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High-Speed Civil Transport Issues and Technology Program

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NOMENCLATURE

AFFTC	Air Force Flight Test Center
AIAA	American Institute of Aeronautics and Astronautics
AIMS	Airborne Instrumentation Modular System
ARC	NASA Ames Research Center, Mountain View, CA
AUTO_SIM	Automated Simulation Development Program
CAD	Computer Aided Design
CAS	Control Augmentation System
CASE	Computer Aided Systems Engineering
CCV	Control Configured Vehicle
CFD	Computational Fluid Dynamics
CG	Center-of-gravity
CGI	Computer Generated Imagery
CRAD	Contractor Research and Development
DATAC	Commercial Flight Data System Bus
DEEC	Digital Electronic Engine Control
DFRF	NASA Dryden Flight Research Facility, Edwards, CA
DMICS	Design Methods for Integrated Control
DOF	Degrees-of-freedom
DPS	Digital Performance Simulation
EMI	Electro-magnetic Interference
EPROM	Erasable Programmable Read-only Memory
FAR	Federal Aviation Regulation
FBL	Fly-by-light
FBW	Fly-by-wire
FL	Flight Level
FMEA	Failure Modes and Effects Analysis
FOCSI	Fiber-optic Control System Integration
FORTRAN	Formula Translation Language
GUI	Graphical User Interface
HiMAT	Highly Maneuverable Aircraft Technology
HIDEC	Highly Integrated Digital Electronic Control
HIRF	High Intensity Radio Frequency Radiation
HSCT	High Speed Civil Transport
HWIL	Hardware-in-the-loop
IFPC	Integrated Flight Propulsion Control
IRAD	Internal Research and Development
ISSD	Inverted-spoiler-slot-deflectors
ITF	DFRF Integrated Test Facility
LADAR	LASER Radar
LaRC	NASA Langley Research Center, Langley, VA
LeRC	NASA Lewis Research Center, Cleveland, OH

LIDAR	LASER Radar
LQG-LTR	Linear Quadratic Gaussian - Loop Transfer Recovery
LRU	Line Replacement Unit
MAC	Mean Aerodynamic Chord
MFD	Multi-function Display
MIMO	Multiple Input - Multiple Output
MMW	Millimeter Wave
NASA	National Aeronautics and Space Administration
NOx	Nitrogen Oxide
PARC	Navier-Stokes Computing Tool for Propulsion Aerodynamic Analysis
PC	Personal Computer
PSC	Performance Seeking Control
PSIM	Parallel Simulation Tool
RDBMS	Relational Data Base Management System
RPV	Remotely Piloted Vehicle
RAM	Random Access Memory
RISC	Reduced Instruction Set Computing
R&D	Research and Development
SAS	Stability Augmentation System
SEU	Single Event Upset
SI	Sensor Imaging
SID	Standard Instrument Departure
SIM	DFRF ITF Simulation Facility
SSD	Spoiler-slot-deflectors
SST	Supersonic Transport
TCA	Terminal Control Area
TECS	Total Energy Control System
UAV	Unmanned Autonomous Vehicle
USAF	United States Air Force
VMS	ARC Vertical Motion Simulator

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ABSTRACT

This report presents a strawman program plan consisting of technology developments and demonstrations required to support the construction of a high-speed civil transport. The plan includes a compilation of technology issues related to the development of a transport. The issues represent technical areas in which research and development are required to allow airframe manufactures to pursue an HSCT development with confidence in its marketability, profitability, public acceptance, safety, reliability, maintainability, and ecological neutrality. The vast majority of the technical issues presented require flight demonstrated and validated solutions before a transport development will be undertaken by the industry. The author believes that NASA is the agency best suited to address flight demonstration issues in a concentrated effort. The new integrated Test Facility at NASA Dryden Flight Research Facility is considered ideally suited to the task of supporting ground validations of proof-of-concept and prototype system demonstrations before night demonstrations. An elaborate ground hardware-in-the-loop (iron bird) simulation supported in this facility provides a viable alternative to developing an expensive full-scale prototype transport technology demonstrator. Dryden's SR-7 l assets, modified appropriately, are a suitable test-bed for supporting flight demonstrations and validations of certain transport technology solutions. A subscale, manned or unmanned flight demonstrator is suitable for flight validation of transport technology solutions, if appropriate structural simularity relationships can be established. The author contends that developing a full-scale prototype transport technology demonstrator is the best alternative to ensuring that a positive decision to develop a transport is reached by the United States aerospace industry.

INTRODUCTION

Fulfilling its traditional mission of aerospace technology researcher, developer, demonstrator and validator, NASA is defining its role in the development of a High Speed Civil Transport (HSCT). HSCT represents a rebirth in the United States of the Supersonic Transport (SST) concept pursued actively in the late sixties by several airplane companies and the United States government. It also represents a follow-on to the Concorde and the TU-144, the only supersonic commercial transports in the world today.

That an HSCT will be operational at some point in time is nearly a foregone conclusion. The business world will eventually demand it. The only questions concern timing. Timing is related to finding solutions to many technical issues, environmental issues, issues of public acceptance, and economic issues. This report addresses the technical issues and contains suggestions for NASA involvement in finding solutions to these technical issues. Some technical issues address environmental, economic, and public acceptance issues as well.

References 1 and 2 describe studies of the technology issues which require research and development to allow aircraft manufacturers to undertake the task of designing, building, and successfully marketing an HSCT. The author was funded to integrate the findings reported in references 1 and 2 with other sources, present a master list of technical issues, and develop a strawman program to support HSCT development. The author relied heavily on references 1 and 2 in structuring this unifying report. Especially helpful was Mr. Chris Carlin whose extensive knowledge in controls, propulsion, and their integration was relied on significantly.

Reference 1 contains an excellent section on HSCT flight and propulsion control requirements which are not duplicated in this report. The mission, configuration, and design requirements presented are comprehensive. They set the basis for the technology issues discussed herein and in references 1 and 2.

All of the technical issues raised in references 1 and 2 in which NASA has expertise and experience are also presented herein in an Appendix. In addition, a number of issues are presented from a variety of additional sources.

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BACKGROUND

Since the days of the SST development, great strides have been made in a number of technical fields related to supersonic transport. These strides are discussed briefly below.

Flight control technology has been advanced significantly since the SST development stalled. Full authority digital fly-by-wire flight control is operational in the F-18 and the B-2. Several operational airplanes were specifically designed to require augmentation to obtain static stability in all or a portion of their flight envelopes in return for gains in operational performance ranging from improved maneuverability to reduced radar cross-section. The unaugmented F-16 is statically unstable in pitch in a small portion of its flight envelope and the unaugmented B-2 is statically unstable directionally throughout its flight envelope. Control augmentation (CAS) is operational in many new military airplanes allowing pilots direct command of observed variables such as pitch rate and load factor. Advances in fiber optics allow designers to consider the use of fly-by-light control. Improvements realized in recent years in component reliability including actuators, sensors, connectors and electronics are of particular importance to commercial aircraft development. These technology advancements have allowed designers to produce designs which meet performance goals which were not previously attainable (refs. 3, 4 and 5).

Variable cycle engine technology has been advanced significantly since SST days. The technology has the potential of providing high propulsive efficiencies over a wide range of operating conditions (ref. 6).

The Air Force and NASA have sponsored significant work in integrated flight and propulsion control (IFPC) (refs. 7, 8, 9, 10, 11, 12, 13, 14, 15 and 16). This work has focused on hardware architectural issues (refs. 8, 17, 18, 19 and 20) involving airborne computer bus architectures, control laws and sensors. IFPC technology promises particular advantages in HSCT applications. NASA's work in Digital Electronic Engine Control (DEEC) (refs. 12, 21, 22, 23, 24, 25, 26, 27 and 28) has shown that it is possible to improve engine performance significantly if stable operation with lower stall margins can be achieved. Performance improvements are possible in specific fuel consumption, range and thrust. HSCT cruise speeds of Mach 2.0+ demand the use of mixed compression engine inlets to achieve reasonably efficient cruise performance. Integrated inlet-flight control promises significant improvements in performance by adjusting inlet stability margin in mixed compression inlets (refs. 29 and 30). Normal shock position is maintained close to the inlet throat to reduce flow stability margin (with the attendant increase in thrust-minus-drag and range) while an ability is maintained to switch to a higher margin in the face of an atmospheric disturbance to prevent inlet unstarts. Active control of inlet spike and bypass doors provides this shock control and also provides reductions in flow distortion and inlet-air-supply/engine-demand matching (ref. 31).

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Forward looking air data sensor technology has been developed since SST days. The technology involves Laser detection of air data disturbances ahead of the airplane (ref. 32). The technology is being investigated specifically for wind shear detection systems. In the HSCT application, it can be used for the purpose of controlling flow stability margin in the mixed compression inlet.

There have been significant advancements in control system design tools since the SST days. The Air Force sponsored Design Methods for Integrated Controls (DMICS) (refs. 33, 34, 35 and 36) program developed a viable approach to control law design for integrated systems based on the linear quadratic techniques of modern control theory (ref. 37). Up to this point, modern control design technology had suffered from a lack of direction and technique for translating the impossible-to-implement full-state feedback linear control law designs it produced to real-world implementable systems. The new Linear Quadratic Gaussian - Loop Transfer Recovery (LQG-LTR) technique (refs. 38, 39, 40, 41, 42, 43 and 44) has shown promise in IFPC control law paper designs.

The Air Force sponsored the development of a significant design methodology for integrated systems known as Performance Seeking Control (PSC). Developed for IFPC control law applications, the methodology has wider applications. It features adaptive parameter estimation for real-time model updating and the on-line, real-time computation of optimized control parameters computed as trims to current control inputs using these updated models.

Active flutter suppression has been demonstrated in wind tunnels with satisfactory results although the technology is not currently sufficiently advanced to be considered for inclusion in a transport design. Gust and maneuver load alleviation, active ride control, active flight envelope protection, active CG management, and other active control techniques are all possible now (indeed some of these techniques are now operational) due to advances in recent years in airborne digital computer throughput, sensors, high bandwidth actuators and motors, bus architectures and digital electronics.

Advances in vision enhancement technology which have been realized to date suggest that it may be possible to consider the development of a windowless HSCT within the next decade (refs. 45, 46 and 47). The requirement to provide flight crew outside visibility is very restricting to HSCT aerodynamic design and requires a physical reconfiguration of the airplane for takeoff, climbout, approach and landing which adds significantly to the weight and mechanical complication of the airplane.

Advances in airborne computer throughput, computer generated cockpit displays, inertial navigation systems, and satellite navigation (global positioning system) have not only provided the enabling technology for integrated systems, but also provide the ability to implement real-time trajectory generation, optimization, and advanced displays in flight path management (refs. 48, 49, 50 and 51).

Even though many of the advancements since the days of the SST have focused on military airplane applications, the concepts are equally applicable to the world of commercial transports. Some of the technologies are operational now in commercial transports. There are, however, far more stringent requirements to be met in the commercial world before new technologies are considered for inclusion in a new design. Components built using new technologies must meet stiff reliability and maintainability requirements. Flight validations and demonstrations often require many thousands of flight hours. There have to be very sound technical and business reasons for including a new technology aboard a new commercial transport.

Because of all these advancements, the industry is now in a position to consider an HSCT development. This report presents the remaining technology shortfalls and suggests strawman plans for NASA to address these shortfalls.

