

NASA-CR-186015

N92-21253

NASA-CR-186015  
19920012010

CONFIDENTIAL

LIBRARY COPY  
JUL 23 1995  
LANGLEY RESEARCH CENTER  
LIBRARY NASA  
HAMPTON, VIRGINIA

A Service of:



National Aeronautics and  
Space Administration  
**Scientific and Technical  
Information Office**



NF00258



**This microfiche was produced according to ANSI / AIM Standards and meets the quality specifications contained therein. A poor blowback image is the result of the characteristics of the original document.**

P.161

---

# High-Speed Civil Transport Flight- and Propulsion-Control Technological Issues

---

J. K. Ray, C. M. Carlin, and A. A. Lambregts

---

(NASA-CR-186015) HIGH-SPEED CIVIL TRANSPORT  
FLIGHT- AND PROPULSION-CONTROL TECHNOLOGICAL  
ISSUES Final Report (Boeing Commercial  
Airplane Co.) 181 p

492-21253

CSCL 91C

Unclas  
G3/03 0079756

Contract NAS2-12722  
March 1992



National Aeronautics and  
Space Administration

NASA Contractor Report 186015

---

# High-Speed Civil Transport Flight- and Propulsion-Control Technological Issues

---

J. K. Ray, C. M. Carlin, and A. A. Lambregts  
Boeing Commercial Airplane Group  
New Airplane Division  
P.O. Box 3707  
Seattle, WA 98124-2207

Prepared for  
NASA Dryden Flight Research Facility  
Edwards, California  
Under Contract NAS2-12722

1992



National Aeronautics and  
Space Administration

Dryden Flight Research Facility  
Edwards, California 93523-0273

## TABLE OF CONTENTS

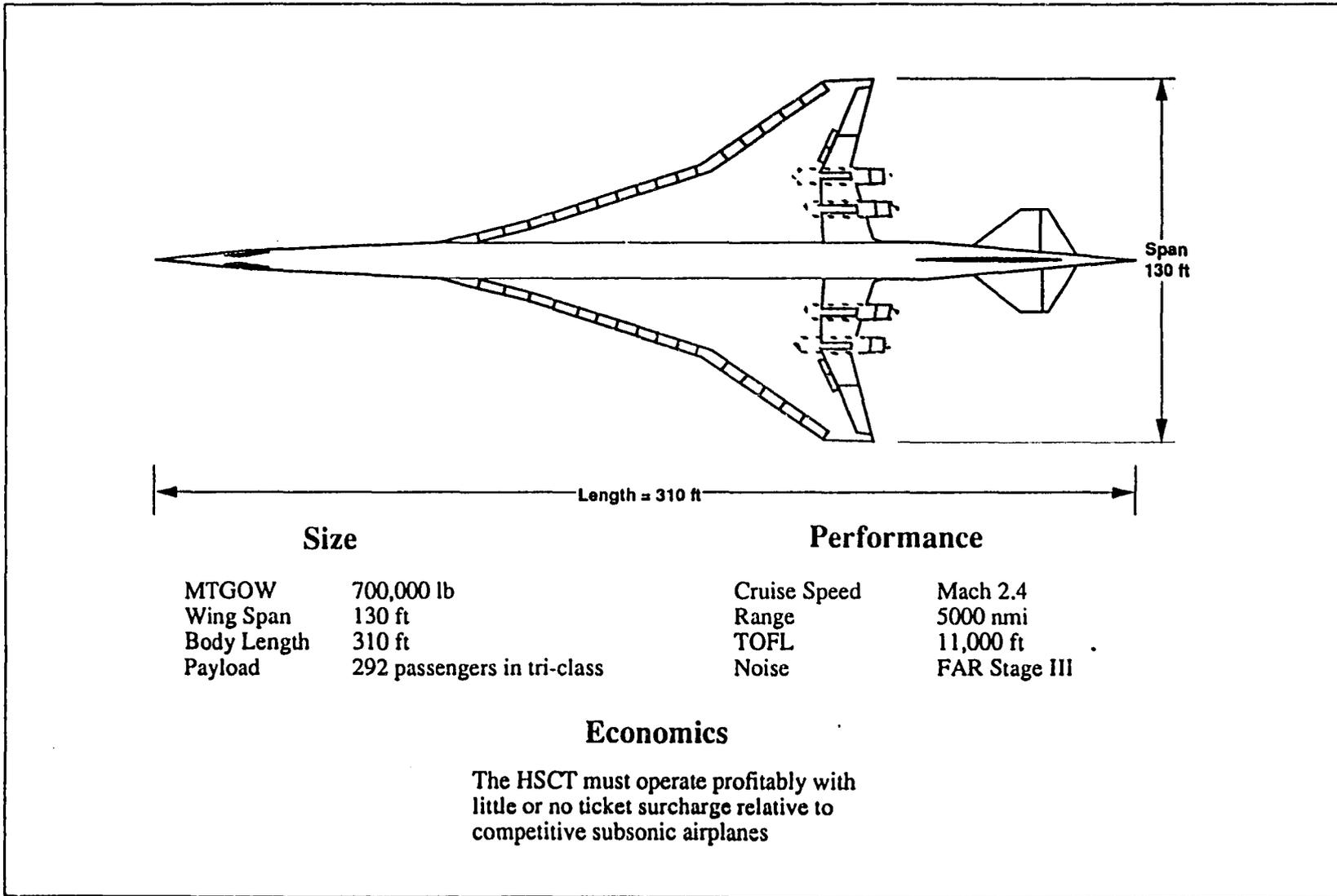
	ABSTRACT	1
1.0	INTRODUCTION AND SUMMARY	2
1.1	Requirements Summary	2
1.2	Technical Issue Summary	5
1.3	Issue Priority Summary	5
1.4	Development and Demonstration Plans Summary	8
1.5	Recommendations Summary	11
2.0	NOMENCLATURE	14
3.0	HSCT FLIGHT AND PROPULSION CONTROL REQUIREMENTS	17
3.1	Mission Requirements	17
3.2	Airplane Configuration Requirements	17
3.3	Control Systems Design Requirements	20
	3.3.1 HSCT Mission Profile Characteristics	20
	3.3.2 Flight Deck and Flight Management	25
	3.3.2 Flight Controls	26
	3.3.3 Propulsion Controls	30
3.4	General HSCT Requirements	35
	3.4.1 Maintainability	35
	3.4.2 Certification	35
	3.4.3 System Engineering	36
4.0	TECHNOLOGY ISSUES	39
4.1	Flight and Propulsion Control	39
4.1.1	Flight Control Algorithms	39
	4.1.1.1 Augmented Manual Flight Control	39
	4.1.1.2 Automatic Flight Control	45
	4.1.1.3 Active Flutter Suppression	52
	4.1.1.4 Gust and Maneuver Wing Load Alleviation	54
	4.1.1.5 Flight Envelope Protection	55
	4.1.1.6 CG Management	56
4.1.2	Propulsion Control Algorithms	57
	4.1.2.1 Propulsion System Automation	57
	4.1.2.2 Engine Inlet Control Law Integration	59
	4.1.2.3 Inlet Sensor Fault Accommodation	59
4.1.3	Integrated Flight-Propulsion Control	60
	4.1.3.1 Flight/Propulsion Control Integration	60
	4.1.3.2 Unstart Avoidance/Accommodation	64
	4.1.3.3 Optimum Trajectory Generation and Tracking	68
	4.1.3.4 Performance Seeking Control	69
4.1.4	Control Disturbance Environment	71
4.2	Hardware	72
4.2.1	Actuation Technology	72
4.2.2	Sensor Technology	74
	4.2.2.1 Fiberoptic Sensor Set	74
	4.2.2.2 Vision Enhancement Technology	74
	4.2.2.3 High Altitude Air Data	75
	4.2.2.4 Multi-function Sensor Technology	76
	4.2.2.5 Shock Position Sensing	78
	4.2.2.6 High Temperature Sensor Technology	80

	4.2.2.7	RF Sensor/Antenna Technology	82
4.2.3		Computational Hardware	84
	4.2.3.1	High Temperature Electronics	84
	4.2.3.2	Computational Hardware Improvements	84
	4.2.3.3	Single Event Upset Phenomena	87
	4.2.3.4	HIRF/EMI Immunity	89
	4.2.3.5	Flight System Data Bus Technology	89
4.3		System Engineering and Architecture	92
	4.3.1	System Engineering	92
		4.3.1.1 Certification Basis	92
		4.3.1.2 Multidisciplinary System Engineering Tools	93
	4.3.2	System Architecture/Redundancy Management	95
		4.3.2.1 General Flight and Propulsion Architectures	95
		4.3.2.2 Flight Critical Systems Architectures	98
		4.3.2.3 Built-in Test and Maintenance	101
5.0		PRIORITIES	105
	5.1	Priority Categories	105
		5.1.1 Safety Issues	105
		5.1.2 Performance Issues	108
		5.1.3 Weight Issues	109
		5.1.4 Reliability/Maintainability Issues	113
		5.1.5 Schedule Issues	114
		5.1.6 Special Benefits	116
	5.2	Priority Summary	117
6.0		TECHNICAL APPROACH	120
	6.1	Technology Development	120
		6.1.1 Control Law Studies	122
		6.1.1.1 Augmented Manual Flight Control	122
		6.1.1.2 Automatic Flight Control	125
		6.1.1.3 Active Flutter Suppression	126
		6.1.1.4 Gust and Maneuver Wing Load Alleviation	126
		6.1.1.5 Active Flight Envelope Protection	126
		6.1.1.6 Active CG Management	127
		6.1.1.7 Propulsion System Automation	127
		6.1.1.8 Engine/Inlet Control	127
		6.1.1.9 Inlet Sensor Fault Accommodation	130
		6.1.1.10 Flight/Propulsion Control Integration	130
		6.1.1.11 Unstart Avoidance/Accommodation	131
		6.1.1.12 Optimum Trajectory Generation and Tracking	132
		6.1.1.13 Performance Seeking Control	132
	6.1.2	Hardware Technology	133
		6.1.2.1 Actuation Technology	133
		6.1.2.2 Fiberoptic Sensor Set	133
		6.1.2.3 Vision Enhancement Technology	135
		6.1.2.4 High Altitude Air Data	135
		6.1.2.5 Multifunction Sensor Technology	136
		6.1.2.6 Shock Position Sensing	136

6.1.2.7	High Temperature Sensor Technology	136
6.1.2.8	RF Sensor Technology	136
6.1.2.9	High Temperature Electronics	137
6.1.2.10	Computational Hardware Improvements	138
6.1.2.11	Single Event Upset Phenomena	138
6.1.2.12	HIRF/EMI Immunity	138
6.1.2.13	Flight System Data Bus Technology	138
6.1.3	System Engineering and Architecture	139
6.1.3.1	Certification Requirements	139
6.1.3.2	Interdisciplinary System Engineering Tools	139
6.1.3.3	General Flight and Propulsion Systems Architectures	141
6.1.3.4	Flight Critical Systems Architectures	141
6.1.3.5	Built-in Test and Maintenance	142
6.2	Technology Demonstration	143
6.2.1	Functional Demonstration	145
6.2.2	Reliability/Maintainability Demonstration	149
7.0	CONCLUSIONS AND RECOMMENDATIONS	151
8.0	REFERENCES	154

## ABSTRACT

This report identifies technology advances required in the flight and propulsion control system disciplines to develop a high-speed civil transport. The mission and requirements of the transport and major flight and propulsion control technology issues are discussed. Each issue is ranked and, for each issue, a plan for technology readiness is given. Certain features are unique and dominate control system design. These features include the high temperature environment, large flexible aircraft, control-configured empennage, limited flight-deck visibility, strong aerodynamic coupling between propulsion and flight control, minimizing control margins, and high availability and excellent maintainability. The failure to resolve most high-priority issues can prevent the transport from achieving its goals. The flow-time for hardware may require stimulus, since market forces may be insufficient to ensure timely production. Flight and propulsion control technology will contribute to takeoff gross weight reduction. Similar technology advances are necessary also to ensure flight safety for the transport. The certification basis of the high-speed civil transport must be negotiated between airplane manufacturers and government regulators. Efficient, quality design of the transport will require an integrated set of design tools that support the entire engineering design team.



*Figure 1-1 Proposed HSCT Characteristics*

## 1.0 INTRODUCTION AND SUMMARY

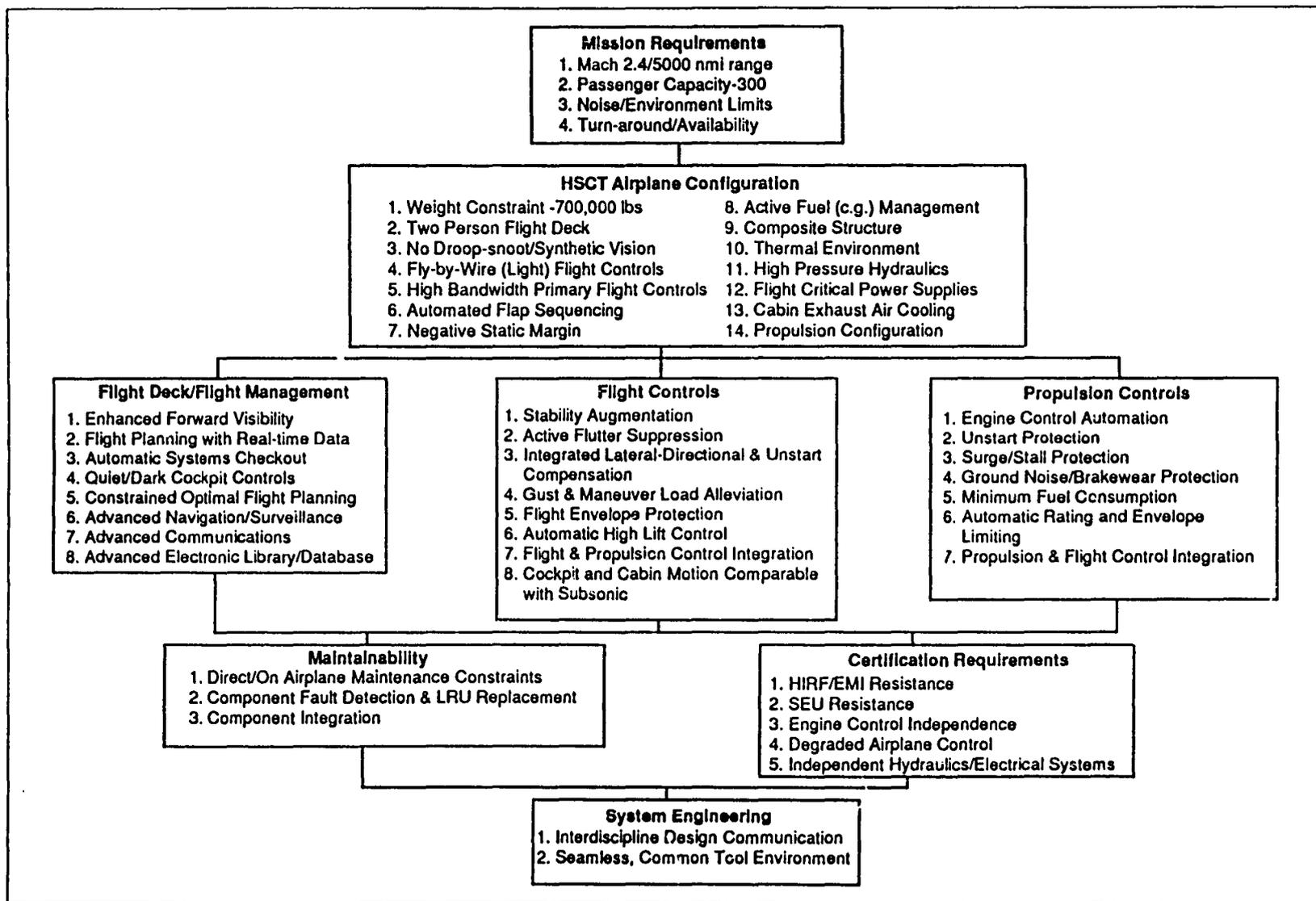
The intent of this document is to identify technology advances required in the flight and propulsion control system disciplines to permit development of an economically viable High Speed Civil Transport (HSCT). A further objective is to develop a plan for achieving these advances. The approach to achieving these objectives and the results of the effort are summarized in the following paragraphs.

This report proceeds from a discussion of the mission and requirements of the HSCT airplane, in Section 3.0, to a description of the major flight and propulsion control technology issues that affect it, Section 4.0. The relative priority of each issue is presented in Section 5.0. Section 6.0 describes a plan for technology readiness to support a year 2000 go-ahead, and Section 7.0 contains Boeing recommendations for NASA support for control system design and development.

### 1.1 Requirements Summary

A year 2005, Mach 2.4, 300 passenger aircraft, Figure 1-1, is selected as the basis for this study. Current Boeing economic and technical studies (ref. 1) indicate this may be an economically and environmentally sound choice. In Section 3.0 the configuration and mission requirements for this vehicle as they relate to controls are identified. These requirements are listed in Figure 1-2 according to the mission, configuration, technology discipline or quality factor with which they are associated. Section 3.0 explains the rationale for each requirement, based on mission and configuration assumptions or the physics required to control the airplane and its propulsion system. Although there are many detailed requirements, some of which are shared with advanced subsonic aircraft, certain features of the HSCT mission and configuration are unique and dominate control system design, namely:

- High temperature environment
- Large flexible aircraft
- Control configured empennage, aft c.g., actively controlled
- Limited flight deck visibility
- Strong aerodynamic coupling between propulsion and flight control
- Planned propulsion performance requires minimizing control margins
- Planned utilization requires high availability and excellent maintainability



*Figure 1-2 HSCT Flight/Propulsion Controls Configuration Requirements*

## 1.2 Technical Issue Summary

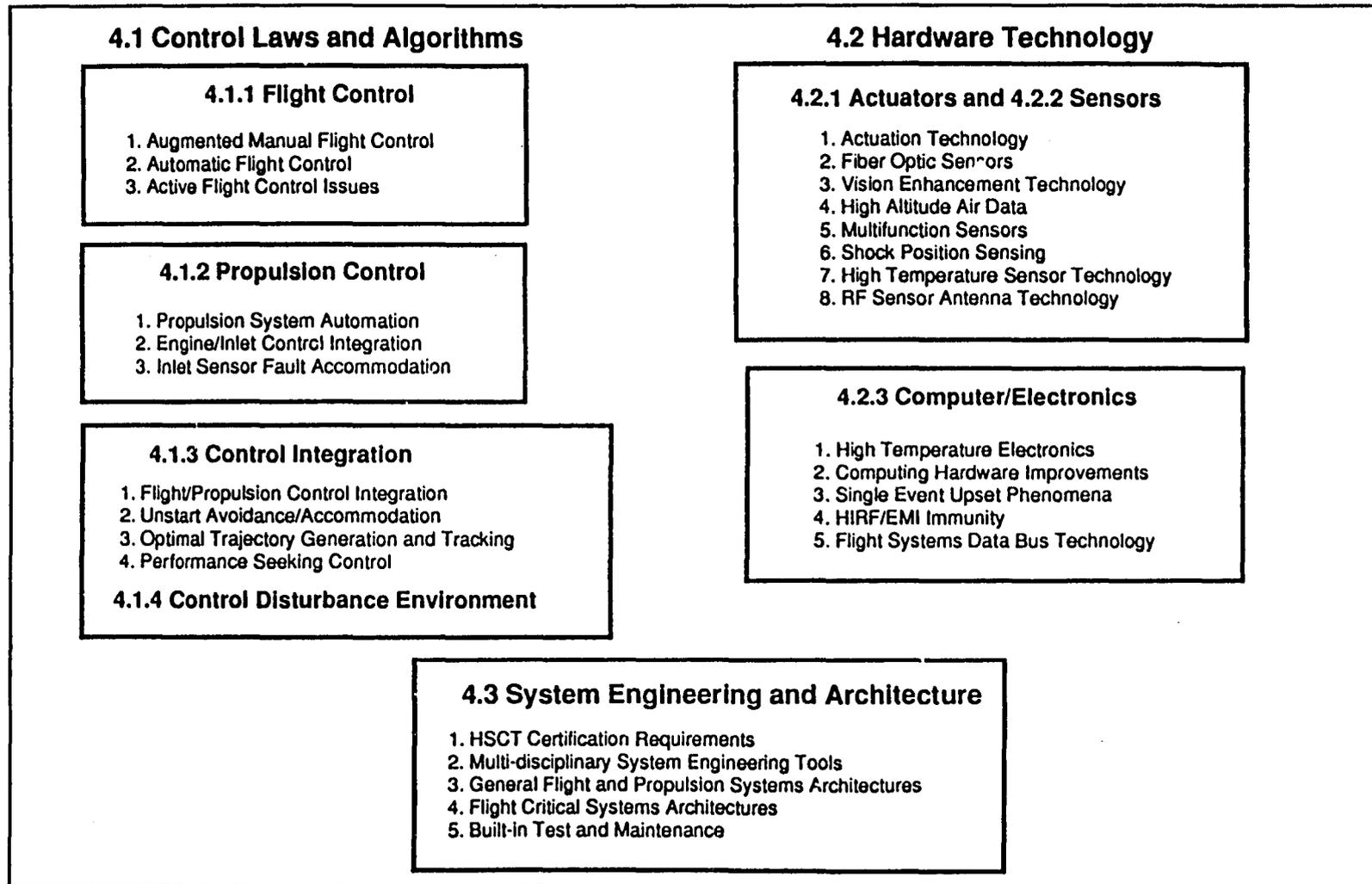
In Section 4.0, the requirements of Section 3.0 are used to identify a comprehensive set of technical issues. The section follows the format shown in Figure 1-3, with a major subsection for each family of issues: Section 4.1 covers Control Laws and Algorithms, Section 4.2 Hardware Technology, and Section 4.3 System Engineering and Architecture. Each family of issues is divided into groups of related and similar issues. These groups are then subdivided into more than 30 paragraphs addressing specific issues. These paragraphs describe each issue, identifying driving requirements, current status of the technology, and shortfalls that create risk for the HSCT. The control law issues result from the physical dynamics of the aircraft. The hardware issues are driven by the high temperature, high altitude environment; maintainability concerns; and stringent measurement and actuation requirements. The novel, complex aircraft also raises systems issues which may be addressed both in development and production by advances in computational technology.

## 1.3 Issue Priority Summary

In Section 5.0, the issues presented in Section 4.0 are prioritized to identify those which require technology development and demonstration prior to go-ahead for a commercially viable HSCT. A list of high priority issues was developed, Figure 1-4, by ranking technology issues in terms of relative impact in the categories of safety, performance, weight, reliability/maintainability, and schedule. High priority issues were selected from the top two issues within each category, as well as issues which appear in the top 10 in more than three categories. While none of the high priority issues is a barrier by itself, none of the high priority issues can be neglected without threatening the economic viability of the airplane itself.

Hardware technology predominates on the high priority list. This comes about because of four characteristics of the HSCT:

1. A high utilization rate is required for economical airplane operations.
2. The temperature/vibration environment is severe and tends to cycle through its extremities.



*Figure 1-3 HSCT Flight/Propulsion Controls Issue Section Organization*

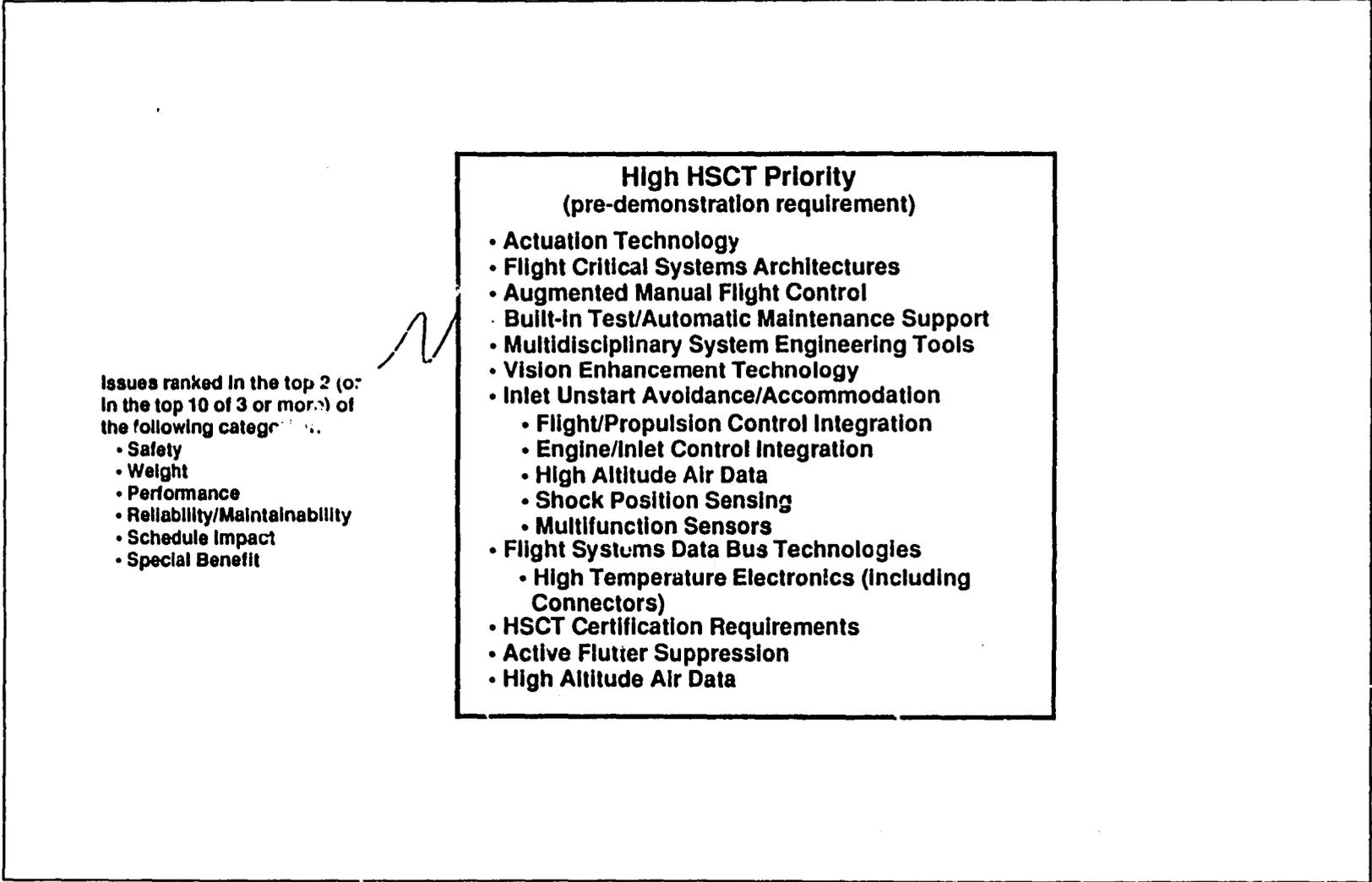


Figure 1-4 High Priority Issues

3. An unusually large number of high duty cycle actuators and precision sensors is necessary to satisfy the control requirements of the large, flexible, supersonic vehicle.
4. The development and certification cycle on new hardware elements is lengthy.

Taken together these requirements mean that appropriate reliable, high temperature, high bandwidth hardware must be developed or the HSCT will not meet its performance or economic requirements. A high priority hardware issue is identified for any component which requires development to satisfy HSCT requirements but lacks strong development support from wider use applications.

The remaining high priority issues relate largely to the efficient design and certification of the aircraft. Certification requirements must be reviewed and probably be revised to account for advanced technology and the unique properties of the HSCT. The revisions must be tailored to permit development of an aircraft which is both safe and economically viable. Architecture is a high priority issue because the relatively complex architectures of current subsonic aircraft when superimposed on the complexities inherent in the supersonic aircraft will create an unwieldy design. A top down design of the flight system architecture for the HSCT should facilitate significant weight, reliability, and maintainability benefits. Finally, HSCT development costs and product quality can be significantly improved if the appropriate integrated simulation, analysis, test environment can be established. This represents an extension or refinement of the environment being used in the design of the 777.

The sorting process also created a group of medium priority issues, Figure 1-5, mostly control algorithm related, which must be proven prior to HSCT program go-ahead. They should be included in the demonstration program, but do not require extensive investment prior to the start of the demonstration program.

#### 1.4 Development and Demonstration Plan Summary

A plan to address technology shortfalls is presented in Section 6.0. This plan consists of a technology development plan and a subsequent technology demonstration plan.

The technology development plan, Figure 1-6, is based on our understanding of the current status of the technologies, our perception of the difficulties involved in advancing them and the time available to do so. The plan, as outlined in Paragraph 6.1, is organized so that the

**Medium HSCT Priority  
(demonstration requirement)**

- Automatic Flight Control
- Wing Load Alleviation
- Propulsion System Automation
  - Inlet Sensor Fault Accommodation
- Fiber-optic Sensors
- General Flight and Propulsion Systems Architectures
  - Computing Hardware Improvements
  - Single Event Upset Phenomena
- Active Flight Envelope Protection
- Optimal Trajectory Generation and Tracking
- Performance Seeking Control
- Active CG Management
- High Temperature Sensor Technology
- HIRF/EMI Immunity

Issues ranked in the top 10 of any of the following categories:

- Safety
- Weight
- Performance
- Reliability/Maintainability
- Schedule Impact
- Special Benefit

*Figure 1-5 Medium Priority Issues*

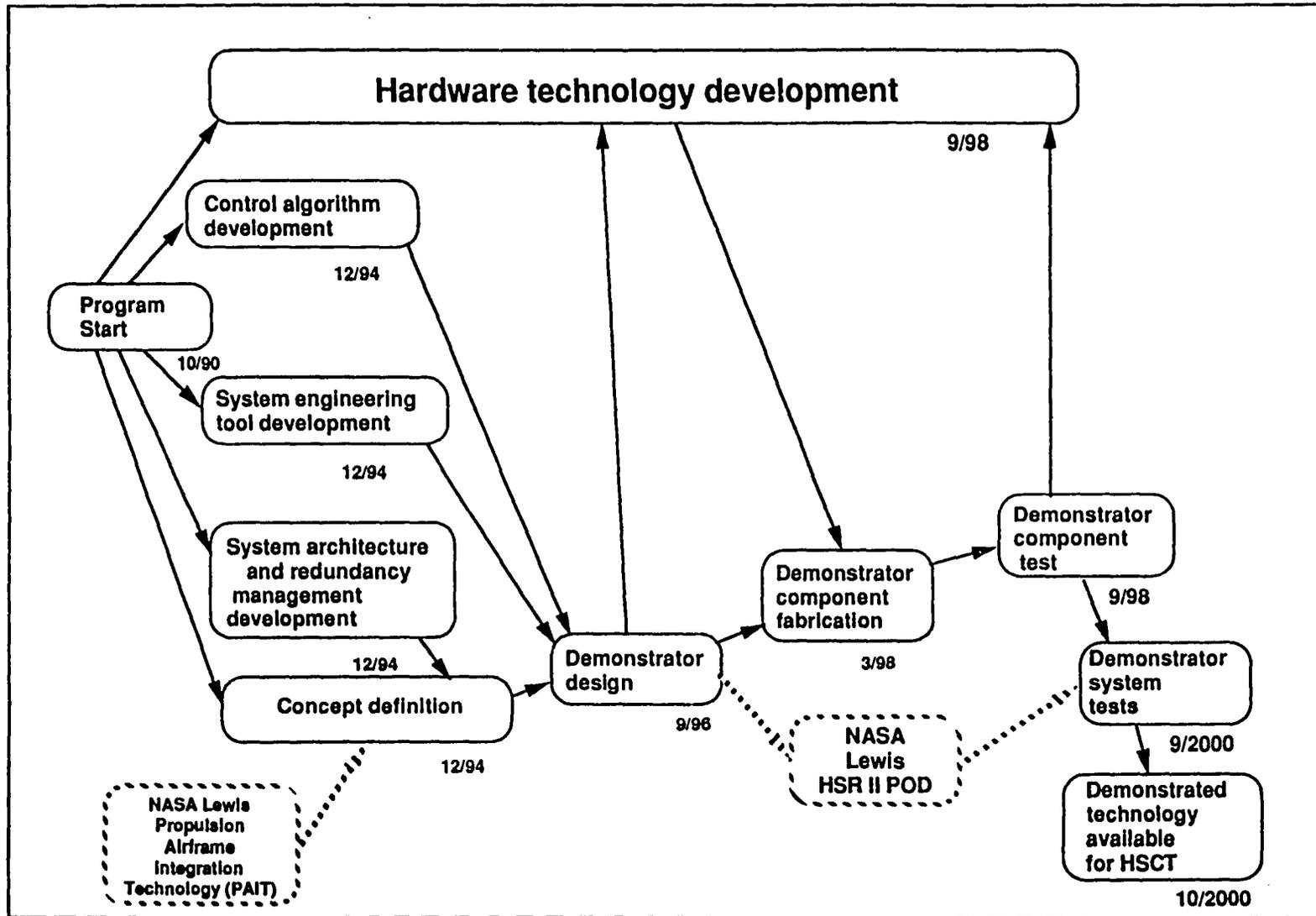


Figure 1-6 Technology Development Plan

more difficult technology development efforts overlap the technology demonstration phase in order to gain enough flow time to perform the effort. Parallel approaches to problems are undertaken so that if some of the riskier technologies do not develop as desired a backup approach is available to support the demonstration effort. Paragraph 6.1 also identifies the tasks required to address shortfalls for each technology issue.

The technology demonstration plan, Figure 1-7, is derived from experience on similar programs such as Integrated Propulsion Control System (IPCS) and Condor. As described in Paragraph 6.2, the demonstration will proceed through a conventional design, ground test, flight test sequence to functionally demonstrate HSCT advanced control technology. The pros and cons of various demonstration vehicles are discussed. A sophisticated iron bird type test is postulated as a lower cost/higher risk alternative to flight test. However, no attempt is made to select a test vehicle since the results of Task 7 of the NASA Langley Systems Study (NAS1-19360) are required to make such fundamental decisions as whether flight demonstrations should be conducted at the subsystem level or the vehicle level. A requirement is also identified for laboratory endurance testing of critical hardware technologies as a substitute for in service testing which would normally be conducted prior to introducing advanced technology into subsonic aircraft.

#### 1.5 Recommendations Summary

The fundamental recommendation of the study, in Section 7.0, is that a coordinated technology development and flight demonstration program, as described in Section 6.0, is required to put the technology in place to support an HSCT go ahead in the year 2000 time frame. The other conclusions are summarized as follows:

1. Failure to resolve a significant number of the high priority technology issues can prevent the HSCT from achieving its economic and performance goals.
2. The flow-time for hardware technology development is lengthy. HSCT unique hardware may require NASA development stimulus since market forces may not be sufficient to assure timely production.
3. Flight and propulsion control technology will contribute significantly to HSCT takeoff gross weight reduction.
4. Flight and propulsion control technology advances are necessary to assure flight safety for the HSCT.

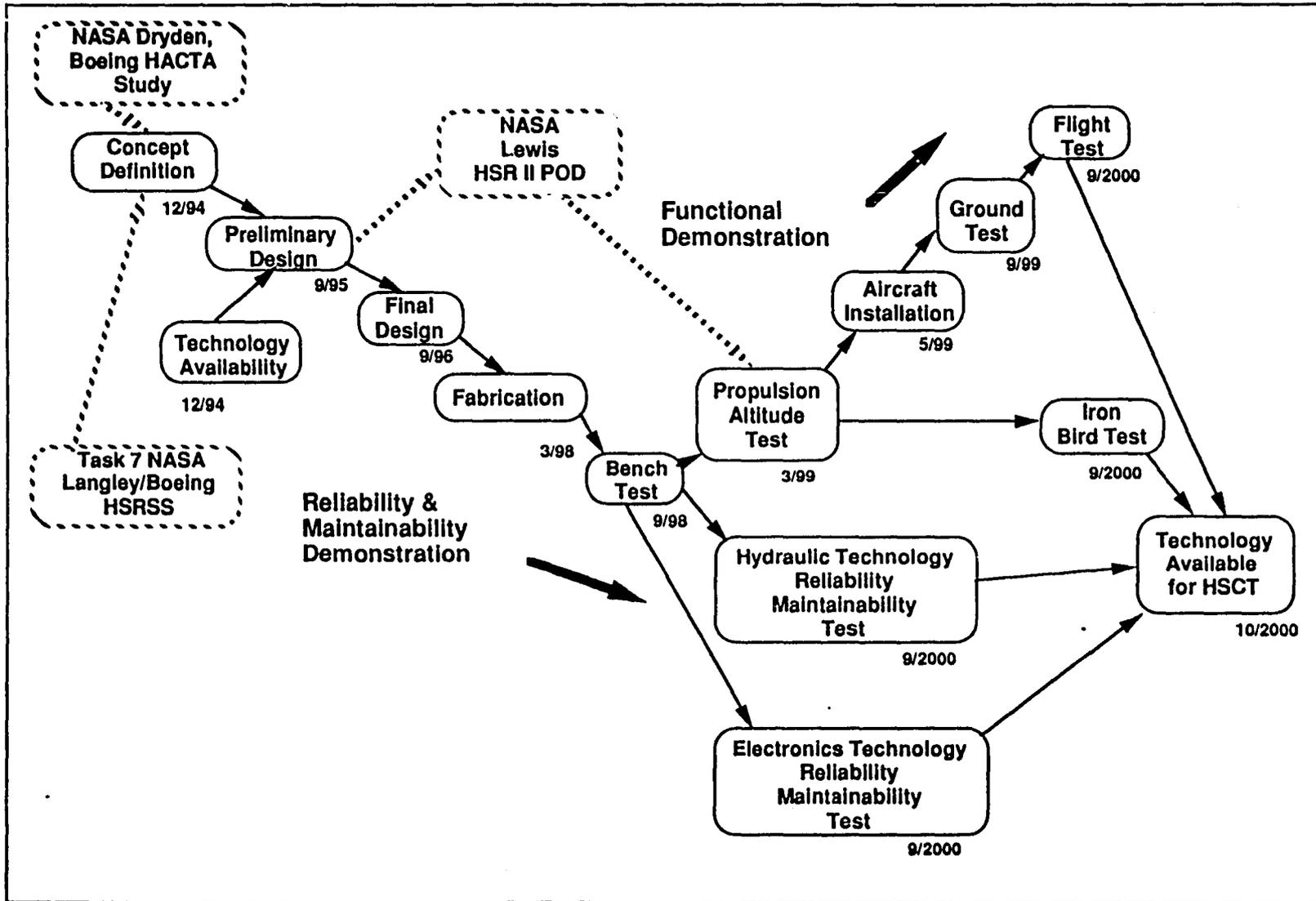


Figure 1-7 Technology Demonstration Plan

5. The certification basis of the HSCT must be negotiated world-wide between airplane manufacturers and government regulators.
6. Efficient, quality design of the HSCT will require an integrated set of design tools that support the entire engineering design team, not just flight and propulsion controls.

2.0 SYMBOLS AND ABBREVIATIONS

- 4-D Four Dimensional, in navigation waypoints: latitude, longitude, altitude and time
- ACE Actuator Control Electronics
- ADS Automatic Dependent Surveillance
- ATC Air Traffic Control
- ATLAS Abbreviated Test Language for All Systems
- CAD Computer Aided Design
- CAS Control Augmentation System
- CASE Computer Aided Software Engineering
- CATIA Computer Aided Three-dimensional Interactive Application
- CFD Computational Fluid Dynamics
- CG Center of Gravity
- CGI Computer Generated Imagery
- DARPA Defense Advanced Research Projects Agency
- DATAc Digital Autonomous Terminal Access Communication (ARINC 629 Precursor)
- EASY-5 Boeing Proprietary Simulation and Analysis Tool
- EGT Exhaust Gas Temperature
- EMI Electro-magnetic interference
- FAA Federal Aviation Agency
- FADEC Full-Authority Digital Engine Controller
- FAR Federal Aviation Regulation
- FBL Fly-by-Light
- FBW Fly-by-Wire
- FOCSI Fiber-optic Control System Integration
- GLA Gust Load Alleviation
- GPS Global Positioning Satellite
- GSA General purpose aerothermodynamic engine simulation program
- GSDS Graphical Simulation Development System
- HACTA HSCT Airframe/Propulsion Controls Technology Assessment
- HIDEC Highly Integrated Digital Electronic Control
- HIMAT Highly Manueverable Aircraft Technology (NASA)
- HIRF High Intensity Radio-Frequency radiation
- HSCT High-Speed Civil Transport
- HSR-II High-Speed Research, Phase II (NASA)

ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
ILS	Instrument Landing System
INCU	Inlet Nozzle Control Unit
INS	Inertial Navigation System
IPCS	Integrated Propulsion Control System
IR&D	Internal Research and Development
LADAR	Laser Radar
LRU	Line Replaceable Unit
MLA	Maneuver Load Alleviation
MMW	Millimeter Wave
MLS	Microwave Landing System
MTGOW	Maximum Take-off weight
N1	N1 Compressor Fan RPM
NASA	National Aeronautics and Space Administration
NPSS	Numerical Propulsion System Simulator
OSF/OSI	Open Systems Foundation/Open Systems Interface
PAIT	Propulsion Airframe Integration Technology
PARC	Navier-Stokes Computing Tool for Propulsion Aerodynamic Analysis
PCE	Pilot Control Electronics
PSIM	Parallel Simulation Tool
QSRA	Quiet Short Haul Research Aircraft
RF	Radio Frequency
RISC	Reduced Instruction Set Computing
RNPC	Required Navigation Performance Capability
RPV	Remotely Piloted Vehicle
SAS	Stability Augmentation System
SEU	Singe Event Upset
SST	Supersonic Transport (1971 Boeing Concept)
TCAS	Traffic Collision Avoidance System
TECS	Total Energy Control System
TOFL	Take-off Field Length
V <sub>1</sub>	Critical Engine Failure Speed
V <sub>2</sub>	Take-off Climb Speed
V <sub>R</sub>	Rotation Speed
V <sub>D</sub>	Maximum Design Dive Speed

---

$\alpha$       Angle of Attack  
 $\beta$       Sideslip angle  
 $\phi$       Roll or Bank Angle  
 $\theta$       Pitch angle

### 3.0 HSCT FLIGHT AND PROPULSION CONTROL REQUIREMENTS

This section identifies the design requirements of the HSCT that influence or drive flight and propulsion control system technology. The flight and propulsion requirements are derived from the airplane configuration, which is driven by the mission characteristics. This study identifies requirements that can be used to identify the control system technology issues relevant to the HSCT concept and mission, and is organized as follows: Section 3.1 introduces the HSCT Mission; Section 3.2 discusses vehicle configuration and related requirements; Section 3.3 identifies flight deck/flight management, flight control and propulsion control related requirements; and Section 3.4 lists general design requirements, including maintenance, certification and system engineering environment.

