# HSCT ANTICIPATED SEAL NEEDS TURBOMACHINERY SEALS COMBUSTOR SEALS

John Henry
General Electric Co.
Cincinnati, Ohio

The High Speed Civil Transport (HSCT) engine concept is a large mixed flow turbofan similar in construction to current military fighter engines. The mission; however, is quite different. The engine will operate for long periods of time at very high Mach numbers and high altitudes. The engine is required to have very low emissions and noise levels to be acceptable in commercial service. The engine will be very large. Current thrust levels are in the 55000 lb range. At the current supercruise speed requirement of Mach 2.4, the Engine inlet temperature will be at least 380 degrees F . This is the lowest cycle temperature expected anywhere in the propulsion system. Seals will be expected to operate at this temperature and higher for thousands of hours without failure. Durability , cost, and weight will all be very important in determining the type of seals selected for a successful HSCT engine.

The next phase of the High Speed Research (HSR) program will be a technology demonstration of a full scale demonstrator engine scheduled to test in 2005. This is a joint effort between NASA, Pratt &Whitney, and General Electric. The ground test will be full size and incorporate as much of the HSCT needed technology as possible at that time. The test will demonstrate noise, emissions, durability , as well as the manufacturing capability to make an HSCT of advanced materials.

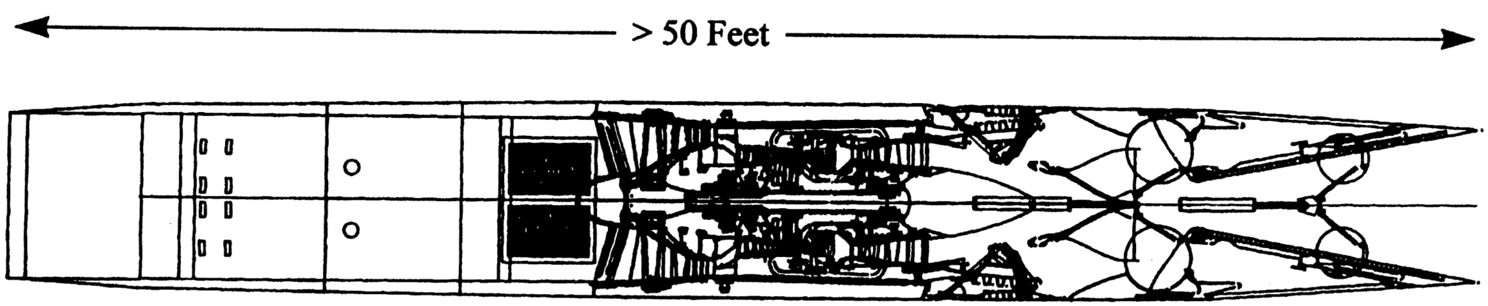
Weight will be very expensive in an HSCT due to the cost of fuel to go Mach 2.4. The weight of the seals will be assessed at a cost about an order of magnitude higher than current subsonic aircraft engines. Temperatures in the aft sumps pressurized with fan discharge air will be at current sealing material temperature limits. Pressures and speeds will be about conventional for current subsonic engines. Engine fluids to be sealed will be commercial current fleet standards, but the proposed high pressure hydraulic fluid(PFPAE) is new to the fleet.

Based on weight considerations, the engines and nozzle accessories will not be contained in an environmental pod as in the past on the GE4 and J93 supersonic engines. This means that the accessories (and electronics) will be required to survive in a temperature environment of 380 to 500 degrees F for very long times. This will be a severe test for the actuator and component fluid seals. The low noise exhaust nozzle will require several high pressure hydraulic actuators for the complex noise suppression and thrust reverse systems for the commercial HSCT.

The HSCT will fly at an altitude that requires that NOx be about 85% less than current combustors. One of the requirements for a low NOx combustor is that cooling air to the combustion liners be reduced to a minimum. This may require the development of a seal similar to the spline seals currently used in turbines for the combustion liner segments to limit parasitic leakage. Another option under study is a ceramic combustion liner. In this case, a seal needs to be developed that is compatible with a metallic dome and with a ceramic liner at very high temperatures and last a long time for the HSCT mission.

