(NASA-TM-X-72790) NASA RESEARCH ON STRUCTURES AND MATERIALS FOR SUPERSONIC CRUISE AIRCRAFT (NASA) 45 p HC $4.00 CSCL 01C

N76-18531

Unclas
G3/39 18466

NASA TECHNICAL MEMORANDUM

NASA TM X- 72790

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NASA RESEARCH ON STRUCTURES AND MATERIALS FOR SUPERSONIC CRUISE AIRCRAFT

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January 1976

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LANGLEY RESEARCH CENTER, HAMPTON, VIRGINIA 23665

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM X-72790		

4. Title and Subtitle	5. Report Date
NASA RESEARCH ON STRUCTURES AND MATERIALS FOR SUPERSONIC CRUISE AIRCRAFT	January 1976
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Paul A. Cooper and Richard R. Heldenfels	
	10. Work Unit No.
9. Performing Organization Name and Address	11. Contract or Grant No.
NASA Langley Research Center Hampton, Virginia 23665	
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
	Technical Memorandum
National Aeronautics and Space Administration Washington, D. C. 20546	14 Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

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17 Key Words (Suggested by Author(s))	18 Distribution Statement
Supersonic Aircraft, Aircraft Structures, Composites, Aeroelasticity, SCAR, Computer-Aided Design	Unclassified - Unlimited Category 39

19 Security Classif. (of this report)	20 Security Classif (of this page)	21. No of Pages	22 Price*
Unclassified	Unclassified	46	$3.75

*For sale by the National Technical Information Service, Springfield, Virginia 22161

ACKNOWLEDGMENT

This paper was made possible by contributions and assistance from many individuals at the Langley Research Center, Lewis Research Center, Flight Research Center and the Ames Research Center.

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NASA RESEARCH ON STRUCTURES AND MATERIALS FOR SUPERSONIC CRUISE AIRCRAFT

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SUMMARY

Since 1972 NASA has pursued a program aimed at advancing the technology and establishing a data base so that sound technical decisions may be made in the future regarding long-haul supersonic cruise aircraft transportation systems. This paper reviews the objectives and status of the research elements in the structures and materials phase of the program. The overall objective of the structures and materials program is to establish an expanded technology base which will permit major reductions in structural mass by research on advanced structural concepts, new light-weight materials, improved loads and aeroelastic predictive techniques and by development of efficient structural design procedures.

INTRODUCTION

In addition to the environmental and economic questions that still remained when the National SST Program was cancelled in 1971, several technical questions needed satisfactory answers. In the structures area, the major unresolved problems were related to the poor flutter characteristics of the aircraft and the high operating empty weight fraction which adversely affected the economics of the airplane. The Department of Transportation funded a follow-on technology program to complete selected tasks in the areas of flutter, titanium honeycomb panel development, and fuel tank sealants. Advanced structural concepts or high temperature composite materials were not included and flutter investigations were limited to the delta wing-type configurations in the National SST Program[1].

Following the cancellation of the U. S. National SST Program, NASA was requested in 1972 to initiate a Supersonic Cruise Aircraft Research (SCAR) program to provide the further data required to make rational decisions in the United States relative to future development of military and civil supersonic cruise aircraft. This paper reviews the objectives and current status of the research elements in the structures and materials part of the SCAR Program.

The SCAR structures and materials subprogram emphasizes technology advances for achieving major reductions in the airframe structural weight of large, flexible, high-temperature, long-life supersonic aircraft. The research and developmental efforts have been formulated to attempt solutions to selected critical technical problems in the areas of advanced structural concepts, structural design procedures, aeroelastic loads and response, and materials applications. In the main, the research programs are independent of specific aircraft configurations. Because of limited resources available under the SCAR program in both funds and manpower, only those research areas with long term potential for high payoff were identified and pursued. No attempt was made to investigate all structural problem areas which would be encountered in the design and manufacture of advanced supersonic cruise aircraft. Furthermore, the modest funding level for structures and materials research, which averaged less than three million dollars per year over the last three years, allowed for the testing of small structural components only and could not support any sizeable structural development activity.

RESEARCH ELEMENTS

Fundamental research applicable to supersonic cruise aircraft research in Structures and Materials is conducted principally by the Langley Research Center with contributions from Flight Research Center on ground and flight tests of structures, from Ames Research Center on fuel tank sealants and from Lewis Research Center on high temperature polymers for use as matrix materials in advanced resin/fiber composites. Primary emphasis is placed on the design and development of advanced structural concepts that will be applicable to high performance supersonic cruise aircraft and to the development, manufacture, and proof test of advanced titanium and composite components for application in both primary and secondary structures. In the area of aeroelasticity, primary emphasis is given to the development of both steady and unsteady loads calculation and flutter calculation methodology for large highly flexible aircraft with emphasis in the transonic flight regime and to the experimental evaluation of long wave length atmospheric turbulence characteristics expected to influence supersonic cruise aircraft design.

Table I contains a listing of contracts funded under the SCAR structures and materials program and Table II contains the total new obligation authority funding support available for the program from fiscal 1973 through fiscal 1976. The reference list includes most reports published to date under the program. The tables, references and research tasks discussed in this report are grouped according to three fundamental research areas: Concept Studies, where studies have been made of the efficiency of candidate structural concepts under varying load indices expected in high performance large supersonic cruise aircraft; Structures Technology, where analytical techniques and design methods are developed and empirical data gathered to support the efficient design of a long range supersonic cruise aircraft; Materials Application, where candidate structural materials are evaluated in the operating environment of a supersonic cruise aircraft from the standpoint of long life performance including the consideration of manufacture of small flightworthy structural components.

Concept Studies

Contractual Studies. - Several of the technological areas that should be investigated to provide a sound basis for design of supersonic cruise aircraft include active control systems, advanced composite materials, development of improved aerodynamic configurations, and advanced analysis and design methods. To establish a baseline flexible structural model of an aircraft for use in such investigations, detailed structural studies were conducted to obtain a realistic metallic aircraft design and an accurate mass estimate for a specific aerodynamic configuration. Since supersonic cruise aircraft tend to be large and flexible, realistic aeroelastic considerations based on finite-element structural analysis and sophisticated aerodynamic loading analysis, both steady and unsteady, are required even in a preliminary design study of such a vehicle. In order to obtain the desired realism, two large contractual studies were undertaken with particular emphasis in the area of aeroelasticity (Contracts NAS1-12288 - Lockheed California Company and NAS1-12287 - Boeing Commercial Airplane Company.) The strong interaction of the various disciplines required the use of computer-aided design methods to improve and expedite the aeroelastic and structural resizing cycle. Thus, in addition to the usefulness of the results obtained for a specific configuration, the studies provided a unique opportunity to appraise some of the computer-aided design methods presently in use by the aerospace industry, and to bring into sharper focus problems and technology areas requiring further study and development.

The arrow-wing configuration, a derivative of the SCAT 15F series (ref. 2), shows promise from an aerodynamic standpoint. Both contractors were given the aerodynamic lines of a reference configuration developed at NASA and were allowed to vary the configuration during an initial configuration study phase of the contracts. As a result, Boeing modified the tail section and both contractors made slight changes in the wing sweep and location on the fuselage to optimize the C.G. location. Lockheed shortened the overall length of the aircraft and both contractors used leading edge high-lift devices and an all movable stabilizer with a geared elevator for pitch control. The Boeing configuration is shown in Figure 1.

The contractors were required to design the aircraft for a total gross takeoff mass of 750,000 lbm and a payload requirement of 49,000 lbm (approx. 230 passengers). The aircraft cruises at Mach 2.7 and was to achieve a 4200 nautical mile range if possible. The engine characteristics were based on previous system studies performed by the contractors; Boeing assumed the use of advanced technology after-burning turbojet engines in the 50,000 lbf thrust category; and Lockheed assumed the use of duct-burning turbofan engines in the 90,000 lbf thrust category.

Lockheed used a multi-disciplinary analysis procedure interfacing two large computer codes NASTRAN (statics, dynamics, and structural stability) and FAMAS (aerodynamic loads, structural response, and flutter analysis) (ref. 3). They used two-dimensional finite-element models of approximately 1050 D.O.F. to represent several structural arrangements and calculated internal loads based on selective maneuver conditions for each arrangement. Several areas of the wing and fuselage were used to conduct point design analyses and sizing of candidate structural concepts. The most promising skin stiffening concepts and internal structural arrangements were selected and refined.

As shown in Figure 2, three structural configurations consistent with an assumed 1980 technology readiness were investigated as primary load carrying alternative concepts for the wing and can be categorized under two general types as: (1) Monocoque - biaxially stiffened panels (2) Semimonocoque - uniaxially stiffened panels. The monocoque construction has biaxially stiffened panels which support the principal load in both the span and chord direction. Two types of semimonocoque concepts were considered; panels supporting loads in the span-wise direction (span-wise stiffened) with a multirib substructure and widely spaced spars, and panels supporting loads in the chord-wise direction (chord-wise stiffened) with a multispar substructure and widely spaced ribs. The chord-wise stiffened concepts make use of structurally efficient beaded-skin designs which, when properly oriented in the airstream, provide acceptable aerodynamic characteristics and allow thermal expansion, thereby minimizing thermal stresses. Of the three configurations, the chord-wise stiffened approach offered the maximum mass saving potential when coupled with selective reinforcement of the basic metallic rib and spar caps with unidirectional boron-polyimide composites. This structural arrangement was used as the primary design concept for the wing with the exception of the outboard wing panels where, because of stiffness requirements, monocoque aluminum brazed titanium honeycomb panels were used. The basic material was Ti-6Al-4V titanium alloy.

A more detailed three-dimensional finite-element model containing approximately 2200 D.O.F. was developed for the final structural analyses. Strength sizing and one resizing were conducted at six wing regions and four fuselage regions. Flutter characteristics were determined on the strength designed structure for three Mach numbers (.6, .9, and 1.85) and additional stiffness was added to correct flutter deficiencies by use of a method of flutter optimization employing computer graphics.

Boeing used a multi-disciplinary analysis procedure depending mainly on the ATLAS Program for static structural analysis, sizing, and dynamic behavior (see the next section of this paper for a brief discussion of the ATLAS code.) Static aeroelastic loads were determined in the FLEXSTAB Program (ref. 4) using elastic properties and geometry supplied by the ATLAS code in a direct interface. Boeing depended on the results of the National SST Program to supply design concepts consistent with a 1975 technology base and the concepts were initially sized based on design loads and environmental conditions from previous study results (SCAT 15F study). The basic structural concept selected was aluminum brazed titanium honeycomb. With structural concepts selected, Boeing generated an ambitious 8500 D.O.F. three-dimensional finite-element model as shown in Figure 3. The sketch in the upper part of the figure depicts the complete model where the wing and adjacent fuselage structure are modeled with two-dimensional elements and the remainder of the aircraft simulated with beam elements. For dynamic analyses, approximately 250 degrees of freedom are retained.

The Boeing Company felt that a model of this complexity was needed for detail in the structural modeling of the engine beams, leading and trailing-edge controls, wing secondary structure, landing-gear and wheel-well cutout, and wing-mounted fins as well as wing primary structure to assure a meaningful analysis. The wing was resized using an automated fully stressed resizing algorithm employing internal forces based on the initial loads evaluation. A check of the sized structure showed that the structure had a flutter deficiency which was partially removed by resizing based on engineering judgment. A more complete description of work performed under this contract is given in reference 5.

The group mass statements of the final aircraft are shown in Table III. In making comparisons, the reader should be cautioned that the configurations were slightly different and whereas Boeing was restricted to 1975 technology, Lockheed was allowed the freedom to project and use a 1980 technology and as a result could utilize composites to design lighter structural concepts. The major contractual effort in both contracts was applied to the wing structural design and thus the wing mass values are more refined than the other values shown on the mass statement. The structural concepts were evaluated using mass and range increments as merit functions and the total ranges as given in the table are highly dependent on projected engine efficiencies which at this time are highly speculative.

The general design constraints of the wing cover for the Boeing design are shown in Figure 4. The wing schematic shows three distinct zones dividing both the upper and lower surfaces of the wing according to the three design requirements that dictated structural sizes. The tip structure was stiffness critical and sized to meet the flutter requirements. The aft box was strength-designed to transmit the wing span-wise and chord-wise bending moments and shears. The forward box structural sizing resulted in minimum gage surface panels and substructure components. Foreign object damage was the governing criterion for selection of minimum gage.

The Lockheed design evidenced the same structural characteristics with a slightly larger tip area defined by stiffness conditions and a slightly smaller area defined by strength considerations. Both aircraft designs have a large wing acreage designed for minimum gage making the arrow-wing configuration a relatively inefficient structure on a mass basis as is the situation for most low aspect ratio configurations.

For the Boeing design, a more detailed breakdown of the mass of the largest component, the wing, indicates that of a total mass of 95,800 lbm, 46,000 lbm of material (48 percent) is actually required to support the imposed load. About 24,400 lbm (26 percent) represents non-optimum mass such as skin pad-ups, core, braze, etc. The leading edge and trailing-edge structures account for the remaining 24,400 lbm (26 percent) Forty-eight percent of the wing

cover area is designed by minimum gage constraints, 44 percent is subject to strength constraints and the remaining eight percent is stiffness critical.

These design studies, using large complex models, provided an opportunity to appraise the effect of the use of an advanced computerized structural design system on design methods. Such a design system should be used as early as possible in the study to reduce manpower requirements. Moreover, for the arrow-wing supersonic cruise configuration, static aeroelastic effects and flutter are important and should be considered as early as possible in the design process so that stiffness constrained members are not unnecessarily resized for strength. Generation and validation of a large, complex finite-element model is a major item in the structural analyses effort, and the use of automated modeling methods and sophisticated graphics capability are highly desirable to decrease both manpower expenditure and flow time for this task. Automated strength resizing during the design cycle is much faster than manual methods. The latter point was illustrated in the Boeing study by the fact that automated resizing of the wing elements was accomplished in an overnight stress run, while manual resizing of the fuselage elements required an additional three man-weeks of effort. Realistic automated strength resizing is an important factor in reducing design cycle time because the finite-element model can be generated more quickly by using unrefined initial estimates of member sizes. Also, considering that the mass addition necessary to prevent flutter, which in the Boeing study was on the order of 10,000 lbm, may be an appreciable fraction of the payload, efficient automated structural optimization for flutter is desirable in computerized design systems. References 3 and 5 - 7 are recent publications summarizing the major activities under these studies.

