General Electric/Pratt & Whitney Summary Report

First Annual High Speed Research Workshop
May 14, 1991
Williamsburg, Virginia

Samuel C. Gilkey
GE Aircraft Engines

Richard W. Hines
Pratt & Whitney Aircraft

T2533.01 - 910507

GE and P&W Agreement

On October 9, 1990, GE Aircraft Engines (GEAE) and Pratt & Whitney (P&W) announced their agreement to cooperate on the development and production of the propulsion system for the next generation of supersonic commercial aircraft, a Mach 1.5 to 3.5 High Speed Civil Transport (HSCT). In teaming, we are combining the best talents of the U.S. propulsion industry to meet the technical challenge of developing an environmentally acceptable and economically viable second generation supersonic transport.

Although the HSCT propulsion system is a logical next step in commercial aircraft engine technology beyond those currently existing or contemplated, its development will undoubtedly require resources significantly greater than are available at any one existing United States engine company. Neither P&W or GEAE could realistically consider developing such a system alone. The HSCT propulsion system technology and development costs will be several times greater than subsonic transport propulsion costs. Considering the limited application of this propulsion system and the long time to recover investments, the HSCT propulsion system becomes a very high-risk project for any individual company to undertake.

Significant research and development is needed over the next decade to establish the framework for the introduction of the HSCT. GE Aircraft Engines and Pratt & Whitney working with NASA plan to lead the world in developing this propulsion system technology.

GE and P&W Agreement

- Restricted to HSCT propulsion system M1.5-3.5
- Two phases
  - Study phase
    - Evaluate technical and market feasibility
    - Technology development
  - Implementation phase
    - Technology development and validation
    - System development
    - Engine certification and production
- Strategy board - study phase
- Program manager - implementation phase

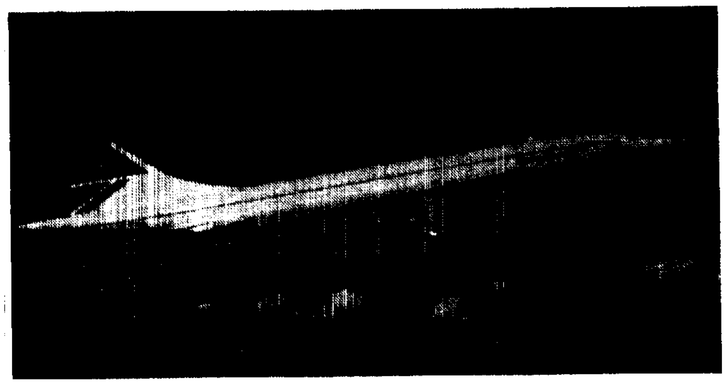
The Technical Challenge

With passengers well aware of the physical and time demands of long subsonic flights, a second generation supersonic transport can have a significant impact on the long range international travel market, provided it is both environmentally acceptable and economically competitive. This is particularly true in the Pacific basin where, for example, the flight time from Sydney to Los Angeles can be reduced to 6 hours from 13 hours.

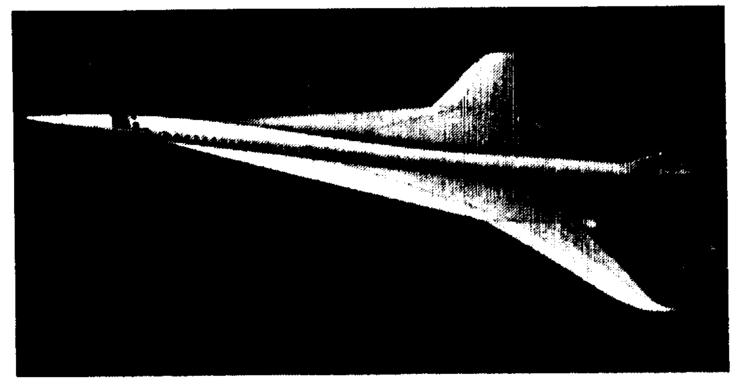
A comparison of the second generation supersonic transport with the first generation SST, the Concorde, highlights major differences between the aircraft, the most significant being the need to improve the operating economics eight times. It should be noted that the Concorde is a significant technical achievement. Concorde has proven that a supersonic airplane can be operated safely and effectively by the airlines. The aircraft cruise Mach number is not significantly different; the second generation SST or HSCT (High Speed Civil Transport) will cruise at Mach 2.0 to 2.5 depending upon the aircraft structural materials and possibly the environmental impact of the engine emissions.

Major differences are in the payload and range of the aircraft and its environmental acceptability. The HSCT's payload is increased from the 105 first class passengers on Concorde to about 300 passengers in three classes (first, business, and coach). Range of the airplane is increased from 3000 nautical miles to 5000 to 6000 nautical miles. Because there are only 14 Concordes in service with the airlines, they operate under special exceptions to the noise regulations, and engine emissions do not represent a major atmospheric concern. Assuming a fleet of 500 HSCT's is needed in the period of 2005 to 2025, it is clear that their impact on the environment must be carefully considered in the design process. The increase in payload and range is not, however, enough to satisfy our goal of an eightfold gain in the operational economics of the airplane. Technology improvements in both the aircraft and, more importantly, in the propulsion system are needed to deliver a competitive and environmentally acceptable aircraft to the market in 2005.

The Technical Challenge



Concorde



HSCT

Second Generation Supersonic Transport Versus Concorde	
Range	2 times greater
Payload	3 times greater
Economics	8 times greater

MAC1-57210-112690

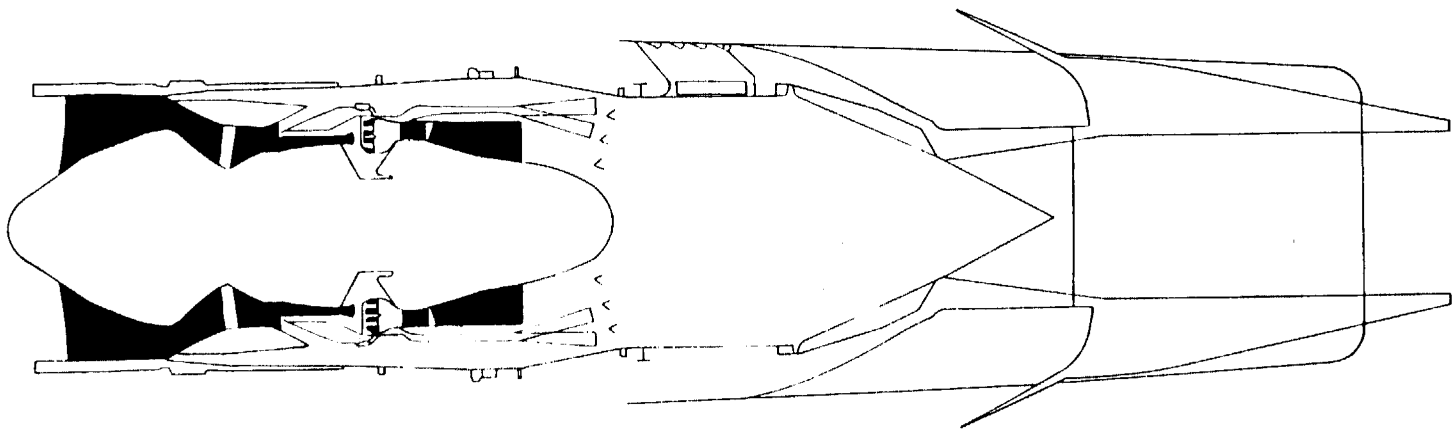
Environmental Challenges

Current research is now focused on addressing the major environmental issues of airport noise, engine emissions, and sonic boom. GEAE and P&W are studying a variety of engine and exhaust nozzle concepts and validating the emissions and acoustics technologies needed for this aircraft.

Two of the three major environmental concerns relative to the HSCT, emissions and airport noise, are directly attributable to the propulsion system. The third, sonic boom, may require the engine to be efficient at subsonic as well as supersonic cruise conditions.

The HSCT mission demands the propulsion system have excellent supersonic cruise performance, good subsonic cruise performance to satisfy the overland sonic boom constraints, and low emissions at cruise for minimal impact on the ozone layer. In addition, the engine must meet the airport noise rules with minimum system weight and performance penalties and deliver years of safe, reliable service with extended engine operation near full power.

Environmental Challenges



- Emissions (compatibility essential)
- Airport noise (compliance essential)
- Sonic boom (alleviation if possible)

MAC1-58366-011791

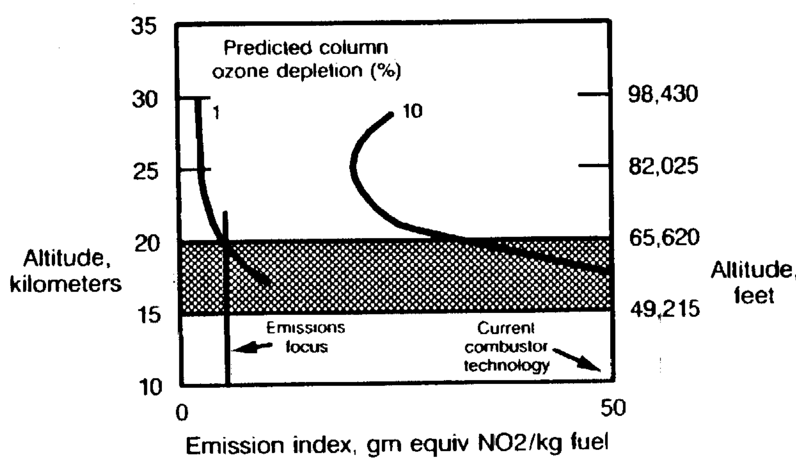
Engine Emissions Assessment

Emissions are a global issue and key to proceeding with the HSCT. Compatibility with the atmosphere is essential; however, the levels of engine emissions required for atmospheric compatibility are not understood at this time. The magnitude of the impact of engine emissions is uncertain and highly dependent on the altitude and latitude at which the engine emissions are occurring, the amount and chemical composition of emissions from a particular engine design, and the aircraft fleet size and operation. In assessing possible atmospheric changes, the modeler also needs to account for changes in the future atmosphere. The assessment of the impact of a HSCT fleet is a major global atmospheric modeling challenge for the scientific community. NASA is addressing this in the Atmospheric Effects of Stratospheric Aircraft (AESA) studies that began in 1990.

The current HSCT designs cruise for best performance between 15 and 20 kilometers depending upon cruise Mach number. It should be stressed that at this altitude there is great uncertainty in the atmospheric models because of the lack of understanding of the transport mechanisms between the troposhere and the stratosphere and the models' resolution. Current models need to be improved to address this critical region.

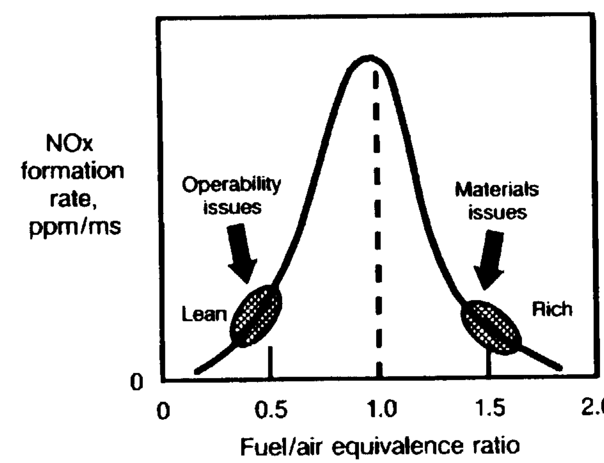
Results from one-dimensional atmospheric models for 500 HSCT's illustrate the importance of cruise altitude and engine emissions. Calculating the amount of NO_X discharged into the atmosphere is a product of the emission index of the combustor, the efficiency of the engine (specific fuel consumption), the airplane mission, and the fleet size. Current combustors have an emission index of around 50 grams equivalent of NO_X per kilogram of fuel burned. The goal of the NASA HSR Program is to validate combustor technology with an emission index of 5 grams per kilogram of fuel. P&W and GEAE are evaluating combustor designs that operate either rich or lean to meet the NASA HSR Program goal.