# *HSCT*
## *HIGH SPEED CIVIL TRANSPORT*

**HSCT PROPULSION SYSTEM**



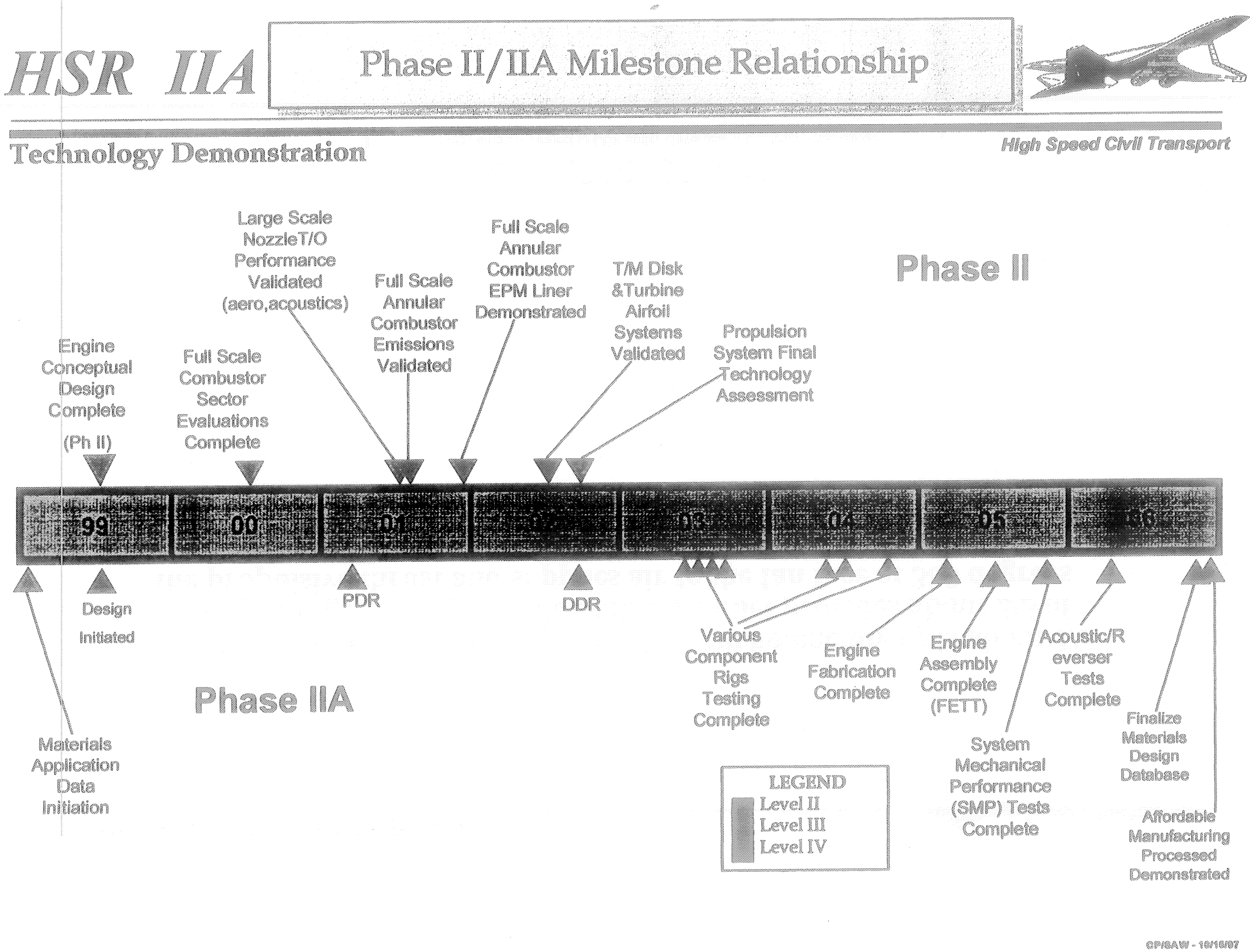

**2D INLET MIXED FLOW TURBOFAN MIXER/EJECTOR NOZZLE**

# HSCT

## HIGH SPEED CIVIL TRANSPORT

### SLIDE 1

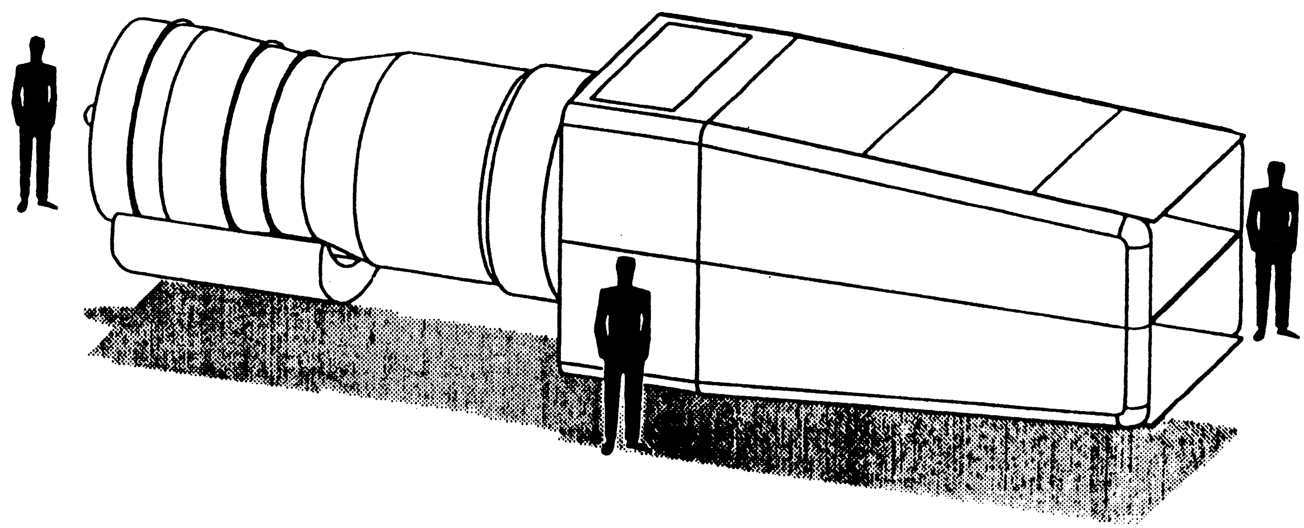
**Overall view of propulsion system. The turbomachinery is about 1/3 of the package. At supersonic cruise the inlet provides about 2/3 of the propulsive thrust and supplies air to the fan face at 380 degrees Fand 18 psia. This is the "lowest" air temperature available to the engine at supercruise.**


HSR IIA
Phase II/IIA Milestone Relationship
Technology Demonstration
High Speed Civil Transport
Phase II
Phase IIA
Engine Conceptual Design Complete (Ph II)
Full Scale Combustor Sector Evaluations Complete
Large Scale NozzleT/O Performance Validated (aero,acoustics)
Full Scale Annular Combustor Emissions Validated
Full Scale Annular Combustor EPM Liner Demonstrated
T/M Disk &Turbine Airfoil Systems Validated
Propulsion System Final Technology Assessment
99
00
01
02
03
04
05
06
Materials Application Data Initiation
Design Initiated
PDR
DDR
Various Component Rigs Testing Complete
Engine Fabrication Complete
Engine Assembly Complete (FETT)
System Mechanical Performance (SMP) Tests Complete
Acoustic/Reverser Tests Complete
Finalize Materials Design Database
Affordable Manufacturing Processed Demonstrated
LEGEND
Level II
Level III
Level IV
CP/SAW - 10/16/97

