

## SEALS AND SECONDARY FLOW NEEDS HSR OVERVIEW

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The leading Aeronautics program within NASA is the High Speed Research Program (HSR). The HSR program's highest priorities are high pay-off technologies for airframe and propulsion systems required for a high speed civil transport (HSCT). These priorities have been developed collaboratively with NASA, FAA and the US Industry (Boeing-McDonnell Douglas, Pratt & Whitney and General Electric).

Phase one of the HSR program started in 1990, and concentrated on the environmental challenges of minimizing NO<sub>x</sub> and noise. The first program goal is to reduce the NO<sub>x</sub> emission index to less than 5 (Concord NO<sub>x</sub> index is 20 and is unacceptable), in order to have little impact on the earth's ozone layer. The second goal is to reduce noise levels to FAR Stage 3 (or better), comparable to those of subsonic aircraft (far below the Concorde noise levels that require exemptions from less stringent standards). This requirement greatly impacts the nozzle design increasing its length and complexity and poses unique sealing challenges.

Phase two started in 1993 and initiated work on the technologies required for an economical HSCT. Materials technologies under development include a ceramic-matrix-composite combustion liner, lightweight materials for the nozzle, as well long-life turbomachinery disk and blade alloys. Other required materials are being developed under the DOD-IHPTET program, where there is close cooperation.

Economic goals translate into the development of technologies for tri-class service, 5000 nautical mile range aircraft with a ticket price no more than 20% over the subsonic ticket price. The potential market could be as large as 1500 aircraft, according to a Boeing study. Technology alone will not enable this airplane, yet without enabling technologies "on the shelf", it will not occur.

The HSCT engine will be the largest engine ever built and operate at maximum conditions for long periods of time posing a number of challenges. The HSR engine mission requires that rotating equipment stay at take-off condition temperatures for hours not minutes per flight. Hence rotating equipment and seals must operate for many thousands of hours at extreme temperatures. It is anticipated that the nozzle will be 12 feet long and roughly 4 ft. by 5 ft. in cross-section with a nominal airflow of 800 lbs/sec. The complex functions of the nozzle (including an ejector for noise attenuation) combined with long life place new demands on nozzle seal design. Three inlet configurations are under consideration with attendant sealing challenges, as will be illustrated herein. Four of these engines are required to propel a 5000 nautical mile class vehicle which demand that component reliability be at the highest possible level.

In response, an HSR seals session was implemented as a part of the 1997 –Seals and Secondary Flow Workshop. Overview presentations were given for each of the following areas: inlet, turbomachinery, combustor and nozzle. The HSCT seal issues center on durability and efficiency of rotating equipment seals (including brush seals), structural seals (including rope seals and other advanced concepts), and high-speed bearing and

sump seals. Tighter clearances, propulsion system size and thermal requirements represent extremes that challenge the component designers.

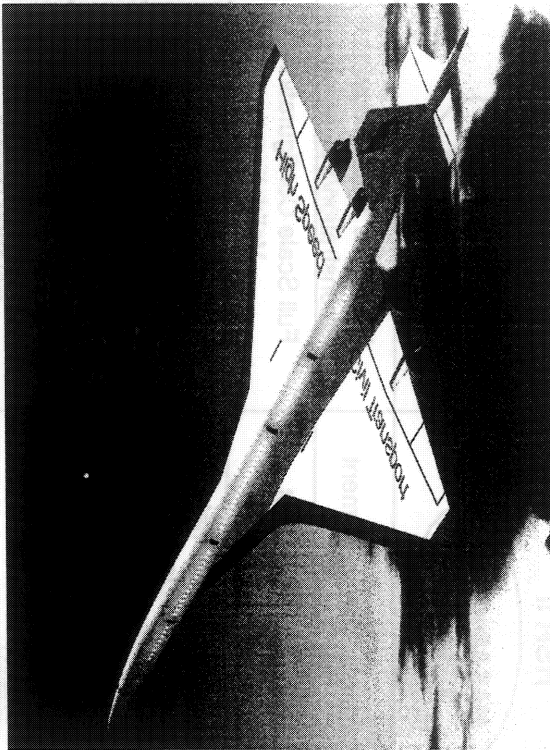
This document provides an initial step toward defining HSR seal needs. The overview for HSR seal designs includes, defining seal objectives, summarizing sealing and materials requirements, presenting relevant seal cross-sections, and identifying technology needs for the HSR office.

