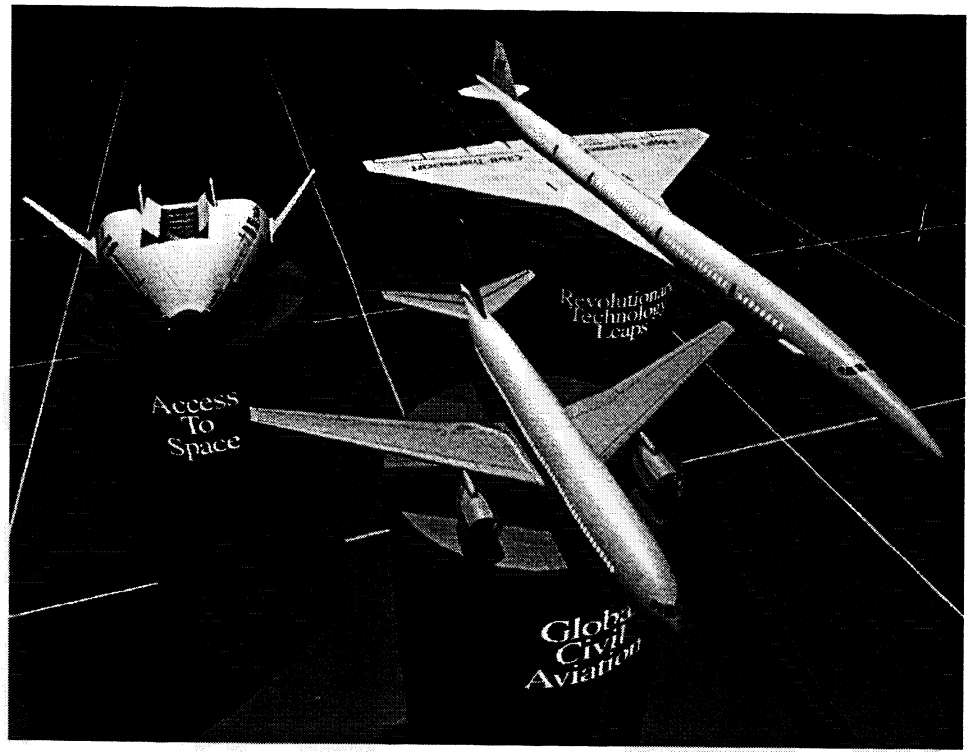
OVERVIEW OF THE HSR PROPULSION PROGRAM

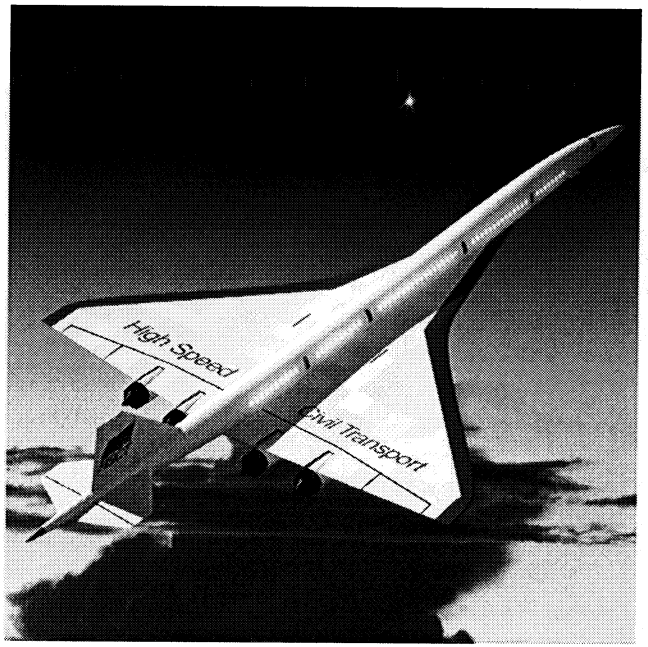
Catherine Peddie
NASA Glenn Research Center
Cleveland, Ohio

Three Pillars for Success

NASA's Response to Achieve the National Priorities in Aeronautics and Space Transportation



Goals for Pillar Two
Revolutionary Technology Leaps



Research to revolutionize air travel: environmentally friendly transoceanic supersonic flights; technology to dramatically improve small aircraft designs, engine, and overall affordability

- **Reduce the travel time to the Far East and Europe by 50 percent within 20 years, and do so at today's subsonic ticket prices**
- **Invigorate the general aviation industry, delivering 10,000 aircraft annually within 10 years, and 20,000 aircraft annually within 20 years**
- **Provide next-generation design tools and experimental aircraft to increase design confidence, and cut the development cycle time for aircraft in half**

HSR Vision

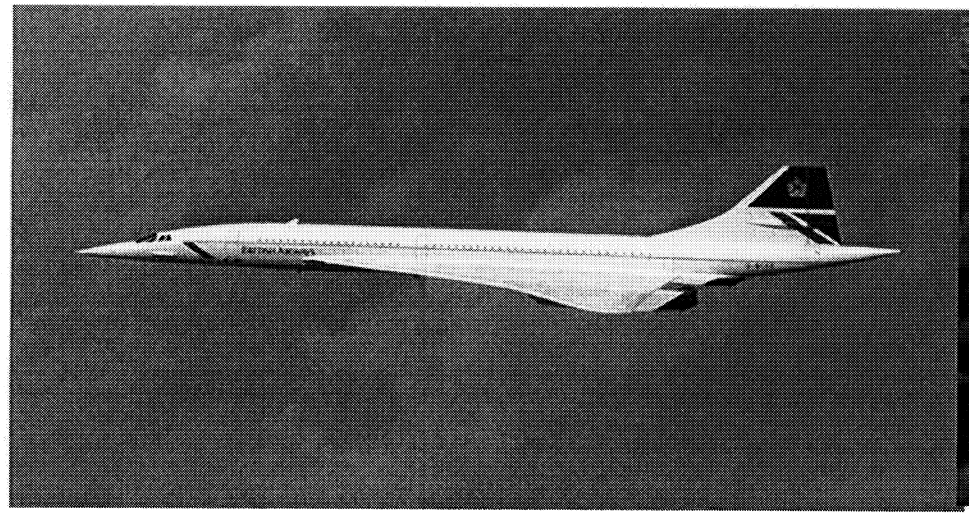
Establish the technology foundation to support the U.S. transport industry's decision for production of an environmentally acceptable, economically viable, 300-passenger, 5000 n.mi, Mach 2.4 aircraft.

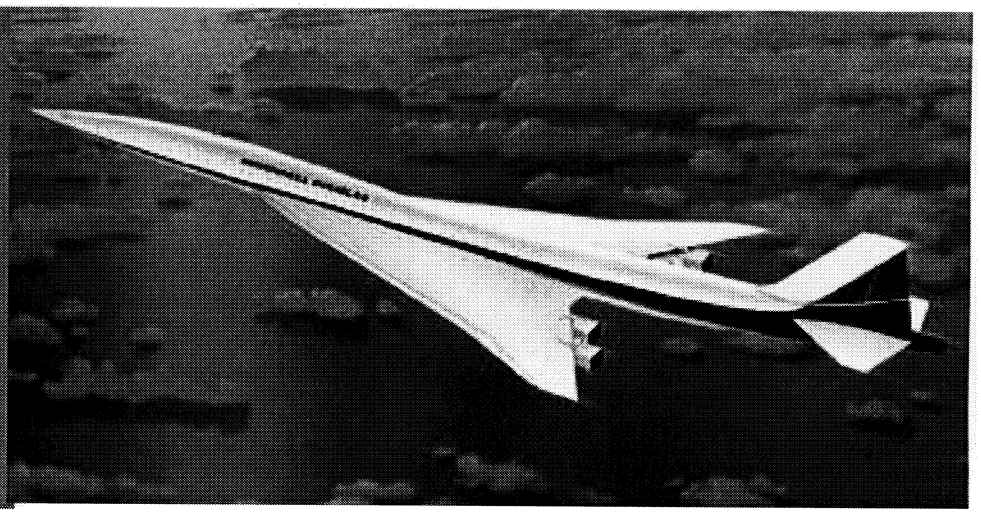
HSR Propulsion Mission

Provide the U.S. aeropropulsion industry with the critical component, enabling engine materials, and full scale system technologies to allow industry's decision on production of an environmentally acceptable, economically viable, 300-passenger, 5000 n.mi., Mach 2.4 aircraft.

Work with the corresponding airframe management team to assure overall HSR project success.