Engine Emissions Assessment



- Column ozone impact depends on total NOx generated
  - Number of aircraft
  - Number of flights
  - Cruise altitude and latitude
  - Fuel burn
  - Combustor emission index

- Current combustors NOx emissions need to be reduced by an order of magnitude
- Advanced combustor concepts operating rich or lean are required
- NASA flame tube testing is encouraging



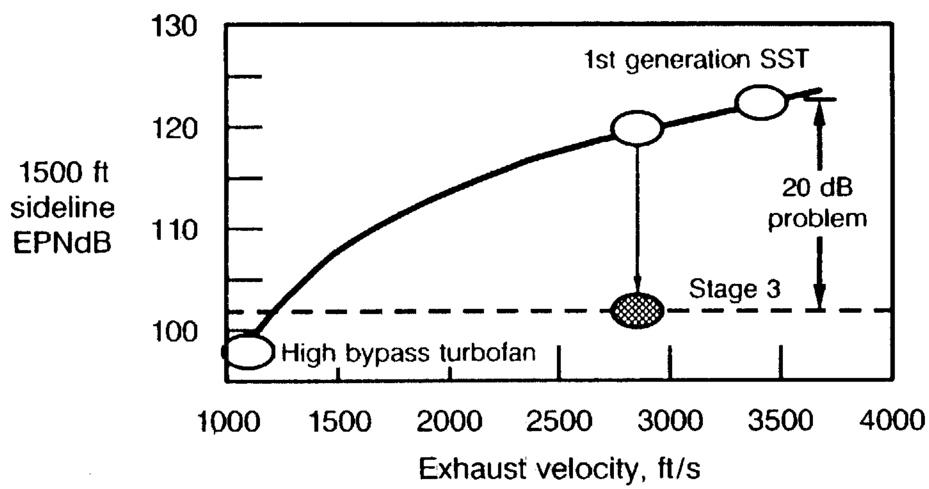
Airport Noise Assessment

It is expected that the HSCT will be required to meet the current subsonic aircraft noise regulations of FAR 36 Stage III. The difference between Concorde operation and Stage III is approximately 15 dB, or in other words, the HSCT must be 3 times quieter than Concorde. Compliance with the airport noise regulations is essential and has a major impact on the economics of the airplane. There is no fundamental scientific limitation on meeting the noise rule. Nevertheless, it is a challenging engineering job to develop the right combination of inlet, engine, and exhaust nozzle in an integrated propulsion system to meet the regulation with minimum impact on airplane TOGW.

The acoustic exhaust system may in all likelihood weigh as much as the engine and will have a major influence on the engine cycle selection. High specific thrust engines are the smallest and lightest weight for supersonic cruise. However, the high specific thrust engines make the most noise because of their accompanying high jet velocities.

In designing the exhaust system, emphasis must be placed on not only the acoustic performance but also the aerodymanic performance at both takeoff and supersonic cruise. In addition, careful consideration of the mechanical feasibility and system weight is needed. There has been significant progress in exhaust nozzle technology over the past 30 years. The pounds of exhaust system per dB of noise reduction has improved considerably since the GE4 engine. In the process, the complexity of the system has increased as evidenced by the number of actuation systems involved.

Airport Noise Assessment



- High specific thrust engines needed for good supersonic cruise performance
- What is the net impact on airplane TOGW and economics?
- Materials, aerodynamics, and acoustic technology have improved significantly since the GE4

Technology level	Nozzle Weight	Actuation systems	Suppression	lb/dB
GE4 (1960s)	4,825	3	4 dB	1,250
AST (1970s)	6,215	6	12 dB	517
HSCT (1990s)	5,065	6	17 dB	298

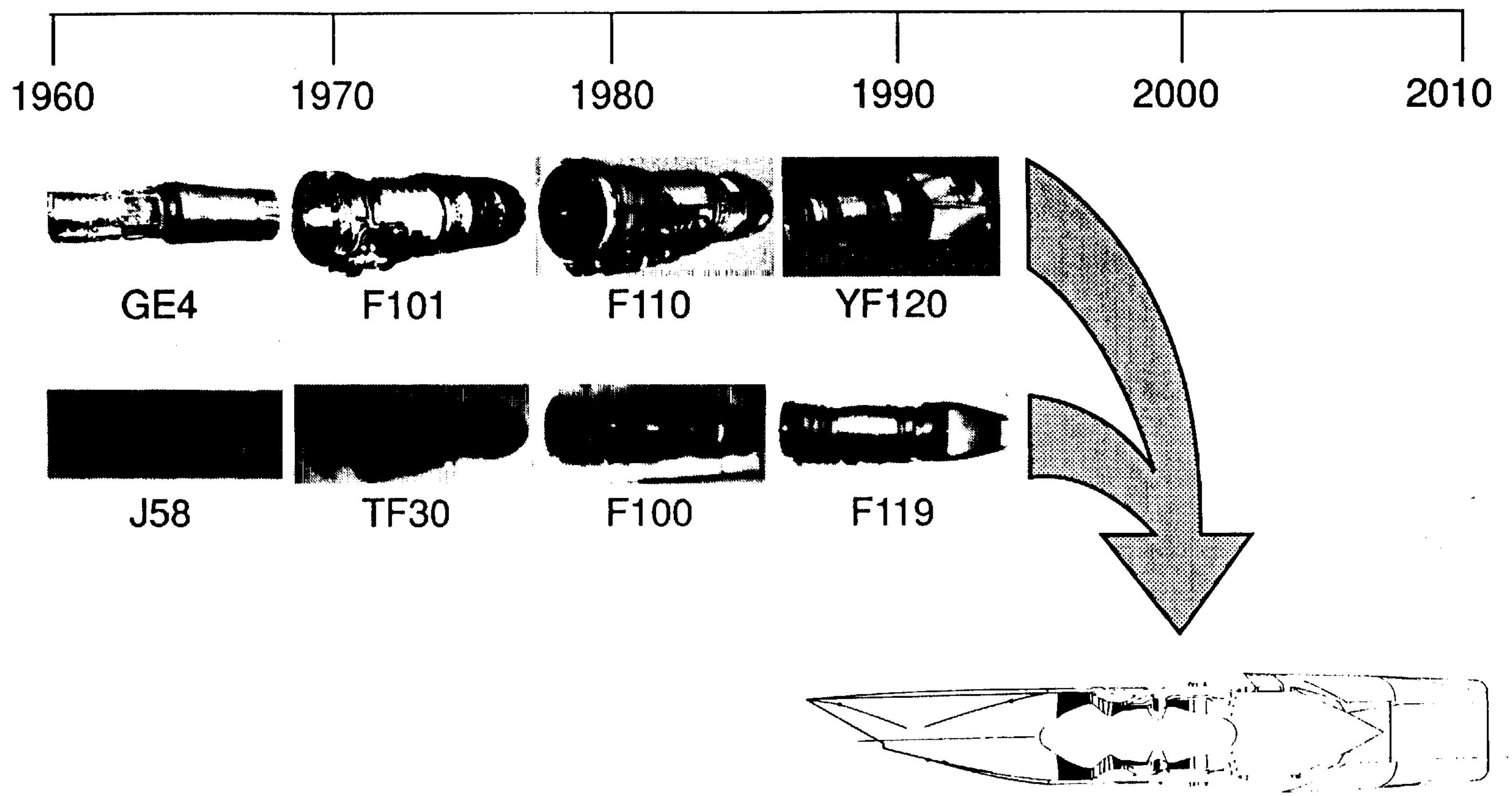
Evolution of Supersonic Engines

GEAE and P&W have a long heritage in propulsion system technology for supersonic flight. GE designed, built, and tested the GE4 turbojet engine for the USA SST program. P&W built the J58 used in the SR-71. Both companies continued to conduct research on supersonic propulsion system technology throughout the 1970's and early 80's. A significant data base relative to variable cycle engine technology including jet noise reductions was established under the NASA sponsored Supersonic Cruise Research and Variable Cycle Engine Technology programs.

In addition, P&W and GEAE continued to design and build supersonic military fighter engines such as the F100 and F110 leading to the development of the F119 and YF120 engines.

The next step in the evolution of supersonic engines is represented by the HSCT. The HSCT mission performance requires a highly integrated, closely coupled inlet-engine-exhaust nozzle design. This means closer working relationships between the aircraft and engine manufacturers.

Evolution of Supersonic Engines



Highly coupled inlet-engine-nozzle

MAC1-58124A-050691

Supersonic Engine Trends

The trends are anchored by the GE4 (EIS date 1972), and extend through AST studies of late 1970's to latest HSCT predictions. Military turbofan experience of 1970's and 1980's are included in thrust/weight and overall efficiency trends.

Gas Generator Ideal Thrust-to-Weight (sea level static conditions)

- Steady upward trend due to improved materials and design

Exhaust Nozzle Effectiveness

- Nozzle Weight/Noise reduction (EPNdB)
- Dramatic reduction (75%) from GE4 nozzle weight

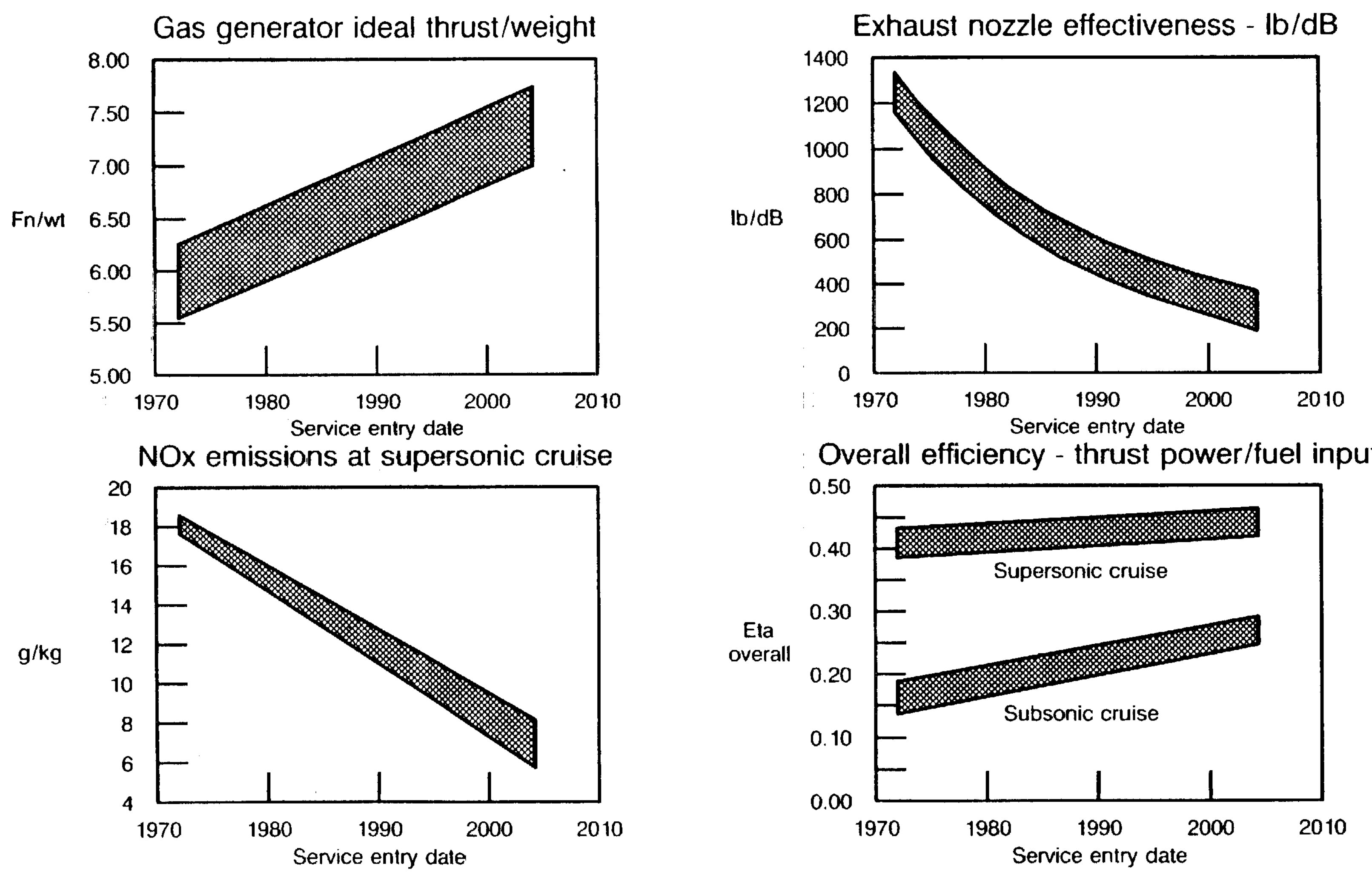
Supersonic Cruise Emissions

- Steady reduction to projected HSCT combustor designs

Overall Efficiency

- Shown for subsonic and supersonic cruise conditions
- Modest improvements at supersonic conditions resulting from advances in design technology; earlier designs were near-optimum cycle
- Improvements at subsonic conditions more pronounced due to use of cycles which give better propulsive efficiency subsonically, while preserving supersonic match.

