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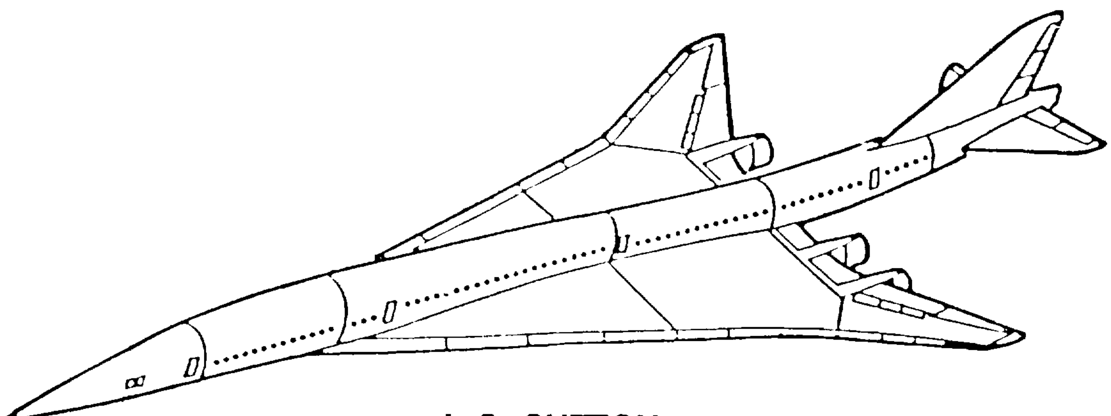
HSCT McDONNELL DOUGLAS

HSCT MATERIALS AND STRUCTURES - AN MDC PERSPECTIVE



J. O. SUTTON

HIGH SPEED RESEARCH WORKSHOP
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HSCT MATERIALS OVERVIEW

This discussion is divided into four parts.

The first section describes the key HSCT features which drive the materials selection.

The second section describes a top-down approach to determining the optimal material selection, considering weight and production economics. This process is based upon the effects of temperature on the material properties of candidate material systems, and the known or anticipated material price and fabrication and assembly costs.

The third section describes a bottoms-up approach to material selection, in concert with the selection of structural concepts. This process applies a point design optimization to specific airframe locations and extrapolates them to determine an optimal material selection. The two methods are then compared for the specific M = 2.4 study baseline aircraft.

The final section describes the key materials and structures related tasks which remain to be accomplished prior to proceeding with the building of an HSCT aircraft.

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HSCT MATERIALS OVERVIEW

- KEY MATERIAL USAGE DRIVERS
- PRELIMINARY MATERIAL EVALUATION
- PRELIMINARY STRUCTURAL EVALUATION
- KEY DEVELOPMENT TASKS

HIGHER MACH NUMBERS DEMAND MORE EFFICIENT AIRFRAMES

The gross weight breakdown of two aircraft with the same payload and range (300 passengers, 5500 nmi) are compared. It is shown that the supersonic aircraft requires considerably higher fuel fraction than the subsonic aircraft to fly the same mission. This places a premium on control of non-payload weights. In particular, the airframe structure weight must be a considerably smaller fraction of the whole, while surviving in a much more aggressive environment. This presents a challenge to the airframe designer to incorporate more efficient materials and structural concepts, with no compromise in safety.

At the same time, the aircraft must be both profitable to operate and to produce. Thus the materials and structural concepts selected must lend themselves to economical production methods, and be both reliable and maintainable in service.