REPORT FORMAT

In organizing this report, the author has placed primary emphasis on the development of strawman technology programs which will support a positive decision by the aerospace industry to develop and market an HSCT aircraft. These programs form the body of this report. The technology issues from which the programs are constructed, are presented in an appendix. These issues are well developed and presented in references 1 and 2: thus, they are not treated as the focus of this report. Appendix A represents an integration and cross-correlation of the issues presented in these references and additional issues which have surfaced from a variety of other sources.

The strawman technology programs include:

1. a demonstration alternatives study,
2. demonstrator developments,
3. technology developments,
4. technology demonstrations.

The demonstration alternatives study is recommended to address the pros and cons of all viable demonstration alternatives. Demonstrator developments are program elements to design and construct the viable demonstrator alternatives discussed in the study. Technology developments include the developments required to address all of the technology issues discussed in the appendix. Technology demonstrations include the program elements in which each technology development is demonstrated.

Demonstration and validation requirements are presented with each technology development. The demonstration and validation requirements reflect the cost of a development program required to solve the issue, and to demonstrate and validate the solution. Basically, these requirements revolve around whether or not a flight experiment, demonstration or validation is considered to be required. To express it another way: R&D funds are limited. Therefore, although it is desirable to build a technology demonstrator to flight demonstrate solutions to every issue, funds may not permit it. What is the minimum demonstration requirement for each issue which the industry considers necessary to include a given technology on the airplane?

The total program is rather large and expensive. The size of the program reflects the very significant developments and demonstrations which must take place to lower the development risks to a level which will allow the industry to reach a decision to develop the airplane.

In Appendix A, technology issues are presented by technology category. A section of the appendix is devoted to each technology category. In Appendix B a bibliography of papers and reports on technologies which are issues for the HSCT is presented.

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The issues are divided into six technology categories as follows:

1. flight and propulsion control issues,
2. hardware issues,
3. system engineering issues,
4. system architecture issues,
5. aerodynamics and performance issues,
6. environmental issues.

At the beginning of each section of the appendix, a summary of the issues is presented in a table. The summary shows:

1. a cross-reference to each issue from references 1 and 2,
2. suggested NASA participation by NASA Center in the development of technology required to provide solutions to the issue,
3. issue priority related to the relative importance of the issue in persuading both industry and government in pursuing an HSCT development, and insuring the success of the development and employment of HSCTs.

This summary is followed by a detailed description of each issue. For each issue the following items are discussed:

1. issue description,
2. technology requirements and benefits,
3. technology status and readiness.

Appendix B contains a bibliography of reference material published in the past ten years on HSCT related technologies.

STRAWMAN TECHNOLOGY PROGRAMS

In this part we present a strawman program plan. The program plan describes a program for addressing all of the technical issues presented. It contains a roadmap which shows the interdependencies between the various elements of the program and their relationship with ongoing IRAD and CRAD programs sponsored by other government agencies plus government in-house developments.

We do not expect that an HSCT will be developed unless and until all of the critical technical issues which relate to the successful design and operational employment of an HSCT are solved and proof-of-concept and/or prototype systems containing these technologies are flight demonstrated. It must be shown without a shadow of a doubt that an HSCT can be built, sold and operated successfully at a profit. We do not expect that any technology which has not been flight demonstrated conclusively as to its usefulness, cost effectiveness, reliability, and maintainability will make it on the HSCT. We have placed emphasis, therefore, in structuring this strawman program on the development of proof-of-concept and prototype systems which are flight demonstrated. Successful flight demonstration is the final objective in most cases.

We propose herein, the development of three demonstration components as follows:

1. a high-fidelity, real-time piloted simulation of an HSCT baseline design,
2. a flight demonstration test-bed and
3. a prototype technology demonstrator.

The real-time piloted simulation will be used in many of the technology developments. A flight demonstration test-bed consists of a highly modified existing aircraft. Potential candidates include the SR-71, Concorde, TU-144 and F-16XL. A prototype technology demonstrator is required to demonstrate solutions to issues which cannot be adequately demonstrated on a modified existing aircraft. There are, in our view, three potential technology demonstration concepts: an elaborate hardware-in-the-loop ground-based simulation; a sub-scale, manned or unmanned technology demonstrator aircraft; and a full-scale technology demonstrator aircraft. If an elaborate hardware-in-the-loop ground-based simulation is used in lieu of a prototype technology demonstrator aircraft, then more dependence is placed on the flight demonstration test-bed to flight validate solutions to technical issues.

We suggest that the development of a full-scale technology demonstrator aircraft is probably required to support a decision to build an HSCT. If one were built and successfully demonstrated with the right technologies on-board, commitment to an HSCT development would likely be assured. Without the dedicated technology demonstrator aircraft, a positive decision is not assured.

The above remarks reflect the conservative, low-risk approach to new aircraft designs which must be taken by the industry to survive in the years ahead. An HSCT development presents enormous risks which the Concorde experience doesn't lighten. Concorde has been a financial failure. It has survived because of government subsidies: a luxury to which United States companies do not have access. The HSCT presents technical risks because of a proposed operational flight envelope which is more than five times as large as any existing commercial transport (2x in altitude: 2.5x in Mach number), economic risks because of the unknown costs of operating and maintaining the aircraft and environmental risks because of noise pollution and the unknown potential damage which HSCT operations may inflict on the earth's Ozone layer.

The strawman technology programs presented in the following sections include:

1. a demonstration alternatives study,
2. demonstrator developments,
3. technology developments,
4. technology demonstrations.

The demonstration alternatives study is recommended to address the pros and cons of all viable demonstration alternatives in all three component categories (simulation, test-bed, prototype. Demonstrator developments are program elements to design and construct the viable demonstrator alternatives discussed in the study. Technology developments include all of the developments required to address all of the technology issues discussed in the appendix. Technology demonstrations include the program elements in which each technology development is demonstrated. These programs are presented in detail in the sections that follow.

Demonstration Alternatives & Requirements Study

The demonstration alternatives study is recommended to address the pros and cons of all viable demonstration alternatives and develop demonstration requirements. We described three demonstration components previously with alternatives within the components as follows:

1. a high-fidelity, real-time piloted simulation of an HSCT baseline design;
2. a flight demonstration test-bed consisting of a highly modified:
   a. TU-144,
   b. Concorde,
   c. SR-71, or
   d. F-16 XL;

3. a prototype technology demonstrator consisting of:
   a. an elaborate hardware-in-the-loop ground-based simulation,
   b. a sub-scale, manned or unmanned technology demonstrator aircraft, or
   c. a full-scale technology demonstrator aircraft.

The demonstration alternatives and requirements study would address the alternatives in items 2 and 3 above.

Basic demonstration requirements are well stated in reference 1. They are restated and expanded below in two lists: basic requirements for a test-bed aircraft and basic requirements for a prototype technology demonstrator. The basic demonstration requirements for a test-bed aircraft are related to performance characteristics. They are:

1. Sustained Mach 2.4 operation above 50,000 feet altitude for a specific period of time. The time period in which cruise must be maintained at Mach 2.4 would be determined in the study. The period must be of sufficient duration to heat soak demonstration prototype electronic components mounted external to the fuselage and internal engine components. In addition, the cruise time period must be sufficient to evaluate the performance of advanced prototype sensors, integrated control concepts and control law performance, and other prototype subsystems which may exhibit characteristics which are dependent on cruise time duration.

2. If a demonstration engine is to be installed,
   a. it must provide a large percentage of vehicle thrust,
   b. it should reproduce the essential features of an HSCT installation,
      1). integrated propulsion pod mounted under wing,
      2). mixed compression inlet.

3. Stability and control (S&C) characteristics similar to proposed HSCT design characteristics including:
   a. S&C modal characteristics,
   b. aeroelastic modal characteristics,

4. Performance characteristics including,
   a. backside-of-the-power-curve approach speeds,
   b. climb, descent, approach and landing speeds,
   c. takeoff, landing, climb and descent performance requirements.
      1). takeoff roll,
      2). landing rollout,
      3). rate of climb,
      4) rate of descent.

5. Size characteristics similar to proposed HSCT design characteristics.

A flight demonstration test-bed aircraft would be used to flight demonstrate system components which are developed in technology development program elements. The specific requirements listed below relate to the ability of the test-bed aircraft to support installations and demonstrations of these system components. As a minimum, the test-bed aircraft would be modified to include:

6. telemetry uplink and downlink interface to support remote computation and datalink,
7. digital flight and inlet control systems (either fly-by-wire or high authority digital augmentation),
8. easily programmable and expandable on-board digital computational capability to support a variety of requirements,
9. avionics cooling to support the added airborne computers,
10. multi-function cockpit display,
11. on-board avionics and control data busses and associated wiring,
12. on-board instrumentation package, bus, sensors and associated wiring.

With respect to item 6, NASA has had considerable experience with the use of remote computation to support flight demonstrations of advanced control laws in specially equipped flight test aircraft. With respect to item 7, it may not be necessary to completely remove a mechanical flight control system and substitute a fly-by-wire system. It may be sufficient to interrupt a mechanical system and provide series actuators with high authority digital augmentation. With respect to item 8, NASA is developing under contract at DFRF an expandable airborne parallel-processing research computer based on transputer technology which may be applicable. With respect to item 10, a multi-function display (MFD) from F-18 assets can be installed in the test-bed aircraft.

The TU-144, Concorde and SR-71 provide reasonable performance matches to proposed HSCT designs. Of the three, the SR-71 is probably the most rigid aircraft and is, therefore, the least desirable from a structural standpoint. In addition, from a propulsion standpoint, the SR-71 is undesirable as a test-bed aircraft because of the inability of the aircraft to support an under-the-wing engine configuration. Since this is the configuration envisioned for an HSCT, and since this configuration presents specific inlet flow characteristics, it is very desirable that the test-bed aircraft use this configuration. Otherwise, the SR-71 provides the closest performance match of the three. The SR-71 also has the capability of supporting the demonstration of solutions to a number of issues which do not require aircraft modification to demonstrate, or require avionic modifications only (digital computation, data bus and cockpit displays).

The F-16XL can be modified to provide a mixed compression inlet in place of the existing fixed geometry inlet. The aircraft has the advantage of providing an under-the-wing engine inlet; however, this propulsion configuration similarity and the availability of the aircraft are the only advantages that the aircraft provides: Mach number is limited, cruise duration at maximum Mach number is severely limited by fuel capacity, and there is no structural similarity as the aircraft is too small and rigid.

Other potential candidates have significant disadvantages. The B-58 comes to mind. Again, Mach number is limited. The flight envelope is not considered expandable because of directional stability problems associated with the small vertical tail. The B-70 might be a consideration. Again, directional stability problems limit the expandability of the flight envelope. We have not investigated the availability of a B-70.

We view the modification of an existing viable aircraft to an HSCT test-bed as a highly desirable activity to pursue. It is particularly important if an elaborate ground-based simulator is used in lieu of a prototype technology demonstrator aircraft.

The basic demonstration requirements for a prototype technology demonstrator are:

1. performance equivalent or relatable to proposed HSCT designs, particularly with respect to its flight envelope (speed, altitude), backside-of-the-power-curve approach speeds and cruise duration;
2. configuration characteristics equivalent or relatable to proposed HSCT designs, including engines mounted under the wing, mixed compression inlets, long fuselage with forward mounted flight deck and restricted or zero visibility from the flight deck;
3. aerodynamic characteristics equivalent or relatable to proposed HSCT designs, including a laminar flow wing;
4. stability and control characteristics equivalent or relatable to proposed HSCT designs, including negative unaugmented longitudinal static margins in some flight regimes;
5. structural characteristics equivalent or relatable to proposed HSCT designs, including the relative separation of aeroelastic and rigid body natural frequencies.