Supersonic Engine Trends

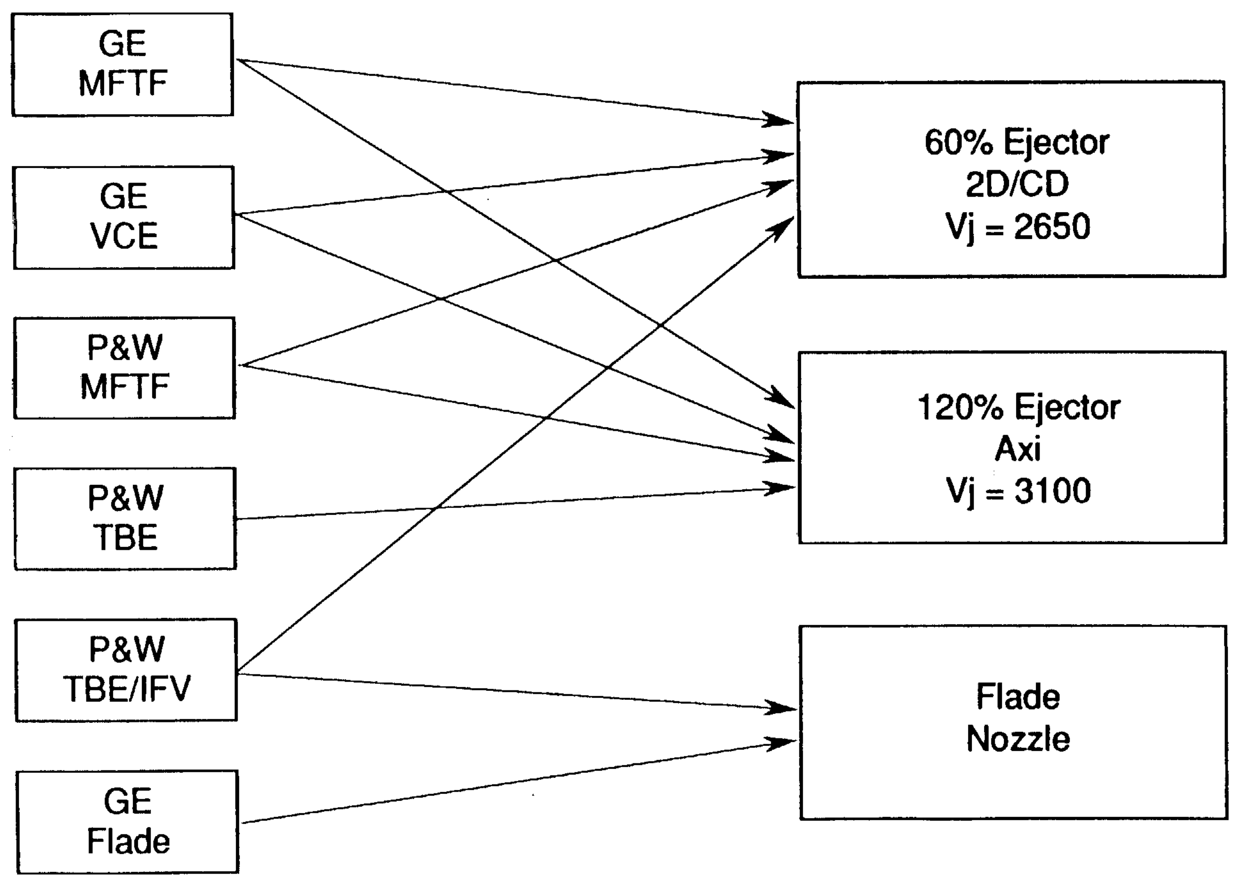


T2533.05 - 910507

HSCT Engine and Nozzle Options - Being Evaluated

P&W and GEAE are evaluating a number of engine concepts, the mixed flow turbofan (MFTF), the variable cycle engine (VCE) (double bypass engine), the turbine bypass engine (TBE), the turbine bypass engine with inverted flow value (TBE/IFV), and the fan on blade (FLADE). Three different exhaust nozzle concepts, one with 60% ejector flow, one with 120% ejector flow, and a fluid shield type nozzle for the FLADE, are being evaluated. Engine cycle studies are being conducted at Mach 2.4 and Mach 2.0 with both NASA and company funding.

HSCT Engine and Nozzle Options – Being Evaluated



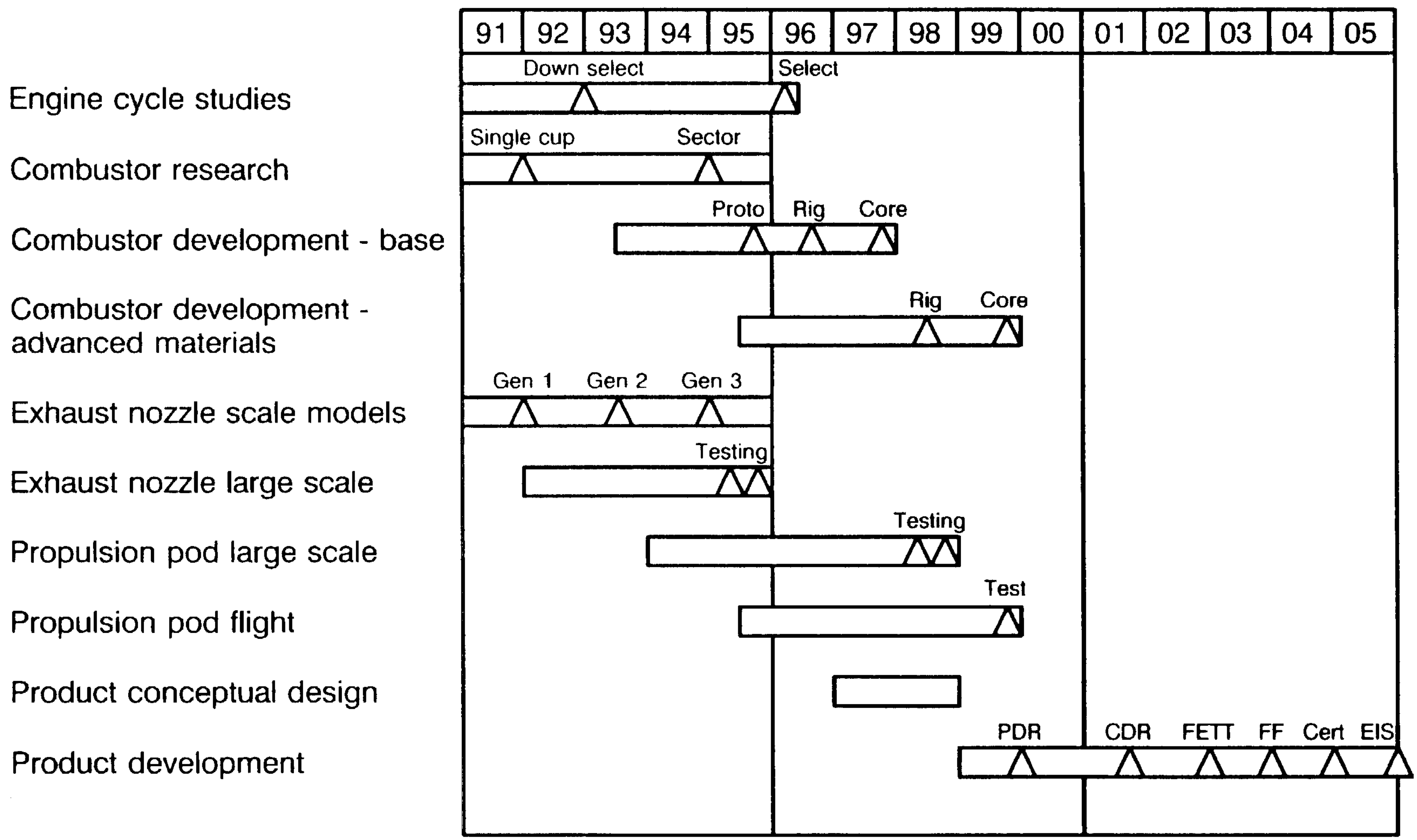
MAC1-60840-050391

HSCT Propulsion Development Schedule

The HSCT Propulsion Development Schedule has been laid out to support an entry into service (EIS) of 2005. This is an aggressive schedule requiring significant funding for technology development beginning in 1992. Several major tests are envisioned including a large scale engine/exhaust nozzle ground test in 1995 aimed at take-off and approach noise; a propulsion pod (inlet-engine-exhaust nozzle) ground test in 1998 aimed at supersonic performance, exhaust nozzle operability, and a second or third generation exhaust nozzle for take-off and approach noise; and a subsonic flight test of the propulsion pod aimed at in flight take-off and approach noise.

The decision to launch into a production engine program in 1998 or 1999 will be based on these key tests, the progress in developing the advanced propulsion materials under the NASA Enabling Propulsion Materials program, and the aircraft companies progress.

HSCT Propulsion Development Schedule



T2533.06 - 910507

THIS PAGE INTENTIONALLY BLANK

1992 Goals

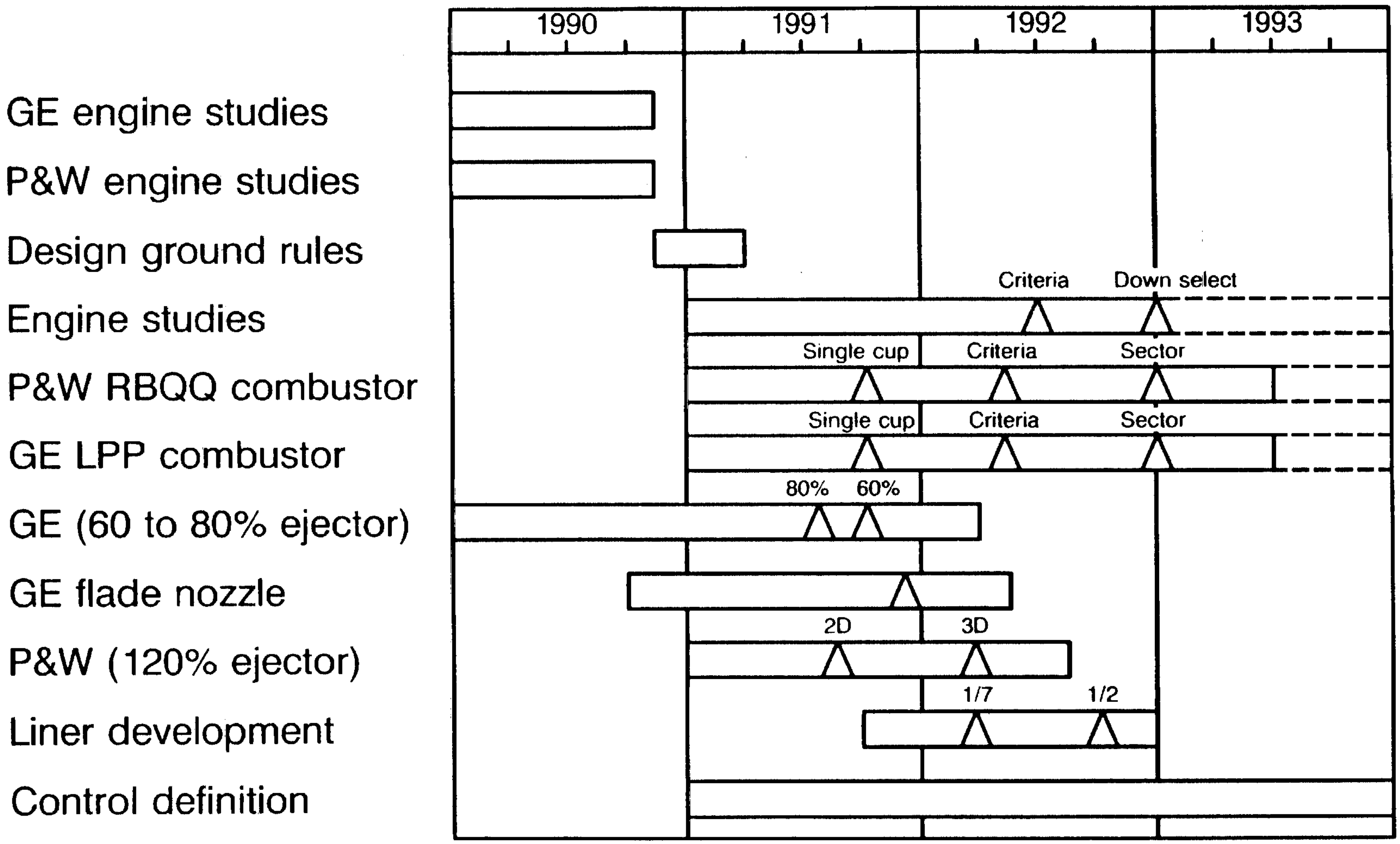
Over the next 2 years, P&W and GEAE are focused on demonstrating progress in addressing the environmental issues and establishing an economically viable, baseline propulsion system. The team plans to:

- Demonstrate 3 to 8 gm/kg NO_X in single cup combustor tests.
- Demonstrate the full range of low emission combustor operation in sector tests
- Demonstrate in scale model testing, practical exhaust nozzle concepts
- Demonstrate in scale model testing, acoustic lining material systems for use in the exhaust nozzle

In addition, the team plans to:

- Define inlet, engine, and exhaust nozzle design criteria and risk elements
- Analytically model exhaust nozzle/wing interaction (impact on entrainment) and propulsion pod/wing interactions
- Select a baseline engine/exhaust nozzle concept with backups
- Identify a "slave" engine from existing assets for HSR Phase II technology validation testing

1992 Goals



1990
1991
1992
1993
GE engine studies
P&W engine studies
Design ground rules
Engine studies
Criteria
Down select
P&W RBQQ combustor
Single cup
Criteria
Sector
GE LPP combustor
Single cup
Criteria
Sector
GE (60 to 80% ejector)
80%
60%
GE flade nozzle
P&W (120% ejector)
2D
3D
Liner development
1/7
1/2
Control definition

1992 Goals

- Demonstrate 3 to 8 gm/Kg NOx in single cup test
- Demonstrate full range of combustor operation in sector test
- Define combustor design criteria and risk elements
- Demonstrate “practical” exhaust nozzle concept (noise and performance)
- Identify “realistic” acoustic lining approach
- Model exhaust nozzle/wing interaction (entrainment)
- Define engine/exhaust nozzle design criteria and risk elements
- Select baseline engine/nozzle and backup(s)
- Identify demo engine from existing assets

Design Ground Rules - Engine Evaluation

The P&W and GEAE design team has developed a set of design groundrules to use as the basis for developing the engine cycles and preliminary designs. This set of groundrules is essential to making a meaningful comparison of the various engine and exhaust nozzle combinations previously identified. All of the new designs are being developed using these assumptions. By the end of 1991, the team will be able to objectively compare the various engines and establish criteria for downselect to a baseline and backup. Elements of risk are to be determined for each of the engines in this process.

Design Ground Rules - Engine Evaluation

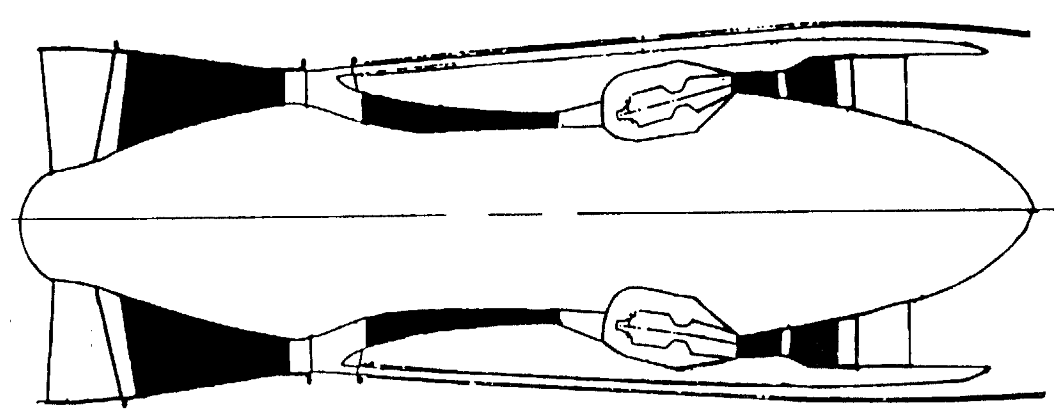
Airflow size	650 lb/sec
Thrust class	50 to 60,000 lb
Mach number	2.4
Cycle temperatures	2900°F max T41 1250°F max T3
Component efficiency	Late '90s technology availability
Materials	Late '90s technology availability
Commercial life	18,000 hrs/9,000 cycles cold section 9,000 hrs/4,500 cycles hot section

P&W and GE Design Teams Are Defining Engines to Common Set of Assumptions

P&W Mixed Flow Turbofan

The P&W Mixed Flow Turbofan is a low bypass ratio turbofan with an overall pressure ratio of 20. The data reflects the common design groundrules. Engine preliminary design weights are still being developed.

P&W Mixed Flow Turbofan



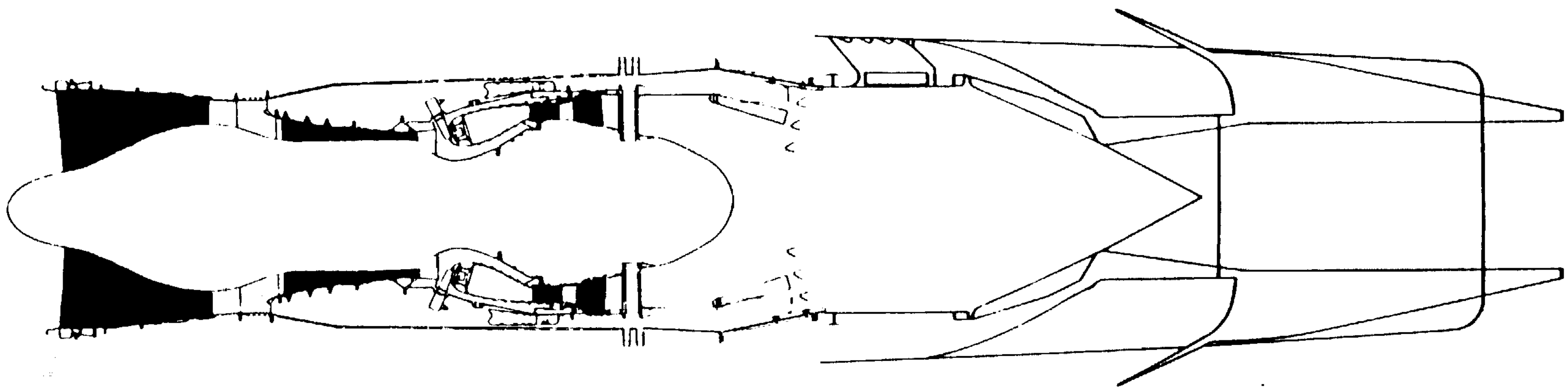
FPR	4-5		SFC subsonic	.88-.95
PROA	19-20		SFC supersonic	1.23-1.27
BPR	.15-.30		T41 cruise	2730°F
Weight	- Core	TBD	T3 cruise	1240°F
	- Exhaust nozzle	TBD	Cfg cruise	.982
	- Total	TBD	Cfg takeoff	.95

MAC1-60844-050391

GE Mixed Flow Turbofan

The GE mixed flow turbofan engine is a low bypass ratio turbofan with an overall pressure ratio of 21.5. This engine is shown with a 2D-CD ejector nozzle with 60% secondary flow entrainment. Nozzle thrust coefficients are based on this exhaust nozzle. The cycle and preliminary design activity on this engine is due to be completed in the next two months.

GE Mixed Flow Turbofan



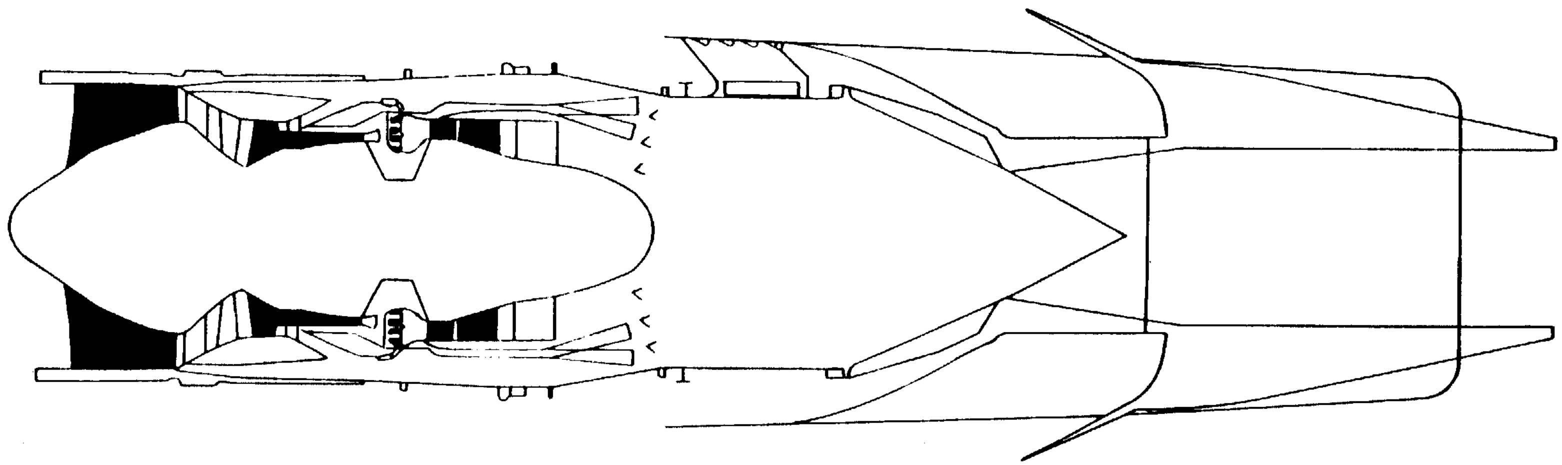
FPR	4.75			SFC subsonic	TBD
PROA	21.5			SFC supersonic	TBD
BPR	0.15			T41 cruise	TBD
Weight	- Core	TBD		T3 cruise	TBD
	- Exhaust nozzle	TBD		Cfg cruise	.982
	- Total	TBD		Cfg takeoff	.95

MAC1-60842-050391

GE Variable Cycle Engine

The GE variable cycle engine is a double bypass engine with an overall pressure ratio of 25 and a bypass ratio of 0.65. The data shown is based on earlier design groundrules. We are in the process of updating this design to reflect the common design groundrules. This engine is shown with a 2D-CD ejector nozzle with 60% secondary flow entrainment.

GE Variable Cycle Engine



FPR	4.8		SFC subsonic	.90
PROA	25		SFC supersonic	1.24
BPR	0.65		T41 cruise	2750°F
Weight	- Core	5951	T3 cruise	1200°F
	- Exhaust nozzle	4979	Cfg cruise	.986
	- Total	10,930	Cfg takeoff	.93

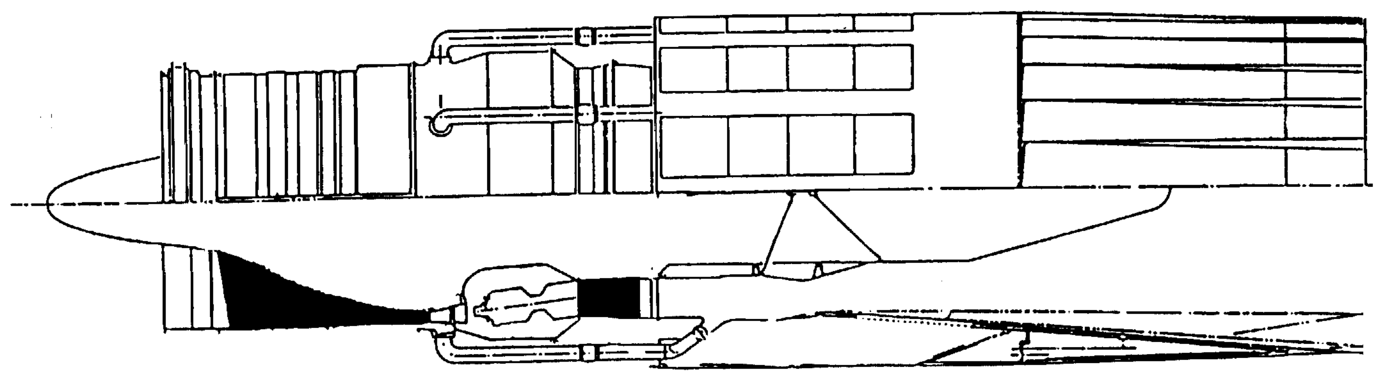
This data is based on GE design ground rules. Engine design is being updated in 1991 to common design groundrules

MAC1-60841-050391

P&W Turbine Bypass Engine (TBE)

The P&W Turbine Bypass Engine is a single spool turbojet with a bleed system around the turbine. It has an overall pressure ratio of 19. An axisymmetric ejector exhaust nozzle with 120% secondary flow entrainment is shown. Engine and exhaust nozzle preliminary design weights are still being developed.