#### 3.1 Mission Requirements

Studies (refs. 1 and 2) have shown that a Mach 2.0-2.5 airplane will be able to penetrate the long-range international air transport market if the seat cost is competitive (within 10%-20% of the subsonic airplane ticket price), and the airplane meets stringent environmental requirements. This implies a number of top-level mission requirements. For example, the HSCT will be large (250-300 passengers), have a trans-Pacific range (5,000-6,000 nautical miles), have rapid landing-departure turnarounds (1 hour), and be operated for long periods of time without unscheduled interruption. For the current Boeing HSCT Baseline, these requirements are summarized as:

1. Mach 2.4 design point: 70,000 ft cruise ceiling, 5,000 nmi range.
2. Passenger capacity 280-310, comparable in cabin temperature and motion characteristics to subsonic fleet.
3. The aircraft must meet community environmental goals and regulations: no significant ozone impact, FAR 36, Stage 3 noise requirement, no boom over populated areas.
4. Daily utilization rate must be maximized. This will require rapid turnaround times.

#### 3.2 Airplane Configuration Requirements

The present HSCT Baseline configuration has evolved from the Boeing Supersonic Transport program, and is being updated, item-by-item, as engineering or market analyses reveal a benefit. The major characteristics of the baseline Boeing HSCT airplane at the time of this writing are summarized in Figure 3-1. Taken with the mission requirements these

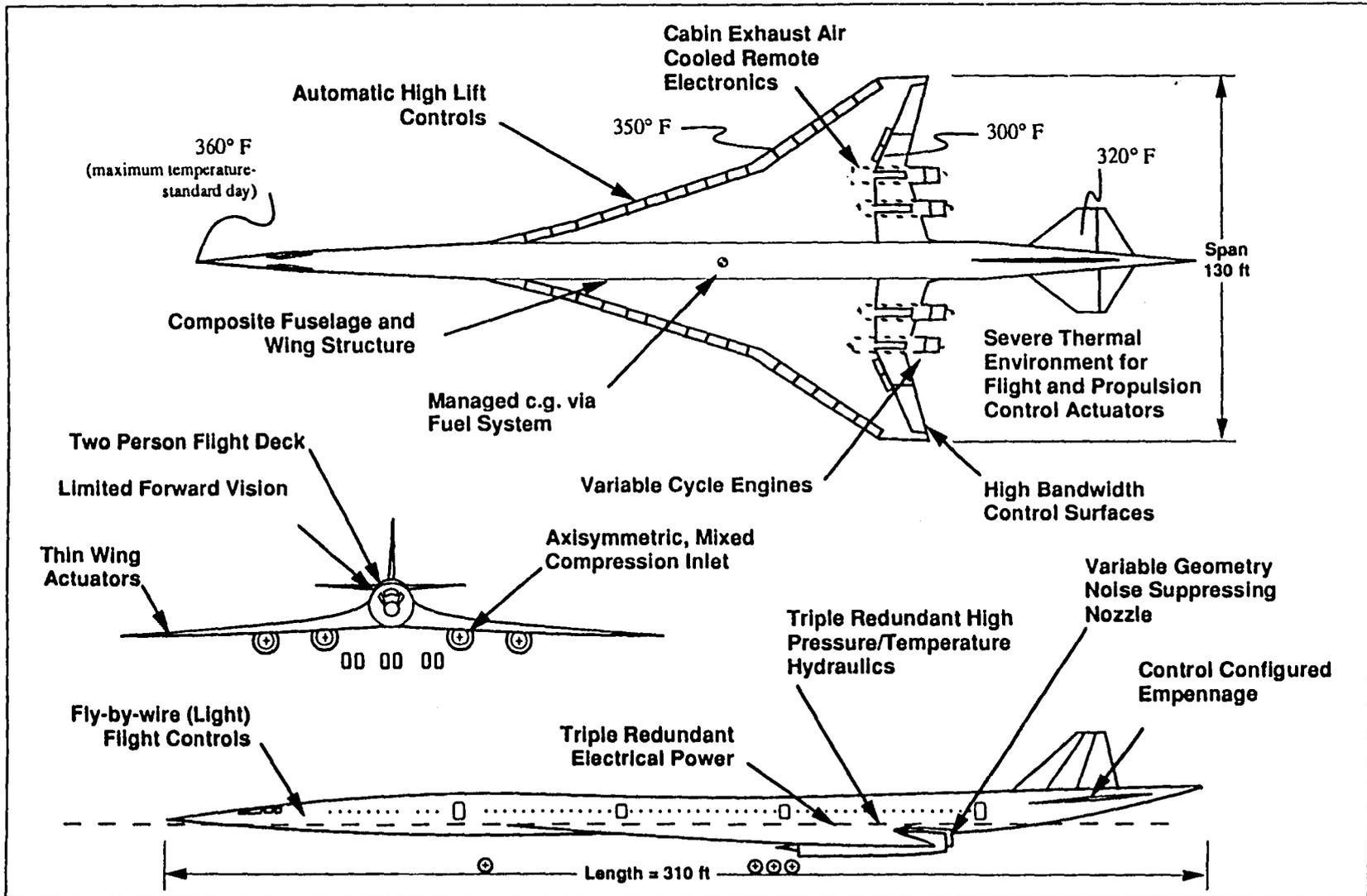


Figure 3-1 Proposed HSCT Characteristics

airplane configuration characteristics dictate many stringent requirements that are not adequately met by present-day technology. The configuration characteristics listed below are typical of the airplanes being evaluated by Boeing at this time.

1. 700,000 lb nominal takeoff weight, compatible with conventional (11,000 ft) runways.
2. Two-person flight deck with electronic primary and secondary displays with no mechanical backup instruments.
3. No droop-snoot and no forward windows; vision augmentation required for forward view.
4. Flight control and propulsion control systems are digital fly-by-wire (or fly-by-light) with no mechanical backup.
5. Primary (high bandwidth) flight control surfaces include: horizontal stabilizer with independently actuated elevator, rudder, flaperons and spoilers.
6. High lift control surfaces include: simple hinged leading and trailing edge flaps, inboard and outboard flaperons, and discretely activated apex fences.
7. Control configured empennage, negative static margin, relies on full-time SAS for longitudinal stability.
8. The fuel system consists of 21 fuel tanks distributed in the wing and body, and the pumps, plumbing, and control valves that are used to transfer fuel for the purpose of adjusting airplane center of gravity, as well to control fuel supply to the engines.
9. The aircraft fuselage and wing structure is predominantly organic composite material. (This implies minimum RF energy attenuation.)
10. The aircraft has a severe thermal environment characterized by 380°F stagnation temperature and 1050°F typical engine bleed air temperature during Mach 2.4 standard day flight. Adiabatic wall temperature ranges from -55 to 330° F over the flight envelope.
11. The aircraft is configured with high pressure hydraulics (i.e., 5000 psi/275°F) to meet expected flight and propulsion actuator duty cycle, envelope, and load requirements.
12. The aircraft is configured with three independent, uninterruptable flight critical power buses.
13. Cabin exhaust air is available for electronic cooling in the avionic equipment bays and in the nacelles.
14. The propulsion system consists of an axisymmetric mixed compression inlet, a turbine bypass turbojet engine, and a variable geometry noise suppressing nozzle.

### 3.3 Control Systems Design Requirements

To be economically successful, HSCT control systems must optimize airplane performance and direct operating costs. In order to meet these goals in its present configuration the HSCT will be a control configured vehicle (CCV). It will fly subsonically with a negative static margin. It will therefore require longitudinal stability augmentation. In addition, since it flies on the backside of the power curve on approach, it may also require flight path control augmentation via an autothrottle during approach. Supersonically the HSCT will only be marginally stable in both roll and yaw axes also creating a requirement for full time augmentation. The complex (approximately 12 major actuated functions per nacelle) supersonic propulsion system incorporating a mixed compression inlet and a variable cycle engine creates requirements for high response automatic control and multi mode operation not encountered in subsonic applications. These requirements affect other areas of avionic system design, as well as the flight and propulsion control systems. The remainder of this section surveys the major characteristics of the HSCT mission profile (Section 3.3.1), and together with the previously stated mission/configuration requirements, specifies the resulting flight deck/flight management (Section 3.3.2), flight control (Section 3.3.3) and propulsion control (Section 3.3.4) system design requirements:

#### 3.3.1 HSCT Mission Profile Characteristics

Figure 3-2 shows a typical profile of an HSCT mission and identifies the major phases in an operational mission. The purpose of this section is to review each phase of the HSCT mission (ref. 1) from takeoff to landing, in order to identify the control system, maintenance, and certification requirements that result from the HSCT mission.

##### 3.3.1.1 Preflight Planning/Mission Initiation/Checkout

**Unique HSCT Flight planning requirements include:**

- 1. avoidance of Noise/Boom sensitive areas,**
- 2. anticipating events such as weather cells, en route traffic, terminal traffic, and airport conditions,**
- 3. requirements of year 2005 communication, navigation and surveillance environment, and**
- 4. super-hub (designated coastal airports with 11,000 ft runways) oriented route structure; occasional use of more inland facilities.**

Advanced ground and satellite datalinks will permit definition of the weather and traffic environment for the flight from beginning to end, before the flight, and updates of flight

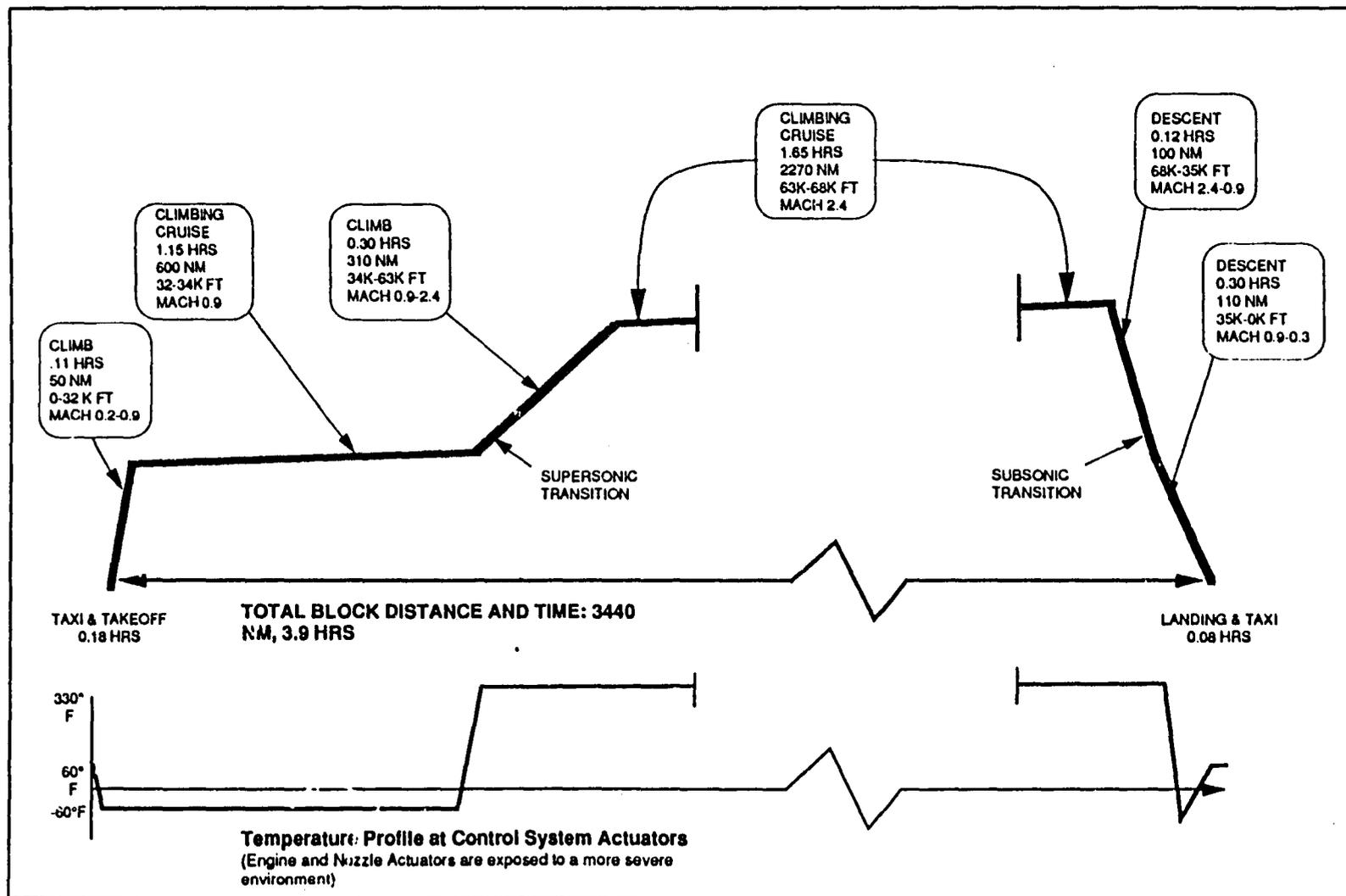


Figure 3-2 Typical HSCT Flight Profile

planning functions throughout the flight. Noise and environmental restrictions and the HSCT's high loiter fuel consumption make automated mission planning more essential for the HSCT than comparable subsonic airplanes.

**Comprehensive automatic initialization/checkout of systems should cover:**

- 1. flight critical electrical power,**
- 2. hydraulic pressure and fluid quantity,**
- 3. flight systems mechanical, hydraulic and electronic components, and**
- 4. propulsion system actuators and electronics.**

Complex and critical subsystems will be started and checked out automatically. Mature central maintenance algorithms will focus on critical faults and ignore transients or faults where remaining redundancy supports safe flight and meets dispatch requirements.

Preflight checklists that require pilot involvement will be computer aided.

#### 3.3.1.2 Taxi-out

**During taxi, enhanced vision and other collision avoidance sensors may be required to provide:**

- 1. adequate forward and circumferential vision,**
- 2. stable cabin/flight deck motion during taxi, and**
- 3. runway collision avoidance.**

The pilot must be able to detect and avoid traffic and obstacles on the runway when taxiing. Peripheral vision adequate for taxiway safety must be provided to compensate for window configuration and flight deck location. Airports, airlines, and communities require propulsion controls that reduce brake wear, noise, and air pollution to acceptable levels. The location of the flight deck relative to the nose gear results in amplified oscillations from uneven taxiways. Active nosewheel strut damping to limit flight deck and cabin motion may be required.

#### 3.3.1.3 Take off

**Pitch limiting or protection on rotation may be required, due to airplane length, to avoid tail strike or stall on takeoff.**

Because of the length of the airplane behind the main landing gear, the risk of tail strike damage during takeoff rotation is greater than it is on subsonic airplanes. Automatic pitch angle limiting, as part of a comprehensive flight envelope protection function, may be needed to avoid structural damage or dangerous takeoff maneuvers. Automatic thrust adjustment to satisfy noise restrictions on takeoff and climbout will be required.

#### 3.3.1.4 Climb/Climbing Cruise/Step Cruise/Cruise/Hold/Descent

**Climb and descent profile guidance/control should accommodate and optimize transonic operation.**

The performance requirements of transonic flight define the flight control system design. The SR-71 dives at 30,000 ft, during the transition to supersonic flight to save fuel. Optimal trajectories can reduce fuel consumption, save time and permit use of smaller engines, actuators, etc..

**Automatic flight planning should meet the air traffic control system requirements, including operating in:**

- 1. traditional subsonic controlled air space (below 45000 ft), and**
- 2. high altitude routes, shared by military, Concorde, and research users.**

Concorde and SR-71 use a climbing cruise above 50,000 ft to keep the airplane at the minimum fuel consumption altitude as fuel (weight) is burnt off.

**Normal supersonic cruise operations result in:**

- 1. rapid closure rates and reduced time for updating flight plan, performing evasive maneuvers, and coping with inflight incidents or emergencies, and**
- 2. unique monitoring requirements related to inlet status, high speed flight, maximum total temperature, clear air turbulence, gusts, thermal shears and wind shears.**

A traditional Boeing concept is that of a quiet and dark flight deck during cruise, however computer monitored instrument status must be available on request, or annunciated when an abnormality requires pilot attention. Integrated automatic control maintaining optimum propulsion/airframe system operation is required. This system must avoid and, in the last resort, compensate for inlet unstarts and accommodate turbulence and gusts.

#### 3.3.1.5 Approach

**Satisfactory handling qualities during approach require both pitch and speed stability augmentation.**

Automatic flight envelope protection may be required to provide angle of attack, minimum speed, maximum speed, roll attitude, normal acceleration, sideslip and propulsion system limiting functions on approach as well as in other phases of flight. Stability augmentation requires integration (ref. 3) of flight and propulsion control systems.

#### 3.3.1.6 Missed Approach

**Automatic go-around mechanization may be required to avoid hard landings or tail strikes.**

The propulsion system may use a choked inlet for noise abatement purposes during approach. This will be an automatic function of which the flight crew must be aware. In the event of a go-around the propulsion system must rapidly and automatically transition from choked operation to full thrust.

#### 3.3.1.7 Landing

**The preferred control mode for landing flare may be automatic.**

Appropriate envelope limiting will be required to avoid tail strike on landing. Autonomous automatic landings may be conducted using various combinations of MLS, GPS, radar altimeter and inertial sensors and avionics.

#### 3.3.1.8 Taxi-in

**Augmented taxi control and enhanced vision may be required to provide:**

- 1. adequate forward and circumferential vision,**
- 2. stable cabin/flight deck motion during taxi,**
- 3. runway collision avoidance, and**

Taxi-in maneuvering will also include precision docking at the gate, where lateral motion of the flight deck is amplified from commands at the nose gear.

#### 3.3.1.9 Engine shut-down/Post-flight

**Comprehensive automatic shutdown procedures should cover postflight checkout of:**

- 1. flight critical electrical power,**
- 2. hydraulic pressure and fluid quantity,**
- 3. flight systems mechanical, hydraulic and electronic components, and**
- 4. propulsion system actuators and electronics.**

System shut down checklists and service maintenance troubleshooting support will be automated because of the complexity and the requirement for quick turn around and high airplane availability. Airplane configuration data, flight and service manuals, and appropriate maintenance histories will be contained in an on-board electronic data base.

#### 3.3.2 Flight Deck and Flight Management Requirements

The flight deck systems will feature advanced displays, possibly including synthetic vision, pathway in the sky and other avionics designed to enhance the pilot's situation awareness and ability to control the airplane safely at all times. Alternate controllers with no back drive are being considered. Throttles will probably be backdriven. Year 2005 state-of-the-

art (ref. 4) air traffic control and navigation functions will provide airplane status to air traffic control operations in over water and low traffic areas. The system and operational requirements that result from the HSCT mission can be summarized as follows:

1. Flight deck visibility (whether windows or sensors/computer generated displays) shall be sufficient to support safe manual control, avoid obstacles in terminal air space, and avoid collisions on the taxi ways.
2. Real-time data from carrier, air traffic and weather services shall be available via data link to automatic mission planning equipment on-board the air plane, so that the mission can be planned from beginning to end on the ground, and updated in real-time throughout the flight (ref. 5).
3. Automatic checkout of avionic, flight control and propulsion control systems shall be provided down to the LRU level for electrical, mechanical, hydraulic, and propulsion systems.
4. Requirement for a quiet, dark, two-person flight deck shall not compromise airplane status data available to the crew.
5. HSCT flight plans must meet environment/noise constraints, keep schedules, use minimum fuel, operate in subsonic and supersonic controlled air space, and provide the same, or better, comfort level to passengers as a subsonic airplane.
6. Due to predominantly over water operations (areas lacking radar surveillance) required navigation performance capability area navigation (RNAV/RNPC) equipment and Automatic Dependent Surveillance transponders shall be provided (ref. 4).
7. The HSCT will require communication systems supporting voice and datalink communication with ATC centers, airline operations centers and passenger telecommunications in all areas that the HSCT shall operate.
8. Electronic library will replace paper manuals for terminal/approach maps, flight manuals, carrier regulations, maintenance procedures, etc.

### 3.3.3 Flight Controls

#### 3.3.3.1 Flight Control Subsystems

To meet the mission requirements, the HSCT will be a control configured vehicle with control surfaces sized and center of gravity selected for optimal vehicle performance, commensurate with adequate maneuver control to meet all design conditions. The resulting vehicle configuration will have an aft c.g. and relatively small control surfaces, possibly using an active stabilizer for primary control, as well as secondary control devices such as

leading edge vortex fences to achieve the required pitch control authority. The c.g. location may be aft of the neutral point (negative static margin) or perhaps even aft of the maneuver point for certain low speed flight conditions. This precipitates the need for pitch stability augmentation.

For approach and landing conditions the airplane will fly on the backside of the power curve (see Figure 3-3), resulting in speed instability at constant thrust, when the flight path is controlled through the elevator. Thus some form of speed stability augmentation will be required. Automatic flap sequencing, and use of flaperons for direct lift control will also be considered to enhance controllability. These active control functions will increase the control surface activity and possibly adversely affect the vehicle ride quality. Furthermore this design approach may well increase the risk of exceeding flight envelope limit parameters (angle of attack, airspeed, sideslip, bank angle, normal acceleration), thus increasing the need for flight envelope protection functions. To maintain optimum performance, the c.g. will need to be shifted aft as the center of lift shifts aft, when accelerating into supersonic flight. Aeroelastic deformation over the flight envelope may also affect the location of the center of lift, requiring c.g. management in order to minimize trim drag.

Active flutter suppression, and gust and maneuver load alleviation will be considered to reduce structural weight.

The avionics, flight and propulsion control systems will consider using advanced component technologies such as fly-by-wire or fly-by-light signaling, smart actuators, photonic (or other new technology) sensors, high speed data buses, and fault tolerant architectural concepts. Figure 3-4 illustrates a fly-by-wire concept that has been proposed for HSCT. Fly-by-wire (light) technologies facilitate the integration of functions. For example the absence of a mechanical linkage between the pilot controls and the control surfaces allows more freedom to command the control surfaces to meet multiple objectives without interfering with the pilot's control objective.

The nature of the control configured HSCT is that many design requirements will have to be satisfied within the same physical system. There is a need for an integrated design approach that effectively deals with the relationship of the functions to avoid partial or complete duplication in various subsystems, and achieve maximum performance with minimal design complexity. Opportunities for elimination of such duplication include:

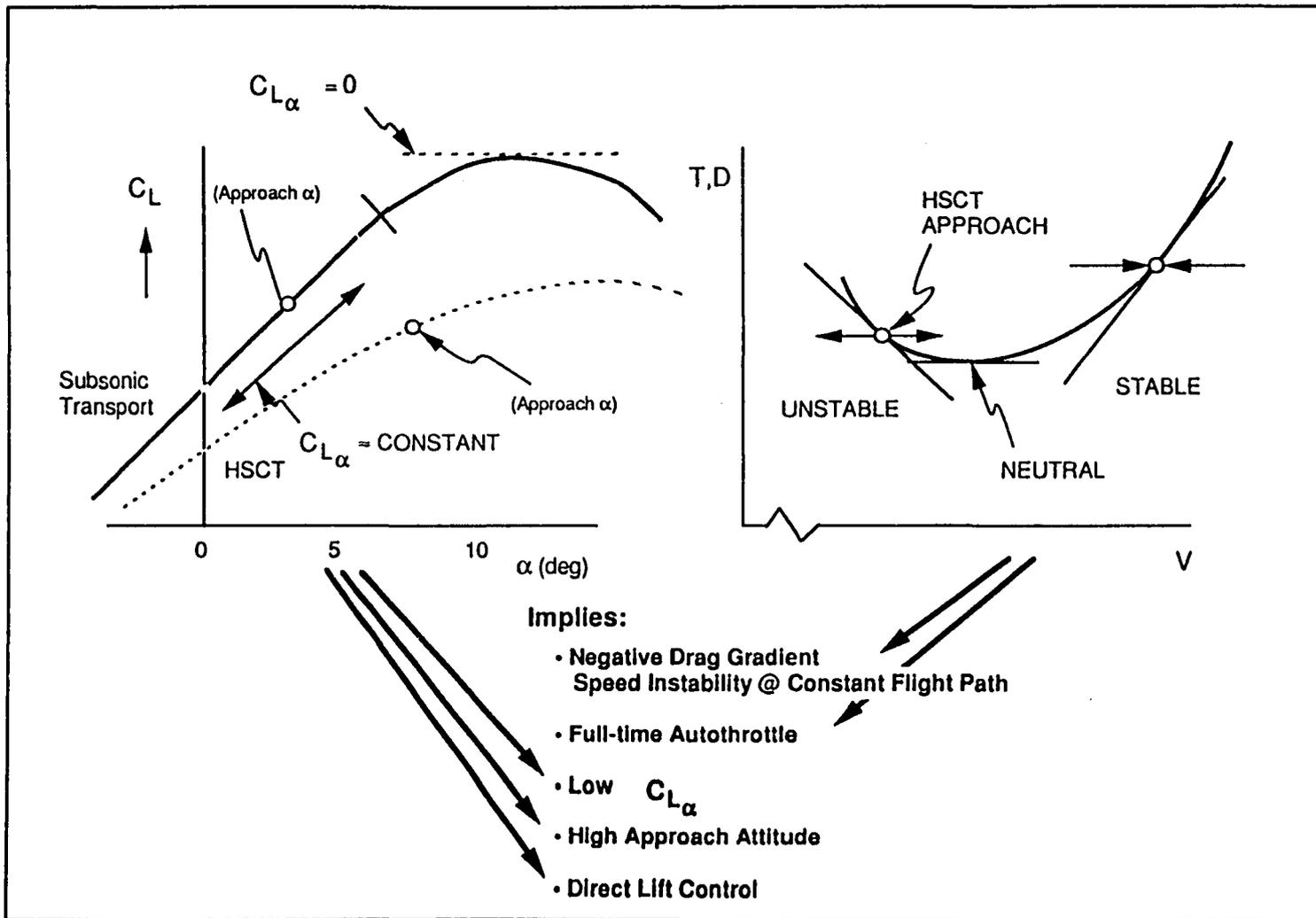


Figure 3-3 HSCT Lift-Drag Fundamentals

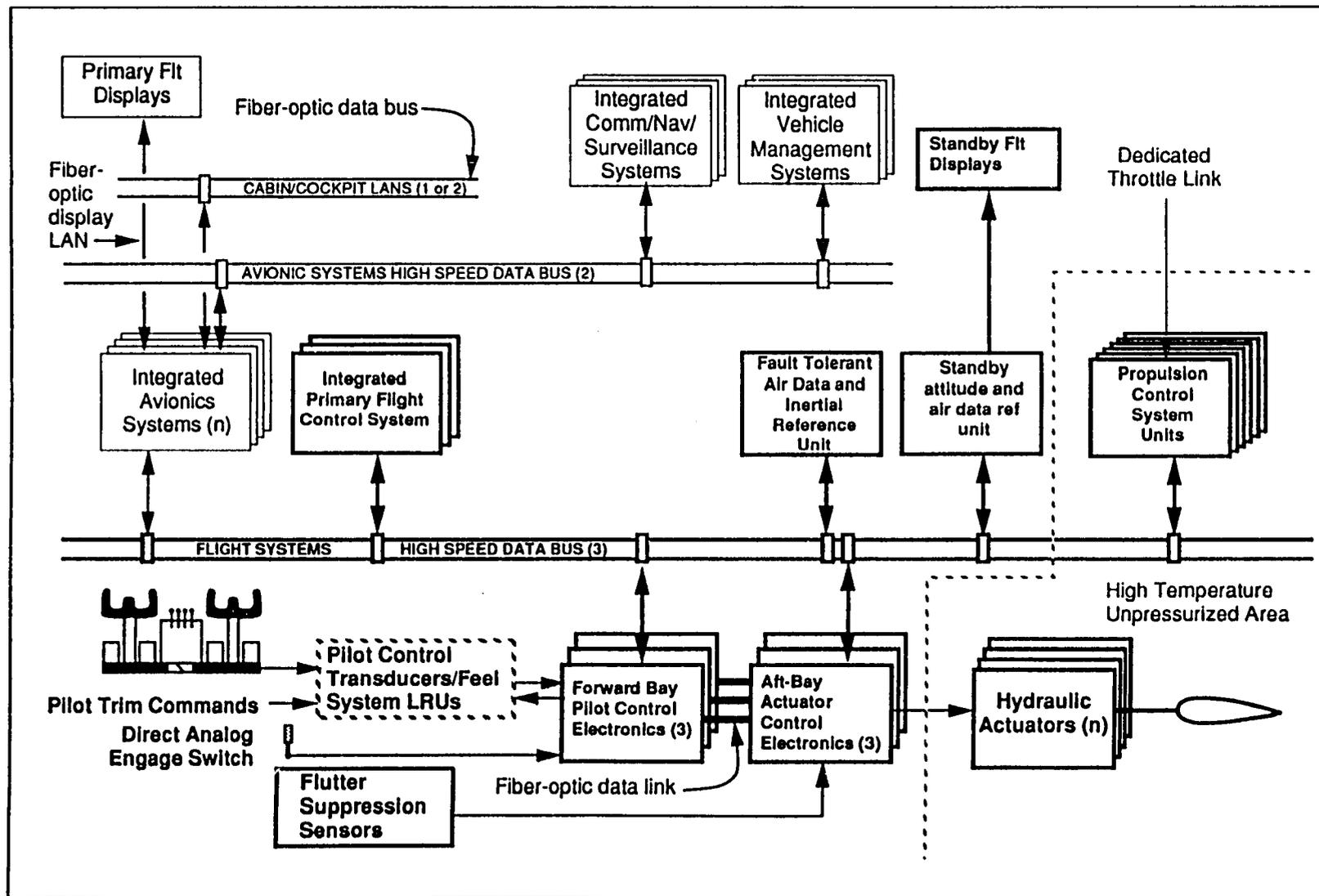


Figure 3-4 Typical HSCT Primary Flight Control System

- Providing air data to both the propulsion control and the flight control system from a single high reliability system.
- Placing the propulsion system data base entirely in the propulsion control system, and passing necessary information to the flight management system via the data bus. With this arrangement, engine configuration revisions would not require updates to the flight management database.
- Functional integration of pilot-in-the-loop SAS/CAS with the autoflight modes, with the autopilot using the SAS/CAS as inner loops.
- Use multi-input/multi-output design strategies to functionally integrate speed control and flight path control in the longitudinal axis, and roll and yaw control in the lateral/directional axes, eliminating separate subsystems, such as autothrottle, yaw damper and turn coordinator.

#### 3.3.3.2 Flight Control Requirements

Many strategies exist for dealing with the design of the control functions and the inherent complexities of physically integrated systems. Some strategies are discussed as technology issues, but certain system requirements also exist. The system must be safe and reliable; it must be physically and functionally robust, that is it must operate correctly in a high temperature, high radiation, high altitude environment on a flexible, supersonic airplane; and the flight control system should weigh as little as possible, without degrading performance or safety of the airplane. The following design requirements apply to the flight control system:

1. Stability augmentation is required for short period and speed dynamics; an autothrottle may be required for flight path control augmentation, when operating on the backside of the power curve.
2. Active flutter suppression may be required to achieve the design weight with a  $1.2V_D$  flutter margin.
3. The lateral-directional control system shall be designed to minimize the dynamic response of the airplane to inlet unstart and engine failure.
4. Automatic gust and maneuver load alleviation may be required to reduce loads on the wings, and to improve ride characteristics for passengers and crew.

5. Flight envelope protection will be provided in all mission phases where particular HSCT characteristic may be hazardous. (i.e., prestall pitch-up, tail strikes, supersonic operation, etc.)
6. Automatic control of high lift, speed brake, and c.g. related fuel management subsystems shall be provided to facilitate the manual flight control.
7. The flight control system and the propulsion control system shall be functionally integrated via the flight systems data bus.
8. Undesirable flight deck or cabin motion, due to the cantilever length of the HSCT fuselage and the position of the landing gear shall be minimized.

#### 3.3.4 Propulsion Controls

##### 3.3.4.1 Propulsion Control Subsystems

Figure 3-5 shows a preliminary design configuration of the propulsion control system. The propulsion control subsystem consists of the inlet control system, the engine control system, the throttle levers, and those elements of software and display hardware which are dedicated to propulsion functions. In addition, the propulsion control system shares communication paths and some basic functions (e.g., propulsion parameter generation for the flight management system, air data computation, and autothrottle commands) with the flight control/avionics system.

The engine/nozzle control system, consisting of dual redundant full authority digital engine/nozzle control units (ENCUs) and dual redundant sensors, controls the engine and nozzle actuators which are redundant at the ENCU interface. The nozzle actuation is supplied hydraulic power from the airframe hydraulic system. The engine actuation is powered by high pressure fuel. With the exception of the manual mode throttle command input, all communication to the ENCUs from the airframe is by a serial digital data bus, shared with the flight control system.

The inlet control system consists of dual digital inlet control units (INCUs), Figure 3-6, mounted in close proximity to the pneumatic probes used to sense the inlet state. The various inlet surfaces are provided with dual redundant actuation, Figure 3-7, operated with position feedback and powered from independent hydraulic power sources. Each INCU contains four of the pressure transducers required to control the inlet. Each inlet control uses the data from its mate's sensors and an inlet model to synthesize a best estimate of the state of the inlet that is being controlled. Since the inlet state can be

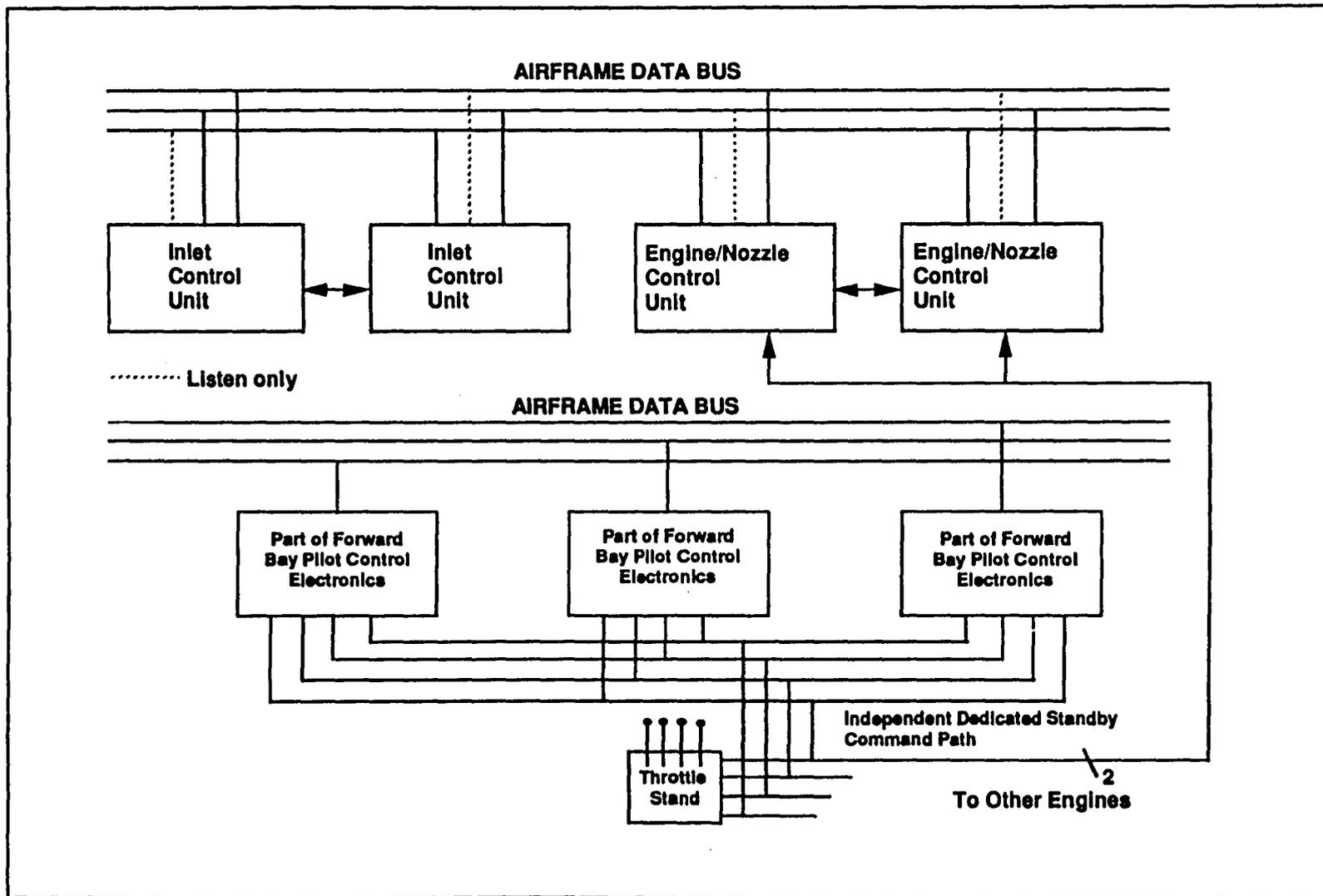


Figure 3-5 PCS /Airframe Communication Paths

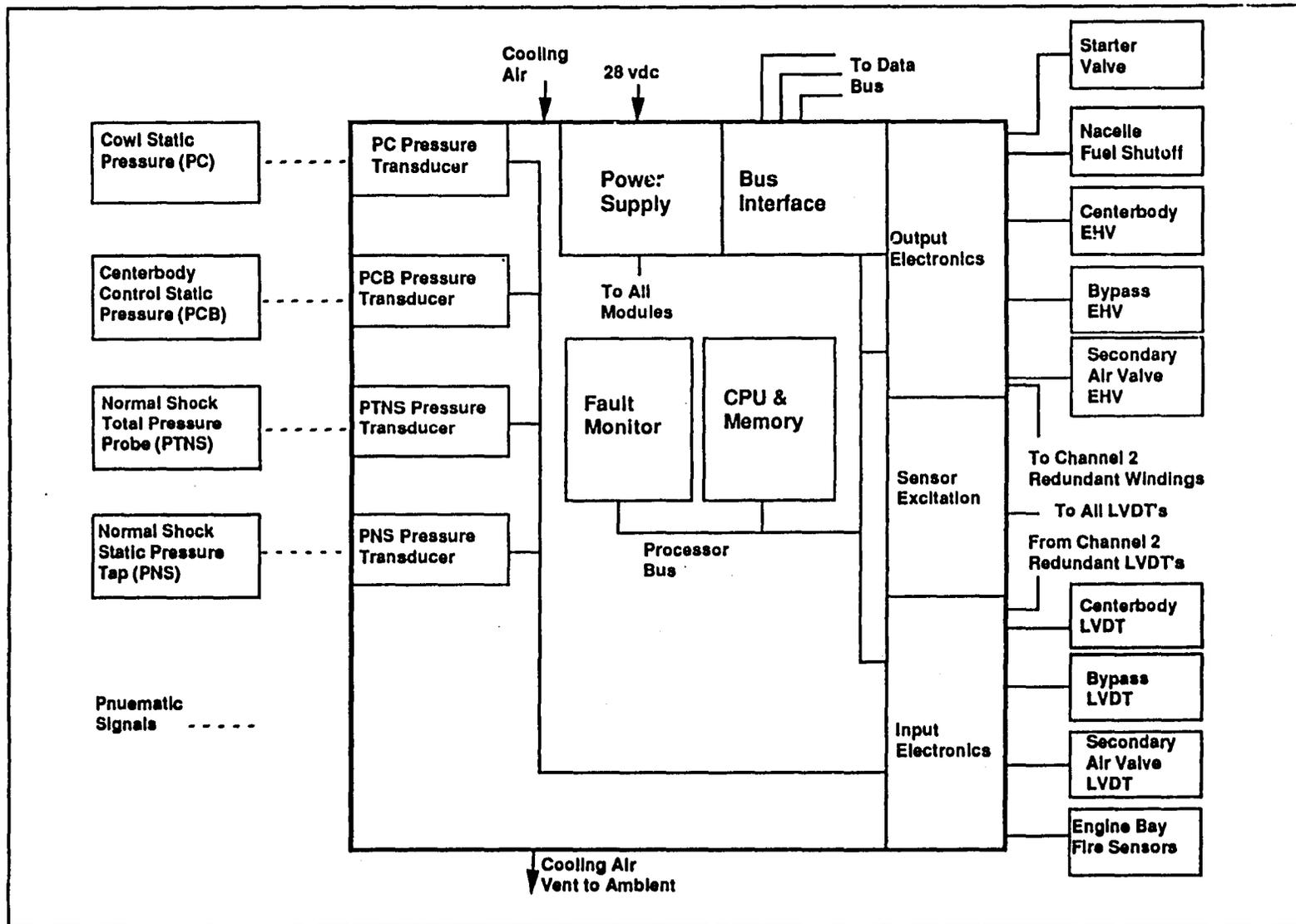


Figure 3-6 Inlet Control Subsystem

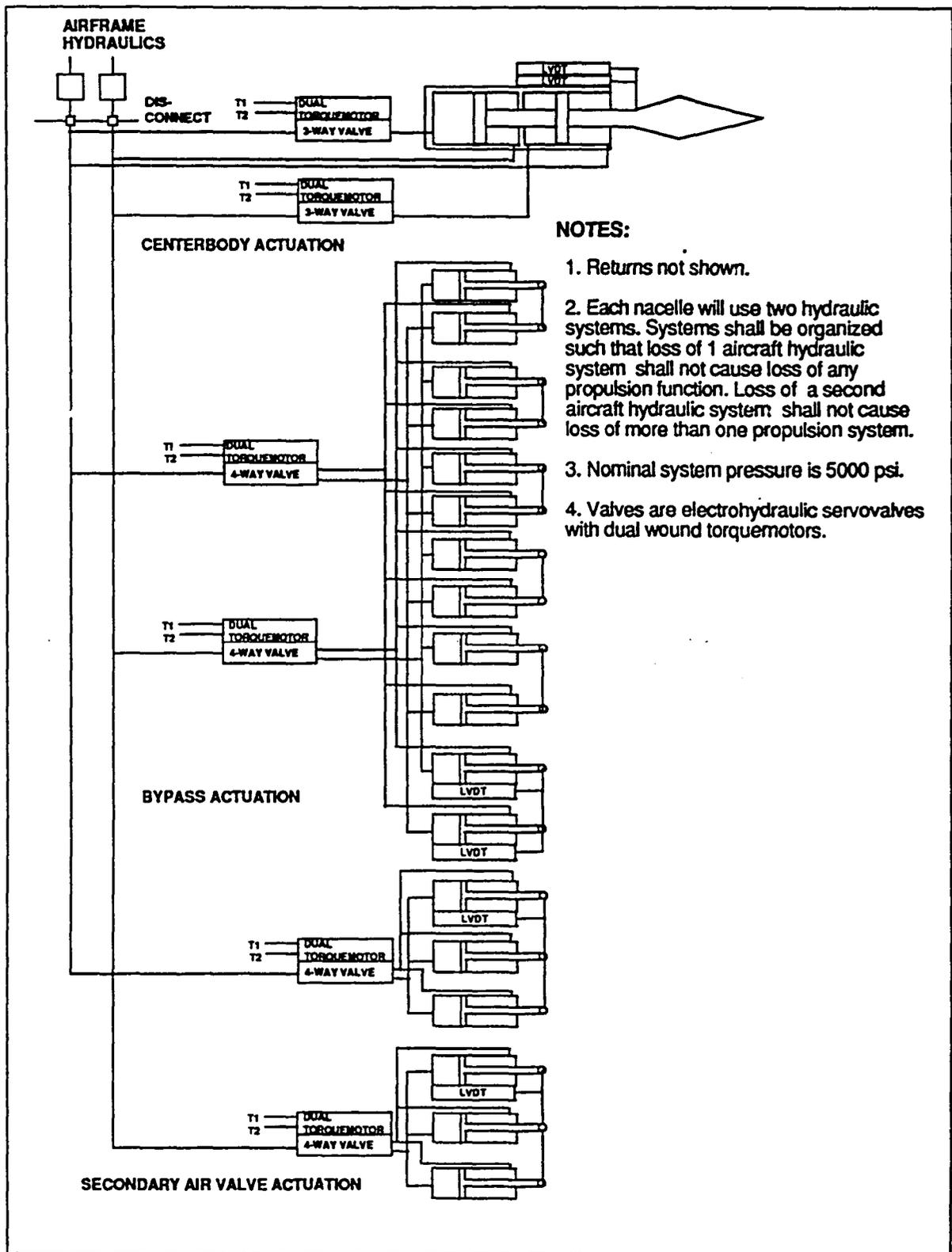


Figure 3-7 Propulsion Control Hydraulic Interface

estimated based on engine, airframe, and inlet surface position data alone, the system provides the capability of operating at some degraded level with all the inlet pressure transducers failed. The performance degradation occurs because the model accuracies won't support the full performance capability of the inlet.

