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$S35-07$

EPM Exhaust Nozzle Team Mission

"Develop and demonstrate by 1999 the materials and fabrication processes, and the design and life prediction methodology for an economically feasible, low noise HSCT exhaust nozzle"

Figure 1

The United States has embarked on a national effort to develop the technology necessary to produce a Mach 2.4 High Speed Civil Transport (HSCT) for entry into service by the year 2005. The viability of this aircraft is contingent upon its meeting both economic and environmental requirements. Two engine components have been identified as critical to the environmental acceptability of the HSCT. These include a combustor with significantly lower emissions than are feasible with current technology, and a lightweight exhaust nozzle that meets community noise standards.

The Enabling Propulsion Materials (EPM) program will develop the advanced structural materials, materials fabrication processes, structural analysis and life prediction tools for the HSCT combustor and low noise exhaust nozzle. This is being accomplished through the coordinated efforts of the NASA Lewis Research Center, General Electric Aircraft Engines and Pratt & Whitney. The mission of the EPM Exhaust Nozzle Team is to develop and demonstrate this technology by the year 1999 to enable its timely incorporation into HSCT propulsion systems.

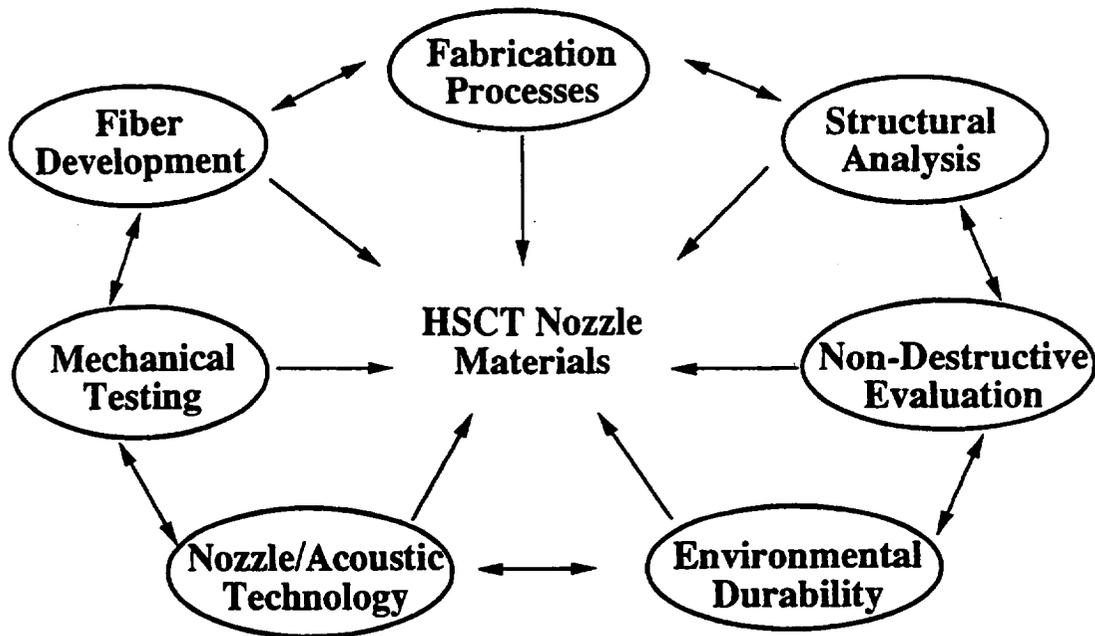# NOZZLE MATERIALS DEVELOPMENT REQUIRES A MULTI-DISCIPLINARY TEAM

Figure 2

The successful and timely development of advanced materials technology for HSCT exhaust nozzle applications requires the integrated efforts of engineers in a variety of technical disciplines. These include material fabrication, fiber technology, mechanical testing, nozzle and acoustic technology, environmental durability, non-destructive evaluation and structural analysis. In addition, technical collaboration in each of these areas must be efficiently coordinated between NASA, GE, Pratt & Whitney and numerous subcontractors such that viable nozzle materials and designs are developed by 1999.

To accomplish this coordination between multiple organizations and technical disciplines, an Integrated Product Development management approach is used in the EPM program, in which technical and management decisions are made by multi-disciplinary teams that are composed of members from each of the three organizations.

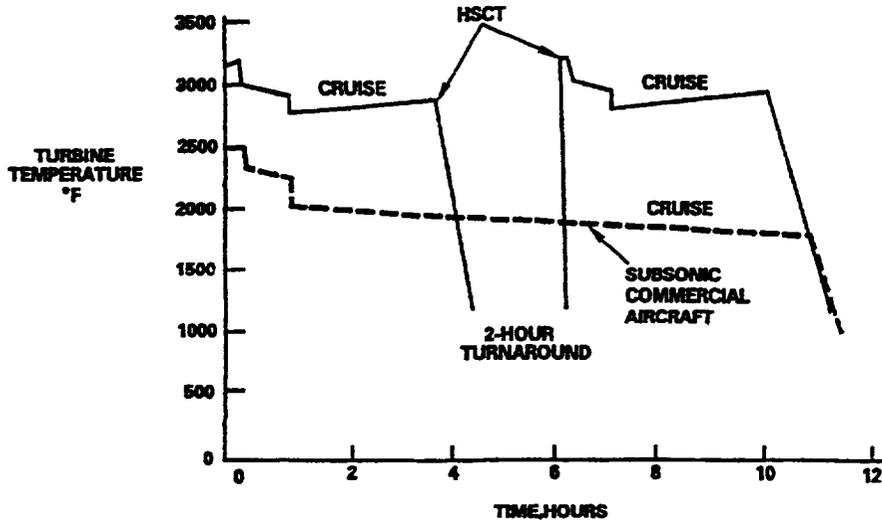# HSCT MISSION CYCLE DEMANDS HIGH TEMPERATURE DURABILITY

Figure 3

HSCT mission requirements are much more severe than those for current commercial engines. This is due primarily to the extended Mach 2.4 cruise, which results in cyclic thermal exposure of the engine materials for four-hour intervals at extreme temperatures, as shown in Figure 3. At cruise conditions, maximum material temperatures in critical nozzle components could range from 1800° to 2000°F. Thrust augmentation could increase temperatures to 2400°F in some components. The durability goal for nozzle materials is an 18,000 hour lifetime, with 3000 hours of that time spent in augmentation.