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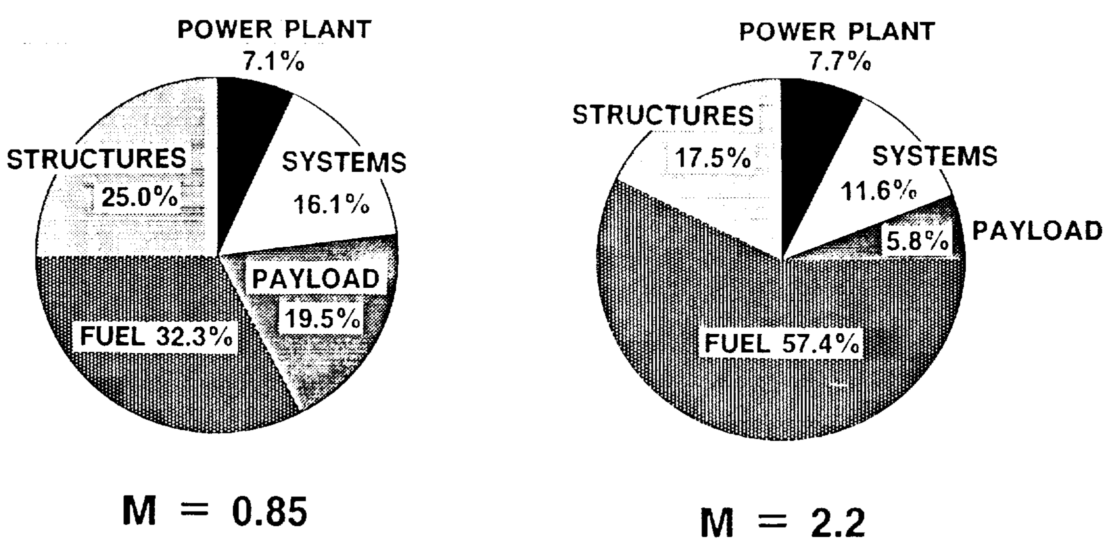
HIGHER MACH NUMBERS DEMAND MORE EFFICIENT AIRFRAMES



HSCT AIRFRAME WEIGHT IS PRIMARILY DRIVEN BY STIFFNESS

An examination of the weight breakdown of the structure of a previous study HSCT project shows that specific fractions of the total weight can be assigned to a small number of dominant design requirements. In particular, the largest single design requirement is for stiffness, either to control buckling, crippling, or aeroelastic phenomena. Thus materials which have a high ratio of modulus of elasticity to density (specific stiffness) should show a weight advantage in such applications.

Similarly, a significant fraction of the weight is determined by the material strength, either in the form of the ultimate strength or a lower strength allowable which permits safe operation with damage, extends the life of the part, or prevents excessive physical distortion over the life of the airframe. For such components, high specific strength will be beneficial.

Finally the smallest fraction of the airframe weight is determined by minimum gauge applications or for other factors unrelated to strength or stiffness, such as paint or sealants. For such applications, low density is the primary means of reducing weight.

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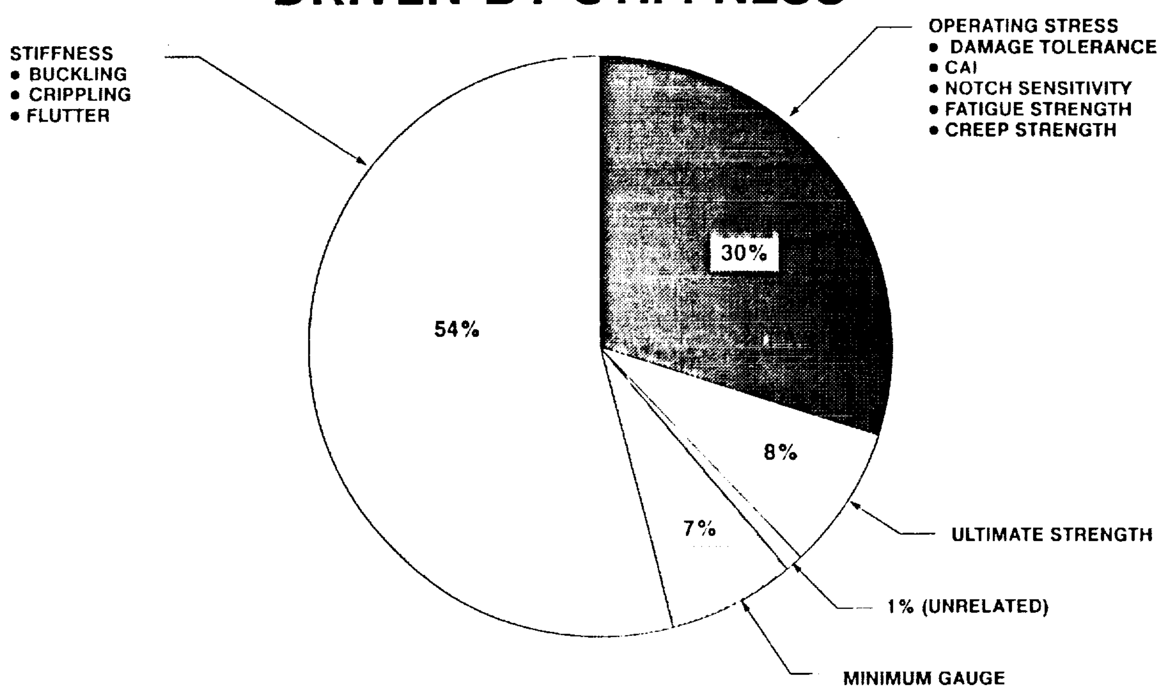
HSCT AIRFRAME WEIGHT IS PRIMARILY DRIVEN BY STIFFNESS