P&W Turbine Bypass Engine (TBE)



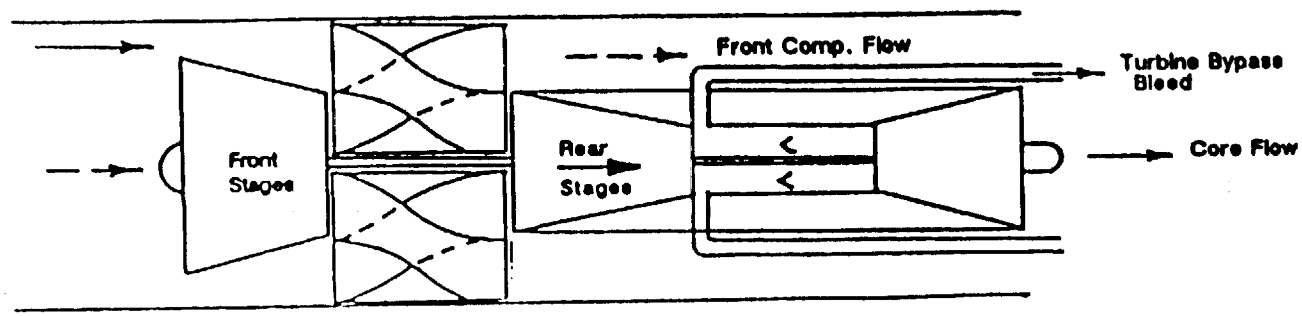
FPR	–		SFC subsonic	.93
PROA	19.0		SFC supersonic	1.29
BPR	–		T41 cruise	2700°F
Weight	- Core	TBD	T3 cruise	1250°F
	- Exhaust nozzle	TBD	Cfg cruise	.982
	- Total	TBD	Cfg takeoff	.95

MAC1-60845-050391

P&W Turbine Bypass Engine with Inverted Flow Valve

The P&W Turbine Bypass Engine with inverted flow value is a high flow engine cycle similar to the flade engine. At takeoff the engine operates like a separate flow turbofan with moderate bypass. At cruise the engine operates like a turbojet with all flow though both sections of the compressor. A fluid shield type exhaust nozzle could be utilized on this engine. The preliminary designs are planned to be completed by the end of 1991.

P&W Turbine Bypass Engine with Inverted Flow Valve



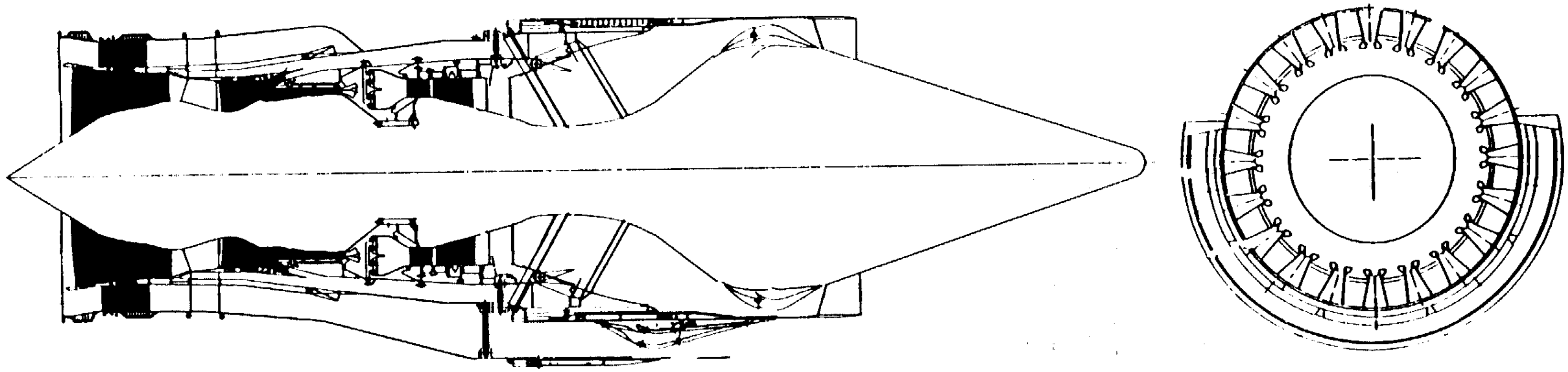
FPR	–		SFC subsonic	.93+
PROA	19.0		SFC supersonic	1.29+
BPR	–		T41 cruise	2700°F
Weight	- Core	TBD	T3 cruise	1250°F
	- Valve	TBD	Cfg cruise	.982
	- Exhaust nozzle	TBD	Cfg takeoff	.95
	- Total	TBD		

MAC1-60846-050391

GE Fan on Blade (Flade)

The GE fan on blade or Flade engine is a double bypass engine with a tip fan on the second stage low pressure fan. The flade flow is ducted around the lower 220 degrees of the main exhaust to form a fluid shield around the exhaust. The flade operates with a higher bypass at subsonic cruise. The core engine is sized for supersonic cruise while the flade is sized for takeoff conditions. An axisymmetric exhaust nozzle with variable exit areas and minimum suppression on the core flow is being used. This data reflects the common design groundrules.

GE Fan on Blade (Flade)



FPR	4.95	
PROA	21.7	
BPR	0.33	
Flade PR	1.8	
Weight	- Core	8180
	- Exhaust nozzle	3805
	- Total	11,985

SFC subsonic	0.92
SFC supersonic	1.31
T41 cruise	2600°F
T3 cruise	1180°F
Cfg cruise	.982
Cfg takeoff	.95

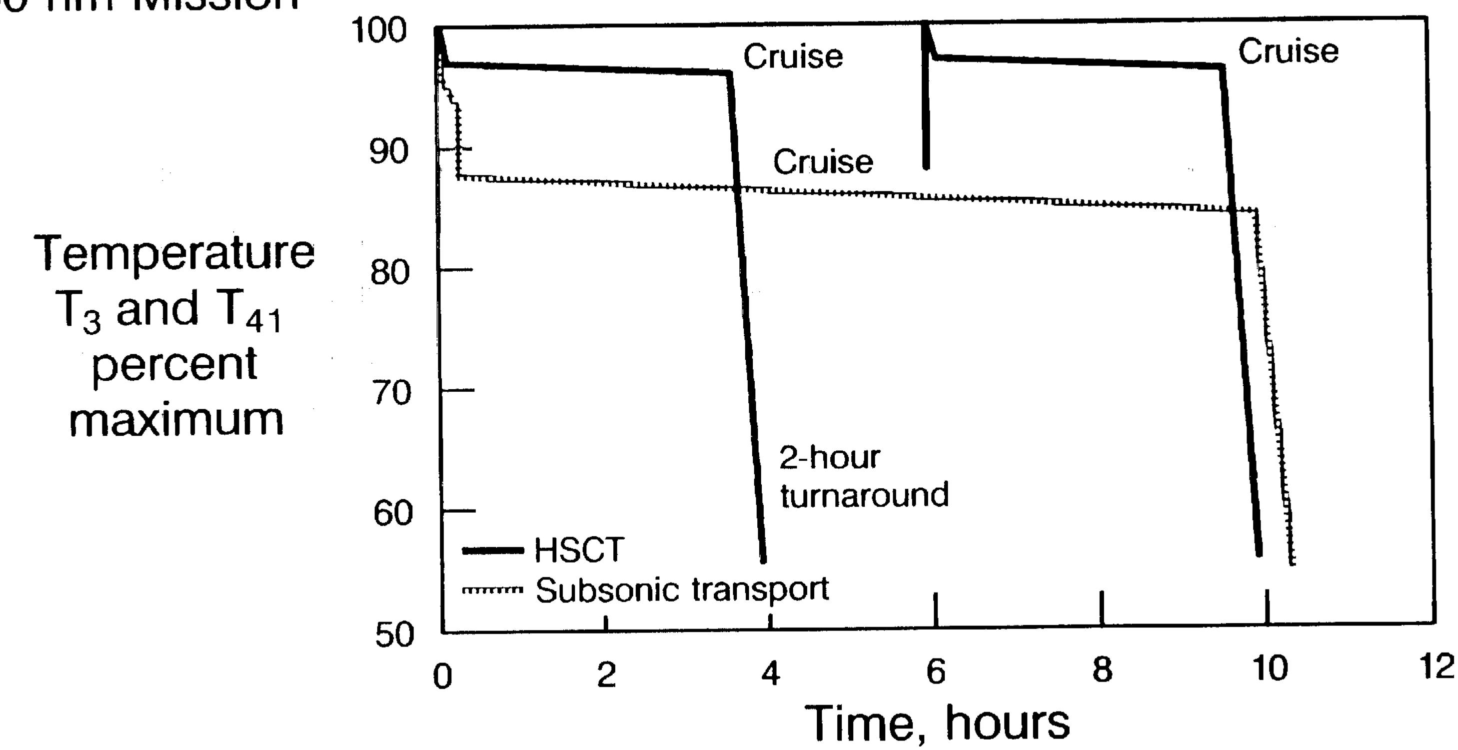
MAC1-60843-050391

HSCT Duty Cycle Significantly Different from Subsonic Transport

When assessing engine materials for the HSCT, the differences in the engine duty cycle relative to current subsonic commercial aircraft need to be addressed. This drives the need for advanced materials technology for both the compressor and hot sections of the engine. The HSCT will fly two legs for a comparable single leg in a subsonic airplane, doubling the temperature cycles per day. In addition, the HSCT engine will operate longer at temperatures closer to the maximum design temperatures both for the compressor and the turbine. Also, the HSCT hot section design temperatures are 20 percent higher than current subsonic engines and the inlet air temperatures are over 400°F hotter. To meet these goals, materials technology and/or additional cooling are required. Resorting to cooling is always detrimental to the engine specific thrust and specific fuel consumption and therefore is not a viable solution. Advancements in materials technology is the key.

HSCT Duty Cycle Significantly Different from Subsonic Transport

5000 nm Mission



- Twice as many cycles
- Sustained operation at higher temperatures

T2280.03 · 901205

Candidate Materials

GEAE & P&W have developed a list of projected HSCT materials by engine component and have compared these projected materials to today's materials as shown in Table 2. On that basis, the HSCT appears to be the initial significant application of composite materials in a commercial aircraft engine. Ceramic matrix composites (CMC) and Intermetallic Matrix Composites (IMC) will be used extensively in the hot section and exhaust nozzle. Polymeric Matrix Composites (PMC) and Metal Matrix Composites (MMC) will be used in the front end of the engine for ducting, casings, and fan blisks.