If the HSCT exhaust nozzle were made using current materials technology, cooling air would be required to reduce the material temperatures. Engine cycle studies have indicated that the use of fan cooling air in the nozzle would impose an acceptably high performance penalty. Therefore, advanced nozzle materials must be developed to operate at high temperatures with no fan cooling air.

TWO NOZZLE CONCEPTS ARE BEING CONSIDERED
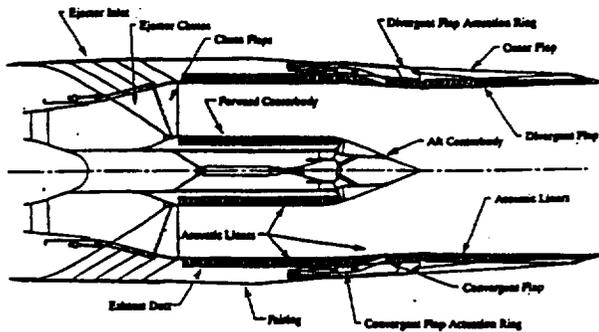
Axisymmetric No Plug Nozzle

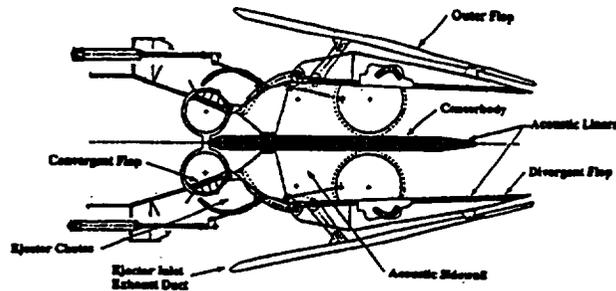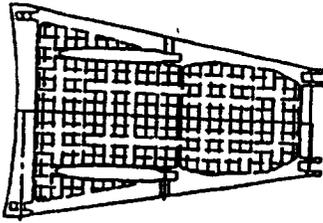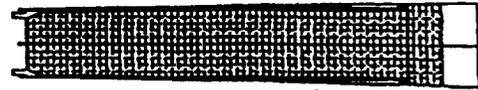**2D Convergent/Divergent Nozzle**

Figure 4

HSCT engines will also require various amounts of nozzle noise suppression in order to meet FAR 36 Stage III noise requirements. The amount of noise suppression required will depend on the exhaust velocity at takeoff, which varies with engine type. To meet the combined challenges of noise suppression and high temperature durability, two types of mixer-ejector nozzle designs are being evaluated, as shown in Figure 4. Depending on the engine exhaust velocity, nozzle flow entrainments of up to 120 percent of the engine core airflow may be required. The specific weight of the nozzle (nozzle weight/engine airflow) increases as the flow entrainment required for jet noise suppression is increased. Nozzle designs must therefore include acoustic/weight tradeoff considerations. In comparison to the 2D design, the axisymmetric nozzle has slightly better performance at the cost of increased design complexity and weight. To reduce weight, high specific strength composite materials will be used in critical nozzle subcomponents. The EPM goal is to develop high temperature, lightweight composite materials such that nozzle weight can be reduced by 30 percent relative to current materials technology, while achieving a life of 18,000 hours at temperatures up to 2400°F.
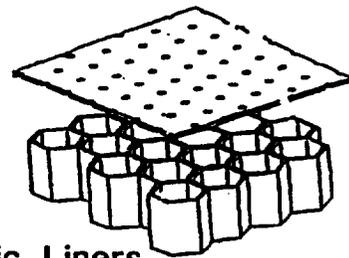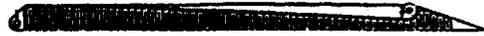
CRITICAL NOZZLE COMPONENTS HAVE BEEN IDENTIFIED

Convergent Flaps

Divergent Flaps

Chutes

Acoustic Liners

Figure 5

An evaluation of the individual nozzle subcomponents resulted in identification of the convergent and divergent flaps, ejector chutes and acoustic liners as critical subcomponents that would require advanced materials for HSCT applications. In addition to high temperature durability, the materials for these components must be damage tolerant to avoid catastrophic failure, and must have high cycle fatigue resistance to withstand acoustic and vibratory loads. The considerations involved in developing conceptual designs for these components, shown in Figure 5, include joining and attachment requirements, as well as ease of fabrication and machining. Geometric complexity is also an important factor when considering material fabrication and shaping requirements.