HSCT MATERIAL SELECTION IS DRIVEN BY:

Considering the previous discussion, the airframe weight may be considered to be strongly influenced by the use factors: stiffness, strength, and density, and the generalized candidate material properties. In addition, other factors such as creep, stability, and producibility and maintainability will enter into the material selection.

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HSCT MATERIAL SELECTION IS DRIVEN BY:

- HIGH SPECIFIC STRENGTH, STIFFNESS
- LONG-TERM STRENGTH, STIFFNESS, DURABILITY, DAMAGE TOLER- TOLERANCE, CORROSION RESISTANCE
- LONG-TERM THERMO-MECHANICAL AND THERMO-CHEMICAL STABILITY
- AVAILABILITY, COST
- ENVIRONMENTALLY ACCEPTABLE PROCCESSING
- GOOD PRODUCIBILITY, MAINTAINABILITY

EIGHT BASIC MATERIAL SYSTEMS WERE SELECTED FOR PERFORMANCE EVALUATION

Materials representing monolithic metals, organic composites, reinforced metals, and metal matrix composites were selected for evaluation over a Mach number range from 1.6 to 2.4. This represents a field surface temperature exposure range of from 100 to 500 F. While stagnation temperatures at the nose, and the leading edge temperatures of wing and tails are considerably higher, these regions represent small fractions of the total airframe weight, and do not influence the general material selection process.

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EIGHT BASIC MATERIAL SYSTEMS WERE SELECTED FOR PERFORMANCE EVALUATION

ALUMINUM (2024)	C/PMR (C6K/PMR-15)
ALUMINUM (2618)	DRETA (TARGET)
TITANIUM (6-4)	AMMC (6061/SCS-8)
C/BMI (IM6/5245C)	TMC (15-3/SCS-6)

PRELIMINARY MATERIAL EVALUATION IS GUIDED BY RELATIVE PERFORMANCE

For the top-down material evaluation study, the airframe weight was assumed to be composed of three parts: that determined by stiffness requirements, by strength requirements, and by non material-related requirements. This was accomplished by determining a relative weight resulting from the product of the use factor (described previously), the performance factor (which is ratio of the strength or stiffness of the evaluated material to a reference material at the relevant temperature), and the density factor (the ratio of the evaluated material density to that of the reference material). Thus the airframe weight for the reference material would always be 1.0, and the weight fractions of the airframe determined for each candidate material could be added in various combinations to determine the relative weight of any mix of materials. This was evaluated at each temperature range from M = 1.6 to M = 3.0.

Similarly, the relative cost to produce each weight fraction in each material could be determined by multipliying the appropriate weight factor, determined above, by the cost factor (the ratio of the cost to produce (material + fab + assembly) a pound of the candidate material relative to the refernce material). Thus, the cost to produce the airframe in the reference material is always 1.0, and the cost fractions of the airframe determined for each candidate material could be added in various combinations to determine the cost of any mix of materials.