# HSR

## High-Speed Research Objective



Help assure Industry's Preeminence in Aeronautics through Technology Development that will enable an Environmentally Compatible and Economically Viable High-Speed Civil Transport



### HSR Phase I

#### Environmental

- Stratospheric Ozone
- Airport Noise
- Sonic Boom

### HSR Phase II

#### Economics

- Range & Payload Capability
- Operating Cost
- Manufacturing Cost

Potential for \$200 Billion in Sales & 140,000 New Jobs

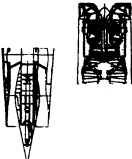


# HSR IIA

## Propulsion Development Path



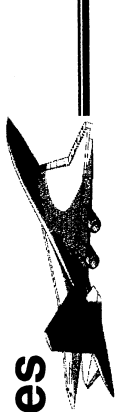
### Technology Demonstration

### High Speed Civil Transport

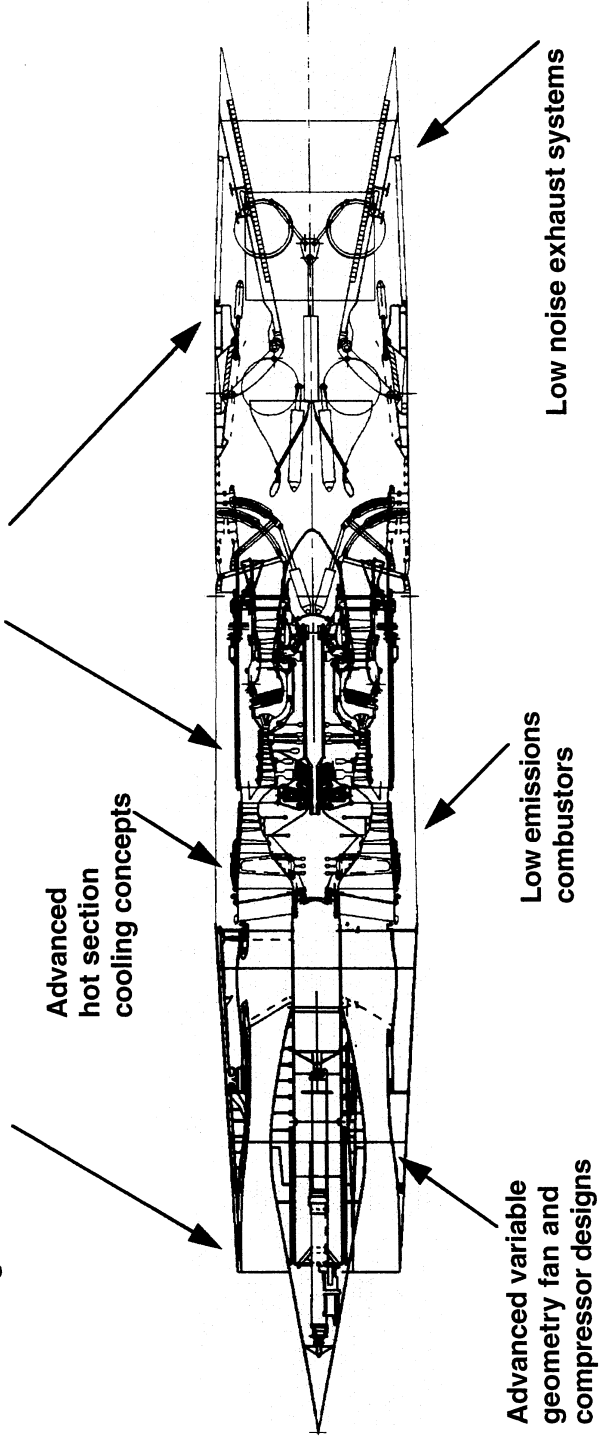
	HSR II NASA/Industry Partnership	HSR IIA NASA/Industry Partnership	Product Development Industry
Focus	Technology Development	Full Scale Technology Demonstration/Validation	Product Launch/Development
Environmental Barrier Issues	Sub-Scale Concept Demonstration	Full Scale Configuration Validation	Propulsion System Certification
Propulsion System Materials	Enabling Materials Selection and Development	Enabling Materials Application	Production Materials and Processes
Fabrication Processes	Laboratory/Test Cell Processes	Pre-Production Processes	Production Processes
Articles Fabricated	Selected Components 	Full Scale Engine and Exhaust Nozzle 	Propulsion System Assemblies 
Extent of Testing	Subscale and Selected Full Scale Demonstration of Technologies	Full Scale Engine Demo Tests (SMP, Acoustic, AMT Method Validation)*	Propulsion System Endurance and Certification
Cost Basis	Industry/NASA Cost Trades	Industry/NASA Cost Trades	Production Costs, Business Plan