EPM MATERIALS DEVELOPMENT IS DIRECTED TOWARD COMPOSITE GOAL PROPERTIES

Physical Properties

Density	0.19 lb/in³
Thermal expansion	6 - 8 in/in - °F
Elastic Modulus	30 - 40 Msi

Mechanical Properties

	Room Temperature	2200° - 2400°F
Tensile Strength	175 Ksi	100 Ksi
Yield Strength (0.2%)	170 Ksi	95 Ksi
Strain to Failure	1 - 2 %	2 - 10 %
Stress Rupture*	N/A	40 - 50 Ksi
Creep Elongation* (o.2%)	N/A	25 - 35 Ksi
Fracture Toughness	10 - 20 Ksi · in$^{1/2}$	10 - 20 Ksi · in$^{1/2}$
LCF (10,000 cycles)	50 Ksi	10 - 20 Ksi

*in 1000 hours

Figure 6

The current conceptual designs of critical nozzle subcomponents are based on projected properties of EPM materials in the year 1999. These "goal properties" were chosen with the assumption that significant improvements in the physical and mechanical properties of MMC/IMC materials would result from the material development efforts in the EPM program. Preliminary physical and mechanical goal properties for HSCT exhaust nozzle materials are shown in Figure 6.

ADVANCED HIGH TEMPERATURE COMPOSITES ARE NEEDED TO REACH MATERIAL GOAL PROPERTIES
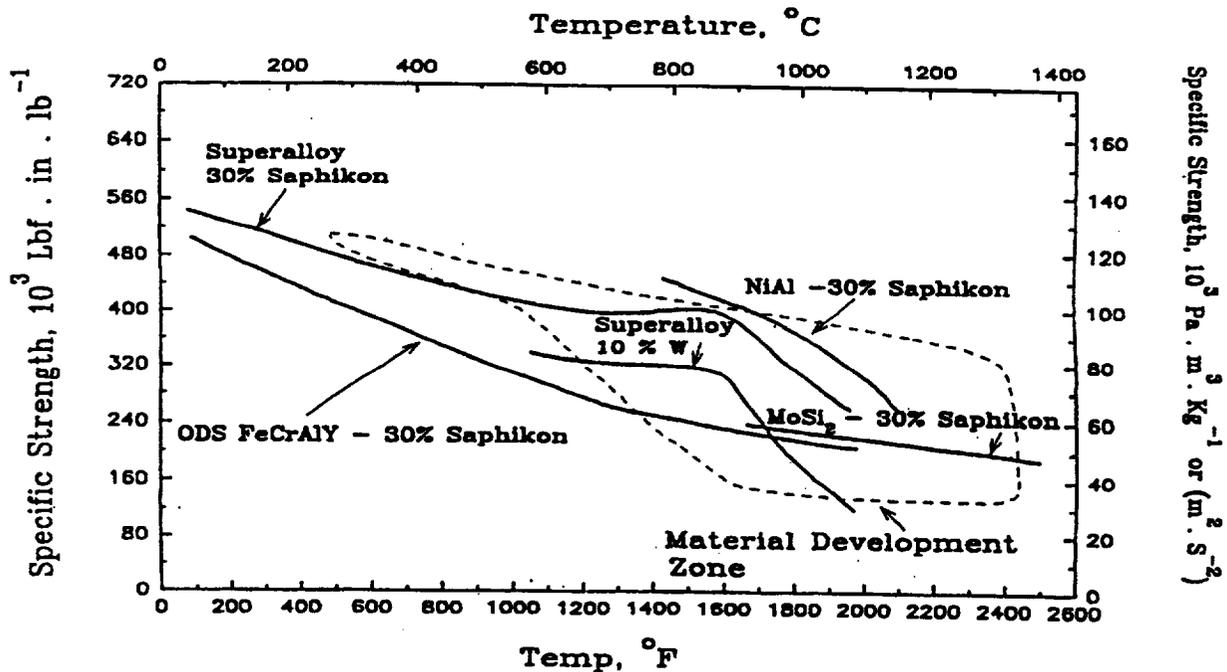

Figure 7

The initial selection of candidate exhaust nozzle structural materials is based primarily on the predicted specific strength and temperature capability of the materials. Specific strengths include tensile, creep, and rupture strength, while temperature capability includes oxidation resistance, microstructural and chemical stability, and durability. Advanced materials such as metal, intermetallic, and ceramic matrix composites (MMC, IMC, and CMC) offer the potential to replace current materials to produce a lighter exhaust nozzle that requires no fan cooling air. MMC/IMC composite systems identified as having the best potential for meeting HSCT exhaust material requirements include $MoSi_2$-, NiAl-, ODS-, MCrAl-, and superalloy-base composites. Commercially available ceramics are being considered for acoustic treatments. Figure 7 shows the material development zone of interest for HSCT nozzle applications, in which predicted specific strengths of candidate MMC and IMC systems are shown. A material development approach has been established that focuses on meeting material property requirements that are defined based on design needs. This development approach includes regular assessments of updated design requirements for material properties, along with consideration of new candidate materials. The materials development plan therefore includes three major efforts: Critical Screening/Process Evaluations, Materials Refinement, and Scale Up.

METAL MATRIX COMPOSITE DEVELOPMENT

- **Haynes alloy 230** (Ni-base alloy)
  - ✓ Good high temperature tensile Strength
  - ✓ High Ductility
  - x Poor Oxidation above 1000°C

- **INCO MA 956** (Fe-base Alloy)
  - ✓ CTE slightly better than Ni-base alloy
  - ✓ Good tensile Strength to 1200°C
  - x Relatively Poor Ductility

- **INCO MA3002** (Ni-base alloy)
  - ✓ Oxidation Resistance Comparable to MA 956
  - ✓ Good tensile Strength to 1200°C
  - ✓ Good Ductility
  - x CTE slightly worse than Fe-base alloy