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PRELIMINARY MATERIAL EVALUATION IS GUIDED BY RELATIVE PERFORMANCE

- **AIRFRAME WEIGHT =**

  $\sum$ **USE FACTOR X PERFORMANCE FACTOR X DENSITY FACTOR**

- **AIRFRAME COST =**

  $\sum$ **WEIGHT FACTOR X ASSEMBLED COST FACTOR**

- PERFORMANCE FACTOR IS BASED ON STIFFNESS AND STRENGTH AT RELEVANT TEMPERATURE
- THERMAL STABILITY OF ADVANCED MATERIALS IS ASSUMED TO BE ADEQUATE THROUGHOUT USE TEMPERATURE RANGE

THE BEST HSTC "MATERIAL" IS A COMBINATION

Following evaluation of the relative weights and costs of each material system candidates across the study speed range, combinations of materials were determined which gave either the lowest airframe weight or the lowest airframe cost. As might be expected, only at the very highest speed/temperature range did a single material appear to optimum for use throughout the airframe. Otherwise, a combination of materials produced the lowest weight, and a different combination produced the lowest cost, although the polymer composite material system did tend to contribute to both low weight and low cost.

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THE BEST HSCT "MATERIAL" IS A COMBINATION

MACH NO.	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2
ALUMINUM - 2024	$	$	$						
ALUMINUM - 2618									
TI 6-4	W	W	W						$
C/BMI	W $	W $	W $	W $	W $				
C/PMR-15						W	W	W	
DRETA				$	$	$	$	$	
AMC									
TMC				W	W	W	W	W	W

POLYMER COMPOSITE AND TMC MIX GIVES LIGHTEST AIRFRAME WEIGHT AT M2.4

Current HSCT studies are limited to the Mach range of 1.6 to 2.4, with the lowest value based on eroding productivity, and the highest on possible environmental and technical risks. Specifically examining the M=2.4 design point, the material evaluation process finds that a mixture of TMC and C/BMI gives the lightest airframe weight. However, it is also very nearly the most expensive. It is interesting to see what the penalties and benefits are of adjusting the material mix to produce a more balanced combination of weight and cost. This is discussed on the next viewfoil.

HSCT MCDONNELL DOUGLAS

POLYMER COMPOSITE AND TMC MIX GIVES LIGHTEST AIRFRAME WEIGHT AT M2.4

MACH NO.	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2
ALUMINUM - 2024	$	$	$						
ALUMINUM - 2618									
TI 6-4	W	W	W						$
C/BMI	W $	W $	W $	W $	W $				
C/PMR-15						W	W	W	
DRETA				$	$	$	$	$	
AMC									
TMC				W	W	W	W	W	W

MANY MATERIAL COMBINATIONS ARE COST EFFECTIVE AT M2.4

Because of the extremely high specific cost of TMC, almost any other combination of materials produces a significantly les expensive airframe. To determine the best compromise, the seven next-best weight combinations were compared to the "ideal" TMC-C/BMI material set on the basis of weight and cost. It is immediately apparent that a combination of Titanium and C/BMI gives a 62% to 71% reduction in airframe cost (4:1!) depending on the fabrication concept used for the C/BMI components, with only a 2.8% penalty in airframe weight.

The third-best compromise substitutes DRETA for Titanium, resulting in an even larger (76%) cost reduction, at the expense of a 7.4% increase in airframe weight. If the specific strength of DRETA could be increased by 10%, the weight penalty would be eliminated and the cost savings increased to 78%.

The conclusion of the M2.4 study is that the combination of Titanium and C/BMI represents the most cost-effective material combination, especially if the low-cost polymer fabrication processes now under development can be perfected. As a back-up, effort shold be made to improve the specific strength of the DRETA material.