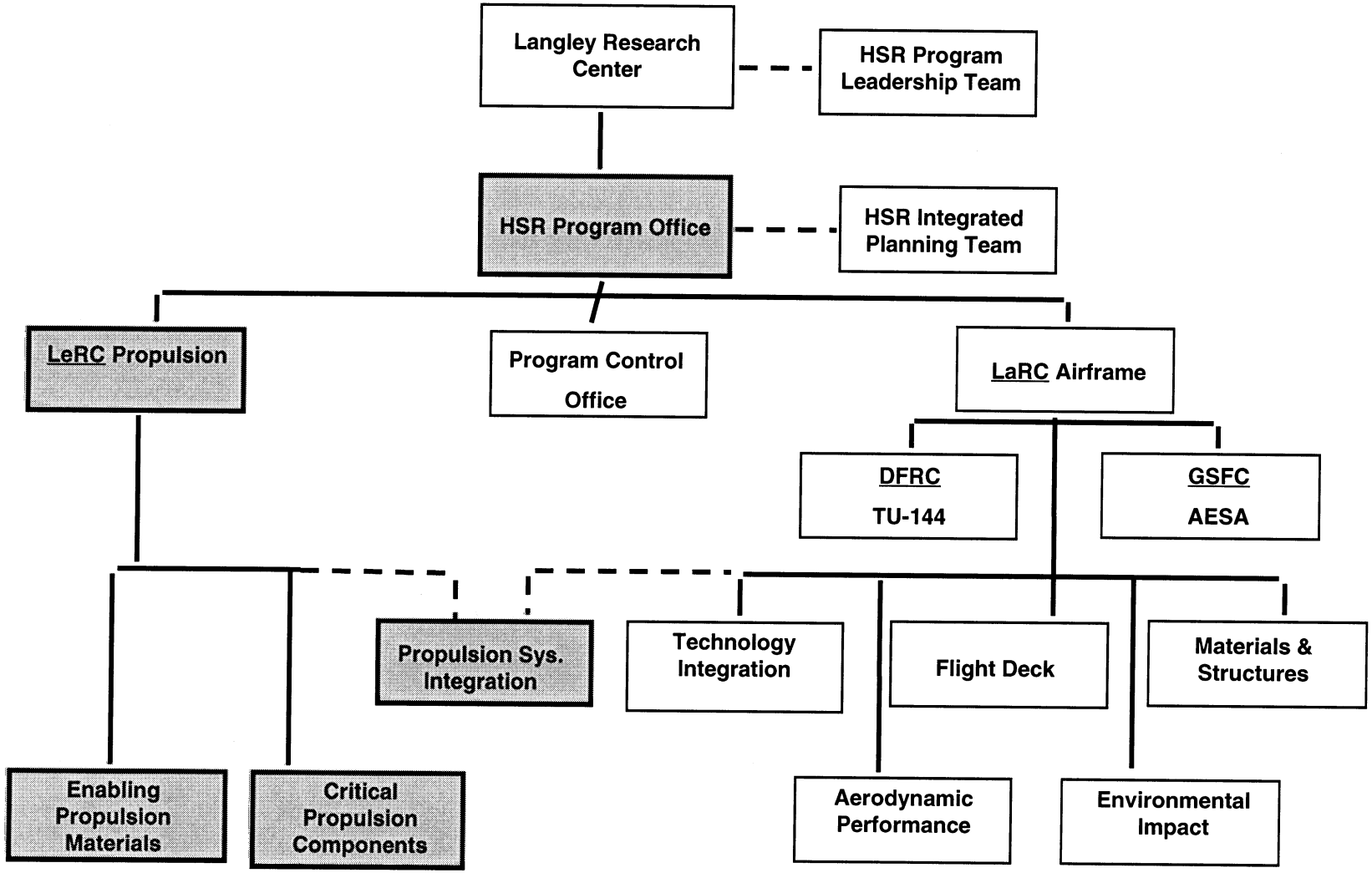
Concorde vs. the High Speed Civil Transport