# HSCT
HIGH SPEED CIVIL TRANSPORT

## HSCT PROPULSION SYSTEM ENGINE CORES ARE VERY LARGE

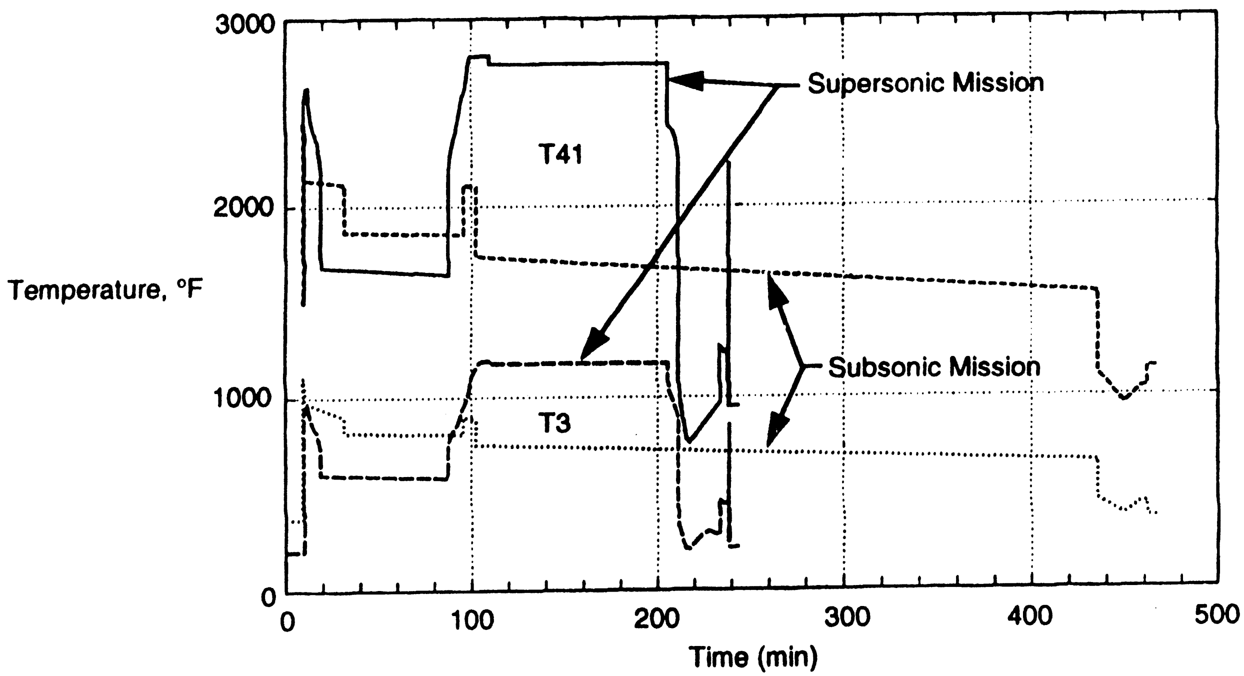
**The Large Size of HSCT Propulsion Systems May Require Advances In Material Processing and Component Manufacturing/Repair Technologies**



## SLIDE 3

**The engine size will be around 800lb/sec and 55000lbs thrust. The fan diameter will be close to a CFM. The core size will be about 525 lb/sec or about 2X current "big"(100,000lb thrust class) commercial turbofans. Note the small "apartment" size exhaust nozzle!**

# Supersonic Mission Tougher




HSCT propulsion system components must operate at max cycle temperatures and stress levels for ≈ 9000 hot hours or 30x that of current commercial transport engines and tactical fighter engines

# HSCT
## *HIGH SPEED CIVIL TRANSPORT*

### SLIDE 4

**High temperature durability is the issue in supercruise engines. The engine is oversized at takeoff for low noise so temperature requirements here are no more severe than for subsonic engines. To supercruise at 70000 ft where the air is thin the cycle temperatures are very high to generate thrust. The hot section will suffer especially, but the whole engine is hot due to the 380 degree inlet temperature. The other point is that a subsonic engine is hot for 2 minutes at takeoff and the sumps never have time to get full hot. This engine sets at its highest cycle temperatures for hours.**

# HSCT

## *HIGH SPEED CIVIL TRANSPORT*

**WEIGHT IS EXPENSIVE ON HSCT @ MO 2.4**

| COMPARISON: | HSCT | A340-300 |
|---|---|---|
| ENGINES | 4 | 4 |
| PAC | 300 | 295 |
| RANGE | 5000 KM | 5000KM |
| MTOW | 765000 LB | 556580 LB |
| BLOCK FUEL | 328064 LB | 137362 LB |
| PAC | 66000 LB | 64900 LB |
| PAC/FUEL | 20.1% | 47.2% |
| | 162 GAL/PASSENGER | 69 GAL/PASSENGER |

**FUEL COST IS ABOUT 2.35 TIMES AS MUCH FOR SAME MISSION**

# *HSCT*

## *HIGH SPEED CIVIL TRANSPORT*

**SLIDE 5**

**A supersonic aircraft will use a lot more fuel per payload. A 1 lb weight increase will require about $2200 reduction in selling price per engine to give the same economic return to the airline. This number is as low as $150 per lb on the current subsonic fleet. Weight will be a big issue on the HSCT.**

# HSCT

## *HIGH SPEED CIVIL TRANSPORT*

### HSCT REQUIREMENTS

| | | |
|---|---|---|
| **ALTITUDE:** | **SLS TO 70000FT** | **14.696 TO .7PSIA** |
| **MACH NUMBER** | **2.4** | **T2 = 380F** |
| **FAN PR** | **3.7** | **T15 = 620F** |
| **COMPRESSOR PR** | **5.7** | **T3 = 1200F** |
| **EGT** | | **T56 = 1800F** |
| **ROTOR SPEEDS** | **100% N2 = 4985RPM**<br>**1005 N25 = 7924 RPM** | Counter rota by machine |
| **FLUIDS** | **OIL: MIL-L-23699 100PSIG,450F**<br>**FUEL: JET A 1500PSIG,300F**<br>**HYDRAULICS: PFPAE 5000PSIG,650F,1.8SG** | |