Item 5 in the above list is particular important if a sub-scale, manned or unmanned technology demonstrator aircraft is to be built to satisfy the prototype demonstrator requirement. It is critical that the aeroelastic characteristics of a sub-scale aircraft be relatable to the full-scale vehicle. The sub-scale aircraft must possess relatable rigid-body and aeroelastic dynamic interaction with the full-scale vehicle. The problem, of course, is that the HSCT is envisioned to be a very flexible aircraft with relatively low first structural mode natural frequencies. These frequencies may be relatively close to rigid-body stability and control natural frequencies (within two orders of magnitude). One can conceive of a dimensionless similarity number (such as Reynolds number for viscous fluid flows) comprised of rigid-body and structural modal characteristics, structural material characteristics, and relative scales which, if matched, would permit an extension of sub-scale results to full-scale predictions with respect to vehicle stability, control, and handling qualities.

In the event that funding is not available to develop a full-scale technology demonstrator aircraft or even a sub-scale technology demonstrator aircraft, it may be feasible to rely on an elaborate hardware-in-the-loop ground-based simulation. This simulation must include:

1. an iron bird type flight control system,
2. a closed loop bench type propulsion control test,
3. actual hardware system components where possible,
4. a real-time digital simulation of all other components,
5. a flight deck with pilot interfaces (piloted simulator).

The NASA Dryden Integrated Test Facility (ITF) is ideally suited to support this type of technology demonstrator. In addition, it may be possible to include heating into the simulation be integrating the ITF facility capability with the Thermo-structures Research Facility (TSF) capability.

A sub-scale technology demonstrator aircraft is also a viable alternative to a full-scale development. From a propulsion point of view, there are significant advantages to the sub-scale development. Specifically, it will not be necessary to fund the development of a new high thrust engine which a full scale development will require. The funding for a new engine in the required thrust category would likely dwarf the cost of the demonstration airframe development. A sub-scale demonstrator provides the most realistic propulsion installation possible and allows the design of a completely integrated control system rather than a system assembled in a compromise fashion around existing equipment (a test-bed)(ref. 1). The aircraft can be scaled to match two NASA Lewis Research Center (LeRC) HSR II "Pod" scale propulsion systems (ref. 1).

An unmanned sub-scale technology demonstrator aircraft is feasible. We envision the vehicle to be operated as a remotely piloted vehicle (RPV) during terminal area operations (taxi, takeoff, climb, descent, approach, landing and taxi), while simultaneously addressing the synthetic vision issue. We envision the vehicle to be operated as an unmanned autonomous vehicle (UAV) during long duration cruise segments on autopilot using GPS assisted inertial navigation. This type of extended operation was demonstrated on the Condor program.

The development of a full-scale technology demonstrator aircraft is the preferred technical approach, although it is the most expensive. It is also the approach which will have the most positive effect on an industry decision to develop an HSCT. We believe that two aircraft must be built with enough spare parts to equip a third aircraft. This philosophy has emerged from years of experience with prototype developments. The proposed study would add substance to the arguments discussed herein and provide NASA with the material necessary with which to base an informed decision on the appropriate approach to demonstrating solutions to HSCT technical issues.

Demonstrator Developments

Demonstrator developments are program elements to design and construct the viable demonstrator alternatives discussed in the study. There are three program elements as follows:

1. the development of a high-fidelity, real-time piloted simulation of an HSCT baseline design,
2. the development of a flight demonstration test-bed and
3. the development of a prototype technology demonstrator.

They are discussed, in turn, below. They are presented as elements of a Demonstrator Development Plan in Figure 1. Figures 2 through 6 (included in later sections) present further breakdowns of components of the Demonstrator Development Plan.

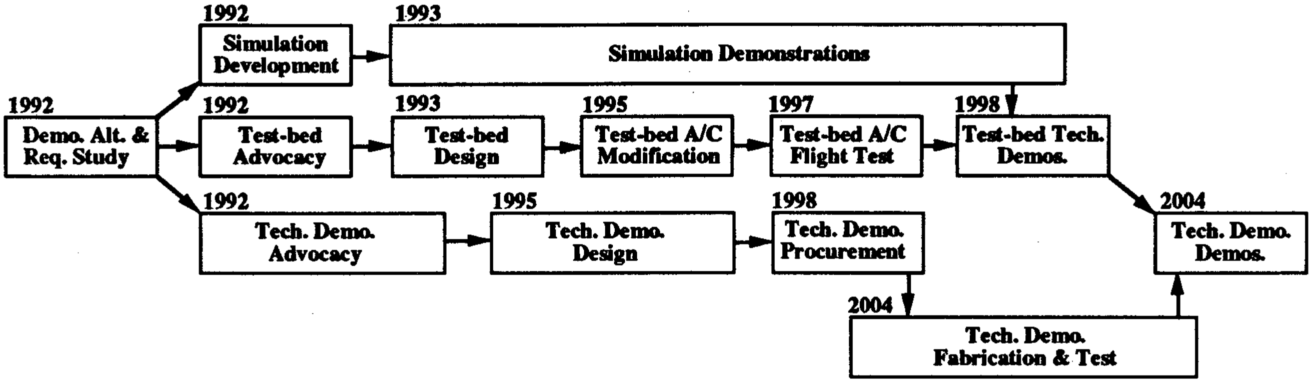

Figure 1 Demonstrator Development Plan

SIMULATION DEVELOPMENT PROGRAM

This program element involves the development of full flight envelope HSCT vehicle and systems simulations hosted within the NASA ITF SIM facility. We suggest that a family of simulations be developed and supported as follows:

1. a 3+ DOF performance simulation capable of supporting operational studies including optimal trajectory generation and flight planning;
2. a multi-DOF real-time, piloted simulation with rigid body, aeroelastic and propulsion modes and an integrated flight/inlet/engine control system capable of supporting control law studies, design efforts, piloted simulation demonstrations and system validations;
3. a high fidelity, nonreal-time multi-DOF systems simulation capable of representing not only structural modes, control system modes and propulsion modes, but also, sensor models and system models capable of supporting systems studies and design efforts;
4. a hardware-in-the-loop real-time systems simulation capable of supporting component demonstrations and systems validations.

We suggest that three versions of each simulation be developed as follows:

1. a version based on the test-bed demonstrator aircraft and its systems,
2. a version based on the NASA Mach 3.0 HSCT baseline design (refs. 52 and 53),
3. a version based on an industry HSCT baseline design (refs. 1, 34, 54 and 55).

The four simulation types are listed below in order of increasing development cost. Each simulation type is considered as a separate program element. There are four elements as follows:

1. performance simulations,
2. piloted simulations,
3. system simulations,
4. hardware-in-the-loop simulations.

Figure 2 shows the Simulation Development Plan as a sub-set of the Demonstrator Development Plan shown in Figure 1.

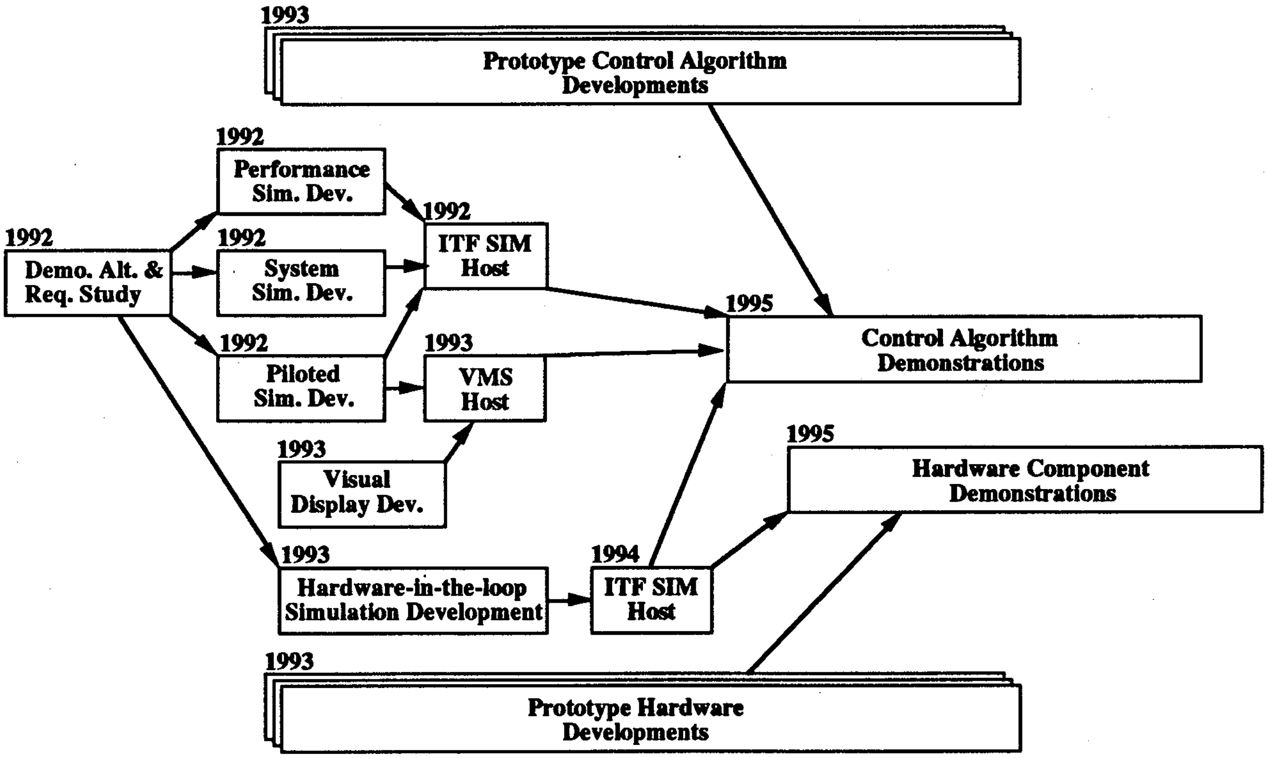

Figure 2 Simulation Development Plan

Performance Simulations

This element involves the development of 3+ DOF performance simulations of the HSCT. They would support operational studies including the development of optimal trajectory generation algorithms and other planning algorithms for HSCT flight path generation. NASA has developed the Digital Performance Simulation (DPS) which could be adapted to this purpose. The author has developed a generic performance simulation facility in their flight test program planning system which is superior to DPS.

Piloted Simulations

This element involves the development of multi-DOF real-time piloted simulations of the HSCT. The real-time piloted simulations would be hosted in the NASA ITF SIM facility and other NASA piloted simulation facilities such as the VMS at the NASA Ames Research Center (ARC). They would be used to support a variety of studies, design efforts, piloted simulation demonstrations and system validations. These include control law designs for integrated flight/inlet/engine systems, handling quality studies, synthetic vision studies, design methodology studies and the validation of simulation demonstration prototype systems from a flight crew interface and operation standpoint.

System Simulations

This element involves the development of nonreal-time system simulations of the HSCT. The systems simulations are envisioned to be batch, nonreal-time simulations which support systems studies including architectural concepts, systems integration issues and conceptual designs.

Hardware-in-the-loop Simulations

This element involves the development of hardware-in-the-loop simulations of the HSCT. The hardware-in-the-loop simulations are envisioned to be hosted in the ITF Facility at DFRF. Hardware would include system components installed in the test-bed demonstrator aircraft, in the technology demonstrator aircraft or simply as stand alone components in a simulation. These simulations would be used to validate components on the ground prior to the conduct of flight demonstrations.