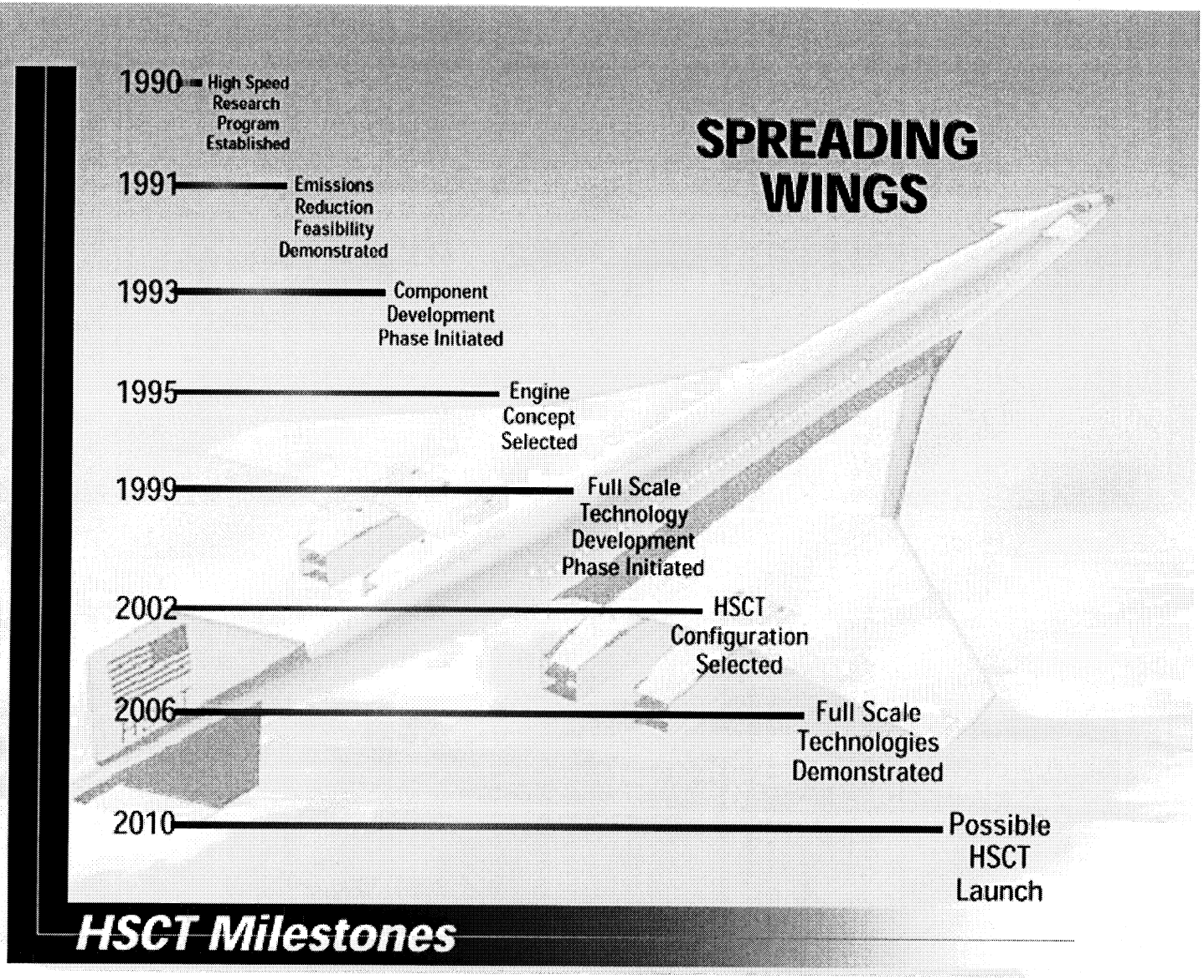




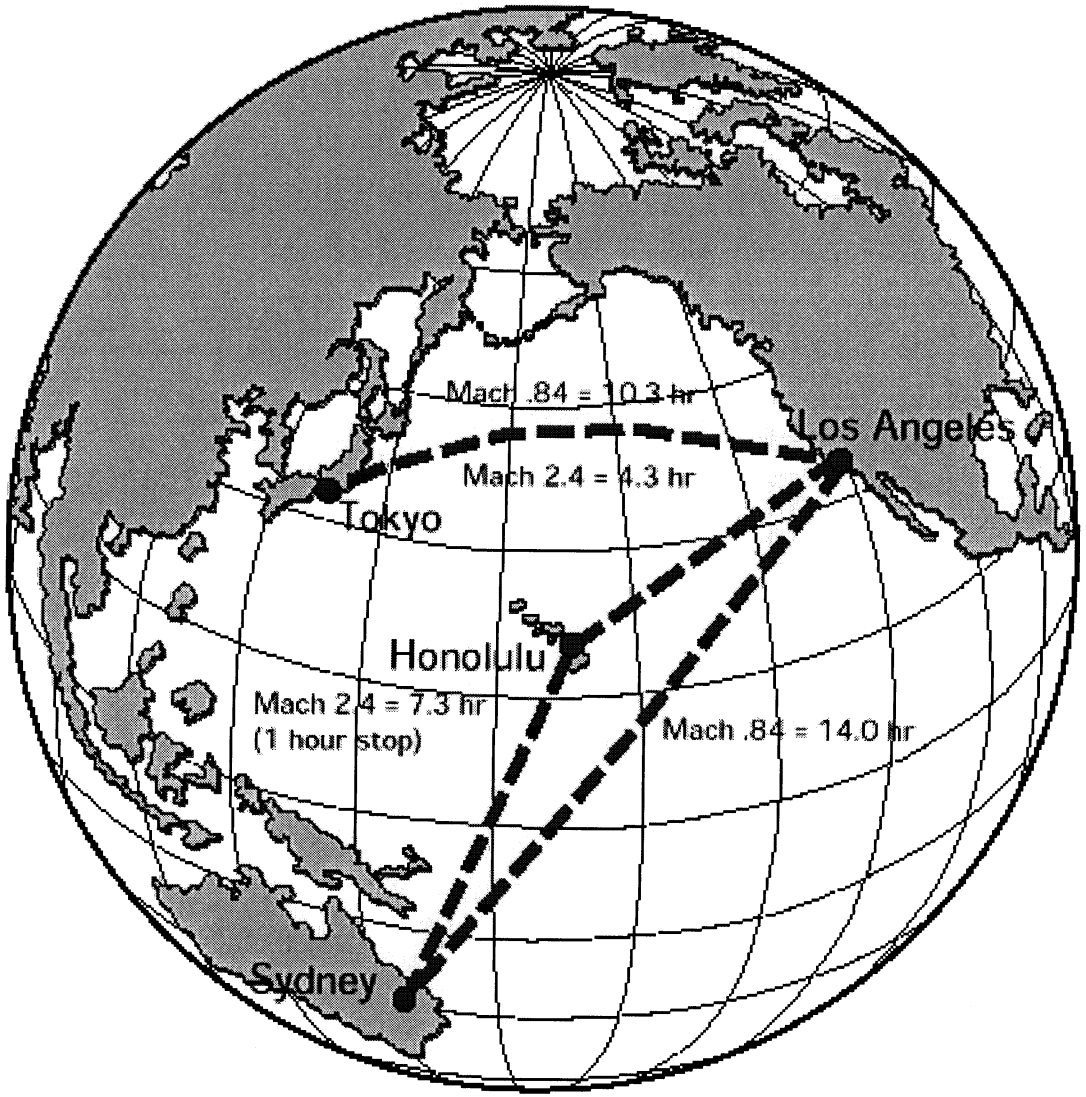
Concorde		HSCT
3,000	Range (n. mi.)	5,000 - 6,500
128	Payload (passengers)	250 - 300
400,000	Weight (lb.)	750,000
Excempt	Community Noise Std.	FAR 36 Stage III - x dB
Premium	Fare Levels	Standard + " 20% Premium
20	NOx, Emission Index	5

HSR Project Structure



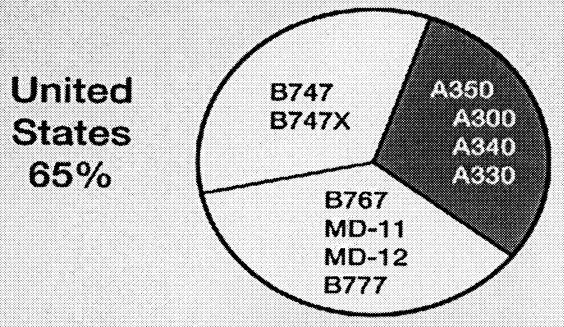

SPREADING WINGS
1990 High Speed Research Program Established
1991 Emissions Reduction Feasibility Demonstrated
1993 Component Development Phase Initiated
1995 Engine Concept Selected
1999 Full Scale Technology Development Phase Initiated
2002 HSCT Configuration Selected
2006 Full Scale Technologies Demonstrated
2010 Possible HSCT Launch
HSCT Milestones

A SMALL WORLD

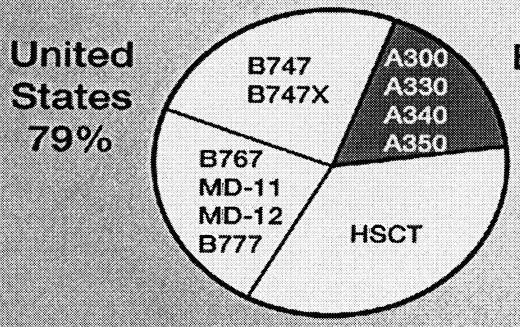


Potential for a $200B Swing in US Sales For Long Range Airplane Market

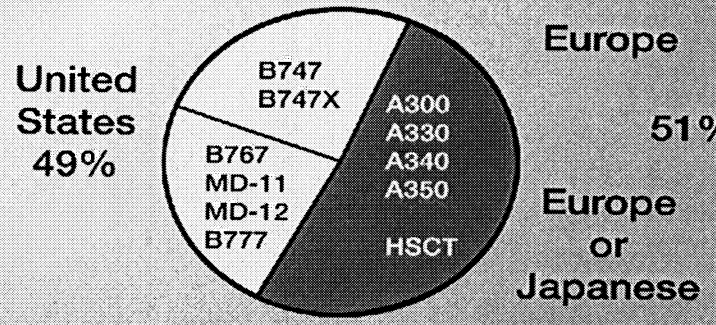
Year 2005–2020



Subsonic Only - No HSCT



U.S. HSCT Program



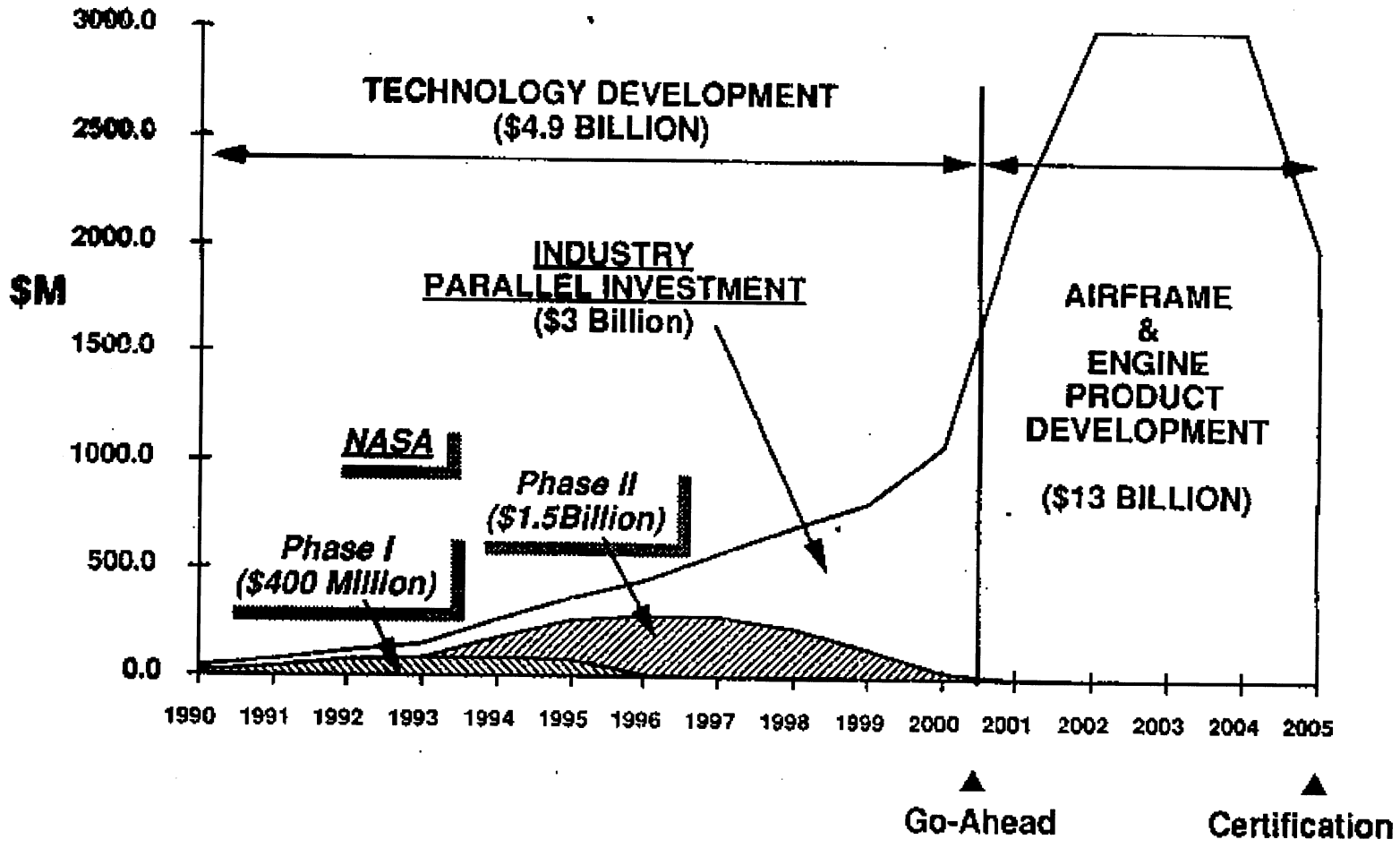
Offshore HSCT Program

National Aeronautics and Space Administration
Lewis Research Center

CD-96-73680

HSCT TOTAL INVESTMENT

INTEGRATED NASA/INDUSTRY NATIONAL PLAN



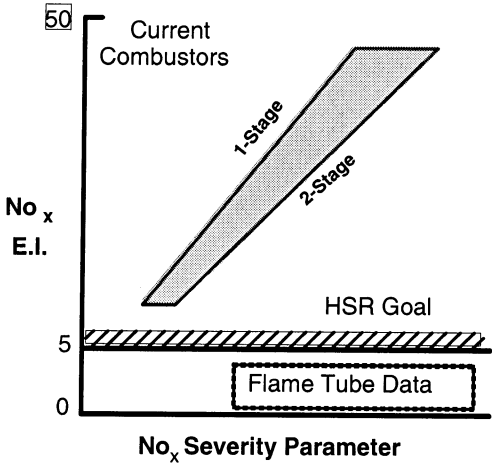
Economic Barriers: Current Economic Baseline