#### 3.3.4.2 Propulsion Control Requirements

In addition to providing specified thrust response to throttle commands in a safe and reliable manner, propulsion requirements are driven by the concern over the consequences of asymmetric thrust in supersonic flight and the complexity of the variable cycle engine/inlet/nozzle configuration. The typical supersonic propulsion system includes 12 actuated functions (Inlet centerbody, bypass doors, secondary air valves, and throat slot bleed; engine fuel flow, compressor variable geometry, combustor air flow, and turbine bypass bleed valve; nozzle throat area, mixer area ratio, thrust reverser/exit area, and deployable noise suppression panels) and a comparably large number of sensors. This results in the following requirements:

1. The propulsion system shall be fully automated, and incorporate extensive condition monitoring.
2. The propulsion control system shall be designed to minimize the probability of an unstart. (Objective:  $p < 10^{-6}$  /flight hour).
3. The propulsion control system shall be designed to minimize the probability of engine surge/stall. (Objective:  $p < 10^{-6}$  /flight hour).
4. Automatic startup/shutdown of the propulsion system may be provided.
5. The propulsion system shall be controlled during taxi to minimize noise, brake wear and fuel consumption.
6. The propulsion system shall be controlled over the flight envelope to minimize fuel consumption and wear while achieving extremely high levels of safety and reliability, and satisfying thrust requests generated by the pilot or flight control system.
7. The propulsion control system shall automatically perform rating functions and provide propulsion system envelope limiting in accordance with flight system operating mode.

### 3.4 General HSCT Requirements

The mission and configuration requirements also drive certain general engineering requirements that are either more stringent or different than those required for comparable subsonic airplanes. The need for more availability, the requirement for low environmental impact, inherent propulsion system complexity and other requirements result in specific maintainability, certification and system engineering requirements that are identified in this section.

#### 3.4.1 Maintainability

In order to meet the basic mission availability requirement, the HSCT will be limited in the amount of time spent in daily, overnight maintenance. This dictates stringent component reliability, comprehensive built-in system tests, and highly modular (ref. 6) components as indicated by the following requirements:

1. Maintenance costs and task times must be consistent with HSCT economic viability.
2. The HSCT shall incorporate an integrated, automated fault isolation/maintenance direction system to facilitate rapid removal and replacement of failed components. In general no manual rigging or calibration shall be required as a result of replacing a component.
3. Components which cannot satisfy the requirements of 2 shall be integrated into a larger assembly which does satisfy the requirement so that necessary maintenance can be conducted off the airplane.

#### 3.4.2 Certification

The HSCT mission and configuration are different from subsonic airplanes in certain parameters such as operating altitude and the need for composite structures. Many certification rules governing these conditions are yet to be defined. SST (B2707-300) and Concorde documents have identified some of the flight and propulsion issues (refs. 7 and 8), but much new technology cannot be implemented without new certification rules. FAA/commercial certification requirements for independence of systems also drive requirements for control system architectural features. The following certification requirements are representative of those that must be accommodated by the HSCT architecture:

1. High intensity radiation (HIRF) and electromagnetic interference (EMI), within the limits specified by certification authority, shall not degrade or damage primary flight or propulsion control components (CFR Part 25.1353.)
2. Electronic memories used for flight critical airplane and propulsion control shall not be susceptible to malfunction due to single bit upset phenomena or other severe environmental conditions. (CFR Part 25.1309g.)
3. Thrust of each engine shall be independently and directly controllable from the flight deck using the throttle levers (CFR Part 25.901c.)
4. The probability that the airplane controllability degrades, due to failures, below the minimum safe level (8) for continued flight and landing shall be extremely remote ( $p < 10^{-9}$ /flight hour) (CFR Part 25.671c.)
5. Automatic takeoff control functions must not require action by the crew in response to an engine failure. (CFR Part 25, I25.1b.)

### 3.4.3 System Engineering Environment

System engineering is itself an issue on an airplane that depends on complex electronic, mechanical and hydraulic systems to control even the most basic functions. In the past, the flight and propulsion control subsystems were developed subsequent to the preliminary definition of the airplane, based on requirements identified during the preliminary design. In a control configured vehicle, the relationship between the structural members, the aerodynamics and the controls is more complex and the design process must be more iterative during the early phases, as shown in figure 3-8. The relationship between structural, aerodynamic, and propulsion design with flight and propulsion control are particularly critical for the HSCT.

A key requirement for achieving this relationship between the design groups, is for all HSCT engineering activities to have a compatible workstation/tool interface/data base environment. Herein a common data base will be available to all design groups and, in order to qualify for the program, individual engineering tools will have to be able to access this data base. Because so many tools are already in place, substantial effort will be required to create such an interdisciplinary environment. The basic requirements for such a system are as follows:

1. The HSCT engineering environment shall provide means for electronically communicating (sharing, evolving and jointly developing) requirements, models, and designs from one engineering discipline to another (i.e., to flight controls, propulsion, performance, weights, etc.).

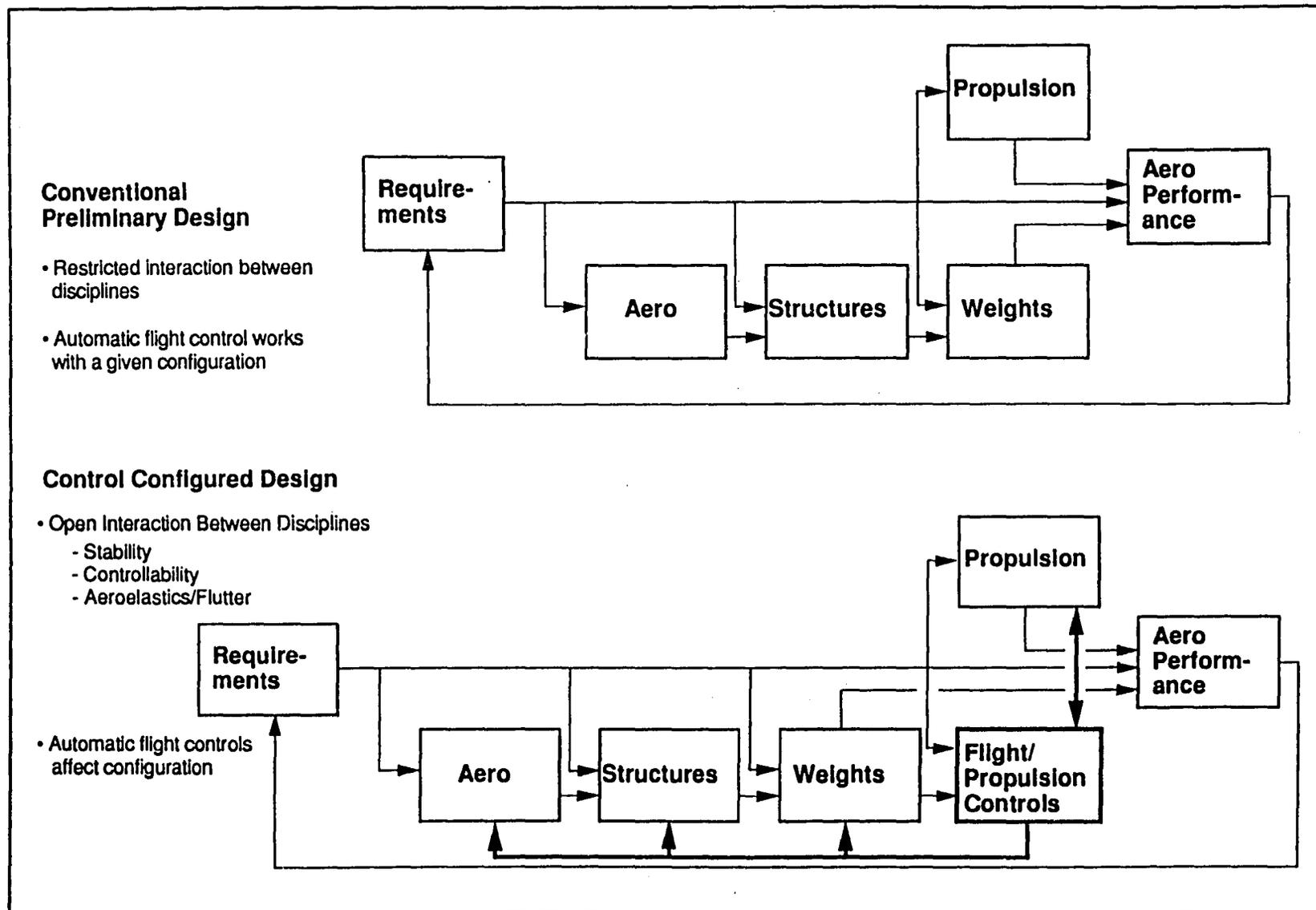


Figure 3-8 Control System Engineering During Preliminary Design

- 29
2. The HSCT engineering environment shall provide integrated, common, computer aided analysis, modelling, engineering and design, simulation, publication, software development and test, and maintenance tools.
  3. The HSCT engineering environment shall be organized around a common configuration controlled data base which includes all relevant data including requirements, structural design details, analytical and test data from all engineering functions, and manufacturing plans and drawings.

## 4.0 TECHNOLOGY ISSUES

Typical High Speed Civil Transport configuration/requirements were defined in Section 3.0. Section 4.0 describes the technology issues that result from these requirements. The issues are sorted into three major categories: 1) flight and propulsion control law issues, 2) hardware technology, and 3) system engineering and architecture. Within each major category a number of minor categories are identified, i.e., flight and propulsion control covers flight control algorithms, propulsion control algorithms, and integrated flight and propulsion control. Each of the minor categories consists of a number of specific issues which are summarized in Figure 4.0-1. In the following paragraphs the issues themselves are described and the current technology readiness or shortfall is discussed. Most of the issues are complex and cannot be completely described in this report. For brevity, the discussion of each issue is confined to one or two pages. Where possible, references are included from which the reader can obtain more complete information.

### 4.1 Flight and Propulsion Control

The flight and propulsion control system is an integral part of the HSCT in terms of meeting performance, weight, cost, and maintainability requirements. When subsonic the HSCT has a negative static margin and requires stability augmentation (SAS). The flight control system design will be affected strongly by aeroelastic vehicle characteristics. In addition, autothrottle integration with the SAS may be required to achieve acceptable handling qualities when operating on the backside of the power curve during approach and departure. The propulsion control system must deal with the problem of preventing unstarts while maintaining high performance, and concurrently the flight control system must be able to compensate for an unstart if one occurs.

#### 4.1.1 Flight Control Algorithms

##### 4.1.1.1 Augmented Manual Flight Control

###### **Requirements:**

Note: The requirements references for each issue refer to the requirements listed in Section 3.0: Mission requirements are listed in paragraph 3.1, Configuration (3.2), Flight Deck (3.3.2), Flight Controls (3.3.3.2), Propulsion Controls (3.3.4.2), Maintainability (3.4.1), Certification (3.4.2), and System Engineering (3.4.3).

- Configuration 2

**Engineering  
Disciplines**

**Technological  
Issues**

	Flight Systems Propulsion	Mechanical/Electrical Systems Flight Deck	Reliability, Maintainability Aerodynamics/Stability & Control	Issue Survey Paragraph
<b>CONTROL ALGORITHMS</b>				
<b>Flight Control Laws and algorithms</b>				
1. Augmented Manual Flight Control	x x	x x		(4.1.1.1)
2. Automatic Flight Control	x x	x		(4.1.1.2)
3. Active Flutter Suppression	x	x	x	(4.1.1.3)
4. Wing Load Alleviation	x		x x	(4.1.1.4)
5. Active Flight Envelope Protection	x x		x x	(4.1.1.5)
6. Active CG Management	x x x		x x	(4.1.1.6)
<b>Propulsion Control Laws and Algorithms</b>				
1. Propulsion System Automation		x		(4.1.2.1)
2. Engine/Inlet Control	x x			(4.1.2.2)
3. Sensor Inlet Fault Accommodation	x x			(4.1.2.3)
<b>Integrated Flight and Propulsion Control</b>				
1. Flight/Propulsion Control Integration	x x			(4.1.3.1)
2. Unstart Avoidance/Accommodation	x x			(4.1.3.2)
3. Optimal Trajectory Generation and Tracking	x x		x	(4.1.3.3)
4. Performance Seeking Control	x x		x	(4.1.3.4)
<b>HARDWARE</b>				
<b>Actuation Hardware</b>				
1. Actuation Technology	x x x	x		(4.2.1.1)
<b>Sensor Technology</b>				
1. Fiber Optic Sensors	x x x			(4.2.2.1)
2. Vision Enhancement Technology	x x x x x		x	(4.2.2.2)
3. High Altitude Air Data	x x		x	(4.2.2.3)
4. Multifunction Sensors	x x x x			(4.2.2.4)
5. Shock Position Sensing	x			(4.2.2.5)
6. High Temperature Sensor Technology	x x x x			(4.2.2.6)
7. RF Sensor/Antenna Technology	x x		x	(4.2.2.7)
<b>Computational Hardware Hardware</b>				
1. High Temperature Electronics	x x x	x		(4.2.3.1)
2. Computational Hardware Improvements	x x x			(4.2.3.2)
3. Single Event Upset Phenomena	x x x			(4.2.3.3)
4. HIRF/EMI Immunity	x x x x x		x	(4.2.3.4)
5. Flight Systems Data Bus Technology	x x x x		x	(4.2.3.5)
<b>SYSTEM ENGINEERING AND ARCHITECTURE</b>				
<b>System Engineering</b>				
1. HSCT Certification Requirements	x x x x x x x			(4.3.1.1)
2. Multi-disciplinary System Engineering Tools	x x x x x x x			(4.3.1.2)
<b>System Architecture/Redundancy Management</b>				
1. General Flight and Propulsion Systems Architectures	x x x	x		(4.3.2.1)
2. Flight Critical Systems Architectures	x x	x		(4.3.2.2)
3. Built-in Test and Maintenance	x x x x x			(4.3.2.3)

**Figure 4.0-1 Flight /Propulsion Controls Issue Summary**

- Flight Deck 1,4,5,8
- Flight Control 1,3,5,7,9
- Certification 3,4,5

**Issue Description:** The HSCT will require stability augmentation for the unstable short period mode related to the negative static margin during subsonic flight. On approach the airplane will operate on the backside of the thrust/speed curve, causing speed instability at constant thrust when the flight path is controlled through the elevator. Under present certification rules there are stability requirements for stickforce-per-G and stickforce-per-Knot (CFR Part 25.173c). Speed stability can be achieved in two ways: 1) at constant thrust by making the elevator SAS control to a speed target (long-term) while the stick is used in effect to bias the speed target to achieve short-term control over flight path, or 2) using both elevator and thrust control augmentation.

The first approach effectively interchanges kinetic (speed) energy with potential (flight path) energy. Phugoid damping can be provided by a combination of attitude feed back (or integrated pitch rate) and vertical speed feedback (or integrated normal acceleration). Thus, using this approach the stick commands effectively a change in attitude or a normal acceleration in the short term. While the above certification rules can be satisfied, all flying qualities may not be satisfactory, because on the backside of the thrust/speed curve, the long term flightpath angle response to stick input will be adverse. Manual thrust control will be needed to satisfy the long term flight path objectives. This is referred to as a "backside control" technique which may provide adequate flying qualities in a benign environment, but inadequate flying qualities for high workload/precision maneuvering conditions.

For the second approach speed stability is achieved by the addition of thrust control augmentation, and the stickforce-per-Knot criterion should not apply since speed is controlled automatically. The control augmentation can use a single input/single output control strategy or a multi-input/multi-output control strategy. The traditional single input/single output control strategy is to dedicate the throttle to speed control and the elevator to flight path control. This leads to undesirable control coupling which yields less than optimum flying qualities. An integrated and coordinated multi-input/multi-output control strategy can provide decoupled flight path response to stick inputs within the limits of thrust authority. Thus the multi-input/multi-output control strategy can in principle provide superior flying qualities. Both concepts must deal effectively with thrust limiting and pilot throttle control override.

The integration of the control augmentation algorithm, the display information used by the pilot to close the loop, and the feel system, will be a challenging problem. The relative contribution of each of these system components to the resulting flying qualities is seldom quantified. For the HSCT, all three will require a deliberate choice, possibly complicated by the various disciplines involved. For example, if a flight path angle based control augmentation system is selected, then a flight path angle display will be needed. The question of what characteristics the feel system should have is even more controversial. For a control configured vehicle, it is not advisable to mimic a simple gearing between control surface and pilot controller (series controller), because the SAS action would interfere with pilot maneuvering and the adverse trim characteristics relative to maneuver initiation could seriously degrade flying qualities. Stick force and stick displacement will need to be harmonized, relative to desired and actual aircraft response.

For lateral-directional control, a yaw damper will be required to meet stability requirements in some regions (i.e., high speed) of the flight envelope. Also turn coordination and airplane dynamic response compensation for inlet unstart/engine failure will be required. The traditional approach would be to design for each of these requirements separately. However, a more effective way is to develop a functionally integrated design from the start in which both roll and yaw control surfaces are commanded simultaneously to provide responsive, well damped turn entry, with minimal sideslip, and yaw control in case of inlet unstart or engine failure. In addition, this approach can provide automatic roll and yaw trim.

Vehicle dynamic response characteristics can be strongly influenced by the aeroelastic effects. Therefore, relatively high fidelity aerodynamic, structural and flight control system models need to be developed and combined into a full flight envelope real-time vehicle simulation during the preliminary design before a configuration can be adequately assessed in terms of performance, stability, controllability, aeroservoelastic effects, and pilot handling qualities. The process of designing a flight control system subject to significant aeroelastic effects is illustrated in Figure 4.1-1. That figure shows the close relationship between structural, aerodynamic and flight control engineering during system design.

The problem of developing a correct understanding and analysis of the aeroservoelastic effects and designing a well performing pilot-in-the-loop SAS/CAS will be one of the biggest challenges in the HSCT program. If the structural mode frequencies encroach on

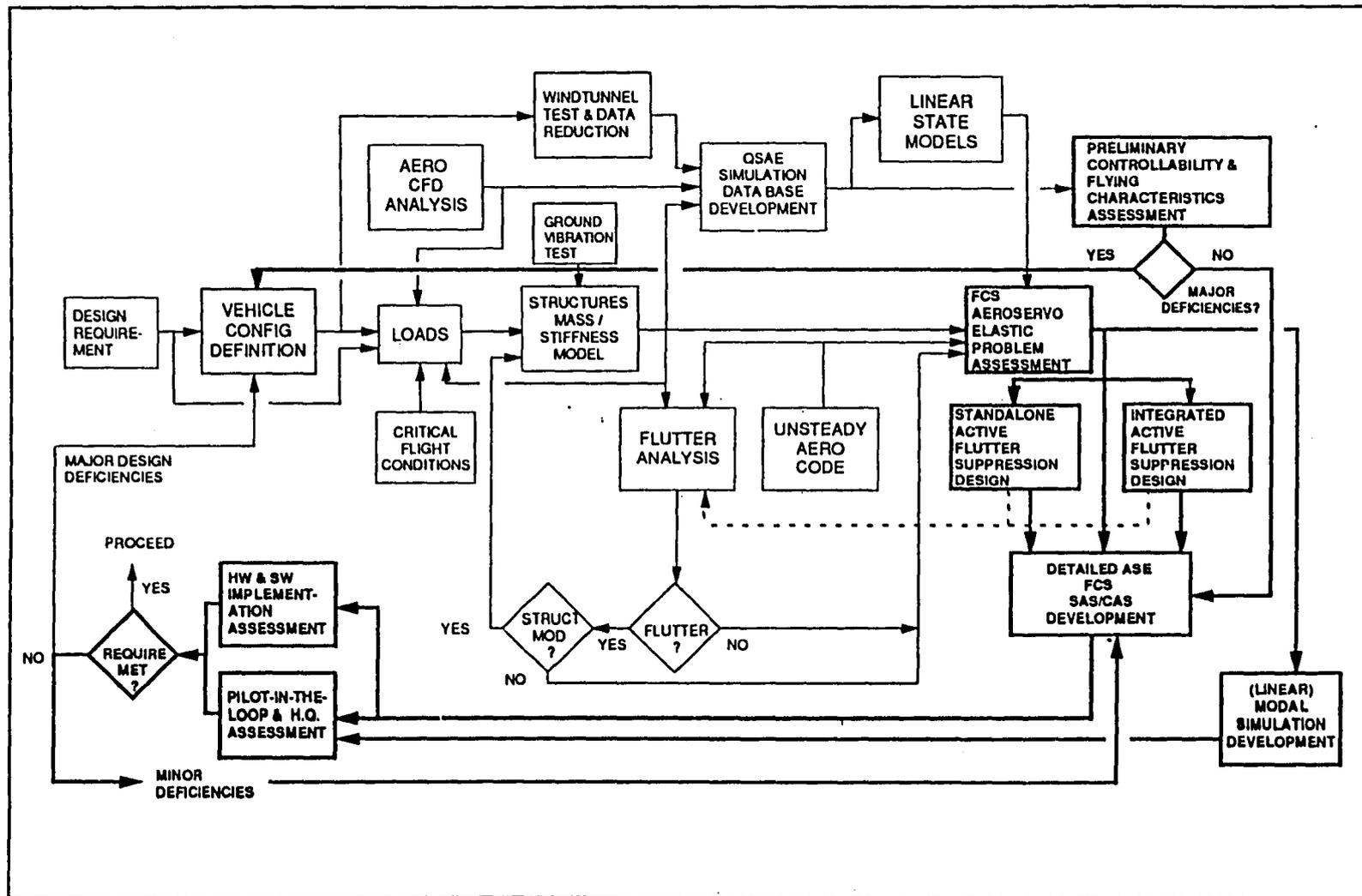


Figure 4.1-1 Aeroservoelastic Control System Development

or overlap the rigid body flight control modes the design problem can be very severe. In that case the design options are to try to actively (phase) stabilize the encroaching or overlapping structural modes or try to find a sensor set and sensor locations for which the residual structural mode pick-up is negligible and tolerable in the basic flight control SAS. This assumes that the structural modes are adequately damped by themselves. A very real problem with trying to actively stabilize structural modes is the risk of pushing up the control bandwidth, driving up actuator cost, and stirring up still higher frequency modes. Active stabilization of structural modes has to be cut-off at some reasonable frequency and this requires a gap of sufficient range in the structural mode frequencies (preferably a decade.) If this gap exists between the rigid body flight control system frequency and the lowest structural modes that can couple with it, then passive decoupling is an option, using "notch filters" on the sensor feedbacks with intolerable structural mode residues, to achieve adequate gain and phase margins. This approach is called "gain stabilization" of the structural modes. A side effect of the notch filters is that they tend to reduce the phase margin for the rigid body frequencies and this can become a serious performance issue. For unmanned vehicles or fully automatic control modes this problem can sometimes be solved by lowering the rigid body control system crossover frequency (control bandwidth), thereby increasing the frequency separation.

Another issue related to active stabilization of structural modes is their controllability through existing control surfaces. Frequently their location and size are far from optimum to make this approach practical. The achievement of flight critical reliability of such a design, using redundant sensors, actuators and/or control surfaces can become a barrier problem.

These considerations and issues are equally applicable to active flutter suppression of structural modes that by themselves are inadequately damped. Here an additional question to be answered is whether to attempt to functionally integrate the flutter suppression function with the basic SAS design or to design an independent system, including dedicated flutter control surfaces.

Particular issues that need to be addressed in the process of designing a manual flight control system for the HSCT, include:

1. Developing an aeroelastic vehicle model of sufficient fidelity to support robust SAS/CAS design.
2. Determining the design requirements and objectives of a non-mechanical, multi-input/multi-output, SAS/CAS flight control system. (i.e., Should the column or

stick control pitch, flight path angle, normal force or speed? :How severe is the aeroservoelastic coupling problem? Will there be effective design options to solve the problem?)

3. Defining the "adequate" flying qualities of the backup system (if there is one). What constitutes minimum acceptable control for safe flight and landing?
4. What gain and phase margins should the SAS have to cover flexible mode, c.g. and other uncertainties? What design approach will yield maximum robustness?
5. Should the pilot's maneuver control authority be limited to provide a reserve for the SAS functions during extreme maneuvers? Should the pilot be able to command the control surfaces to the stops?
6. What are the proper design requirements and objectives for direct lift control, when used to reduce wing root bending moments and pitch control activity during vertical maneuvering?
7. What will the certification basis be for the HSCT? In particular, will a full-time autothrottle be required for approach speed/flight path stability, and will reconfiguration of secondary controls during take-off and landing be acceptable?
8. Can suitable design requirements and objectives be developed for the feel system and display system to assure a well integrated SAS/CAS design with good flying qualities?
9. Determining the design requirements and objectives of the flight envelope protection function (i.e., hard limiting vs soft, pilot overridable, limiting).
10. Determining the level automation to be provided for inlet unstart/ engine failure response (i.e., will dedicated unstart detection and compensation functions be needed or will the basic design meet unstart compensation requirements?)

**Technology Readiness:** Most of the control strategies proposed for HSCT have been used for military airplanes or in engineering demonstrations on existing airplanes. Most of the issues center on methods and strategies that have not yet been applied to a production commercial transport airplane.

#### 4.1.1.2 Automatic Flight Control.

**Requirements:**

- Mission 1
- Configuration 2
- Flight Deck 4,5
- Flight Control 1,3,5,7
- Certification 3

**Issue Description:** The traditional way of developing the automatic flight control system is to design each mode separately and independently using single-input/single-output design approach, i.e., separate speed control autothrottle and path control autopilot, yaw damper, and roll autopilot. This design approach often results in design integration and performance problems that are discovered late in the program, precipitating further design complexity and cost escalation. Typical problems (refs. 9, 10 and 11) include:

1. Incompatibility of modes that have not specifically been designed to work together (i.e., speed control autothrottle instability when used in combination with unaugmented, manual elevator control),
2. Variation in performance and stability depending on autopilot mode combinations and flight conditions,
3. Poor performance for off-design flight conditions because the control strategy is inappropriate (i.e., elevator flight path control at constant thrust near or below the minimum drag speed),
4. Adverse control coupling due to miscoordination of controller commands (i.e., speed deviation in response to path control maneuvers or vice versa, both in single-input/single-output and multi-input/multi-output designs),
5. Lack of design balance between competing performance objectives (i.e., low control activity in turbulence versus tight control tracking in windshear), and
6. Wrong choice of feedback sensors and non-optimum sensor signal processing to achieve the desired performance.
7. Lack of automatic roll and yaw trim and sideslip control to handle engine out or unstart.

Dissatisfaction with the performance of one mode has given rise to design of still more specialized modes. This has resulted in overly complex designs with high non-recurring and recurring costs, using more sensors, computers and software than strictly necessary, when compared to a better integrated design approach, see Figure 4.1-2. The single-input/single-output design approach makes it difficult to achieve multiple design objectives and certain operational characteristics, particularly if the interfacing designs are carried out by competing individuals or groups, without coordinated objectives and adequate arbitration. For example pitch autopilots have often been designed to achieve tight flight path control at the expense of the autothrottle performance, by making use of the superior elevator control authority. Such autopilots convert turbulence induced flight path deviation into speed deviation, contributing to poor autothrottle performance with

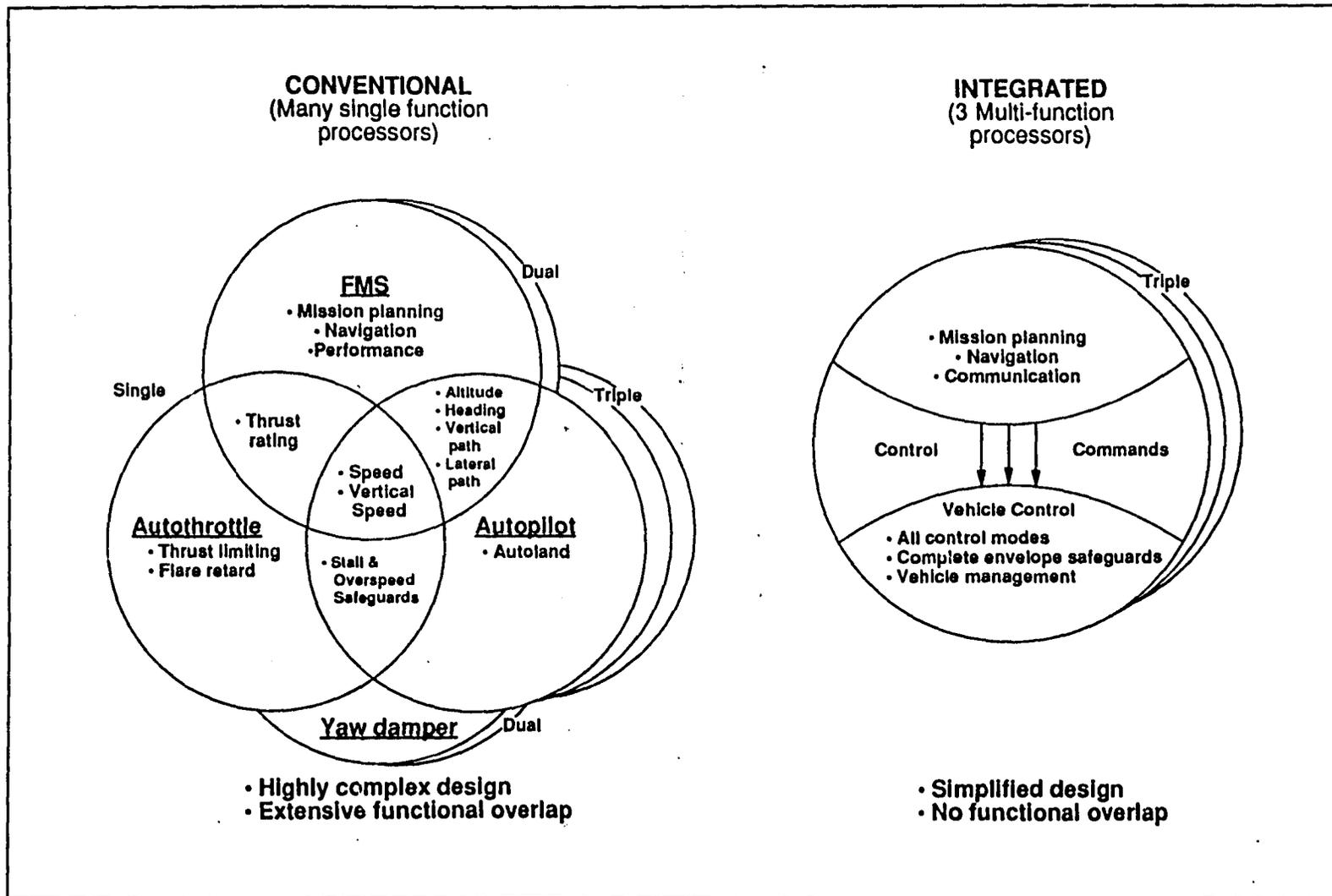


Figure 4.1-2 Automatic Flight Control Systems Architectures

excessive control activity. Another example is the traditionally designed roll autopilot and yaw damper. The main purpose of the yaw damper is to provide dutch-roll damping. However, depending on the design, the yaw damper may deteriorate passenger ride quality in turbulence. Turn coordination and decrab capability for landing are often added in a later design stage, making functional integration a much more difficult job. The lack of automatic directional trim makes it mandatory for the pilot to manually trim the rudder in case of an engine failure in order to maintain safe operation of the roll autopilot.

Multi-input/multi-output control design strategies can compensate for most of these control system performance and integration problems. The Total Energy Control System (TECS) concept is an example of a multi-input/multi-output control algorithm using thrust to control the total energy state of the aircraft and elevator to control energy distribution. In this concept the outerloop flight path and speed control modes (Figure 4.1-3a) are fully implemented in a generic way based on point mass kinematic requirements without regard to vehicle aerodynamic characteristics, and while innerloops are custom designed to provide the force and moment generating mechanism for execution of the outer-loop commands and providing stability augmentation (Figure 4.1-4). TECS was evaluated in extensive subsonic simulations, and was flight demonstrated on the NASA B737 during the NASA Terminal Configured Vehicle Program. An analogous generalized design approach for the lateral-directional control modes called Total Heading Control-System (THCS) has also been developed at Boeing (Figure 4.1-3b). Here, a roll attitude command is developed from the sum of heading error and sideslip error and a coordinated yaw rate command is developed from the difference of roll attitude error and heading error. Both TECS and THCS were used successfully on the Condor high-altitude-long-endurance aircraft.

Modern control theory analysis tools (LQR,  $H^\infty$ ,  $\mu$ -synthesis) are becoming well established to help conduct the design trade-offs that must be considered. However, many of the classical tools and an understanding of the underlying physics of the problem remain indispensable. For example the concept of separating innerloop feedbacks (force and moment generation) from outerloop feedbacks (point-mass trajectory guidance) based on frequency is very useful in designing the system hierarchy in a systematic way. Also gain scheduling based on known physical phenomena are preferable over empirical ones, often produced when applying modern methods without adequate physical insight. Plant uncertainties relate almost always to the aerodynamic force and moment generating

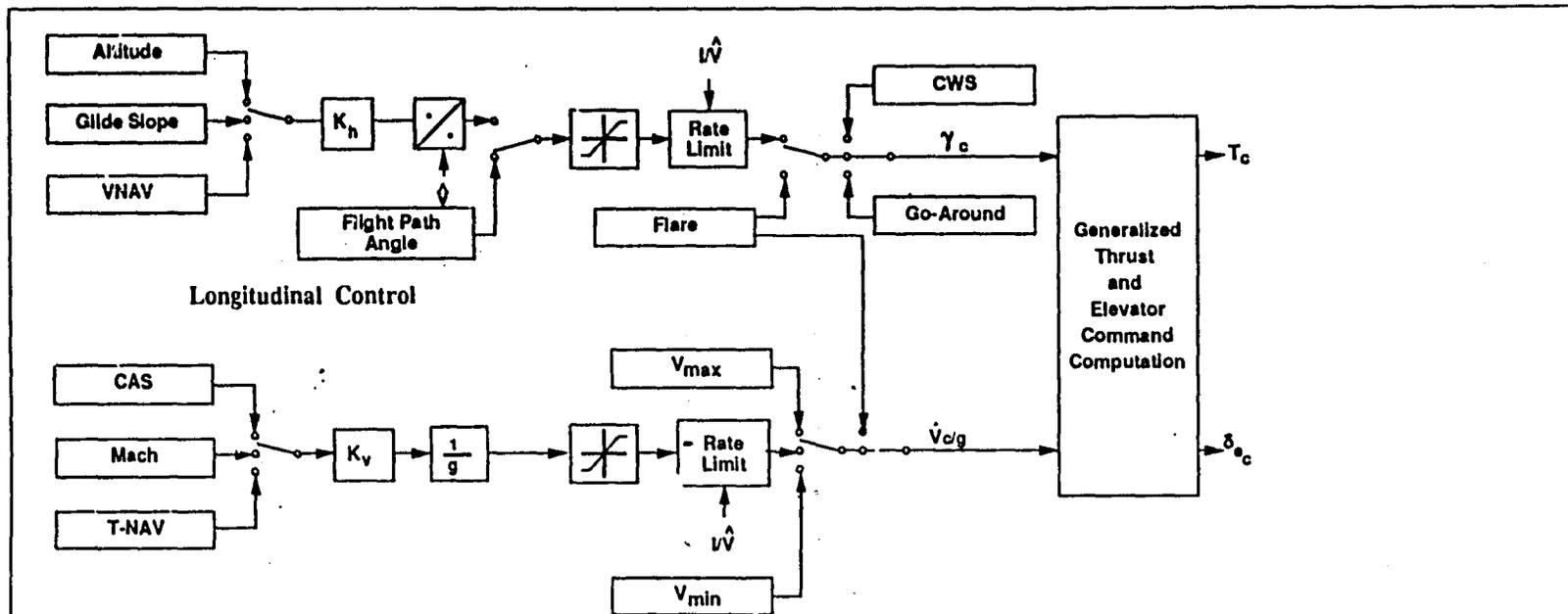


Figure 4.1-3a TECS Architecture And Mode Hierarchy

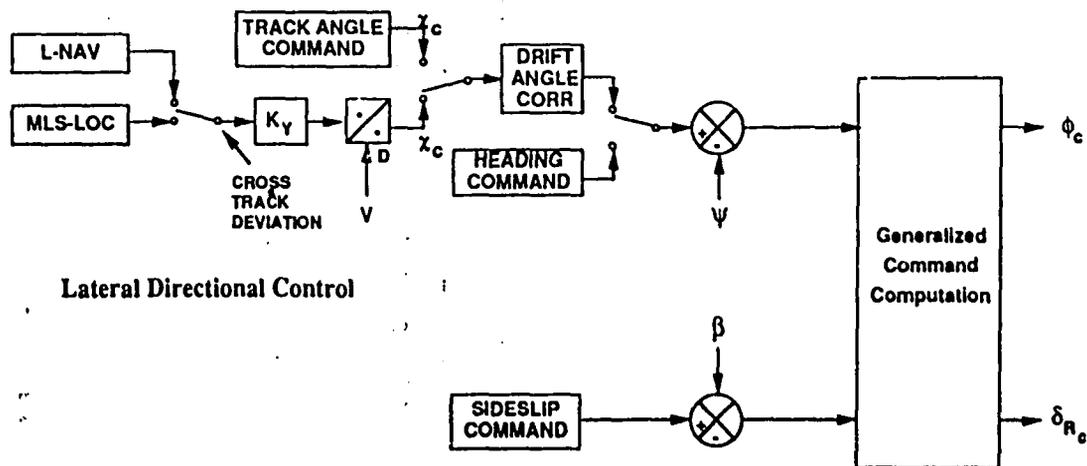


Figure 4.1-3b THCS Architecture And Mode Hierarchy



mechanism and having a well partitioned inner-loop/outer-loop design is invaluable in quickly identifying and correcting problems that can occur in flight test.

The HSCT will face a unique control problem during cruise, above 60,000 feet. For such altitudes existing barometric sensors may not have fine enough pressure resolution to avoid control limit cycling, when using an Altitude Hold mode. Barometric pressure sensors with a resolution of ~10 feet would be needed. Also the atmospheric effects of air density, temperature variation and wave action turbulence may cause unacceptable performance in terms of altitude tracking under current air traffic control separation standards, passenger comfort, and control activity. Alternate control strategies need to be considered, i.e., Mach-hold climbing cruise at constant power, and air data/inertial sensor blending will need to be employed to achieve satisfactory performance.

On the Condor aircraft, the control strategy was to maintain constant speed control bandwidth throughout the flight envelope and decrease the altitude and Total Energy (thrust) Control bandwidth with increasing altitude. As a result atmospheric disturbances were channeled almost entirely to altitude, while speed was maintained tightly. Altitude variations of several hundred feet were seen under unsteady atmospheric conditions.

Issues pertaining to automatic flight control include:

1. The selection of the proper set of design requirement for low altitude (balanced flight path and speed) control.
2. At HSCT cruise altitudes (up to 70,000 ft.) the static pressure is extremely low (65 psia). Pressure altitude sensors, with the resolution required for satisfactory closed loop altitude control, are not readily available (Section 4.2.7). The effect of high altitude atmospheric disturbances on altitude tracking (for ATC separation), passenger comfort and control activity may be unacceptable. Alternate control strategies may need to be considered.
3. The selection of an integrated functional design that avoids functional duplication and effectively accommodates the requirements.
4. The use of identical control strategy of automatic and augmented manual control, allowing use of common inner loops, flight envelope protection an engine unstart compensation functions.

**Technology Readiness:** Effective design approaches to develop a functionally integrated multi-input/multi-output automatic flight control system have been developed

and demonstrated. Suitable analysis tools are available, both classical and modern. The high altitude disturbance environment and appropriate control strategy to best deal with it needs to be determined.

#### 4.1.1.3 Active Flutter Suppression

**Requirements:**

- Configuration 1,5,6,11
- Flight Control 2

**Issue Description:** The Mach 2.4 composite airplane, being considered for HSCT at this time is stiffer and less subject to flutter than earlier metal configurations. Composite configurations that have been analyzed did not require flutter suppression within the  $V_D$  envelope, but for  $V_D < V < 1.2V_D$  flutter mode suppression was required, as shown in Figure 4.1-5. Potentially, a substantial savings in structural weight may be achieved by relying on an active flutter suppression system to fulfill flutter mode stability requirements, particularly if metal structures are used. Successful active flutter suppression system design depends on:

1. Accurate knowledge of inflight vehicle configuration in terms of mass distribution, and flight parameters consisting of vehicle altitude, Mach number and dynamic pressure.
2. Accurate modelling of vehicle structural dynamics, steady/unsteady aerodynamics and system components (sensors, actuators and processors) including computational lags and granularity.
3. Validation of vehicle structural dynamics through ground vibration testing.
4. Proven design and analyses methods, tools and procedures.
5. Adequate robustness of the flutter suppression system with respect to sensor inaccuracy and inaccurate in the knowledge of the vehicle state (mass distribution and stiffness characteristics).
6. Understanding of interactive effects of flutter suppression and primary controls when using dedicated flutter control surfaces or common control surfaces with the primary controls.
7. Failure tolerant design such that the airplane is flutter free following any single failure, allowing the airplane speed to be reduced to a restricted operational boundary.
8. Effective failure detection together with system redundancy, reconfiguration or automatic flight envelope limiting.