Advanced Composite Applications. - The Boeing contract has been extended to provide an in-depth evaluation of mass reductions that might be achieved by utilization of advanced composite materials and structural concepts that will be available in the 1980's. Previous studies have indicated that a reduction in OEM (Operating Empty Mass) of about nine percent (32,000 lbm) can be achieved in this way through a potential reduction of 18 percent in structural mass. It is believed that further refinement and/or substantiation of this estimate, by application of the integrated analysis and design tools that were used in the design studies, will provide guidelines for research planning on advanced materials applications and concept development. Detail design and concept studies will consider representative sections of major components of the baseline structure so that results of the study will be directly comparable to those obtained based on the 1975 technology baseline titanium structure.

Critical design loads will be revised to reflect the effects of revised structural stiffness and mass distribution. Structural members will be sized based on the revised critical design loads and the best available allowable stress data. The flutter characteristics of the revised airplane will be evaluated.

Trade Studies. - Parallel structural concept trade studies are being performed at the NASA Langley Research Center with aid from LTV engineering personnel (contract NAS1-13500) using large-scale computer-aided tools. The majority of the work to date has been performed using the SAVES system of computer codes developed at Langley. (See the next section of this report for a brief discussion of the SAVES code.) An initial study has been published in reference 8. During one recent investigation the arrow-wing configuration was strength sized using the SAVES system for structural analysis. However, after flutter analysis of this fully-stressed design, it was found that the structure did not meet the flutter requirement. In fact, three distinct flutter modes, as shown in Figure 5, fell within the requirement envelope. As an aid in the understanding of the flutter behavior, stiffness was added separately to three different areas of the airplane and the sensitivity to movement of each flutter mode boundary was measured in increased speed per pounds of material added. From these results, and a certain amount of engineering judgment, a least weight flutter fix for the arrow-wing can be approximated by a judicious mix of stiffness additions. The main emphasis of the trade studies is currently directed towards application of filamentary composite materials in the design of supersonic cruise aircraft.

Structural Technology

Analytic techniques, design methods, and empirical data required for the structural design of a long-range aeroelastic supersonic cruise airplane are being developed to provide for an improved design in less time. Analytic techniques for predicting steady and unsteady transonic loads are being developed and compared with wind tunnel data, and landing load alleviation techniques for highly flexible aircraft are also being developed. In-flight measurements of atmospheric turbulence, important to supersonic cruise aircraft, are being made by B-57 aircraft, and flutter analysis and experimental techniques are being improved through a series of theory developments and wind tunnel tests. Procedures for the consideration of critical structural design problems, including design for fatigue and fracture prevention, thermal stress, and flutter prevention are being advanced and consolidated into computer codes that can reduce design cycle time by one-half to one-third. Some details of these programs follow.

Advanced Design Codes. - Two major integrated structural analysis and design codes and a study code are currently being developed to aid in the preliminary design of supersonic aircraft.

The first code called ATLAS is an integrated structural analysis and design system developed by the Boeing Commercial Airplane Company (ref. 9). This modular system of computer codes is integrated within a common executive and data base framework that is operational on the Control Data Corporation (CDC) 6600/CYBER computers. System capability is under continuing development and refinement in a cooperative effort by Boeing and the Langley Research Center under Contract NAS1-12911. These capabilities may be grouped into three categories: executive, technical, and data handling.

The extensive executive capability derives from the use of the control module and several precompilers which permit user control of the design process by specification of the sequence and mode of execution of selected computational modules. Design process flow is prescribed through a control deck that may be input with the problem data or obtained from a previously stored file. The control deck consists of ATLAS system statements for data description and process flow control with standard FORTRAN programming available to the user to perform additional functions such as interfacing with an external program. The technical capabilities available in ATLAS include modules for stiffness, stress, mass, strength-resize, vibration, and interpolation calculations. Recently, modules for unsteady aerodynamics and flutter calculations have been added to the code. The data handling capabilities include data storage in a data base accessible to all system modules, data transfer to and from external programs, data transfer to and from restart tapes, and plotting and other forms of output presentation. The use of a common data base provides automatic compatibility of data among modules, rapid access to data on disc storage and requires tapes only for archival storage.

The second design code called SAVES was developed at the NASA Langley Research Center (ref. 10) to calculate flexible aerodynamic loads and size the structure for strength. Initially the program was organized in the conventional design sequence as shown on the left in Figure 6 where three iterative loops were employed to arrive at a converged fully-stressed design. In Loop A, the aerodynamic loads were iterated until convergence; in Loop B, these loads were then applied to the structure until a converged set of resized elements was obtained. These loops were located within a large one, Loop C, and were passed through until the loads and resized members were both converged. This method proved time consuming and costly. Therefore, the SAVES program was restructured into the parallel iteration architecture shown on the right in the figure so that the aerodynamic loads and structural resizing were calculated at the same time (ref. 11). The same structural analysis was used for both operations. In this arrangement there exists only one loop and the airloads and element sizes converge simultaneously. Because of fewer iterations and analyses, a savings of approximately 80 percent was achieved in computer CPU time. Convergence is achieved more quickly and the results are more accurate with the continuously updated airloads. A review of the design procedures under development and some advances in the computer software aspects of the SAVES code are given in reference 12.

A computer code called WIDOWAC (Wing Design Optimization With Aeroelastic Constraints) used to study synthesis procedures has been developed under Grant NGR 52-012-008. The WIDOWAC computer program is a preliminary design research tool used to develop an accurate minimum-mass sizing capability for finite-element wing models that must satisfy multiple design constraints. The rigorous math programming sizing algorithm used in WIDOWAC has the generality to allow any number of different kinds of design constraints to be imposed during the design process. Multiple flutter (subsonic and supersonic), stress, strain, displacement, buckling and minimum gage constraints can be imposed, as well as discontinuous or "hump" mode flutter constraints. Minimum-mass designs can be obtained for multiple mechanical, thermal, and inertial loading conditions. Kernel function aerodynamics is used for subsonic conditions and second order piston theory is used for supersonic conditions (see refs. 13 - 17).

Design Synthesis Procedures. - Three studies are underway to improve structural sizing procedures. A recently completed study (NAS1-12121) examined some of the component processes involved in sizing structure to meet flutter requirements. These included examination of efficient forms in which to cast unsteady aerodynamic parameters for use in repetitive flutter calculations, efficient methods for performing the flutter calculations themselves, and the characteristics and efficiency of several procedures for minimizing structural mass subject to flutter constraints (see refs. 18 - 20).

An existing weight estimating computer program has been modified under Contract NAS1-12506 to include fracture and fatigue sizing modules. The module calculates allowable stresses which are used to size the structure. The allowable stresses satisfy fatigue life, crack-growth life, and residual strength requirements chosen by the user. A finite-element program is also being developed under Contract NAS1-13605 to analyze cracked anisotropic sheets and a grant to study fracture of advanced composites NSG-1228 has been initiated.

An improved fully stressed design algorithm has been developed for sizing simple structural members subjected to combined thermal-mechanical loading. The algorithm has been shown to converge in fewer interations than ordinary fully stressed design for situations where thermal stress are of comparable magnitude to/or dominate the mechanical stresses (ref. 21).

Flutter Technology. - Experience in the design of supersonic aircraft increasingly emphasizes the need for adequate consideration of aeroelastic effects during early stages of the design cycle. This need is particularly apparent for large flexible aircraft wherein the structural design often is dictated on the basis of stiffness rather than strength requirements. In such cases aeroelasticity plays a prominent role in other disciplines such as stability and control, performance, and aerodynamic loads. In particular, consideration of the dynamic aeroelastic instability, flutter, is of paramount importance throughout the design cycle. The goal of achieving an advanced flutter methodology by 1980 is being pursued both theoretically and experimentally. Contractual efforts (NAS1-13002, NAS1-13986, NAS1-13613) are underway to develop and evaluate sophisticated unsteady aerodynamic modules for flutter prediction programs (e.g. ref. 22) as well as programs to investigate through in-house wind tunnel studies the flutter characteristics of supersonic cruise aircraft.

The weakest links in the chain of unsteady aerodynamic theories is in the Mach number range where lifting surfaces are most prone to flutter; that is, in the transonic range. Therefore, the advanced transonic unsteady theories currently being developed will be verified by means of appropriate experimentally-determined oscillating pressures. To obtain transonic unsteady pressure data, a 3-dimensional sidewall mounted oscillating model wing with leading and trailing-edge oscillating controls is being fabricated under Contract NAS1-12984. The model, which is scheduled for wind tunnel testing in early 1976, will be used to measure pressures as the wing oscillates in pitch and roll.

Under Grant NGR-22-004-030 a general, efficient, and unified unsteady aerodynamic capability based on finite-element potential-flow theory, applicable to complete aircraft configurations in steady or unsteady motion at subsonic or supersonic speeds, is being developed (refs. 23 - 27).

Flutter Tests. - Three series of flutter tests have been performed to date under the SCAR program. To permit successful testing of models near Mach numbers of 1.0, wind tunnels must be designed with some type of wall opening, normally slots or perforations (holes), in the test section. The degree of openness or wall porosity is usually indicated as the percentage of open wall area relative to total wall area. To evaluate the effects of tunnel size and porosity on the flutter characteristics of models, an SST-type semi-span flutter model was tested in three different tunnels having ventilated test sections (ref. 28). Cooperative tests in the French Modane S2 tunnel, in which the tunnel porosity could be varied, were supported by Contract NAS1-11997. The Modane studies indicated that wall porosity effects on the flutter dynamic pressure were appreciable at Mach numbers from 0.8 to at least 0.92 and that the effects of porosity are more pronounced at the higher Mach numbers, particularly at the lower values of porosity. The porosity effects are probably accentuated by the size model tested which was relatively large for the Modane facility.

In another study, a 1/50-scale model of an arrow-wing was tested to obtain experimental flutter data for correlation with analysis and to determine the location and magnitude of the flutter speed dip in the transonic region. The basic wing (without engine nacelles) was modified by cutting a slit along the root chord to obtain a lower bending and torsion stiffness. The results show that this type wing has a rather severe transonic dip in the flutter dynamic pressure and that by lowering the bending and torsion stiffnesses the flutter boundary was reduced throughout the Mach number range studied without substantially changing the relative magnitude of the transonic dip. The addition of engine nacelles to the modified wing drastically changed the shape of the boundary, substantially raising it subsonically and further lowering it supersonically. The minimum flutter speed was also shifted to a higher Mach number. These results emphasize the extreme configuration dependency of the flutter characteristics of this type wing.

Take-off and transonic acceleration maneuvers of large supersonic commercial aircraft require large trim changes which conventionally are provided by the horizontal tail and elevator. For these airplanes, tail designs, consisting of all-movable horizontal tails with geared elevators, have been proposed to reduce the tail size and required tail deflections (and, therefore, the tail actuator system requirements). A study was undertaken jointly by the Boeing Company and NASA to provide experimental transonic flutter characteristics of a typical advanced geared-elevator configuration for later correlation with analysis. The elevator gear ratio is defined as the angular deflection relative to the free stream for the elevator divided by that for the main tail surface. Tests results show that at Mach numbers from .9 to 1.1, an increase of the gear ratio to 2.8 raised the dynamic pressure required for flutter about 17 percent.

<u>Loads Technology</u>. - The Loads Technology program is comprised of three subelement areas which include research in transonic loads, landing loads, and acoustic loads. The long range goal of each of these areas is to provide aeroelastic load prediction methodology, active landing gear design methodology, and improved acoustic fatigue life prediction methodology, respectively.

For the design of large flexible aircraft, accurate analytical techniques are required for the prediction of aerodynamic load distributions including aeroelastic effects. The problem of accurate load prediction becomes particularly acute when critical design conditions occur in the transonic and supersonic speed regimes. In these regions, at typical design angles of attack and control deflections, the predictions become more difficult due to nonlinear effects caused by flow separation, leading edge vortex separation as shown in Figure 7, shocks and mixed flow. The degree to which the intelligent application of the best state-of-the-art theoretical techniques or combination of theory and experiment can account for these flow conditions is known in only a few circumstances.

For typical low aspect ratio configurations and/or transonic flight conditions where various nonlinear phenomena become important, no satisfactory methods of incorporating experimental data from rigid models into aeroelastic solutions have been developed. Until a validated analytical or empirical approach has been developed, the need for expensive and time-consuming wind tunnel test programs simulating each flight design condition on the flexible aircraft will remain.

A wind tunnel test program of an arrow-wing-body configuration employing both a twisted and a flat wing, as well as a variety of leading and trailing-edge flap deflections has been conducted under Contract NAS1-12875 to provide an experimental pressure distribution data base for comparison with theoretical methods. The purpose of this comparison was to delineate conditions under which the theoretical predictions of pressure distributions are valid for aeroelastic calculations and to explore the use of empirical methods to correct the theoretical methods where theory is deficient. The configuration selected to obtain experimental pressure data is a highly swept thin wing on a slender body. Two complete wings were constructed, one with no camber or twist, and one with no camber but a span-wise twist variation. Both wings were designed with a full-span, 25-percent chord leading-edge segment with the wing span measuring 39.4 inches from tip to tip. The sting mounted model was tested in the Boeing Transonic Wind Tunnel (fig. 8) where seven Mach numbers were tested from 0.40 to 1.11, with angle of attack varying from -8° to +16°.

A comparison of experimental and theoretical surface pressures at an angle of attack of 8° for a low aspect ratio wing with twist is shown in Figure 9 for M = 0.85. The potential flow theories used are based on inviscid theory and attached flow. The pressure distributions described by the solid lines were calculated using a unified subsonic/supersonic panel technique contained in the Boeing computer code FLEXSTAB. The distributions described by the dashed line were calculated based on an analysis employing a panel solution to the exact incompressible potential flow equation satisfying boundary conditions of the exact configuration surface. This analysis is incorporated into the Boeing computer code TEA-230 and is limited to subsonic Mach numbers. Comparisons are also shown in the figure for an inboard wing station where the twist is 1° and near the tip which has 4° twist. The theoretical pressure distribution compares very well with the experimental data at the most inboard wing section. Proceeding outboard, the formation of the leading-edge vortex becomes quite evident as shown by the experimental data on the figure. The FLEXSTAB and TEA-230 results do not compare well with the experimental data at the outboard station. The presence of the leading-edge vortex has completely changed the nature of the flow over most of the wing and the attached potential flow theoretical method cannot predict the experimental results (see refs. 29 and 30).

Attempts to introduce empirical corrections to account for elastic deformations and thus improve surface pressure distribution predictions have been unsuccessful to date since theoretical corrections are linear and work only in those situations where the actual flow changes due to aeroelastic distortions are also linear. In the study described above, there were significant differences between the flat-wing data theoretically corrected for twist and the twisted-wing results at the outboard stations since the twist changed the location and strength of the leading-edge vortex.