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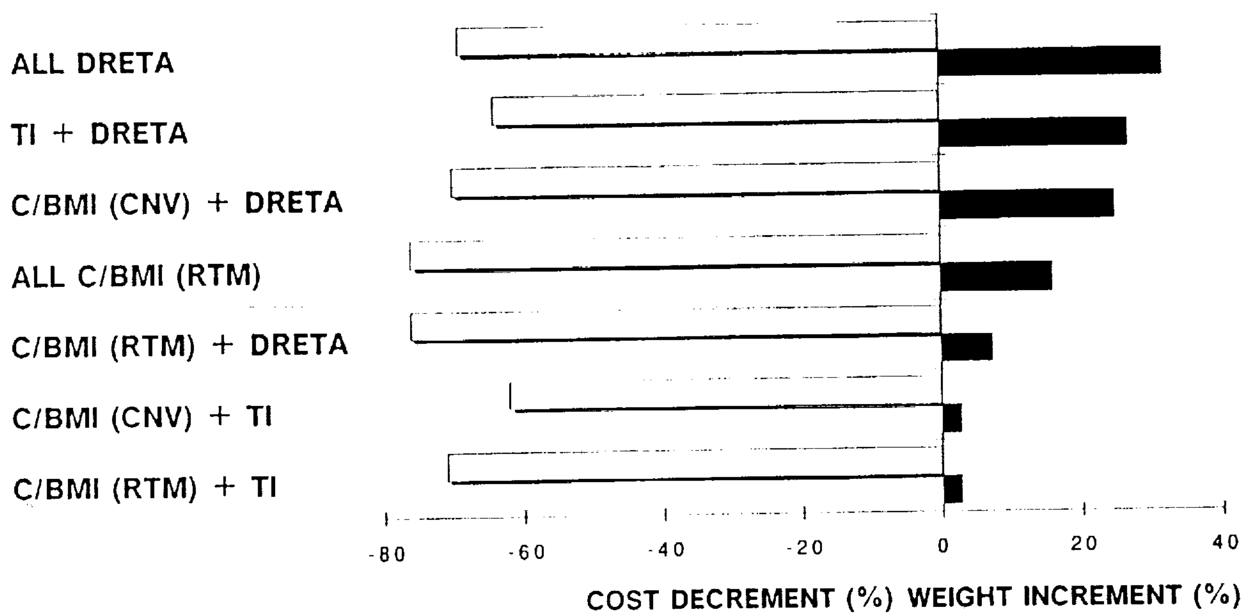
MANY MATERIAL COMBINATIONS ARE COST EFFECTIVE AT M2.4



(COMPARED TO LIGHTEST COMBINATION: C/BMI + TMC)

POLYMER COMPOSITE AND TI MIX GIVES LIGHTEST AIRFRAME WEIGHT AT M1.6

When the results of the material evaluation process are applied to the lowest end of the speed/temperature range, the results are somewhat different. Here, the C/BMI material is again selected based on both high specific stiffness, low density, and the potential for very low fabrication costs. However, rather than TMC, Titanium emerges as the most weight efficient companion material based on high specific strength. From the standpoint of cost, the low relative cost of conventional aluminum alloy structure makes them the logical choice for the cheapest airframe.

As with the M=2.4 example, it is instructive to examine the cost/benefit possible with other combinations of materials at this speed range. This is done on the next viewfoil.

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POLYMER COMPOSITE AND TI MIX GIVES LIGHTEST AIRFRAME WEIGHT AT M1.6

MACH NO.	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2
ALUMINUM - 2024	$	$	$						
ALUMINUM - 2618									
TI 6-4	W	W	W						$
C/BMI	W $	W $	W $	W $	W $				
C/PMR-15						W	W	W	
DRETA				$	$	$	$	$	
AMC									
TMC				W	W	W	W	W	W

MATERIALS AND STRUCTURAL CONCEPTS

In order to confirm that the top-down material selection process described above is reasonable, a bottom -up approach was taken by the point design of specific structural panels at various points on the fuselage and wing, weight-optimizing those panels in each material system for each of four structural concepts, and extrapolating the results to the complete aircraft. The best-weight combination was selected to compare to the material selection from the top-down approach.

The optimization process includes the effects of the in-plane forces resulting from the temperatures, and the out-of-plane moments resulting from through-the-thickness thermal gradients. It does not include the complex three-dimensional thermal forces resulting from the overall thermal load distribution on the entire airframe. This type of study would require a full-up FEM solution of the airframe, and will be accomplished after the preliminary material selections and internal structural optimizations are accomplished.