- From the airline standpoint
  - Ticket premium
  - Direct operating cost
  - Acquisition cost
  - Return on investment
- As the manufacturer sees it
  - Development cost
  - Manufacturing cost
  - Market size
  - Market price
- History of commercial supersonic aircraft
  - 20 Concordes built, 14 delivered to airlines
  - Concorde development cost ≈ 7.9 billion (1995$)
  - Concorde roundtrip transatlantic fare -- $8,475
  - 777 fuel burn/seat mile ≈ 20% of Concorde
  - 17 Tu-144's built, none in service today

Key Technical Challenges are Emissions, Noise and Durability

Emissions

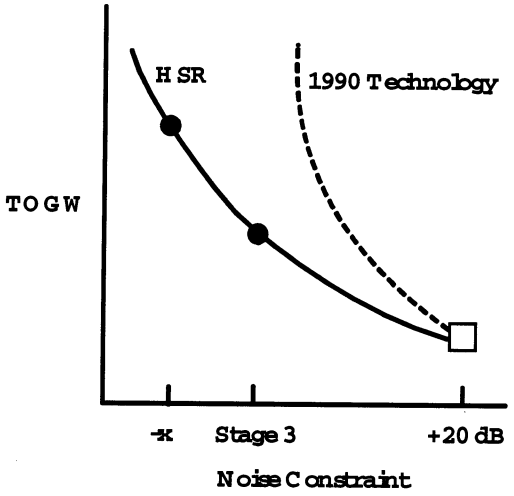
A Mach 2.4 HSCT will cruise at altitudes coincident with the highest concentration of atmospheric ozone. Advanced combustors are required to reduce NOx emissions to levels which have no significant impact on the Earth's ozone layer.



This challenge requires novel combustors and advanced materials.

Noise

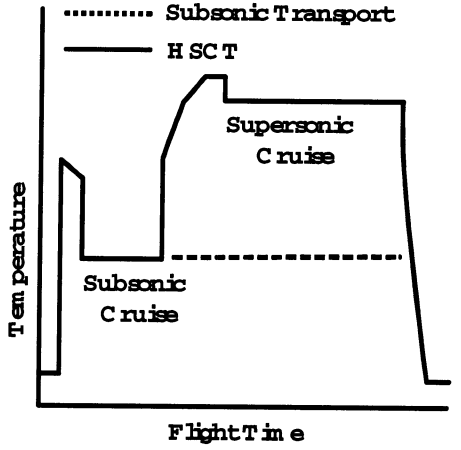
High specific thrust engines optimized for supersonic cruise have high jet velocities and are inherently noisy. Unconventional engines/nozzles are required to achieve compliance with FAR 36 Stage 3 noise regulations while providing acceptable subsonic and supersonic cruise performance.



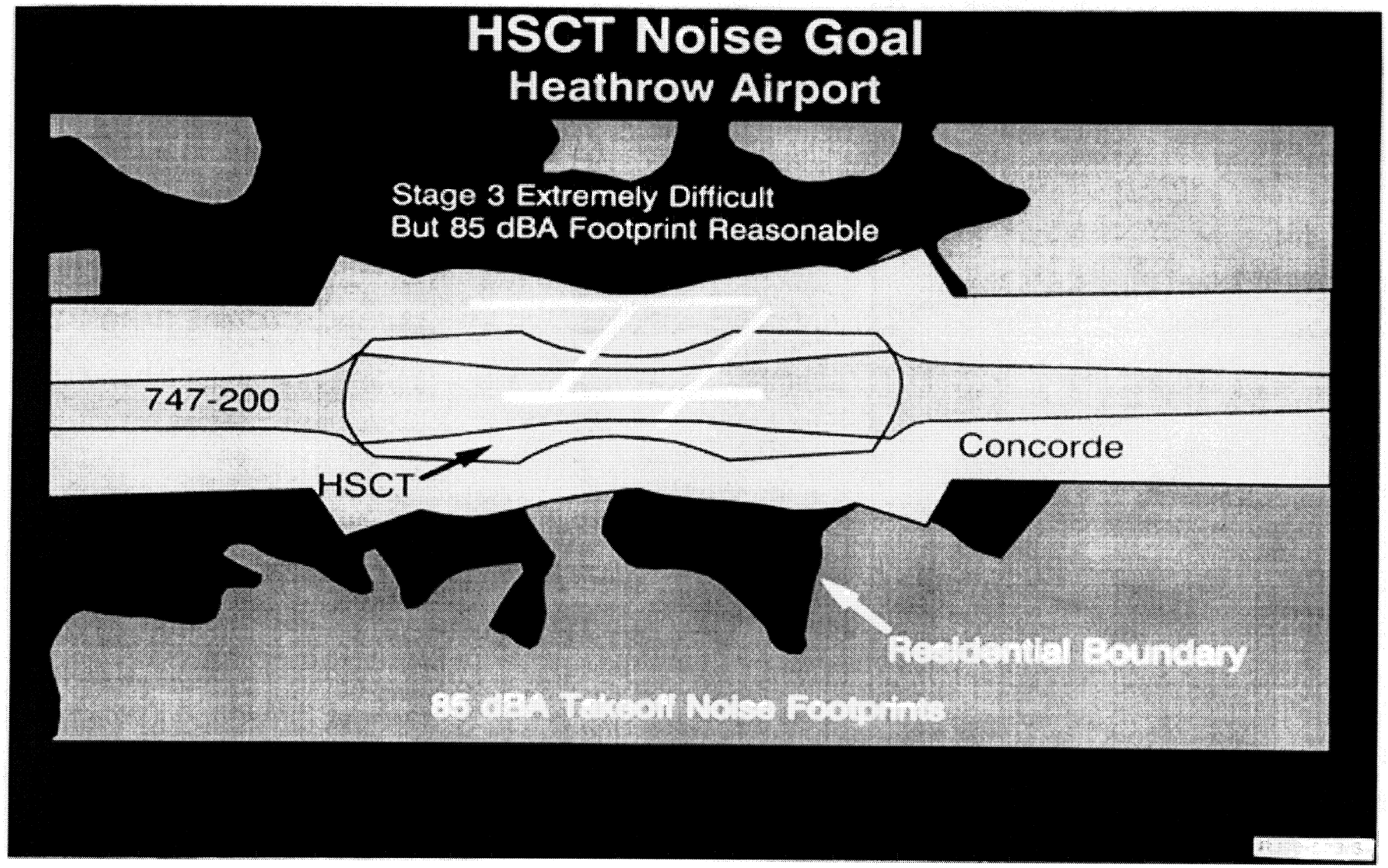
This challenge controls inlet, engine, nozzle selection.

