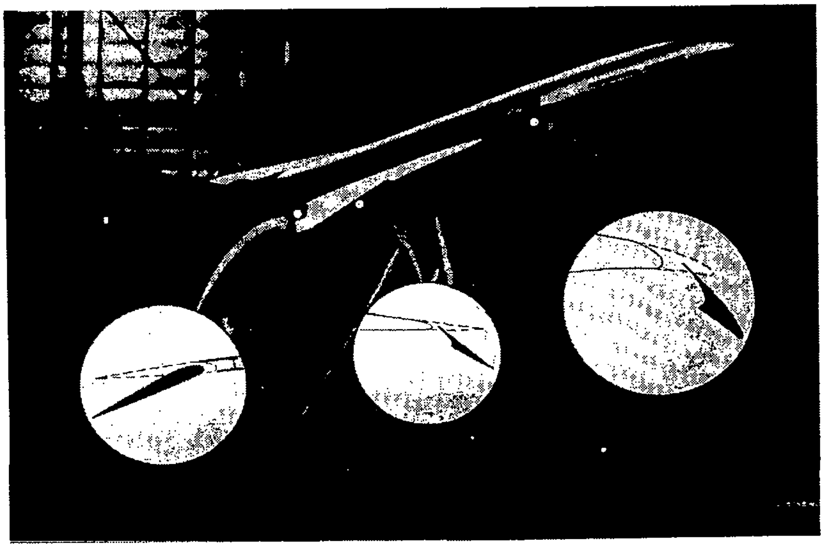


Figure 7.- Artist's rendering of NASA low-speed model.

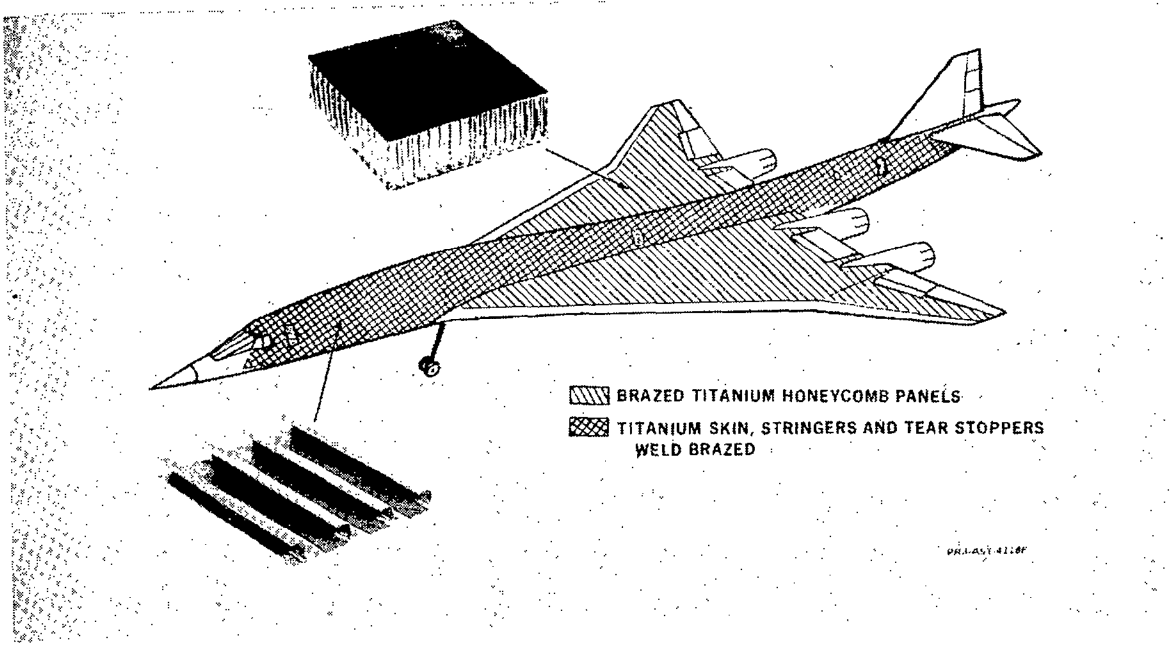


Figure 8.- Baseline materials and constructions.

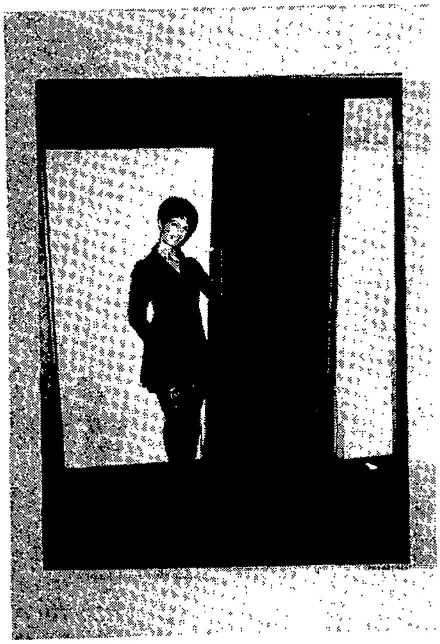


Figure 9.- Aluminum brazed titanium honeycomb panel.