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MATERIALS AND STRUCTURAL CONCEPTS

MATERIAL SYSTEMS

CONVENTIONAL ALUMINUM ALLOYS

ELEVATED TEMPERATURE ALUMINUM

- MONOLITHIC
- DISCONTINUOUSLY REINFORCED
- CONTINUOUSLY REINFORCED

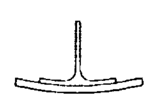
TITANIUM PRODUCTS

POLYMERIC CARBON FIBERS WITH RESINS:

- EPOXY
- THERMOPLASTIC
- BMI
- PMR

STRUCTURAL CONCEPTS

HAT



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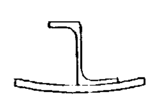

ZEE

HONEYCOMB

SANDWICH STRUCTURE PROVIDES LOWEST WING PANEL WEIGHTS

In the outboard wing, which is the most highly loaded region, the optimum solution strongly favored a sandwich construction. In terms of the material system, the basic Titanium alloy was the lightest selection, closely followed by the DRETA.

In the less-highly loaded forward inboard wing, there was not a strong trend in construction concept; however, the Polymer Composite material was strongly indicated. Since this material's lowest cost construction mode lends itself to stiffened sheet construction, the Zee-stiffened panel concept was selected.

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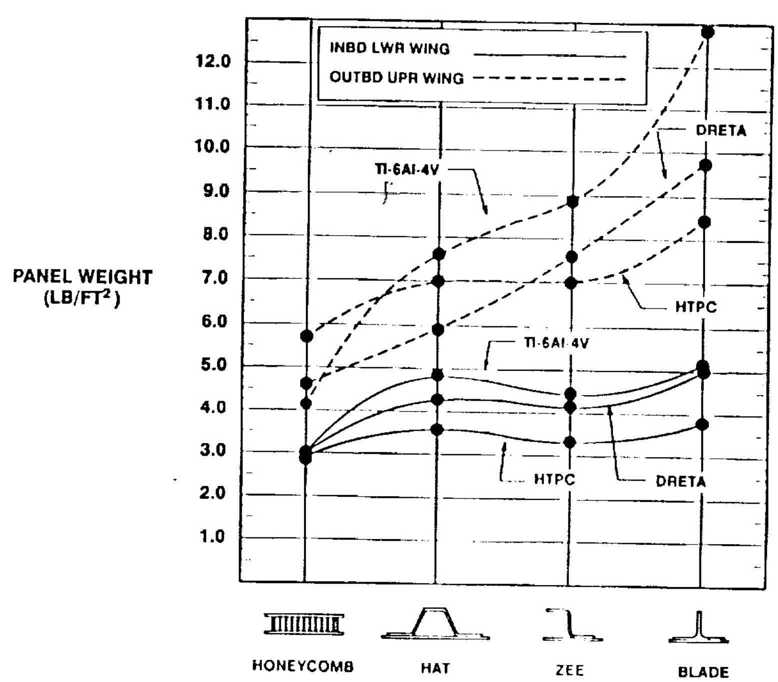
SANDWICH STRUCTURE PROVIDES LOWEST WING PANEL WEIGHTS



STIFFENED SHEET STRUCTURE PROVIDES LOWEST FUSELAGE PANEL WEIGHT

In the highly loaded aft fuselage region, the Titanium sandwich concept was again the most weight efficient; however, the Zee-stiffened Polymer Composite construction was virtually identical in weight, and considerably lower in cost.

In the more lightly loaded forward fuselage, the Polymer Composite material provided the lightest panel weights, regardless of the construction concept. Considering that a uniform construction concept is preferred throughout the fuselage (at least in the pressurized section) a further study was performed limiting the entire fuselage to one material and one construction concept. In that case, the Zee-stiffened Polymer Composite concept produced the lightest fuselage structure.