Durability

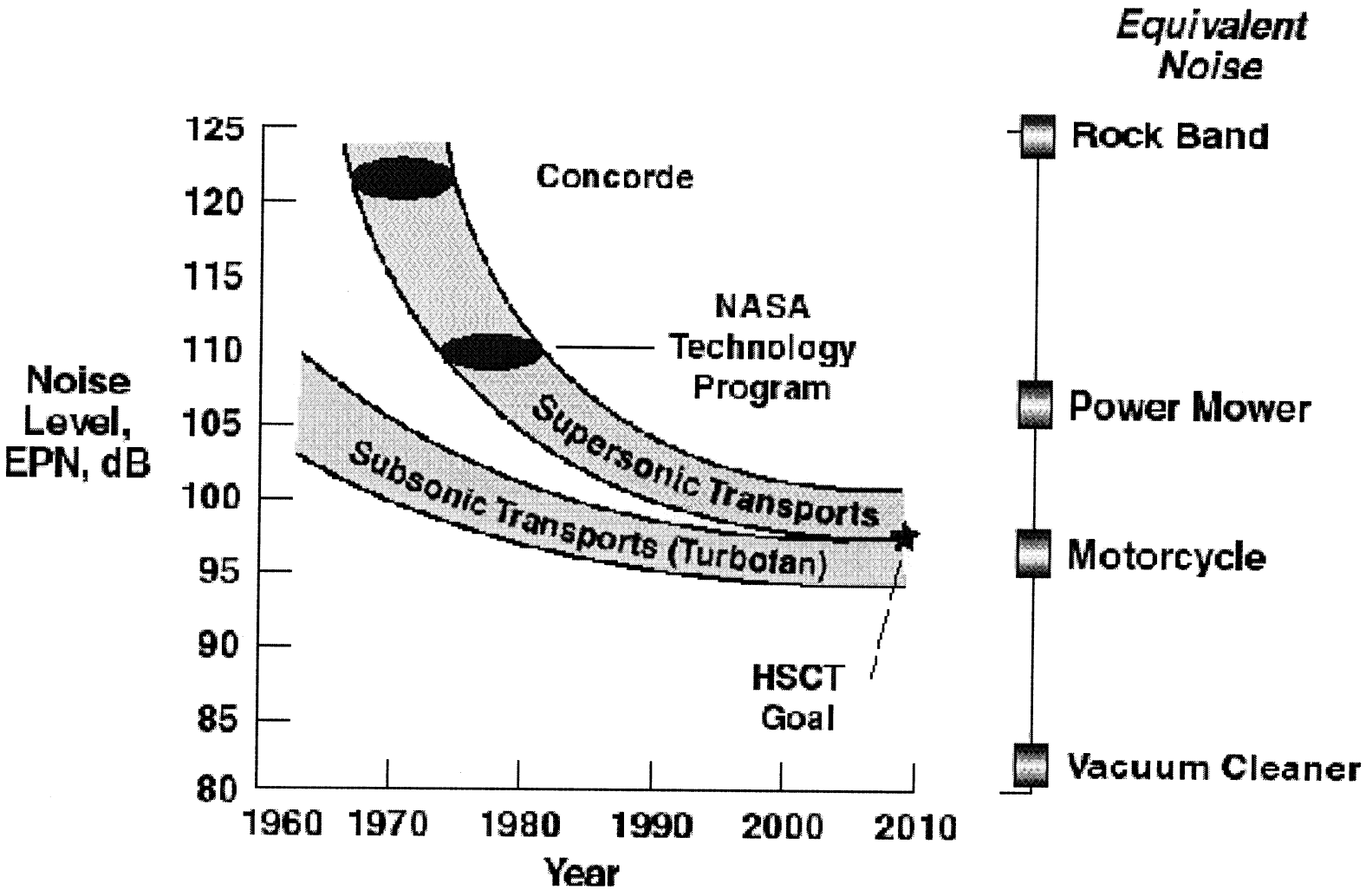
Over their entire life, current tactical fighter and subsonic commercial transport engines accumulate 250 to 300 hours at max cycle temperatures and stress levels. HSCT propulsion systems must operate at these conditions for 9,000 hours. Thus, the HSCT duty cycle is 30X that of current engines.



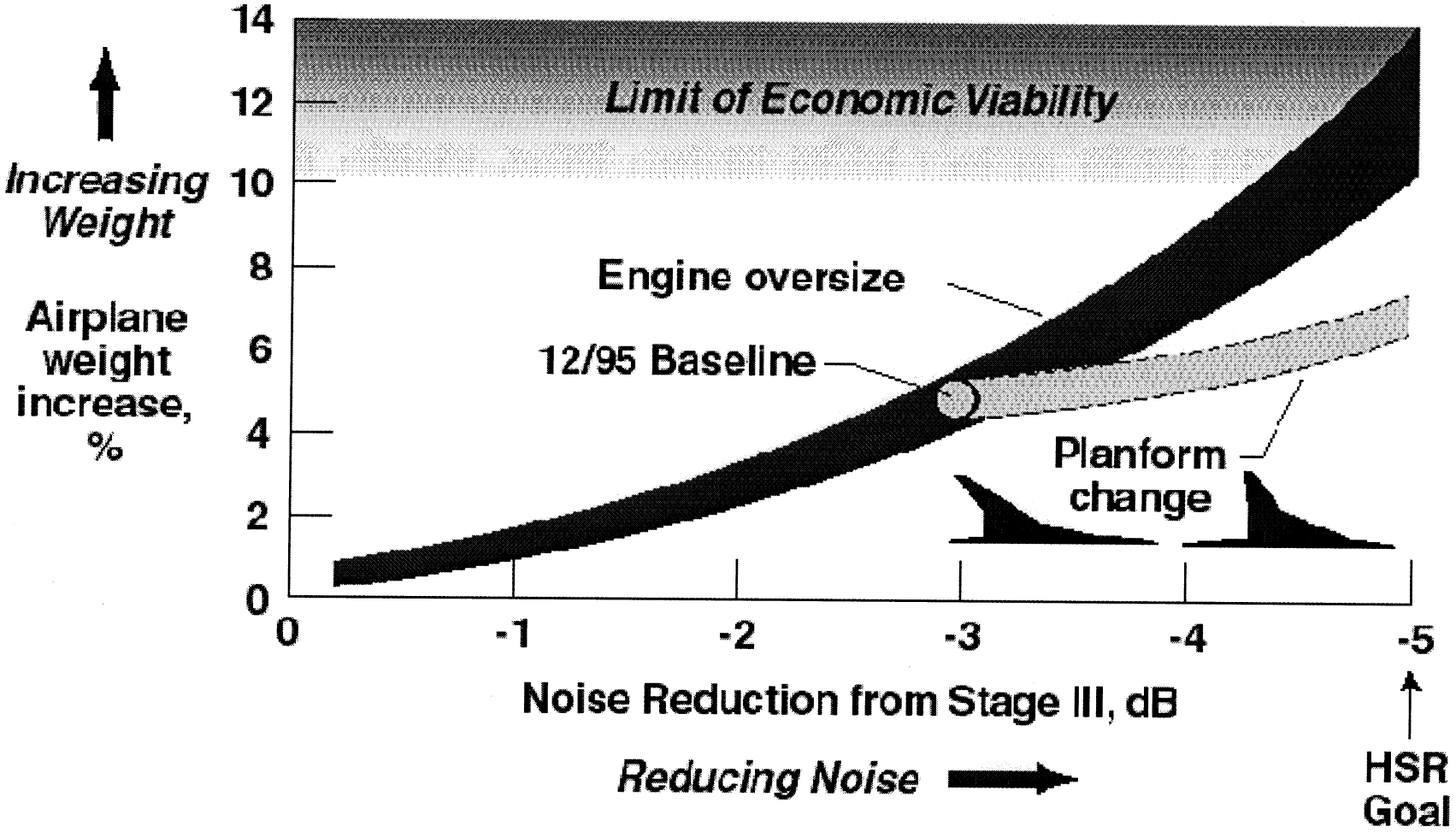
This challenge demands advanced high-temp materials and cooling schemes.


HSCT Noise Goal
Heathrow Airport
Stage 3 Extremely Difficult
But 85 dBA Footprint Reasonable
747-200
HSCT
Concorde
Residential Boundary
85 dBA Takeoff Noise Footprints