TEST-BED DEMONSTRATOR DEVELOPMENT PROGRAM

There are four primary viable aircraft which, appropriately modified, could be used as the test-bed demonstrator. They are:

1. TU-144,
2. Concorde,
3. SR-71, or
4. F-16 XL.

DFRF possesses SR-71 assets and is currently in custody of the two F-16XL aircraft. Consideration of the TU-144 requires negotiations with the Russian Ministry of Aeronautics. Consideration of the Concorde requires negotiations with appropriate departments in the English and French governments, and British Airways. In any case, the test-bed aircraft would require the modifications presented previously. These modifications would render the test-bed useful in flight demonstrating the following categories of system prototypes:

1. integrated flight/inlet/engine control concepts and system architectures,
2. control laws for integrated systems,
3. control laws for SAS, CAS for high speed, high altitude flight path control,
4. control laws for mixed compression inlet control,
5. air data sensors (free stream disturbances, inlet shock position),
6. remote electronic components,
7. flight planning (trajectory generation) algorithms and associated displays.

The test-bed demonstrator would also be useful in conducting experiments in:

1. ozone layer depletion with high altitude cruise flights,
2. air traffic control problems associated terminal area (TCA) control of mixed traffic (high speed HSCT aircraft, medium speed standard airliners and low speed general aviation aircraft),
3. noise profiles.

If the test-bed demonstrator were to host a demonstration propulsion system including an engine and inlet, then additional technology demonstrations related to propulsion would be possible.

The flight control system of the aircraft selected to become a test-bed demonstrator must be replaced with either a high authority digitally augmented mechanical system or a digital fly-by-wire system. Although a full authority, all axis digital fly-by-wire system would be preferred to provide the most flexible and capable test-bed for the demonstration of integrated control concepts, a high authority digitally augmented system superimposed on an existing mechanical system would be far less expensive and would meet most demonstration objectives.

The flight control system must be designed to incorporate ground based control law computation, and telemetry uplink (surface commands) and downlink (sensor data, pilot control inputs). DFRF is thoroughly familiar with, and has extensive experience in this technique for demonstrating advanced control law concepts. It has proven feasible even for pilot-in-the-loop handling qualities flight demonstrations.

The test-bed demonstrator requires an instrumentation package which supports all of the demonstrations contemplated herein. The package must include telemetry links, sensors, instrumentation bus and on-board recording devices. We suggest that the

Airborne Instrumentation Modular System (AIMS) computer now under development be used for this application. This transputer based, parallel, expandable, modular processing system is ideal for the test-bed application.

The test-bed demonstrator would likely require additional on-board computational capability, programmable cockpit display capability, data bus and associated telemetry uplink and downlink to support the on-board computational load imposed in many of the demonstrations. We suggest that the transputer based parallel processing research computer under contract development for NASA be used for this purpose. We further suggest that a multi-function display (MFD) from F-18 assets be used as the programmable cockpit display system. DFRF engineers have demonstrated a system in the laboratory which features a MFD driven by a transputer based computer through an personal computer (PC). The PC - MFD interface used was a MIL-STD-1553B time division multiplexed data bus. The proposed concept allows the use of ground based computers in system loops for various purposes in system demonstrations including display generation, trajectory generation, control law computation, system monitoring, and any other heavy computational load which would eventually reside in on-board computers in the HSCT. Ground based computation allows flexible programming with no requirement for flight safety verification prior to a demonstration. It also allows all computation in demonstration software to be coded in FORTRAN since throughput available to meet required execution speeds is not a problem in the ITF SIM facility.

We envision that the test-bed development will be assigned to DFRF and performed through a combination of in-house and contracted work. Figure 3 shows the Test-bed Development Plan as a sub-set of the Demonstrator Development Plan shown in Figure 1.

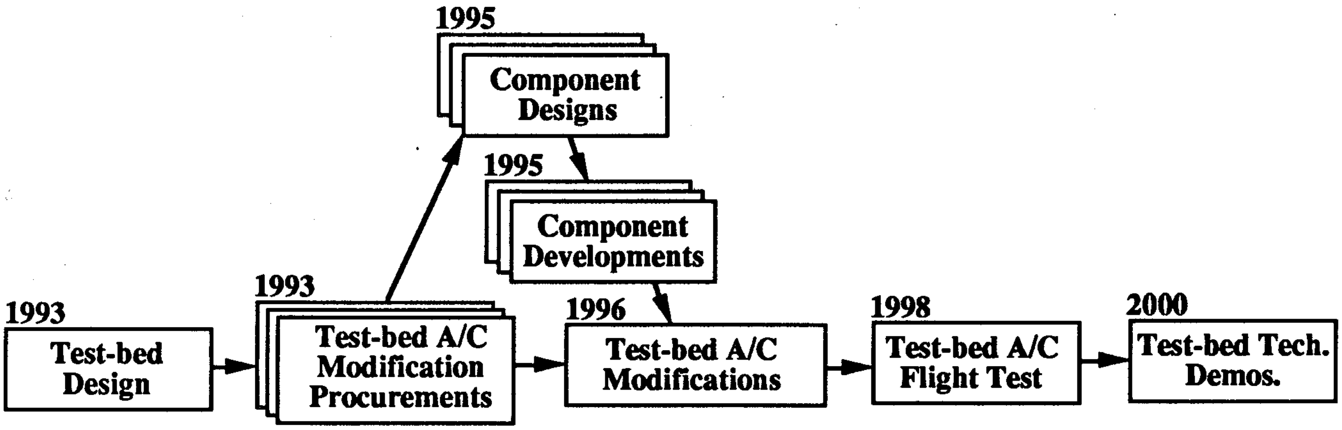

Figure 3 Test-bed Demonstrator Development Plan

TECHNOLOGY DEMONSTRATOR DEVELOPMENT PROGRAM

There are three alternatives as previously discussed:

1. an elaborate hardware-in-the-loop ground-based simulation,
2. a sub-scale, manned or unmanned technology demonstrator aircraft, or
3. a full-scale technology demonstrator aircraft.

Each alternative is discussed below:

Ground-Based Simulation Option

We envision an elaborate, high fidelity ground-based hardware-in-the-loop simulation hosted in the ITF facility as a viable low cost alternative to a technology demonstrator aircraft. This simulation must include:

1. an iron bird type flight control system,
2. a closed loop bench type propulsion control test,
3. actual hardware system components where possible,
4. a real-time digital simulation of all other components,
5. a flight deck with pilot interfaces (piloted simulator).

The primary advantage of this simulation is its low development cost in comparison to a prototype flight demonstrator. We believe the difference is between two and three orders of magnitude. The simulator will provide a showcase for the DFRF ITF facility and its capabilities. We, therefore, suggest that DFRF be assigned the responsibility for the development of this technology demonstrator alternative if this option is exercised.

Figure 4 shows the Technology Demonstrator Development Plan (Ground-based Simulation Option) as a sub-set of the Demonstrator Development Plan shown in Figure 1.

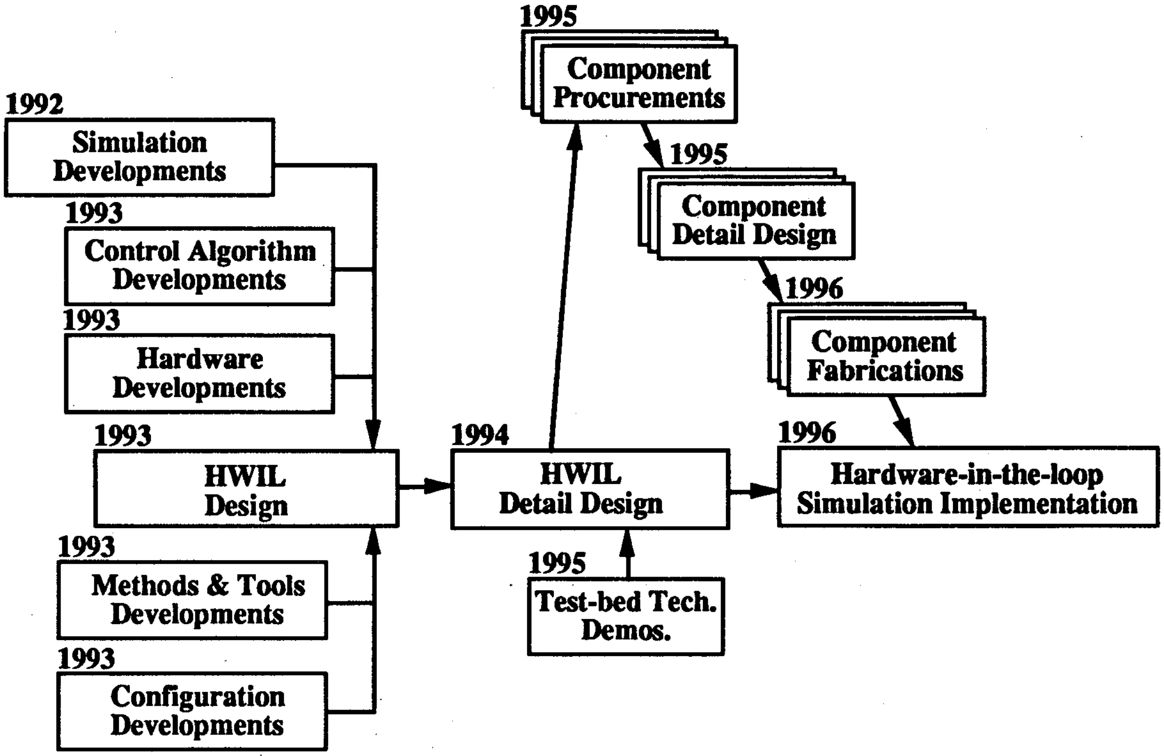

Figure 4 Technology Demonstrator Development Plan - Ground-Based Simulation Option

Sub-Scale Technology Demonstrator Aircraft Option

There is considerable experience at DFRF and in the aerospace industry to support the development of and flight demonstrations with a sub-scale manned or unmanned technology demonstrator aircraft. The NASA HIMAT, F-15 free flight spin model and Condor programs provide the required background.

The development must be pursued in the same fashion as a full-scale technology aircraft development. The scale must be chosen so as to support the use of existing engines in the aircraft. We suggest that ARC, the NASA Langley Research Center (LaRC) and the LeRC jointly manage this program.

Figure 5 shows the Technology Demonstrator Development Plan (Sub-scale Aircraft Option) as a sub-set of the Demonstrator Development Plan shown in Figure 1.