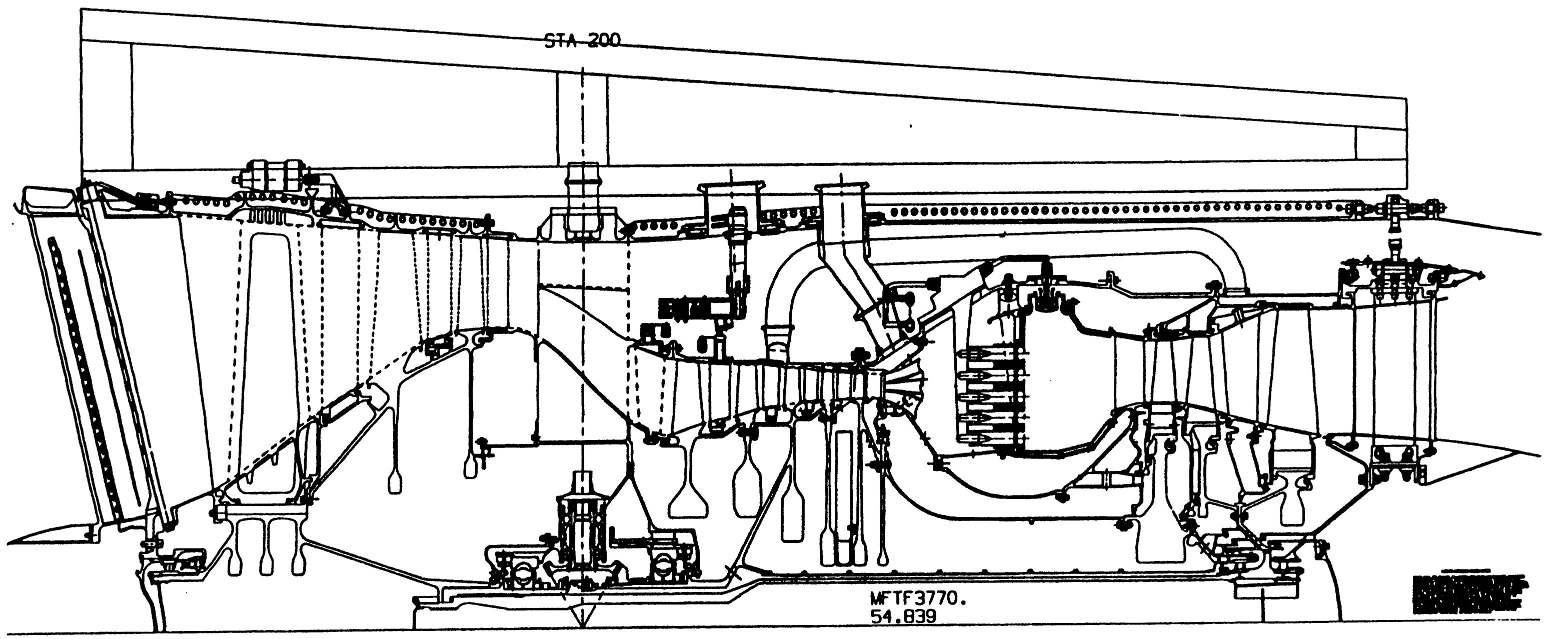
*HSCT*

*HIGH SPEED CIVIL TRANSPORT*

## SLIDE 6

**Typical cycle conditions for the long supersonic leg of the mission. Typical sump pressurization is fan discharge at 620 degrees F and 40 psia. Sink pressure for the tank,sumps, and separators is less than 1 psia. Rubbing speeds for the seals will depend on the final concept selected but in general the speeds will be well within current experience.**

# HSCT
## HIGH SPEED CIVIL TRANSPORT




**TURBOMACHINERY WITH LPP COMBUSTOR**

## *HSCT*
***HIGH SPEED CIVIL TRANSPORT***

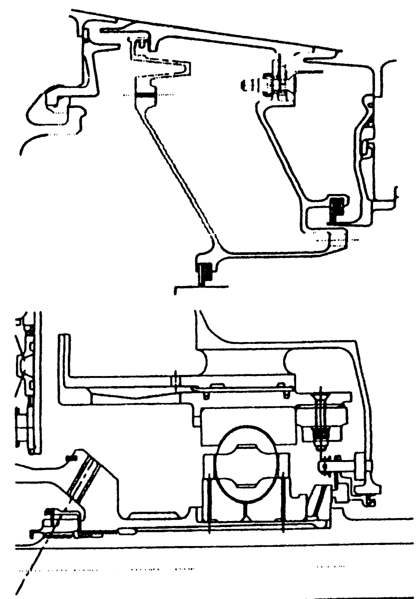
### SLIDE 7

**Conceptual engine is a mixed flow turbofan with carbon seal sumps, and labyrinth air seals. Air seal pressure drops are low compared to high bypass subsonic engines due to temperature limitations for long life. Overall pressure ratio is about 20 :1.**