Figure 8

Superalloy and MCrAlY base matrices are considered good candidate materials for exhaust nozzle applications due to their high ductility and toughness at low temperatures, and proven oxidation resistance at temperatures as high as 2200°F. Composite metal matrix candidates include Fe and Ni base matrices such as MA 956 and Haynes 230, where elemental additions are designed to increase oxidation resistance or to provide high temperature strengthening. Candidate reinforcements can be separated into two categories: ceramic and refractory metal fibers. The first category includes alumina single crystal fiber and polycrystalline fiber tows. The alumina single crystal fiber is thermodynamically stable in the metal matrix alloys being considered, possesses relatively low density and is environmentally stable. Marginal strength at elevated temperature and fiber damage due to processing are major concerns, however. Protective coatings are being developed to minimize fiber damage during processing, and tailored fiber/matrix bonding approaches are being investigated. A comparatively small effort to develop composites using refractory metal reinforcements is also being considered. Concerns regarding refractory fibers include their relatively poor oxidation resistance and possible reaction with the MMC matrices.

INTERMETALLIC MATRIX COMPOSITE DEVELOPMENT

NiAl-Base Composite:

- **Stoichiometric NiAl:**
    ✓ Excellent oxidation resistance
       (isothermal and Cyclic up to 2200°F
    x Low Ductility at Room Temperature
    x CTE Mismatch with Sapphire fibers

MoSi2-Base Composite:

   ✓ Excellent High Temperature oxidation
      (Isothermal and Cyclic up to 2400°F
   ✓ Elevated Tensile Strengths
   ✓ Ductility above 1800°F
   ✓ CTE close to Sapphire Fiber
   x Pesting

Figure 9

Two material systems, NiAl-base alloys and $MoSi_2$-base alloys, are being considered as matrices for the development of intermetallic matrix composites. The stoichiometric NiAl compound has low density, excellent oxidation resistance, thermal stability to approximately 2000°-2200°F and reasonable strengths, but limited ductility at room temperature. Alloying additions are being investigated by several research groups within the EPM program to improve the ductility and strength of NiAl. Alumina single crystal fiber would be used as the reinforcement for this system. The effect of thermal expansion mismatch between the matrix and the fiber may require either the use of protective fiber coatings or the addition of a low thermal expansion phase to the matrix.

Molybdenum disilicide ($MoSi_2$) has excellent high temperature oxidation resistance, both isothermal and cyclic, to at least 2400°F, elevated temperature tensile strengths comparable to silicon carbide and silicon nitride, and ductility at temperatures above 1800°F. The evaluation of accelerated low temperature oxidation of $MoSi_2$, known as "pesting," is being addressed during the first critical screening phase of the program. The thermal expansion of $MoSi_2$ very closely matches that of sapphire, thereby minimizing thermal fatigue problems arising from fiber/matrix thermal expansion mismatch.

ACOUSTIC TESTING OF CANDIDATE LINER MATERIALS IS UNDERWAY
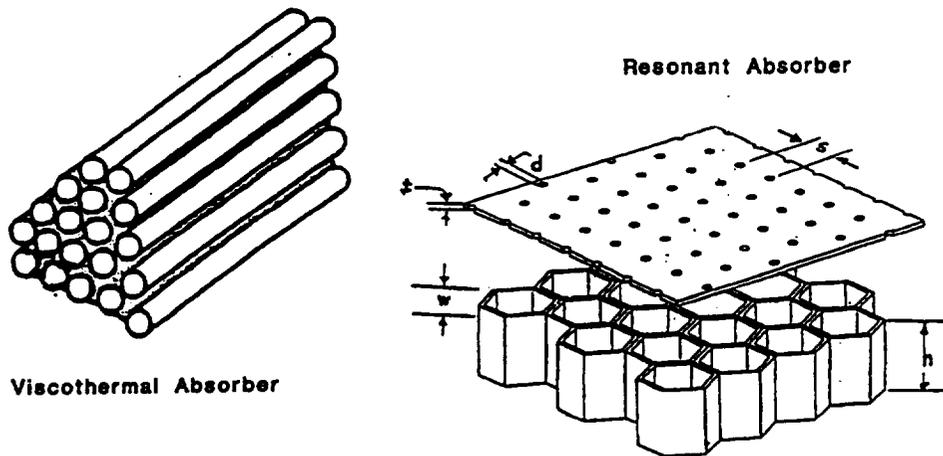
Resonant Absorber

Viscothermal Absorber

Figure 10

Acoustic liners are used to attenuate mixing noise generated by the entrainment of ambient air into the nozzle exhaust flow. Engine cycle analyses have shown that the temperatures of the acoustic liners could reach 2400°F during augmentation. A conceptual design of the HSCT exhaust nozzle assumes that the acoustic liner treatment is a ceramic matrix composite (CMC) tile of a lightweight bulk absorber material. The CMC tiles would be configured as an attenuator, analogous to current metal treatments, which consist of perforated plates with bulk absorbers or perforated plates with honeycomb attenuation structures, as shown in Figure 10. The materials under consideration for use in the nozzle acoustic liners include ceramic bulk absorbers, viscothermal absorbers, and CMC honeycomb resonant absorbers, which would present significant material fabrication challenges. An assessment of supplier fabrication capabilities is underway, and an industry consortium consisting of Boeing, 3M, McDonnell Douglas Technologies, Westinghouse and Dupont Lanxide has been formed to conduct acoustic trade studies and to perform the first in a series of laboratory acoustic tests on a variety of bulk absorber ceramics as part of the HSCT Ejector Liner Acoustic Technology Development Program.