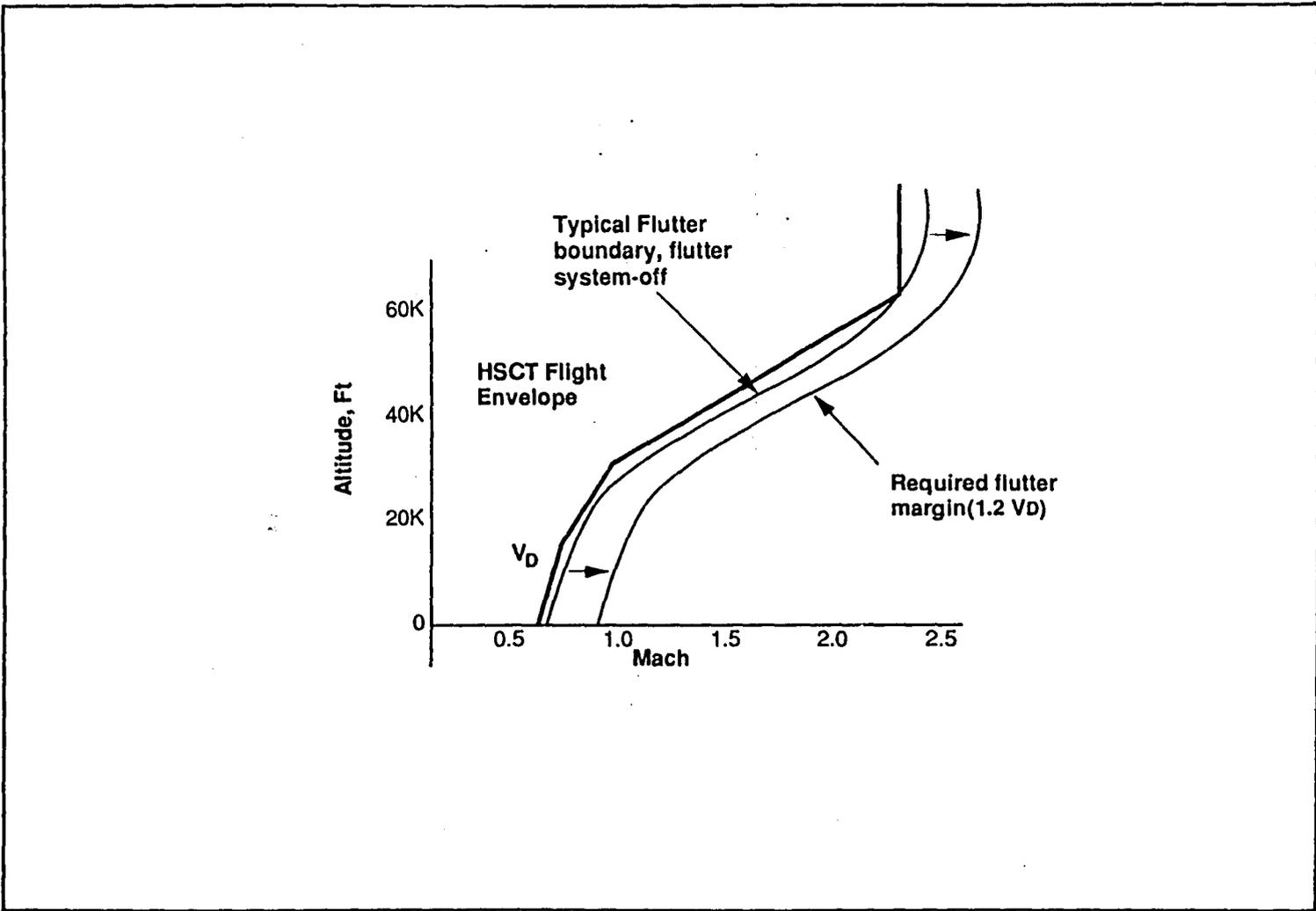


Figure 4.1-5 Typical Flutter Margins on Composite HSCT

9. Availability of reliable hardware (actuators, processors and sensors) to handle the duty cycle and environmental requirements of the flutter control system.

**Technology Readiness:** Currently, the design methodology for active flutter suppression systems to augment structural damping is not mature. No commercial airplane has yet been certified that depends on such a system. To be able to commit to a flight critical flutter suppression system on the HSCT, extensive validation efforts are required. These efforts should include:

1. Repeated, successful, first time prediction of open loop flutter modes on a flutter wind tunnel model, over a range of dynamic pressures and Mach numbers for different configurations.
2. Consistently successful first attempt stabilization of predicted flutter modes by an active flutter suppression design as proven through testing.
3. Demonstration of the attainment of satisfactory design robustness with respect to the misprediction of open loop flutter characteristics, sensor and vehicle state.
4. Successful inflight demonstration of an active flutter suppression functional design on a representative free flying model or research aircraft.
5. Satisfactory demonstration through testing that flutter suppression system control surface servos, actuators, and hardware will perform reliably for extended periods.

#### 4.1.1.4 Gust and Maneuver Wing Load Alleviation

**Requirements:**

- Mission 2
- Configuration 1
- Flight Control 4,10

**Issue Description:** Currently the wing structure is dimensioned by loads resulting from specified maneuvers and discrete gusts. Wing root bending moments can be reduced by shifting lift inboard using inboard wing control surfaces in response to gust or maneuver demands. The issue is whether structural weight can be reduced by incorporating a wing load alleviation system that reduces maneuvering and/or gust loads.

Successful design of load alleviation systems depends on:

1. Modification of CFR (certification) rules to give credit for wing load alleviation.
2. The amount of structural weight reduction that can be achieved.

2. The successful realization of sensor performance required for gust anticipation both subsonic and supersonic flight.
3. The acceptability of side effects on passenger ride quality, control activity, performance and added maintenance.
4. Formulation of accurate models of structural, aeroelastic and aeroservoelastic effects for evaluation of system performance, handling and ride qualities.

**Technology Readiness:** Some wing load alleviation control is inherently achieved through the full -time SAS. For turbulence, flightworthy LADAR sensors are planned for demonstration in 1993 that are sufficient for measuring airspeed, sideslip and angle of attack from 5 to 10 meters from the body. LADARs that could provide gust information from 200 to 500 meters ahead of the airplane would be required to allow the gust load alleviation system a one second response time.

#### 4.1.1.5 Active Flight Envelope Protection

**Requirements:**

- Mission 3
- Configuration 2,5,6,
- Flight Control 1,5,6
- Propulsion Control 2,3

**Issue Description:** The issue of active flight envelope protection for automatic and pilot-in-the-loop controls for advanced airplane configurations using FBW/FBL technology needs to be addressed. In the past, partial flight envelope protection has been provided through separate systems such as:

1. Oral stall warning
2. Stick shakers
3. Stick pushers
4. Throttle control override based on angle of attack
5. Flap placard,  $V_{MO}/M_{MO}$  warning, etc.

With the introduction of relaxed static stability and FBW/FBL control, some of the traditional warning systems such as stick shakers and stick pushers may not be a desirable design approach. There is a need to develop more general flight envelope protection concepts and integrate their functions into the basic pilot-in-the-loop and autopilot control functions. Functions to be researched include:

1. Angle of attack limiting
2. Minimum speed limiting
3. Maximum speed limiting

4. Bank angle limiting
5. Normal acceleration limiting
6. Thrust command limiting.

Issues related to implementing these functions include:

1. Determining the design and performance requirements and objectives of the flight envelope parameter limiting functions (i.e., hard versus soft limiting, control bandwidth, damping, control priority, pilot override capability by control force or by other actions.)
2. Integration of envelope protection functions with inner loop SAS/CAS and the autoflight control modes.

**Technology Readiness:** First generation subsonic flight envelope limiting are functions are being developed for present day FBW transport aircraft (Boeing 777, and Airbus 340). Extension of system requirements to address the specific problems related to the supersonic, control configured HSCT must be addressed in analyses, simulation research and flight demonstrations.

#### 4.1.1.6 Active CG Management

**Requirements:**

- Mission 1
- Configuration 6
- Flight Control 7,10

**Issue Description:** The HSCT will require accurate knowledge of total weight, weight distribution and c.g. to determine the proper setting of the stabilizer for takeoff, and to schedule the flight control system parameters for vehicle stabilization. Flight control systems must also manage in-flight fuel transfers to optimize the center of gravity for minimum drag and to compensate for the aerodynamic center of pressure shift during transonic flight. Technology issues include:

1. Accuracy requirements for weight, weight distribution and c.g. location to satisfy general control system performance requirements.
2. Use of nose and main gear sensed pressure/extension to compute takeoff trim settings.
3. Integration of c.g. control with the primary flight control system to provide optimal flight configuration in each flight phase.
4. Technology for achieving accurate reliable economical fuel gaging systems capable of operation in the HSCT environment.

5. Flight critical implications of fuel and c.g. management in various regions of the HSCT flight envelope.
6. Implications of additional complexity associated with active control systems on airplane reliability and operating costs.

**Technology Readiness:** The Concorde is certified with an active fuel management system. The A330/340 and MD-11 airplanes have tail tanks used to keep the center of gravity as far aft as possible. While this technology does exist, the task is to certify a particular flight critical fuel management system.

#### 4.1.2 Propulsion Control Laws/Algorithms

##### 4.1.2.1 Propulsion System Automation

**Requirements:**

- Mission 1,3,4
- Configuration 2,14
- Flight Deck 4,3
- Flight Control 1,3
- Propulsion Control 1,2,3,4,5,6,7
- Certification 3

**Issue Description:** The HSCT will operate with a two man crew. The propulsion system, its operating modes, and operating constraints are more complex than in current commercial systems. Thus successful operation of the system will require a high degree of automation. Some indication of the complexity of the problem is provided by a preliminary propulsion mode diagram, Figure 4.1-6. The object of automation will be to limit the pilots' mandatory tasks to requesting engine start, establishing desired thrust level, and requesting engine stop. However in order to take into account emergencies and unforeseen circumstances provision must be made to allow the flight crew to override the automatic systems. Automatic condition monitoring, see paragraph 4.3.2.3, will contribute to this process. Developing and proving the automation concepts and the related crew interface must be done prior to commitment to a production aircraft. Some study of the applicability of neuron logic and fuzzy logic to facilitate pattern recognition and decision making required in this application may be appropriate.

**Technology Readiness:** The necessary tools to deterministically develop an automated system are available. The implications in terms of computer resources to achieve the automation are not known. The acceptability of high levels of automation, and related FMEA issues in the commercial environment are not well understood.

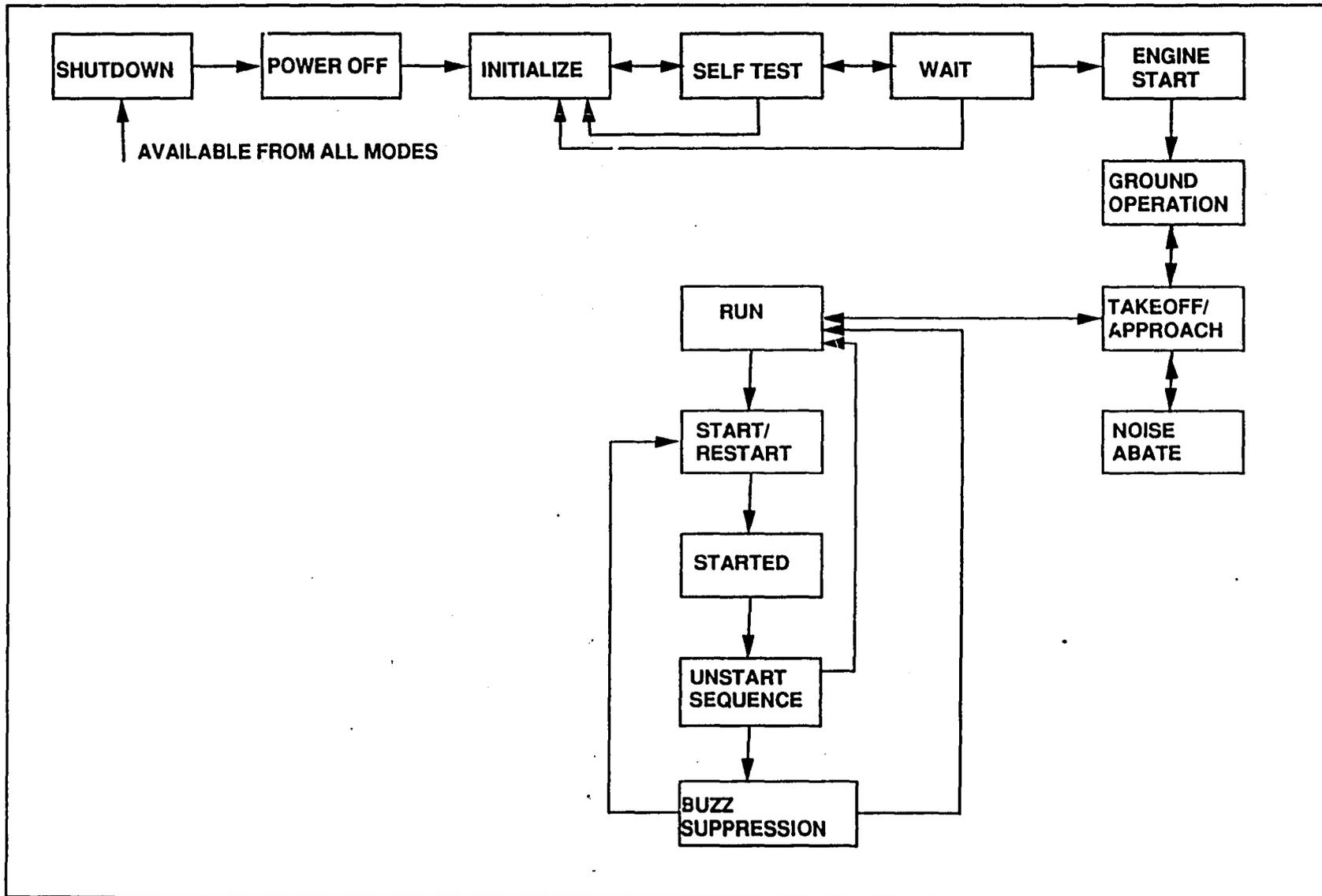


Figure 4.1-6 Mode Transitions

#### 4.1.2.2 Engine/Inlet Control

**Requirements:**

- Mission 1
- Flight Control 8,3
- Propulsion 2,3,6
- System Engineering 1,2,3

**Issue Description:** The SST inlet control system treated engine airflow variations caused either by system noise or thrust commands as disturbances. No attempt was made to adjust compressor stability margin as a function of inlet distortion. Stall recovery was treated as a fixed sequence of events with minimal communication between engine and inlet control. Digital technology and data bus communication will permit integration of HSCT inlet and engine control laws to any desired level. The primary features which may be incorporated with such integration are:

1. Command feed forwards from engine to inlet
2. Constant stall margin over the propulsion system operating envelope
3. Automatic stall and unstart recovery incorporating interlocks to prevent component damage and/or repeated stalls
4. Automatic buzz suppression at minimum achievable thrust.

The benefits of this integration include improved propulsion system performance, reduced unstart probability and improved engine life.

**Technology Readiness:** All concepts have been evaluated to one degree or another in tactical airplane research studies using external compression inlets. Flight demonstration of them in the commercial context using a mixed compression inlet is required before their introduction into commercial service. Attention must be paid to the development methodology and to the allocation of responsibilities among the various organizations involved in developing the integrated system.

#### 4.1.2.3 Inlet Sensor Fault Accommodation

**Requirements:**

- Flight Control 8
- Propulsion control 1,2,3,6

**Issue Description:** Inlet variable geometry must be adjusted to accommodate flow field properties in front of the inlet and airflow extracted from the inlet. Generally speaking, the available air data has sufficient information available to define the flow field in front of the inlet and the engine control computes engine airflow. With this information and position control of the inlet servos it should be possible to control the inlet geometry without using dedicated inlet aerodynamic sensors, if the accuracy and

repeatability of airframe and engine data are adequate. In external compression inlets, the technology would permit elimination of expensive high accuracy pressure transducers and their associated plumbing. In a mixed compression inlet, the accuracy requirements are such that the concept would be used as a model based backup to the primary control sensors, as shown in Figure 4.1-7. This would reduce the total number of sensors in a redundant high reliability application, substantially reduce the associated plumbing and electronics cost and complexity, and improve the overall fault tolerance of the system. **Technology Readiness:** Proof of concept in the flight environment is required. The primary issue is accuracy and repeatability of the airframe and engine data used. Of particular concern are variances caused by unit to unit differences as well as those caused by wear of a given unit (ref. 12).

#### 4.1.3 Integrated Flight / Propulsion Control

##### 4.1.3.1 Flight / Propulsion Control Integration

**Requirements:**

- Flight Control 1,3,8
- Propulsion Control 1,2,3,7

**Issue Description:** Flight Propulsion Control Integration on the HSCT raises a number of issues. One is the interchange between and use of flight critical data by conventionally isolated systems, as shown in Figure 4.1-8. Some examples of data interchange are:

1. The use of air data, and flight control command and feedback data to provide dissimilar redundancy and feedforward information within the propulsion control system, largely with reference to inlet operation.
2. The use by the flight control system of propulsion system model data such as actual thrust and min and max thrust limits.

The dynamic response and accuracy requirements for each piece of interchanged data must be established. Due to the size, structural flexibility, and speed of the aircraft and the relatively large number of interchanged variables contemplated this is a significant task. The closed-loop, automatic use of the propulsion system as a force generator both symmetrically and asymmetrically within the flight control laws requires precise definition of the thrust command interface between propulsion and flight control. A proposed configuration for the propulsion/flight control system interface (Figure 4.1-9) raises a number of issues:

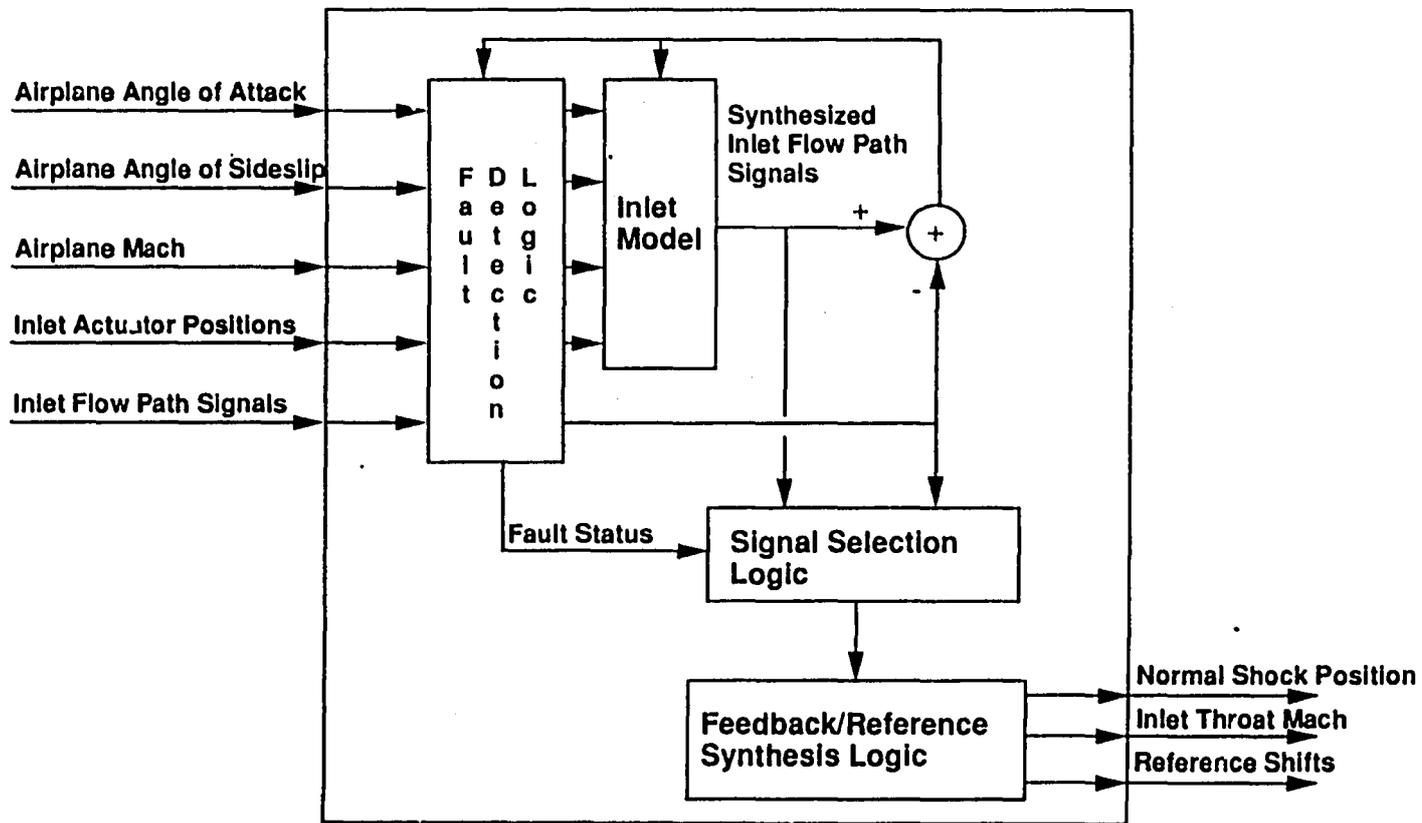


Figure 4.1-7 Inlet Fault Accommodation

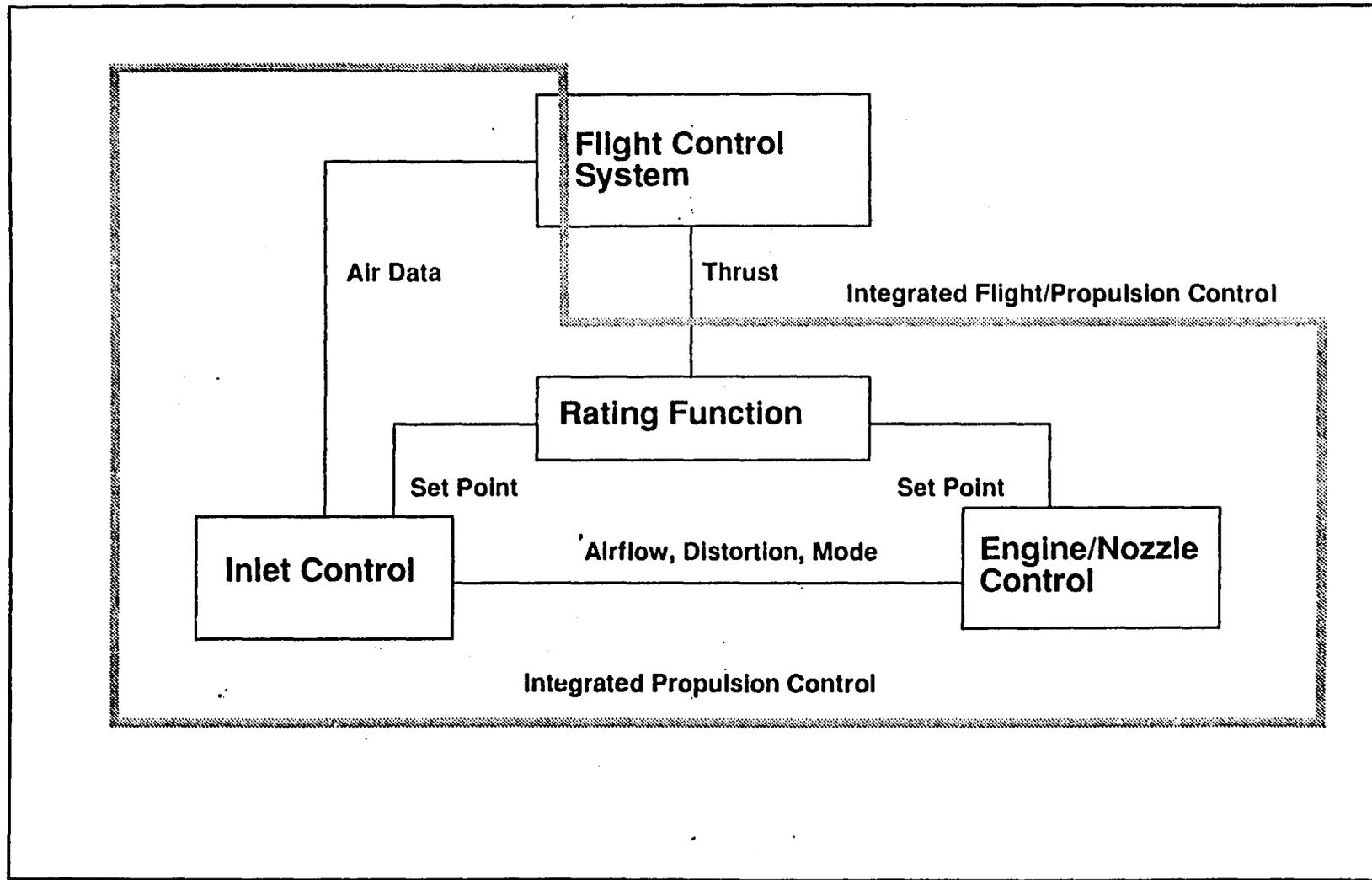


Figure 4.1-8 Integrated Flight and Control

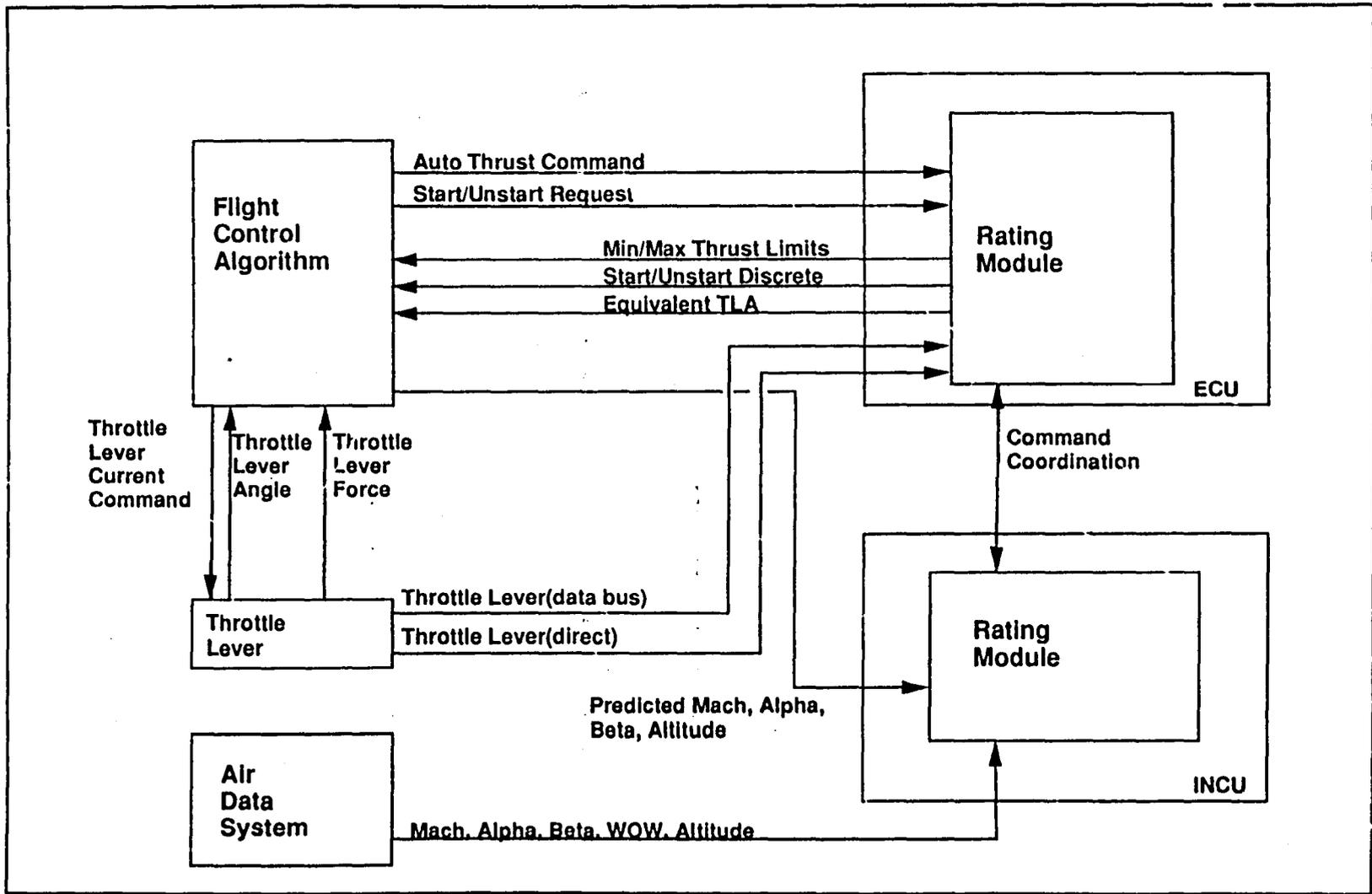


Figure 4.1-9 Propulsion-Flight Control Interface

1. What should the interface parameter be? Power lever angle, total thrust, net thrust, installed thrust or something less obvious.
2. What should throttle lever characteristics be in terms of linearity and sensitivity?
3. Should the automatic flight control system command the engines directly via the bus or indirectly via the throttles?
3. What discretized and interlocks are required to assure ultimate pilot control authority over the engines?
4. What is the propulsion system performance in terms of dynamic response and accuracy required to satisfy the flight control design?

Characteristics of the airframe/propulsion system operating at high altitude and the associated control problems raise a number of questions:

1. What is the combined propulsion/airframe/control system sensitivity to disturbances?
2. What should control priorities be when limit conditions are reached?

**Technology Readiness:** The concepts and tools to develop the control laws exist as a result of various programs including the USAF DMICS and NASA Dryden COOP and HIDEDEC programs. The concepts must however be implemented and tested in a realistic environment prior to their use on a commercial vehicle.

#### 4.1.3.2 Unstart Avoidance/Accommodation

**Requirements:**

- Mission 1,2
- Configuration 2
- Flight Control 6
- Propulsion Control 2,3

**Issue Description:** The HSCT will incorporate a mixed compression inlet which while providing high performance levels, Figure 4.1-10, can produce abrupt thrust minus drag changes which have the potential for causing dramatic aircraft motions. An example of the effect of a 2 second unstart/restart cycle on the open loop response of a typical HSCT aircraft is shown in Figure 4.1-10. Although these data indicate an ability to simulate the effect of an inlet unstart the unstart forces and moments used are based on limited small scale wind tunnel test results. The tolerance on these data precludes drawing other than qualitative results from the simulation.

Inlet unstart occurs when the terminal shock which is aft of the inlet throat in normal (started) operation is rapidly expelled. This creates a large bow shock (high drag) and

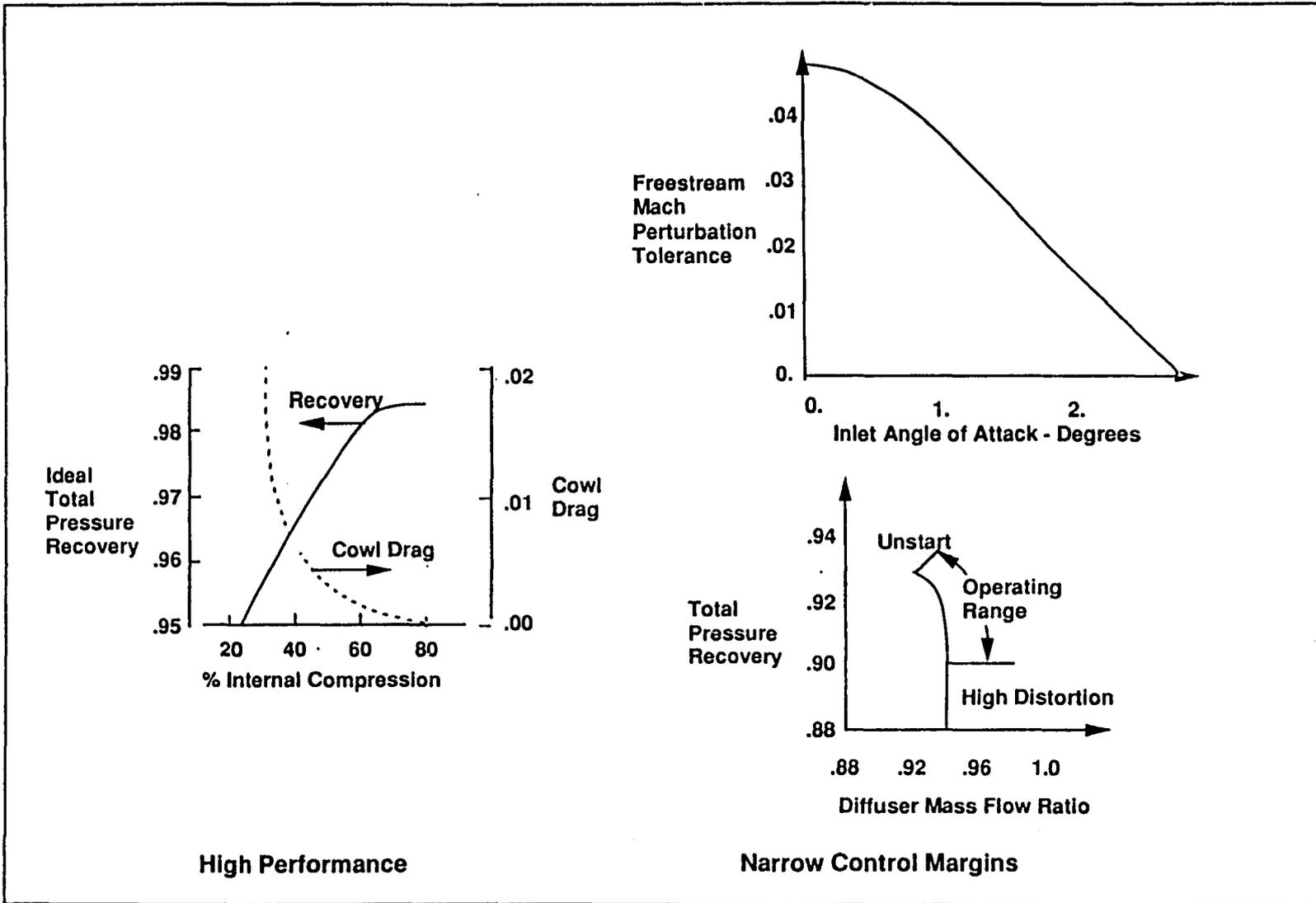


Figure 4.1-10 Mixed Compression Inlet Properties

dramatically reduces recovery (low thrust). The unstart occurs either due to choking of the inlet throat or motion of the terminal shock forward of the throat. Throat choking comes about due either to reductions in freestream Mach number or excessive inlet angle of attack. Figure 4.1-11 shows the resulting unstart boundary for a typical mixed compression inlet. Motion of the shock forward of the inlet throat occurs due to reduction in engine airflow as shown in the inlet flow versus recovery curve of Figure 4.1-11. Optimum inlet performance is achieved at operating conditions very close to unstart, typically .05 freestream Mach margin and a few percent engine airflow margin. Significant effort is required to devise hardware and control laws which will reduce the probability of inlet unstart given these margins. Automatic compensation for unstart is also a challenge because the countervailing force must be as large and applied almost as rapidly as the unstart occurs. False triggering of the unstart compensation must be guarded against since it will be as dramatic as the unstart itself.

Given a definition of the disturbance spectra, known actuator performance, known inlet aerodynamic performance and known control system reliability a system satisfying the unstart probability criteria can be designed (ref. 13). Unfortunately such a system may not satisfy performance requirements because the margins required to satisfy the unstart criteria may be excessive. In order to achieve high performance with low unstart probability improvements are required in various areas including:

1. Definition of the free stream disturbance environment.
2. Real time prediction of free stream disturbances (see paragraphs 4.2.2.4, 4.1.3.1).
3. Normal shock position measurement capability ( see paragraph 4.2.2.5).
4. Analytical estimates of inlet characteristics and performance.
5. Development of inlet control laws which take maximum advantage of anticipatory information from the flight and engine control systems.

Accommodation of inlet unstarts requires:

1. Improved estimates via wind tunnel or analysis of the unstart generated forces and moments on the aircraft.
2. Definition of the inlet unstart effect on hydraulics/electric power and vehicle dynamics.
3. Better understanding of the interaction between the behavior of the inlet during an unstart/restart cycle and the engine compressor. In engines with significant bypass inlet interaction with the nozzles may also be an issue.

### Typical HSCT without Control Augmentation

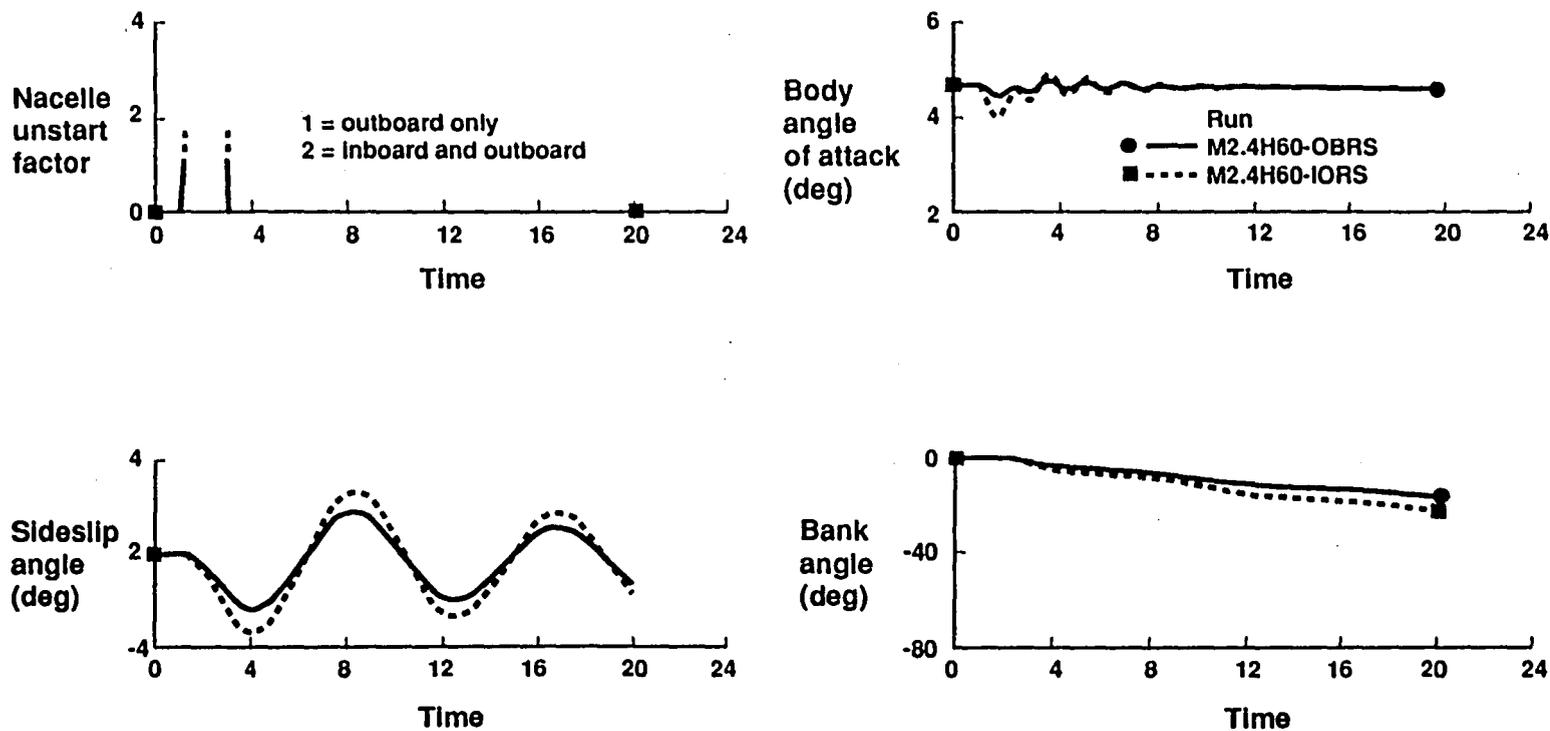


Figure 4.1-11 2-Second Unstart Response

62E1-01  
M.F. 19

The latter is particularly important because the only available data base is from the SR-71/J58. The information available suggests that the J58 was very robust and tolerant of the high distortion and dramatic pressure variations experienced during unstart. An HSCT engine may not be as tolerant which could lead to difficulties in accommodating or recovering from a surge or unstart event.

**Technology Readiness:** The fundamental phenomena of unstart is understood. However the ability to analytically predict the detailed aerodynamics involved is lacking. CFD techniques are just now reaching the point where they may begin to augment wind tunnel tests as a means of establishing inlet performance. Comparison of wind tunnel tests with CFD analyses is required to improve and validate static and dynamic CFD codes so that they can be used reliably in future commercial programs to establish both inlet unstart behavior and the magnitude of unstart disturbances on the airframe configuration involved. Development of accurate high response direct measuring shock sensors and predictive air data systems is required to permit reduction of operating margins and thus improve performance. A flight demonstration program of an engine inlet combination incorporating an integrated control system is required to demonstrate system reliability and performance for the commercial application.

#### 4.1.3.3 Optimum Trajectory Generation and Tracking

**Requirements:**

- Mission 2,3
- Flight Deck 3,5,6,7

**Issue Description:** Proposed military/strategic flight management systems (23) employ automatic trajectory management to provide optimal performance and flight path generation for all phases of flight (take-off, climb, cruise, descent, and landing), and to accommodate threats encountered during portions of the mission. It is possible that trajectory generation techniques can be used in commercial IFR routes to cope with weather and terminal traffic conditions. Developmental issues include:

1. Pilot interface with the on-line and off-line mission generation system.
2. Energy management computations and automatic configuration control to minimize fuel consumption.
3. Timing of thrust cut-back, throttle closure, and speed commands, based on prevailing wind to meet a desired community noise footprint on takeoff and landing.

4. Flight path and gear/flap deployment command computation to meet a target in a desired aircraft state, in spite of misprediction of wind profiles, aircraft weight and performance characteristics.
5. Precision navigation for departure, en route and landing guidance using satellite (GPS) resources in conjunction with ground based (MLS/ILS) or autonomous (INS) resources.

**Technology Readiness:** Optimizing mathematics is well understood, but the computational requirements of optimal control and expert systems are relatively high for real-time application in flight systems. Applicability of expert systems and neural network algorithms should be evaluated and compared with other algorithmic solutions to flight planning problems. The utility of the trajectory management technology which constantly changes altitude in controlled airspace requires evaluation.