\* Note: SMP=System Mechanical Performance  
AMT=Accelerated Mission Test

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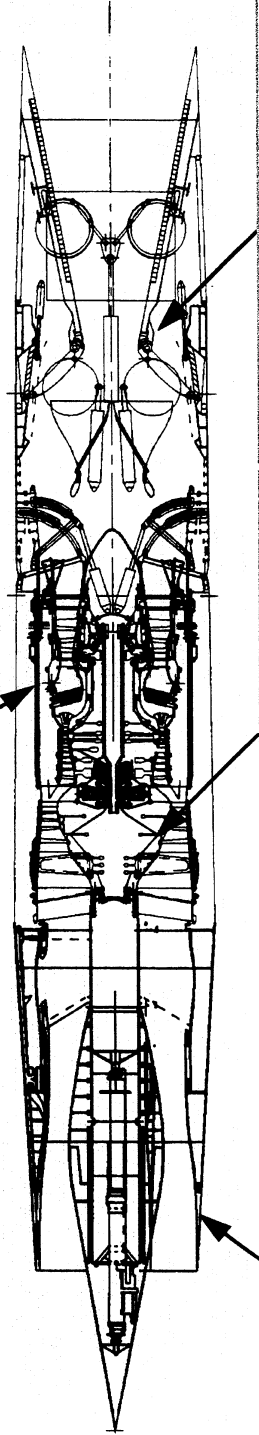


- High temperature, lightweight materials and coatings
- Integrated airframe/inlet/engine/nozzle controls



# HSR

- Completed initial subscale flame tube and sector tests for a variety of Lean Pre-mixed, Pre-Vaporized (LPP) and Rich Burn, Quick Quench, Lean Burn (RQL) concepts and demonstrated ultra low  $\text{NO}_x$  potential of both approaches.
- Developed a CMC material which shows great promise for use as HSCT combustor liner which meets environmental and economic requirements.