The impact phase of the ground-air-ground cycle of aircraft operations and the large scale roughness of runway and taxiway surfaces impose large structural loads on the airframe of aircraft during takeoff, landing, and taxiing operations. Problems resulting from landing loads will be magnified in supersonic cruise aircraft because of the aircraft's greater size, increased flexibility, and higher takeoff and landing speeds. The application of active control landing gear systems in the design of supersonic cruise aircraft could result in aircraft which have longer operational lives, safer ground handling characteristics, and more acceptable ride quality. A preliminary analytical study of active control application has been conducted for a series-hydraulic control actuator in series with a modified version (increased stroke and pneumatic volume) of a passive gear design. The active control gear reduced the wing force by 26 percent with an increase in strut stroke of 15 percent. The reduction in wing force would increase the fatigue life for an aluminum wing structure by a factor of approximately 4.5 times that of the passive gear. A test program is underway to validate the active landing gear study results. A computer code for takeoff and landing analyses with aircraft flexibility effects has been formulated under Contract NAS1-13259 (see refs. 31 and 32). An experimental validation of this code has been initiated based on instrumented readings of takeoff and landing loads from a NASA YF-12 aircraft flown at the NASA Flight Research Center.

A joint NASA-Lockheed test was conducted in the Langley anechoic facility in August 1974, to study community noise shielding with overwing engines and to determine fluctuating pressures in the engine jet impingement area. Results of the test indicated that both the maximum flyover noise and the noise exposure time can be reduced using overwing engines (ref. 33). Future tests now being prepared include measurement of fluctuating surface pressures in the jet impingement areas of the wing and fuselage for an engine having a jet Mach number of 1.4. In addition a Contract NAS1-13978 was initiated in June 1975 to develop methods of predicting fluctuating pressures on full-scale arrow-wing configurations using model results.

Atmospheric Turbulence. - A program to measure atmospheric turbulence is currently underway at NASA-Langley Research Center (ref. 34). The goal is to obtain measurements of gust velocity over a wide altitude range and in different meteorological conditions. Principal meterological conditions of interest include the jet stream mountain waves, and flight at low altitude (or in the earth's boundary layer). The same instrumentation and data reduction procedure is to be employed for all measurements covering altitudes from near sea level to about 60,000 feet and the various meteorological conditions. The operational plan for this program is to locate atmospheric turbulence associated with specific meteorological conditions, to sample it, and to study the resulting time histories and spectra. For samplings up to 50,000 feet, the instrumentation system is installed on a B-57B aircraft (fig. 10). The aircraft seats a NASA test pilot and a meteorologist flying as an observer. The meteorologist performs post flight analyses to define meteorological conditions encountered during the flight, makes turbulence forecasts and assembles meteorological information from reports from the National Weather Service and Turbulence Plot messages from Northwest Airlines as well as pilot reports through FAA Air Traffic Control Centers.

In the Von Karman description of atmospheric turbulence spectra, a value L essentially defines the location of the "knee" in a curve of power spectral density vs. frequency. Thus if the intensity level σ and L are known, the power spectrum is completely defined. For SCAR-type aircraft, variations in L below values of about 2500 feet have a pronounced effect on aircraft response. Thus a knowledge of appropriate L values is needed in this range. A principal objective is to determine if the Von Karman equation is appropriate for clear air turbulence in various meteorological conditions, and if so, to define the appropriate L values. Figure 11 shows a power spectrum of vertical gust velocity from a flight at 43,000 feet in wind-shear associated turbulence. The Von Karman equation with L taken as 1000 shows excellent agreement with the measured results. Seventy-six data runs from a total of 46 flights are presently at some stage in processing. Results from this program should assist in clarifying the nature of the power content of atmospheric turbulence at low frequencies and will be particularly important for design studies of supersonic cruise aircraft. Future plans are to install the instrumentation in a B57-F airplane for measurements above 50,000 feet.

Materials Application

The use of new materials offers the greatest potential for reducing the structural weight of supersonic cruise aircraft. If advanced composite materials could be used extensively, structural weight reductions up to 25 percent could be achieved compared to a similar titanium structure. Successful applications of new materials, however, require extensive and detailed data on material performance under the long-time, high-temperature environment of supersonic cruise flight and the development of economical and reliable manufacturing methods. In this program, some new materials, particularly fuel tank sealants, are under development and environmental testing, and fatigue and fracture testing and advanced fabrication and joining process development for titanium and advanced composite materials are underway. The manufacturing technology program is producing small wing skin panels (for the YF-12 airplane) that are subjected to extensive ground tests and limited flight service evaluations.

Advanced composite materials are very attractive for all structural applications because of their low density and high strength and stiffness. Very little data was available at the initiation of the SCAR program on the suitability of these materials for supersonic cruise applications. Therefore, investigations of the environmental resistance of representative fiber-matrix combinations under simulated supersonic transport environments were initiated to establish time, temperature, and stress capabilities. In addition, some development of new resin matrices is supported in the SCAR program.

The materials application program is investigating both titanium alloys and advanced composites; however, future emphasis will be on resin and metal matrix composites. Testing of titanium will continue to completion but no new titanium activity is planned at present.

New Materials. - Two areas of new material development are supported in this program. The first is the de..lopment of long-life high-temperature fuel tank sealants; the second is the development of long-life, processable polyimide resins for the matrix of high-temperature filamentary composites.

The objective of the fuel tank sealant program is to provide flight-proof, fully characterized, predictable fuel tank sealants and includes the synthesis, characterization, formulation and curing of the new elastomer candidates (NAS 2-7331, NAS 7-100, NAS 2-7112, NAS 2-7981, NAS 2-8103). The sealants program is described in reference 35. Degradation mechanisms of candidate sealants have been identified including reversion, which is characterized by shrinkage in joints above 400°F; low tear strength, caused by the formation of cracks and a resultant loss in tensile strength at high temperatures; and poor adhesion to titanium (ref. 36). Actual-time simulated tank studies have been conducted at Boeing under Contract NAS2-7341. The experimental fluorosilicone (DC 77-028) sealant was installed in a test chamber and subjected to pressures and flight cycle temperatures. The tank was constructed to examine the three types of seals normally found in aircraft fuel tanks. In February 1975, test specimen of DC 77-028 were installed in the No. 5 inboard wing tank of the NASA test YF-12A. The flight tests are a coordinated effort among NASA-Ames, NASA Flight Research Center, Boeing, Lockheed, and JPL. In addition to these tests, new perfluoroether sealants are being developed (ref. 37 and 38) with higher temperature stability than the state-of-the-art sealant (DC 77-028).

One of the most promising class of resins for high-temperature composite structures are polyimides. These materials have the potential of performing satisfactorily for long periods at temperatures in the 450°F to 600°F range. Considerable difficulty has generally been encountered in the application of these materials because of variable properties and complex processing manufacturing problems. No large scale application of polyimide-type composites has been demonstrated successfully to date in an aerospace application.

Because of the difficulties associated with the application of polyimides, a contract effort was undertaken by the Langley Research Center with the General Electric Research and Development Center (NAS1-12079) to exploit their newly-discovered polymer called polyetherimide. This material appeared to possess the properties that would make it amenable to structural applications. It is an aromatic polyetherimide that is soluble and can be processed in an autoclave at nominal temperatures and pressures. In addition, it can be made in required quantities from economical, readily available starting materials.

A promising new high temperature polyetherimide resin has been prepared that appears to warrant further optimization and thorough evaluation on graphite fiber. Also, the cure reactions developed in the latter phase can be effectively used with polyphenylquinoxalines and other polymers such as polyethersulfones whose weak point is their thermoplastic nature at elevated temperature. During the next year further efforts will be made to optimize the polyetherimide and to conduct a materials evaluation program on a limited number of graphite-polyetherimide specimens.

Studies on high-temperature resin development were also undertaken by the Lewis Research Center with the hope of improving processability and retaining useful mechanical properties to 600°F. Emphasis was placed on development of autoclavable polyimides and polyphenylquinoxalines (NAS3-16799, NAS3-17770, NAS3-17824).

In-house studies at Lewis Research Center have resulted in the development of a class of highly processable, high-temperature resistant polyimides, known as PMR (Polymerization of Monomer Reactants) (ref. 39). Tests of the 600°F flexural strengths of HTS graphite fiber composites fabricated with a PMR polyimide showed that, after 600 hours of exposure in air at 600°F, the flexural strength of the PMR composite was 50 percent higher than that of a composite made with a commercial polyimide. Of even greater significance is the broad applicability of the concepts embodied in PMR polyimides to other polymer systems (ref. 40). The PMR polyimide is currently being investigated for possible application to structural panels for the YF-12 aircraft panel program discussed later in this report.

Environmental Effects. - The resistance of structural materials to long-time service at elevated temperatures is a vital factor in selecting materials for a supersonic cruise aircraft. Extensive testing of titanium alloys was conducted during the National SST program and some of this work is continuing under the SCAR program. A major SCAR activity has been the initiation of similar research and testing on advanced composite materials that could be used on a supersonic transport.

The principal environmental study, including fatigue resistance, of available composites materials is being done under contract by General Dynamics-Convair (NAS1-12308). In a two-phase effort, phase I evaluated existing data for the baseline material in each of five classes of composites and conducted environmental simulation for cumulative exposure to 10,000 hours followed by mechanical property tests and material evaluations to determine exposure effects. In phase II, the experimental and analytical characterizations will be extended to cumulative exposure up to 50,000 hours. The filaments and matrices selected as baseline are as follows for the five material classes: 4 mil boron/5505 epoxy; AS graphite/3501 epoxy; 5.6 mil boron/P 105A polyimide; HTS graphite/710 polyimide; 5.6 mil boron/6061 aluminum alloy, diffusion bonded. At this time the B/PI material has been removed from the program because of excessive variability of matrix controlled properties and rapid degradation of B/PI specimens during short time exposures.

The complex flight simulation equipment shown in figure 12, in which both accelerated and real time tests are conducted, applies random load spectra on a flight-by-flight basis and programed temperature histories with independent load and temperature levels for each of the materials systems under test. Up to 100 specimens can be tested simultaneously. The static exposure and accelerated flight simulation data are used in analyses based on modified wearout concepts to predict materials behavior after long flight simulation exposures. If the 50,000-hour exposure data correlate with these predictions, a significant advance will have been made toward efficient design of advanced composite components for long-time, elevated temperature aircraft service.

As shown in figure 13, aging of B/E at 350°F in air at atmospheric pressure for 10,000 hours produces a sizable decrease in 350°F tensile strength. Similar exposures at 250°F, atmospheric pressure, and at 350°F, 2 psi air, had no effect on 350°F tensile strength. The tensile strength degradation was caused by absorption of moisture by the epoxy systems which caused a significant decrease in short time elevated temperature strength. The results point out the need for a moisture-proof coating when these materials are subjected to long periods in ambient environments. Similar behavior was experienced by the G/E material system.

Static thermal aging of G/PI at 550°F in air for 5,000 hours produces a decrease in 550°F tensile strength of unidirectional material, but no effect on crossply material. Similar exposures of G/PI at 450°F have produced no significant changes in tensile strength.

The SCAR program is currently supporting the continuation of two items from the DOT/SST follow-on program on titanium: (1) environmental resistance of aluminum-brazed titanium sandwich construction and (2) flight service evaluation of titanium honeycomb core spoilers for the Boeing 737 airplane.

In November 1974 (under Contract NAS1-13681) NASA assumed responsibility for continuation of the program of long time exposure tests on small titanium honeycomb-core material specimens consisting of laboratory exposures at 450°, 600°, and 800°F, subsonic flight environment (-40°F to 160°F) on Boeing 727 commercial transports, supersonic flight environment (-40°F to 500°F) on YF-12 aircraft and engine exhaust to 900°F. Short time exposure tests consist of alternate exposure to aircraft fluids and elevated temperatures (450°, 600°, 800°, and 900°F; corrodents include sodium chloride, sodium carbonate and calcium sulphate). Coated specimens are also exposed with lubricants or salt spray. Total program duration is 4 years.

Cumulative exposure times will achieve up to 50,000 hours for some specimens. Mechanical and metallurgical testing will be conducted to establish the effects of the various environments on the performance of the brazed specimens.

In May 1975 (NAS1-13897), NASA assumed responsibility for a flight service program on titanium spoilers, approximately 22 by 52 inches, that weigh 15.4 pounds, on the B-737 airplane. The Boeing Company fabricated three such spoilers which are approximately 20 percent heavier than the current production aluminum spoiler because no special attempt was made to optimize the spoiler design. The titanium spoiler is wedge-shaped in cross section and was used to demonstrate the feasibility of brazing tapered titanium honeycomb-core structure utilizing the 3003 aluminum braze material. The current contract is for three years of flight service with annual on-site inspections by the Boeing Company for corrosion or other problems. Following the flight service, the spoilers will be removed from the aircraft and subjected to nondestructive evaluation and limit load testing by The Boeing Company.

Fatigue and Fracture. - The unknown effects of aerodynamic heating and long cruise times are a primary concern in structural fatigue resistance of supersonic transport materials and structures. For subsonic airplanes, structural fatigue strength is usually verified by a full-scale fatigue test. However, a full-scale fatigue test of a supersonic transport would be very expensive and time consuming since the cyclic thermal environment can be duplicated only in real time. Consequently, development of test-acceleration procedures are considered necessary. Two of the objectives of the fatigue studies in the SCAR program focused on the determination of real time and thermal exposure effects on fatigue strengths of candidate materials and structures and on development of procedures which would permit performance of accelerated fatigue tests. Two programs were undertaken to determine the governing fatigue parameters.

At the initiation of the DOT/SST program, Lockheed-California Company in 1965 undertook a study to determine the lives of notched titanium-alloy coupons for both real-time/temperature/stress tests and accelerated fatigue tests (ref. 41). NASA assumed responsibility for the study in January 1972 with the SCAR program under Contract NAS1-11820. The objective of this study is to subject titanium specimens to flight-by-flight loading and heating and to apply approximately 5000 real time flights per year. Lockheed's tests employed six titanium-alloy materials (Ti-8Al-1Mo-1V sheet, mill, duplex, and triplex annealed; Ti-8Al-1Mo-1V mill annealed extrusion; Ti-6Al-4V mill annealed sheet; and Ti-6Al-4V solution treated and aged extrusion) and four test conditions. All of the tests were conducted with flight-by-flight fatigue loading. Real time tests simulated the real time cyclic heating of wing-skin material for a supersonic transport. The other three test conditions (accelerated tests) neglected the real time aspect of the supersonic transport service environment and were conducted with rapid cyclic temperature, constant elevated temperature, and constant room temperature.