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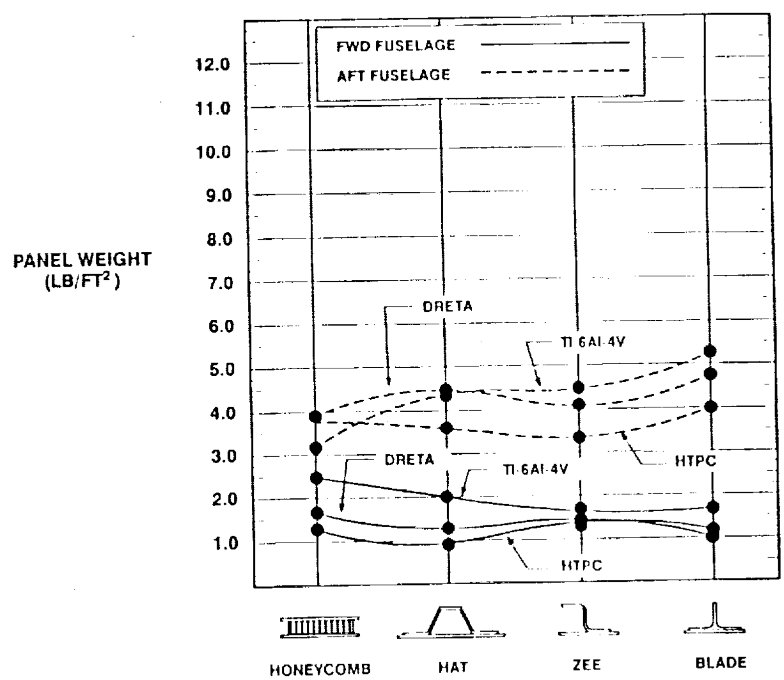
STIFFENED SHEET STRUCTURE PROVIDES LOWEST FUSELAGE PANEL WEIGHTS



MDC 1991 M2.4 MATERIAL STUDY DESIGN FEATURES MULTIPLE MATERIALS

Comparing the results of the top-down material property-oriented material evaluation process with the bottom-up point design approach shows that for the Mach 2.4 study vehicle, there is no contradiction. Each approach confirms that a Polymer Composite (C/BMI) and Titanium airframe represents the best mix of light weight and affordability. Each approach also confirms that with some incremental improvement, The DRETA material can be an effective economical substitute for Titanium in this speed range.

A small portion of the airframe, driven by the much higher temperatures of the nose stagnation region and the engine supports will remain as conventional Titanium stiffened sheet structures.

Further work will extend this material selection process validation to the Mach 1.6 aircraft, and later to an intermediate Mach number.

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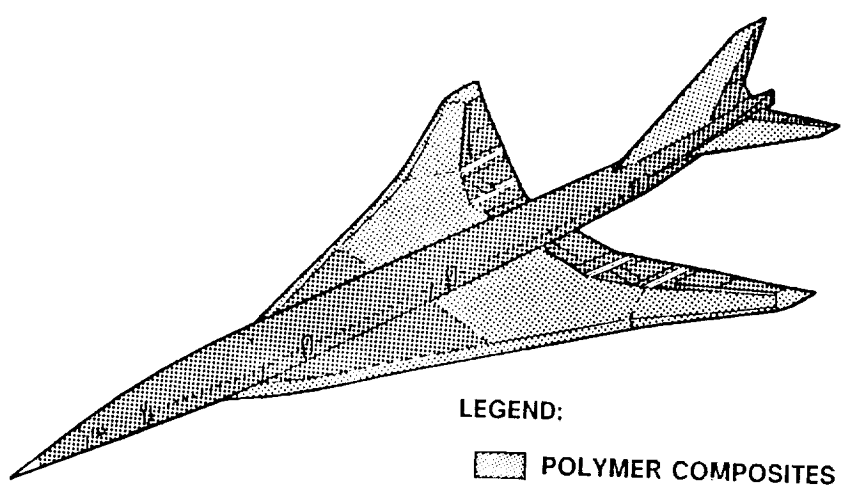
MDC 1991 M2.4 MATERIAL STUDY DESIGN FEATURES MULTIPLE MATERIALS



LEGEND:

POLYMER COMPOSITES

TITANIUM SANDWICH

TITANIUM STIFFENED SHEET

PANEL ANALYSES SHOW GENERAL DESIGN CONCLUSIONS

A few general design conclusions may be drawn from the foregoing work. In general, lightly loaded and minimum gauge structure is best made from Polymer Composites, where the inherently low density and higher specific stiffness are used to fullest advantage. Lightly loaded sandwich structure is not the best solution, unless it is designed by buckling requirements. Otherwise there is a tendency for lightly loaded sandwich to provide two minimum gauges instead of one.