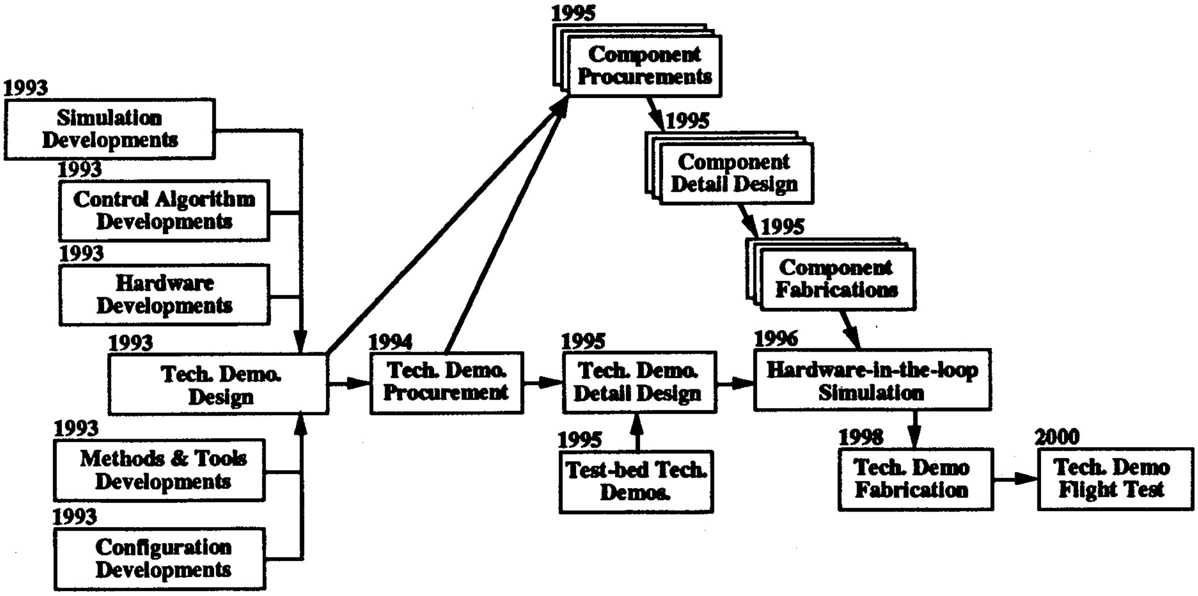

Figure 5 Technology Demonstrator Development Plan - Sub-Scale Aircraft Option

Full-Scale Technology Demonstrator Aircraft Option

This is a program which would pursue the same development path as that of the X-29, X-31 and other development prototypes. It is likely to be far more expensive than any previous prototype development especially if an engine development is involved. We suggest that ARC, LaRC and LeRC jointly manage this program. Figure 6 shows the Technology Demonstrator Development Plan (Full-scale Aircraft Option) as a sub-set of the Demonstrator Development Plan shown in Figure 1.

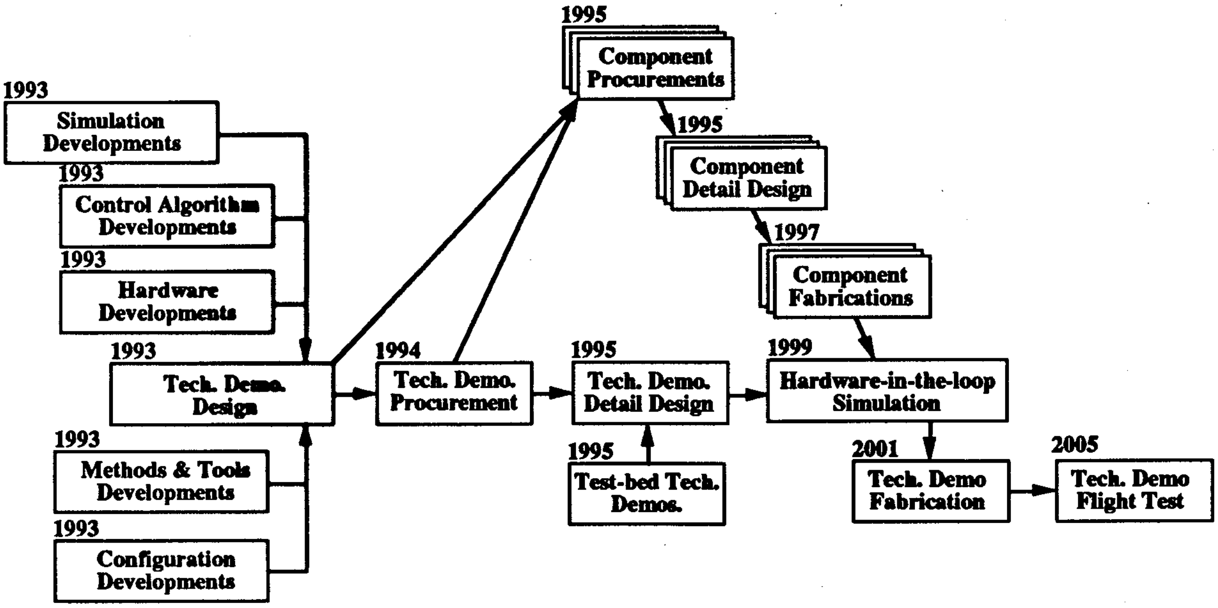

Figure 6 Technology Demonstrator Development Plan - Full-Scale Aircraft Option

Technology Developments and Demonstrations

Technology developments include all of the developments required to address all of the technology issues discussed in the appendix. They are grouped into five programs as follows:

1. control algorithm development and demonstration program,
2. hardware development and demonstration program,
3. methodology and tools development and demonstration program,
4. architecture development and demonstration program,
5. configuration development and demonstration program.

Each program is presented, in turn. A development plan is presented in graphical form.

CONTROL ALGORITHM DEVELOPMENT AND DEMONSTRATION PROGRAM

We recommend the construction of a program to address the following issues which are discussed in the appendix.

1. augmented manual flight control,
2. automatic flight control,
3. active flight envelope protection,
4. trajectory generation and tracking,
5. propulsion system automation,
6. engine/inlet control law integration,
7. inlet sensor fault detection and accommodation,
8. unstart avoidance/accommodation,
9. flight/propulsion control integration,
10. gust and maneuver load alleviation,
11. performance seeking control,
12. active flutter suppression,
13. active CG management.

The program involves ARC, DFRF, LeRC and LaRC. The program consists of the following phases:

1. controls analysis (ARC, DFRF, LeRC and/or LaRC),
2. control algorithm developments (ARC, DFRF, LeRC and/or LaRC),
3. verification and validation of the control algorithms using the simulations developed in the Simulation Development Program (ARC, DFRF, LeRC and/or LaRC),
4. demonstrations of the control algorithms in simulations (ARC, DFRF, LeRC and/or LaRC),

5. hardware-in-the-loop simulations hosted in the ITF using the control algorithms (DFRF),
6. flight demonstrations of the control algorithms in the test-bed demonstrator using remote computation (DFRF),
7. flight demonstrations of the control algorithms in the test-bed demonstrator using on-board computation (DFRF),
8. demonstrations of the control algorithms in the technology demonstrator (DFRF).

We suggest that the program be divided into program elements exactly paralleling the issues presented in the appendix. We suggest that a lead center be assigned to each program element. The program elements are presented below. Each of the elements involves most of the eight phases presented above. The phases involved are listed after the element title. A development plan is presented in Figure 7.

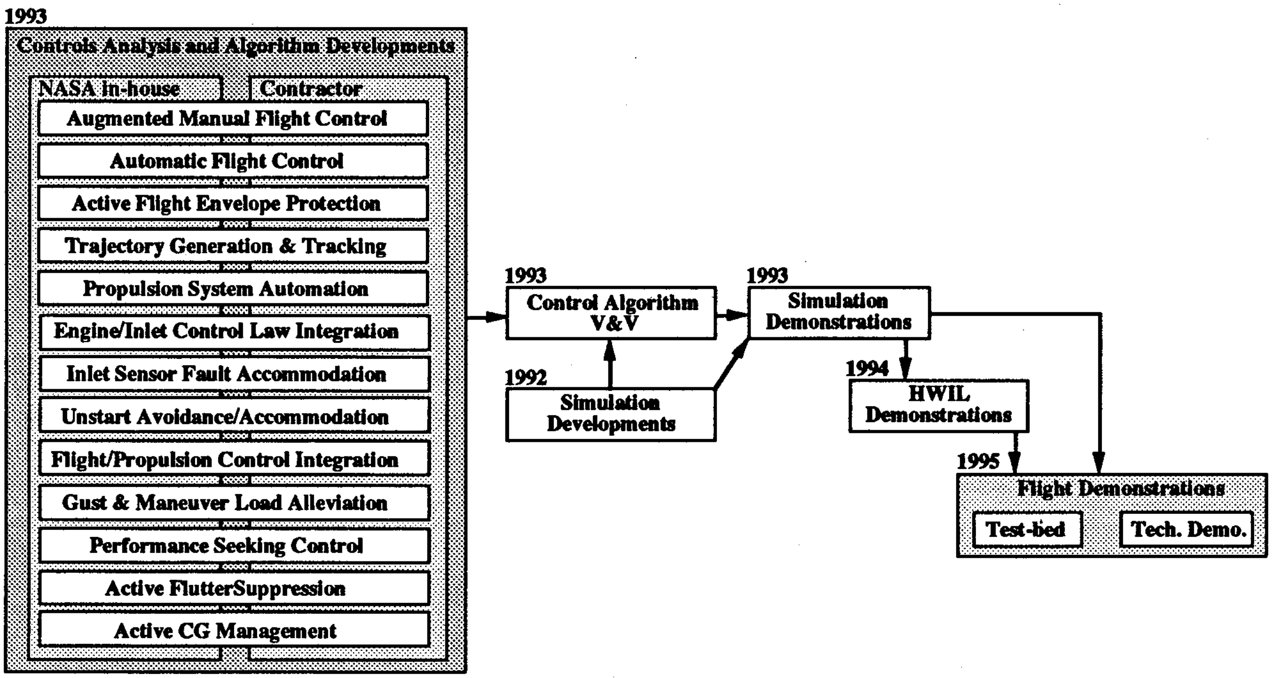

Figure 7 Control Algorithm Development and Demonstration Plan

<u>Augmented Manual Flight Control (Phases 1-8)</u>

This program element addresses the stability control augmentation required in the flight control system control laws to provide adequate handling qualities and flight path control to the HSCT. In addition to Phases 1-8 the program element includes:

1. the installation of the full flight envelope HSCT simulation on the NASA Vertical Motion Simulator (VMS) at ARC, and the development of visual displays for the HSCT and their installation on the VMS;
2. a study to determine appropriate control law design concepts for the HSCT with particular emphasis on integrated flight/engine/inlet system concepts;
3. the design and implementation of simulation prototype control law designs to control the HSCT simulation using the latest tools and design methods available.

Item 1 involves hosting the simulation on the ARC VMS. Visual displays must be developed to simulate both the actual vision available from the HSCT flight deck and the suggested artificial visual scene. The primary purpose of this effort is to develop, demonstrate and validate artificial visual scene generation technology of sufficient quality to be used as a substitute for natural vision in the HSCT; to investigate the effects of advanced control laws in piloted simulation in a moving base simulator, and to investigate the effects of the high amplitude flight deck motions expected from an HSCT on flight crew performance during full mission profiles.

Item 2 involves conducting studies in control law design to determine appropriate SAS and CAS concepts. A specific goal of this phase is to determine the effects of aeroelastic modes on control surface effectiveness, stability derivatives, lift and drag predictions and HSCT performance during representative mission profiles. The simulations would be used to investigate anticipated short period instability and high altitude precision flight path control discussed in the issue description. Low speed flight control can only be investigated partially in the ITF SIM. A complete investigation of low speed flight control and the effect of rotational motions on the flight crew requires the extended vertical motions available in the VMS to simulate the motions which will be encountered at the flight deck in the HSCT. Extended horizontal motion is also desirable to simulate dutch roll motions at the flight deck; however, the pitch axis motion is considered of dominating importance.

Item 3 involves the design SAS and CAS control laws using a variety of design methods and tools including methods developed in the Design Methods for Integrated Controls (DMICS) (refs. 34 and 35) program (Linear Quadratic Gaussian with Loop Transfer Recovery (LQG-LTR) (refs. 38, 39, 41, 42, 43 and 44) and others for the purpose of performing comparative evaluations of methods, and highlighting methodology and tool shortfalls.