FIBER DEVELOPMENT

SINGLE CRYSTAL OXIDE
MONOFILAMENTS

{
- Increase high temperature strength of Al_2O_3 fibers by process optimization
- Add small amount of dopant to alumina fibers to improve strength
- YAG and Al_2O_3/YAG fibers for better fiber toughness

POLYCRYSTALLINE ALUMINA
FIBER TOWS

{
- Increase creep resistance of fiber by adding a small amount of other oxides

Figure 11

Because the matrix materials for many intermetallic and superalloy-based composites do not have the required high temperature strength for HSCT nozzle applications, fibers are expected to carry practically all of the load at high temperatures. Single crystal and polycrystalline oxide fibers have been selected for NiAl-, superalloy-, and $MoSi_2$ - based composites, because of their chemical compatibility with the matrices and their environmental stability.

Initial development efforts have focused on alumina fibers. Single crystal (c-axis) alumina monofilaments with room temperature strengths greater than 400 ksi are currently commercially available from Saphikon, Inc. However, the strength of Saphikon fibers decreases to 100-150 ksi at 2000°F, which does not meet the requirements for HSCT nozzle materials. Therefore, development efforts have been initiated at Saphikon to increase the high temperature strength of Saphikon fibers. Several approaches are being pursued, including:

- Optimizing processing parameters for single crystal fiber growth

- Adding a small amount of dopant to the fibers.

Preliminary results from the process optimization studies are encouraging. Future efforts on single crystal oxide fiber development will include YAG and Al_2O_3 - YAG fibers.

FIBER COATING DEVELOPMENT

FUNCTION OF THE COATING	COMPOSITE SYSTEM		
	$NiAl/Al_2O_3$	Superalloy/ Al_2O_3	$MoSi_2/Al_2O_3$
Strengthen Fiber/Matrix Bond	X	X	
Reduce Residual Stress due to CTE Mismatch	X	X	
Increase Fracture Toughness at Room Temperature	X		X
Increase Fracture Toughness at Use Temperature			X
Prevent Fiber Strength Degradation During Processing	X	X	X

Figure 12

The fiber-matrix interface plays a key role in determining the mechanical properties of a composite material. The fiber/matrix interface can be modified via application of interfacial coatings to obtain the desired composite properties. Fiber coatings are needed for many different reasons, and are therefore system specific. The functions of fiber coatings in each of the composite material systems under consideration for HSCT nozzle applications are given below.

Al_2O_3/Superalloy
- Strengthen fiber-matrix bond
- Reduce the residual stresses due to CTE mismatch
- Prevent fiber strength degradation after processing

Al_2O_3/NiAl
- Strengthen fiber-matrix bond
- Reduce residual stresses due to CTE mismatch
- Increase room temperature fracture toughness
- Prevent fiber strength degradation after processing

Al_2O_3/MoSi$_2$
- Increase fracture toughness of composite
- Prevent fiber strength degradation after processing

Fiber coatings must be chemically compatible with both the matrix and the fiber; otherwise reaction barrier layers are required between the coating and the fiber or the matrix. The multiplicity of requirements for the fiber coatings, which are sometimes in contradiction to each other, make it difficult to select a coating composition for any given composite system. Multi-layer fiber coatings are sometimes used to accommodate conflicting coating requirements.

MATERIAL PROCESSING/FABRICATION APPROACHES ARE BEING EVALUATED

For MMC

- Tape Casting
- Foil/Fiber/Foil Processing
- Transient Liquid Consolidation
- Low Pressure Plasma Spray

For NiAl-base IMC

- Tape Casting
- Melt Infiltration
- Fiber Coating by PVD
- Foil/Fiber/Foil Process
- Infiltration with Matrix Powder
- Directional Solidification

For MoSi2-base IMC

- Tape Casting
- Chemical Vapor Infiltration
- Reactive Infiltration

Figure 13

The timely availability of advanced high temperature composites for use in HSCT engines depends upon our successful use of concurrent engineering concepts to develop acceptable fabrication processes for these materials. There are several potential methods of fabrication for each material under consideration in the EPM program. The applicability of any process depends on the particular material system that it is applied to, and the structural application. The processes under evaluation can be grouped into five general categories:

- Powder
- Foil
- Thermal Spray
- Casting
- Reaction

The specific processes that will be used to fabricate each of the composite material systems are shown in Figure 13.

EVALUATION CRITERIA GUIDE PROCESS DOWN-SELECTION

1	**PROVEN FEASIBILITY**
2	**EXPERIENCE**
3	**REPRODUCIBILITY**
4	**PROPERTIES**
5	**FIBER ARCHITECTURES**
6	**ADAPTABILITY TO DESIGN REQUIREMENTS**
7	**COST**
8	**SUBCONTRACTOR BASE**
9	**SCALE-UP POTENTIAL**

Figure 14

Critical assessments of the variety of fabrication processes investigated under the EPM program will be used to downselect those processes that are the most promising for the fabrication of nozzle materials. Initial process evaluations, based on characterization of the materials produced, will enable the early identification of material fabrication problems, and will provide insight into relationships among processing, structure, and material properties that will be used in down-selecting processes for further development. A critical test plan has been established to guide the evaluation of processes and to provide data for use in the down-select process. Nine separate criteria will be considered in the process down selection: proven feasibility, experience base, reproducibility, material properties, fiber architectures, adaptability to design requirements, cost, subcontractor base, and scale-up potential.