Candidate Materials

Engine component	Today's technology	HSCT materials
• Fan blisks	Ti alloy	Ti MMC
• Fan stator and case	Ti alloy	700°F PMC
• Containment	Nickel base alloy	500°F fiber
• High pressure compressor casing	Waspalloy	Ti Al
• Combustion liner	Hastelloy + TBC	2400°F CMC
• Combustor case	Waspalloy	Ti Al
• High pressure turbine nozzle	Nickel base alloy	2400°F CMC
• Turbine frame	Waspalloy	2400°F CMC and waspalloy
• Exhaust nozzle liner, chutes and cascades	Hastelloy + TBC	2400°F CMC
• Exhaust nozzle structure	Nickel base alloy + Ti alloy	2200°F IMC

Initial Significant Application of Composite Materials

T3000.82 - 901203

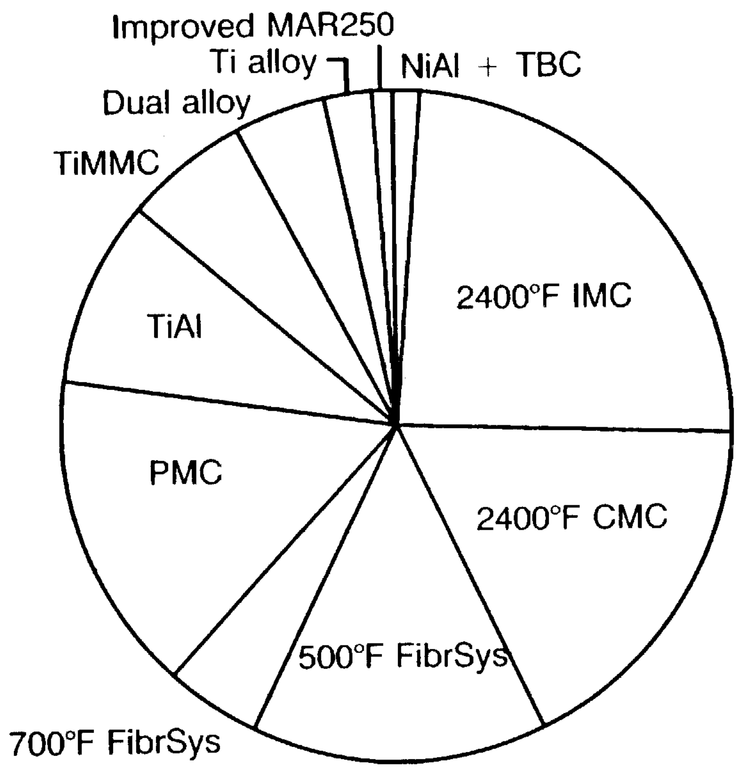
Material Technology Influence

Analysis has clearly indicated the importance of utilizing advanced materials in the engine. Relative to today's materials, propulsion system weight will decrease by over 24 percent and cruise performance will improve by 4 percent using these advanced materials. This weight decrease and performance increase has a major impact on the economics of the HSCT.

Advanced propulsion system materials impact the engine performance and, more importantly, propulsion system weight. When these improvements are cycled through the aircraft designs, the result is a lighter weight aircraft with reduced drag, therefore a smaller, lighter propulsion system is required. The result is a significant reduction in both acquisition cost of ownership (smaller airplane) and fuel burn.

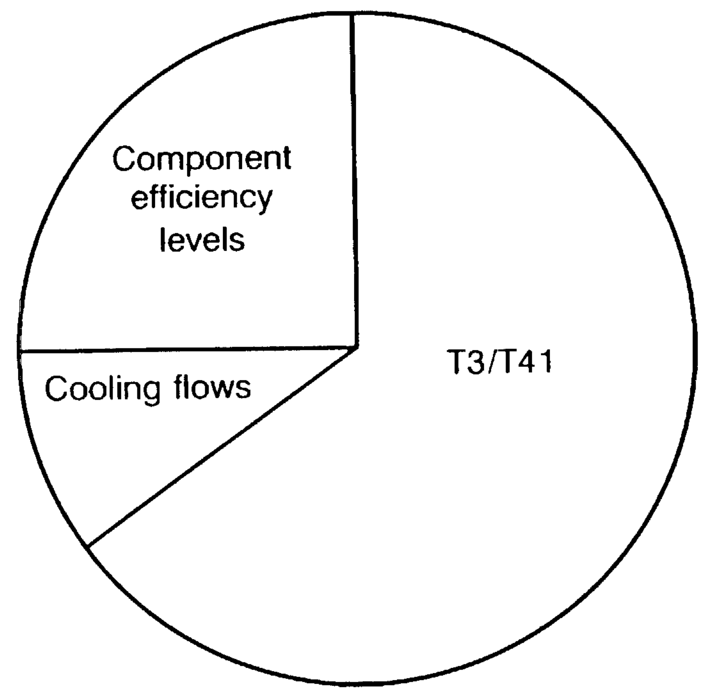
Material Technology Influence

Materials



24% impact on propulsion weight

Cycle



4% impact on cruise efficiency

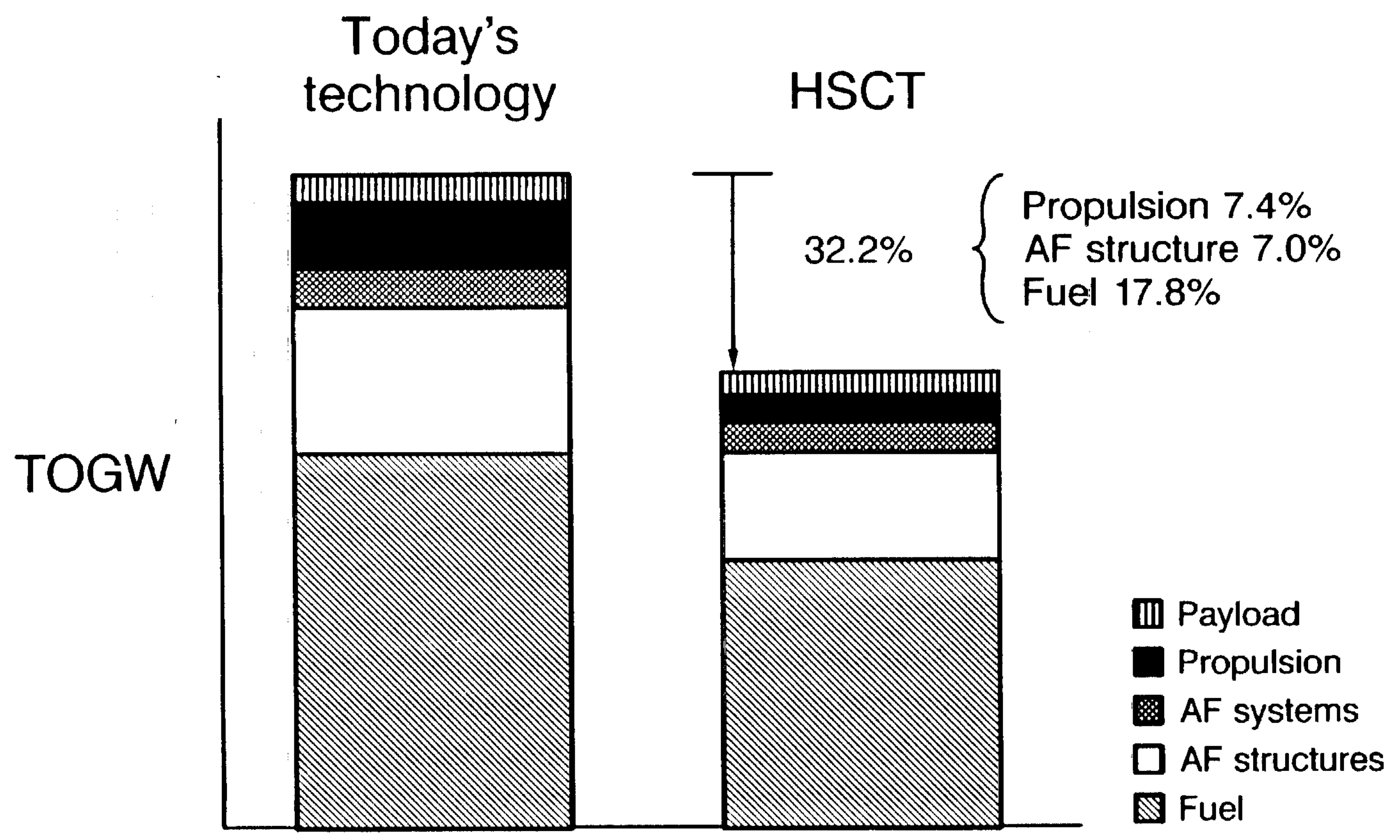
T2280.01 - 901205

Propulsion Technology Impact on TOGW (5,000 n.m. Mission)

A measure of the economic challenge of the HSCT is to develop a design capable of payload fractions approaching that of subsonic aircraft. A supersonic aircraft with a payload fraction significantly lower than current subsonic aircraft operates at a significant competitive disadvantage, requiring premium fare structures to make a profit. A payload fraction approaching 7.5 to 10 percent is viewed as a reasonable goal to assess the economic competitiveness of the aircraft design. The takeoff noise requirements have a negative impact on our current configuration's ability to reach the target. The incorporation of advanced materials and aerothermal cycle improvements have helped us get close to our payload fraction target. We have made progress since Concrode and must continue to strive to improve the HSCT propulsion system designs to increase the airplane's payload fraction.

Comparing today's technology propulsion system with an HSCT propulsion system designed for entry into service in the year 2005, it is clear that significant progress is being made. With the same payload, the TOGW of the HSCT is projected to be over 32 percent lower than that available with today's engine technology. In the analysis, the improvement is totally a function of the propulsion technology as the operating characteristics and level of structural technology of airplane were not changed. The reduced TOGW is a function of the improved specific fuel consumption of the engines, improvements in acoustic suppression technology, and the reduction in engine weight as a result of the incorporation of advanced materials.

Propulsion Technology Impact on TOGW (5,000 n.m. Mission)



T3000.93 - 910108

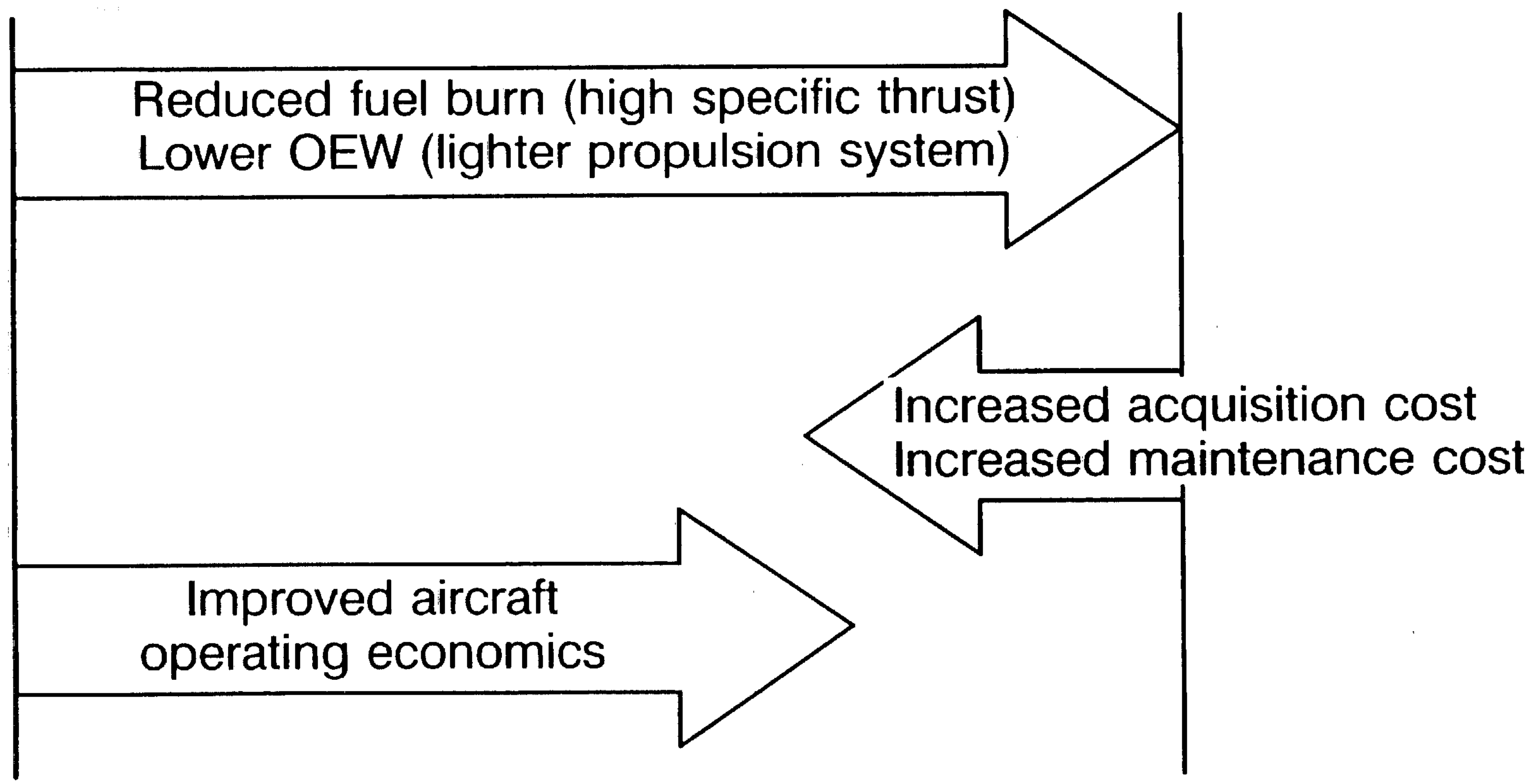
Engine Materials Impact

Advancements in engine materials technology are expected to have a major impact on the overall economic viability of the HSCT. The use of advanced engine materials can reduce the block fuel burn through increased efficiency via higher operating temperatures and smaller size via increased specific thrust of the engines. Advanced materials also lower Operating Empty Weight (OEW) of the airplane through lighter weight propulsion systems. A reduction of 1 pound of total propulsion system weight reduces the aircraft weight by 24 pounds for a 4 engine HSCT. The benefits need to be weighed against the increased acquisition and maintenance costs associated with the incorporation of advanced materials in the engine designs. This assessment needs to be done at the component and subcomponent level and evaluated at the aircraft level in order to verify the ultimate economic value to the system.