# *HSCT*
## *HIGH SPEED CIVIL TRANSPORT*

**TURBOMACHINERY SEAL "TOOLBOX"**

**AIR SEALS :** **LABYRINTH SEALS**
**BRUSH SEALS**
**STATIC SEALS**



**SUMP SEALS:** **FACE CARBON SEALS**
**BORE CARBON SEALS**
**INTER SHAFT CARBON SEALS**
**INTER SHAFT LABYRINTH**

**SELECTION BASIS: 1) DOC +I**
**COST**
**WEIGHT**
**MAINTENENCE COST**
**PERFORMANCE**
**2) EXPERIENCE**

*HSCT*

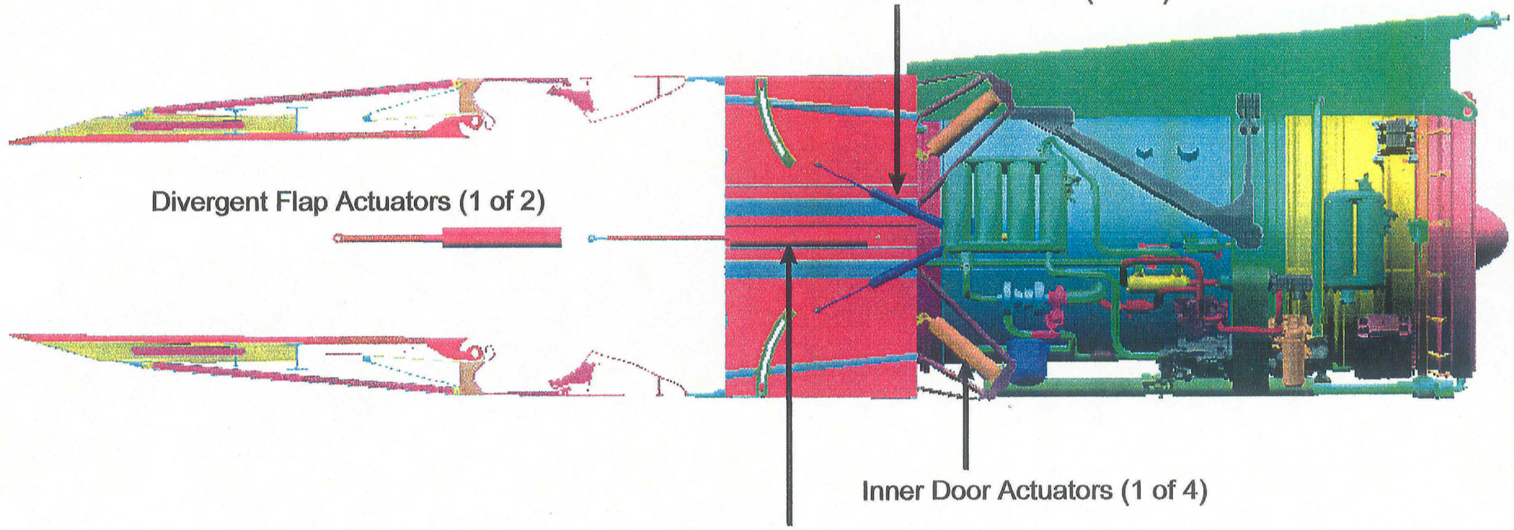
***HIGH SPEED CIVIL TRANSPORT***

**SLIDE 8**

**"Toolbox" of seals under design consideration for the HSCT turbomachinery. The final selections will be made considering DOC+I ($) , experience, and unique demands.**