Automatic Flight Control (Phases 1-8)

This program element addresses the development and demonstration control laws for automatic flight control of an HSCT using the Total Energy Control System (TECS) concept for outer loop design (refs. 56, 57, 58 and 59). In this concept, outer loop flight path and speed control mode requirements are fully defined in point mass kinematic terms without regard to vehicle aerodynamic characteristics, while inner loops are custom designed for specific vehicle aerodynamic characteristics. The fundamental simplicity of the TECS concept makes it an attractive alternative for application to the HSCT autopilot development.

We envision the implementation of control laws for a prototype autopilot using the TECS concept for an industry HSCT baseline standard design such as that contained in reference 55.

Active Flight Envelope Protection (Phases 1-8)

This program element involves a study of active flight envelope protection to determine the system requirements, to develop concepts and to implement prototype systems in simulation using the HSCT simulations developed in the Simulation Development Program.

Active flight envelope protection provides control inputs which prevent envelope escape in all manual and automatic flight control modes. It can be thought of as a CAS system. It provides control inputs (including propulsion inputs) which prevent aerodynamic stall; and prevents load factor limits, dynamic pressure limits, Mach limits, airspeed limits, and others from being exceeded. It may actively prevent the deployment of devices such as flaps and landing gear if the aircraft state is not within certain limits. It may go so far as to prevent the application of power for takeoff if the aircraft configuration (flaps, for example) is not correct for a given gross weight; or if runway length and density altitude are not compatible with a safe takeoff; or if sensed payload is not within safe limits from either a center-of-gravity (weight and balance) or distribution viewpoint.

Active flight envelope protection is a sensitive issue with flight crew. Military experience with departure prevention systems, automatic stick pushers and other automatic limiting devices dictates that a representative cross-section of airline pilots and industry representatives should take part in a demonstration program. We suggest that a prototype simulation system be developed for an existing operational airliner and installed in an appropriate operational flight trainer at a training facility. Further demonstrations will be given over an extended period to build flight crew acceptance of the concepts.

Trajectory Generation and Tracking (Phases 1-4, 6-8)

We suggest the construction of a program element to develop a family of trajectory generation algorithms for ground-based preflight planning with the necessary features to support optimal takeoff, climb, cruise-climb, descent, approach and landing profiles in the presence of controller imposed limitations and instructions, wind profiles, weather restrictions, local area restrictions, standard instrument departure (SID) procedures and published approach procedures.

Potential applications in preflight, ground-based optimal trajectory generation include (ref. 1):

1. energy management computations and automatic configuration control to minimize fuel consumption (ref. 1),
2. timing of thrust cut-back, throttle closure, and speed commands based on prevailing wind to meet prescribed noise footprints for takeoffs and landings (ref. 1),
3. flight path and gear/flap deployment command computation to meet a target position in a desired state, considering fluctuating wind profiles, aircraft weight and performance characteristics (ref. 1),
4. precision navigation and landing guidance in terminal areas using both ground based and satellite resources (ref. 1),
5. optimal takeoff, climb, cruise-climb, descent, approach and landing profiles in the presence of controller imposed limitations and instructions, wind profiles, weather restrictions, local area restrictions, standard instrument departure (SID) procedures and published approach procedures.

We suggest that the trajectory generation algorithms be developed using a variety of constrained optimization techniques. In addition to the standard optimization techniques employing first and second order gradient methods to minimize quadratic performance measures by open loop computer solutions, we suggest that dynamic programming and adaptive learning networks (ref. 60) be investigated for this application.

We suggest that significant emphasis be placed during this development on the design of the graphical user interface (GUI) which provides the required interface between the end user and the algorithms. That is; significant emphasis must be placed on how the preflight planner system is used in the context of the typical preflight planning environment and how the flight crew interfaces with it.

We suggest that a prototype system be developed and demonstrated first in the DFRF ITF SIM facility and then in a flight program using unmodified SR-71 assets to fly the profiles developed by the preflight planner. We suggest that the flight demonstration effort be coordinated with the FAA by involving Los Angeles Center, Oakland Center and Edwards Approach Control in the technology validation. The SR-71s used would require no modification in such a flight demonstration program.

Finally, we suggest that the algorithms be recoded for execution in an on-board computer, installed in the test-bed demonstrator and demonstrated in an in-flight replanning application. This installation requires the development of appropriate displays for the test-bed MFD and integration of the MFD with the on-board computer.

Propulsion System Automation (Phases 1-8)

This program element involves using the simulations developed in the Simulation Development Program to conduct studies in propulsion system automation in the ITF SIM facility. The concept involves limiting the crew's mandatory propulsive system management tasks to requesting engine start, establishing desired thrust levels, maintaining thrust required to hold desired parameter set points in specific flight maneuvers (hold Mach, hold angle-of-attack, hold altitude, etc), and requesting engine shutdown (ref. 26).

The HSCT simulations would require expansion to include propulsive models of sufficient fidelity to support studies in propulsive system automation. These models can probably be obtained from the industry. Automatic control laws would have to be developed for the expanded HSCT simulation which include automatic start, shutdown and advanced autothrottle concepts applicable to all flight segments.

In addition, NASA should consider the application of the Intelligent Engine Condition Monitoring Systems (IECMS) to the HSCT in-flight monitoring system for engine condition.

Engine/Inlet Control Law Integration (Phases 1-8)

We suggest that a program be constructed to develop integrated flight/inlet control system control laws to demonstrate:

1. programmable engine stall margin over the propulsive system operating range (either a constant stall margin can be maintained, or a reduced stall margin can be programmed with attendant thrust-drag improvements in steady state operation),
2. programmable inlet flow stability margin which is adjusted as a function of flight condition (sideslip, angle-of-attack) and air disturbances,
3. automatic stall and unstart recovery incorporating interlocks to prevent component damage and repeated stalls and unstarts,
4. automatic buzz suppression at minimum achievable thrust.

This program element must address advanced sensor technology for detecting air disturbances sufficiently in advance, as well as the integrated control issues presented above.

Inlet Sensor Fault Detection and Accommodation (Phases 1-8)

This program element involves a research study to develop concepts in inlet sensor fault detection and accommodation. Airframe air data should have sufficient information available to define the flow field in front of the inlet. This data, combined with engine airflow from the engine, should make it possible to control the inlet geometry without using inlet aerodynamic sensors (ref. 1). This would reduce the number of sensors required for inlet control thereby reducing costs and improving fault tolerance. Concepts which show promise would be programmed and tested in simulation.

Unstart Avoidance/Accommodation (Phases 1-8)

This element involves a program to address the five following issues in unstart avoidance and accommodation:

1. methods to improve definition of the free stream disturbance environment,
2. methods to improve the prediction of free stream disturbances,
3. methods to improve the terminal (normal) shock position measurement,
4. methods to improve analytical estimates of inlet characteristics and performance,
5. methods to improve estimates of the effect of unstart generated forces and moments on aircraft designs.

We suggest that this study be followed by applications of the methods developed to the design and implementation of an improved flight/inlet control system for demonstration.

Flight/Propulsion Control Integration (Phases 1-8)

We suggest that a program be constructed to develop and demonstrate an integrated flight/propulsion system. This system features the sharing of data between conventionally isolated systems including:

1. the use of air data, and flight control command and feedback data to provide dissimilar redundancy and feed-forward information within the inlet control system;
2. the use by the flight control system of propulsion system model data such as actual thrust and minimum and maximum thrust limits;
3. the use of the propulsion system as a force generator both symmetrically and asymmetrically within the flight control laws.

The benefits to an integrated system are significant. The integration requires study and flight demonstration of a prototype system before implementation on an HSCT is possible.

Gust and Maneuver Load Alleviation (Phases 1-8)

This program element addresses the development of gust and maneuver load alleviation control laws for a simulation prototype system to be demonstrated in the SIM. The simulation must include the necessary aeroelastic modes for the HSCT baseline design to support both an active gust and maneuver load alleviation system control law and simulated actuation system design.

A successful gust load alleviation system design depends on (ref. 1):

1. identification of flight and engine control requirements for gust load alleviation,
2. identification of sensor technology requirements for gust prediction,
3. determination of the performance penalty (increased drag and thrust required) associated with the use of active gust and maneuver load alleviation,
4. formulation of the appropriate aeroelastic modes in simulation models for gust and maneuver load alleviation system design and a real-time simulation validation of a design including its effect on handling qualities.

Performance Seeking Control (Phases 1-8)

Performance Seeking Control (PSC) consists of a control law implementation strategy which allows adjustments to be made to control variables on-line to obtain near optimal performance in the presence of off-design conditions. PSC has been flight demonstrated in a propulsion control system for a modified F-100 engine in a specially configured F-15 (the HIDEC F-15 at DFRF), however, the technology has not been employed in any production military or commercial airplanes.

This element involves the construction of a program element to apply performance seeking control (PSC) to an integrated flight/engine/inlet control system. A concept and trade study is envisioned which would develop the HSCT application of PSC and compare it to the application of both classical and modern control based methods (refs. 33, 34, 35, 38, 39 and 40) to control law design.

If the results of the study were satisfactory, we suggest that a proof-of-concept design for an integrated flight/engine/inlet control system be implemented and validated in simulation.

Active Flutter Suppression (Phases 1-8)

Active flutter suppression presents an excellent opportunity for NASA to pursue an important technology and make a significant contribution to HSCT development. A strong, aggressive program would have to be pursued to convince airframe manufacturers to include active flutter suppression as a flight critical system on an HSCT in order to realize the potential weight savings which are possible.

We suggest that a program be structured consisting of a comprehensive study of the potential benefits of active flutter suppression to the HSCT design. It would include an evaluation of design methods, prediction and analysis methods, and tools. It would also involve considerable simulation studies with a structural model of the HSCT modified in structural design so as to require active suppression. An active suppression system would be coded and demonstrated in simulation for an HSCT component such as a lightened tail section design.

This study would be followed by the development of the design methodology required including tools.

These studies would be followed by the construction of a wind tunnel model using the results of the studies with an active flutter suppression system. The system would be demonstrated in a supersonic wind tunnel.

We believe that it is necessary to show that flutter can be detected and suppressed in a wind tunnel model on the first try for the test to be declared a success. If an adjustment must be made to the system after the first test to achieve successful suppression, the test is a failure. We believe that this type of performance must be repeated on several different models if the technology is to receive acceptance for inclusion on the HSCT.

Active CG Management (Phases 1-8)

We suggest that NASA construct a program to develop and flight demonstrate proof-of-concept and flight demonstration prototype systems for active CG management.

The systems demonstrated might include:

1. use of nose gear load sensing with known gross weight to calculate CG position,
2. improved accuracy fuel measurement systems,
3. payload sensing and on-board automated CG calculation based on it.

HARDWARE DEVELOPMENT AND DEMONSTRATION PROGRAM

We recommend the construction of a program to address the following issues which are discussed in the appendix.

1. actuation technology,
2. fiber optic sensors,
3. vision enhancement technology,
4. high altitude air data,
5. forward looking sensors,
6. multi-function sensor technology,
7. shock position sensing,
8. high temperature electronics/sensors,
9. computational hardware improvements,
10. single event upset phenomena,
11. HIRV/EMI immunity,
12. flight system data bus technology.

The program involves ARC, DFRF, LeRC and LaRC. The program consists of the following phases:

1. hardware developments (ARC, DFRF, LeRC and/or LaRC),
2. hardware-in-the-loop simulations hosted in the ITF (DFRF),
3. flight demonstrations involving prototype hardware installations in the test-bed demonstrator (DFRF),
4. demonstrations involving prototype hardware installations in the technology demonstrator (DFRF).