#### 4.1.3.4 Performance Seeking Control

**Requirements:**

- Flight Control 7
- Propulsion Control 6

**Issue Description:** In a vehicle such as HSCT designed for optimum operation at a specific operating condition with large numbers of controlled variables both in the propulsion and flight control system there may be, for off design conditions, optimum adjustments of the control variables that are not established by the normal functioning of individual subsystems. Figure 4.1-12 shows the interactions involved for the baseline propulsion system. The problem becomes more complex if other cycles under consideration such as the tandem fan or FLADE are considered. An integrated performance seeking control mode may be beneficial in finding the optimum operating point for these off design conditions.

A number of issues must be resolved prior to application of such a scheme in a commercial system:

1. What is the potential benefit of such a scheme relative to a system which operates along an off line generated, nominally optimal, fixed schedule.
2. What is the PSC performance improvement available in an HSCT designed to optimize cruise performance?
3. How is the benefit of such a system factored into performance guarantees and fuel reserve requirements?
4. Is such a system certifiable?

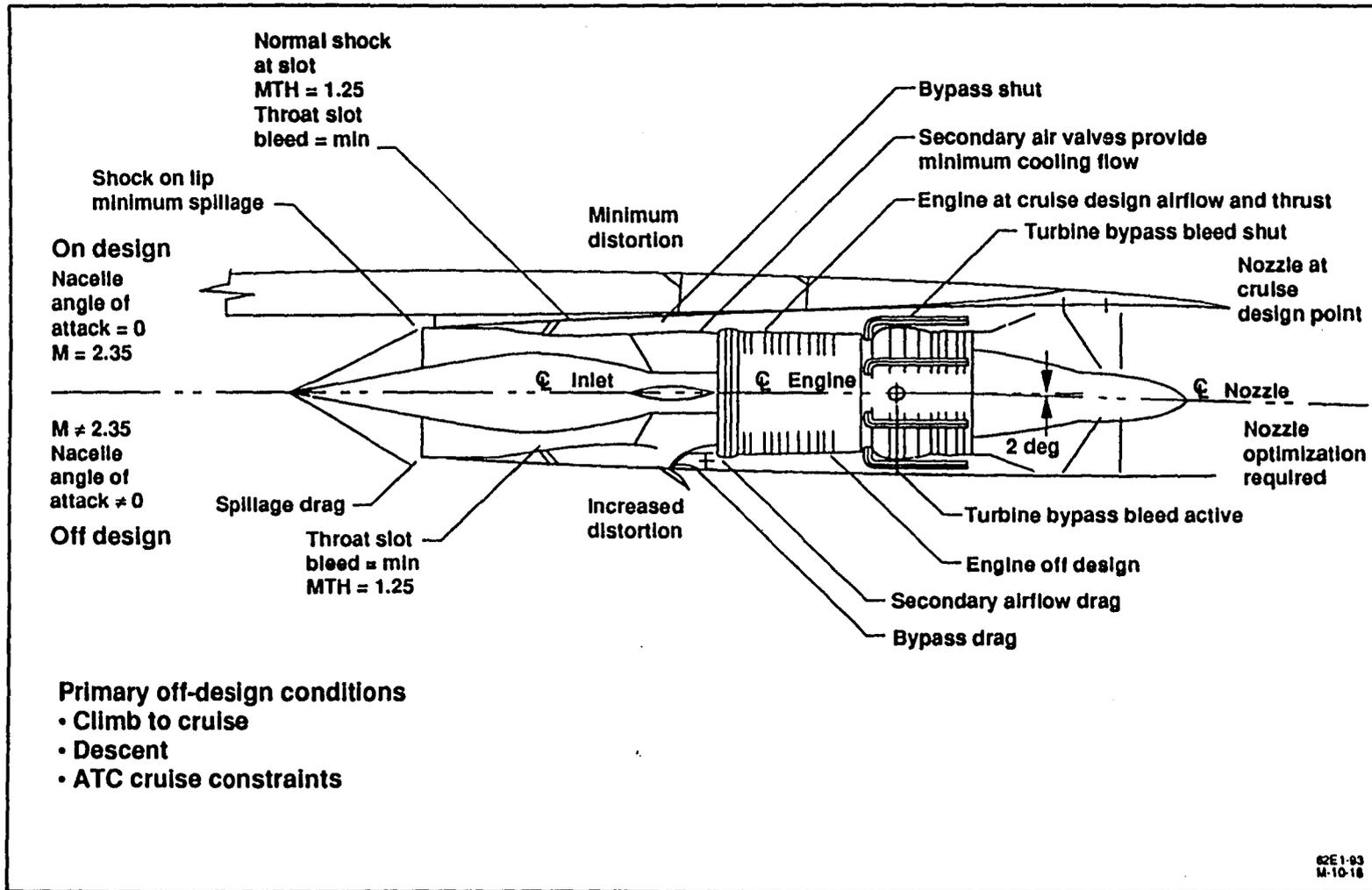


Figure 4.1-12 Propulsion System Performance Interactions

5. Should PSC be a pilot selected operating mode or be transparent to the pilot?
6. What is the relation of the PSC system model to those used for fault accommodation?

**Technology Readiness:** The basic technology has been developed for military aircraft on the NASA HIDEDEC PSC program. It requires evaluation on a typical HSCT configuration to determine if it provides significant benefits for the HSCT configuration.

#### 4.1.4 Control Disturbance Environment

**Requirements:**

- Flight Control 4
- Propulsion 2

**Issue Description:** During and for some time subsequent to the SST program, efforts were made to define the high altitude disturbance environment which might be encountered by SST's in commercial operation. This environment is critical to design of the flight control system from a ride quality and structural load prediction standpoint and to the propulsion control system in defining the design requirements for achieving a specified inlet unstart probability. Barry (ref. 13) established an analytical relationship between the power spectral density of Mach number variation at altitude, the inlet control system bandwidth, and achievable inlet recovery for a given unstart probability. Both Barry and Rachovitsky, who performed similar work (ref. 14), concluded that the serious weakness in their analysis was uncertainty in the power spectral density of the atmospheric variations. Concorde, as operations were expanded into tropical areas, experienced thermal variations which caused revisions to both the inlet and flight control systems. Concorde's flight frequency and route distribution, although probably larger than any other supersonic cruise airplane, do not provide an adequate statistical database for design both due to lack of coverage and the fact that most data are anecdotal since the in-service aircraft do not carry a research oriented data system. The GRAMMS (ref. 15) atmosphere which has been developed more recently for NASP and other applications addresses a very large volume, sea level to 700 km globally, but does not address the short period variations particularly thermal ones which are critical to the inlet behavior.

**Technology Readiness:** The existing atmospheric models are not sufficiently reliable in predicting both the statistical and short period variations in freestream temperature along the anticipated flight paths of HSCTs with the degree of confidence necessary to permit design of a maximum performance HSCT.

## 4.2 Hardware Technology

### 4.2.1 Actuation Technology

#### **Requirements:**

- Mission 1,4
- Configuration 5,6,10,11,14
- Flight Control 2,6,10
- Propulsion Control 1,2,3,6
- Maintenance 1,2
- Certification 1,2,4

**Issue Description:** As shown in Figure 4.2-1, certain actuation technology improvements may be necessary for an economically successful HSCT. The main issues include:

1. Actuator loop closure (local/remote),
2. Redundancy architecture,
3. Material/fluid technology,
4. The total airplane actuator count will be higher than current standards,
5. Which technology improvements are suitable for incorporation in a commercial HSCT?

The following are examples of potential technology improvements that determine the best answers for each issue:

1. High temperature hydraulic fluid and long life seal designs to satisfy thermal environment, and maintainability requirements.
2. Composite actuators for weight reduction.
3. Thin profile (hinge line) actuation to minimize aerodynamic drag (lockup failures must be addressed).
4. High pressure hydraulics to reduce actuator weight and size, and enhance control surface stiffness.
5. Engine mounted actuation using hydraulic fluid rather than fuel for improved reliability.
6. High frequency response actuators for wing flutter control.
7. Electric powered actuation in the form of EMA or EHA, if high temperature electronics required to support it become available.

In general, high reliability, low maintenance and relatively low acquisition cost will be a crucial element in actuation system selection.

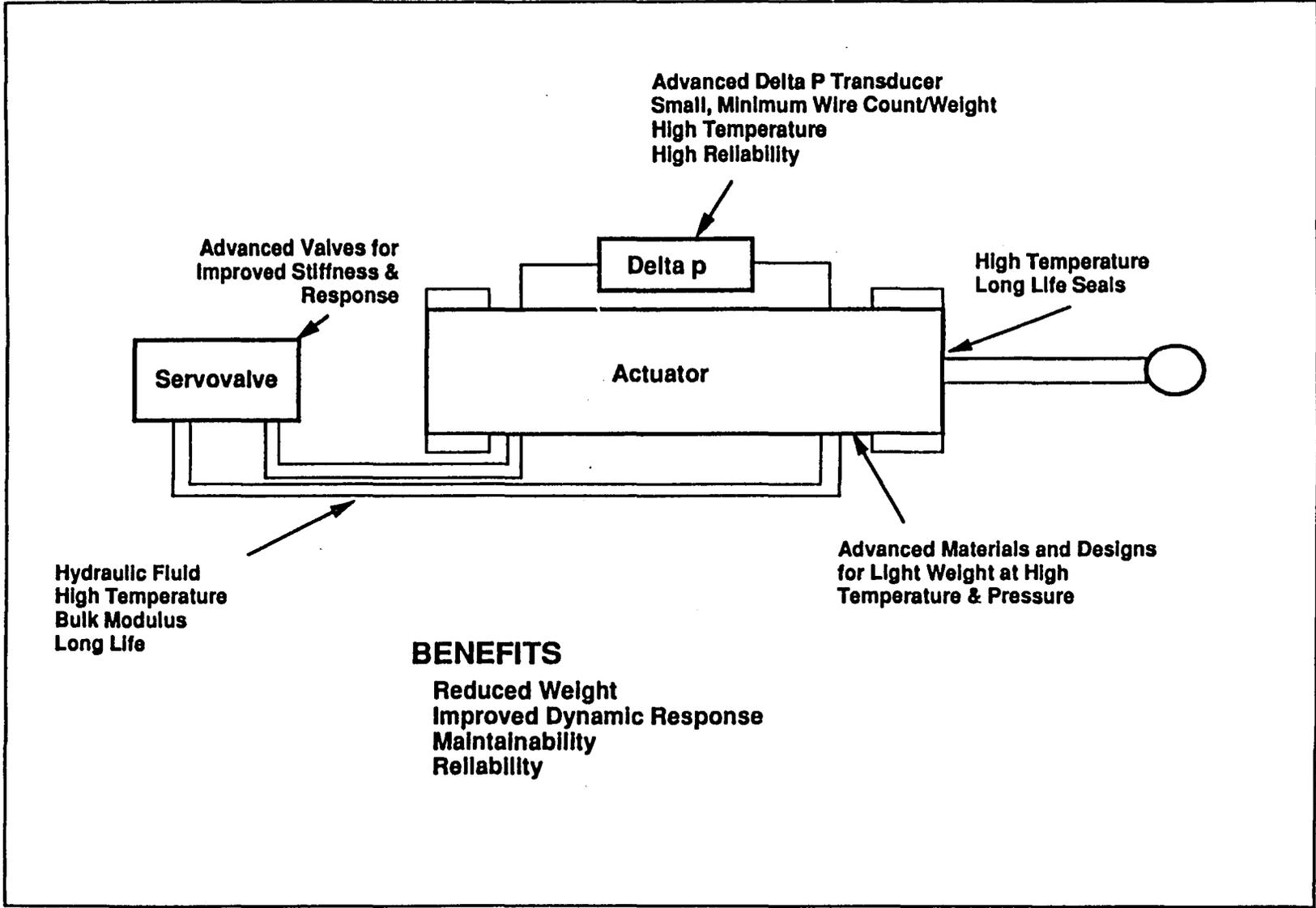


Figure A2-1 Actuation Technology

**Technology Readiness:** Some military technology and actuator supplier research and development have been applied to these actuation issues. Extensive effort is required to bring this technology to a level of readiness to meet HSCT requirements.

#### 4.2.2 Sensor Technology

##### 4.2.2.1 Fiberoptic Sensor Set

**Requirements:**

- Configuration 10
- Flight Control 4
- Propulsion Control 1
- Certification 1

**Issue Description:** Conventional electromechanical and solid state transducers (pressure, temperature, rotational speed, displacement) suffer a number of disadvantages: Most require some level of development to operate at high temperature, they require active on board electronics to reduce dedicated wire count, and their output is to one degree or another HIRF EMI sensitive. Fiberoptic transducers are attractive because they are in some cases amenable to both high temperature operation and passive multiplexing. They are also inherently EMI/HIRF immune. The issues for HSCT are: 1) whether fiberoptic sensors will achieve technology readiness in time to meet HSCT production dates, and 2) whether the use of fiberoptic sensors is cost effective for commercial airplanes, where the HIRF environment may not be as severe as for military airplanes.

**Technology Readiness:** Equipment is in laboratory testing. FOCSI program will provide open loop demonstration of most necessary sensor operation. Also see paragraphs 4.2.2.3, 4.2.2.4, and 4.2.2.5 for sensors not specifically addressed by FOCSI.

##### 4.2.2.2 Vision Enhancement Technology

**Requirements:**

- Configuration 2,3
- Flight Deck 1

**Issue Description:** The flight deck will feature advanced displays, possibly including synthetic vision and avionics systems interfaces designed to enhance the pilot's situation awareness, both in the air and on the ground. This is required to compensate for the fact that:

1. cockpit windows will probably not provide a good view, forward and down,
2. the extreme length will make it difficult to see obstructions near the wings and landing gear, and

3. the position of the cockpit relative to the nose gear will add another dimension to steering on the ground.

There are two differing approaches being considered for HSCT application: 1) Computer Generated Imagery (CGI) which reconstructs a scene from maps and data on board the airplane, and 2) Sensor Imaging which senses and displays images of the obstacles in its field of view. A third technique involves a combination or fusion of CGI and sensor images. Synthetic vision technology must address many issues, including:

1. Determination of design requirements for the synthetic vision perspective generation technology, i.e., field of view, pathway, symbol generation for airplanes, color, transport delay, etc.
2. System performance in weather or other atmospheric conditions, and the effects of sensor failures.
3. Determination of the sensor and imagery combination that best meets the synthetic vision system requirements.
4. Determination of the minimum synthetic vision required for safe flight and landing.

**Technology Readiness:** CGI and Sensor Imaging have been demonstrated separately, usually on large (relative to avionics) laboratory computers. A demonstration of full image fusion, where a sensor image and a CGI are processed and combined into one image, is being undertaken at this time. No vision enhancement system is ready to meet HSCT requirements at the time of this report.

#### 4.2.2.3 High Altitude Air Data

**Requirements:**

- Mission 1
- Flight Control 4,6

**Issue Description:** At HSCT cruise altitude (up to 70,000 ft.) the static pressure is extremely low. As a result, pressure altitude resolution degrades to about 200 feet per least significant bit using currently available sensors. There is significant evidence from U-2, SR-71 and Condor programs that significant atmospheric disturbances do occur at high altitude that can pose a problem for aircraft control, structural loading, passenger comfort and safety. As a result the performance of a conventional altitude-hold control may not be satisfactory in terms of passenger comfort, ATC altitude tracking requirements and control activity. Furthermore the aerodynamic performance requirements of the HSCT may require the use of flush mounted air data probes that may further degrade resolution and performance in the high altitude flight envelope. The

choice of an air data configuration depends both on the performance characteristics of available air data concepts and the requirements of the control law. The issues to be resolved are:

1. Alternatives to tight altitude control during cruise that would be acceptable to air traffic control authorities.
2. High altitude air data requirements to meet airspeed, and flight path stabilization requirements for various control concepts.
3. The blend of air and inertial sensor data that will yield optimal vehicle performance and passenger comfort.
4. The need for and the specific requirements of sensors that provide gust anticipation to prevent engine unstart.

**Technology Readiness:** Proof of concept optical and flush air data systems have been or are being demonstrated by DARPA, NASA Dryden, NASA Langley, and at least two commercial vendors (ref. 16). These systems operate between 45,000 and 80,000 feet. Boeing High Tech Center is currently developing proof of concept for a combined optical air data sensor/Ladar altimeter, but even these systems may not meet the ride, safety and altitude tracking requirements of passenger flight.

#### 4.2.2.4 Multifunction Sensor Technology

**Requirements:**

- Mission 1,4
- Configuration 3
- Flight Deck 1
- Flight Control 4
- Propulsion Control 1,2,3,6,7

**Issue Description:** The HSCT has identified requirements for sensors to improve detection of clear air turbulence, windshear/microbursts, obstacle/terrain on approach and taxiway/runway boundaries under poor visibility conditions. High speed/high altitude operations have also indicated a need for improved sensing of altitude and airspeed and prediction of thermal and velocity variations which may cause inlet unstart or autopilot upset.

As an example of the utility of a look-ahead capability, Figure 4.2-2 qualitatively depicts a look-ahead capability combined with a distortion management system for unstart prevention. As shown, detection of a Mach number variation ahead of the airplane allows an anticipatory adjustment of inlet throat area. This results in greater unstart margin during the transient event than would prevail with a conventional system. The

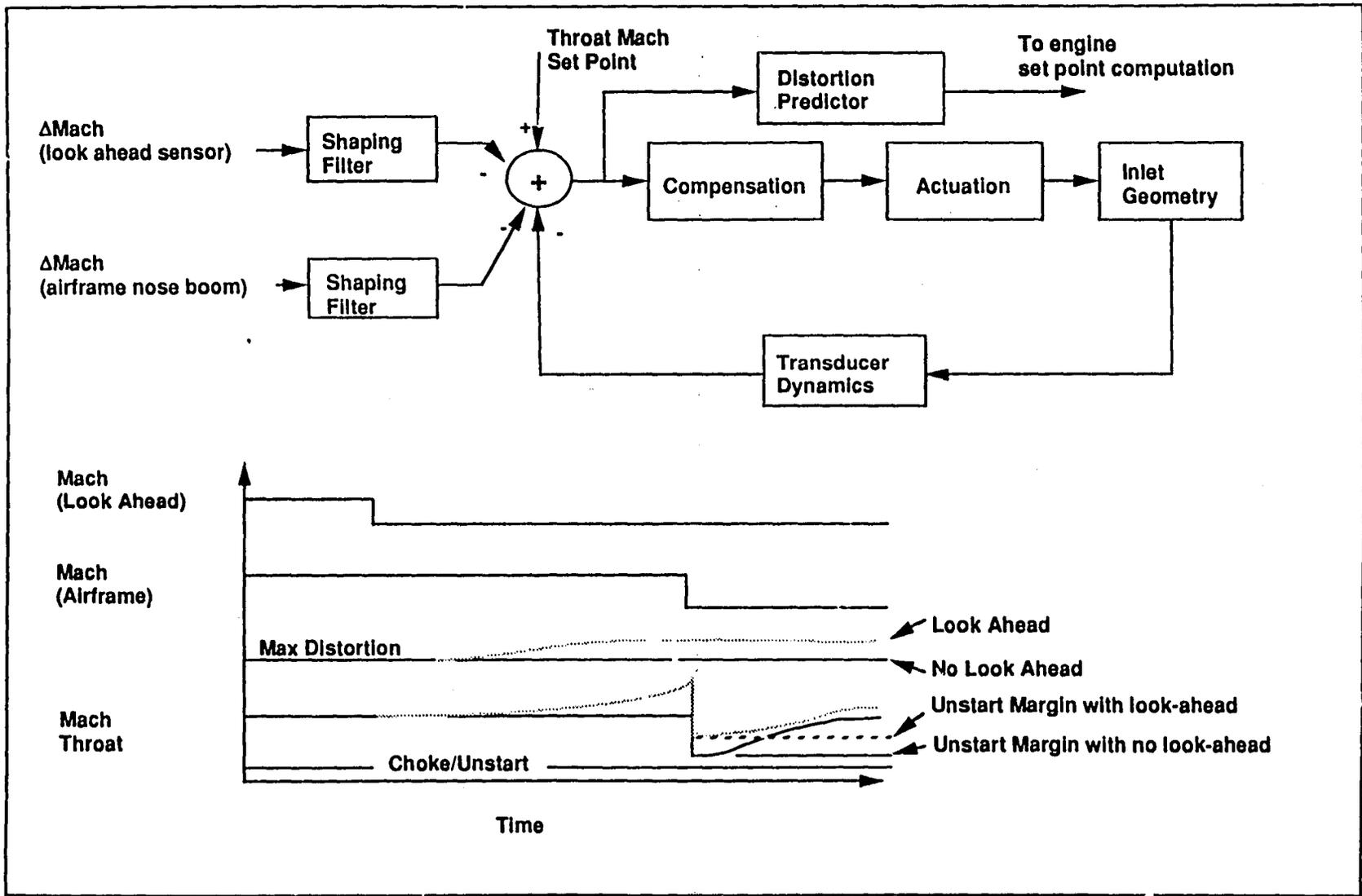


Figure 4.2-2 Inlet Disturbance Anticipation

technique allows a reduction in steady state Mach number margin and thus improved inlet performance.

New, forward-looking sensor technologies show significant promise in each of these areas, but there is a complication. In the past, sensors have generally been developed for specific functions, operated independently, and provided to the pilot or control system through a unique interface or display. As additional sensors are placed on board, pilot workload and stress increase dramatically under adverse conditions if the sensor information is not integrated. There is a need to automatically process data from diverse sensors in a way that does not add to the pilot's burden. Multifunction sensor technology addresses this need in two ways:

1. Data fusion from several sensors to establish a given state.
2. Distribution of data from a single sensor to all functions that require it, rather than each function having its own redundant sensor.

Figure 4.2-3 shows the capability for specific sensors to support various avionic, flight and propulsion control functions. The issue is to determine the best suite of advanced sensors (and strategy for using them) that provides data needed to: 1) avoid inlet unstart, 2) avoid obstacles in the flight or taxi path, and 3) provide the pilot with a clear representation of flight conditions.

**Technology Readiness:** Boeing Aerospace & Electronics IR&D is investigating laser radar (Ladar), X-band, millimeter wave (MMW) radar, and infrared focal plane arrays. A prototype sensor suite, comprising the most promising technologies will be defined in 1992, and in 1993 a prototype will be constructed and demonstrated in flight. A BCAG IR&D Multifunction Sensor Research effort is expected to develop and test, with supplier support, a forward looking multi-function sensor for implementation in the 1995 time frame. NASA Langley has a substantial research effort underway in Advanced Sensor and Imaging Systems Technology (ASSIST) that should yield HSCT applications.

#### 4.2.2.5 Shock Position Sensing

**Requirements:**

- Mission 1,4
- Propulsion Control 1,2,3,6,7

**Issue Description:** To date inlet normal shock position has been determined indirectly by measuring static pressures in the vicinity of the shock or by determining duct exit Mach number based on appropriate pressure measurements. Such measurements require

MFS FUNCTIONS	SENSORS				
	EXISTING C/X BAND	NEW X-BAND DOPPLER	MMW	FLIR/ RADIOMETER	LACAR
WX Detection	●	●			
Windshear/Microburst		●	○	● R	●
Clear Air Turbulence				● R	●
Obstacle Avoidance (Ground Only)		●	○		
Imaging Aid for Approach and Landing			●	● I	
Ground Taxi & Takeoff (CAT IIIa and Below)			●	● I	
Improved Ground Mapping		●			
Integration of Ground Proximity		●			
Wake Vortex Detection				○ R	●
Volcanic Ash Detection				● R	●
Dry Hale Detection					●
○ - Limited Capability                      R - Radiometer ● - Full Capability                          I - Imaging					

Figure 4.2-3 Multifunction Sensor Capabilities

high accuracy pressure transducers. Also, as shown in Figure 4.2-4, they are affected by inlet operating conditions such as angle of attack and throat Mach number. Therefore significant calibration and computation is required to extract the desired feedback signal from them. They either use long manifolds to develop a pressure representative of shock position or large numbers of transducers. The former introduces a bandwidth limitation and the latter creates a reliability problem. These pressure transducers also must be capable of operation in the high ambient temperature environment or be air conditioned since they must be located close to the pressure taps to avoid excessive pneumatic line dynamic response degradation. Alternatively shock position may be measured directly via optical or acoustic techniques. The optical approaches provide high bandwidth and a more direct indication of shock position eliminating some of the detail calibration required when pressure signals are used to infer shock position. High temperature pressure transducers provide improved reliability, reduced system complexity. Direct Shock sensing provides improved system performance (+1% recovery), improved dynamic response, and reduces test time to develop control schedules.

**Technology Readiness:** NASA Lewis conducted research using distributed pressure transducers in the 1970's (ref. 17) and more recently using various technologies under contracts NAS3-25446, and NAS3-25447. Substantial work is required to reduce the concepts explored in these efforts to practical transducers.

#### 4.2.2.6 High Temperature Sensor Technology

**Requirements:**

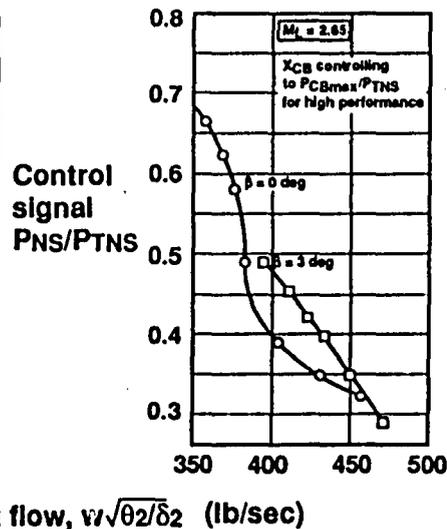
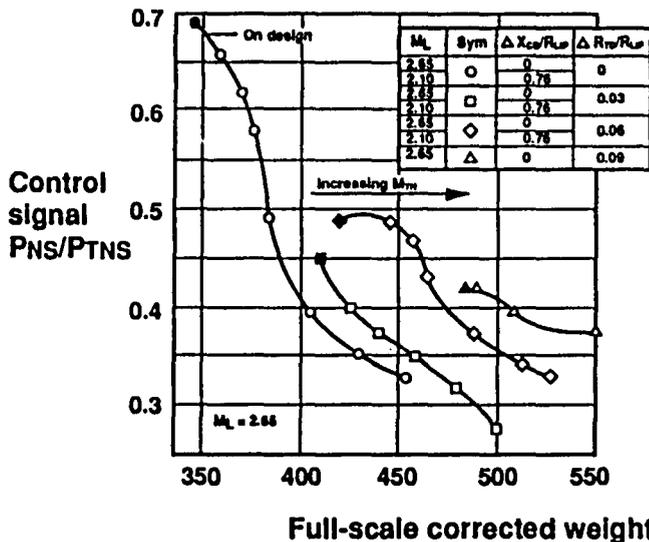
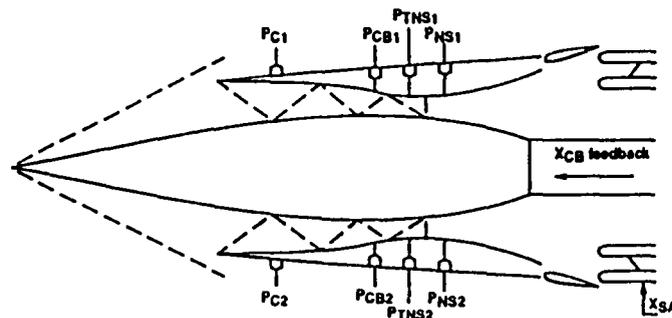
- Mission 1,4
- Configuration 10,11,13
- Propulsion Control 1
- Maintenance 1,2

**Issue Description:** The high temperature environments of the HSCT combined with its extreme performance requirements create a situation in which off-the-shelf pressure, motion, and position sensors may not satisfy HSCT requirements. Elsewhere we have identified sensor technology using novel technology (fiberoptics) here we point out that conventional technology transducers will require incremental work to function in the HSCT environment. Although this is detail work involving such things as high temperature varnishes, sealants, solder, and improved thermal compensation it is work which must be done if HSCT control systems are to be developed.

**Technology Readiness:** Detail design issues must be clearly identified by 1994. Development of suitable components can be performed as part of HSCT technology demonstrator. Boeing is investigating several semiconductor technologies including bulk

**Current technology**

- Strategically located pressure measurements
- Plumbing is potential maintainability issue
  - Accessibility/testability
  - Large number of transducers
- Transducer requirements are severe
  - High accuracy and high temperature
- Sensor data are correlated to inlet performance
  - Correlation affected by throat Mach, surface position, and angle of attack and detail design change



**Research requirements**

- Pressure transducers
  - High accuracy
  - High temperature
  - Fiber optic
- Direct shock sensing
- Estimation of supersonic flow field from airframe or FAR field data

• Solid symbols denote value at intake unstart

62E1-92  
M-10-16

Figure 4.2-4 Inlet Flow Measurements

CMOS and silicon-in-insulator technologies, to determine their potential for operation over the temperature range required by the HSCT.

#### 4.2.2.7 RF Sensor Technology

**Requirements:**

- Mission 1
- Configuration 3,9
- Flight Deck 6,7
- Certification 1

**Issue Description:** The HSCT configuration and mission present many technical issues regarding the integration of avionics antennas:

1. Employment of a common-module sensor system concept. In this architecture, broadband antennas perform multiple RF functions to be serviced out of a minimum set of apertures on a real-time basis. This will require switching common RF modules between apertures by using optical techniques to minimize electromagnetic interference.
2. Compensating for electromagnetic effects of composite airframe/skin material on antenna performance. This involves dealing with RF leakage through the structural joints of the skin (See paragraph 4.2.3.4, HIRF/EMI immunity).
3. Conformal VHF antennas are desired. Structural cut-outs and graphite-epoxy for antenna ground plane are concerns that need further study. Use of current technology blade antennas is not acceptable, aerodynamically, for HSCT.
4. Multi-band Ogive Radome. Supersonic radome must be capable of housing and operating both microwave weather radar, and millimeter-wave vision enhancement radar antennas (See Section 4.2.5, Multifunction Sensor Technology).
5. Aluminum antenna structures. Dissimilar materials such as graphite and aluminum, in contact, in the presence of moisture, will corrode because of galvanic action. A bonding connection, protected from moisture and air, that can withstand HSCT temperature and vibration environment, must be developed.

The number and location of RF sensors planned for the HSCT, assuming Year 2000 technology and navigation environment, is shown in figure 4.2-5.

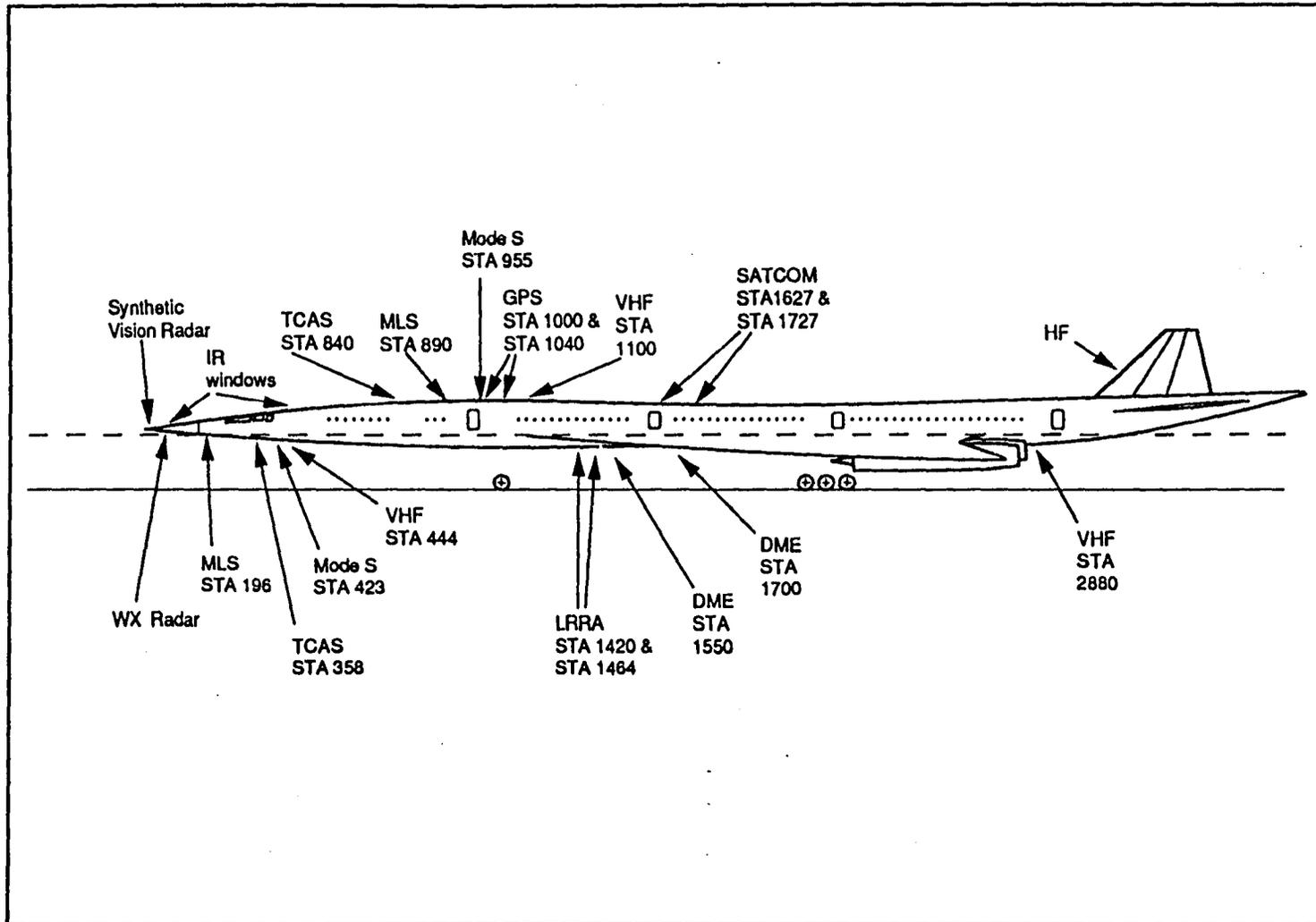


Figure 4.2-5 Proposed HSCT Antenna Locations

**Technology Readiness:** Further study is required to define an integration concept that meets the needs of a commercial airplane, does not increase EMI problems, and works well on a graphite composite plane body.

#### 4.2.3 Computational Hardware

##### 4.2.3.1 High Temperature Electronics (or Cooling)

**Requirements:**

- Mission 1,4
- Configuration 10,11
- Flight Control 8
- Propulsion Control 1
- Maintenance 1

**Issue Description:** In the current HSCT design electronics installed external to the fuselage require dedicated cooling systems since the ambient temperature is as high as 200°C. Engine nacelle temperatures will be substantially higher. Electronics capable of operating with a 200°C coldplate would allow remote location of electronics either without dedicated cooling or with simple ram air cooling (for engine bay equipment), and improve system weight and reliability by eliminating long, heavy, shielded, high conductor count, wire bundles.

As shown in Figure 4.2-6, the first issue for HSCT high temperature electronics is to select a semiconductor material which satisfies the temperature requirements and is available at HSCT development time at reasonable cost. Once a semiconductor technology is selected, other issues must be addressed regarding connectors, circuit boards and material compatibility as shown in Figure 4.2-7. No matter what strategy for high temperature LRU design is chosen, high temperature connectors will be required for HSCT. After actuation, connectors, as stated by Ganley (ref. 18), may be the most significant hardware issue.

**Technology Readiness:** Poor in terms of having adequate capability to support demonstrations starting in 1995. However, various uncoordinated proprietary efforts are being pursued.

##### 4.2.3.2 Computational Hardware Improvements

**Requirements:**

- Configuration 3
- Flight Deck 1,4,8
- Flight Control 2,4
- Propulsion 1,2,3,6,7
- Maintenance 1,2,3

## **Semiconductor Materials Technology for HSCT**

### **Conservative HSCT Requirements**

- Free Stream Temperature = ISA+10°C @ Mach 2.4, 60K Ft
- Ram (Cooling) Air Temperature = 100°C
- Thermal Rise: Junction to Cold Plate = 50°C
- Operating Junction Temperature = 250°C

### **Materials considerations**

- Silicon
- GaAs
- SiC

### **Silicon based approaches are most likely to satisfy HSCT requirements**

- Uses existing technology infrastructure
- Required level of investment consistent with HSCT market
- Device performance demonstrated to 300°C

### **Effort required prior to system demonstration (1995)**

- Select Process ( BICMOS, CMOS/SOI, CMOS/SOS)
- Demonstrate long-term stability, reliability
- Develop essential library of devices

**HSCT could use other technologies if they became available**

## **HSCT High Temperature Packaging/Connector Requirements**

- **Connectors Are a Major Source of Unreliability**

**Rule of Thumb 30% of Control System Failures are Connector Related**

**Primary Source of Maintenance Problems and Unrepeatable Faults**

**High Temperature Operation will Exacerbate Problem**

**From Concorde " As important as any other improvement for the next generation will be an electrical connector that will work reliably at the temperatures to be found in a super sonic engine bay."**

- **Semiconductors Are Only Part Of High Temperature Controller Requirements**

**Thermal Compatibility of Components**

**Board Design and Materials**

**Lead Connection Techniques (Conventional Solder Melts Around 350 degrees F.)**

**Passive Component Stability / Operability**

**Connectors**

**Thermal Management Within the Unit**

*Figure 4.2-7 High Temperature Packaging/Connectors*

- Certification 2

**Issue Description:** Significant performance improvements and cost and size reductions have occurred in many computational products, including: Reduced Instruction Set Computing (RISC), solid state mass memory, graphic geometry processors, massively parallel processors and optical data processing or logic. The issue concerns what needs to be done to qualify advanced, high density computer products for the HSCT temperature, vibration, and radiation environment (see section 4.2.3.3). Furthermore experience has shown that the value of raw performance is limited unless each component is engineered and integrated into a reliable system. Configurations that reduce the physical complexity of system interconnections and increase the performance of the flight and propulsion control systems are necessary to meet availability and reliability goals.

**Technology Readiness:** Introduction of up-to-date hardware into a flight system creates risks that need to be addressed in the development cycle.

#### 4.2.3.3 Single Event Upset (SEU) Phenomena

**Requirement:**

- Mission 1
- Certification 2
- Propulsion 2,3

**Issue Description:** It has been observed that high-density, low power memory devices, such as static RAM, dynamic RAM, and EEPROM, operating in space or at high altitudes (40,000+ ft), are subject to upset due to cosmic radiation. The impact of cosmic radiation on high density semiconductors is shown in Figure 4.2-8. Integrated circuits, such as microprocessors and memories that are used in computer and control applications, are also susceptible to transient upsets, particularly if high-density commercial electronic parts are used. The issues are 1) that we do not yet know the extent that the high-density, critical control system, memory and bus electronics are susceptible to such effects, nor 2) given a level of potential disruption, what design (N-level redundant, self detecting and repair) strategy will be best suited to compensate for it.

**Technology Readiness:** Various vendor, government and Boeing Company groups are conducting tests focused on the advanced LSI and VLSI electronics used in the 777. Boeing, cooperating with the IBM Corporation, is conducting scientific/engineering studies on SEU effects and hardening strategies for avionics (Jan 1991). Although some of this data can be applied to the HSCT, no research, focused on the HSCT flight envelope, has been conducted or proposed at this time.

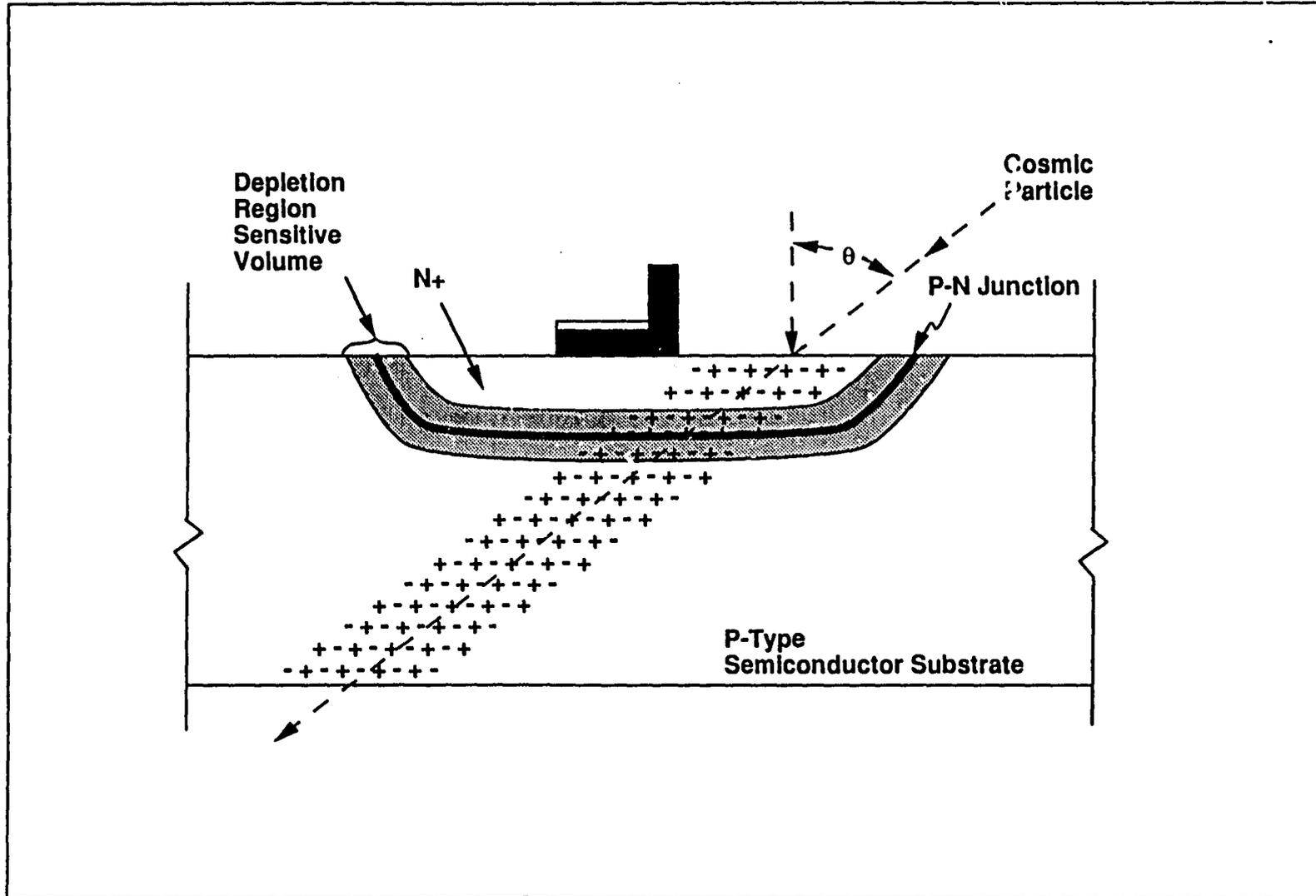


Figure 4.2-8 Single Event Upset

#### 4.2.3.4 HIRF/EMI Immunity

**Requirements:**

- Mission 1
- Configuration 9
- Flight Deck 6
- Certification 1

**Issue Description:** The HSCT is affected by High Intensity RF interference in many ways: 1) The non-metallic airframe exposes the electronics and the wire paths to the full effects of any RF radiation fields through which the airplane might pass; 2) Radio functions on the airplane generate EMI which can interfere with other electronic functions that are co-located in the same modular cabinet; and 3) Chassis packaging designed to limit RF interference may interfere with maintenance operations. For example: conventional aircraft LRU's are disassembled and repaired in a maintenance area. A proposed improvement in aircraft avionics has been the use of line replaceable modules (LRM) each one of which would have the functionality of a conventional LRU but would plug into a rack or chassis which would provide common resources such as power and communication. A maintenance issue has been raised with respect to this arrangement, that is if the chassis is opened in the field to remove an LRM how can the integrity of the chassis EMI gasket be ensured. The fundamental problem is that a small break in the EMI gasket creates a latent fault since the system may operate perfectly with the flawed gasket until subjected to a particular RF environment. If LRMs are to be used in the HSCT, a requirement exists for contamination or damage proof EMI gaskets or for a practical portable technique for testing their integrity.