Fatigue lives for real time tests were within the range of lives for the three kinds of accelerated tests (except for the Ti-6Al-4V sheet which had longer lives than any accelerated test). Fatigue lives for real time tests of all materials were longer than the lives from accelerated tests with constant elevated temperature. For most of the materials, the accelerated tests at room temperature and the accelerated tests with cyclic temperature yielded fatigue lives which more closely represented the real time fatigue lives than the fatigue lives from the constant elevated temperature tests.

In order to investigate the influence of thermal stresses on fatigue life of structural elements and to establish test methods to shorten and simplify fatigue testing, a contract (NAS1-12501) was awarded to The Boeing Company in 1974. The structural element utilized in the test program consists of a flat sheet with a hat-section stringer attached with rivets. Thermal stresses were developed through non-uniform heating to simulate supersonic transport aerodynamic heating environments. The fatigue life and failure locations were established in the tests. Rapid thermal cycling and load cycles were employed in the tests. The results of the contract are empirical stress/number-of-cycles (S-N) curves for the titanium structural elements and analysis that accounts for thermal soak effects. For information on related work performed at the Langley Research Center on real time and accelerated fatigue tests see references 42 and 43. The fatigue lives from the Boeing accelerated tests of Ti-6Al-4V annealed specimens with cyclic temperature, were about the same as those obtained in the Lockheed real time tests.

Design methods and structural concepts are being developed to make composite structures that can tolerate significant amounts of damage without failing catastrophically. These developments are necessary to make composite structures "failsafe" like metal structures in current transport aircraft. The approach to achieving these objectives contains two major activities: (1) development of a fracture theory for cross-plied laminates that can be used to predict the strength of damaged laminates and (2) development of methods of analysis that can be used to predict the influence of softening strips, stringers, and other damage tolerant features on the residual strength of damaged structures.

Under Contract NAS1-12675, several graphite/epoxy laminates of the (0/±45/90) family and several boron/aluminum laminates of the (0/±45) family are being fabricated for testing at the NASA Langley Research Center to obtain predictions in the reduction in strength of cross-plied laminates due to crack-like flaws. Tests will be conducted at both room and elevated temperatures. The effect of fatigue loads on fracture toughness will also be evaluated and the mechanism of fatigue-crack growth will be identified. The resulting experimental data will then be analyzed to evaluate the applicability of existing theories for the estimation of the fracture toughness of various laminates.

Manufacturing Technology. - One of the major areas of technology improvement required for the successful undertaking of a future supersonic cruise airplane is development of economical and reliable manufacturing methods for metal and composite aircraft structures. Both in-house and contractural efforts are underway with principal activity focused on wing surface panels for the YF-12 airplane.

Advanced fabrication and joining processes for titanium (ref. 44) and high temperature composite materials are being investigated with Lockheed-ADP as the prime contractor (AF Contract FO 4606-73-C-0013) and under Contract NAS1-13095 (ref. 45). Full-scale structural panels are being designed and fabricated to replace an existing integrally stiffened shear panel in the upper wing surface of the NASA YF-12 aircraft. The program includes ground testing and Mach 3 flight testing of five types of full-scale structural panels and laboratory testing of representative structural element specimens.

For each concept, element type specimens are tested at room temperature after constant temperature exposure or cyclic exposure. At constant temperatures of 400°, 600°, 800°, or 1000°F, specimens are exposed for up to 10,000 hours. For cyclic exposure, exposure times are limited to 1000 cycles where each cycle contains a temperature hold at 600°F to simulate 3-hour flight times of an aircraft with 2 hours at supersonic speeds. Some cyclic exposure tests are at constant sea level pressure while for others the pressure is varied to simulate 70,000 ft. altitude when the specimens are at 600°F.

Two titanium panel concepts are being investigated in this program. One is a skin-stringer panel (fig. 14) made of weldbrazing, a joining process developed at NASA-Langley Research Center (refs. 46 and 47) which combines resistance spot-welding techniques that creates a controlled gap at the faying surfaces, and brazing to produce a continuous high-strength joint. Titanium "Z" stiffeners were spotwelded to the face sheet, aluminum braze alloy was placed along the edge of the stiffeners, and the assembly was brazed in a vacuum furnace at a brazing temperature of 1250°F for 10 minutes in a vacuum of 10^{-5} torr. Under these conditions the braze alloy melts and flows by capillary action into the faying surface gap. The weldbrazed panel weighs 8.5 lb., the same as the integrally stiffened panel it is designed to replace. One panel has experienced approximately 200 flight hours with 60 hours above Mach 2.6 of which almost 47 hours were at Mach 3.0. No exposure and 100-hour exposure tests at room temperature and at 600°F were conducted as "proof of design" before beginning flight service of a panel. The tests after cyclic exposure (1000 cycles at atmospheric pressure) and 10,000-hour constant temperature exposure showed no degradation in shear strength.

The second titanium panel concept tested under the flight test program is a Rohrbond honeycomb-core panel. Rohrbond is a Rohr Industries, Inc. titanium joining method that uses a proprietary liquid interface diffusion process. The components to be joined are selectively electroplated with several layers of material which act as an eutectic to aid diffusion bonding. The panel consists of a titanium frame fusion welded at the corners, titanium honeycomb-core, and titanium face sheets. The Rohrbond panels weigh 12 percent less than the weld-brazed and integrally-stiffened panels. The flight service panel has experienced 47 flight hours with 14 hours above Mach 2.6 with almost 8 hours logged at Mach 3.0.

Three composite panel concepts are being investigated. The schematic representations of these concepts are shown in Figure 15. McDonnell Douglas Astronautics Company-East is studying brazing and manufacturing methods for panels with boron/aluminum face sheets and a titanium honeycomb-core. NASA-Langley Research Center is studying fabrication methods for borsic/aluminum panels with titanium honeycomb-core (ref. 48) as well as panels with graphite/polyimide face sheets and glass/polyimide honeycomb-core. Weight saving estimates for the composite panel designs compared to the original YF-12 titanium panel vary from 30 percent for the metal-matrix designs to 55 percent for the graphite/polyimide design. Fabrication processes for these panels are being developed. Reference 49 summarizes results to date.

A study at NASA-Langley Research Center has been inititated to develop optimum stiffened compression panel designs based on elevated temperature operations (450°F) using borsic/aluminum metal matrix composite material. The material has boron fibers coated with silicon carbide to alleviate chemical reaction of the boron with the aluminum matrix at elevated temperatures. Five different configurations have been evaluated analytically over a range of loadings including hat stiffened, corrugated stiffened, open corrugated, honeycomb sandwich and hat stiffened honeycomb sandwich panels. Study results have shown that a more than 30 percent structural weight decrease over corresponding titanium panels may be obtainable with an optimally designed stiffened borsic/aluminum honeycomb concept.

Two experimental programs to complement these studies are currently in the planning stages. The first is a materials characterization program to evaluate the tensile and shear properties of various borsic/aluminum layups for temperatures up to 450°F. The second is a buckling allowables program for stiffened borsic/aluminum compression panels at both room and elevated temperatures.

FUTURE EMPHASIS

Future emphasis in the SCAR structures and materials program will be, as now, on high payoff areas, particularly those that can be used in the long term (1990 technology readiness). The scope and depth of activity will depend on funding available with the following general order of priority:

Primary emphasis on composites because of their high potential for reducing both weight and cost of future supersonic cruise aircraft structures. Determination of their long-time resistance to elevated temperatures and other environmental factors will have continued support with additional materials and tests being added periodically to the time-temperature-stress investigation that is expected to continue into the mid-1980's. Design technology, fatigue and fracture, and manufacturing processes for composites also will be included.

Next, continuing support for development of better and faster computer-aided analysis and design techniques. This includes integrated structural analysis and design systems, such as further growth of systems similar to ATLAS; analysis modules for calculation of steady and unsteady loads; and design modules that provide for automated, optimized design that include consideration of flutter, fatigue and thermal stress. All these computer codes will handle composite structure.

Finally, as funds permit, continue to advance other technology areas such as prediction of nonlinear, aerodynamic loads, acoustic loads and landing loads; new structural concepts and materials; flutter testing and analysis in the transonic speed range; and continued in-house trade studies based on computer-aided design systems.

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47. Bales, T. T.; Royster, D. M.; and Arnold, W. E., Jr.: Weldbrazing of Titanium. SAMPE Quarterly, April 1974.

48. Royster, D. M.; Bales, T. T.; and Wiant, H. R.: Joining and Fabrication of Metal-Matrix Composite Materials. NASA TM X-3282, September 1975.

49. Hoffman, Edward L.; Payne, LeRoy; and Carter, Alan Lyman: Fabrication Methods for YF-12 Wing Panels for the Supersonic Cruise Aircraft Research Program. Presented at the 7th National SAMPE Conference Albuquerque, NM, October 14-16, 1975.

TABLE I - SCAR STRUCTURES AND MATERIALS CONTRACTS AND GRANTS

a. Concept Studies

NUMBER	TITLE	COMPANY	AWARD COMPLETION	COST $K
NAS1-12288	Study of Structural Design Concepts for an Arrow-Wing Supersonic Transport Configuration	Lockheed-California Company	May 1973 Feb 1976	688*
NAS1-12287	Study of Structural Design Concepts for an Arrow-Wing Supersonic Transport Configuration	Boeing Commercial Airplane Company	June 1973 Sept 1976	871*
NAS1-13500	Non-personal Services Support Contract	LTV Aerospace Corporation	Oct 1973 -	354

*Additional Funding was provided by other sub-elements of the SCAR Program. The total cost of the Lockheed contract was $864K and the Boeing contract $1089K.

TABLE I - SCAR STRUCTURES AND MATERIALS CONTRACTS AND GRANTS (Cont.)

b. Structures Technology

NUMBER	TITLE	COMPANY	AWARD COMPLETION	COST $K
NAS1-12911	Extension of the ATLAS Integrated Analysis and Design System	Boeing Commercial Airplane Company	Jan 1974 Jan 1977	304
NGR 52-012-008	Automated Wing Structural Design	Technion R & D Foundation, Ltd.	Oct 1973 -	30
NAS1-12121	Development of Flutter Modules Applicable to Automated Structural Design of Supersonic Transport Configurations	Lockheed-California Company	Feb 1973 Apr 1975	239
NAS1-12506	Computer Program to Assess Impact of Fatigue and Fracture Criteria on Weight and Cost of Transport Aircraft	General Dynamics San Diego	July 1975 Feb 1976	50
NAS1-13605	Finite-Element Computer Program to Analyze Cracked Orthotropic Sheets	Lockheed-Georgia Company	Dec 1974 Jun 1975	30
NAS1-13002	Solution of Transonic Flow Around Oscillating Wings	Boeing Commercial Aircraft Company	Mar 1974 Jul 1975	63
NAS1-13986	General Purpose Computer Program for Interacting Supersonic Configuration	Bell Aerospace Company	Jun 1975 -	59
NAS1-13613	Improvement and Generalization of Computer Program for Calculating Transonic Unsteady Aerodynamic Forces	Lockheed-Georgia Company	Nov 1974 Sep 1976	27
NAS1-12984	Design, Fabrication, and Test of a Three-Dimensional Oscillating Pressure Wind Tunnel Model	Lockheed-Georgia Company	Mar 1974 Nov 1975	216
	Miscellaneous Hardware			38

TABLE I - SCAR STRUCTURES AND MATERIALS CONTRACTS AND GRANTS (Cont.)

b. Structures Technology (Cont.)

NUMBER	TITLE	COMPANY	AWARD COMPLETION	COST $K
NAS1-10120	TDT Software for Oscillating Pressure Measurements	Kentron Company	Oct 1974 May 1977	86
NGR-22-004-030	Research on Compressible Unsteady Potential Aerodynamic Flow Around Lifting Bodies Having Arbitrary Shapes and Motions	Boston University	Jul 1973 Dec 1975	105
NAS1-11997	Support of Flutter Model Tests at Modane France	Boeing Commercial Airplane Company	Oct 1972 Jan 1973	86
NAS1-12875	Transonic Loads Measurement and Prediction	Boeing Commercial Airplane Company	Jan 1974 Jul 1975	320
NAS1-13259	Addition of Flexible Body Option to the TOLA Computer Program	McDonnell Douglas	Jun 1974 Aug 1975	60
NAS1-13978	Sonic Environment of Aircraft Structure Immersed in a Supersonic Jet Flow Stream	Lockheed Company	Jun 1975 May 1976	32
NAS1-13709	Non-Stationary Spectral Descriptions for Atmospheric Turbulence	Bolt Baranek and Newman	Dec 1974 Oct 1975	16
	Landing Loads - Miscellaneous Items			53
	Miscellaneous			21
	Support Activity to Measurement of Atmospheric Turbulence Program			254

TABLE I - SCAR STRUCTURES AND MATERIALS CONTRACTS AND GRANTS (Cont.)

c. Materials Application

NUMBER	TITLE	COMPANY	AWARD COMPLETION	COST $K
NAS2-7331	Synthesis of Perfluorinated Polyesters for Sealant Application	Peninsula Chemical Corporation	Dec 1972 -	91
NAS7-100	Prediction of Service Life of Sealant Materials	Jet Propulsion Lab	-	85
NAS2-7112	Characterization of Polybenzimidole Composite Foams	Whittaker Corporation	-	18
NAS2-7981	Crosslinking and Degradation Mechanisms in Model Sealant Candidates	Ultra Systems, Inc.	-	29
NAS2-8103	Synthesis of Heterocyclic-Block	Stanford Research Institute	-	16
NAS2-7341	Design, Fabrication and Operation of a Fuel Tank Sealant Exposure Apparatus	Boeing Commercial Airplane Company	Nov 1972 -	48
NAS1-12079	Improved Resins for AST Composites	General Electric Research	Jan 1973 Oct 1976	400
NAS3-16799	Development of Polyphenylquinoxaline/ Graphite Composites	Boeing Company	Mar 1973 -	89
NAS3-17770/ NAS3-17824	Development of Autoclavable Polyimides	TRW, Incorporated	Jun 1973 -	193
NAS1-12308	Study of Time - Temperature-Stress Capabilities of Composite Materials for Advanced Supersonic Technology Application	General Dynamics Corporation	Jun 1973 Apr 1976	919
	Miscellaneous Polyimide Resin Support			33

TABLE I - SCAR STRUCTURES AND MATERIALS CONTRACTS AND GRANTS (Cont.)

c. Materials Application (Cont.)