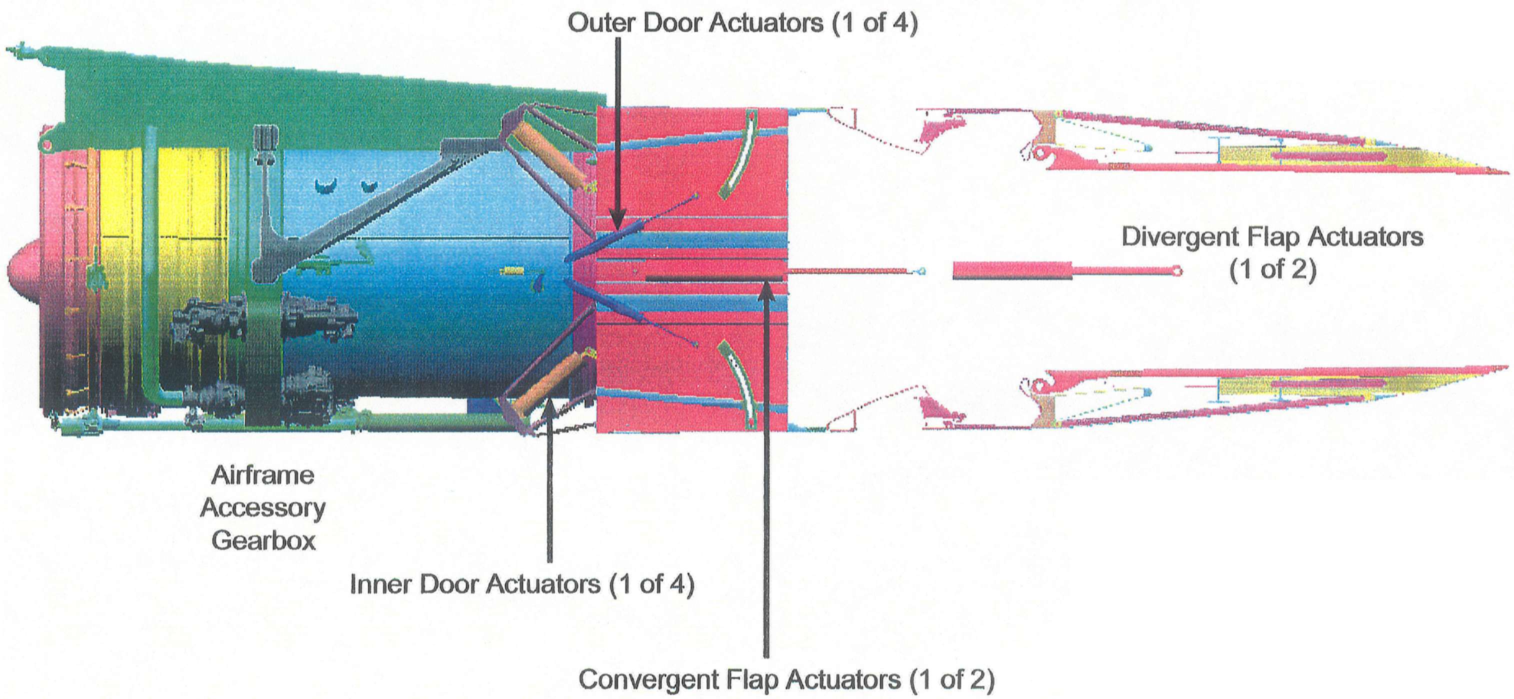
# HSR - CPC

***Mechanical Systems Design Review***




**Engine and Nozzle, Engine Accessory Side**

Oct 8, 1997



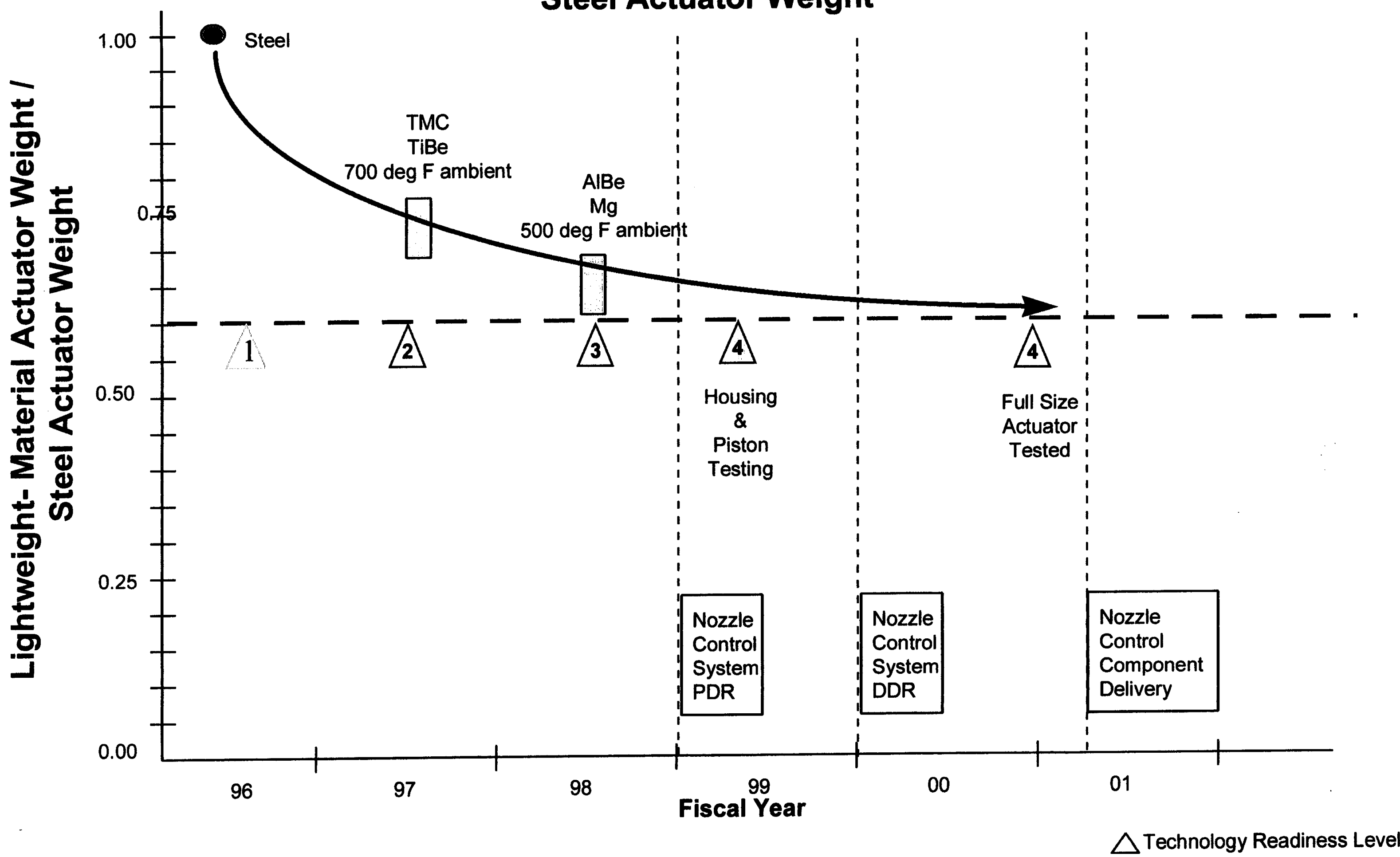

## Engine and Nozzle, Aircraft Accessory Side

Oct 8, 1997

**HSR II -CPC** **Controls Technology Metric P-X1**

*Technology Tracking and Assessment*

## Lightweight-Material Actuator Weight / Steel Actuator Weight




FILE: METRICS2.PPT 09/19/97

# *HSCT*

*HIGH SPEED CIVIL TRANSPORT*

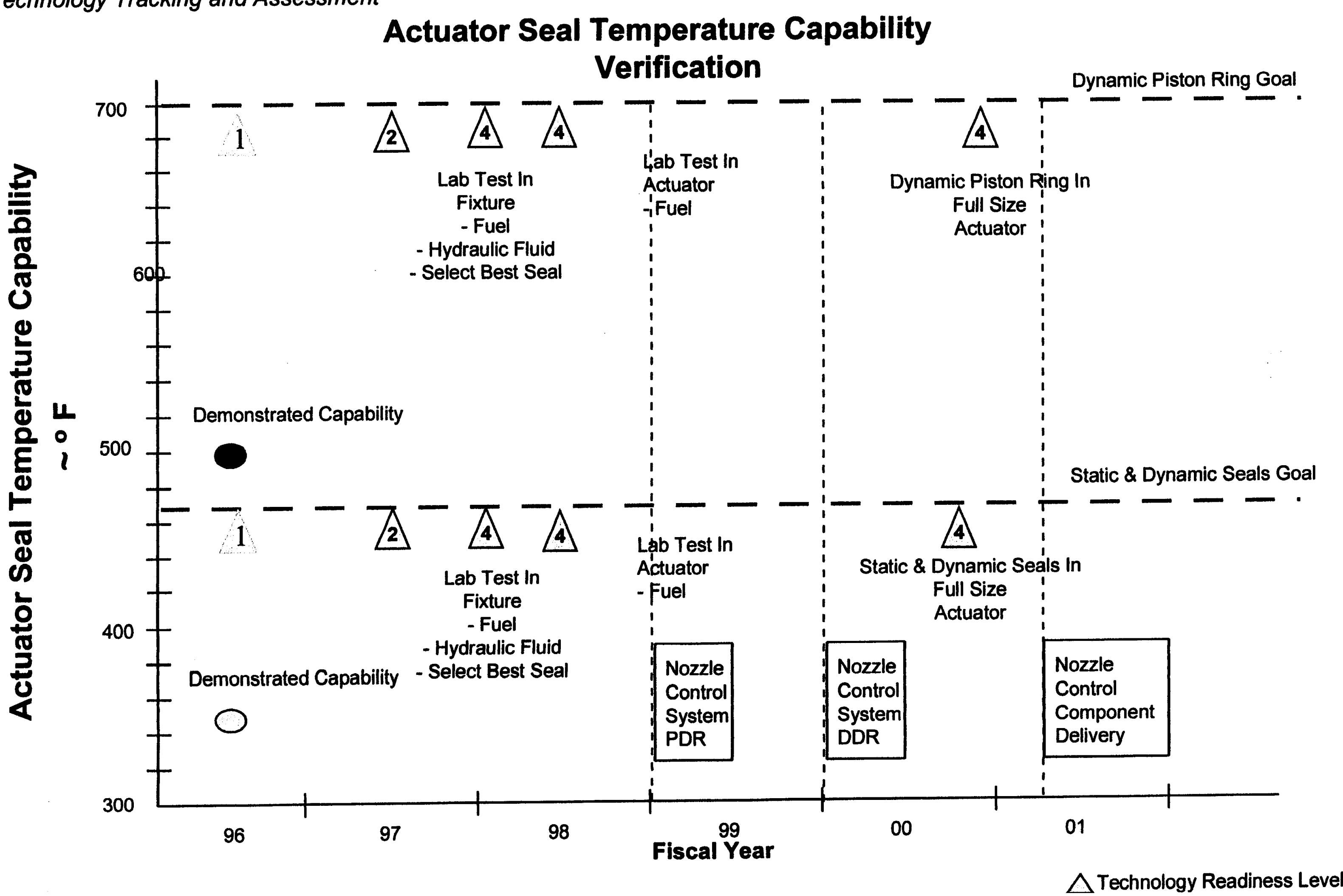
## SLIDES 10 AND 11

**These are metric charts for the external actuators and seals. They show the advancement in temperature capability and reduction in weight expected to get to the HSCT level of technology required.**

## HSR II -CPC

# Controls Technology Metric P-X2

*Technology Tracking and Assessment*