One of the key uncertainties is the acquisition cost of the advanced propulsion system materials. They require a new manufacturing base devoted to nonmetallic composites using innovative processing concepts for fiber/matrix distribution and intelligent processing. Raw material cost may be lower and new suppliers may emerge. Significant investment in new plant, equipment, and processes is needed in the 1990's to make these materials a commercial reality.

The economic viability of an aircraft is a balance between airplane cost and commercial value. In this day of rapidly changing technology and world conditions, it is important to recognize that operating costs are critical from an airline's point of view. Airlines cannot afford to purchase technology for technology's sake. Technology must not only improve the productivity of the aircraft but also contribute to reducing operating expenditures such as fuel and maintenance costs. Also, the manufacturers cannot ignore the costs of ownership-depreciation, interest, and insurance in developing any new transportation system.

Engine Materials Impact



Utilization of Advanced Propulsion Materials Contribute Significantly to Economic Viability Goals of HSCT

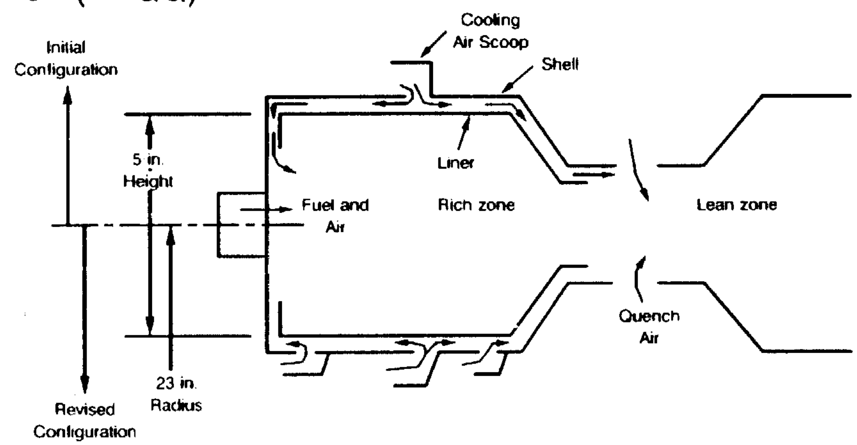
T3000.81 901203

Low Emission Combustor Concepts

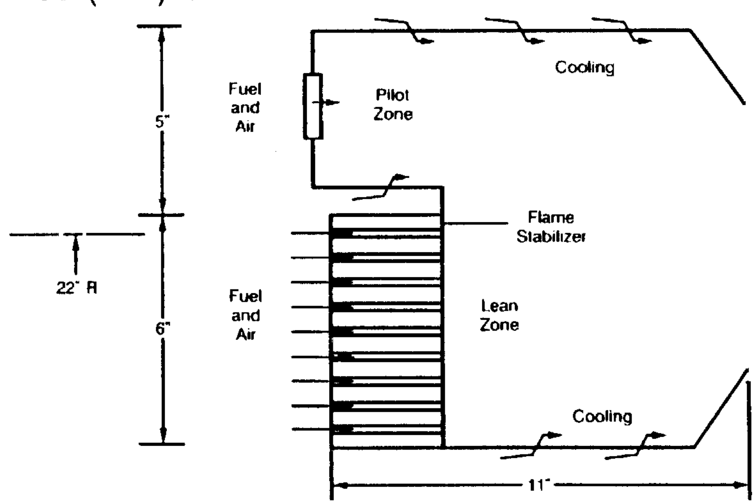
P&W and GEAE have been looking at several advanced combustor concepts capable of meeting the NASA goal of 5 grams NO_X per kilogram of fuel burned. These combustor concepts are based on combustion occurring in either the lean or rich condition. There are significant engineering challenges associated with controlling combustion at these conditions. When operating lean, combustion in occurring near the stability limit raising the operability issue of "blow out." There is also the risk of premixing duct flashback and autoignition. When operating rich, the combustion liner cannot use conventional film cooling as the introduction of cooling air will alter the combustion process away from the rich condition. The combustion liner must therefore be convection cooled requiring advanced high thermal conductivity and high temperature materials. In addition, the remainder of the fuel from the rich combustion must be quickly quenched (in around 1 millisecond) to the lean condition in order to complete the combustion with minimum NO_X formation. Research is underway on both approaches starting with flame tube testing in 1990 leading to combustor rig testing in 1991 and 1992. These advanced combustor concepts do not have a major impact on the overall economics of the airplane. They are similar in size to conventional combustors and operate with similar fuel efficiencies.

Low Emission Combustor Concepts

Rich Burn, Quick Quench (RBQQ)



Lean, Premixed, Prevaporized (LLP) Combustor

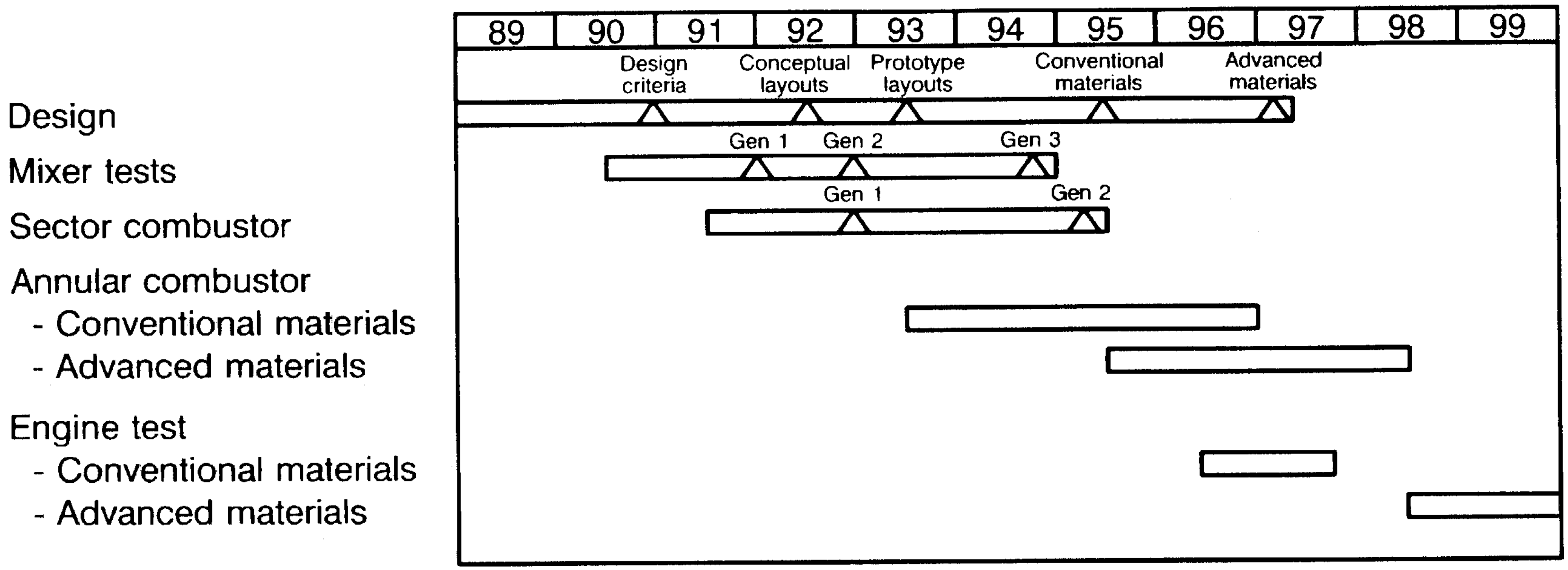


T2533.10 - 910507

HSCT Low Emission Combustor Status

The low emission combustor work is focused on progressively demonstrating 3 to 8 gm/kg NO_X in single cup, sector, annular, and finally engine testing. Two prime combustor concepts are being investigated, the Rich Burn Quick Quench (RBQQ) and the Lean Premixed Prevaporized (LPP). both concepts are to be taken into sector and possibly annular testing. Only one of the concepts is planned to be taken to engine testing. Ceramic Matrix Composites (CMC) materials being developed in NASA's Enabling Propulsion Materials Program will feed into the combustor development program at the end of 1997 with annular testing in 1998 and engine testing in 1999. Test results to date from cold flow mixing test and hot rig testing at NASA are encouraging.

HSCT Low Emission Combustor Status



Accomplishments

- Predicted benefits of advanced materials and variable geometry
- Assessed/developed analytical capabilities for combustor design (CFD, chemical kinetics)
- Conducted cold flow mixing tests to identify preferred fuel injection location and verify CFD predictions
- Developed improved diagnostics (NO_2 LIF and laser Raman) for combustors
- Initiated single cup rig tests to demonstrate 3-8 g/kg NO_x