In highly loaded regions, metallic sandwiches were generally lightest, because they could most easily be forced into a strength-critical failure mode, thus taking advantage of their generally higher specific strength. Polymer Composite sandwich construction tends to optimize to thicker sections, which are not always allowable for reasons of space, thus driving the cover sheets to heavier than optimum thicknesses.

Without detailed evaluation of individual point-design cases, it is not possible to generalize about the lightest construction and/or material when considering biaxial or combined thermo-mechanical loads, which are strongly influenced by the CTE of the material.

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PANEL ANALYSES SHOW GENERAL DESIGN CONCLUSIONS

IN LOWLY LOADED AREAS -

- STIFFENED POLYMERIC COMPOSITES ARE LIGHTEST
- SANDWICH STRUCTURE CAN BE VERY HEAVY WITH HIGH MINIMUM MARGINS

IN HIGHLY LOADED AREAS -

- TITANIUM SANDWICH IS GENERALLY LIGHTEST
- POLYMERIC COMPOSITES ARE HEAVIER IN SPITE OF LOWER THERMALLY-INDUCED LOADS

SPECIFIC TRENDS REGARDING MATERIAL AND STRUCTURE ARE NOT APPARENT EVEN WITH SIMPLE LOADINGS

MANY KEY TASKS REMAIN

Reduction of technical and economic risk is of paramount importance in commiting to an HSCT. Generations of work have gone into the demonstration and validation of materials and methods for conventional aircraft, all of which must be duplicated in a very short period of time to ensure an equivalent level of safety and risk.

Each of the advanced, and some of the conventional, materials which may contribute to the success of the HSCT must be fully characterized for their long-term behavior under thermal-mechanical loadings. This applies as well to the construcrtion concepts and joining technologies.

In order to provide such characterization, it is essential to develop, verify and standardize the testing processes required. In particular, it is essential to develop trustworthy accelerated testing processes.

Some incremental improvement of properties in advanced materials could open the way to considerable cost reduction by the replacement of Titanium in the airframe.

Finally, it is crucial that LFC technology be integrated at the earliest possible date into design concepts, as it may be expected to markedly influence the selection of bosth materials and structural concepts.

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MANY KEY TASKS REMAIN

CHARACTERIZATION OF LONG-TERM THERMAL BEHAVIOR OF POLYMER COMPOSITES, ADVANCED METALS, AND JOINTS

PERFECTION OF LOW-COST FABRICATION METHODS FOR POLYMER COMPOSITES

10% - 12% IMPROVEMENT IN DRETA SPECIFIC STRENGTH

LFC VALUE MUST BE VERIFIED FOR EARLIEST INTEGRATION WITH STRUCTURES AND MATERIAL SYSTEMS

DEVELOPMENT, VERIFICATION AND STANDARDIZATION OF ACCELERATED AGING TEST METHODOLOGY

DEVELOPMENT, VERIFICATION AND STANDARDIZATION OF METHODOLOGY TO PREDICT TMF CRACK INITIATION AND GROWTH RATE

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This publication is in four volumes and represents the compilation of papers presented at the First Annual High-Speed Research Workshop held in Williamsburg, Virginia, on May 14-16, 1991. This NASA-sponsored workshop provided a national forum for presenting and discussing important technology issues related to the definition of an economically viable, and environmentally compatible High-Speed Civil Transport. The Workshop and this publication are organized into 13 sessions, with Session 1 presenting NASA and Industry overviews of the High-Speed Civil Transport Program. The remaining sessions are developed around the technical components of NASA's Phase I High-Speed Research Program, which addresses the environmental issues of atmospheric emissions, community noise and sonic boom. Because of the criticality of the materials and structures technology area, and the long-term nature of the supporting research requirements, a session was added in this area to capture the ongoing work at NASA Lewis and NASA Langley and within industry.

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