TAPE CASTING APPROACH WILL BE USED
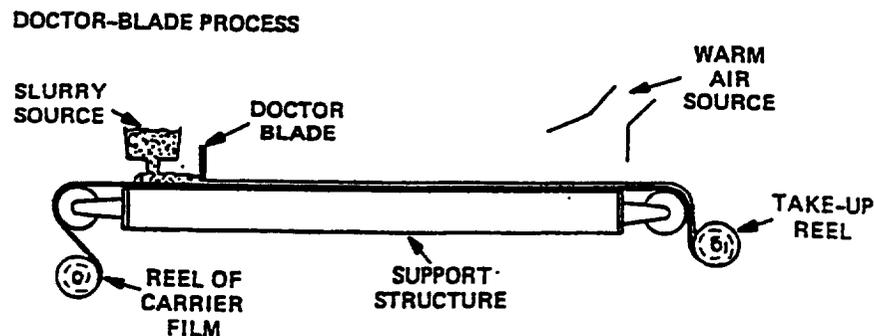# TO FABRICATE NOZZLE MATERIALS

DOCTOR-BLADE PROCESS

Figure 15

Tape casting is a primary candidate for fabrication of nozzle materials due to its simplicity, ease of operation, potential for scale-up and low cost. This process produces a flat monotape containing fugitive binders, and is well suited for fabrication of the large, flat sheets of material that will be required in much of the nozzle structure. Matrix material in the form of powder is combined with a binder and a solvent to obtain a slurry of the desired viscosity. As shown in Figure 15, this slurry is then spread as a film over a fiber mat which is fixed to a flat panel or cylindrical drum. After the solvent has evaporated, the material takes the form of a flexible monotape which binds the fiber at the desired spacing with the required volume fraction of matrix material. Monotapes produced in this manner are assembled into the desired architecture of fiber orientations and subsequently consolidated into a fully dense multi-ply panel. The primary technical issues involved in this fabrication process are determining the most suitable binder material and design of the consolidation process. One of the key aspects of consolidation is facilitating proper unzipping/decomposition and removal of the binder.

Consolidation Process Parameters Control
The Extent Of Densification

8 - ply Al2O3/ MA 956 MMC VIA TAPECASTING
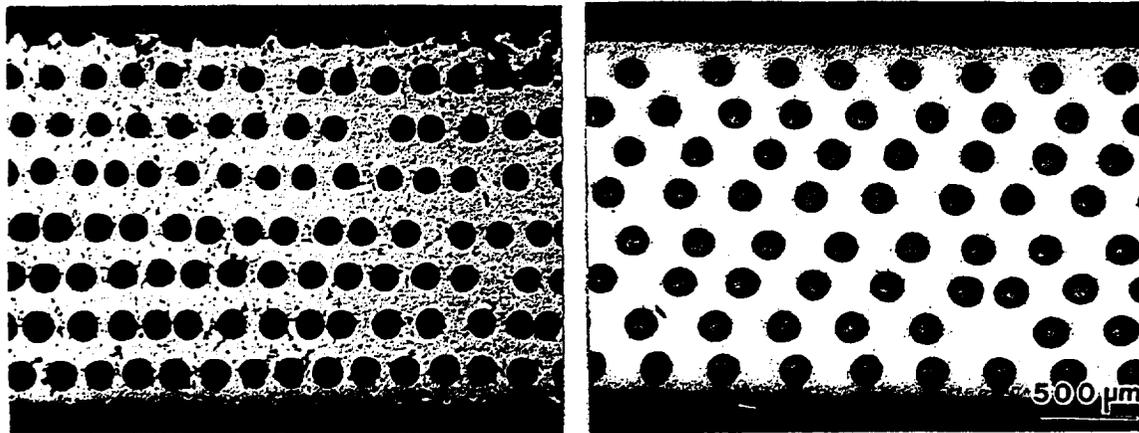
(a) Partial Consolidation   **(b) Complete Consolidation**

Figure 16

After the consolidation step in the fabrication process, the composite materials must be characterized to evaluate the process used. Microstructural analysis is one of the critical assessments made in evaluating the materials fabricated. It provides important information on the matrix, the fiber, and the interface which is created between the two as a result of the fabrication process. It also reveals the spacing distribution of the fiber resulting from the process and whether a fully dense structure has been achieved. Figure 16 displays microstructures from two panels of one of the composite materials being developed under EPM. This material is an eight-ply, superalloy MMC of MA956 matrix reinforced with sapphire ceramic fiber. The composite panels were consolidated using different conditions from monotapes fabricated by tapecasting. The porosity evident in Figure 16(a) indicates that the consolidation process conditions were initially inadequate. A subsequent increase in the consolidation temperature produced full consolidation, as shown in Figure 16(b).

CRITICAL TESTS MEASURE PROGRESS
IN MATERIALS DEVELOPMENT

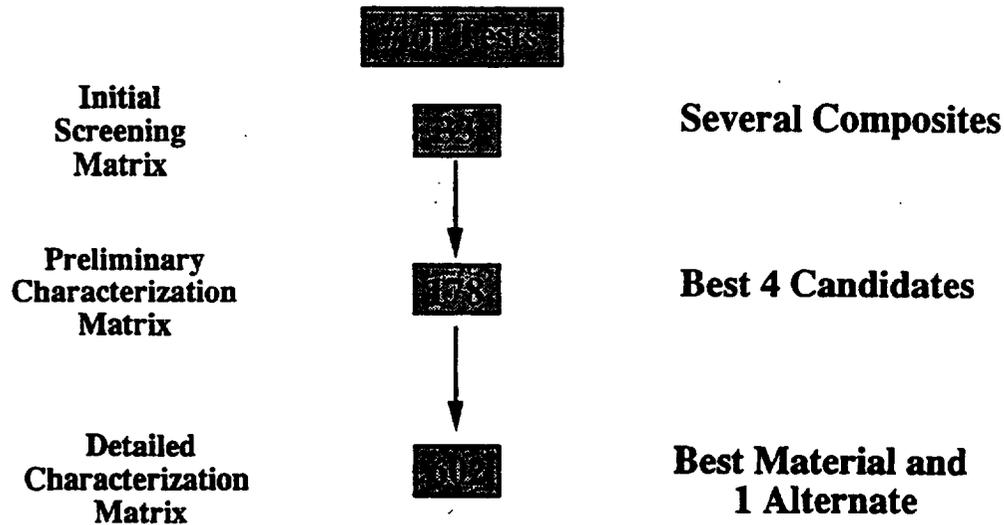| Initial Screening Matrix | | Several Composites |
| Preliminary Characterization Matrix | | Best 4 Candidates |
| Detailed Characterization Matrix | | Best Material and 1 Alternate |