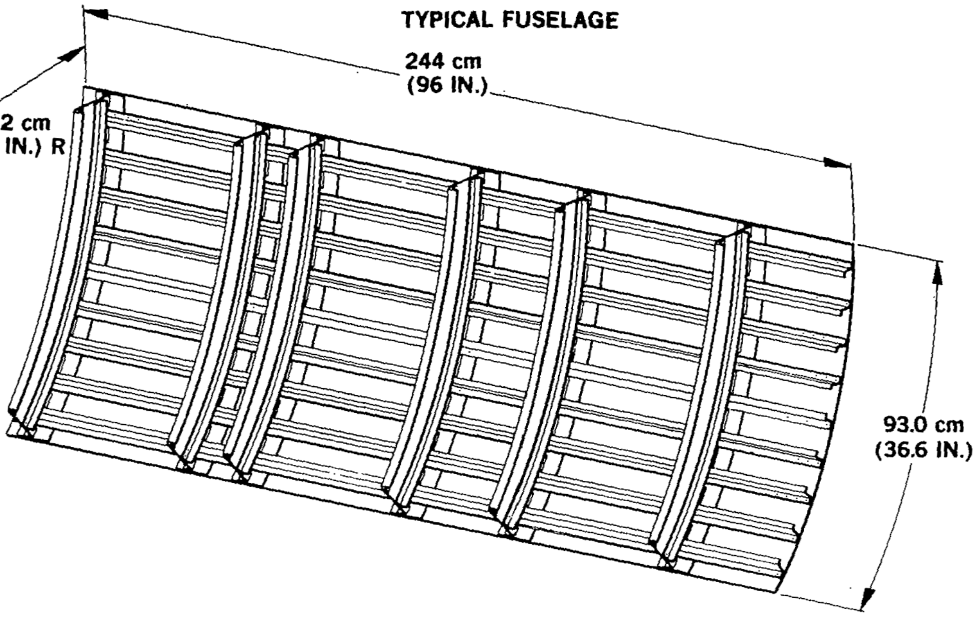
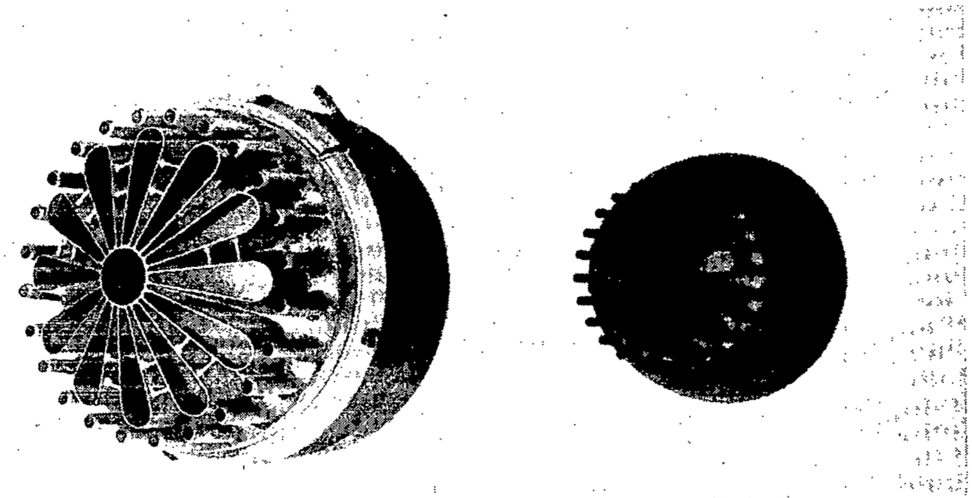


Figure 10.- Weld-brazed titanium panel.



- FOR MDC PROPULSION TESTS
- FOR MDC-NASA COOPERATIVE AMES 40 x 80 ACOUSTIC TESTS

FOR MDC-ROLLS ROYCE SPIN RIG TESTS

Figure 11.- Mixer nozzle for nozzle/suppressor/reverser design of MOC baseline.

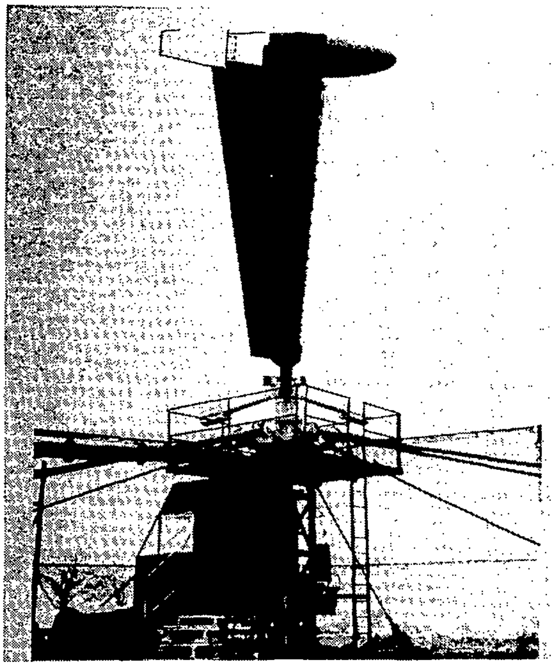


Figure 12.- Rolls-Royce acoustic test facility.