NUMBER	TITLE	COMPANY	AWARD COMPLETION	COST $K
NAS1-13681	Effects of Simulated Service and Flight Service Environments on the Performance of Aluminum Brazed Titanium Honeycomb-Core Sandwich Construction for Supersonic Cruise Aircraft Research	Boeing Commercial Aircraft Company	Nov 1974 Jan 1979	68
NAS1-13897	Flight Service Evaluation on Boeing 737 Aircraft of Two Aluminum Brazed Titanium Spoilers for Supersonic Cruise Aircraft Research	Boeing Commercial Aircraft Company	May 1975 Nov 1978	33
NAS1-11820/ NAS1-13649	Continuation of Real-Time Testing	Lockheed-California Company	Jan 1973 Jun 1976	111
NAS1-12501	Acceleration of Fatigue Tests for Advanced Supersonic Transports	Boeing Company	Jun 1973 -	235
	Miscellaneous Structural Panels			80
NSG-1228	Fracture of Advanced Composites	George Washington University	Sep 1975	31
NAS1-12675	Fabrication of Graphite/Epoxy Specimens	McDonnell Douglas Aircraft	Oct 1974	190
AF Contract FO 4606-73-C-0013	AST Structural Panel Program	Lockheed-California Company	Oct 1972	934
NAS1-13095	Fabrication of Structural Tests Specimens	DWA Composite Specialties, Inc.	Apr 1974 Sep 1975	15
NAS1-13306	Borsic/Aluminum Panels	United Aircraft Hamilton Standard	Apr 1974 -	12

TABLE II. - SCAR STRUCTURES AND MATERIALS NEW OBLIGATION AUTHORITY
(Thousands of dollars)

Fiscal Year	FY73	FY74	FY75	FY76
Concept Studies	675	879	353	124
Structures Technology	753	845	806	690
Materials Application	1844	1247	1121	1291
TOTAL	3272	2971	2280	2105

TABLE III. - ARROW-WING STUDY GROUP MASS STATEMENT (Lb_m)

	BOEING			LOCKHEED		
			%GTOW			%GTOW
STRUCTURE		224,400	29.9		201,300	26.8
WING	95,800			90,600		
HORIZONTAL TAIL	6,500			7,900		
VERTICAL TAIL	5,800			5,400		
FUSELAGE	56,100			42,100		
MAIN GEAR	37,300			27,400		
NOSE GEAR	3,800			3,000		
NACELLE	19,100			24,900		
PROPULSION		56,800	7.6		58,100	7.8
SYSTEMS		77,100	10.3		54,400	7.2
OEW		358,300	47.8		313,800	41.8
PAYLOAD *		49,000	6.5		49,000	6.5
FUEL		342,700	45.7		387,200	51.7
GTOW *		750,000	100		750,000	100
RANGE	4000 NAUTICAL MILES			4200 NAUTICAL MILES		

* NUMBERS HELD CONSTANT THROUGHOUT STUDY

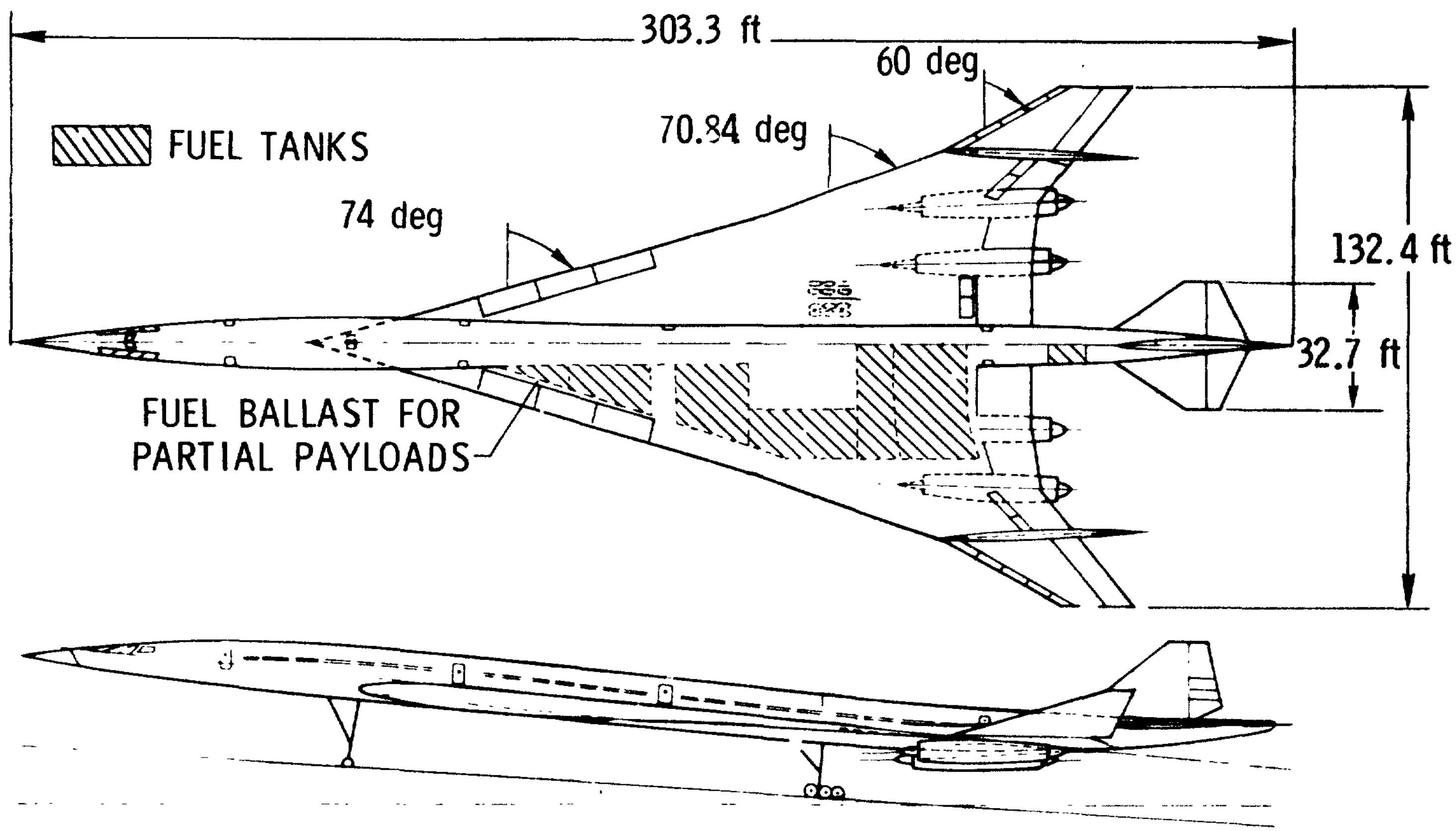


FIGURE 1. - AIRCRAFT CONFIGURATION AND FUEL TANK LOCATION

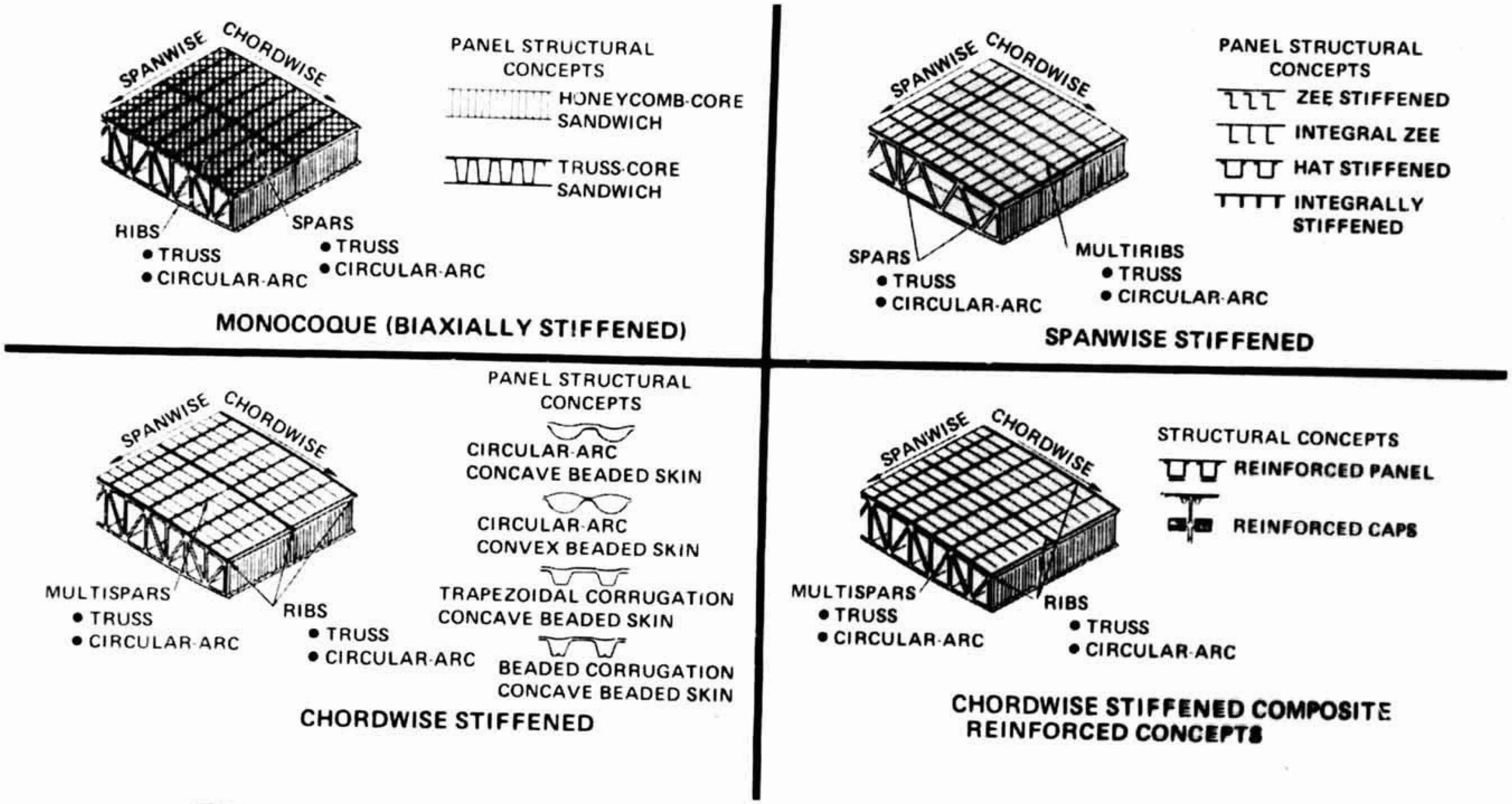


FIGURE 2. - STRUCTURAL CONCEPTS FOR AN ARROW-WING SUPERSONIC AIRCRAFT-LOCKHEED CO.

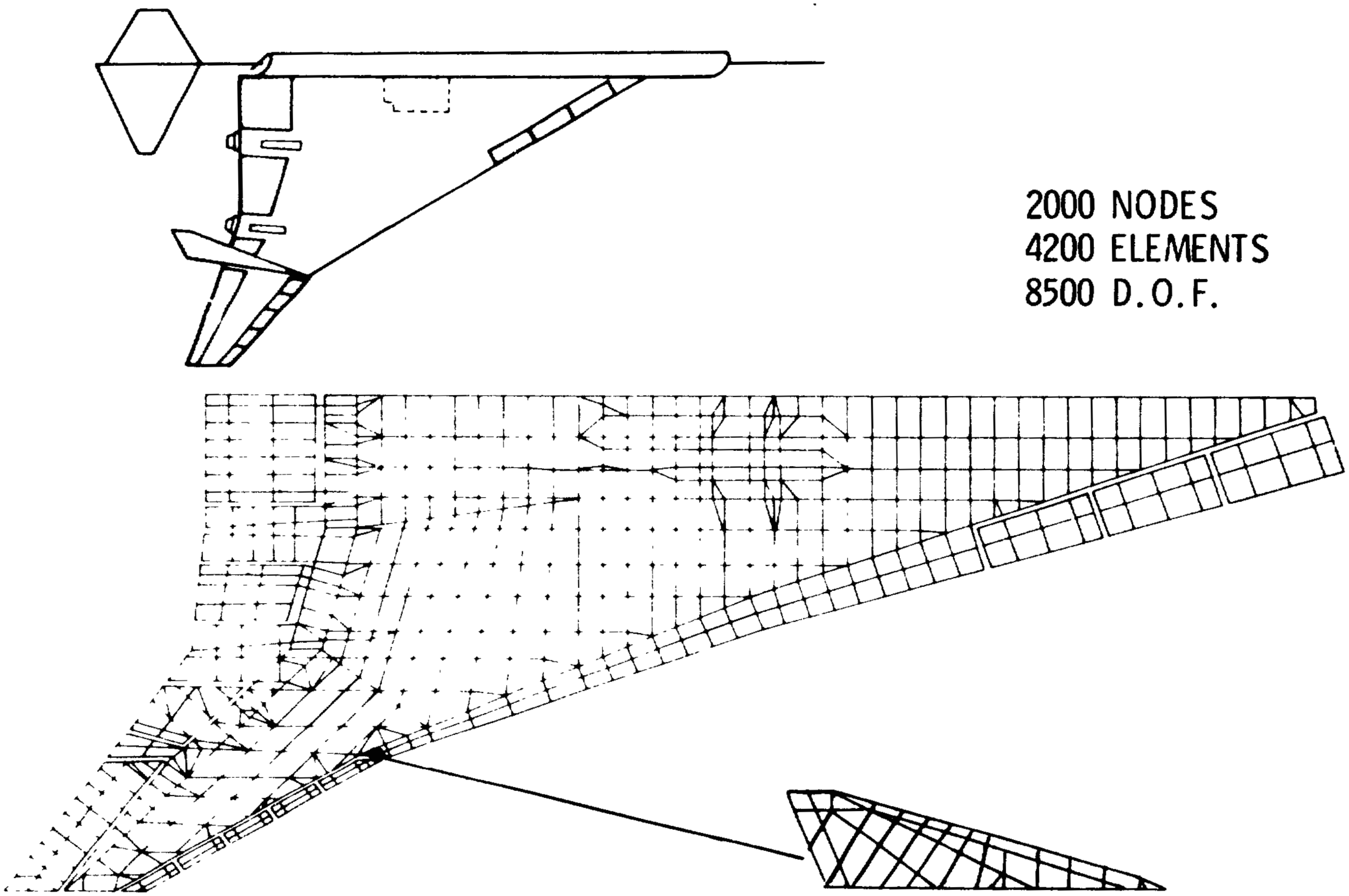


FIGURE 3. - FINITE ELEMENT MODEL OF AN ARROW-WING SUPERSONIC CRUISE AIRCRAFT-BOEING CO.