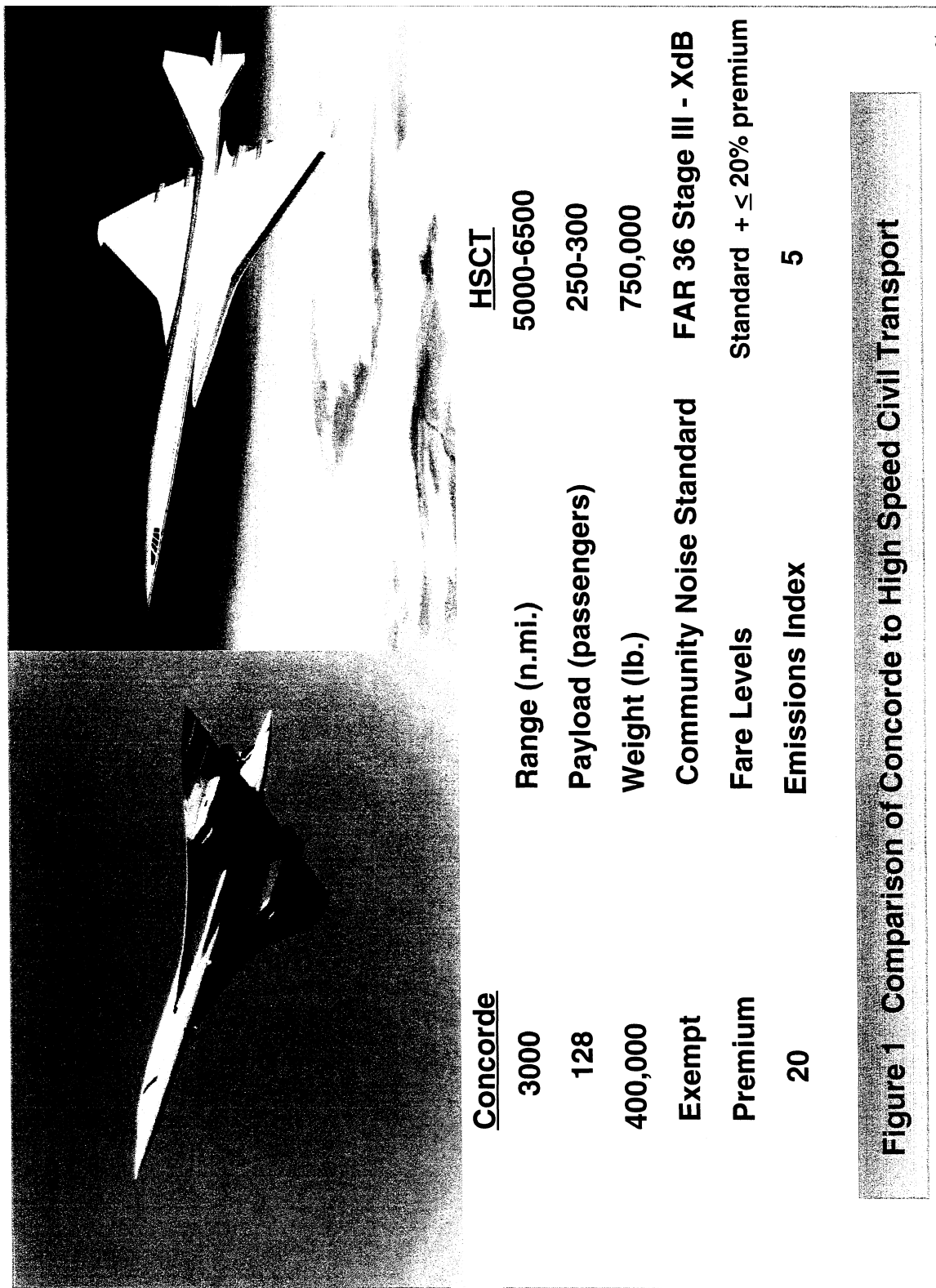


- Completed subscale tests of candidate axisymmetric and two dimensional concepts.
- Completed large scale inlet/engine operability tests as part of US/Russia TU 144 program.

- Developed experimental alloys for turbomachinery disk and turbine airfoil applications which show promise of meeting HSCT design requirements.

- Completed initial small scale nozzle tests of configurations which meet aerodynamic and acoustic performance goals. Have identified approaches for further performance improvements.
- Completed evaluation of candidate materials systems for nozzle and demonstrated fabrication scale up capabilities.