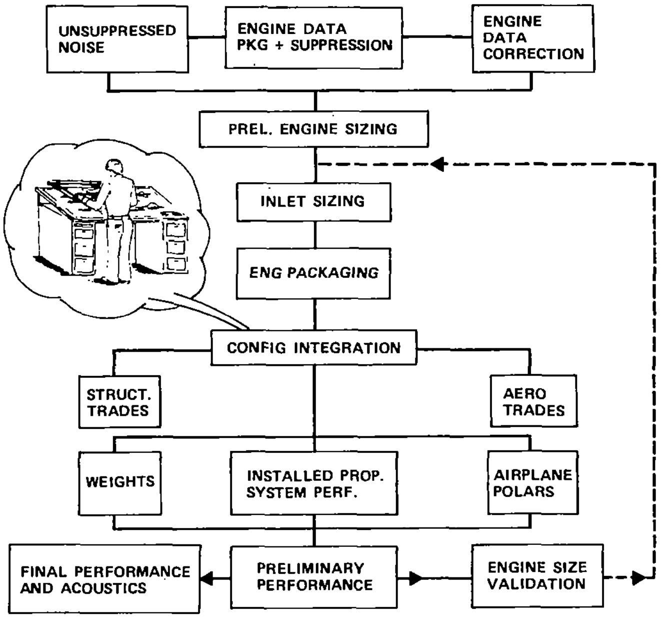


Figure 13.- Engine integration.

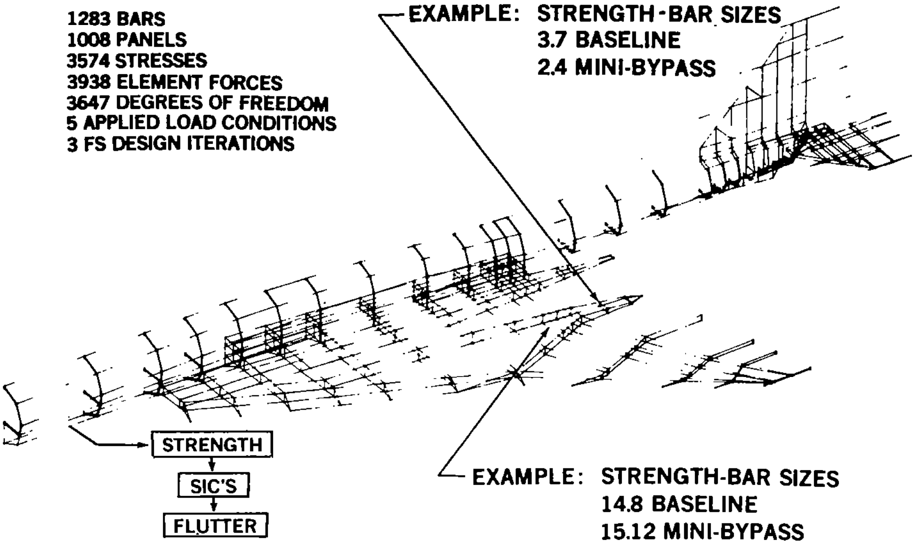


Figure 14.- Typical structures analysis.

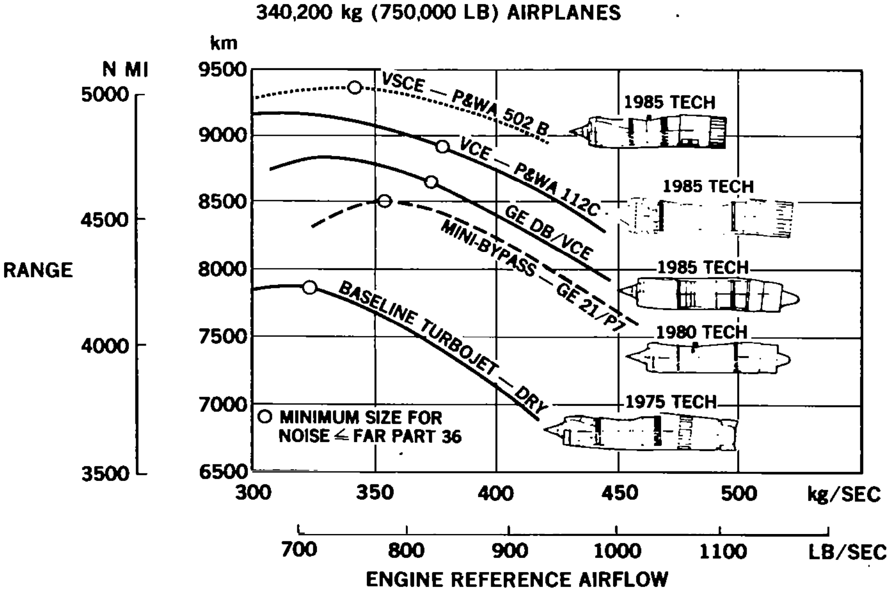


Figure 15.- Engine cycle selection.