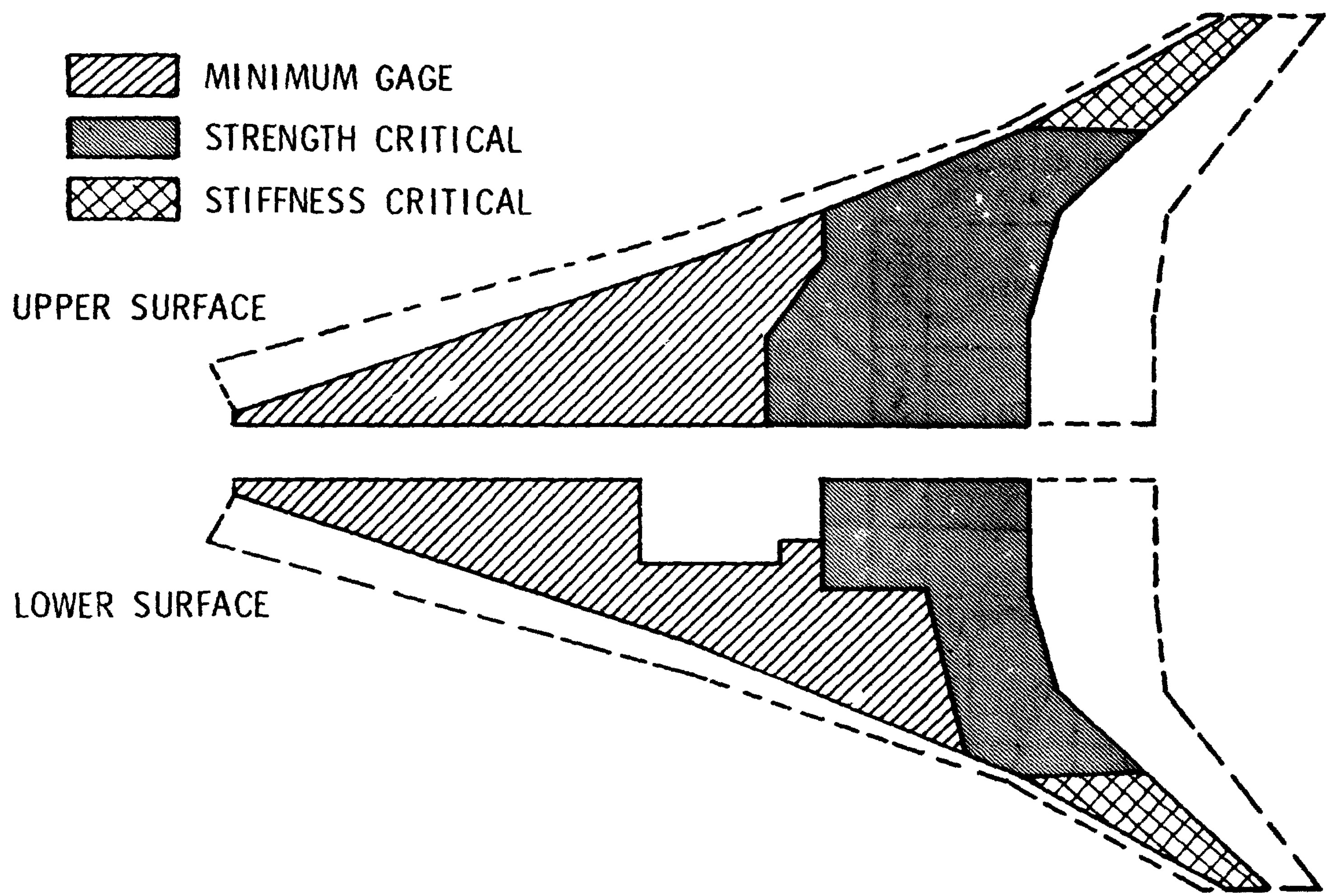
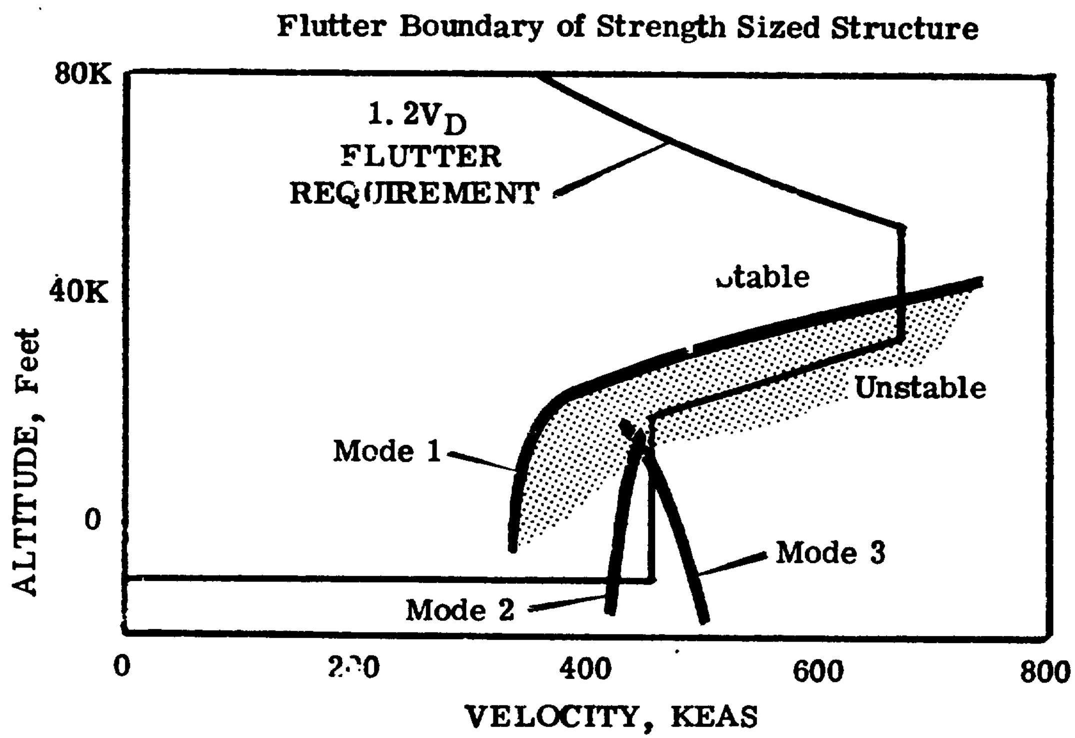
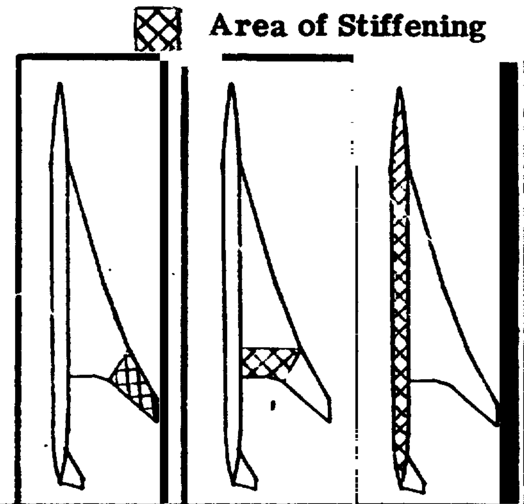


FIGURE 4. - WING COVER CRITICAL DESIGN CONDITIONS

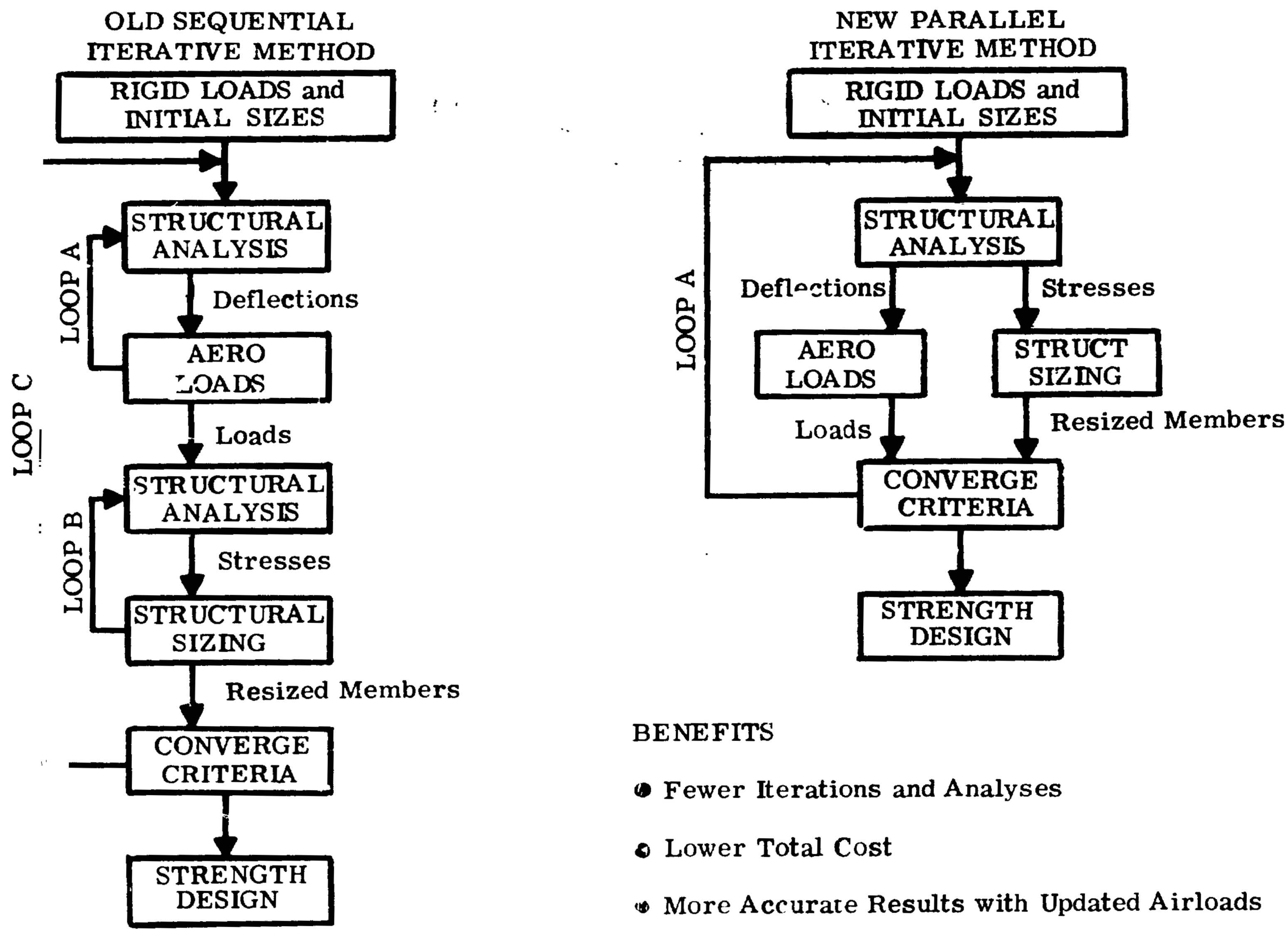




Mode 1	.152	.002	0
Mode 2	.126	-.006	0
Mode 3	-.055	.037	.033

Measure of Effectiveness of Stiffening in ΔKEAS/ΔPound

FIGURE 5. - EVALUATION OF VARIOUS FLUTTER FIXES



BENEFITS

- Fewer Iterations and Analyses
- Lower Total Cost
- More Accurate Results with Updated Airloads