**Technology Readiness:** HIRF shielding, research and testing is being provided for 777 to meet stringent FAA requirements. 777 solutions may be difficult in terms of weight for HSCT because of its structure and length. Photonic sensors (Section 4.2.2), datalinks and buses (Section 4.2.12) may be required to meet weight budgets for HSCT. An accepted strategy for protecting LRMs from EMI has not yet been developed.

#### 4.2.3.5 Flight System Data Bus Technology

**Requirements:**

- Mission 1
- Configuration 4,10,13
- Flight Deck 3
- Flight Control 8,9
- Propulsion 1,2,6,7
- Maintenance 2,3
- Certification 1

**Issue Description:** High speed multiplexed data bus technology appears to offer a great benefit to HSCT performance: 1) Buses to propulsion control units and flight system actuators offer potential weight savings by eliminating many discrete data lines. 2) In order to integrate propulsion and flight control systems, more shared airplane and engine state data, data bases and sensor data will be required. A high speed data bus may be the most effective way to connect the flight control system to the propulsion units in the nacelles. 3) Furthermore it may be necessary to connect different communication, navigation and surveillance functions to shared antennas, whereas in the past each function had its own transmitter and sensor resources, and 4) Data buses provide a more flexible network topology and potentially can improve reliability for a given configuration of equipment.

For current new airplanes, data bus technology used depends on the application. Flight systems uses ARINC 629, RF Nav/Communications uses ARINC 429, and cabin/electronic library systems uses FDDL. Ideally, a common protocol, that would permit flight control and communication application interface, would improve overall system performance and would probably reduce the cost and weight of the overall system.

Integration of flight and propulsion controls may increase bus traffic beyond the capacity of ARINC 629 and 429 buses. or for that matter any copper wire bus technology. If data rates in excess of 20 megabits/sec are required, fiberoptic signalling is preferred to limit the bit error rate. A number of issues regarding the performance and the robustness of data buses operating in the HSCT environment can be listed:

1. Trade-offs between copper wire bus implementations and various fiberoptic high speed data bus technologies.
2. Connector (phonic or copper wire) reliability in severe vibration and temperature environments.
3. HIRF/EMI effects on electronic bus lines (or phonic connectors and repeaters) that are routed outside electronics bays.
4. Data bus redundancy levels required for flight safety and engine independence (see paragraph 4.3.1.1, Certification Issues).
5. Robust partitioning of transmission data (what is the effect of engine bus traffic on flight critical flight controls, and vice versa?).
6. Definition of requirements that drive non-passive versus passive repeater strategies for bidirectional data bus architectures.

7. Identification of a protocol that meets both the open system interface needs of FAA and airline operations and the synchronous, high performance requirements of flight and propulsion control systems.

**Technology Readiness:** Copper wire ARINC 629 is just now being accepted in flight critical service. Photonic implementations of ARINC 629 offer no throughput advantages. Other high speed fiberoptic data bus technologies have not yet met certification/standardization requirements for use in flight critical applications.

### 4.3 System Engineering and Architecture

#### 4.3.1 System Engineering

##### 4.3.1.1 HSCT Certification Requirements

**Requirements:**

- Mission 3
- Flight Deck 5,6
- Flight Control 2,9
- Propulsion Control 1, 2,3,7
- Certification 1,2,3,4

**Issue Description:** Some existing flight systems airworthiness certification requirements may not be appropriate for the HSCT, while other substantial requirements have not yet been imposed. An important cooperative activity between government agencies and industry will be to develop an appropriate set of requirements for HSCT certification. The specific requirements that need to be defined through government / industry cooperation are:

1. Define the static longitudinal stability requirement (CFR Part 25.173c) for constant thrust and automatically controlled thrust cases of the HSCT.
2. Define certification rules for envelope protection functions, automatic reconfiguration of secondary controls during take-off and final approach, active flutter suppression, automatic inlet restart, and c.g. management.
3. Define minimum handling qualities for sustained flight and landing for backup designs.
4. Define minimum vision enhancement and synthetic vision requirements for backup vision systems.
5. Define separation rules for high altitude controlled airspace considering high altitude sensor limitations, performance optimization requirements and disturbance environment.
6. Determine requirements for propulsion system isolation, i.e., use of extremely ( $p < 10^{-9}$  failure rate) high integrity data bus to communicate with engine controls and command thrust versus commanding thrust exclusively through the throttle levers.
7. Define rules and procedures for certification of individual LRMs and co-hosted software modules without recertifying the entire host cabinet.

**Technology Readiness:** Some certification requirement changes were proposed for the SST and then established for Concorde. The process of updating these proposals to

cover other certification issues that could affect safe and economical HSCT operation has been initiated.

#### 4.3.1.2 Multidisciplinary System Engineering Tools

**Requirements:**

- Propulsion Control 1,2,3,4,5,6,7
- Flight Control 1,2,4,5,6,7
- System Engineering 1,2
- Maintenance 1,2,3

**Issue Description:** Development of a control configured HSCT will require more cooperation between engineering disciplines, than was required for subsonic airplanes. Current tools used by different engineering groups are mostly incompatible such that considerable manual effort must be expended to transfer data between groups. In order to efficiently design, build, and test the HSCT, an appropriate set of tools integrated through a common data base, as shown in Figure 4.3-1, will be required. Such a common tool data base must address some specific concerns, including:

1. Definition of interoperability standards for structures, aerodynamics, propulsion, and flight control system analysis tools and data bases and enforcement of such standard within engineering disciplines and among the tool vendors.
3. Implementation of software tools that support development, installation, verification and maintenance of flight certified software modules.
4. Development of dynamic vehicle simulations that address: flight and propulsion system interaction, aeroelastic effects, and handling qualities

The **interdisciplinary tool set/data base** will include the tools used for analysis and simulation by the structures, aerodynamic, and the flight and propulsion controls design organizations. Since many individual tools are available and are in use, but are not compatible with each other, the issue is how to modify them to meet HSCT interoperability requirements.

Subsystems that have been traditionally delivered as labeled line replaceable units (LRUs) may be delivered as **software modules** that are part of some integrated vehicle or flight management system. The issue here is to establish standards and tools that provide for delivery of warrantable flight software modules by individual vendors. In this context the availability of certifiable automatic programming tools for real-time flight software development is also an issue.

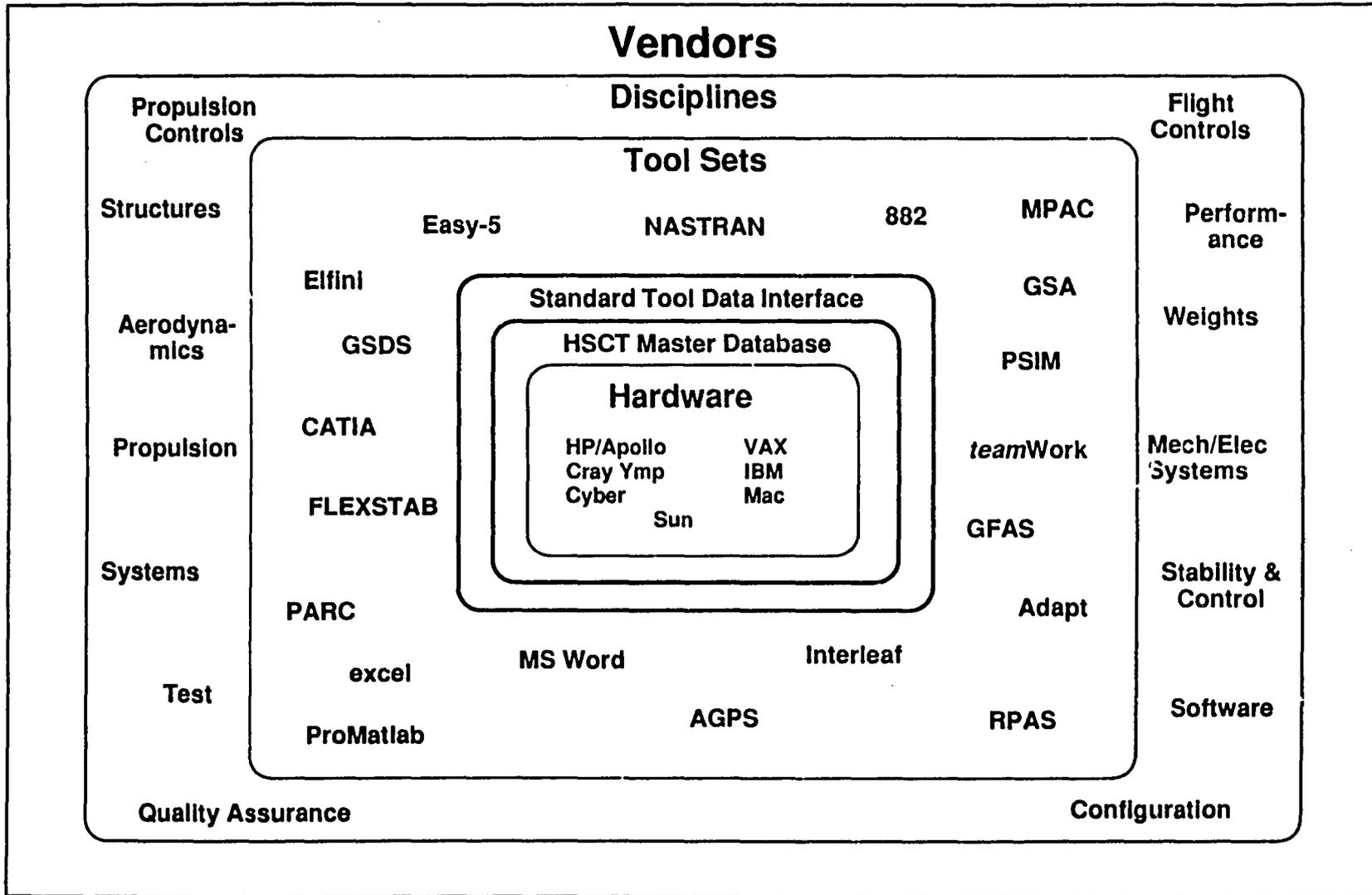


Figure 4.3-1 System Engineering Tool Environment

Several technical problems require specialized simulations in varying levels of precision. Modelling and analysis tools that support these simulations must address both the need for quick turnaround for trend analysis, and extremely high accuracy for final design of aeroelastic controls and flight system architectures.

**Technology Readiness:** No present (1991) generation computer automated system engineering environment provides the breadth necessary to integrate more than one or two major tools (from different engineering disciplines). Most proprietary tools have proprietary data interface formats. Military avionics committees (i.e., JAIWG) have attempted to promote a "software backplane" approach to computer automated system engineering systems, but they have not yet identified an integration standard that is satisfactory to the community of engineering participants and tool designers.

#### 4.3.2 System Architecture/Redundancy Management

At the current time airplane avionics/flight system architectural design (Boeing 777, Airbus A340) is undergoing trends that will impact the development of the HSCT flight and propulsion systems: 1) fly-by-wire control systems that do not rely on electro-hydro-mechanical linkages for primary control or backup purposes, 2) multi-function systems that implement, in a single LRU, numerous functions that traditionally were implemented as separate LRUs, and 3) high integrity functional units (LRUs) that can function properly in the event of failures because of internal (circuit or chip level) redundancy. There are additional architectural issues that come up because of HSCT configuration characteristics (i.e., operating temperature of some components.) The purpose of this section is to identify the issues that result from these characteristics and trends that affect the design of an HSCT with a year 2000 go-ahead. The section is divided into two parts: Section 4.3.2.1 discusses general avionics, flight and propulsion control system architectural issues that affect both flight critical and non-flight critical functions. Section 4.3.2.2 identifies architectural issues that most directly affects the flight critical functions.

##### 4.3.2.1 General Flight and Propulsion System Architectures

**Requirements:**

- Mission 4
- Configuration 4,7,9,10,11
- Flight Deck 3,7,8
- Flight Control 8,10
- Propulsion Control 1,2,4,5,6,7

- Maintenance 1,2,3
- Certification 1

**Issue Description:** In the past, major avionic functions (autothrottle, yaw damper, autopilot, stabilizer trim, inertial navigation, to name a few) have been designed and implemented as independent subsystems. Often this design approach has led to system integration problems discovered late in the program, precipitating additional growth in functionality and complexity of the subsystems. The end result is an overly complex avionics/flight system architecture with computational hardware, software, sensors and interfaces in excess of a desired minimum. The adverse impact on system performance, reliability, development cost and maintenance cost is obvious.

This situation can be improved by the current trend to consolidate subsystem hardware units into multi-function avionic cabinets. Physical consolidation reduces weight, overall hardware and maintenance cost, and improves reliability. The co-location of subsystem functions will be stimulated by the availability of more powerful computational hardware and flight-qualified multi-processing operating systems, making it possible, in principle, to co-host many functions. Lambregts has shown (ref. 12) that separate functions such as pitch autopilot, autothrottle and roll autopilot, yaw damper can be effectively integrated into a multi-input/multi-output control system resulting in a simpler architecture with a substantial reduction in overall software and improved performance when compared to the set of separate functions, with independent control loops.

Further reduction in software complexity is made possible by careful hierarchical and generalized system design using a functional building-block approach (i.e., implementing complex functions from simpler, reusable, functions).

An improvement in reliability can be gained if duplicated overhead (i.e., operating system, redundancy management, signal selection) functions can be consolidated, and certain hardware resources (i.e., memories, bus interface units, processors, sensors) can be shared. Architectural integration techniques, now being developed (ref. 20), simultaneously improve airplane performance, safety and availability by permitting internally-carried spares to be shared by subsystem functions. Spares provided at a component or chip level can be applied to any failing function. The advantage for an integrated architecture is that individual subsystem functions need not provide their own dedicated spares or the overhead functions associated with managing them. In this way the desired function reliability and availability can be achieved at reduced cost.

For the HSCT, as well as the Concorde, the reliability problems associated with connectors in a high temperature environment (ref. 19) may have important architectural implications. The architectural strategy can significantly affect connector count and placement in the airplane (see digital data bus technology issues-Section 4.2.3.5). Also, HIRF and EMI effects, combined with weight of long shielded cable runs in a non-metallic environment make it necessary to consider the merits of fiberoptic cabling vs copper wire for both data buses and data links. Since some of the EMI effects are generated by the avionic subsystems themselves, placement of sensitive functions on the airplane must also be considered.

The traditional business approach to flight and propulsion control systems development is to implement various functions as separate line replaceable units (LRUs), each manufactured and warranted by a single vendor. The airplane manufacturer is ultimately responsible for overall integration of electronic hardware, algorithms (software) and the system to be controlled (e.g., nacelle, engine, rudder, etc.) If a specific function (i.e., software developed by a subcontracted vendor) of an integrated system providing many other functions is to be installed or modified, how can one be sure that other functions of the system are not affected unintentionally? Can flight certification of a function be accomplished independently from the other functions that share the cabinet?

The issues that affect the overall systems architecture of the HSCT airplane may be summarized as follows:

1. Determining the optimal level of functional integration and subsystem hardware consolidation for vehicle management, automatic flight control, propulsion control, flight management, communication/navigation and flight deck controls/displays, considering:
  - Potential for sharing hardware resources,
  - Potential for integration -derived algorithm improvements,
  - Reduction in connector count and wiring,
  - HIRF/EMI effects,
  - System reliability, availability and hardware maintenance, and
  - Software maintenance and certification of cohosted functions.
2. Development of integrated multi-input/multi-output control and redundancy management algorithms that facilitate simplification of the overall system (hardware and software) design.

3. Design of avionic cabinets and maintenance equipment so that hardware and software modules can be swapped without compromising integrity of neighboring modules or cohosted functions.
4. Performance of available hardware (i.e., mass memories, processors and buses).
5. Reliability/availability requirements for each function in the system.

**Technology Readiness:** Honeywell and Boeing are developing and certifying the multi-function Airplane Information Management System (AIMS) for the 777, which implements line replaceable modules. Qualification of the AIMS is being negotiated with certification authorities at this time (ref.20). Boeing and Honeywell are also developing an integrated air data and inertial reference computer following a somewhat different (high unit integrity) approach to functional system integration. The performance of both designs will be evaluated in service and influence the architectural approach for HSCT avionics.

#### 4.3.2.1 Flight Critical System Architectures

**Requirements:**

- Configuration 4,9,10,11,12
- Flight Deck 3,4,8
- Flight Control 1,2,8,9
- Propulsion Control 1,2,3
- Maintenance 2,3
- Certification 3,4

**Issue Description:** Flight critical systems are by definition those systems that are indispensable for safe flight and, by failing, could cause the airplane to crash. Most avionics and automatic flight control system functions for conventional subsonic airplanes are designed to be fail-safe or fail-passive; that is: individual failures, except some with extremely remote probability of occurrence, will not cause the airplane to be uncontrollable. The autoland function, when used below CAT III decision height, is flight critical and designed to be fail-operational. Due to the control configured nature of the HSCT, the primary flight control system requires an integrated stability augmentation function. This brings a number of sensors and components into the flight critical architecture, making the reliability and availability requirements harder to meet.

The prime issue is to determine what functions must be provided to accomplish minimally safe flight. This may be controversial. For example, the autothrottle is not considered to be flight critical in subsonic airplanes, but for the HSCT, throttle control may be flight

critical due to backslidiness on approach (see Section 4.1.1.1). Once the flight critical functions are determined, a design can be developed to meet the flight critical reliability and availability requirements. Non-flight critical functions can be implemented in flight critical hardware components to meet the overall design integration objectives discussed in the previous section, if these functions share the same hardware and if the additional software does not have a significant impact on the integrity of the flight critical function or the certification thereof. Overall development cost, certification and maintainability will affect these architectural decisions.

Another issue is the distribution of electronic components throughout the airplane. Physical separation of redundant flight critical control components helps to limit the possibility of a single cause catastrophe (i.e., compressor disintegration, water leak, explosion) impacting more than one control path. An example is the actuator control electronics. Co-location of the control electronics with the actuator allows direct digital commanding via the flight critical bus, and local position loop closure, resulting in substantial weight savings by the elimination of wiring and connectors. It also provides an opportunity to incorporate fault monitoring, thereby producing "smart actuators" that report health status to a central redundancy management function.

Latent defects in design or implementation of the hardware and software are a very serious issue in flight critical systems designs. A number of strategies has been employed to eliminate or compensate for such design faults: 1) use of simple configurations of totally proven components and algorithms, 2) use of dissimilar hardware or software (N-level redundant) channels, with cross channel monitoring, and 3) exhaustive hardware-in-the-loop testing of the integrated system, comparing its performance with results produced by an independent simulation of the system. For the HSCT, the issue is select cost effective strategies and technologies that effectively eliminate latent defects.

Engine control architecture on a multi-engine airplane is not traditionally considered flight critical because 1) In normal flight, loss of an engine should not endanger the airplane, and 2) the cost of flight critical system redundancy is unacceptable for propulsion systems. Engine controls are typically dual channel, consolidated, and engine mounted to reduce complex wire runs and simplify the testing and management of the engine unit. Because variable geometry inlet and nozzles on the HSCT propulsion system are much more complex than on a subsonic airplane and their control depends more on flight systems data, the flight and propulsion control systems will probably be

integrated via the flight systems data bus. The architecture of the flight systems bus would then be affected by independence requirements of the engines, the high temperature environment in the nacelle, the data communication requirements of the propulsion systems, and the integrity requirements of the flight critical systems connected to it. Condor demonstrated a solely data bus commanded (control and data interface between flight and propulsion control) propulsion system that should be evaluated for transport application if certification issues can be resolved. However, for the HSCT, providing data bus independent engine control and override capability by the pilot through the throttles, remains an issue.

In summary, the following issues should be considered for flight critical HSCT flight and propulsion control systems:

1. Determining the flight criticality of automatic thrust control for pilot-in-the-loop landing and approach control.
2. Determining the need for a functional partition between a simple "hard SAS" that provides adequate flying qualities, and failure probability:  $p < 10^{-9}/hr$ ; and a "full-up" augmentation system providing top-level flying qualities, with reduced reliability.
3. Determining the configuration of sensors (i.e., air data and IRU) that are required for both flight critical and non-flight critical functions. Where should the processing of this data be hosted?
4. Determining the safety, weight, maintainability, and other design trade-offs affecting consolidated and distributed architectural strategies.
5. Determining the most effective and cost effective architectural strategy for dealing with potential latent design defects, i.e.,
  - Dissimilar hardware and/or software,
  - Flight critical function monitoring with reversion to backup function or system for malfunctions, and
  - Apriori proof of correct intended function of components and absence of unintended function.
6. Determining the integration requirements of the propulsion and flight control systems. i.e.,
  - Acceptability of a bus interface between the throttles, the flight control system and the propulsion control system,
  - The optimum architecture and physical location for propulsion control hardware, and

- Integration of propulsion condition monitoring functions in the flight critical systems architecture.

**Technology Readiness:** New subsonic airplanes under development, such as 777, A330/340 and MD12, are addressing many of the issues, using a variety of approaches. The ground rules that dictate the range of HSCT designs that are acceptable in terms of complexity and performance and certifiability will be better known after the present generation of new airplanes are certified.

#### 4.3.2.3 Built in Test and Maintenance Algorithms

**Requirements:**

- Mission 4
- Configuration 8,11,12,14
- Flight Deck 3,4,8
- Flight Control 8,9
- Propulsion Control 1
- Maintenance 1,2,3

**Issue Description:** The economic viability of the HSCT is dependent on aircraft availability for very high daily utilization. This represents a major challenge for maintenance because there are more flight and propulsion control parts, and more of the parts are flight critical, than on current long range subsonic aircraft. The resolution of this dilemma is dependent on basic improvements in hardware technology, and on the algorithms used to predict, detect, and isolate faults and manage repair of hardware components. In the propulsion area (Figure 4.3-2) there is a large body of technology addressing engine condition or health monitoring already available. There also is some experience with structural system cycle logging and condition monitoring.

What will be required for HSCT is an airplane-wide systems technology (building on the existing technology base) that automatically, in real-time, detects and isolates faults down to module level virtually 100% of the time. The system then must: 1) determine which faults require in flight attention, correction at the next aircraft turnaround, or permit deferred maintenance, 2) provide the maintenance technician with on-line guidance for the repair of the problem and the airline operations department with planning information so that the correct technicians and components are available when they are required, and 3) due to the flight safety implications of some of the decisions involved, the system must allow for human evaluation of the automated decisions, particularly those associated with dispatch criteria.

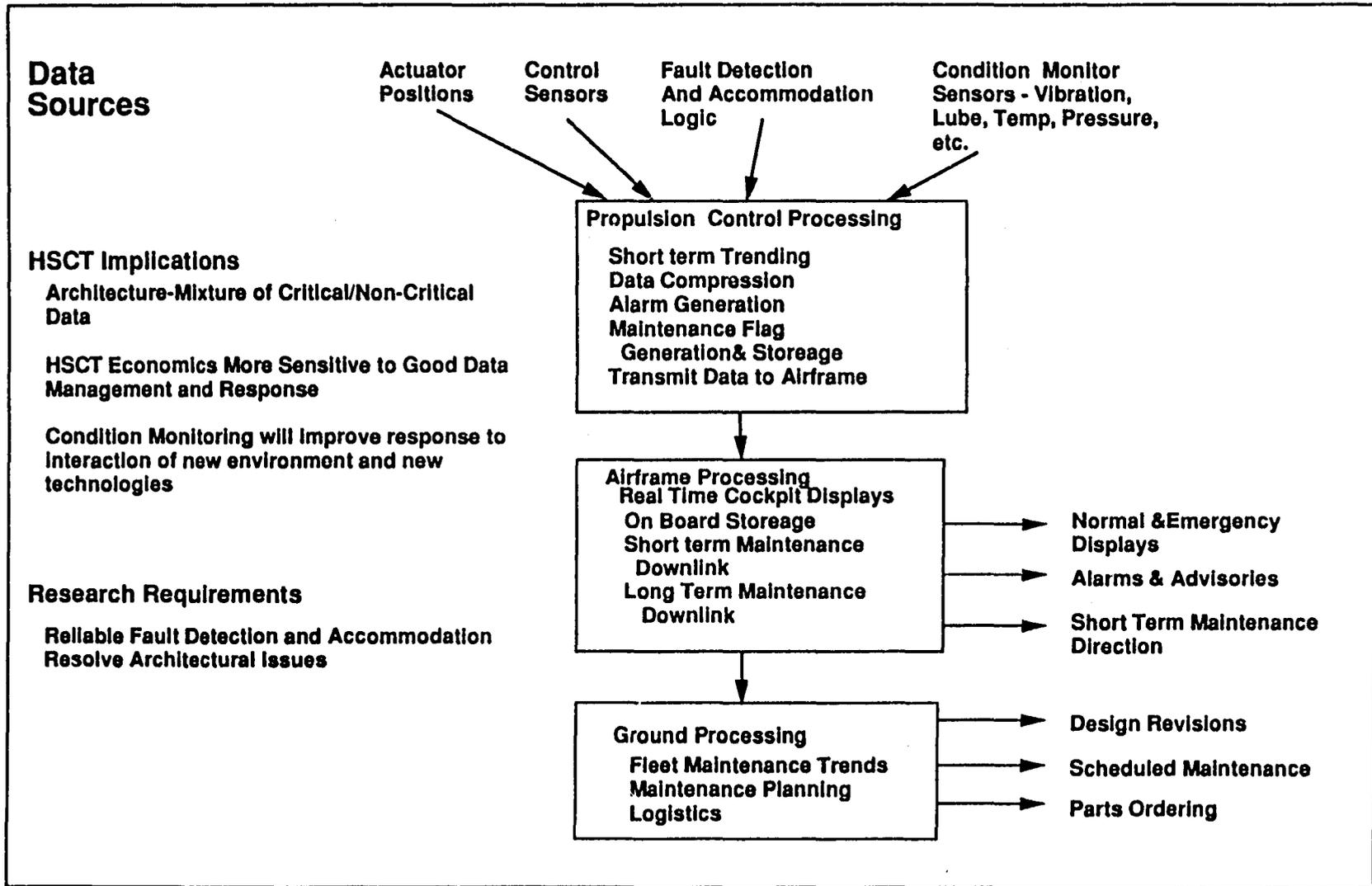


Figure 4.3-3 Automatic Condition Monitoring

In summary the following maintenance issues should be addressed for the HSCT:

1. Designing systems for easy maintenance, high availability, while at the same time satisfying more complex requirements than those prevailing on current airplanes.
2. Developing techniques to improve failure coverage without increasing false alarm rates.
3. Developing effective strategies for identifying and dealing with false and transient alarms that are operationally acceptable to the airlines.
4. Determining which is the most cost effective maintenance strategy for the HSCT:
  - Ultra-long life avionics with little or no maintenance outside of the overhaul cycle
  - Ultra-easy maintenance supported by line crews with automated (on-board/off-board) diagnostic support.
5. Determining the requirements for a service maintenance data acquisition and distribution system, considering:
  - Flight system complexity
  - Airline operator requirements
  - Manufacturer requirements

**Technology Readiness:** Maintenance monitoring technology exists as a result of prior military and commercial effort. Each new airplane system architecture must prove its own on-board maintenance monitoring concept. The concept for an integrated maintenance system that will support a larger number of flight critical/safety critical components without impacting availability through false alarms should be developed and demonstrated for HSCT.

## 5.0 PRIORITIES

The approach to prioritizing the issues identified in Section 4.0 was to rank them in relative importance within a given category: i.e., safety, performance, weight, reliability/maintainability, schedule impact or some special benefit. Barrier issues that require solution to make the HSCT viable, such as ozone depletion, sonic boom and noise, were considered as a category, but after some consideration it was established that no controls issues are true barriers although there is a collection of issues of which a large percentage must be successfully resolved if the HSCT is to be an economic success. Since these issues are addressed in the categories mentioned above, no separate category was created for them.

After ranking within categories, an overall priority (high or medium) was assigned to each issue. The following rationale was used: The top two issues within each of the categories were considered high priority, and any issues that were in the top 10 of four or more categories were also considered high priority. All issues that were in the top 10 of any category were considered medium priority. Figure 5-1 shows the priority ranking of each issue within each category. Section 5.1 provides the rationale for the ranking of the issues within each category. Section 5.2 presents the overall priority of each issue.

### 5.1 Priority Categories

#### 5.1.1 Safety Issues

In this discussion, the safety issues are defined as those flight or propulsion technology issues whose resolution is required to assure safe operation of the HSCT during normal flight operations. In other words, the safety issues are those control technologies that are necessary to make a windowless, control configured supersonic airplane with variable cycle engines safe to fly. The technology issues are ranked in the order of their overall impact on safety, as follows (1=highest impact):

1. **Flight Critical Systems Architectures.** The HSCT is entirely electronically (or photonically) controlled. There are no cables or links that can be used in the event of a system failure to control the airplane or the engines. The architecture must be fail-operational for critical flight and propulsion control system functions.
2. **Vision Enhancement Technology/Multifunction Sensors.** The synthetic vision technology must function in a way that does not cause the pilot to mishandle the airplane, and it must not fail during critical phases of the mission. The airplane

## Priority Summary

### Technology Issues

### Priority Categories

	Safety	Performance*	Weight*	Reliability/Maintainability	Schedule	Special Benefit	Comments
Augmented Manual Flight Control (enabling CCV)	3	1	3	10	8		
Automatic Flight Control (flight management)	8			10	8	3	Non-recurring and recurring costs
Flight/Propulsion Control Integration		2	4				
Propulsion System Automation			4	8			
Engine/Inlet Control Integration		2	4	8			
Inlet Sensor Fault Accommodation			4	8			
Unstart Avoidance/Accommodation	5	2					
Optimal Trajectory Generation and Tracking		5	4				
Performance Seeking Control		8	4				
Active Flutter Suppression	6	4	3	7	9		
Wing Load Alleviation		4	3	9			
Active Flight Envelope Protection	4			10	10		
Active CG Management	7	6					
Built-in Test/Automatic Maintenance Support				1			
Actuation Technology		3	1	3	1		
Fiber Optic Sensors				8	8		
Vision Enhancement Technology	2		5		2		
High Altitude Air Data		7	6		5		
Multifunction Sensors	2	2	6	9	6		
Shock Position Sensing		2	6				
High Temperature Electronics (Including Connectors)			2	5	4		
High Temperature Sensor Technology			6				
Computing Hardware Improvements				6			
Single Event Upset Phenomena	9			6			
HIRF/EMI Immunity	10		8				
Flight System Data Bus Technology			2	4			
HSCT Certification Requirements					3	2	Facilitate high benefit technologies
Multi-disciplinary System Engineering Tools					7	1	Engineering Coordination
Flight Critical Systems Architectures (redundancy management)	1		7	2			
General Flight and Propulsion System Architectures				6			
Disturbance Environment		2					

\*Duplicate numbers represent issues that are considered to be related.

Figure 5-1. Flight-Propulsion Controls Priority Assessment

cannot be safely operated in terminal airspace without some kind of operational vision enhancement system. Multi-function sensors will support vision enhancement.

3. **Augmented Manual Flight Control:** Stability augmentation is an integral part of the primary flight control system. The HSCT has two fundamental open loop instabilities, 1) The vehicle is unstable about the pitch axis particularly in subsonic operation due to the combination of c.g. and c.p. travel inherent in the configuration, 2) The HSCT flies on the backside of the power curve on approach making the unaugmented airplane speed unstable at constant thrust. As a result at least the SAS function must be viewed as flight critical.
4. **Active Flight Envelope Protection.** Little experience exists with certification and operation of a fly-by-wire control configured airplane near the performance limits of the airplane. The tradeoffs between envelope limits and pilot authority must be studied to assure safe operation.
5. **Unstart Avoidance/Accommodation** The unstart event, unless prevented or rapidly and properly countered by coordinated action of both the flight and propulsion control system, could endanger the airplane.
6. **Active Flutter Suppression:** If the final HSCT structural design has flutter problems within the design envelop, failure of the flutter suppression function could result in airplane loss.
7. **Active CG Management.** Improper response of the fuel transfer algorithm could reduce stability/control margins beyond the limits of the stability augmentation function. Erroneous weight computation could compromise safety due to unacceptable airplane or subsystem performance.
8. **Automatic Flight Control.** Outerloop flight path and speed control capabilities become safety critical during approach and autoland phases of flight. The system must be fail-operational during CAT III operations for all failures except those considered extremely remote.
9. **Single Event Upset:** Single event upset must be viewed as a significant safety concern until it is better understood and quantified. The physical phenomena which can result in an otherwise correctly functioning digital circuit changing state and thus function due to exposure to radiation at high altitude has been identified as a threat to high altitude aircraft and spacecraft. However, documented instances of its occurrences are rare because such events mimic software errors or computer glitches caused by a variety of noise phenomena. Recent experience (soon to be published) on military airplanes with error detecting and correcting computers has

confirmed existence of the phenomena. In the HSCT it represents a major concern because the airplane depends on flight critical electronics at all times, and the HSCT generally flies at altitudes which expose avionics to the phenomena. The potential exists for such faults to remain latent until they manifest themselves, possibly, in critical functions (i.e., autoland). Unless directly addressed SEU has the potential for becoming an adverse publicity issue.

10. **HIRF/EMI Immunity:** The lack of natural protection in a composite structure makes it important that the design of the flight and propulsion system contains the effects of lightning, high power RF fields and EMI leakage between RF generating avionic functions.

#### 5.1.2 Performance Issues

The HSCT requires certain flight and propulsion control algorithm and hardware technology to meet performance objectives. The performance issues are listed in order of potential impact:

1. **Augmented Manual Flight Control.** To enable the HSCT to be designed as a control configured vehicle and realize its performance potential, a full-time SAS/CAS, with satisfactory stability, maneuverability, and handling qualities, is required.
2. **Unstart Avoidance/Accommodation.** This topic must be addressed to achieve the planned level of HSCT inlet performance. Achieving the desired level of performance while satisfying the probability of unstart requirement requires that the following issues are addressed:
  - 1) Flight Propulsion Control Integration
  - 2) Engine Inlet Control Integration
  - 3) Shock Position Sensing
  - 4) Disturbance Environment Definition
  - 5) Multifunction Sensors (gust anticipation)

Therefore all of these are ranked two in the performance category.

3. **Actuation Technology.** Improved dynamic response of actuation systems will bound the performance capabilities of the system in two ways. First: the degree of relaxed static stability that can be achieved safely is closely related to the slew rate and bandwidth of the actuation system. Second: the ability of the inlet control system to accommodate disturbances and thus its performance is directly related to inlet actuation system bandwidth.

4. **Active Flutter Suppression/Wing Load Alleviation.** The composite HSCT may need to rely on active flutter suppression to meet certification requirements (positive flutter damping up to  $1.2V_D$ ). If active flutter suppression cannot be certified a heavier structure with lower performance may result. Wing load alleviation may be justified if credit can be obtained to reduce structural weight.
5. **Optimal Trajectory Generation and Tracking** In order to reach destinations and meet time and fuel constraints, it may be necessary to generate trajectories that optimize the airplane's performance. Trajectories that involve descent and climb maneuvers during supersonic transition, and climbing cruise may be required to achieve performance goals.
6. **Active CG Management.** Active CG management is used to trim the airplane for minimum drag.
7. **High Altitude Air Data.** Performance optimization at high altitude (i.e., 60-70,000 ft) may require development of new accurate air datasensors. To minimize performance penalties flush-mounted air data and RF sensors will be required.
8. **Performance Seeking Control.** Control algorithms that can maintain the optimal operating point for both normal and off design conditions may provide a substantial part of the performance increment necessary to make the HSCT an economic success.

### 5.1.3 Weight Reduction Issues

Weight is probably the biggest economic factor in comparing various technical issues. Due to the time and financial constraints of the program and also due to the impact of baseline characteristics on weight estimates, weight increments accruing to the various technology issues were estimated for a revised list of issues as shown in Figure 5-2. The approaches to computing weight increments and the reasons for consolidating issues are discussed in the following paragraphs. In the potential weight reduction category the issues have not been prioritized according to numerical order. Instead, single high benefit issues such as actuation and bus technology have been given higher priority than conglomerate issues like controls, that depend on the successful integration of a number of technologies to achieve an overall higher benefit potential.

1. **Actuation Technology:** The IHPTET program is developing propulsion technology in various areas. One of them is light weight actuation. Weight improvements of as much as 30% have been projected. HSCT actuator weight is approximately 6000 pounds. Because all of the schemes for weight reduction

Issue	Estimated TOGW Reduction	Other Benefits
Actuation Technology	4140 lbs 	+M, +F
High Temperature Electronics (or cooling)/Fiberoptic Data Bus	3321 lbs 	+M, +R
Structural Mode Control	10000 lbs 	+P
Propulsion & Flight Control Algorithms <i>(including CCV enabling SAS)</i>	14000 lbs 	+S, +P
Vision Enhancement	3680 lbs 	+S
Improved Sensors	7000 lbs 	+F
Architectural Strategies		+R, +M
Built In Test and Maintainability		+R, +M, +E
Multi-disciplinary Analysis, Design & Test Tools		+F, +E
<b>Total</b>	<hr/> 42141. lbs  or 6.0% TOGW	
<b>Priority Benefits:</b>	+S - Safety +F - Facilitation (Required to permit other technology benefits) +M - Maintainability/Reliability Improvement +P - Performance +E - Cost Reduction/Economic Benefit	

Figure 5-2 High Priority Weight Issues

proposed on that program may not be applicable to HSCT and because the relations among component parts of the hydraulic system may not be the same for the engine and airframe application the potential benefit was reduced to 15%. This leads to a 900 pound reduction in actuator weight and via linear sensitivity relations a 4140 pound reduction in takeoff gross weight.

2. **High Temperature Electronics/Flight System Data Bus Technology:** The potential benefit quoted in Figure 5-2 is between a centralized system in which all inlet control and airframe actuation electronics are fuselage mounted and a distributed one in which an inlet controller is mounted in the inlet and actuator controllers are efficiently distributed close to the actuators. The two technology issues are merged because use of fiberoptic bus technologies in high temperature areas (i.e., engine nacelles) depends on high temperature electronics (or cooling).

The weight assessment assumes a fiberoptic rather than a copper wire data bus. When an assessment of wire weight reduction was done it was observed that the weight of wire data buses to serve relatively small distributed controllers, such as those associated with individual actuators, almost equalled the weight of the dedicated sensor and valve wiring replaced. Thus unless the data bus can be lightened (i.e., fiberoptic) the payoff of high temperature electronics is limited to the inlet and engine control application where the controller functions as a data concentrator. It is also important to note that the weight penalty for air cooling a group of closely grouped electronics boxes such as the inlet and engine control units is relatively small, on the order of 8 pounds per nacelle. Thus the weight benefit claimed for high temperature electronics is only applicable if forced air or fuel cooling of the electronics is ruled out to eliminate the safety, reliability, maintainability and cooling line routing problems associated with it.

In the centralized system cooling air is required at the nacelle for inlet pressure transducers and for the engine control unit. In the distributed system no cooling air is required beyond that provided by allowing some inlet exit air to provide flow through cooling of the nacelle. In both cases the engine control unit is engine mounted.

3. **Active Control:** This category includes CCV SAS (part of the manual flight control technology issue), flutter suppression, maneuver and gust load alleviation, and active control of aircraft flexible modes. The difficulty in assigning weight benefits in these areas is that the results are strongly configuration and certification

ground rule dependent. For example a metal aircraft benefits substantially more from active flutter suppression than a stiffer composite aircraft. If hard maneuver limits are implemented and allowed to be used for computing maximum aircraft loads for certification substantial weight reduction is possible. The 10000 pounds TOGW reduction shown in Figure 5-2 is an engineering estimate based on various internal studies of the probable collective contribution of the various forms of active control. Because the design of gust load alleviation systems is dependent on definition of the disturbance environment this issue is also a rank of 3 under weights.

4. **Control Algorithms:** This category estimates the combined benefits that result from all the propulsion and flight control algorithms affecting vehicle performance and includes engine/inlet control integration, performance seeking control, trajectory optimization, etc. A recently published NASA paper (ref. 21) assessed the weight benefits potentially accruing to an HSCT for various integrated flight propulsion control concepts based on a series of tactical aircraft research programs. The total improvement projected was roughly 4% TOGW. Because the benefits are not necessarily additive and because the magnitude of the benefits in a modern cruise optimized airplane may be less than that achieved in an older tactical airplane the paper's estimate was arbitrarily cut to 2% TOGW.
5. **Vision Enhancement:** Vision Enhancement in this context means replacement of forward looking windows and a droop snoot with an all weather window like display. The indicated weight reduction was achieved by removing the weight of the droop snoot related hardware (1200 pounds) and adding back an estimated 400 pounds of electronics and displays required to provide an adequate window like display.
6. **Improved Sensors:** The indicated weight reduction is a rough estimate of the impact of performance benefits resulting from using Ladar and infrared imaging techniques to identify disturbances before the inlet encounters them and of measuring shock position with higher accuracy and bandwidth than heretofore possible. The performance benefit estimate is based on a review of results reported in (ref. 13).
7. **Flight Critical Systems Architectures.** Bidirectional databuses can be used to reduce wire weight (item 2). The level of consolidation and redundancy of flight critical functions can significantly affect system weight.

- 29
8. **HIRF/EMI Immunity:** Providing HIRF/EMI protection in a composite airplane can have an adverse impact on weight, depending on data signaling media (wire or fiberoptic) technology.