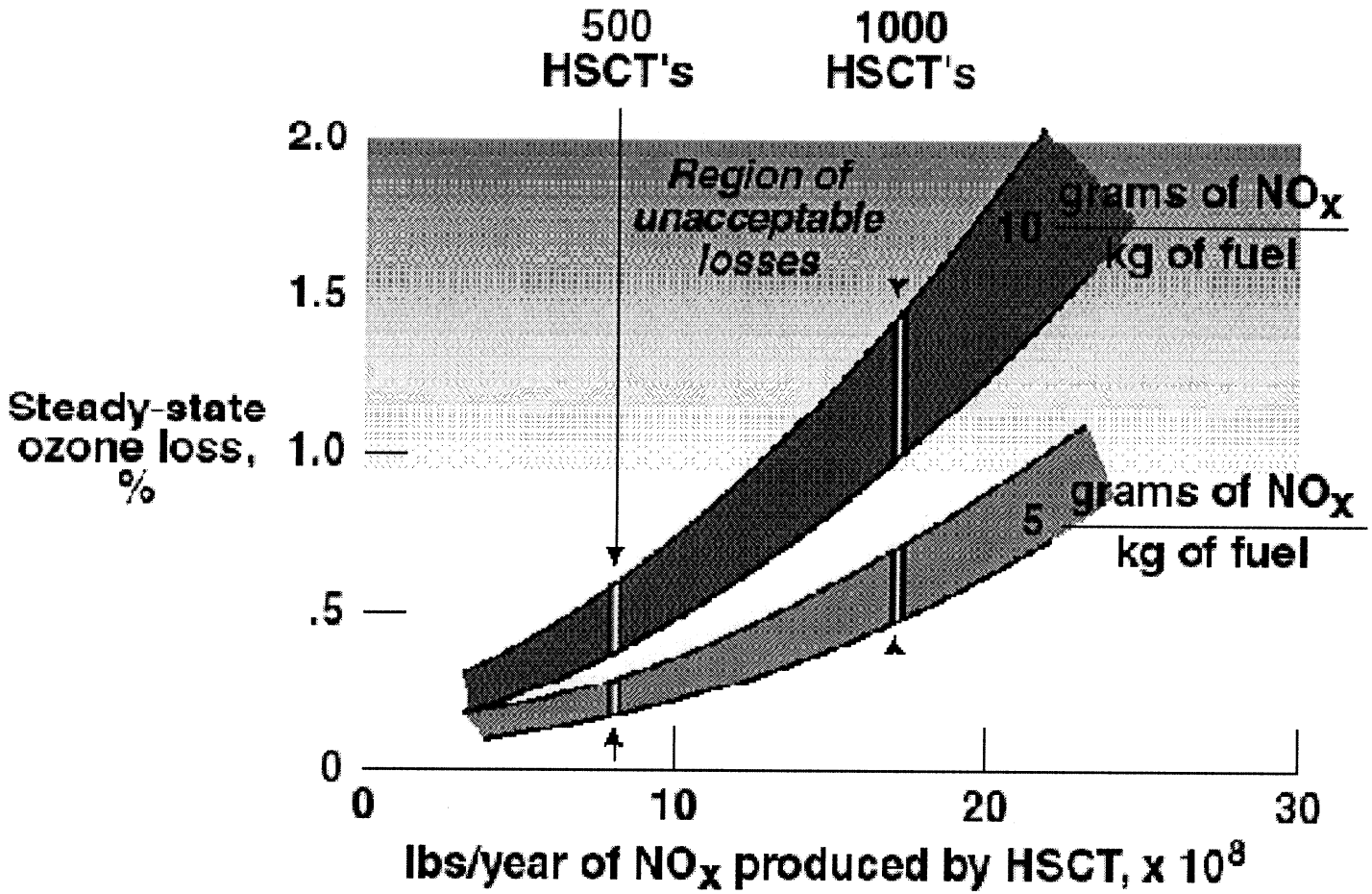
HSCT NOISE REDUCTION CHALLENGE



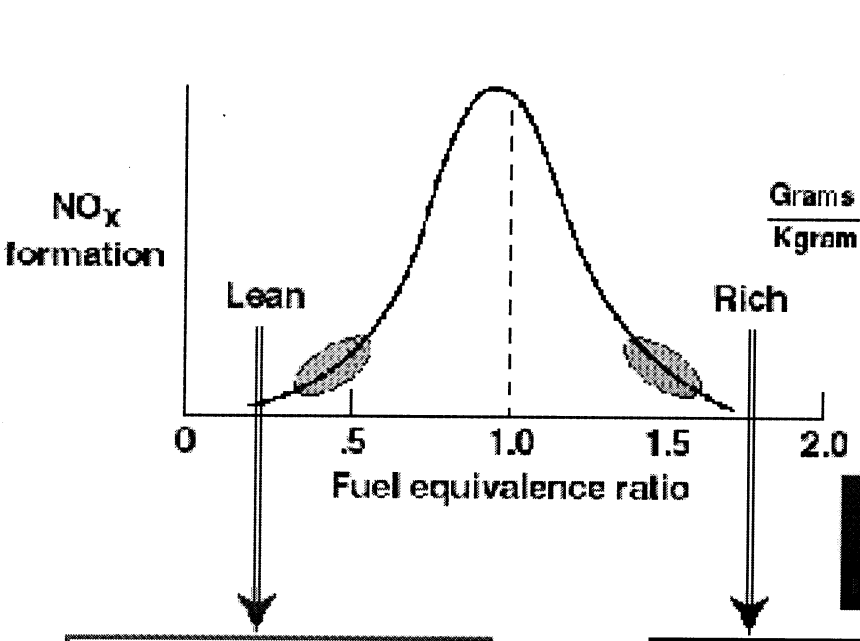
HSCT Weight Penalty for Achieving Noise Goals

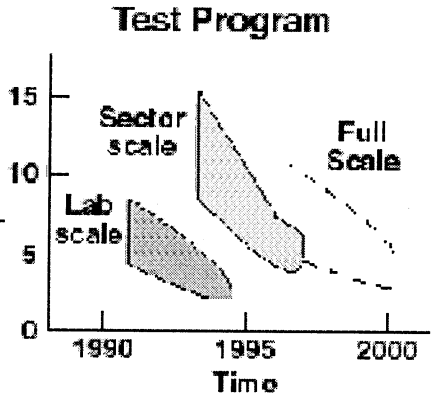


OZONE LOSS vs TOTAL NO_X PRODUCTION

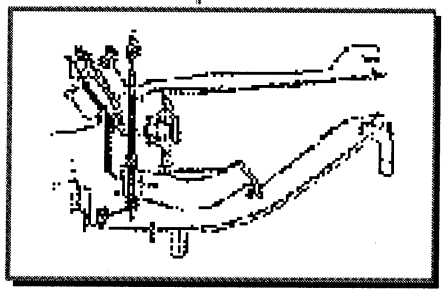


LOW NOx COMBUSTOR CONCEPTS

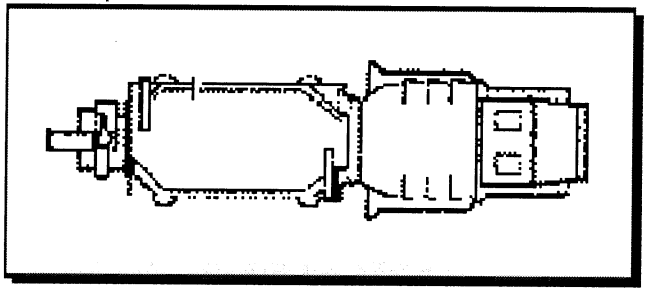




Low emissions combustor must operate in lean or rich burn mode to avoid high Nox



Lean Concept
(LPP)



Rich / Lean Concept
(RQL)

Environmental & Economic Barriers = Technical Challenges

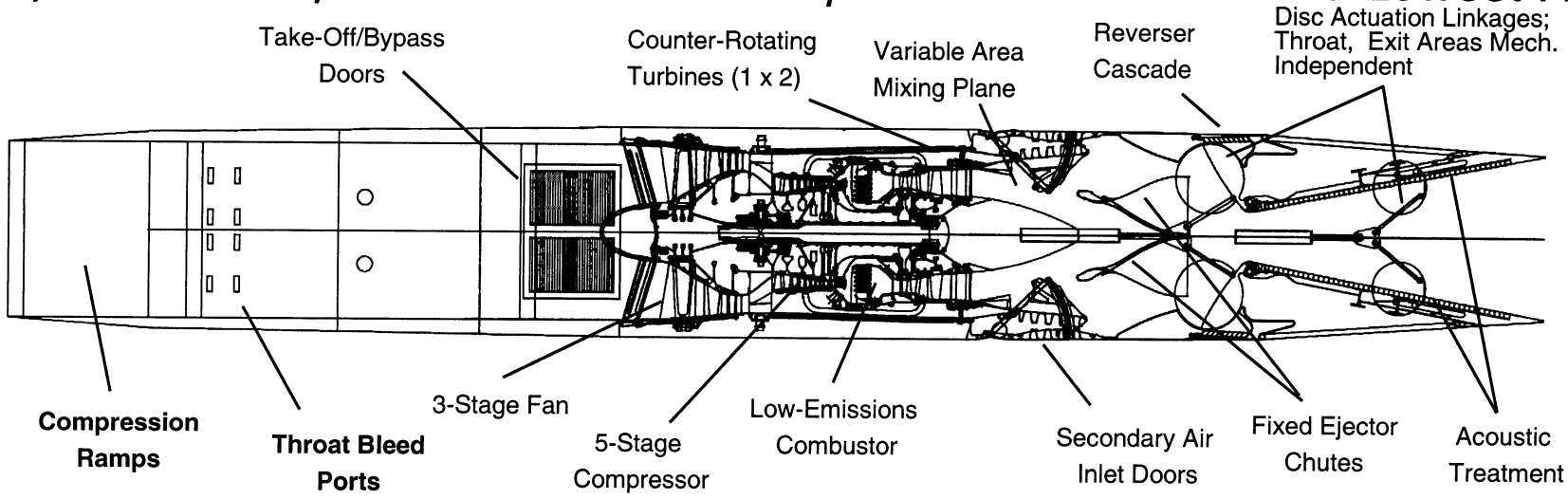
- Propulsion System Challenges
  - Ultra low NOx emissions levels assure no adverse impact to the Earth's ozone layer
  - Community noise levels (takeoff, cutback, approach) equal to or lower than the subsonic fleet
  - High temperature engine/nozzle materials which have acceptable characteristics for durability, weight, performance, and safety when incorporated in an HSCT propulsion system design
  - Sufficient thrust needed to combat the extra drag of supersonic flight while minimizing transonic and supersonic fuel burn

Near-term Technical Solutions: Propulsion System Advances

- High specific thrust cycles for efficient supersonic cruise which simultaneously achieve compliance with at least FAR 36 Stage 3 noise regulations
- Ultra-low Nitric Oxide emissions combustors
- High performance mixed-compression inlets with high stability margins for safe operation
- 30 fold increase in operating time at maximum temperatures and stresses over current commercial and military engines