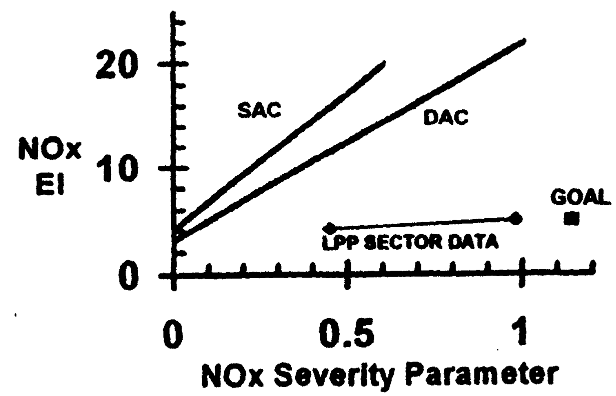

FILE: METRICS2.PPT 09/19/97

HSCT
HIGH SPEED CIVIL TRANSPORT

# Mission: Establish Technology Readiness by 2001 of Viable, Ultra-Low NOx, High Efficiency Combustor

- NOx emissions
  - Supersonic cruise NOx EI below 5
  - Subsonic cruise NOx EI below current best technology
  - Meet EPAP (tentatively, using 1984 supersonic proposed)
- CO and UHC emissions
  - Meet EPAP (tentatively, using 1984 supersonic proposed)
- Combustion efficiency
  - 99.9% during supersonic cruise
  - 99.5% during subsonic cruise
  - 99% everywhere on mission profile
- Life
  - 9000 hours

**Supersonic Cruise NOx EI**
Current technology, Goal, & HSCT LPP sector data




Cruise emissions goal requires an 85% reduction in NOx EI from current technology