#### 5.1.4 Reliability/Maintainability Issues

Issues which impact vehicle reliability/maintainability are tabulated as follows:

1. **Built-in Test/Central Maintenance.** High availability systems, that continue to operate properly in the presence of component failures, will have to be able to detect failures with a high degree of coverage and keep track of overall system status.
2. **Flight Critical Systems Architectures.** Proper integration of flight critical system functions can decrease complexity that will affect maintenance cost.
3. **Actuation Technology.** Actuation system and component failures are factors in maintainability and overall reliability. Actuation system failure rates have been reduced to acceptable levels in subsonic aircraft. However the larger number of actuators and the severe temperature environment could raise the number of failures to unacceptable levels unless development and extensive testing of seals and fluids in a realistic environment is conducted.
4. **Flight System Data Bus Technology.** Bidirectional buses in the engines and wings eliminate wires (that add weight and can break) and connectors that are failure prone.
5. **High Temperature Electronics (including connectors).** By making bidirectional bus terminals feasible in the engines and wings, a large number of connector pins associated with dedicated signal wires can be eliminated. This will significantly improve system reliability since it is generally recognized that wiring, principally connector, faults are a major source of control system unreliability. Experience has shown on various programs that wiring harness failures usually constitute at least 30% of the unreliability of a system. Due to their intermittent nature and frequently difficult access they generate an even higher percentage of the control system maintenance activity. As stated by Ganley (ref. 18), "As important as any other improvement for the next generation will be an electrical connector that will work reliably at the temperatures to be found in a supersonic engine bay."
6. **General Flight and Propulsion System Architectures/Single Event Upset Phenomena/Computing Hardware Improvements.** To support higher utilization, the HSCT will have to be more integrated (i.e., fewer, more

reliable LRUs) than subsonic transports. Poorly designed system architecture and redundancy management can impact design complexity, safety and increase maintenance cost. Random changes to semiconductor memory will undermine mean-time-between failure rates for most electronic systems, unless compensated in the engineering design. Higher speed and density computing components makes integrated modular electronic components that share processing resources more feasible.

7. **Active Flutter Suppression.** The additional complexity due to sensors actuators, and computer hardware tends to decrease flight system reliability and affects maintainability adversely.
8. **Propulsion System Automation/Engine-Inlet Control Integration/ Inlet Sensor Fault Accommodation.** The HSCT propulsion system will be substantially more complex than prior commercial propulsion systems including Concorde. HSCT will operate without a flight engineer. Therefore not only must a fully automatic rating, limiting, and regulation system be included in the control to permit the pilot to position the throttle at will anywhere in the flight envelope, but also an automated fault identification and accommodation system must be incorporated both for in-flight safety and post-flight maintenance.
9. **Wing Load Alleviation.** Gust load alleviation (GLA) and maneuver load alleviation (MLA) can both affect reliability and maintainability adversely. GLA requires complex multifunction sensors and both functions require higher bandwidth flap actuators than do unalleviated designs.
10. **Augmented Manual Flight Control/Automatic Flight Control.** Effective building block design can eliminate unnecessary duplication of functions and complexity in the SAS/CAS and the automatic flight control system that can adversely affect flight system maintainability.

#### 5.1.5 Schedule Issues

Technology schedule issues which must be resolved prior to the start of the HSCT technology demonstration (1995) are assigned the highest priority. Those issues that can be resolved between the start of the demonstration (1995) and program go-ahead (year 2000) are ranked as lower priority. In general, this represents a need to demonstrate more mature technologies as elements of an integrated system, in a manner to prove that they are ready for commercial application.

1. **Actuation Technology.** Composite, high pressure, high temperature smart actuator technology needs to be ready for the demonstration of actuator prototypes in laboratory and flight test scenarios, beginning in 1995.
2. **Vision Enhancement Technology.** Sensor and computer generated imagery technology needs to be ready for the 1995 demonstration and proof of concept to be available for the 1998 go-ahead for full scale development synthetic vision.
3. **HSCT Certification.** Unique requirements for HSCT flight certification should be available to influence technology decisions for the 1995 demonstrations.
4. **High Temperature Electronics/Electronic Cooling.** High temperature electronic device technology or cooling technology needs to be ready for the 1995 demonstrations of flight and propulsion control system prototypes.
5. **High Altitude Air Data.** The readiness of competing high altitude, non-intrusive air data technology needs to be flight demonstrated under critical conditions before being selected to support flight and engine control algorithm designs
6. **Multi-function Sensors.** Multi-function sensors are new technology that is critical to some forms of vision synthesis and to unstart prevention algorithms. Technology issues should be resolved to support flight demonstrations beginning in 1995.
7. **Multi-disciplinary System Engineering Tools.** Considering the CCV preliminary design requirements for interaction between structures, propulsion, aerodynamics and flight controls, the tool integration standards should be already established. Work-arounds and brute force methods are still being used to coordinate design data at this time. If tool standards are not in place by 1995 the program schedule could be at risk. Appropriate vehicle simulations and system reliability models must be in place before flight control system architectural design can be validated.
8. **Augmented Manual Flight Control/Flight and Propulsion Control Integration.** A common control strategy for augmented manual and automatic flight control mode will facilitate the use of the SAS as an innerloop for the automatic flight control modes, and reduce the integration task. Detailed attention to the integration of control algorithms, control feel system, and displays will be needed to reduce schedule risk. If fibre-optic sensors are to be used, technology reliability would need to be demonstrated, to reduce schedule risks.
9. **Active Flutter Suppression.** Active flutter suppression could become a schedule risk item if flutter prediction is found to be deficient. Extensive

technology demonstrations would be needed to reduce risks in terms of system performance, safety and reliability.

- 10. Active Flight Envelope Protection.** The integration of flight envelope protection with augmented manual and automatic flight control will be a challenging task, requiring early and detailed attention.

#### 5.1.6 Special Benefits

Some issues have an impact on other characteristics of the HSCT than those categories featured in this report. Issues which provide special benefits, other than the main categories, include:

- 1. Multi-disciplinary System Engineering Tools.** The introduction of powerful, multidisciplinary system engineering tools makes it possible to communicate requirements from discipline to discipline. The use of such tools should improve design quality, and reduce the cost of initial development and of updating flight and propulsion systems. Detailed airframe/system simulations and models are needed to develop high quality control algorithms and resolve design issues. Some issues such as flutter suppression can only be addressed if the aeroservoelastic models accurately predict airplane behavior. The flight system architecture must be analyzed by reliability models, and validated through simulations, analytic means, as well as tests and demonstrations to prove that safety and performance requirements are met.
- 2. HSCT Certification.** While not specifically a technology issue, major technology benefits cannot be realized unless a way to certify them for commercial airplane application has been worked out (i.e., vision enhancement, special HSCT trajectories and active controls are new to commercial air transports and may require modification of the CFR and ATC regulations to be accommodated.)
- 3. Automatic Flight Control (Flight Management).** The design approach for the automatic flight control and flight management function can significantly influence the resulting avionics/flight systems hardware architecture, the total amount of flight certified software, and the need for certification flight testing. A hierarchical functional design, using a building block approach with a generalized (point-mass) multi-input/multi-output control strategy that can serve all automatic and pilot in the loop control modes, will greatly simplify control algorithms, improve performance, and avoid functional overlap.

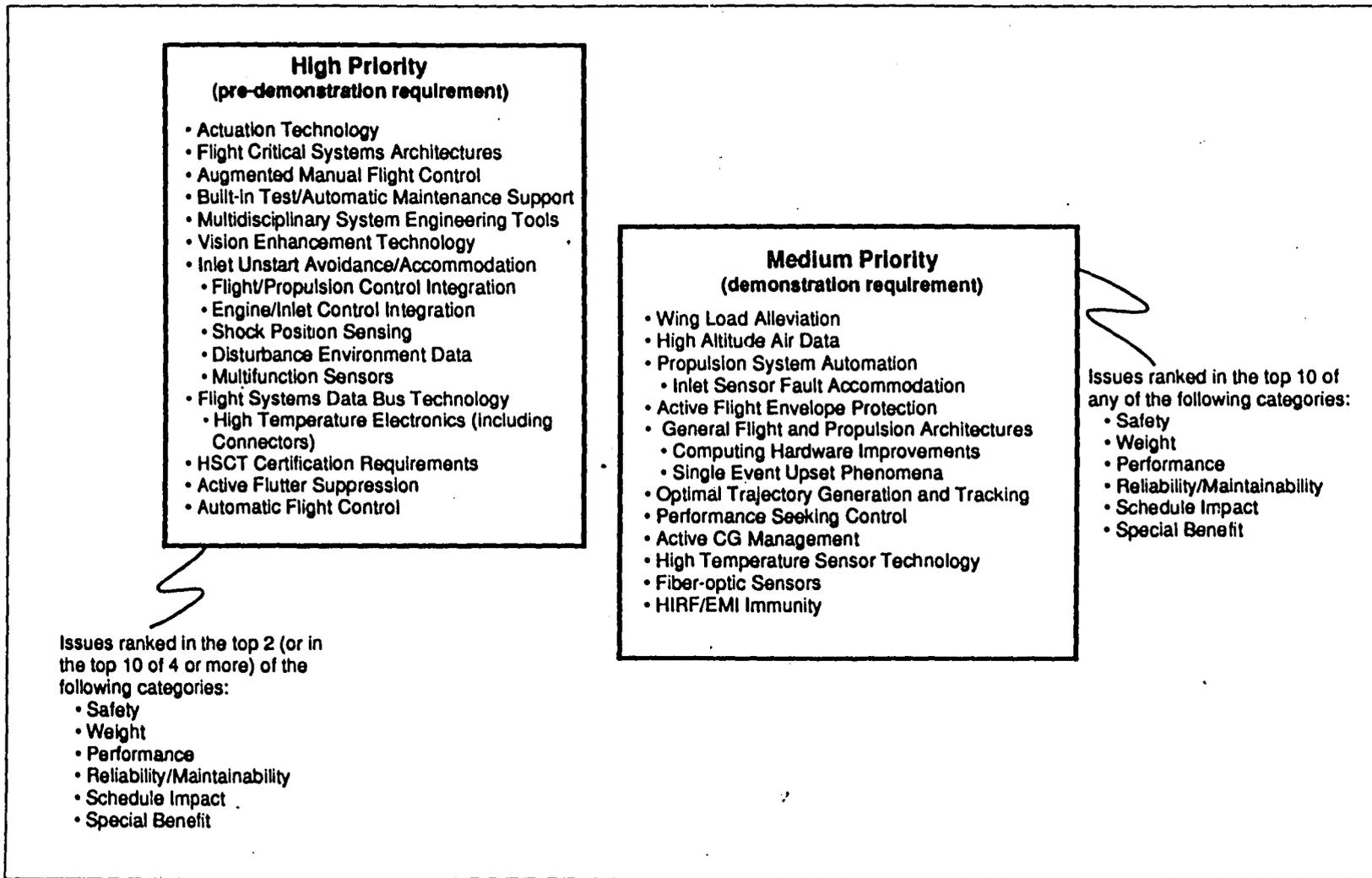
This approach reduces control algorithm software by two-thirds, compared to mode-by-mode design, facilitates subsystem hardware integration and reduces flight testing substantially because the common innerloop design is the only design uncertainty that requires flight testing to verify.

## 5.2 Priority Summary

The issues are subdivided into high and medium priority categories, as shown in Figure 5-3. High priority issues are those that are essential to developing an optimized HSCT control system and generally have long lead time. The medium priority issues are either less critical or constitute design/technology development tasks that can be accomplished in the time schedule for program go-ahead. Issues that are not included in any of the benefit category priority lists are considered low priority for HSCT development. None of the issues identified in this report are low priority.

The issues tabulated below in priority order are considered to be high priority, because they are either 1) the first or second issue within a benefit category, 2) they impact four or more benefit categories, or 3) they are required to implement a first or second priority issue:

1. Actuation Technology. Weight (1), Schedule (1), Reliability (3)
2. Flight Critical Architectures. Safety (1)
3. Augmented Manual Flight Control. Safety (3), Performance (1), Weight (3)
4. Built-in Test/Central Maintenance. Reliability/Maintainability (1)
5. Multi-disciplinary System Engineering Tools. Special Benefit (1)
6. Vision Enhancement Technology. Safety (2), Schedule (2)
7. Unstart Avoidance/Accommodation Performance (2), Safety (5)
  - Flight Propulsion Control Integration-(support unstart avoidance)
  - Engine/Inlet Control Integration-(support unstart avoidance)
  - Shock Position Sensing-(support unstart avoidance)
  - Disturbance Environment-(support unstart avoidance)
  - Multifunction Sensors-(support unstart avoidance)
8. Flight Systems Data Bus Technology. Weight (2).
  - High Temperature Electronics or Electronic Cooling-(support data bus).
9. HSCT Certification. Special Benefit (2): Commitment basis for new technology
10. Active Flutter Suppression. Safety (9), Performance (4), Weight (3), Reliability (7), Schedule (9)



*Figure 5-3 Flight/Propulsion Controls Issue Priority Summary*

- 7.
11. Automatic Flight Control. Safety (8), Reliability/Maintainability (10), Schedule (8), Special Benefit (3): Cost

The following medium priority issues are tabulated in order of estimated importance to HSCT viability and schedule:

1. Wing Load Alleviation. Performance (4), Weight (3), Reliability/Maintainability (9)
2. High Altitude Air Data. Performance (7), Weight (6), Schedule (4)
3. Propulsion System Automation. Weight (4), Reliability/Maintainability (8)
  - Inlet Sensor Fault Accommodation-(support propulsion)
4. Active Flight Envelope Protection Safety (4), Schedule (10)
5. General Flight and Propulsion System Architectures. Reliability/Maintainability (6)
  - Computing Hardware Improvements-(support general architectures)
  - Single Event Upset Phenomena-(support general Architectures)
6. Optimum Trajectory Generation and Tracking. Performance (5), Weight (4).
7. Performance Seeking Control. Performance (8) Weight (4)
8. Active CG Management. Safety (7), Performance (6)
9. High Temperature Sensor Technology. Weight (6)
10. Fiberoptic Sensors. Reliability/Maintainability (8), Schedule (8)
11. HIRF/EMI Immunity. Safety (10), Weight (8)

## 6.0 Technical Development Approach

The overall schedule for the technology development program is shown in Figure 6-1. This program consists of: 1) technology research and development to address the issues raised in Section 4.0 and 2) a technology demonstration intended to validate the technologies in an integrated system. The technology development efforts have already been initiated at a low level on corporate IRAD but will require HSR focused funding to be ready to begin demonstrations by 1995. The schedule shows the technology demonstration starting in January 1995, to be completed by October 2000, the currently planned go ahead date for the HSCT program. The general position of this report is that all of the technologies identified in the report should be thoroughly evaluated on the ground and, in almost all cases, demonstrated in flight before being applied to production design. This is especially true for new technologies that are unique to the HSCT.

### 6.1 Technology Development

The technology development efforts are grouped to correspond to the issue categories established in section 4.0: Control Laws, Hardware Technology, System Engineering and Architecture.

**Control law studies** consist of largely independent studies of the benefits and implementation details of various flight and propulsion control algorithms and design alternatives. Subsequently, in the design and fabricate phases of the demonstration, control law elements will be brought together into an integrated system.

In the **hardware technology** development phase, elements of the system will be raised to a level of maturity where they can be incorporated into a demonstration system. The hardware technology development phase will concentrate on high temperature sensors, electronic devices and connectors, actuator fluids and seals. It will also address unique requirements such as sensing inlet normal shock position, and determination of conditions ahead of the airplane.

**System engineering tools** should also be demonstrated prior to final HSCT design. The most practical time for that demonstration is during the design of the demonstration system itself. Thus the most complete set of "beta" test versions of the tools that it is possible to assemble and integrate by 1995, should be used throughout the flight and

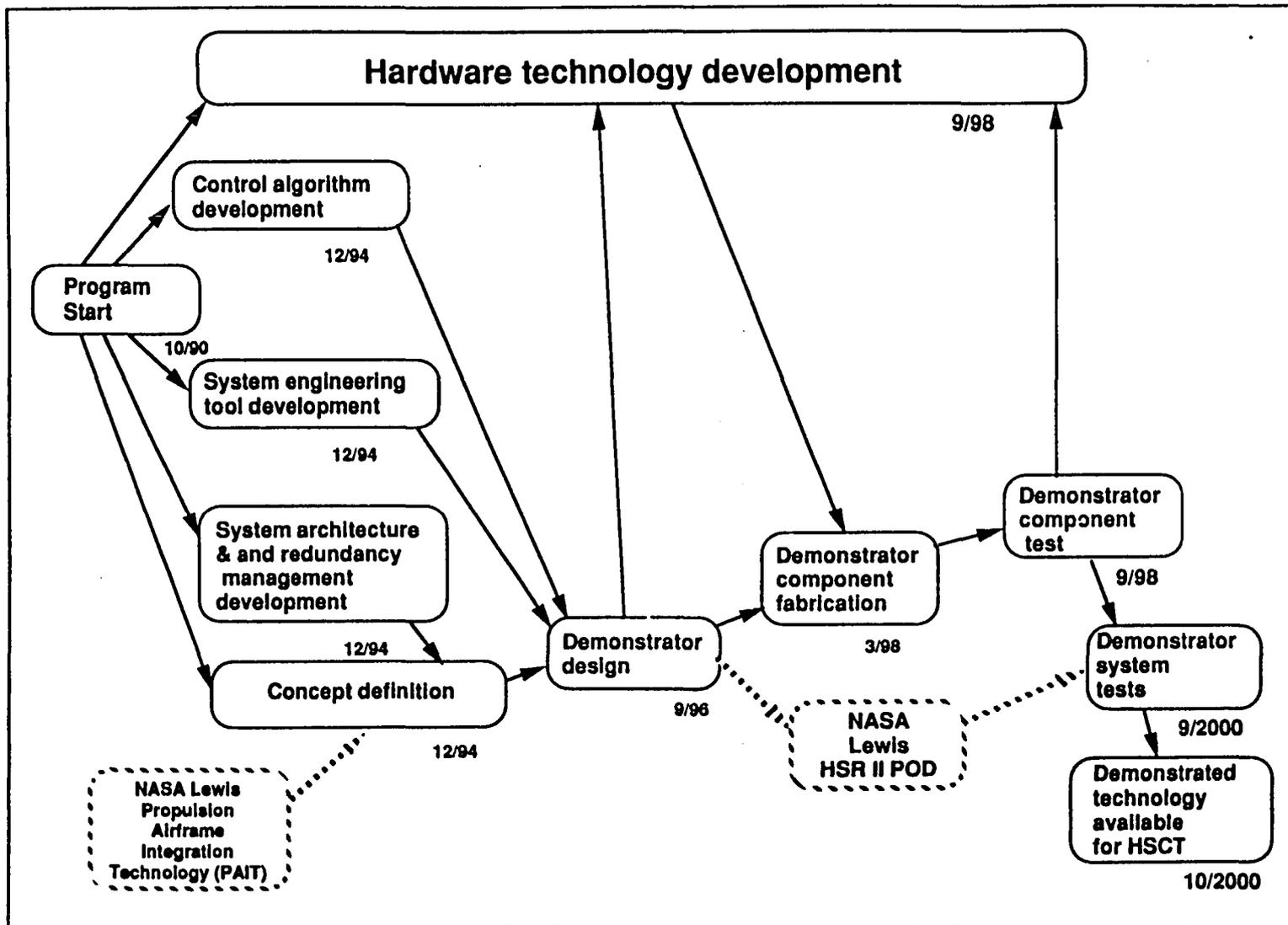


Figure 6-1 Technology Development Plan

systems demonstrations. These tools will be evaluated by application in the design, fabrication, and test of the demonstration system in order to be ready for full scale HSCT design.

The system architecture studies will establish the system architectural concept as a starting point for demonstration system design. Although these studies are shown as an independent entity they are in fact strongly affected by efforts in the other areas since the hardware and control law technology available have a strong effect on the selection of system architecture.

#### 6.1.1 Control Law Studies:

The control law studies to be conducted are depicted in Figure 6-2. There are 14 studies organized to correspond to the issues raised in section 4.0. Those shown on the upper part of the figure are largely flight system oriented, those on the lower part are propulsion oriented. The efforts are parallel and although substantial data is exchanged between them they proceed independently until sufficient information is gathered to develop a design concept for development in the system demonstration phase. The demonstration system design concept will include provision for all algorithms which appear to have promise in a production system even though this may imply carrying multiple approaches to a particular problem through the demonstration phase. The demonstration will validate technology elements, not a production prototype system.

##### 6.1.1.1 Augmented Manual Flight Control

**Task Description:** Conduct trade studies to determine the relative merits of various SAS/CAS design concepts in terms of:

1. handling qualities and pilot workload
2. impact on airworthiness certification
3. impact on pilot training and type rating
4. performance in turbulence and windshear
5. complexity of design impact on system performance and safety.
6. design compatibility with automatic control modes

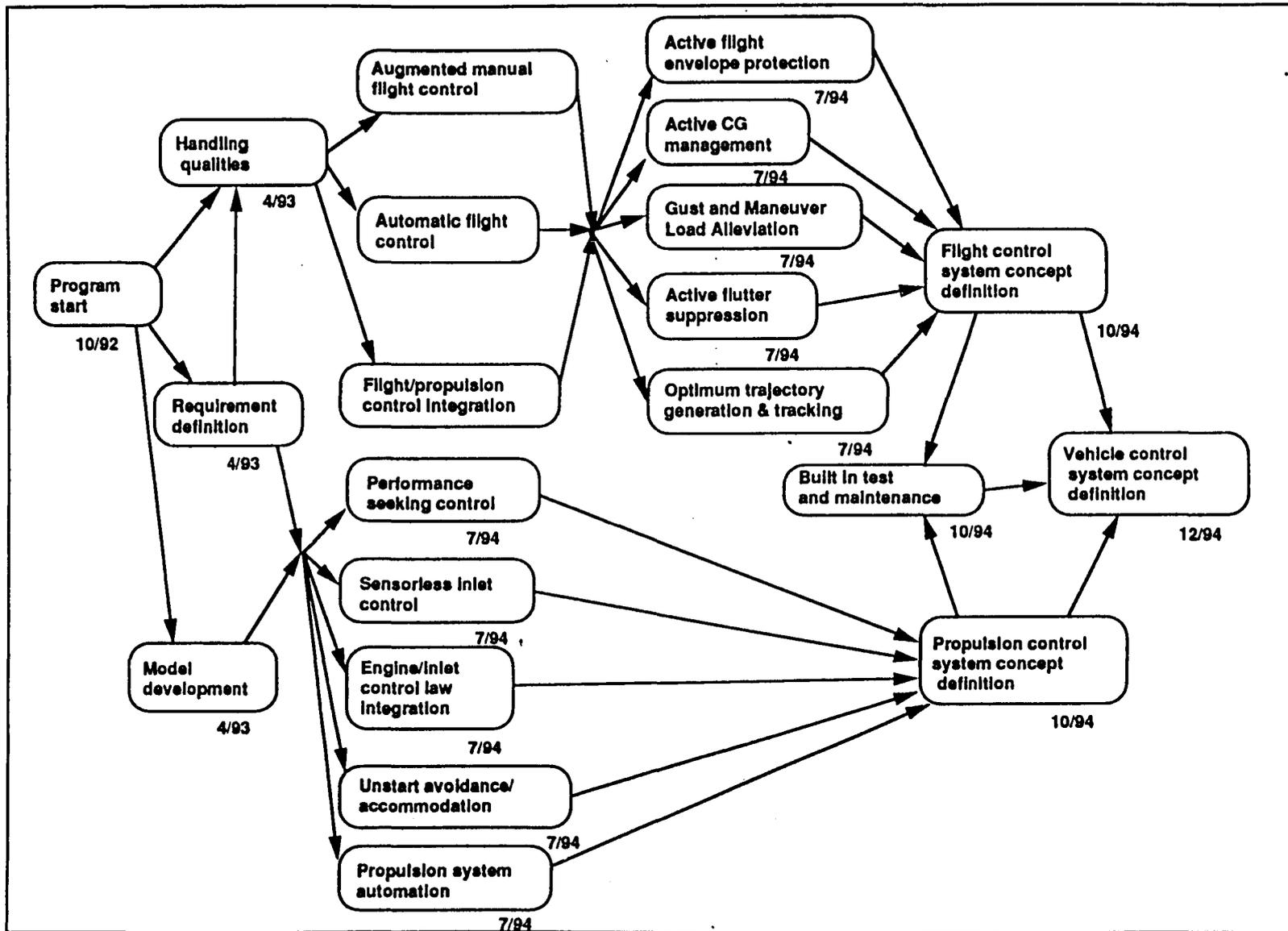


Figure 6-2 Control Algorithm Development

Conduct an HSCT control augmentation study and determine the minimum safe and acceptable handling qualities that must be provided if the primary stability and control augmentation system has failed.

Conduct research relative to manual/automatic flight systems interfaces appropriate for a year 2005 HSCT, addressing:

1. flight control and flight management functions to be provided
2. effective complement of sensors
3. pilot displays
4. pilot controls and interfaces with automatic systems
5. pilot communication with air traffic control, air carrier operations, and passengers
6. system criticality, redundancy, and levels of degraded control capability

Investigate the affect of limited outside vision (due to vehicle configuration) on terminal areas operations and landing. Determine key display information and format needed to make pilot controlled landing with limited outside vision safe and acceptable. Conduct simulated synthetic vision research to determine general system requirements.

Conduct detailed HSCT pilot-in-the-loop simulations, using high fidelity vehicle dynamics, candidate flight and propulsion system models, a representative HSCT flight deck geometry and vision system, candidate flight instrumentation layout and control loading provisions, as well as a high fidelity flight deck motion system. Investigate various control handling qualities and human factors aspects and issues related to manual flight safety and pilot acceptance of the proposed HSCT configuration, i.e.

1. integration of controls, displays and feel systems
2. flight instrument layout, information content/format and medium (i.e., head-up/head-down)
3. pilot and co-pilot task integration
4. recognition and handling of emergency conditions (i.e., back-up flight control modes and instruments)
5. pilot workload under normal and emergence conditions

Determine if satisfactory handling qualities, performance and safety can be achieved for critical flight operations such as final approach with turbulence and wind shear, using manual throttle control. Evaluate various multi-input/multi-output flight path angle control design options:

1. Conventional "front side" piloting, using column to control flight path, and throttle to control speed.
2. Alternate "back-side" piloting, using throttle to control flight path, and column to control speed.
3. Decoupled control, where pilot input is automatically coordinated into elevator and thrust commands to yield a response of only flight path or speed, as desired.

Evaluate the impact of various primary flight display information concepts on handling qualities and performance.

Determine the impact of using direct lift control surfaces on the wing to enhance short term vertical acceleration response (i.e., to reduce pitch attitude excursions).

Evaluate multi-input/multi-output control concepts providing inherent turn coordination, yaw damping, engine-out trim, and uniform, satisfactory handling characteristics in all flight conditions.

#### 6.1.1.2 Automatic Flight Control.

**Task Description:** Develop methods for applying modern control theory techniques (LQG,  $H^\infty$ ,  $\mu$ -synthesis, etc.) for design and analysis of innerloop control in conjunction with Total Energy Control (TECS) for the longitudinal outerloop and Total Heading Control for the lateral-directional outerloop structure. Conduct fundamental flight path and speed control performance trades for a full state feedback design with a total energy control outerloop mode structure:

1. using various flight path/speed control bandwidths, and
2. showing transient command responses, stability, cross coupling responses, tracking performance, and control activity in turbulence and wind shear.

Conduct a benefit versus design complexity trade study, using inverse non-linear aerodynamic and propulsion force and moment modelling to develop coordinated control commands to minimize undesirable cross coupling disturbances in flight path and speed control. Investigate various approaches to reduce the number of feedback sensors while maintaining system performance, using Kalman Filtering or other feedback signal synthesis technologies. Investigate the effects of automatic flight control on flight deck and passenger comfort.

#### 6.1.1.3 Active Flutter Suppression

**Task Description:** Develop a multi-disciplinary approach, involving structures, aero and systems, for demonstrating flutter prediction accuracy on HSCT representative flutter wind tunnel models over a range of dynamic pressure, air density and mass distribution, Determine key reasons for success and failure. Develop follow on programs to address any technology short fall.

Develop a program for demonstrating the effectiveness of active flutter suppression system design approaches. Identify key technology prerequisites for successful active flutter suppression designs in terms of modelling methods, analysis tools, control law design and hardware/software implementation.

Conduct a sensitivity study to determine the required accuracy of vehicle state knowledge needed for satisfactory vehicle flutter suppression. Determine sensor accuracy and actuator duty cycle requirements for flutter suppression; and determine system viability and technology shortfalls.

#### 6.1.1.4 Gust and Maneuver Wing Load Alleviation

**Task Description:** Conduct benefit/cost analyses for a gust load alleviation system on an HSCT. Determine the impact of such a system on passenger ride comfort at various stations in the passenger cabin. Determine key requirements for forward looking aircraft state sensors (i.e., lead time for optimal gust attenuation).

Conduct a benefit analysis for a maneuver load alleviation system.

#### 6.1.1.5 Active Flight Envelope Protection

**Task Description:** Conduct flight envelope protection research to develop a preliminary consensus of requirements for the functional characteristics of flight envelope parameter limiting functions (i.e., hard versus soft limiting, control bandwidth, damping, control priority, pilot override capability by control force or by other action). Consider vehicle performance implications in turbulence, windshear, operations for takeoff, landing climb, cruise and descent under normal and emergency operations (i.e., engine out) and partial flight control failures. Develop concepts for integrating various flight envelope protection features into the pilot-in-the-loop and autopilot control systems. Conduct design analyses

for the various protection functions and evaluate the emerging concept through piloted simulations.

Military propulsion systems impose envelope limiting on the engine.

#### 6.1.1.6 Active CG Management

**Task Description:** Investigate ways to integrate an automatic weight and balance function using nose and main gear sensed pressures/displacements with an automatic takeoff stabilizer trim setting function. Develop ways to incorporate this trim function in the basic automatic control system, allowing for a fixed stabilizer setting during takeoff, manual override capability and reversion to a "flying stabilizer" for rotation and normal in-flight operations.

#### 6.1.1.7 Propulsion System Automation

**Task Description:** Determine the propulsion system modes of operation over the flight envelope. Establish the mode transition criteria, and develop algorithms/logic to automatically achieve the mode transition. Inlet starting is an example of an event which may require unique logic to transition from one operating mode to another.

Based on the above information, define the pilot interface with the propulsion system for both normal and abnormal operation. Since the intent of the system is to provide the pilot with a fully automated system, the task is to determine under what circumstances the pilot might wish to override the automatic system and how such overrides should be implemented. Since operation of the propulsion system is largely automatic and pilot involvement will only be required under abnormal circumstances, this task is closely related to the condition monitoring task, see below.

#### 6.1.1.8 Engine/Inlet Control

**Task Description:** Control system algorithms are developed as shown in figure 6-3. Four operating points will be addressed in the study. The first is cruise, the second is emergency descent, the third is start/unstart/restart transition at Mach = 1.6, and the fourth is noise abatement approach. In each study representative Mach number and altitude variations around the nominal operating point will be considered but no attempt will be made to create a full envelope operating capability. The flow for each task is essentially the same.

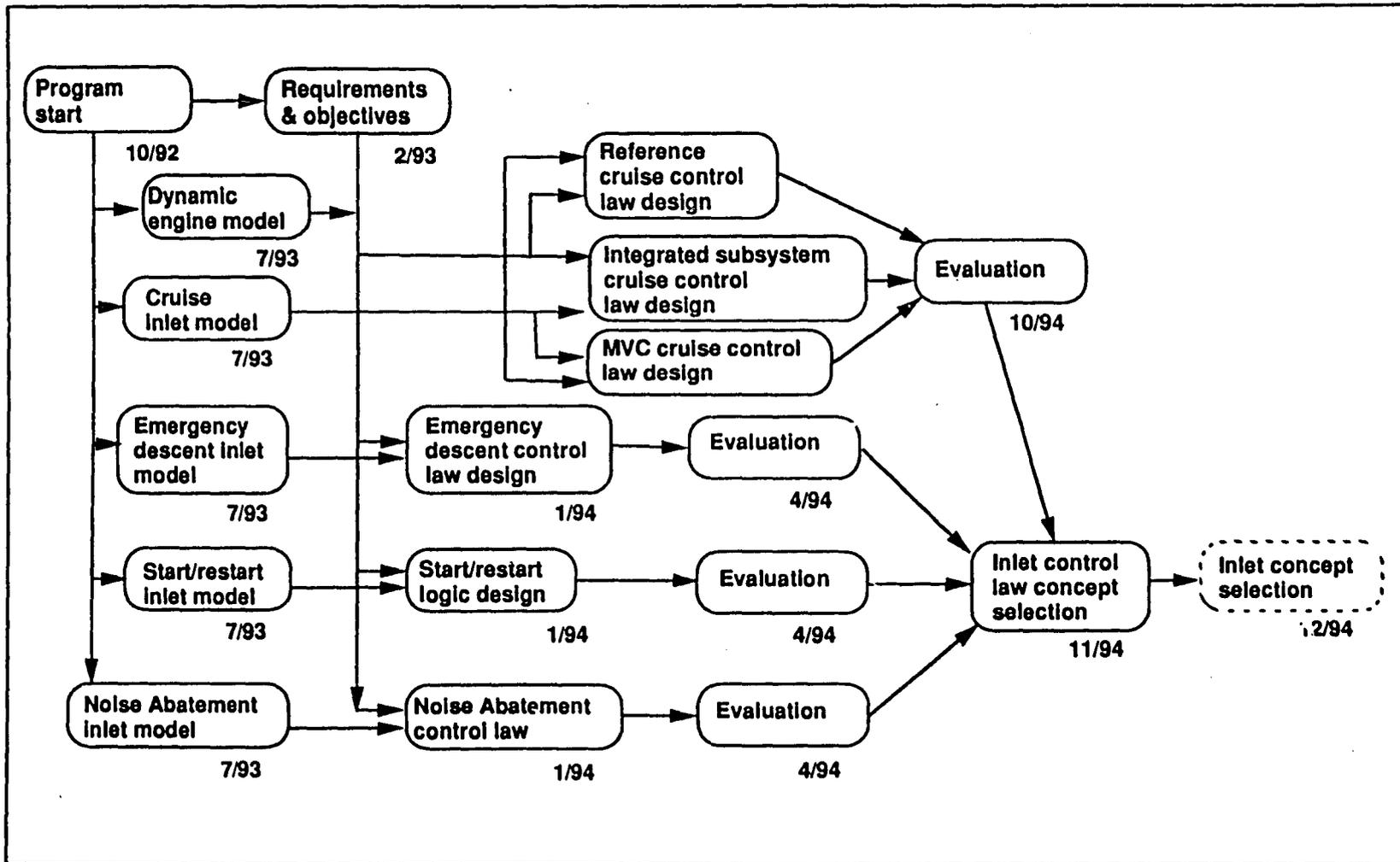


Figure 6-3 Inlet/Engine Control Integration

**Model Development:** The necessary model development is assumed to be partially completed under IRAD prior to initiation of contracted work in FY 1993. The models are completed by mid 1993 to support the analysis work. An aerothermodynamic engine model with full envelope capability defines the engine characteristics for study. Specialized inlet dynamic models are developed for each operating region. In some cases multiple models may be used. For example a 3-D viscous CFD model may be used to derive data for incorporation into a lumped parameter model for use in analysis of the cruise condition. The models developed and the development process itself also contribute to the process of developing system engineering tools to be used in the technology demonstration phase.

**Control Algorithm Development:** Objectives and requirements for each control algorithm are developed in parallel with model completion. Control algorithm design to satisfy the requirements is initiated when the model is available. Although the control modes are substantially different, in that the objectives and to some degree the feedbacks are different at the different operating conditions, an emphasis is placed on casting them within a common organizational structure, and on minimizing the number of different actuators and sensors required to satisfy the functions. The efforts on noise abatement, Mach 1.6 transition, and emergency descent are completed within a year since they are relatively simple problems.

The objectives of the cruise control law design studies are to:

1. Demonstrate viable inlet and engine control laws for a typical HSCT propulsion system
2. Quantify the benefits of control integration
3. Quantify the benefits of alternative control law development techniques.

The primary control requirements addressed by the cruise control law design study are minimization of shock static margins (inlet recovery maximization), and constant distortion margin maintenance (increased engine efficiency) in conjunction with stall/unstart/surge-free operation for realistic disturbances and component variability and degradation.

In order to achieve these objectives three control laws are designed over a period of a year and a half: 1) the baseline control law uses an absolute minimum of communication between the airframe, inlet, and engine control systems. This design, which is expected to have high actuation bandwidth requirements, is used as a reference for the other two integrated designs; 2) because a number of effectors is available to modulate inlet duct exit airflow and they have differing effects on distortion, thrust, recovery, and drag, it may be

beneficial to cast the integrated design problem as a multivariable one, and 3) It is possible to view the problem as the integration of two local subsystems: the engine or airflow pump and the inlet or airflow source. Since both approaches have advantages and disadvantages the approach is for two groups to address the problem in parallel. One group casts the problem as a multivariable design problem viewing the entire plant ( airframe/inlet/engine) as one system to be controlled while the other looks at the problem as one of integrating three locally controlled subsystems with free communication between the subsystems.

The evaluation process then compares the results of the three design efforts in terms of computational resource requirements, actuation and sensor performance requirements, propulsion system cruise performance, and compatibility with certification and organizational constraints. Based on the comparison one or more of the design concepts will be selected for full envelope application in the demonstration phase.

The NASA Lewis HSR II pod program is expected to address many of the activities outlined in this task in the 1993 1994 time frame.

#### 6.1.1.9 Inlet Sensor Fault Accommodation

**Task Description:** The issue to be resolved with regard inlet sensor fault accommodation is whether or not the model and Kalman filter used to replace pressure sensor feedbacks can provide adequate accuracy using real world noisy air data and engine airflow signals. Although in the long run the concept requires validation on a mixed compression inlet, useful development information could be obtained by implementing the system for the F-15 inlet and flight testing it on the HIDEDEC F-15. This particular airplane is chosen because the necessary data base for designing the control mode is conveniently available and the airplane is already configured with hardware required to implement it. A flight test implementation is selected since it insures in the most direct manner possible that all the real world variability that must be considered is correctly taken into account.

#### 6.1.1.10 Flight / Propulsion Control Integration

**Task Description:** Establish a satisfactory interface between the propulsion and flight control systems and demonstrate, at key design points, successful integration of the two systems. A satisfactory interface definition is one that balances simplicity required for reliable operation with the complexities created by the multiple operating modes (functions) of both systems and commercial requirements for fault isolation and accommodation.

The flight /propulsion control interface has numerous functional components:

1. Thrust command and feedback,
2. Air data and feedforward commands to the inlet control system,
3. Unstart/surge/restart coordination,
4. Noise abatement coordination,
5. Fault isolation and redundancy management,
6. Thrust limit information, and
7. Engine performance data for flight management prediction algorithms.

An interface will be defined for two key design points, landing approach and Mach 2.4 cruise. The remainder of the flight envelope will be reviewed to identify any required additions to the interface definition. The interface definition will include data base definition, sample rate and signal bandwidth requirements, propulsion system dynamic response requirements, and aircraft response requirements. The interface definition will become part of the design requirements for algorithm development planned within other tasks. The propulsion and flight control law designs developed for these design points as part of the other tasks will be integrated and evaluated using appropriate analyses and simulations. The evaluation results will be used to establish the necessary flight/propulsion control interface definition with which to start the demonstration phase.

#### 6.1.1.11 Unstart Avoidance/Accommodation

**Task Description:** Unstart avoidance will be addressed in the development of the integrated inlet control law discussed in section 6.1.1.8 above. Unstart accommodation in so far as it implies automatic restart will be addressed in the propulsion automation effort discussed in section 6.1.1.7. In addition a study will be conducted to establish the best strategy for minimizing passenger disturbance resulting from an unstart. Two concepts have been considered in the past: sympathetic response of the opposite inlet to achieve matched operation of the two propulsion systems as rapidly as possible, and automatic rudder/spoiler kickers. Unfortunately both of these techniques produce major disturbances if they are engaged due to a spurious signal. Therefore significant effort will be devoted to developing techniques for validating unstart indications in addition to simply countering unstart. This capability of the basic lateral directional airframe control to provide adequate engine inlet unstart/engine out dynamic response attenuation must be investigated.

#### 6.1.1.12 Optimum Trajectory Generation and Tracking

**Task Description:** Techniques for generating optimum trajectories have been established for both subsonic and supersonic application over the last twenty years. Studies will be conducted to determine optimum trajectories for HSCT missions and to establish the penalties for deviating from them to satisfy ATC and passenger comfort constraints. Studies will also be conducted to identify any HSCT unique problems associated with tracking these trajectories.

#### 6.1.1.13 Performance Seeking Control

**Task Description:** The control laws discussed elsewhere assume a deterministic plant and do not address redundancy management. Therefore in this study a model of the installed propulsion system will be developed for the region around the cruise operating point. An analysis of the steady state behavior of the plant model taking into account anticipated component and operating point deviations from the nominal will be conducted. This study will serve to 1) establish the nominal optimum configuration of the propulsion system which will serve as the setpoint information for the deterministic control law developed in task 6.1.18, and 2) establish the performance penalties associated with operating the system based on the deterministic model with real world variability in component performance. If significant performance penalties are found performance seeking logic will be developed and demonstrated at the cruise design point. An additional related study will be conducted to determine the performance consequences of using model data to replace that normally provided by a failed sensor or set of sensors. Error data developed in task 6.1.1. will be used as input to this study defining the model accuracy. An evaluation of the results of these studies will be conducted to establish which control law elements show sufficient promise to be incorporated in the demonstration.

#### 6.1.2 Hardware Technology

As shown in figure 6-4 there are a large number of hardware technologies which need development to improve HSCT economic viability. In each the minimum program required to position the technology for demonstration in a system in the 1995 time frame is outlined in the following paragraphs.