FIGURE 6. - NEW SAVES SYSTEM FOR STRUCTURAL DESIGN

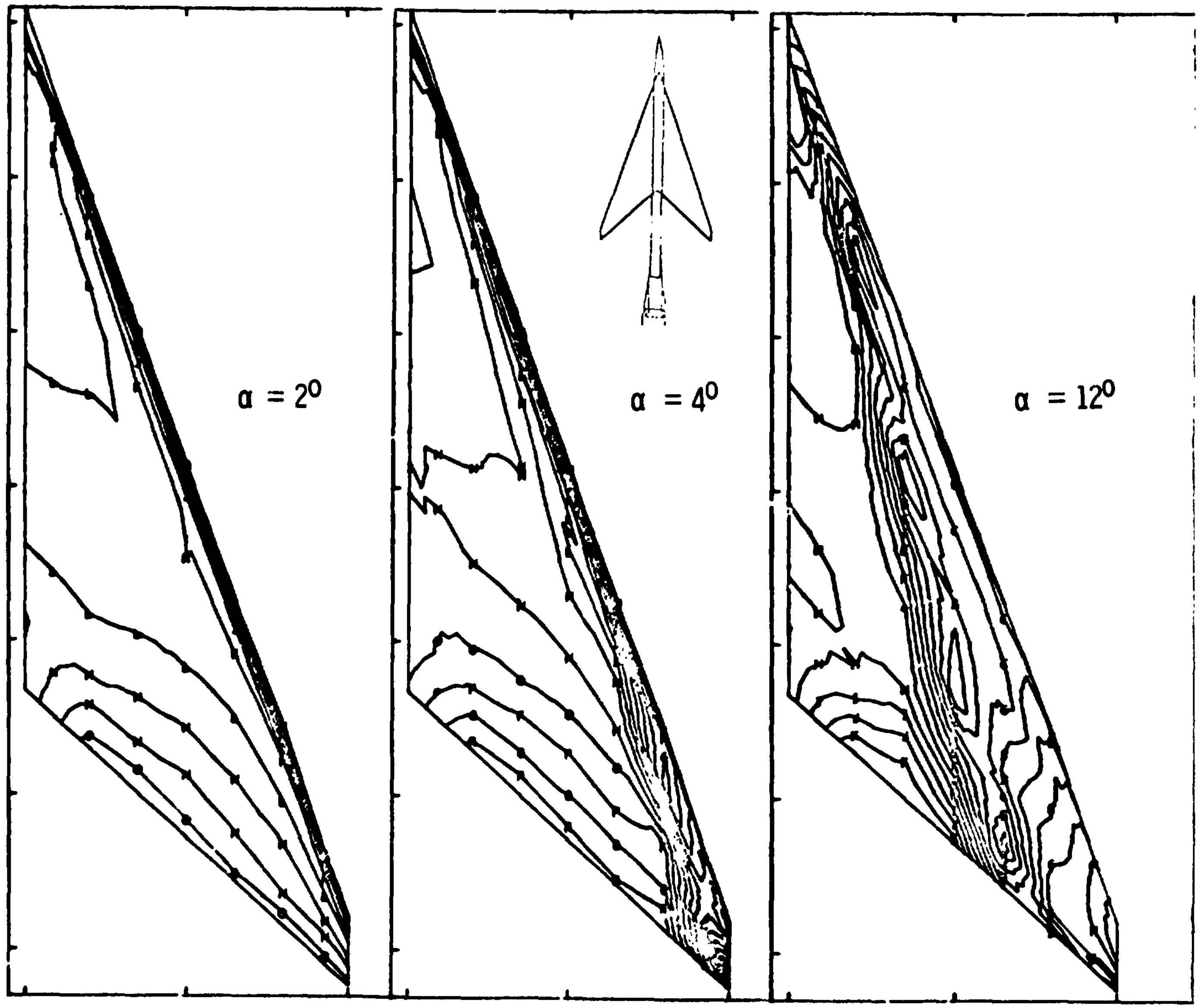


FIGURE 7. - EFFECT OF SEPARATED VORTEX ON UPPER SURFACE ISOBAR CONFIGURATION, M = 0.95

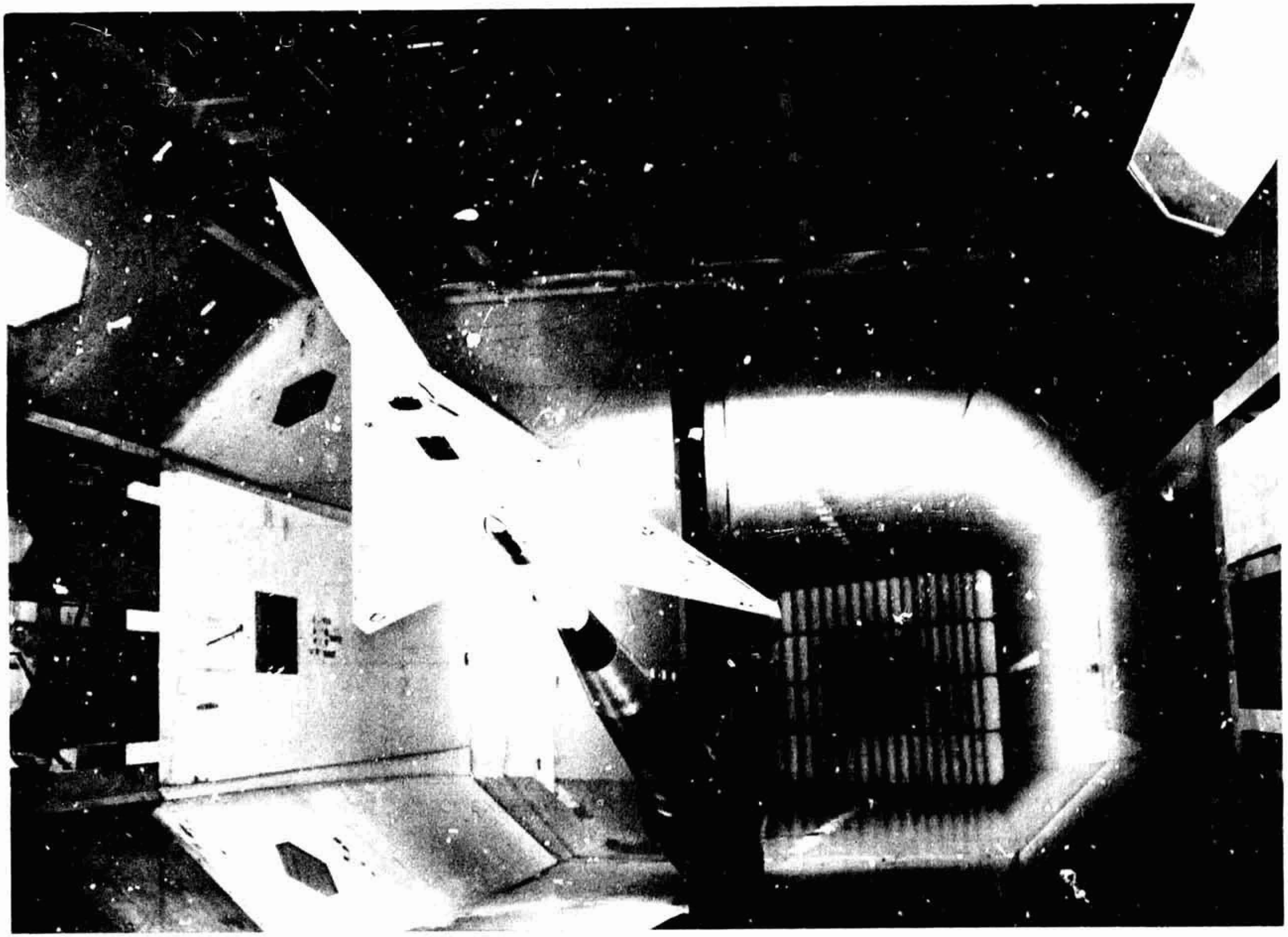


FIGURE 8. - LOADS PREDICTION AND MEASUREMENTS PROGRAM EXPERIMENTAL TEST SETUP

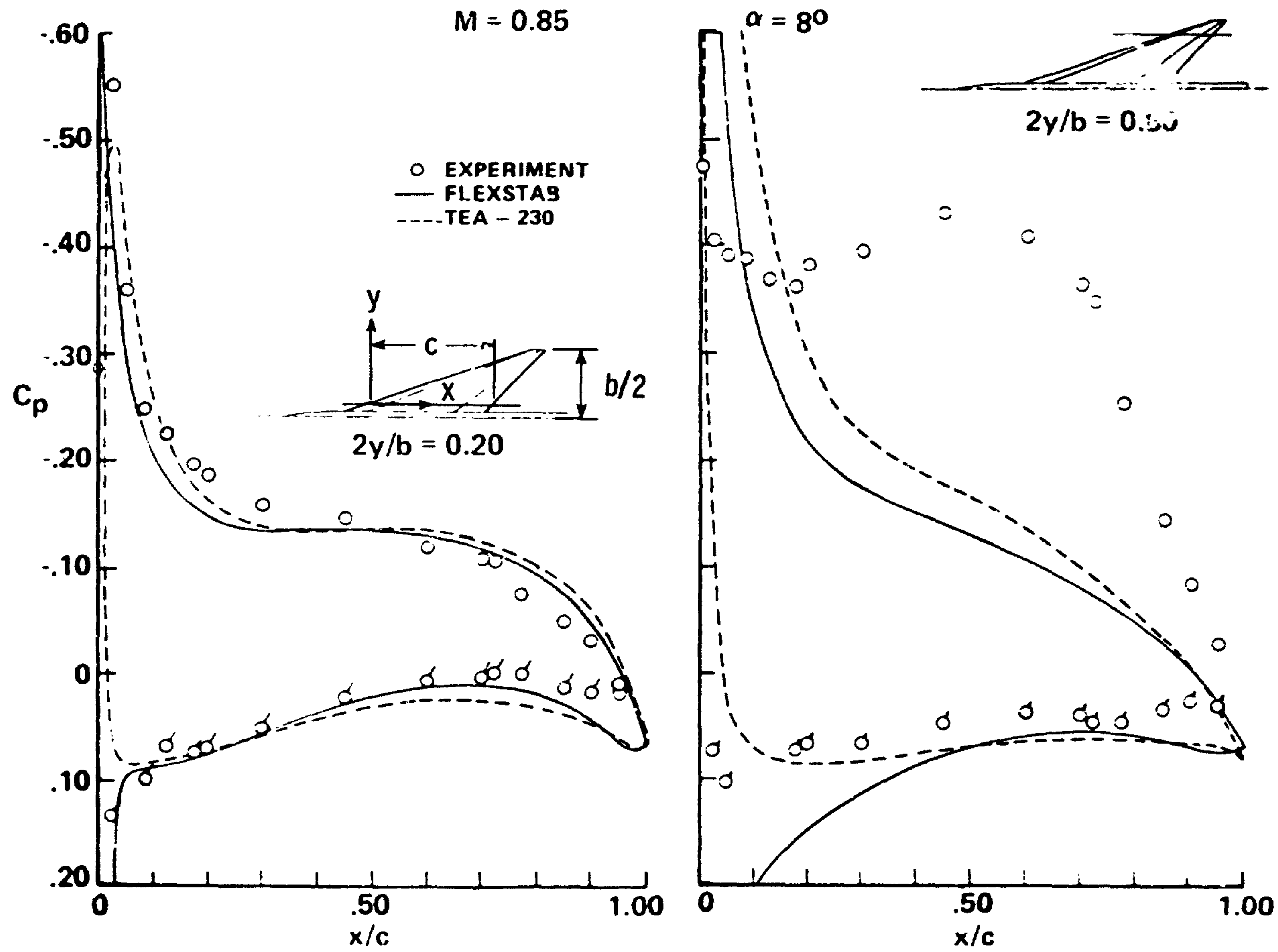


FIGURE 9. - TWISTED WING PRESSURE DISTRIBUTION, M = 0.85

L-74-5998

FIGURE 10. - B-57B AIRCRAFT INSTRUMENTED WITH SPECIAL NOSE BOOM AND VANES FOR MEASURING ATMOSPHERIC TURBULENCE

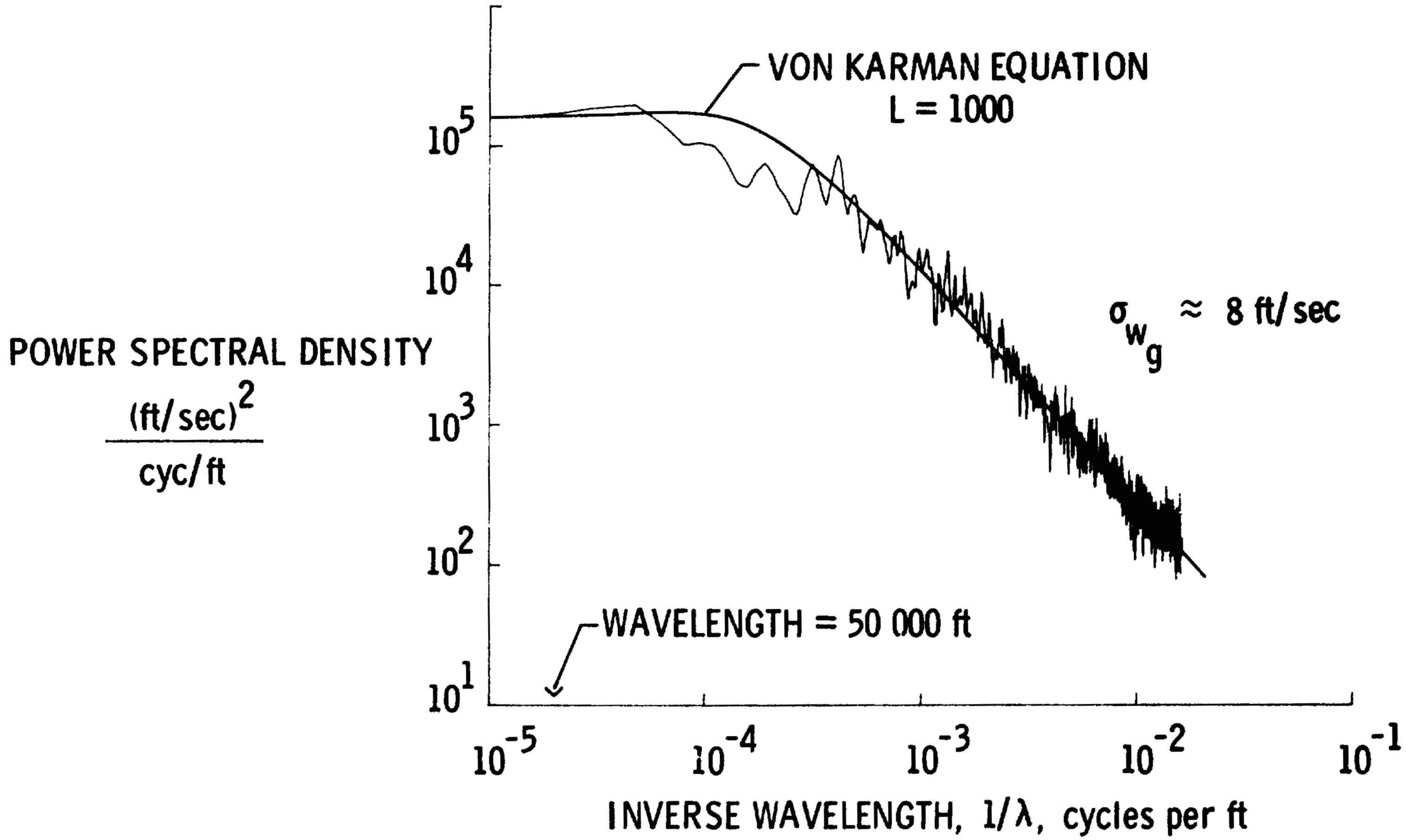