We suggest that the program be divided into program elements exactly paralleling the issues presented in the appendix. We suggest that a lead center be assigned to each program element. The program elements are presented below. Each of the elements involves the four phases presented above. The phases involved are listed after the element title. A development plan is presented in Figure 8.

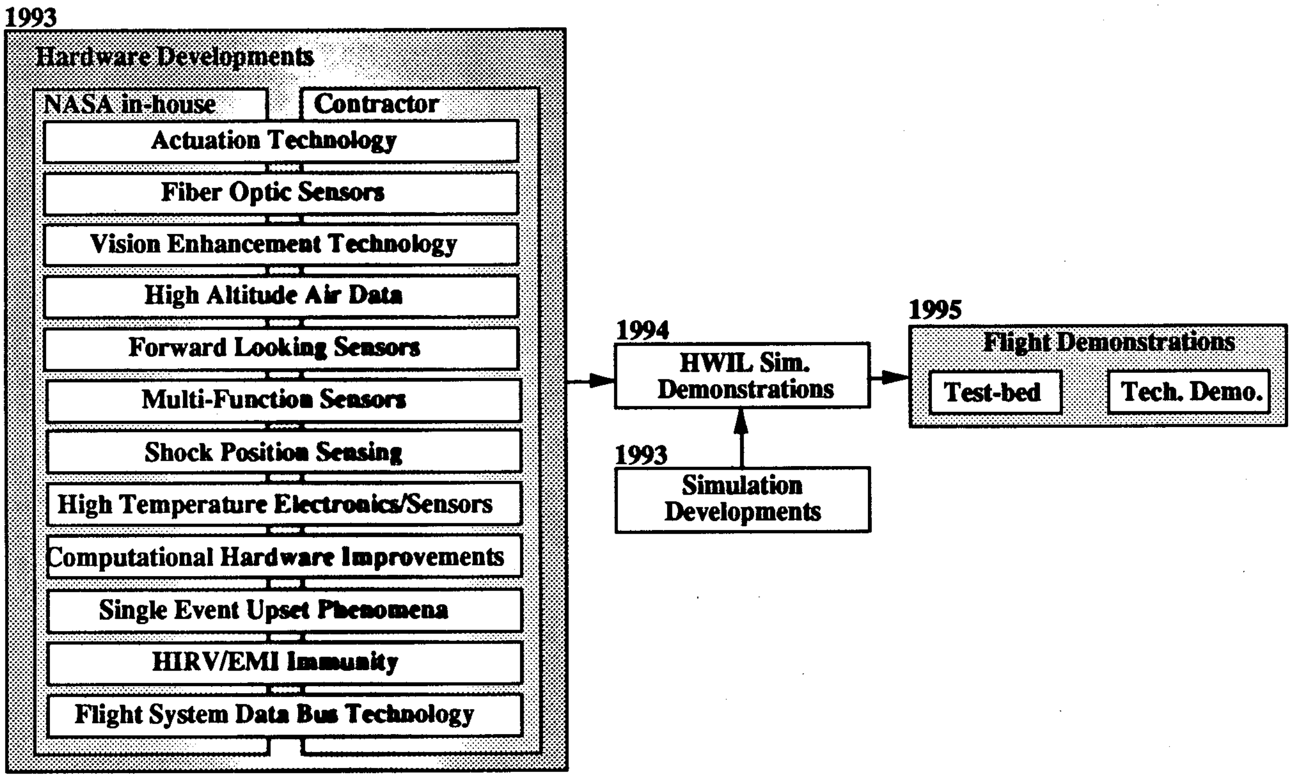

Figure 8 Hardware Development and Demonstration Plan

Actuation Technology (Phases 1-4)

We suggest the construction of a program element to demonstrate the following actuator technologies for possible inclusion on the HSCT as follows:

1. high temperature hydraulic fluids,
2. high pressure hydraulic systems,
3. composite actuators,
4. thin profile actuators,
5. high bandwidth actuators,
6. high bandwidth electric actuators,
7. fiber optic - mechanical transducers.

Many vendors support significant IR&D studies in actuator technologies for aerospace applications. We suggest that this program element feature the development of a cooperative effort with actuator vendors to develop prototypes for installation and flight demonstration on the test-bed demonstrator. The following prototypes should be considered:

1. an isolated control system installation of a high pressure hydraulic system which used high temperature fluid controlling non-flight critical aerodynamic panels (it may be possible, for example, to split aileron surfaces into two sets of panels, one of which is controlled by the high pressure system);
2. a control system using local actuator loop closure through electronics installed near a remotely located actuator;
3. a control system using a multiplexed wire or fiber optic data bus for remote actuator loop closure.

It may be possible to split aileron surfaces on the test-bed demonstrator, for example, into two sets of panels one set of which is controlled by an experimental actuator system driven by a separate power source. The system must be implemented such that the remaining roll control with the experimental system disconnected is adequate to support all flight phases. It must be possible to disconnect hydraulic power to the system from the cockpit. An auxiliary power unit might be used as the secondary power source for this system. The system would be reconfigured to support flight demonstrations of a variety of prototype actuators, control architectures and hydraulic fluids.

Fiber Optic Sensors (Phases 1-4)

We suggest that NASA use the test-bed demonstrator to conduct flight demonstrations of fiber optic sensors components developed in industry and other government agencies.

Vision Enhancement Technology (Phases 1-4)

We suggest that a program element be constructed to demonstrate synthetic vision in the ARC VMS. The primary purpose of this program is to develop, demonstrate and validate artificial visual scene generation technology of sufficient quality to be used as a substitute for natural vision in the HSCT; and to investigate the effects of the high amplitude flight deck motions expected from an HSCT on flight crew performance during full mission profiles.

Two approaches are being considered for the HSCT application (ref. 1):

1. computer generated imagery (CGI),
2. sensor imaging (SI).

CGI involves reconstructing a scene from maps and data on board the airplane. SI senses and displays images on the obstacles in its field of view. A third approach combines the two. Sensor vision technology must address the following current shortfalls:

1. perspective generation technology,
2. sensor performance in weather or other atmospheric conditions,
3. pilot acceptance,
4. backup architecture,
5. certification requirements.

CGI and SI have been demonstrated separately in dome simulations and other very high performance computing and display systems. A commercial aircraft manufacturer has undertaken a demonstration of full image fusion, where a sensor package and a CGI are processed and combined into one image (ref. 1). No existing vision enhancement system is presently sufficient to meet HSCT requirements (ref. 1).

We suggest that a program element be constructed to design and implement modifications to the HSCT simulation to host it on the VMS. This includes the development of the necessary visual displays.

This would be followed by a study of the effects of the rotational motions at the cockpit with pitch changes because of the location of the flight deck well forward of the center of gravity, and low speed flight control with and without automatic thrust control using the VMS as the study/demonstration tool. Visual displays would be developed to simulate both the actual vision available from the HSCT flight deck and the artificial visual scene.

High Altitude Air Data (Phases 1-4)

We suggest that DFRF continue work in high altitude air data sensor development and flight demonstration. For the HSCT application the following considerations must be addressed:

1. very accurate static pressure measurement,
2. possible application of advanced concepts in filtering to static pressure measurements,
3. flush mounted sensors.

Forward Looking Sensors (Phases 1-4)

We suggest that a program be constructed to demonstrate prototypes of forward looking air disturbance sensors. These sensors are required on the HSCT to detect:

1. clear air turbulence in cruise flight,
2. windshear and microburst in terminal areas.

Multi-function Sensor Technology (Phases 1-4)

This program element involves a study of the application of data fusion technology to the HSCT. We suggest that data fusion algorithms be developed using assumed sensor suites and models. These algorithms should be integrated into the HSCT simulations developed in the Simulation Development Program and demonstrated.

We suggest that an appropriate data fusion algorithm suite be developed and flight demonstrated on the test-bed demonstrator in two phases. First, the algorithm suite should be hosted in ground-based computers in the RAV facility. Sensors which are not available on the airplane, but are assumed to be available on the HSCT could be modeled to provide simulated data to the data fusion algorithms. The MFD and research computer installed in the test-bed demonstrator could be used to present appropriate information displays. Second, the data fusion algorithms could be hosted on-board the test-bed demonstrator in the research computer and a second series of flight demonstrations conducted.

Shock Position Sensing (Phases 1-4)

This element involves a program to develop a prototype or proof-of-concept direct normal shock sensing system for a mixed compression inlet. We suggest that the system be designed for the test-bed demonstrator so that a flight demonstration of the system can eventually be accomplished. This system would be based on recent studies conducted at LeRC.

High Temperature Electronics and Sensors (Phases 1-4)

We suggest that NASA continue the developments currently underway at DFRF in developing cooling methods for the transputer-based Airborne Instrumentation Modular System (AIMS). We suggest that work in high temperature electronics at LeRC and industry be reviewed with the goal of developing prototype systems for flight demonstration. In the event appropriate prototype developments can be identified, we suggest that they be flight demonstrated on the test-bed demonstrator.

Computational Hardware Improvements (Phases 1-4)

This program element involves a study to define the environment which avionics components will be subjected to in the HSCT application. Several environments must be defined from the cooled avionics bay to remote, external fuselage locations. The environment must include temperature, vibration and radiation levels. We suggest that the test-bed demonstrator be equipped to perform component evaluations and qualifications of avionic components through flight demonstrations and that a structured program be set up to do this type of flight qualification.

Single Event Upset Phenomena (Phases 1-4)

We suggest that NASA equip the test-bed demonstrator to conduct in-flight, high altitude tests on selected digital computing components to determine the extent of the SEU problem.

HIRF/EMI Immunity (Phases 1-4)

This issue can be addressed in conjunction with the previous element. We suggested that the test-bed demonstrator be equipped to perform component evaluations and qualifications of avionic components through flight demonstrations and that a structured program be set up to do this type of flight qualification.

Flight System Data Bus Technology (Phases 1-4)

This issue can be addressed in conjunction with the previous element. We suggested that the test-bed demonstrator be equipped to perform component evaluations and qualifications of avionic components through flight demonstrations and that a structured program be set up to do this type of flight qualification.

METHODOLOGY AND TOOLS DEVELOPMENT AND DEMONSTRATION PROGRAM

We recommend the construction of a program to address the following issues which are discussed in the appendix.

1. certification requirements,
2. integrated engineering design methods and tools,
3. documentation/specification/programming methods and tools,
4. verification/validation methods and tools,
5. controls design methods and tools,
6. simulations and models,
7. structural analysis methods and tools,
8. aerodynamic analysis methods and tools.

The program involves ARC, DFRF, LeRC and LaRC. The program consists of the following phases:

1. studies (ARC, DFRF, LeRC and/or LaRC),
2. methods and tools developments (ARC, DFRF, LeRC and/or LaRC),
3. methods and tools applications to the development of prototype systems for the HSCT (ARC, DFRF, LeRC and/or LaRC).

We suggest that the program be divided into program elements exactly paralleling the issues presented in the appendix. We suggest that a lead center be assigned to each program element. The program elements are presented below. Each of the elements involves some combination of the phases presented above. The phases involved are listed after the element title. A development plan is presented in Figure 9.