Figure 17

In order to generate the data required to support materials development, materials selection and component design for the exhaust nozzle, a wide variety of room and elevated temperature mechanical tests are planned. To ensure that all data are "correct" and consistent, standardized test procedures for MMC, IMC and CMC materials are being developed among NASA, GEAE and Pratt & Whitney. The nozzle testing flow-down plan is shown in Figure 17. Initially, a large number of candidate materials will be evaluated using a screening test matrix (33 tests per material) which will include tensile and thermal fatigue cycling, as well as environmental and physical property testing. The results of these tests will be used to provide feedback to the material development process. At the end of this phase, a preliminary characterization (178 tests per material) of the four leading candidate materials will be performed. A review of these results will lead to the selection of the final material for scale-up and detailed characterization, which will include 602 tests, and may also include limited testing on an alternate material. The detailed test matrix will involve a large number of cyclic and thermal mechanical fatigue tests, with emphasis on interactive effects and long-time durability.

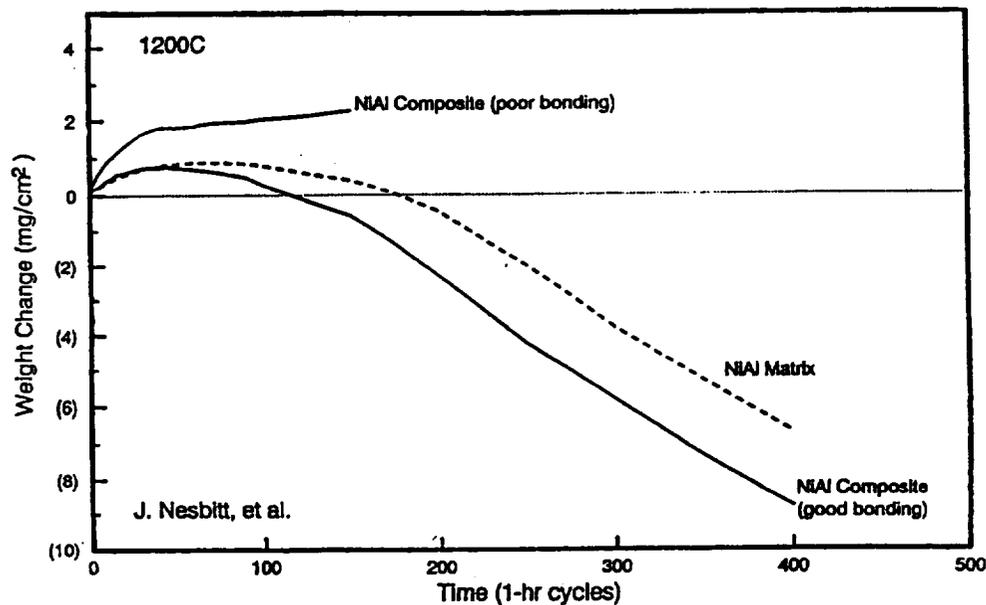# CYCLIC OXIDATION IS A MAJOR DURABILITY CONCERN

Figure 18

Nozzle materials must demonstrate 18,000 hour durability in oxidizing environments at temperatures up to 2400°F. Resistance to cyclic oxidation is a major concern because of the thermal cycling nature of engine applications. Oxidation resistance of the matrix and fiber alone do not guarantee oxidation resistance for the composite. The major issue in the oxidation of composites is the oxidation along the fiber/matrix interface. To produce oxidation resistant composites, strong bonding at the fiber/matrix interface is required so that the interface remains intact through thermal cycling and does not act as a fast diffusion path, allowing rapid oxidation.

The initial rate of weight gain in cyclic oxidation is similar to the isothermal rate, but it eventually goes through a maximum and then decreases. Weight loss in cyclic oxidation, which is the result of oxide spalling, represents a more rapid consumption of the alloy. The test data in Figure 18 show the effect of fiber/matrix bonding on the cyclic oxidation of a sapphire-reinforced NiAl composite. The composite with good bonding (5 percent fiber volume ratio) exhibited a weight change similar to monolithic NiAl. In this case, microstructural examination using a scanning electron microscope showed no oxidation along the fiber/matrix interface. However, the composite with poor bonding (30 percent fiber volume ratio) showed extensive oxide formation along the fiber/matrix interface after 150 cycles, resulting in a very high weight gain.