## HSR (Propulsion) Major Technology Advancements

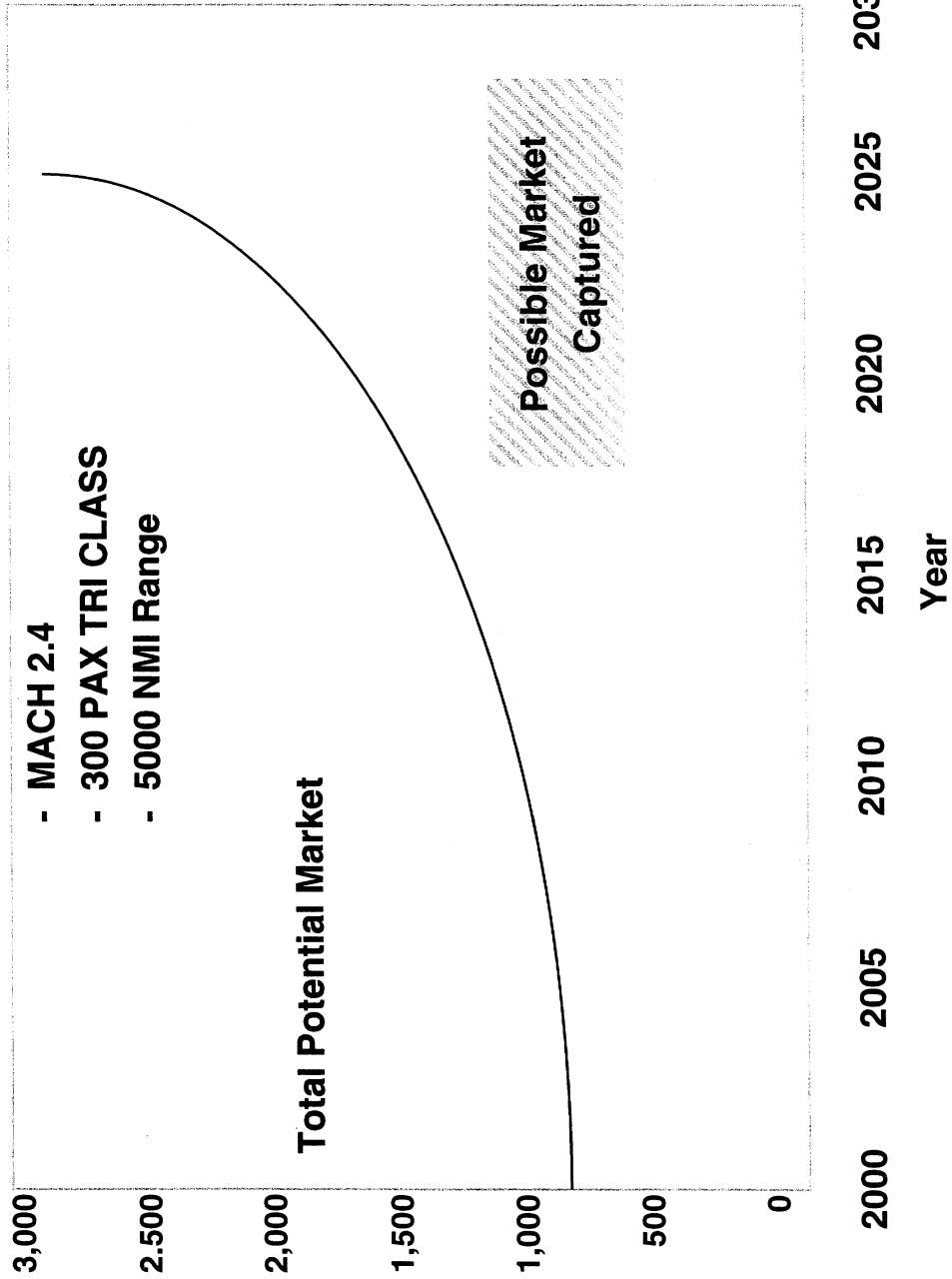


**Figure 1 Comparison of Concorde to High Speed Civil Transport**

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### Range of Market Capture

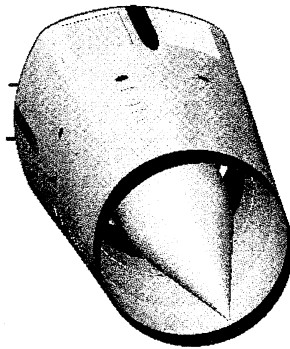






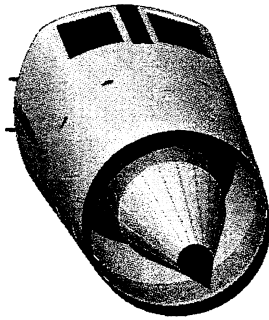
## Inlet Concepts

Translating Center Body  
(TCB)



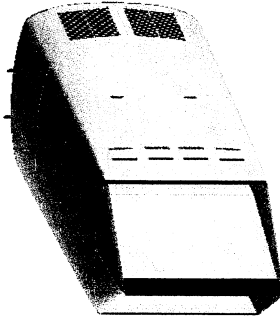
$L/De = 2.3$   
Wt = 3310 lb

Variable Diameter Center Body  
(VDC)



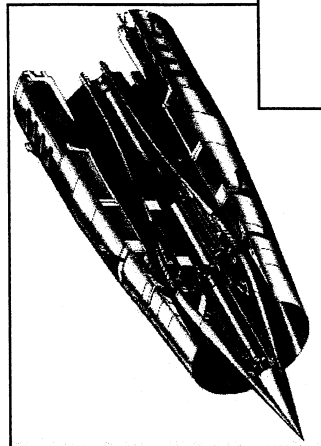
$L/De = 2.1$   
Wt = 3840 lb

Two Dimensional Bifurcated  
(2DB)