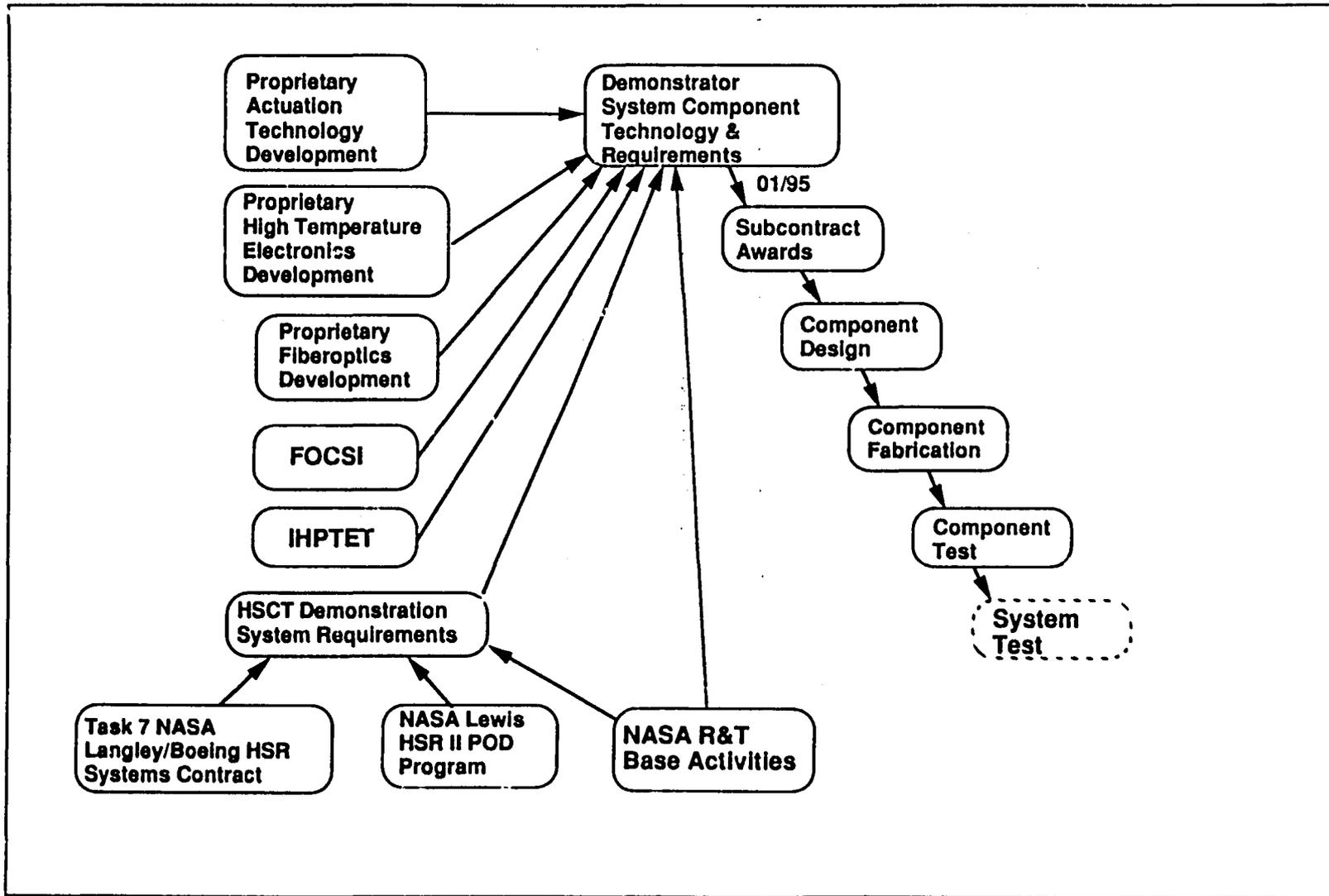


Figure 6-4 Hardware Technology Plan

#### 6.1.2.1 Actuation Technology

**Task Description:** There are four critical areas in actuation technology: temperature, maintainability and advanced materials and advanced capabilities. Substantial work, that has been done in these areas on a variety of other programs, should be focused on the purposes of HSCT during the 1993-95 time frame:

1. **Temperature.** Hydraulic fluid that meets HSCT heat absorption and rejection specifications would be tested using typical seals, valves, connectors, and materials under HSCT representative thermal cycles over an extended time. Fluid properties and the effects on components would be sampled periodically and noted. Fluid properties would be revised as indicated by the test results.
2. **Maintainability.** Actuators with long-life seals would be stroked over typical usage patterns for long periods of time. Seal behavior and leakage would be noted and corrections made.
3. **Advanced Materials.** Composites weigh as much as 30% less than conventional materials used in the same application. Comparable composite and conventional high pressure actuators would be fabricated and subjected to life cycle tests.
4. **Advanced Capabilities.** Remote actuator electronics for flight control (smart actuators) will eliminate a large amount of actuator wiring and connectors by commanding the actuators directly via the flight critical data bus and closing the position loop locally. It also provides the opportunity to simplify fault detection and redundancy management by incorporating self-monitoring.

#### 6.1.2.2 Fiberoptic Sensor Set

**Task Description:** Other programs are developing fiberoptic technology that can be applied to HSCT, with two notable exceptions: Shock sensing and high accuracy pressure transducers. In addition, components being developed on other programs do not generally meet HSCT temperature requirements. As a result the fiberoptics technology development effort consists of: 1) developing an optical shock sensor, 2) developing a high accuracy, high temperature pressure transducer, and 3) a review of the existing development programs against HSCT requirements to determine if any other directed development is required.

### 6.1.2.3 Vision Enhancement Technology

**Task Description:** Develop and evaluate computer generated imagery (CGI) displays for a synthetic vision system, featuring:

1. Terrain/ground feature depiction, considering information requirements, presentation techniques, perceptual evaluation,
2. Field of view requirements,
3. Pathway-in-the-sky techniques,
4. Instrument integration, and
5. Transport delay issues.

Develop and evaluate sensor based imaging displays, featuring:

1. Imaging sensor development,
2. Image quality evaluation,
3. Image processing enhancements, and
4. CGI issues 2,3,4, and 5 as they apply to sensor displays.

Develop and evaluate data fusion techniques, featuring:

1. Sensor/sensor fusion,
2. Sensor/CGI fusion, and
3. Dual displays (CGI and sensor)

Determine the best integration of synthetic vision into the air traffic control environment.

### 6.1.2.4 High Altitude Air Data

**Task Description:** Investigate high altitude static pressure sensor concepts that will provide altitude resolution at 65,000 ft. comparable to current sensors at sea level. Investigate the feasibility of flush mounted air data probes, providing static pressure, total pressure (or dynamic pressure), total temperature, angle of attack and sideslip.

Investigate optical laser radar (Ladar) true airspeed sensors and forward looking air data sensors for detection and avoidance of weather cells, windshear and clear air turbulence. Identify key issues and technology shortfalls. Develop signal processing concepts and requirements.

### 6.1.2.5 Multifunction Sensor Technology

**Task Description:** Survey the state-of-the-art in forward looking terrain and object imaging technology required for synthetic vision and all weather pilot situation awareness.

Identify key issues and technology shortfalls, and develop concepts for integrating this technology into existing avionics and flight deck systems

Investigate ways to reduce the number of RF antennas by applying digital (i.e. open systems interface (OSI)), rather than analog data transmission technology and by integrating data transmission functions. Develop flush mounted RF antenna concepts.

Determine the operational acceptability of using GPS/MLS as the navigation reference for future terminal area guidance and automatic landing.

Determine if GPS combined with on-board inertial navigation will be able to provide satisfactory terminal area and autoland guidance without a ground based system.

#### 6.1.2.6 Shock Position Sensing

**Task Description:** Develop a shock position sensor which satisfies the following requirements:

1. Shock position resolution of 1 millimeter,
2. Operable in the inlet thermal and vibration environment without cooling or vibration isolation,
3. Bandwidth greater than 100 hertz.
4. Intrinsically good reliability and maintainability characteristics.
5. Relatively simple interface and calibration requirements.

#### 6.1.2.7 High Temperature Sensor Technology

**Task Description:** Conduct a study to determine the availability of sensors meeting flight and propulsion control accuracy and environmental requirements. In cases where satisfactory transducers are not available off the shelf initiate development of appropriate devices.

#### 6.1.2.8 RF Sensor Technology

**Task Description.** Determine the minimum suite of conformal antennas for all RF functions considering the 1995-2000 capabilities of broadband, multifunction, shared aperture technology. Antennas and transmitters should be located as close together as possible for highest total system DC-to-radiated power conversion efficiency. Develop redundant, integrated sensor signal processing that can perform the functions required by the entire set of RF navigation, communication, and surveillance subsystems.

Develop fiberoptic network that can interface various RF subsystems, provided for common functions that can be shared, and reduce the potential for EMI leakage between subsystems.

#### 6.1.2.9 High Temperature Electronics

**Task Description:** The initial activity is a study to determine what semiconductor technologies best address the HSCT uncooled thermal requirement of 200 degrees C. and to determine the cooling options that would allow the use of conventional mil-spec electronics in the high temperature locations. The result of this study is to select one or more paths for developing high temperature semiconductor technology, and one or more paths for reliably cooling a conventional electronic control (Our technology assessment at this point eliminates the possibility of developing fluidic or optical devices of sufficient complexity to address the computational requirements involved). After selection of the preferred semiconductor technology small scale sample components will developed and tested to validate the processes involved. This activity is projected to be complete by the end of the year, 1994.

In 1995 development of the demonstration system is initiated based on the lowest risk combination of conventional electronics and the most attractive cooling scheme. Selected components would use the most promising form of high temperature electronics. If the high temperature technology failed to work, a lower risk cooled component would be substituted. If the uncooled component performed satisfactorily, it would be carried through the entire program. Electronic systems used to conduct laboratory and flight demonstrations would also be subjected to component durability tests.

#### 6.1.2.10 Computational Hardware Improvements

**Task Description:** Investigate the feasibility of using RISC processor technology to: 1) consolidate processing of functions (due to higher processing speeds), and 2) reduce the dependance on dissimilar redundancy (relying on its more verifiable instruction set). Identify functional partitioning alternatives that allow reduction of the overall part count by co-location of functions.

Investigate ways to reduce signal wiring and connectors (i.e., by application of multiplex data bus technology, fiberoptics and massive function integration).

#### 6.1.2.11 Single Event Upset (SEU) Phenomena

**Task Description:** Investigate the effects of device scaling and processing changes on the SEU vulnerability of VLSI electronics, and determine the sensitivity of various semiconductor technologies in the HSCT's atmospheric radiation environment. Determine ways to overcome SEU effects in memory (i.e., error correcting memory circuits), microprocessors and control circuitry (i.e., chip-level redundancy). Establish VLSI component selection criteria for HSCT that reduce SEU vulnerability, taking into account multiple errors and latchup as well as single errors.

#### 6.1.2.12 HIRF/EMI Immunity

**Task Description:** Validate HIRF/EMI shielding requirements for copper wire flight control/propulsion control/avionics on HSCT airplane. Determine the weight advantages of equivalent system connected by means fiberoptic buses and data links. Determine the semiconductor technology that best addresses HIRF/EMI related problems.

#### 6.1.2.13 Flight System Data Bus Technology

**Task Description:** This effort is closely related to the high temperature electronics effort in that high temperature electronics will be required to implement uncooled bus interface units for use in the wings and nacelles. Within this task the remaining technology necessary to develop severe environment data buses will be developed. The specific efforts to be conducted are:

1. Select both a wire and optical bus concept including protocols and impedance characteristics for HSCT use.
2. Develop and test conductor assemblies for both technologies. Emphasis should be placed on demonstrating the life, reliability, and maintainability characteristics of the assemblies and on evaluating the impact of thermal cycles and the HSCT radiation environment on the media.
3. Develop and test connectors for both technologies. Emphasis is required on the same as areas as for wires. It may prove convenient and cost effective to combine the test programs for conductors and connectors.
4. Develop optical receivers and transmitters capable of meeting the requirements for uncooled electronics - 250. degree C. junction temperature.

### 6.1.3 HSCT System Engineering and Architecture

A number of tasks related to design methodology and ground rules for the HSCT design are grouped under this heading. Certification requirements are included since they are crucial both to architecture design and system functional requirements. The integrated engineering tools task addresses development of a seamless data base oriented work environment which will permit efficient design of the HSCT. The next two tasks are flight/propulsion control system architecture studies intended to establish a safe, lightweight, and economical architecture for the HSCT based directly on HSCT requirements. Finally, a task is provided to develop a built in test and maintenance concept for the HSCT, since this area will be vital to the HSCT's economic success.

#### 6.1.3.1 Certification Requirements

**Task Description:** For any FAR requirements that are not appropriate for a control configured HSCT: Gather environmental and airplane configuration data that may pertain to certification. Conduct pilot in the loop simulation studies to evaluate the appropriateness of airworthiness requirements for the HSCT. Work with certification groups to develop alternative/supplemental airworthiness requirements. Evaluate alternative/supplemental airworthiness requirements to cover HSCT specific conditions not covered adequately by the general requirements.

#### 6.1.3.2 Interdisciplinary System Engineering Tools

**Task Description:** Survey computer automated system/software engineering tool sets and integration strategies. Establish a multi-disciplinary taskforce to define a common database and operating system backplane for HSCT system/software engineering tools. (Tools selected should provide means of converting non-compatible data to interoperability formats required by the common tool set and data base). Convert essential aerodynamic, structures, propulsion, mechanical/electrical and flight systems data, models and simulations into formats that meet database requirements. Convert tools or acquire new tools that are compatible with interoperability standards.

**Documentation/Specifications/Programming Methods/Tools:** Survey documentation and programming tools as part of the same multi-disciplinary task describe in the previous paragraph. Establish a seamless environment that takes specialty engineering products (i.e., aero models, flight system simulations) and produces real-time

operational software products, automatically or with a minimum of engineering intervention.

Investigate the feasibility to apply more standardized software for generic functions to:

1. Complete functions such as navigation and outer loop aircraft guidance and control.
2. Automatic code generation within individual control functions

Conduct a pilot project to demonstrate and quantify the reduction in software development time/cost and quality improvement obtainable by adopting a single interdisciplinary methodology and process for requirements verification through functional simulation, using automatic simulation code generation/documentation/code upgrading to operational flight standards/testing, and rehosting to run on the target processor. The objectives are to eliminate as many as possible of the software development stages where interpretation and implementation errors can occur, develop a better definition and understanding of the requirements and allow time for a more thoroughly tested final product.

**Verification/Validation Methods/Tools:** Survey configuration management, test and validation tools as part of the multi-disciplinary tasks described in the previous two paragraphs. Establish a seamless environment that operates on specifications, operational software, simulation software and test software to support requirements-driven testing.

**Propulsion and Flight System Analysis Tools:** Establish a CAD/CASE work bench environment for designing integrated propulsion and flight control system for an HSCT. This environment should consist of a database as described in the previous paragraphs, specific analysis and simulation tools such as EASY 5 and GSA, CFD tools such as PARC, and software simulation and development tools such as GSDS and PSIM.

**Simulations and Models:** The first task will be to develop detailed, dynamic models of the HSCT airplane and propulsion systems, and subsequently to integrate these models. The model formulation shall be quasi-static lumped parameter (Level 2 in the LeRC NPSSS terminology). The model will use data from Computational Fluid Dynamic (CFD) analyses to calibrate/validate the lumped parameter representations. Simulation trade studies will be conducted to evaluate control augmentation concepts, control techniques, feel systems, and primary flight information display concepts. High altitude atmospheric disturbance data will be gathered from various programs for incorporation in HSCT simulations supporting airplane and control system response analyses.

A full flight regime simulation will be developed that represents the dynamic effects of dominant structural modes on overall vehicle dynamics (aeroservoelastic coupling) and at specific locations on the airplane structure.

#### 6.1.3.3 General Flight and Propulsion Systems Architectures

**Task Description:** Conduct avionics/flight/vehicle functional decomposition and recomposition analyses for basic sensing, signal processing (including subsystem component failure detection/identification), and actuation functions. Identify alternative functional partitions, allowing reduction of the LRU count by co-location of functions. Investigate the feasibility of using high performance RISC processor technology to support multi-programming of co-located functions. Investigate the performance, maintenance, certification and cost implications of massive functional integration. Determine the impact of integration, together with fiberoptics, on the weight and reliability of signal wiring and connectors. Conduct a multi-disciplinary, multi-vendor pilot project to design and demonstrate a modular flight control and vehicle management system.

#### 6.1.3.4 Flight Critical Systems Architectures

**Task Description:** Conduct avionics, flight and propulsion system architecture studies for an HSCT and define concept for functional partitioning and hardware redundancy commensurate with reliability and availability requirements of flight critical functions. Define concepts for application of advanced technology sensor, bus, actuator, processor and memory components where justified from a performance, maintenance or cost point of view. Investigate the practicality of splitting control surfaces and using a single actuator per surface in order to simplify the multi-channel design. Investigate other means of eliminating actuator cross channel equalization when multiple actuators must be used to control a surface. Investigate options for managing the redundancy of the flight systems bus and their impact on functional reliability. Investigate the practicality of eliminating actuator position feedback by reliance on control loop closure through aerodynamic sensors.

#### 6.1.3.5 Built-in Test and Maintenance

**Task Description:** Establish built in test and maintenance requirements based on the preliminary control system design. Perform a preliminary design of the organization, processes, and system logic required to satisfy the requirements. Study the accessibility of controls components versus their estimated maintenance intervals and requirements.

Influence the control system design and installation to maximize its maintainability. Develop a concept for an integrated multilevel fault processing system which distributes fault information selectively to the person responsible for acting on it. Develop a structure for propulsion system condition monitoring and identify condition monitoring requirements that are unique to the HSCT.

## 6.2 Technology Demonstration

The technology demonstration phase of the activity is initiated in 1995 as shown in Figure 6-5. The definition of the technology demonstrator vehicle is completed as part of the technology development activity in 1994. The technology to be incorporated in the demonstrator is also developed in that phase as outlined in section 6.1.

The objective of the technology demonstration effort is to validate all control technologies which in 1995 appear to have potential for a year 2005 HSCT. Validation requires three things:

1. Functional integration of the technology into a complete control system,
2. Thorough exercise of the integrated control system in a realistic environment.
3. Demonstration of the individual component technologies in a realistic environment for periods of time long enough to ensure that there are no latent maintainability, reliability, or durability problems with the equipment.

Items 1. and 2. are best achieved through closed loop flight test of the system.

For subsonic aircraft, Item 3. has been satisfied either by gradual introduction of the technology into designs or by piggy back, in-service tests. An example of the former is introducing a new structural material in small non critical applications and then applying it to progressively more critical applications as service experience is gained. An example of the latter is the in-service piggyback test of FADECS conducted by Boeing, PWA, and Bendix on airline operated 727's in the 1970's. This program acquired a total of 366,479 hours on FADECS using a total of 45 units. The high time unit acquired 25,521 hours. Although even this level of testing is not adequate to achieve a totally correct statistical indication of reliability it is sufficient to identify design and process flaws and provide some confidence in reliability projections.

The first four phases of the demonstration program are basically those of any control system development - preliminary design, detail design, fabrication, and bench test (hardware-in-the-loop simulation) validation of the system. Subsequent to bench test, two different activities are undertaken: one is a functional demonstration of the control system, the other is a reliability and maintainability demonstration of the system components or groupings of them.

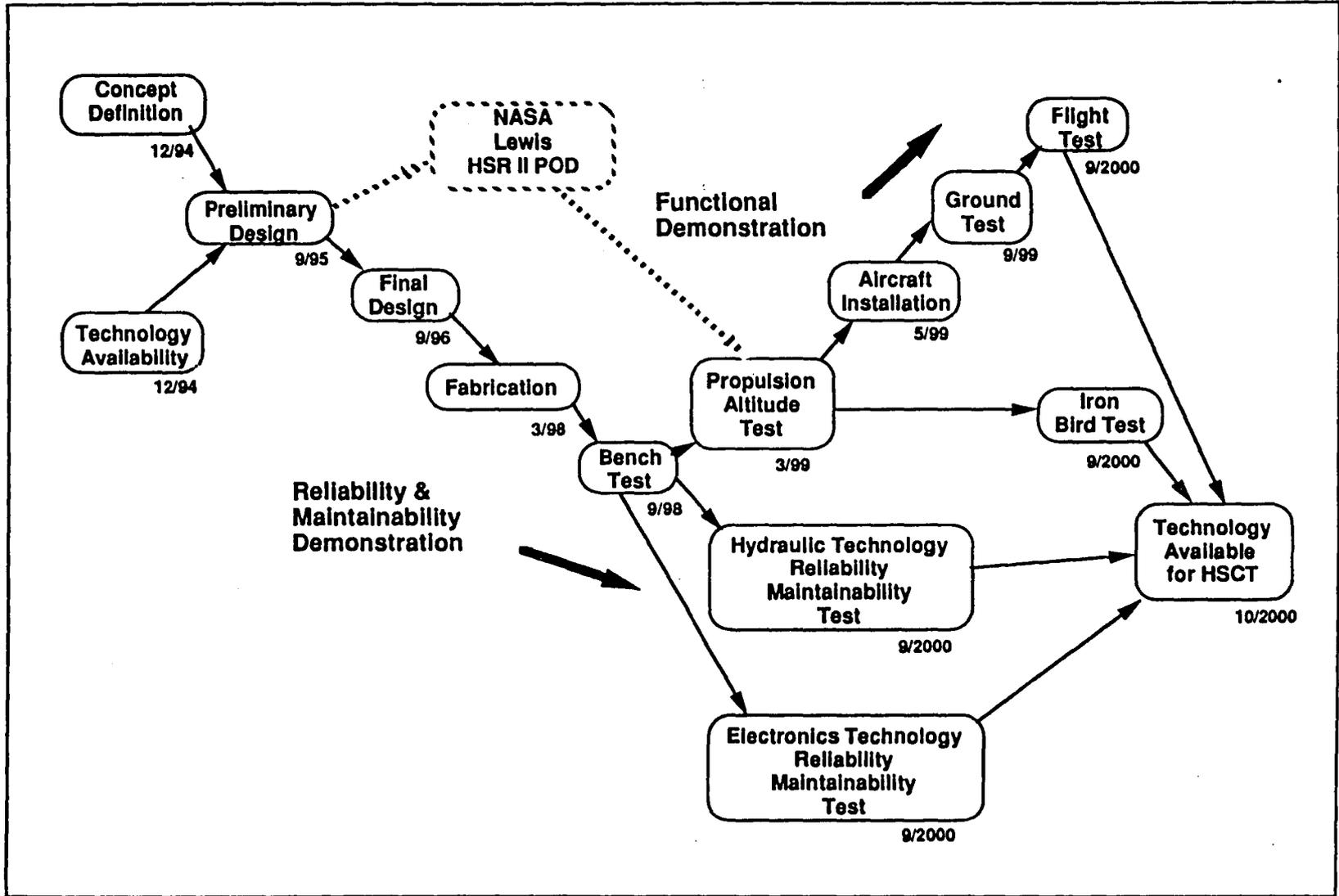


Figure 6-5 Technology Demonstration Plan

A significant effort is required during the concept definition phase to decide which of various flight and system demonstration options will be pursued to implement these programs. The NASA LaRC Systems Study Task 7 which evaluates various flight test candidates at the HSCT system level is a first step in concept definition. Another increment will be achieved under the NASA LeRC HSR II propulsion system program. In the following discussion some of the options and issues are identified but no specific approach for the demonstration program is recommended.

#### 6.2.1 Functional Demonstration:

There is a range of possible approaches to the functional demonstration. At one extreme a flight test of a complete demonstrator vehicle incorporating all HSCT technologies of interest including structures, propulsion, controls etc., is a possibility. At the other extreme, an elaborate laboratory evaluation of the control system using a hardware-in-the-loop simulation, might satisfy control system technology demonstration requirements.

The demonstration requirements are:

1. The propulsion system installation should reproduce the essential features of the HSCT installation: integrated propulsion pod mounted under wing, mixed compression inlet.
2. The vehicle should be capable of Mach 2.4 operation.
3. The vehicle should be capable of Mach 2.4 cruise to evaluate fuel behavior, materials, and unstart avoidance over realistic time periods.
4. The propulsion test article should provide a large percentage of vehicle thrust so that meaningful flight propulsion/control integration, in the thrust manipulation sense, can be demonstrated.
5. The vehicle aerodynamics and performance should roughly approximate those of the HSCT in general, particularly in approach backside and aeroelasticity, though not necessarily in scale.

Four demonstration strategies are considered: 1) a manned subscale HSCT demonstrator, 2) an existing airplane adapted with HSCT representative equipment, 3) an unmanned HSCT demonstrator, and 4) an elaborate ground demonstration. Figure 6-6 summarizes the approaches and indicates the suitability of each strategy as a means of demonstrating flight and propulsion controls technology issues. A brief discussion of each demonstration strategy is presented in the following paragraphs:

Demonstrator Alternatives	Cost	Propulsion Configuration	Integrated Flight Propulsion Control Capability	Flight Control Rigid/Flexible
Full Scale Prototype	Very High	Excellent	Excellent	Excellent/Excellent
Large Testbed (TU144/Concorde)	High	Excellent	Excellent	Good/Good
Subscale Demonstrator (manned/purpose built)	High	Excellent	Excellent	Fair/Fair
Subscale Demonstrator (unmanned/purpose built)	High	Excellent	Excellent	Fair/Poor
Existing Aircraft (Limited Scope)				
B 58	High	Good	Excellent	Fair/Poor
SR 71	Medium	Fair	Good**	Fair/Poor
F 106	Low	Good	Poor	Poor
F 15	Low	Fair	Poor	Poor
F 4	Low	Poor	Poor	Poor
F 111	Low	Poor	Poor	Poor
F 16	Low	Good*	Good	Poor
Ground Simulator	Medium	Poor	Good	
				* Assumes replacement of F 16 inlet is practical
				**Assumes integration of both J 58's and HSCT test POD with flight control system

Figure 6-6 HSCT Flight and Propulsion Control Demonstrator Position

**Subscale Demonstrator Vehicle:** A complete demonstrator vehicle developed from scratch would be relatively expensive. Because of schedule pressure, the control system technology content will tend to be reduced to that essential to meet demonstrator vehicle objectives, rather than operational HSCT objectives. This will tend to eliminate technology features which encounter development difficulties, unless they are absolutely essential to the obvious success of the demonstrator. On the other hand such a demonstrator will provide the most realistic propulsion installation possible and allows design of a complete integrated control system rather than a system assembled in a compromise fashion around existing equipment. The latter is probably what will occur if a demonstration is hosted on an existing airplane.

**Existing Airplane Demonstrator:** The approach which lies in between the two extremes is to develop an HSCT control system demonstrator aircraft. Almost any of the existing tactical aircraft are candidates for this application. In addition some larger aircraft such as Concorde, and the TU-144 may be candidates. However none of them conveniently satisfy all the requirements which one would like to establish for the demonstrator. The difficulty in aircraft selection becomes apparent if some possible candidates are considered in light of these requirements.

The F-15, F-106, and F-4 are all probably capable of carrying a J-85 scale HSCT propulsion system underneath their wings. However in each case the ratio of test propulsion system thrust to primary propulsion system thrust is poor so thrust management strategies are difficult to implement. Furthermore J-85 exhaust velocities aren't high enough to satisfy noise technology demonstration requirements. In addition none of them are capable of sustained flight at  $M=2.4$ . In the case of the F-106 and F-4 the  $Mach = 2.4$  condition probably exceeds the flight envelope and in the case of the F-15 the residence time is limited by fuel capacity if not by thermal constraints.

The SR-71 satisfies the Mach and cruise duration requirement but if the test propulsion system is a piggy back engine, as frequently shown in drawings, it doesn't provide the desired under wing installation nor does it provide representative flight/propulsion control integration. The SR-71 may be useful for demonstrating mechanical/electrical system properties in a bonafide severe environment.

The F-16XL might be modified to install a mixed compression inlet in place of the existing fixed geometry inlet. No attempt has been made to look at the mechanical and aerodynamic difficulties in implementing this modification. It is also incapable of addressing asymmetric

thrust issues, which are of significant interest in flight propulsion control integration. A solution to this and some other problems would be to convert this airplane to a twin engine installation. In either case the cruise Mach number capability of this airplane is probably limited to about 1.8 by thermal considerations.

**Unmanned Demonstrator:** An unmanned demonstrator could be built following the NASA HIMAT and Boeing Condor experience. Such a vehicle would be scaled to match two LeRC HSR II "Pod" scale propulsion systems. Properly organized it would be possible to address synthetic vision and cockpit issues on the ground while operating the vehicle as an RPV. There are a large number of issues to be addressed in considering such an approach. Some of these are:

1. Is the research and confidence development benefit to program cost ratio sufficiently better in this approach than a manned demonstrator to justify this approach?
2. Is the lead time for technology implementation substantially less than it is for the manned demonstrator?
3. Would the military be interested in participating?
4. Can an adequate test range be established to provide tracking and command and control functions over relatively long, say 500 miles, cruise legs?
5. Can a vehicle with adequate endurance be developed at relatively small scale?
6. Can a relatively small scale vehicle provide reliable noise data?

**Ground Based Simulator:** The other extreme in demonstration is to rely on an elaborate ground based simulation. The minimum approach would be an iron bird type flight control system test integrated with a closed loop bench type propulsion control test. In order to achieve the desired level of confidence in the results the hardware components used would have to be designed to meet flight environment, weight, and size requirements and the bench and iron bird, in addition to satisfying interface and load requirements, would have to simulate the flight thermal, vibration, and pressure environments. Since in the baseline design most of the equipment exposed to severe environment is installed on the propulsion pod one interesting variation on this basic concept is to co-locate the flight control iron bird with the planned NASA LeRC pod test, probably subsequent to the basic pod tests now planned for 1998. A similar exercise could then be done at NASA Ames to address the low speed portion of the envelope, installing the propulsion system in the 40x80 wind tunnel. This ground evaluation is more involved than would be required if a

flight test were conducted subsequently. The question is: will it give a sufficient experience base to proceed to full-scale HSCT development?

#### 6.2.2 Reliability/Maintainability Demonstration:

Since the primary concern in the reliability and maintainability demonstration is the commercial viability of the equipment in the supersonic environment, airborne piggyback testing on in-service aircraft will not achieve the desired experience. Therefore the recommended approach is an intensive ground test designed to look at the durability, reliability, maintainability aspects of the HSCT technologies rather than at the functional operation of the system. The recommended approach is to replicate the same basic system fabricated for the functional demonstration test, install the replica components in various appropriate test facilities and conduct endurance tests of them.

The objective of the ground based, iron bird/pod test mentioned above (Paragraph 6.2.1) is to demonstrate the function of the system as a whole and represent the environment as accurately as possible within facility constraints. Total hours accumulated on components will tend to be relatively short. Even where long hours are accumulated there will be a tendency to revise the configuration as the test progresses so that reliability issues will tend to become blurred. The reliability/maintainability test on the other hand will be specifically designed to establish the reliability of particular component technologies in the most realistic possible environment and with a realistic utilization pattern. It is structured as a pair of related subtests:

1. Actuation technology. A hydraulic system incorporating all elements of the demonstration system would be assembled and installed in a facility capable of subjecting the actuators and related components to the loads, duty cycle, vibration, thermal, and altitude environment expected in commercial operation. The system would then be operated for a number of years around the clock to accumulate the necessary reliability data. Hardware deficiencies would be recorded and corrected as necessary.
2. Electronics and sensor technology: A full suite of electronics and a representative collection of sensors would be installed in suitable facility capable of exposing them to the anticipated HSCT environment, including radiation. They would have installed in them an operational version of the software and would be operated in conjunction with an electronic simulation of the plant. The system would then be repeatedly flown through typical missions with both random and scheduled variations and deviations built in. The objective of the test is largely to accumulate

many hours on the hardware in a controlled environment. Secondly it serves as a vehicle to identify unexpected hardware /software interactions.

## 7.0 CONCLUSIONS AND RECOMMENDATIONS:

Based on the requirements, issues, priorities, and plans presented in the prior sections, the following conclusions are drawn:

1. No single flight or propulsion control technological issue is a barrier to HSCT development at this time. However, failure to resolve a significant number of issues would prevent the HSCT from achieving its economic and performance goals.
2. Hardware issues tend to predominate the priority lists because of the time required for new technology hardware to become flightworthy and the lack of a general market for components that meet HSCT environment and reliability requirements.
3. Flight and propulsion control technology will contribute significantly to HSCT takeoff gross weight reduction. The weight reduction is the result of a collection of smaller improvements resulting from reductions in control hardware weight, improvements in propulsion system performance through reduced control margins permitted by advanced technology controls, and reductions in structural weight and aerodynamic drag due to advanced flight control laws.
4. Flight and propulsion control technology advances are necessary to assure flight safety for the HSCT, because: 1) automatic control is essential to safe operation of the complex, flexible, relaxed static stability vehicle, and 2) automatic controls are required to avoid/accommodate inlet unstart, and to permit management of the complex propulsion system by a two man flight crew.
5. While the certification basis of the HSCT will be negotiated world-wide between airplane manufacturers and government regulators, knowledge developed by NASA concerning the operating environment, disturbance characteristics and failure management is essential to defining safe and achievable regulations for HSCT.
6. Efficient, quality design of the HSCT will require an integrated set of design tools communicating through a common data base. The performance and accuracy of these tools (CFD and structural analysis codes, software development tools, control system analysis tools, and others) will require validation and demonstration prior to their application on a production program.

Development of an economically competitive HSCT faces many challenging technological hurdles as described in this report. Military technology spin-off and market economics alone will not be sufficient to mature many of the high priority technologies required for commercial HSCT airplane application. Therefore a cooperative, coordinated control technology development effort between NASA and industry is essential if program go ahead on an American HSCT is to be realized within the next decade.

Functional and flight demonstrations are required to put the necessary control technology in place to support an HSCT go-ahead by the year 2000. Figure 7-1 indicates many activities in which NASA could contribute to readying technology for a demonstration that would begin in the 1995 time frame, including: sensor and high temperature electronics development, control laws for operating points specific to the HSCT, development of architectural concepts, and the contribution of specific tools for supersonic flight and propulsion control system development.

Task 7 of the NASA Langley/Boeing HSRSS study, using data from this report as one of its inputs, will establish a recommended plan and vehicle configuration for an HSCT technology demonstration program.

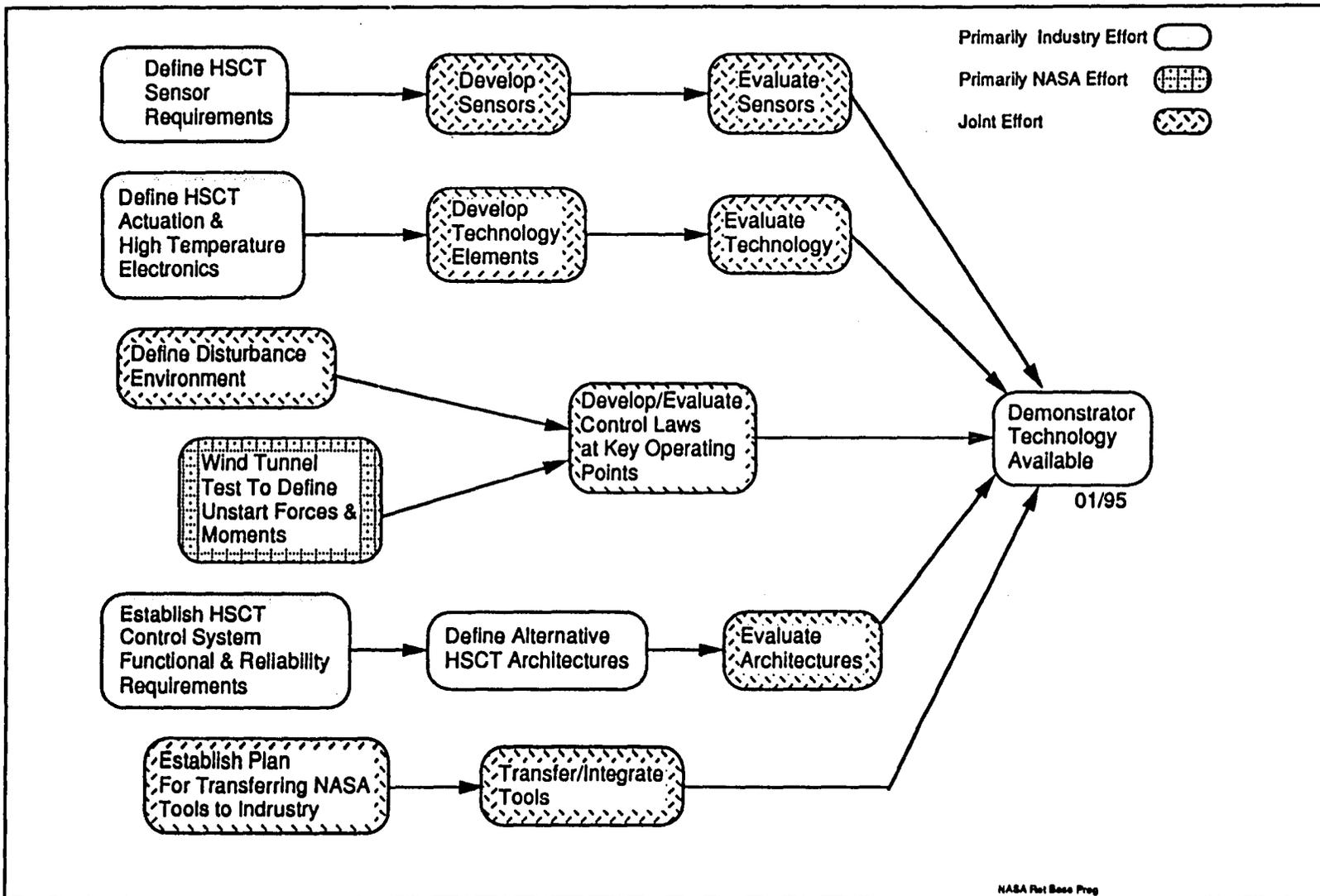


Figure 7-1 Recommended NASA/Industry Cooperative R & T Base Activities



## 8.0 REFERENCES

1. "High-Speed Civil Transport Study," Boeing Commercial Airplane Group, NASA CR-4233, 1989.
2. "High Speed Civil Transport Program Review," Boeing Commercial Airplane Group Public Information Brochure, 1991.
3. I. Kaminer, R. A. Benson, E.E Coleman, Y. S. Ebrahimi, "Design of Integrated Pitch Axis for Autopilot/Autothrottle and Integrated Lateral Axis for Autopilot/Yaw Damper for NASA TSRV Airplane Using Integral LQG Methodology," NASA CR 4268, 1990.
4. "Report of the Fourth Meeting-Special Committee on Future Air Navigation Systems," FANS/4, International Civil Aviation Organization, Montreal, May 20, 1988.
5. A. D. Churchman, M. Johnson, J. K. Ray, T. M. Richardson, D. T. Spotswood, "Strategic Flight Management Concepts for Large Aircraft," WRDC/FIGL F33615-88-C-3614, January 1991.
6. "Design Guidance for Integrated Modular Avionics," ARINC Report 651, Aeronautical Radio, Inc., November 9, 1991.
7. "Special Conditions for the Societe Nationale Industrielle Aerospatiale/British Aircraft Corporation Concorde Model Airplane," Special Conditions No. 25-43-EU-12, Annex R 25.
8. "Tentative Airworthiness Standards for Supersonic Transports," Department of Transportation, Federal Aviation Administration Flight Standards Service, January 1, 1971.
9. A. A. Lambregts, "Vertical Flight Path and Speed Control Autopilot Design Using Total Energy Principles," AIAA-83-2239, August 1983.
10. A. A. Lambregts, "Operational Aspects of the Integrated Vertical Flight Path and Speed Control System," SAE Technical Paper Series (831420), October 6, 1983.

11. A. A. Lambregts, "Integrated System Design for Flight and Propulsion Control Using Total Energy Principles," AIAA-83-2561, October 1983.
12. C. M. Carlin and W. J. Hastings, "Propulsion Control Sensor Sharing Opportunities," AIAA-83-0536, January 1983.
13. F. Barry, "Frequency of Inlet Unstart due to Atmospheric Turbulence," NASA CR-137482, October 1973.
14. E. Rachovitsky, "A Discrete Gust Method for Establishing Gust Criteria for The SST Intake Control System Design," D6A11413-1TN, The Boeing Company, March 1970.
15. C. G. Justus, et.al., The NASA/MSFC Global Reference Atmosphere Model-Mod 3, NASA CR-3256, March 1980.
16. V. M. Walton, "Advanced Air Data System Requirements, Concepts, Wind Tunnel Calibration and Iterative Onboard Algorithms," D180-32042-1, The Boeing Company, July 10, 1990.
17. M. O. Dustin, G.L. Cole, "Continuous Output Terminal Shock Position Sensor for Mixed Compression Inlets Evaluated in Wind Tunnel Tests of YF-12 Aircraft Inlet," NASA TM-X-3144, December 1974.
18. G. A. Ganley, "Concorde Propulsion - Did We Do It Right," SAE Paper 912180, September 1991.
19. David L. Sebring, "Fault-Tolerant Avionics on the Boeing 777 Aircraft," NAECON 91, May 1991.
20. D. A. Martinec, "Report of the Integrated Modular Avionics (IMA) Certification Seminar Held August 26, 1991 in Seattle Washington," Airlines Electronic Engineering Committee (AECC) Letter 91-238, September 13, 1991.
21. F. W. Burcham, Jr., G. B. Gilyard, P. A. Gelhausen, "Integrated Flight-Propulsion Control Concepts for Supersonic Transport Airplanes", SAE Technical Paper Series (901928), October 4, 1990.

# REPORT DOCUMENTATION PAGE

Form Approved  
OMB No. 0704-0188

While reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE March 1992	3. REPORT TYPE AND DATES COVERED Contractor Report-Final	
4. TITLE AND SUBTITLE High-Speed Civil Transport Flight- and Propulsion-Control Technological Issues			5. FUNDING NUMBERS  NAS2-12722	
6. AUTHOR(S)  J. K. Ray, C. M. Cariin, and A. A. Lambregts			8. PERFORMING ORGANIZATION REPORT NUMBER  H-1794	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Boeing Commercial Airplane Group New Airplane Division P.O. Box 3707 Seattle, Washington 98124-2207			10. SPONSORING/MONITORING AGENCY REPORT NUMBER  NASA CR-186015	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)  National Aeronautics and Space Administration Washington, DC 20546-0001				
11. SUPPLEMENTARY NOTES  This report was prepared for PRC Inc., P.O. Box 273, Edwards, California 93523-0273 by Boeing Commercial Airplane Group under subcontract ATD-91-BCA-7201. NASA Technical Monitor was Bruce G. Powers, NASA Dryden Flight Research Facility, P.O. Box 273, Edwards, California 93523-0273. NASA Contracting Officer's Technical Representative for PRC Inc.: Donald C. Bacon, Jr., 805-258-3484.				
12a. DISTRIBUTION/AVAILABILITY STATEMENT  Unclassified — Unlimited Subject Category 08			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words)  This report identifies technology advances required in the flight and propulsion control system disciplines to develop a high-speed civil transport. The mission and requirements of the transport and major flight and propulsion control technology issues are discussed. Each issue is ranked and, for each issue, a plan for technology readiness is given. Certain features are unique and dominate control system design. These features include the high temperature environment, large flexible aircraft, control-configured empennage, limited flight-deck visibility, strong aerodynamic coupling between propulsion and flight control, minimizing control margins, and high availability and excellent maintainability. The failure to resolve most high-priority issues can prevent the transport from achieving its goals. The flow-time for hardware may require stimulus, since market forces may be insufficient to ensure timely production. Flight and propulsion control technology will contribute to takeoff gross weight reduction. Similar technology advances are necessary also to ensure flight safety for the transport. The certification basis of the high-speed civil transport must be negotiated between airplane manufacturers and government regulators. Efficient, quality design of the transport will require an integrated set of design tools that support the entire engineering design team.				
14. SUBJECT TERMS  High-speed civil transport			15. NUMBER OF PAGES 160	
			18. PRICE CODE A08	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT	

**END  
DATE  
FILMED**

APR 24 1992

**End of Document**