HSCT Inlet/Engine/Nozzle System

Propulsion Components Selected for Optimum Economics and Lowest Risk



2D Bifurcated Mixed-Compression Inlet

- Lowest overall risk
- Low mechanical complexity
- Lightest weight when required acoustic treatment area is included

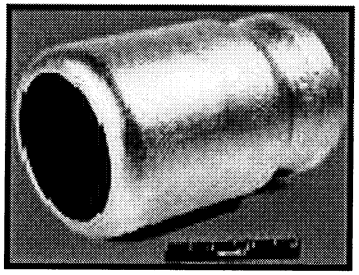
Mixed-Flow Turbofan Engine

- Moderate-risk, conventional turbomachinery
- Flexibility to match aircraft thrust requirements and noise suppression limitations

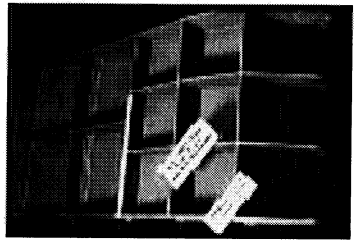
2-D Mixer-Ejector Exhaust Nozzle

- Moderate-risk noise suppression concept
- Avoids over-sizing of inlet and engine

- Propulsion Technology Concept selection met HSR Level 1 milestone
  - Lowest take-off gross weight, most economically attractive vehicle

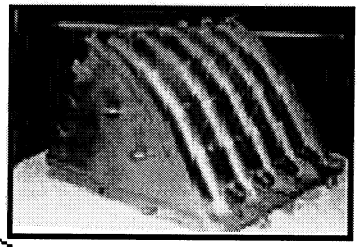


Ceramic Matrix Composite
Liner for
Low NOx Combustor

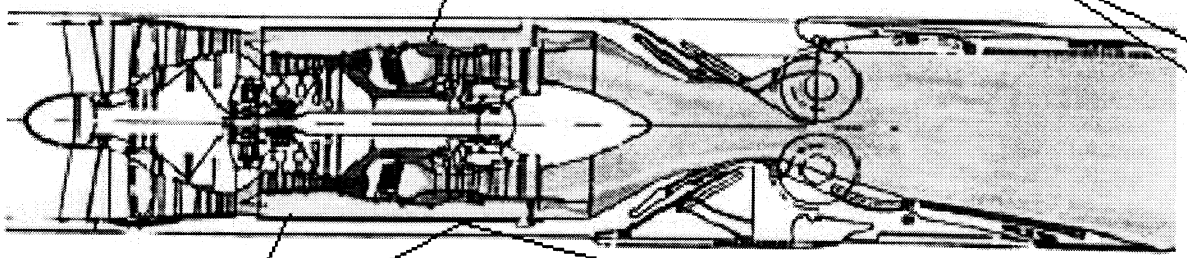


Cast Gamma TiAl

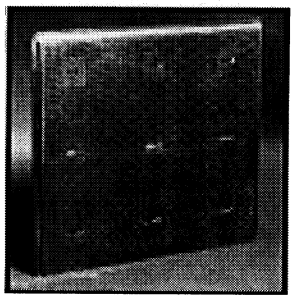
Lightweight Low Noise
Exhaust Nozzle
Materials



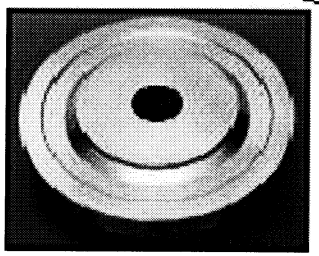
Cast Superalloys



Lightweight
Acoustic Treatment

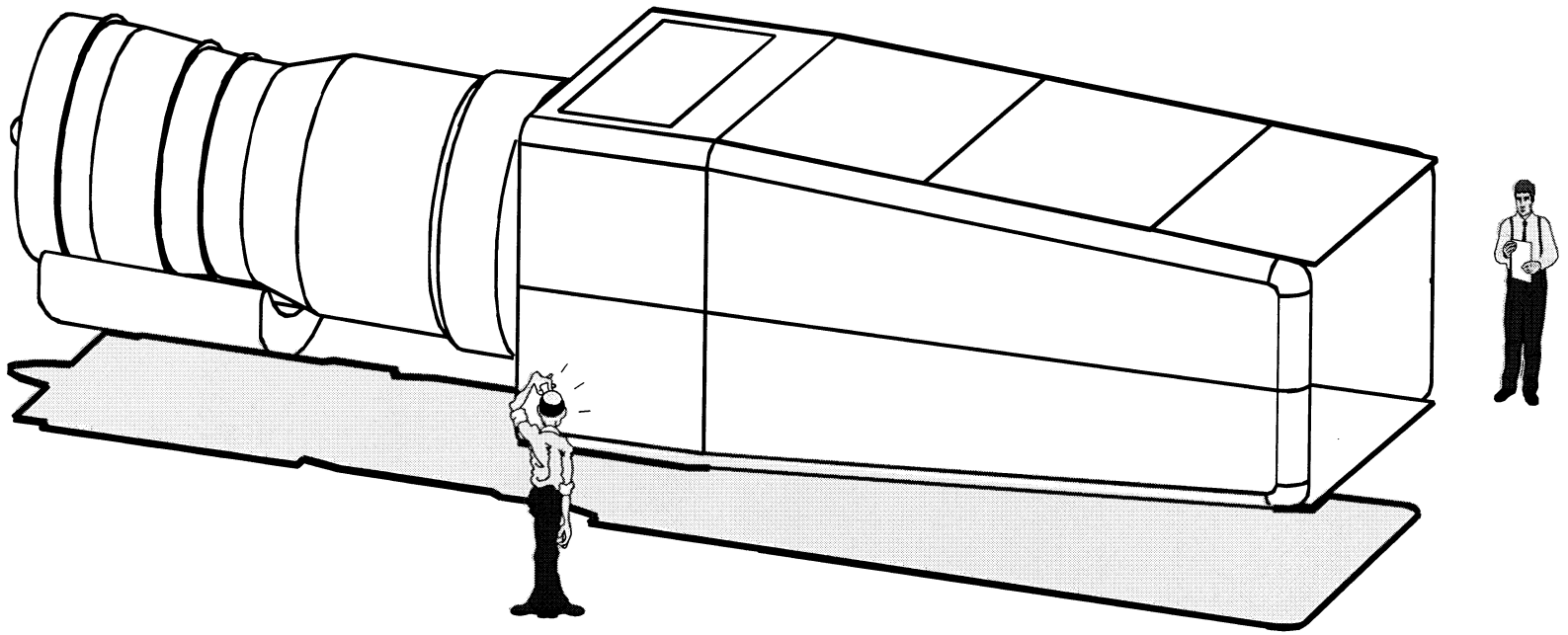


Long Life Turbine Airfoil
Material System Single Crystal
and Thermal Barrier Coating



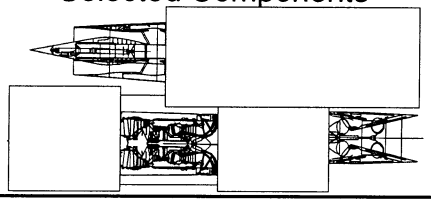
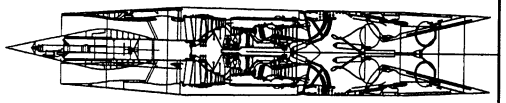
Long Life
Compressor/Turbine Disk
Nickel Material

HSCT Engine Part Sizes Approach Manufacturing Limits



- **Forging Limits For Fan And Compressor Blisks & Turbine Disk**
- **Heat Treatment For Thick Bore Turbine Disks**
- **Casting of Large Size Turbine Airfoils With Complex Internal Features**
- **Casting of Large Size, Thin Wall Nozzle Components**
- **Fabrication of Large Diameter Ceramic Matrix Composite Combustor Liners**