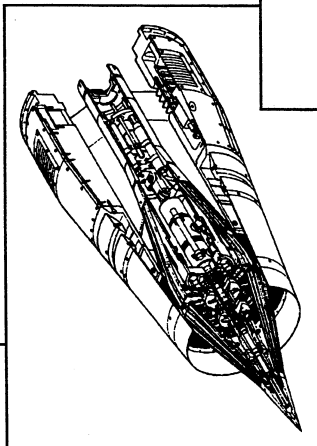
$L/De = 2.9$   
Wt = 3880 lb

Completed Full Scale Designs Provide Inlet Weights, Geometry, and Performance for Aircraft  $\Delta$  TOGW and  $\Delta$  DOC Evaluations



### Axi-Translating Centerbody

- Simple
- Light Weight
- Limited Operability/Stability
- Limited Airflow Variability



### Axi-Variable Diameter Centerbody

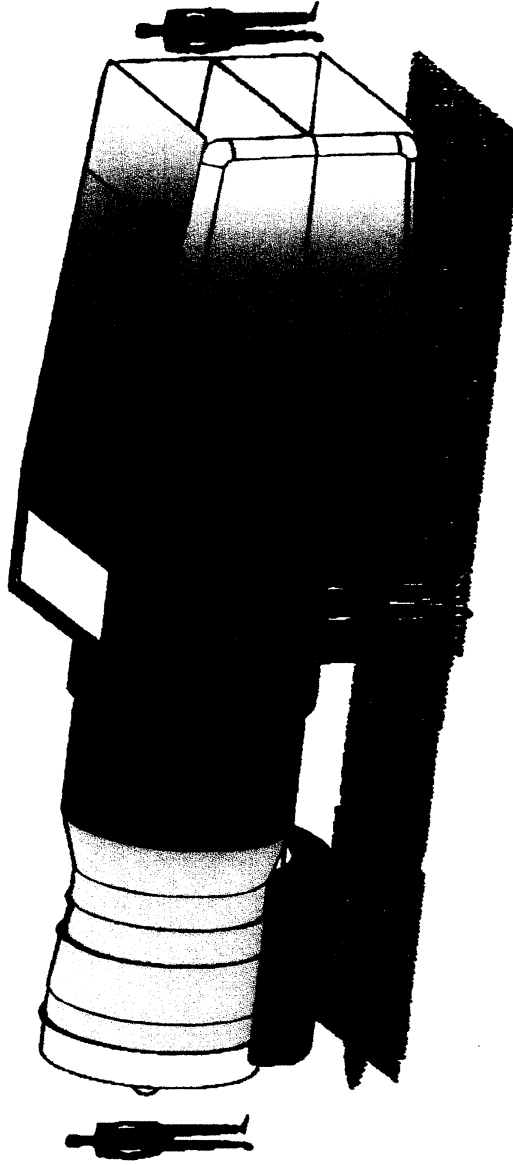
- Wide Airflow Variability
- Complex Actuation
- Good Operability/Stability
- Moderate Weight



### Two-Dimensional Bifurcated

- Widest Airflow Variability
- Simple
- Good Operability/Stability
- Heavy

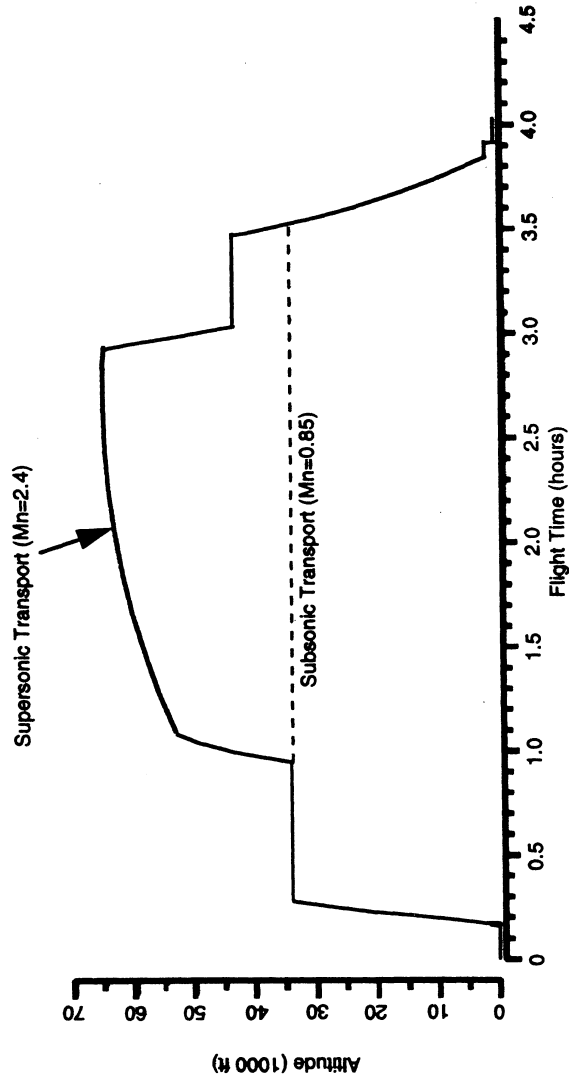
# HST Propulsion Systems Are Big Engines