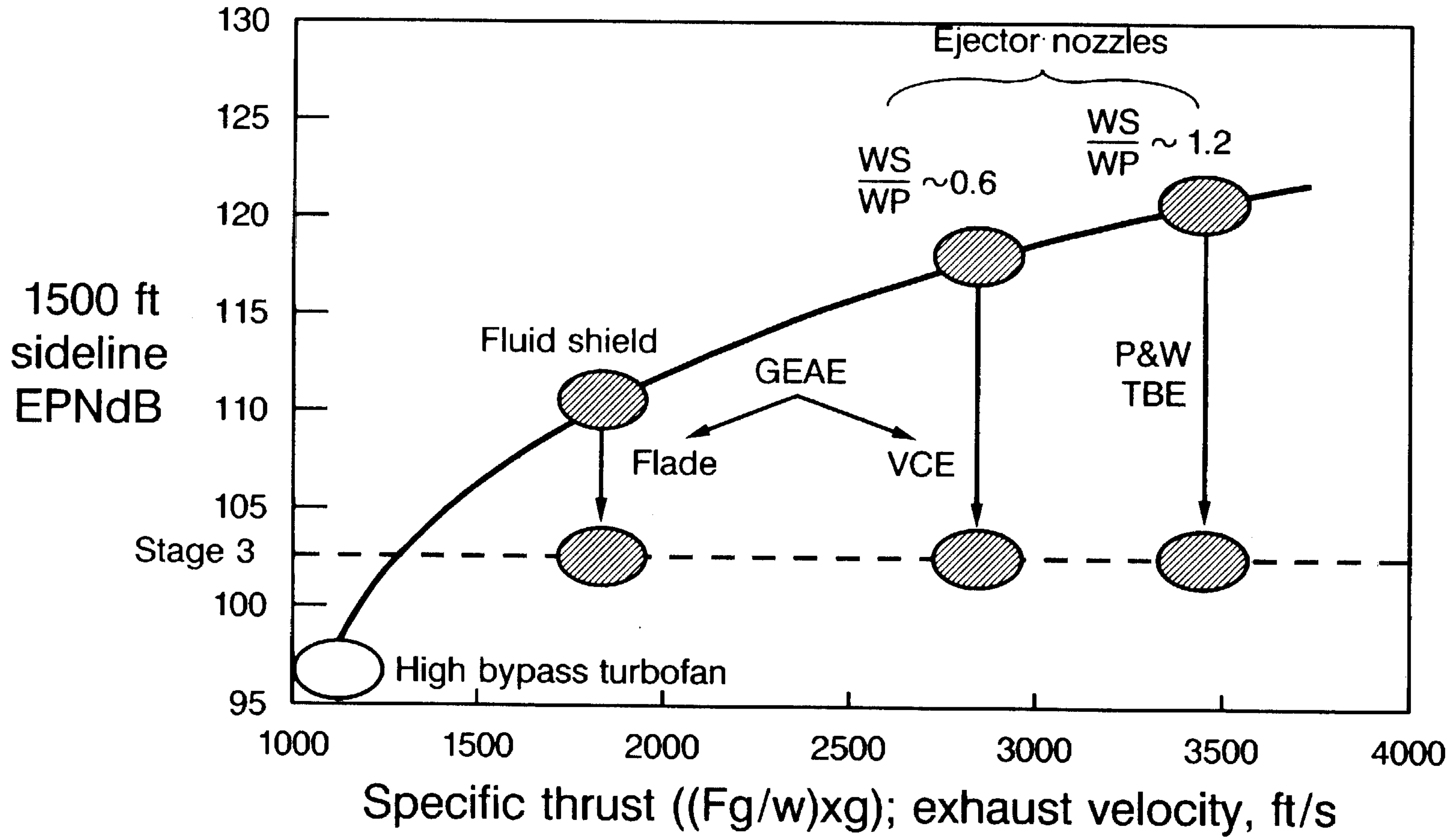
T2533.11 - 910507

Two Basic Noise Reduction Approaches

Two different approaches to noise reduction are being investigated. One involves breaking the jet into many smaller jets, high levels of ambient air entrainment, and acoustically treated panels for high frequency noise absorption. The second approach involves reducing the jet velocity via additional airflow through the engine, some ambient air entrainment, and mean shear reduction for high frequency noise absorption. Acoustic model testing of several promising concepts is being conducted in 1991. This testing will provide key input into the propulsion system selection process for the HSCT.

Two Basic Noise Reduction Approaches

- High flow engine + modest noise reduction
- High specific thrust engine + aggressive noise reduction

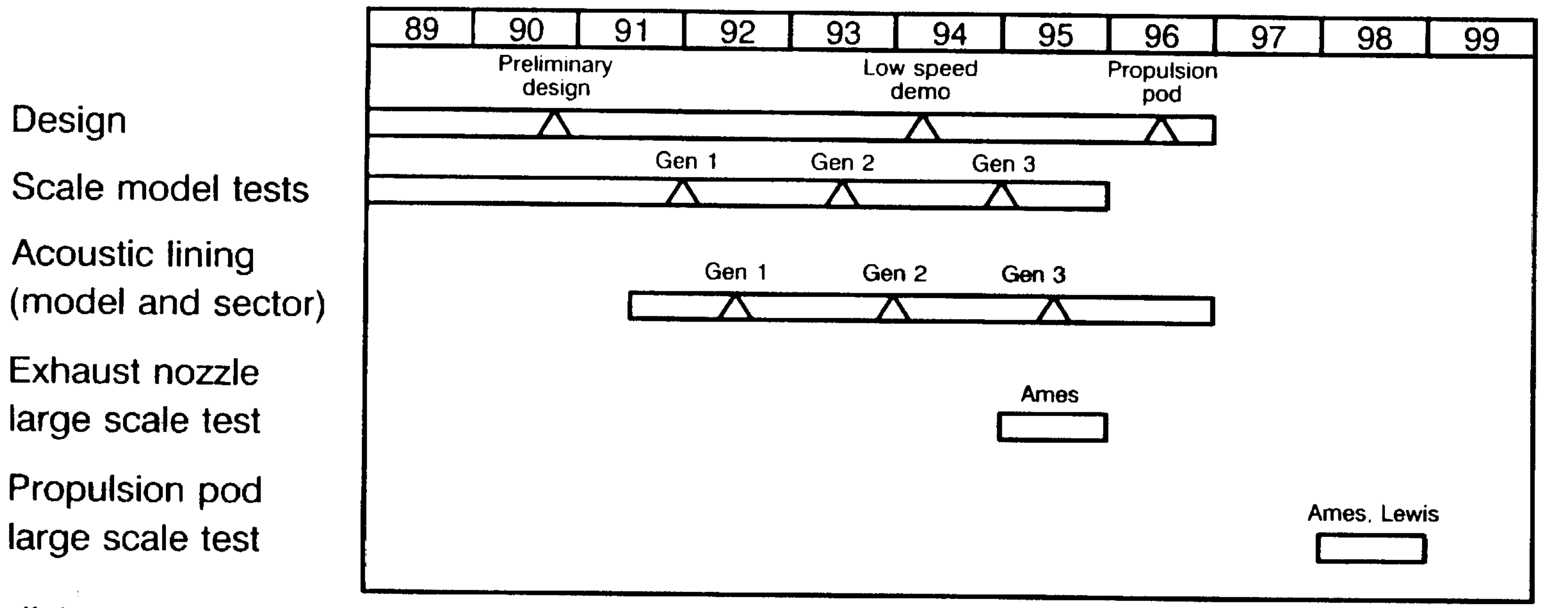


HSCT Exhaust Nozzle Status

The HSCT exhaust nozzle technology development involves significant aerodynamic and acoustic scale model testing. Initial screening tests are planned to be completed by the end of 1991 to evaluate the various approaches to noise reduction. Enhanced computational capability is being used in the exhaust nozzle designs. Exhaust nozzle acoustic lining has been identified as a critical technology and plans are underway to begin to develop this technology. The need for an early large scale exhaust nozzle test to verify the scale model results has been identified. Testing is planned to be conducted in the Ames 40 x 80 wind tunnel. A second large scale test incorporating a second or third generation exhaust nozzle is planned for 1998. This nozzle will be tested in the Lewis 10 x 10 supersonic tunnel, in addition to the Ames facility.

C-3.

HSCT Exhaust Nozzle Status



Accomplishments

- Preliminary designs of 3 exhaust nozzle systems
- Tested 2 high entrainment ejector concepts
- Initiated 3 additional generation 1 model test programs for 1991
- Assessed/developed analytical tools for nozzle design (aero and acoustics)
- Identified acoustic lining as critical technology
- Utilized ANOPP to evaluate aircraft takeoff noise and impact of operational procedures and aircraft low speed performance

T2533.13 - 910507

Take-off Noise Impact

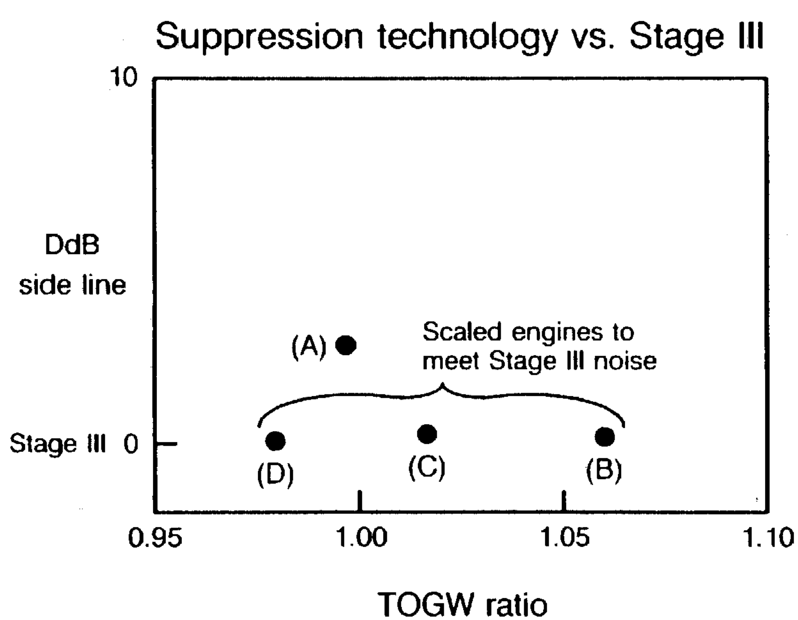
Our current studies indicated that FAR 36 Stage III noise requirements can be met with projected exhaust nozzle suppression technology and modifications to the aircraft takeoff profile without oversizing the engine. The projected sideline noise for an engine design with an exhaust velocity of 2800 feet per second and 50,000 pounds of thrust is approximately 2.5 dB above FAR 36 Stage III, assuming no changes in takeoff procedures. In order to meet Stage III, the engine size was increased by 19 percent dropping the exhaust velocity to 2590 feet per second. This increase in engine size, when factored into the aircraft design, increased the TOGW by 6.4 percent as noted by point B.

Several avenues of improvements outside the exhaust nozzle can be explored to further reduce the aircraft TOGW while maintaining the noise level at FAR 36 Stage III. The takeoff profile can be modified by setting a higher power during ground roll where ground attenuation reduces the noise. This higher powered ground run requires a thrust reduction at the 35-foot obstacle in addition to the cutback at 689 feet altitude allowed under the current regulations. This modification to current fixed throttle requirements in the FAR can reduce aircraft TOGW by nearly 4 percent as noted by point C.

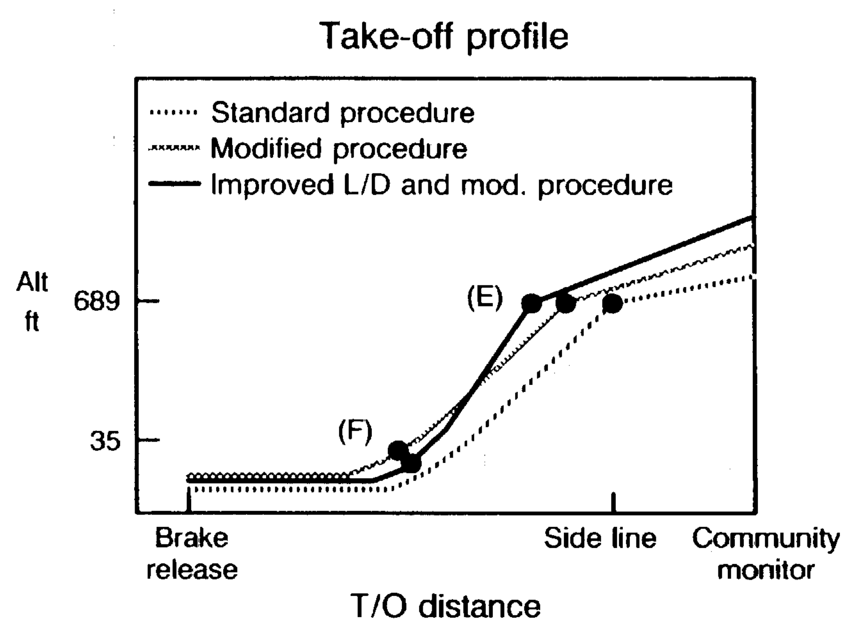
Improvements in aircraft takeoff performance could further reduce the TOGW. Based on NASA wind tunnel work an 18 percent improvement in takeoff L/D is possible. This can reduce the TOGW by another 4 percent as shown in point D. At point D, the aircraft is smaller than the original baseline designs by 1.5 percent while still meeting the noise goals.

Take-off Noise Impact

Projected suppression technology can meet Stage III with modifications to the take-off profile



(A) Current baseline design
(B) Standard T/O profile
(C) Modified T/O profile
(D) Modified T/O profile and improved L/D



(E) Standard noise abatement thrust cut back (689 ft)
(F) Thrust roll-back

Summary

The technology developments needed to address the environmental issues of airport noise and engine emissions represent the threshold level for a viable program. These technologies must be introduced in concert with the propulsion system materials technologies and other aircraft technologies to reduce both the cost of ownership and the direct operating cost of the HSCT. They are key to the environmental compatibility and economic viability of a HSCT for entry into service in the year 2005.

GEAE & P&W are encouraged by the technical progress being made toward addressing the propulsion system-related environmental challenges and the improvements in the HSCT system economics. There is, nevertheless, a great deal of work required to turn the promises of today into tomorrow's reality. As we in the propulsion industry continue to work the technology areas, we must ask ourselves if the economics are good enough to launch an engine development program. The technical and commercial risks will need to be assessed in much greater detail in order to answer this question. We are hopeful that it can be answered in the positive by the late 1990's in order to make the HSCT a reality in the year 2005.

Summary

T3000.99 - 910204

THIS PAGE INTENTIONALLY BLANK