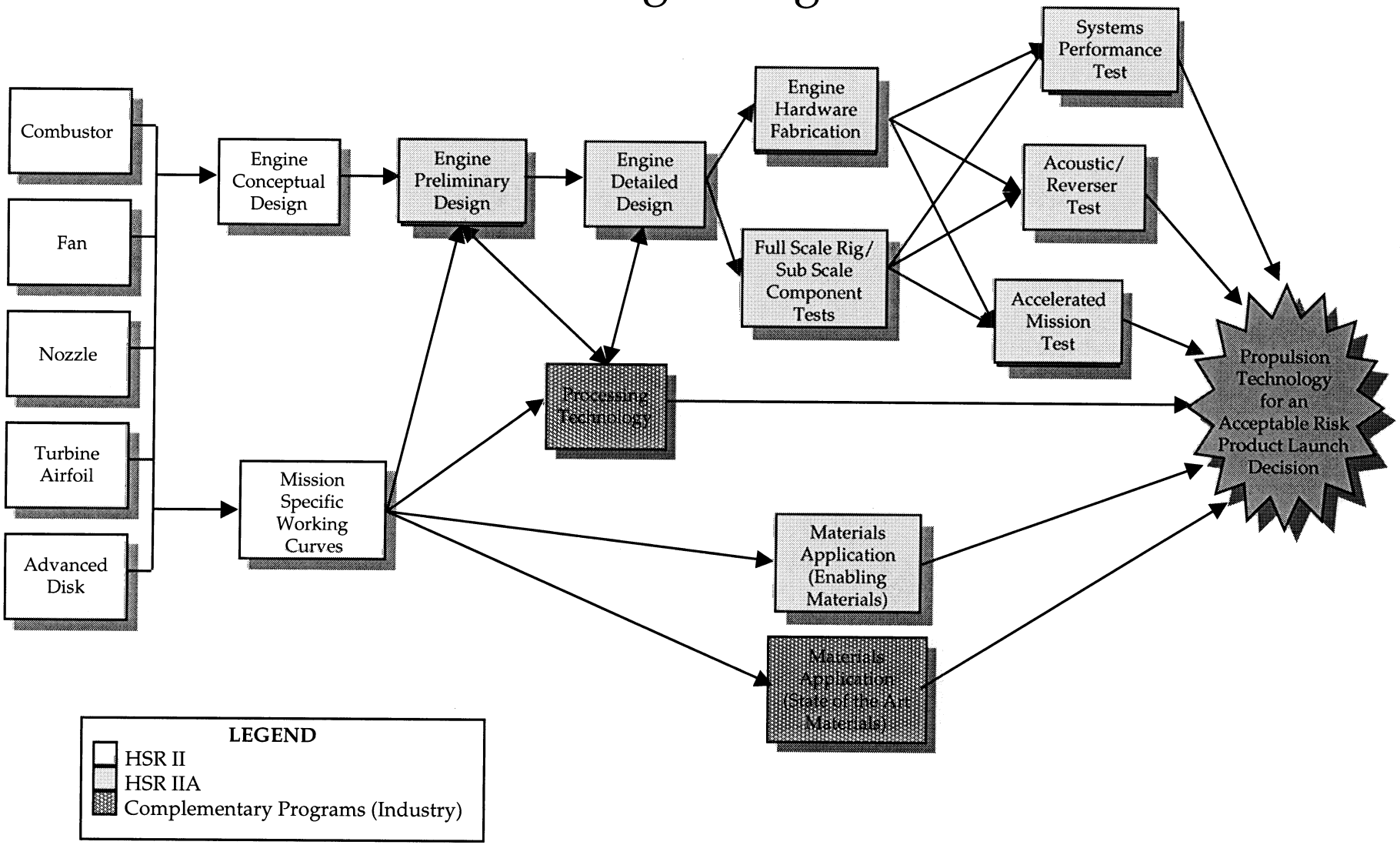
Propulsion Development Path

	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

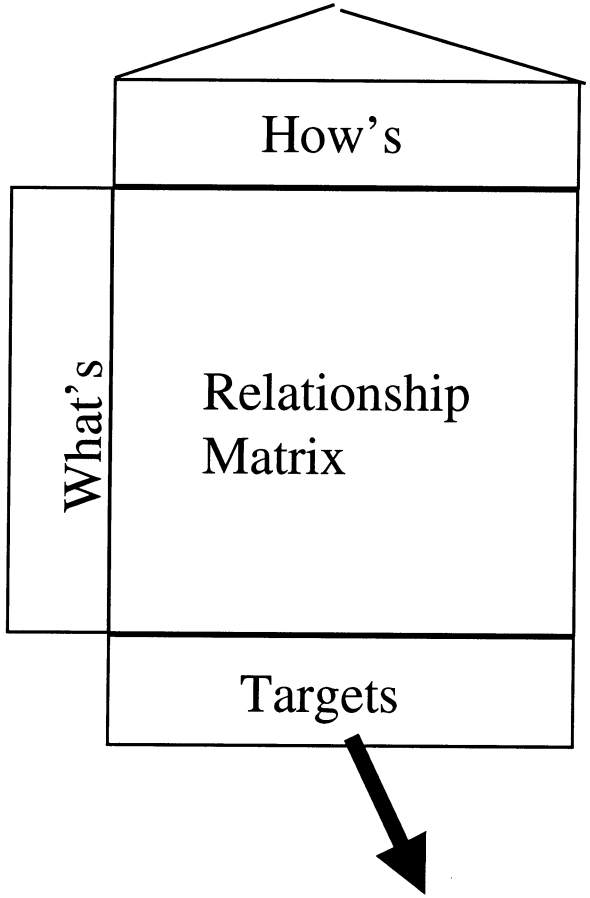
* Note: SMP=System Mechanical Performance
AMT=Accelerated Mission Test

Full Scale Engine/Nozzle Technology Demonstrator

Overall Logic Diagram



QFD-The "House of Quality" -Applied to HSR Propulsion



Technical Metrics

NRC House
Boeing requirements document

↓

Product propulsion house

↓

IIA system demo house

Fan/compressor house

Nozzle house

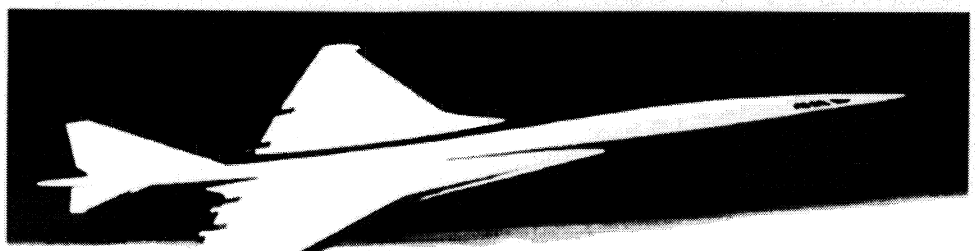
Combustor house

Turbine house

QFD process yields a consistent set of technical metrics driven by system requirements.

ТУ-144ЛЛ
ЛЕТАЮЩАЯ ЛАБОРАТОРИЯ
LABORATORY
СВЕРХЗВУКОВАЯ ЛЕТАЮЩАЯ
Tu-144LL SUPERSONIC FLYING

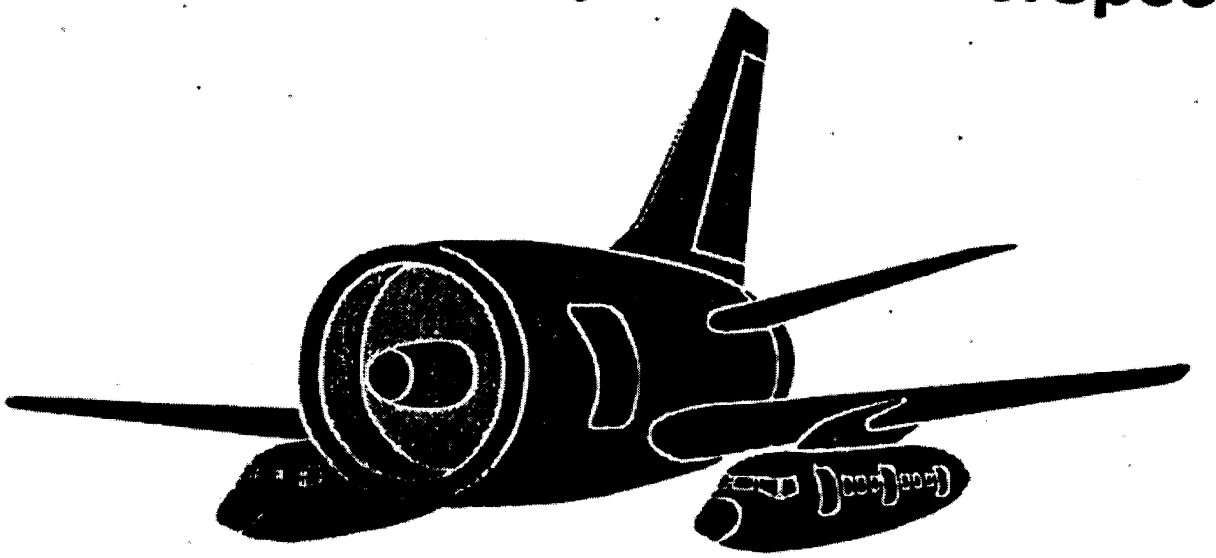
SUPERSONIC CRUISE PROPULSION RESEARCH



SYSTEMS STUDIES
- Variable cycle engines
- Supersonic through flow fan engines

FUNDAMENTAL R&T
- Analysis codes
  - ▲ Inlet
  - ▲ Supersonic fan
  - ▲ Combustor
  - ▲ Nozzles (aero/acoustic)
- Fluid physics
  - ▲ Shear flow control
  - ▲ Fundamental aeroacoustics

FOCUSED TECHNOLOGY PROGRAMS
- Environmental concerns
  - ▲ NO_x emissions
  - ▲ Community noise
- Supersonic through flow turbomachinery
  - ▲ Fan stage
  - ▲ Inlets
- Conventional supersonic inlets
- Enabling propulsion materials

CD-90-51195

New Propulsion Systems in Perspective