NON-DESTRUCTIVE TESTING PROVIDES QUALITY CONTROL

Spectral Magnitude of Undamaged MMC Specimen — FREQUENCY

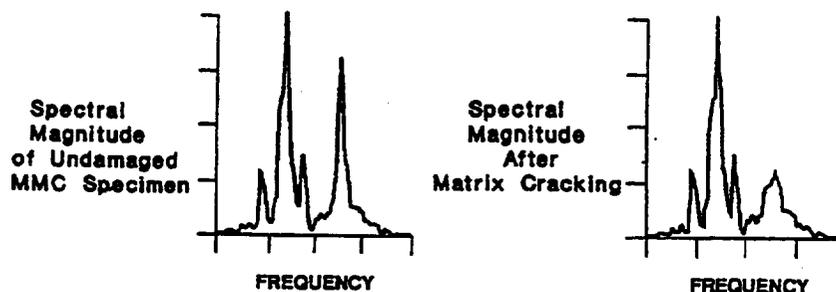**Spectral Magnitude After Matrix Cracking** — FREQUENCY

Figure 19

Non-Destructive Evaluation (NDE) methods have historically contributed to the development of state-of-the-art materials and structures, both as tools for the inspection and quality control of newly fabricated materials and for verifying the integrity of finished structural components. The non-destructive inspection of EPM developmental composite materials presents unique challenges because complex or experimental fabrication processes that may be used offer many opportunities for introducing a variety of defects into the materials. NDE techniques will be used to inspect EPM nozzle materials for potential defects such as matrix cracks, porosity, second phase content, fiber breakage, inhomogeneity and delamination. These defects would degrade the mechanical or thermal properties of a composite material, which in turn would reduce the lifetime of the structure. Specific NDE methods that will be applied to EPM nozzle materials include:

● Ultrasonic imaging, conventional and microfocus x-ray and thermography techniques will be used for screening panels, segments, sectors or liners for quality and homogeneity.

● Acoustic microscopy and acoustic emission methods will be used, along with those methods mentioned above, to characterize and monitor damage accumulation in support of analytical model development.

● Dynamic resonance, ultrasonic velocity and acousto-ultrasonics measurements will be used to verify material uniformity and will be correlated with micro- and macro- structural material characteristics to monitor damage accumulation, as shown in Figure 19.

Interdisciplinary Computational Analysis Methods Predict Design Feasibility

temperature
(°R)

Ejector Chute
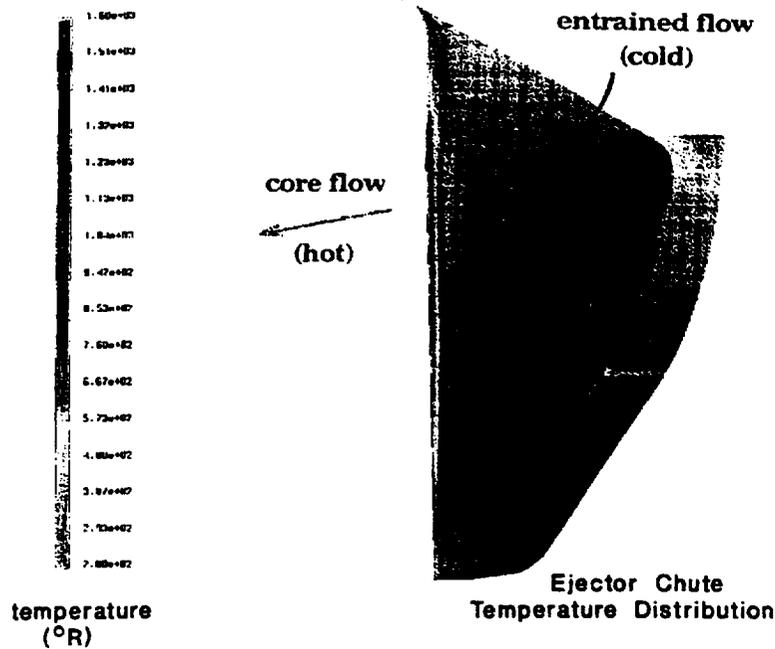Temperature Distribution

Figure 20

Computational structural analysis methods are being used to support the EPM materials development effort in two ways:

● Parametric studies are being conducted with several micromechanics-based computer codes to determine the mechanical properties of the fiber, matrix and interface that will be required to achieve the composite goal properties shown in Figure 6.

● The results of a series of computational fluid dynamics analyses are being used to calculate the aero/thermal loading on critical components (convergent and divergent flaps, chutes and acoustic liners) of candidate exhaust nozzle configurations. For example, the calculated temperature distribution on the cold side of an ejector chute structure from a 2DCD nozzle under takeoff conditions is shown in Figure 20. The temperature and pressure distributions calculated in this manner are used to define the loading for a thermal/ structural finite element analysis, from which stresses in the critical components are calculated. By comparing these stresses with the strengths of candidate nozzle materials, a feasibility assessment of proposed material/design combinations can be made.

CRITICAL HSCT EXHAUST NOZZLE COMPONENTS NEED HIGH TEMPERATURE COMPOSITE MATERIALS

COMPONENT	1999 MATERIAL	TEMPERATURE RANGE (°F)
Convergent Flaps	IMC	1200 - 2300
Divergent Flaps	IMC	600 - 2400
Ejector Chutes	MMC	1600 - 2000
Acoustic Liners	Ceramic or CMC	1000 - 2400

Figure 21

The EPM Nozzle Integrated Product Development team has completed the initial identification of materials and structural approaches for advanced material technology (1999) exhaust nozzles. The convergent and divergent flaps, ejector chutes and acoustic liners require advanced materials for HSCT applications. Recommendations for the initial selection of materials for these critical nozzle components are shown in Figure 21. The divergent flaps will operate in the 600° - 2400°F temperature range; IMC materials are the primary candidates for these subcomponents, as well as for the convergent flaps. MMC materials are being considered for the ejector chutes, which will operate in temperatures up to 2000°F. Ceramic or CMC materials are designated for the acoustic liners, which will be exposed to 1000° - 2400°F temperatures during the engine cycle.