***HSCT***

***HIGH SPEED CIVIL TRANSPORT***

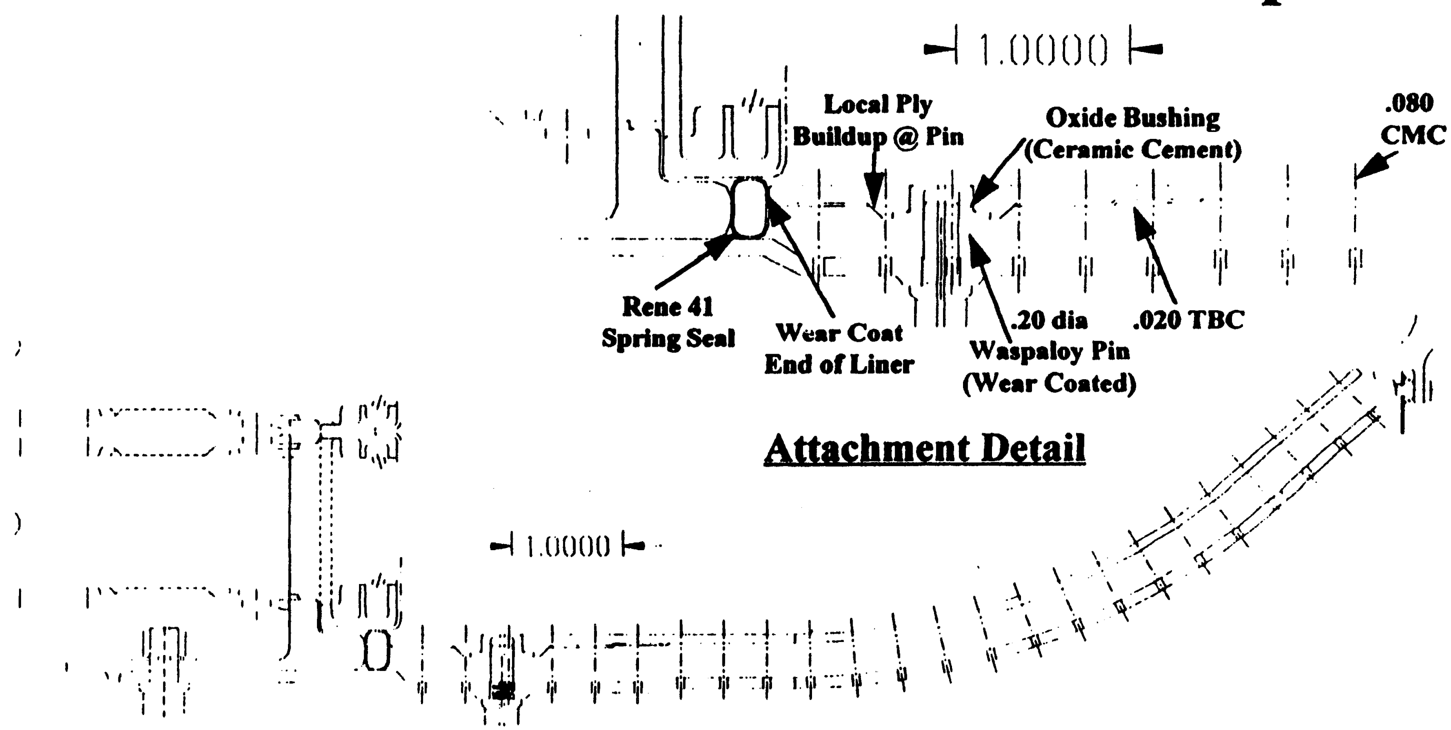
**SLIDE 12**

**Since the HSCT must fly in the stratosphere NOx generation at supersonic cruise has been limited to 5EI. This required an "invention " in combustor technology. The liners can leak little or no air into the initial combustion zone. GE has demonstrated this low level of NOx using an LPP(lean premixed/prevaporized ) approach. Either CMC or high temperature metallic combustor liners can be used depending on the life requirements accepted.**

# HSR-EPM

## Combustor Liner Materials Development Prog.

## ID Liner - Hot Pin Attachment Concept



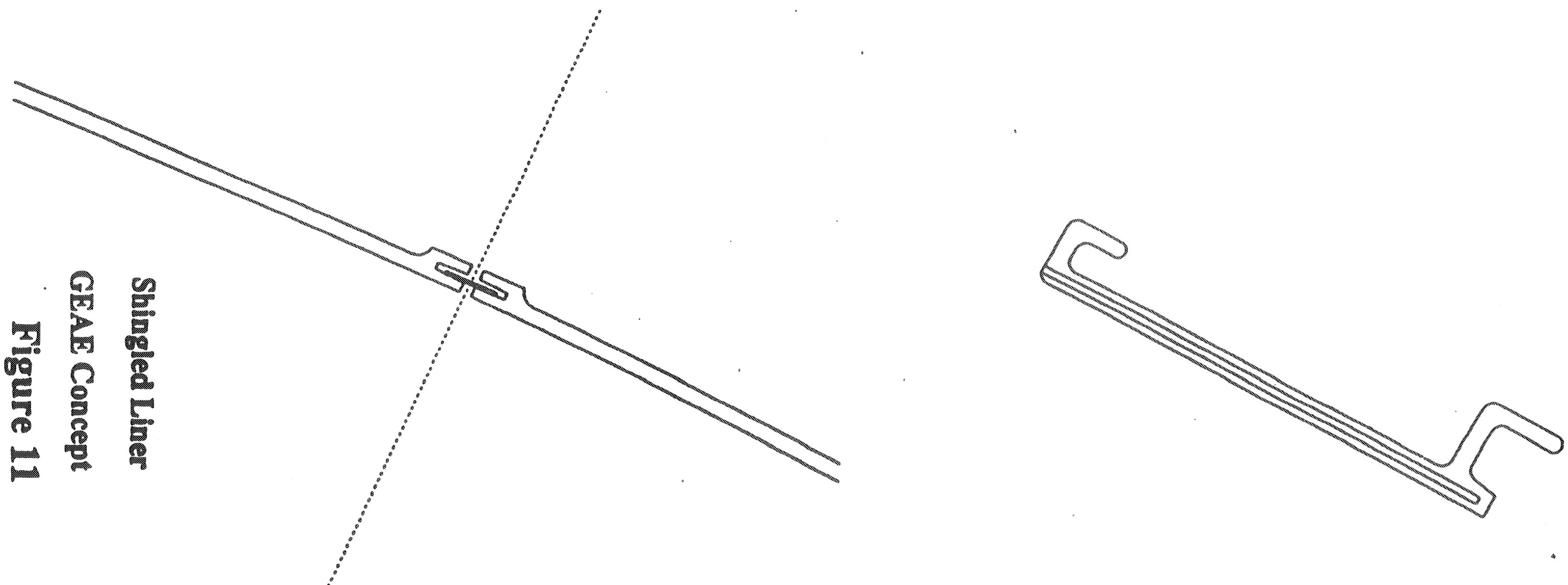
# *HSCT*
***HIGH SPEED CIVIL TRANSPORT***

## SLIDE 13

**This chart shows a conceptual seal for a CMC liner connection to an LPP dome. The real seal is an "invention" TBD if the ceramic liner is downselected next year. Several other attachments are under consideration.**

## *EPM* *Combustor Back-Up Materials Program*

## LPP Shingle Axial Spline Seal Design Concept



Shingled Liner

GEAE Concept

**Figure 11**

- Retained by Aft hook on upstream shingle.
- Conventional Design - Results in ~.002 equivalent gap width.
- Easy to assemble/Good Compliance
- Seal Strip Material: HS188 or L605
- Relatively low delta pressure loading could result in accelerated wear.

## SLIDE 14

**This slide shows a segmented metal liner with a rather conventional spline seal. The seal may be as little as an overlap to a more sophisticated "cloth"seal developed at GE CR&D), depending sector test data on allowable leakage. "Cloth" seals will be tested on a CFM56 sector test with segments incorporated into the aft end of the combustor liner.**

# *HSCT*

***HIGH SPEED CIVIL TRANSPORT***

## SUMMARY

**1) The big drivers for the HSCT seal design will be weight, cost, durability, temperature, and size.**

**2) The controls and actuation systems sealing requirements are challenged by temperature, size, pressure levels, and durability.**

**3) The combustor static seals may be as simple as an overlap to as complex as an invention.**