FIGURE 11. - POWER SPECTRUM OF VERTICAL GUST VELOCITY

~43,000 FT. ALTITUDE, WIND SHEAR TURBULENCE

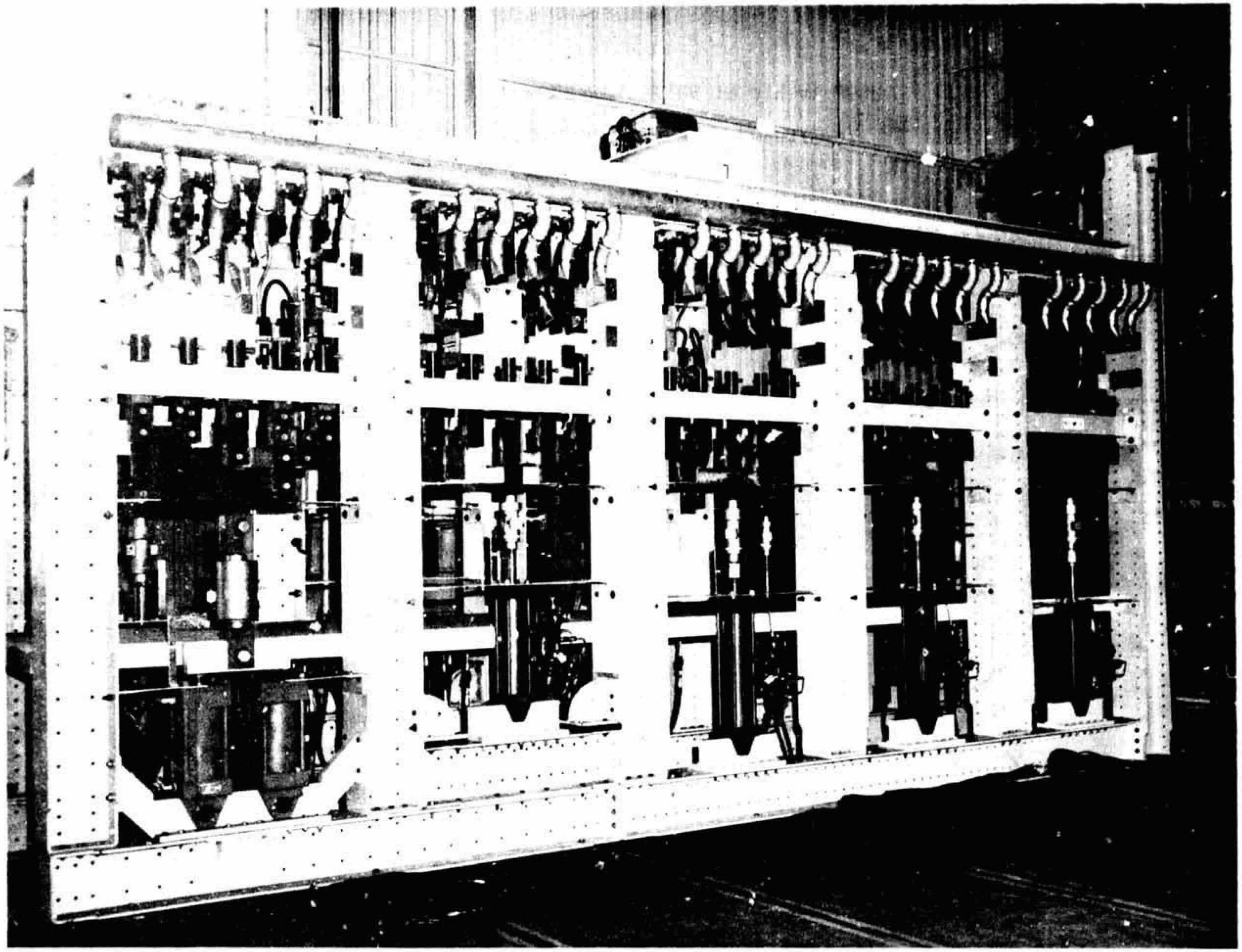


FIGURE 12. - FLIGHT SIMULATION TEST STAND FOR ACCELERATED AND REAL TIME TESTS

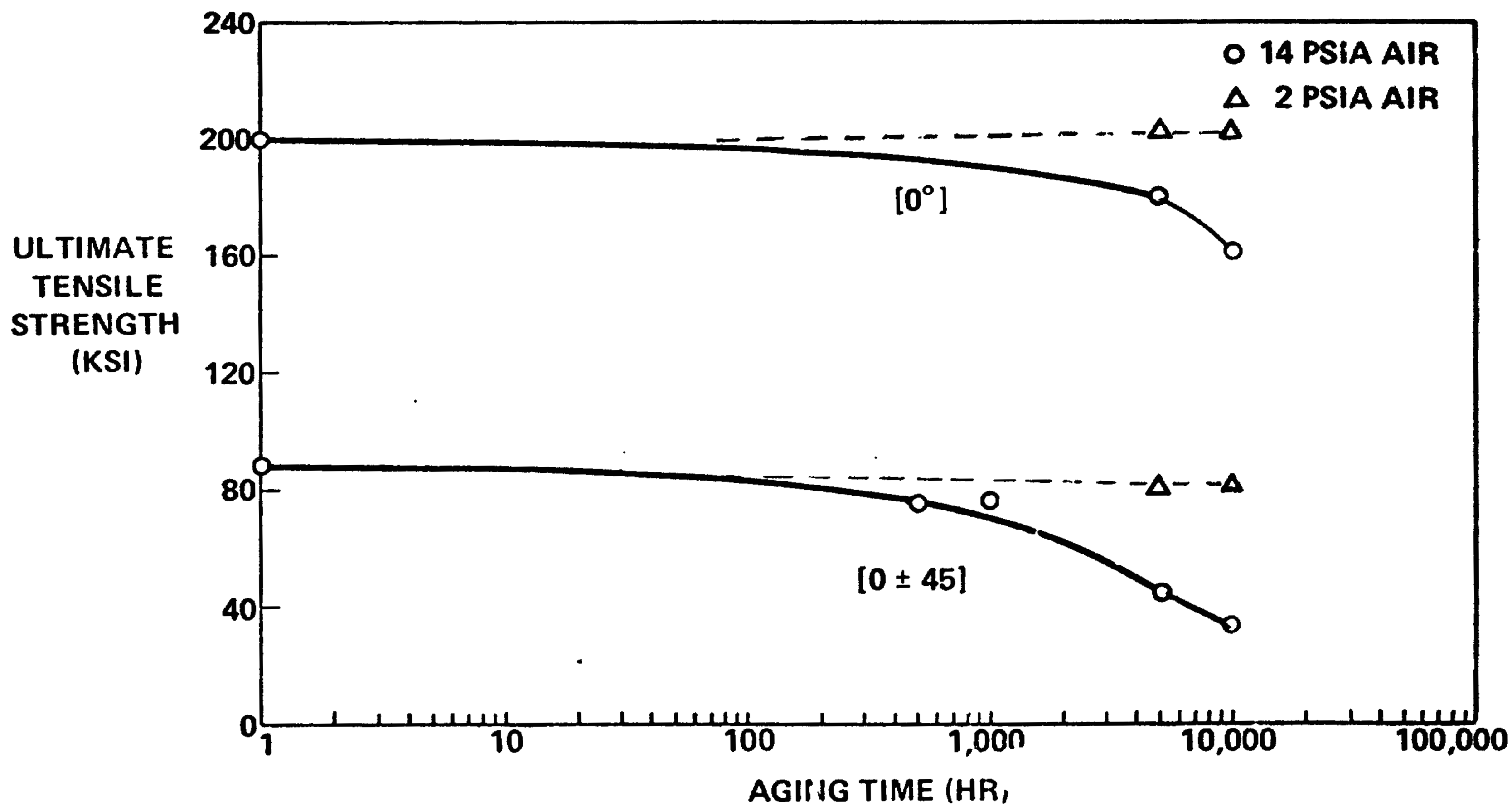


FIGURE 13. - TENSILE STRENGTH OF B/5505 BORON/EPOXY AT 350F
AFTER THERMAL AGING IN AIR AT 350F

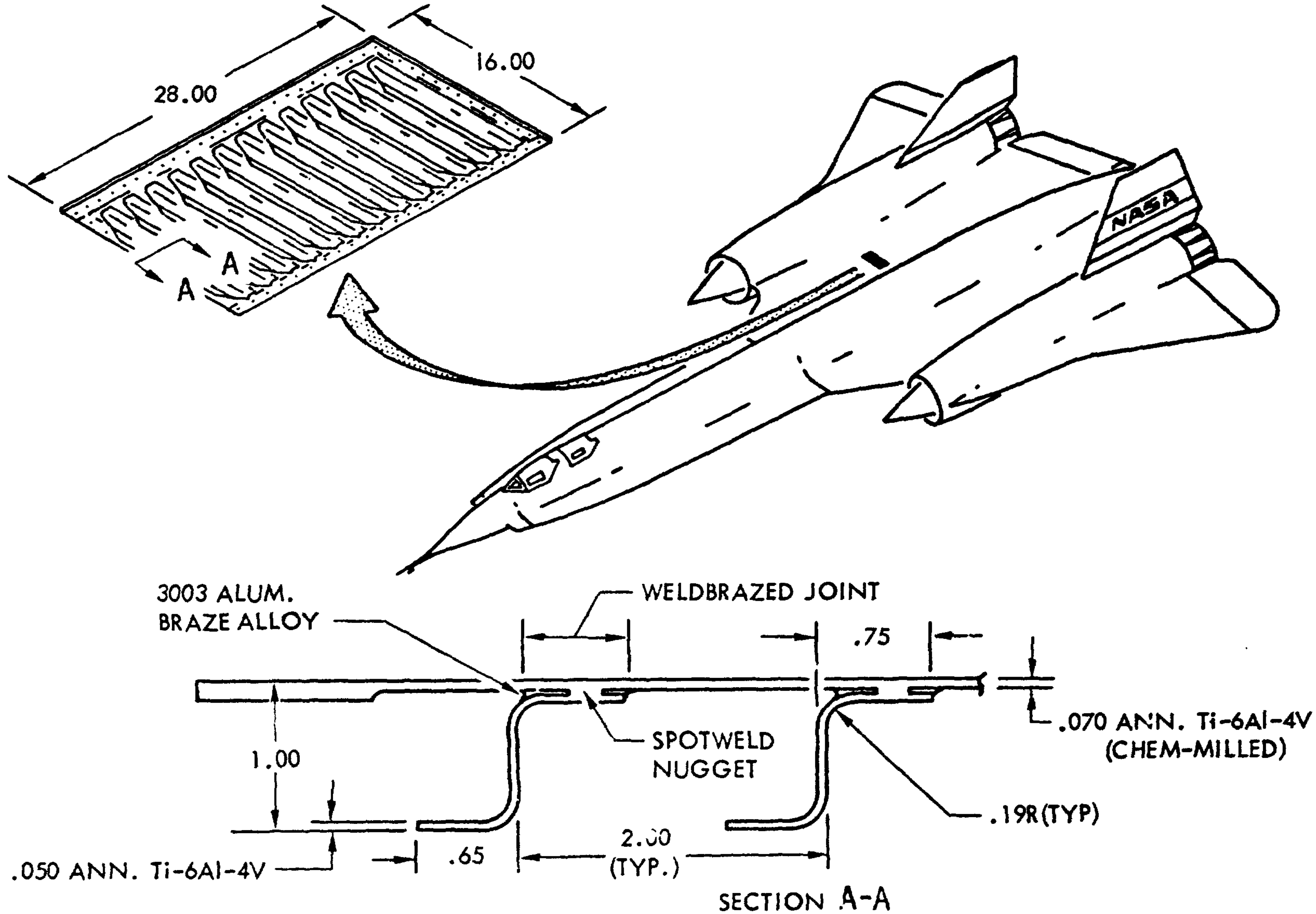


FIGURE 14. - WELDBRAZED TITANIUM SKIN-STRINGER PANEL, MEASUREMENTS IN INCHES

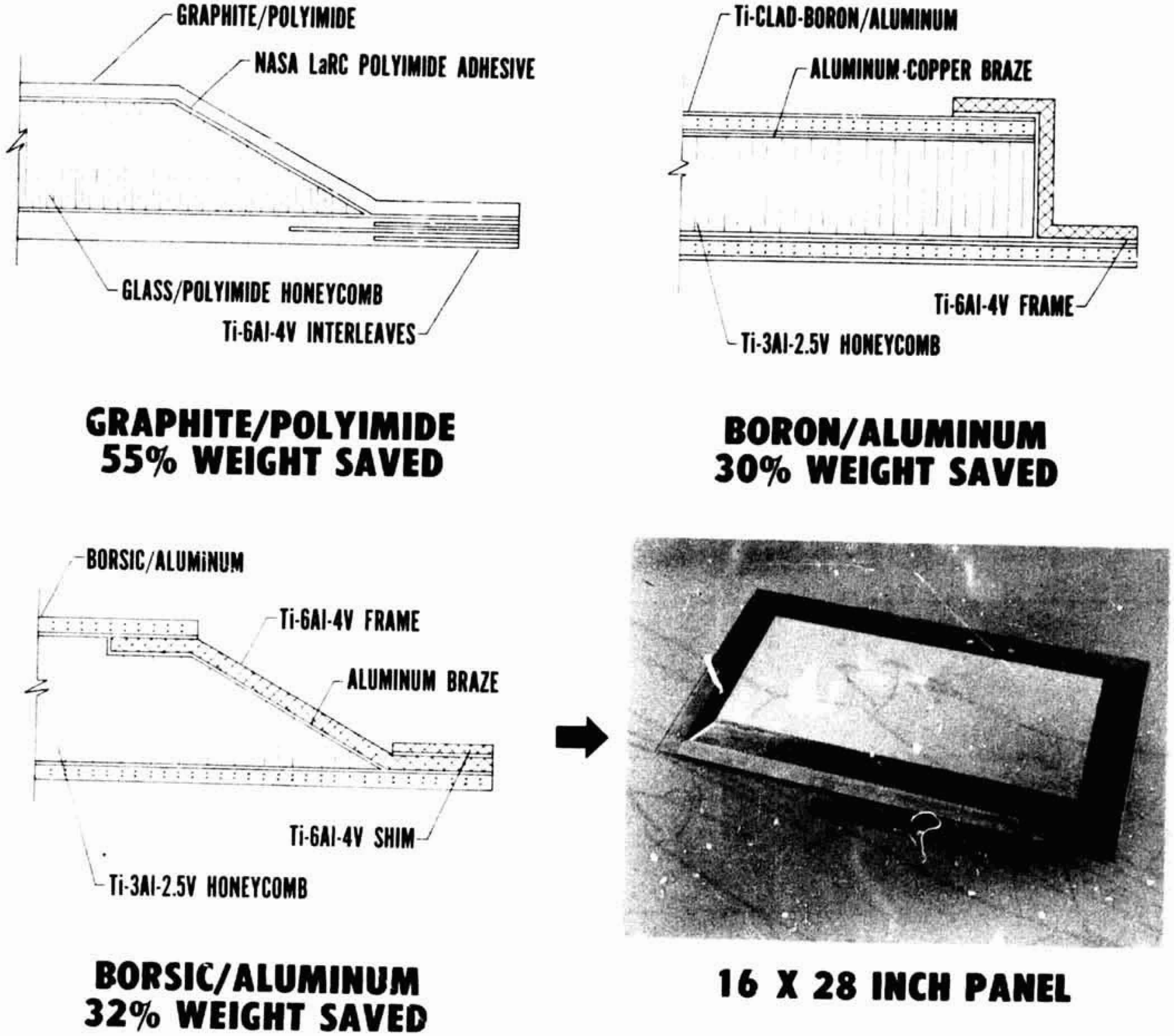


FIGURE 15. - COMPOSITE PANELS FOR SUPERSONIC AIRCRAFT

NASA-Langley, 1976