Artist's concept of the full scale HST propulsion system

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# HST Engine Design Challenges



## OPERATING CONDITION

Total High Temperature/High Stress Operation (hours)  
 Sustained High Temperature/High Stress Operation (hours)

SUBSONIC TRANSPORT	MILITARY FIGHTER	SUPERSONIC TRANSPORT
<300	<400	9,500
0.03	0.15	2.0

## **HSCT Seals Issues and Challenges**

- **Durability and efficiency of brush seals**
  - **Oxidation**
  - **High temperature materials (eg ceramics)**
  - **Hard face coatings to protect parent rotor material while minimizing bristle wear**
- **Tight seal clearances**
  - **Rub tolerant, complaint seals**
  - **Rotating seals**
- **Propulsion system size**
  - **Large diameter rotors (full hoop seals)**
  - **Large surfaces moving back and forth rapidly**
    - **Exhaust nozzle flap and sidewalls**
    - **Inlet centerbody**
- **High-speed seals for the bearing compartment**

## HSR Seals Session Goals and Objectives:



- Provide overview of HSR baseline seal designs
- Present cross-sections of candidate seals
- Summarize anticipated seal requirements/specifications (where defined)
  - seal size
  - air temps/pressures
  - temperatures (air/metal)
  - time at temperature
  - sliding distance
  - sliding rates
  - seal drag force (e.g. actuator load issues)
  - Other
- Identify Candidate materials: Seal and counterface (i.e. coating etc)
- Seek problem solution through possible synergy
- Address where seal development is required:
  - Identify gaps in seal technology currently available vs. required
- Make recommendations to HSR Program Office

## Nozzle Seal Design Considerations

**Level of Seal Technology Readiness Level (TRL) can be determined by assessing following criteria and comparing to state-of-the-art**

- **Temperature**
  - Passively vs. actively cooled seals
- **Seal Pressures**
- **Sliding Speed**
- **Nozzle Panel-to-Sidewall Relative Thermal/Structural Growths**
- **Adjacent Wall Condition:**
  - Waviness/Sealability
  - Maintaining minimum waviness requires stiffer/heavier nozzle panels
  - Surface Roughness: Wear; long term durability.
- **Actuation Forces:**
  - Actuator Weight and Size (packaging)
  - Actuator response for nozzle transients
- **Seal Materials:**
  - Resist scrubbing damage
  - Resist Oxidation
- **Integration of seals with nozzle:**
  - Space Claim in movable nozzle panel
  - Nature of sidewalls: Acoustic tiles pose unique challenges:
    - » Gaps between acoustic tiles => Leaks
    - » Woven tiles: Durability of seals; Durability of Acoustic panels
- **Survivability/ Durability:**
  - High Acoustic Loads
  - Long “On-wing” performance
  - Cyclic durability at temperature

## Nozzle Seal Exit Criteria (Preliminary)

- **Seals demonstrated at: Required operating temperatures/pressures/acoustic levels**
- **Seals exhibit satisfactory durability/change in leakage over required cycle life**
- **Seals conform to and seal unique sidewall conditions**
  - **Acoustic Tiles and Gaps Between**
  - **Accommodate anticipated waviness**
- **Seal friction loads within acceptable limits for nozzle actuators**
- **Seal failure modes and effects documented and exhibit minimum/acceptable risk**
- **Cost and Availability to meet schedule**