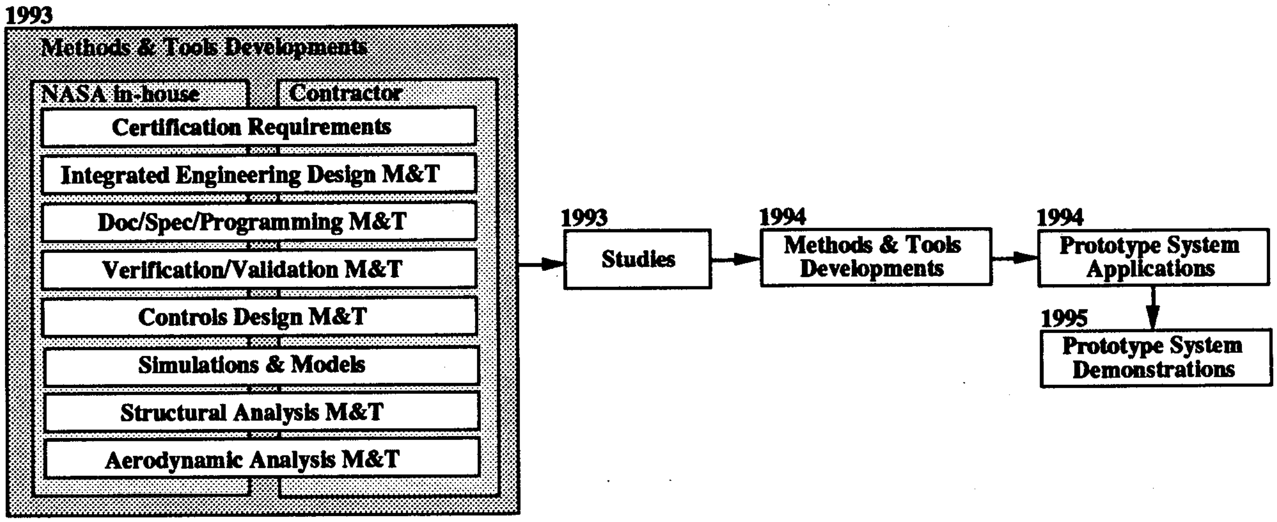

Figure 9 Methodology and Tools Development and Demonstration Plan

Certification Requirements (Phase 1)

This program element involves a study to develop an appropriate set of airworthiness certification requirements and air traffic control regulations for the HSCT by working with industry and other government agencies. The study would address the following regulations:

1. FAR 91.121 high altitude vertical traffic separation requirements (2000 ft beginning at flight level (FL) 290),
2. FAR 91.70 aircraft speed restrictions (less than 250 kn below 10,000 ft and 200 kn within an airport traffic area),
3. FAA Instrument Flight Rules for approach time separations (2 minutes),

4. FAR 36, Stage 3 noise requirements,
5. FAR 91 Appendix B ATC supersonic flight restrictions (special authorization required with no measurable sonic boom overpressure at the surface),
6. full fly-by-wire system certification,
7. mixed compression inlet certification.

This element requires significant interface with the Federal Aviation Agency (FAA).

Integrated Engineering Design Methods and Tools (Phase 2 and 3)

This program element involves the initiation of a program to develop software design and analysis inter-operability standards using data base and/or knowledge base technology. The data/knowledge base would consist of vehicle data from all engineering disciplines. For a new aircraft the data base would receive its first entries in conceptual design. Follow-on entries would be added/modified/deleted from specifications, Requests-for-Proposals (RFP), proposals, preliminary design, detail design, manufacturing, testing and, finally, end-user operations.

The standards would take advantage of data base technology, knowledge base technology and open system computing technology. It must be possible to network dissimilar workstations using different operating systems and share information seamlessly with ease.

We suggest that a two phase program element be constructed. Phase 2 would consist of a study of appropriate inter-operability standards and the development of methodologies for imposing them. Phase 3 would consist of the development of a proof-of-concept demonstration which would include two or more design tools which were integrated using the proposed standard. This system would provide a skeleton implementation of a standard developed by NASA.

In addition, this element should address the standardization of Graphical User Interfaces (GUI). The element must identify design and analysis tools for which either source code or data structures are known which are candidates for state-of-the-art GUI development. Tools which were developed under government sponsorship are candidates for this effort. We suggest that GUIs be developed for the selected tools.

The GUIs developed would be used as the basis for standards. These standards would be developed and promoted through the technical committees of professional societies such as the American Institute of Aeronautics and Astronautics (AIAA). The idea would be that the industry as a whole including the concerned government agencies would refuse to buy software or develop software which did not meet the GUI standard.

Graphic programming, program specification, compilation, debug and maintenance tools exist and are improving with maturity. Inter-operability is a problem at this time. Safe methods for multi-programming flight critical programs are not yet fully accepted.

Documentation/Specification/Programming Methods and Tools (Phases 2 and 3)

We suggest that this issue also be pursued as a part of both phase 2 and 3 discussed in the previous section.

DFRF is sponsoring a Phase II SBIR which address some of the components of this issue. The SBIR supports the initial development of AUTO_SIM, a knowledge based design, development and coding environment. The development will create a real-time simulation code library of reusable modules, automated documentation, automatic coding, and a state-of-the-art GUI for UNIX and VMS based workstations.

AUTO_SIM will be installed and evaluated in the NASA SIM facility of the ITF.

Verification/Validation Methods and Tools (Phases 2 and 3)

This program element addresses verification and validation methods and tools. A tool, TEST_PLAN) exists. TEST_PLAN is in use at DFRF (F-18 high angle of attack program) and in industry. TEST_PLAN addresses inter-operability through the availability of data structures and a well developed interface with relational data base management systems (RDBMS).

We suggest that TEST_PLAN be adopted at DFRF as the automated test planning and project management system.

Controls Design Methods and Tools (Phases 2 and 3)

We suggest that NASA construct a program element to validate the design of an integrated system in which the control laws are designed by the methodology developed in the DMICS program, specifically, the methodology reported in references 33, 34, 35, 38, 39, 40 and 43.

We suggest that the integrated system for consideration be a prototype demonstration flight/inlet control system for test-bed aircraft. We suggest that the control laws be designed by classical methods and by DMICS (LQG-LTR with decoupling) methodology.

Simulations and Models (Phase 1)

We suggest the development of a program element to address the following areas in which shortcomings exist to support an HSCT development:

1. atmospheric modeling,
2. propulsion modeling,
3. inlet flow modeling,
4. aerodynamic modeling,

5. sensor modeling,
6. aeroelastic mode modeling.

Structural Analysis Methods and Tools (Phases 1, 2 and 3)

We suggest that a program element be constructed to study the blending the rigid body and flexible body models together into one unified aeroelastic plant model. We suggest that methods be studied, developed and demonstrated which will permit an extension of sub-scale results to full-scale predictions of the aeroelastic properties of flight vehicle structures and their effect on vehicle stability, control, and handling qualities.

Aerodynamic Analysis Methods and Tools (Phases 1, 2 and 3)

We suggest that a program element be constructed to design, build and test in a wind tunnel, models for obtaining steady and unsteady aerodynamic data for spoilers, spoiler-slot-deflectors (SSD) and inverted-spoiler-slot-deflectors (ISSD).

ARCHITECTURE DEVELOPMENT AND DEMONSTRATION PROGRAM

We recommend the construction of a program to address the following issues which are discussed in the appendix:

1. flight critical architectural strategy,
2. general flight and propulsion architectures,
3. built-in test and maintenance.

The program involves ARC, DFRF, LeRC and LaRC. The program consists of the following phases:

1. hardware developments (ARC, DFRF, LeRC and/or LaRC),
2. hardware-in-the-loop simulations hosted in the ITF (DFRF),
3. flight demonstrations involving prototype hardware installations in the test-bed demonstrator (DFRF),
4. demonstrations involving prototype hardware installations in the technology demonstrator (DFRF).

We suggest that the program be divided into program elements exactly paralleling the issues presented in the appendix. We suggest that a lead center be assigned to each program element. The program elements are presented below. Each of the elements involves the four phases presented above. The phases involved are listed after the element title. A development plan is presented in Figure 10.

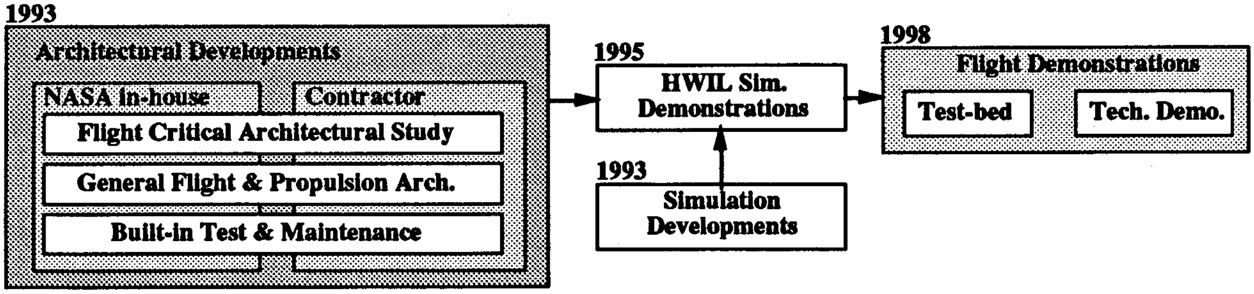

Figure 10 Architectural Development and Demonstrations Plan

Flight Critical Architectural Strategy (Phases 1-4)

We suggest the NASA construct a program element to study architectural issues concerning flight control system design which must be considered for the HSCT. They include:

1. digital/analog fly-by-wire/light,
2. mechanical/hydraulic with digital/analog SAS/CAS,
3. mechanical/hydraulic (no SAS),
4. hydraulic/electric power,
5. backup control modes.

The redundancy concepts developed in the USAF Reconfiguration Control program need to be studied for possible commercial application to the HSCT. The germane concept is that of aerodynamic redundancy; the idea of building a primary flight control system which features multiple panels individually controlled by single channel control and power actuators; each actuator using its own hydraulic power supply. If a system fails, the panel is aligned with the airstream. Redundancy is provided aerodynamically throughout the remaining panels with adjusted gains although some control authority may be lost: a concept which is readily accepted in propulsion (it is easy to argue that you can not get the same thrust out of three engines after an engine failure than you can with four), but which has never been accepted in flight control.

General Flight and Propulsion Architectures (Phases 1-4)

This issue addresses the demonstration of modular avionics proof-of-concept and demonstration prototype systems. In order for the HSCT to be competitive, operational availability must be significantly higher than conventional airliners. HSCT flight and propulsion control systems must be composed of fewer, more reliable LRUs and fewer, more reliable, connectors than competing airplanes.

Built-in Test and Maintenance (Phases 1-4)

We suggest the construction of a program element to study the application of artificial intelligence technology to system monitoring for HSCT applications. Concepts should be developed which address the presentation of appropriate data to the flight crew and decision aiding. Built-in test and maintenance systems must be able to automatically detect and isolate down to the Line Replacement Unit (LRU) level virtually 100% of faults in real time. The system must be able to sort these faults into categories for in-flight attention, correction during the next turn-around or correction during scheduled maintenance periods (ref. 1). Because of the flight critical nature of some of these faults, the system must also provide decision aiding or, possibly, automated decision activation particularly with respect to dispatch criteria (ref. 1).

CONFIGURATION DEVELOPMENT AND DEMONSTRATION PROGRAM

We recommend the construction of a program to address the following issues which are discussed in the appendix.

1. high lift device data,
2. laminar flow wing design,
3. overpressure minimization,
4. ozone layer depletion,
5. noise abatement.

The program involves ARC, DFRF, LeRC and LaRC. The program consists of studies in each of the program elements. We suggest that the program be divided into program elements exactly paralleling the issues presented in the appendix. We suggest that a lead center be assigned to each program element. The program elements are presented below. A development plan is presented in Figure 11.

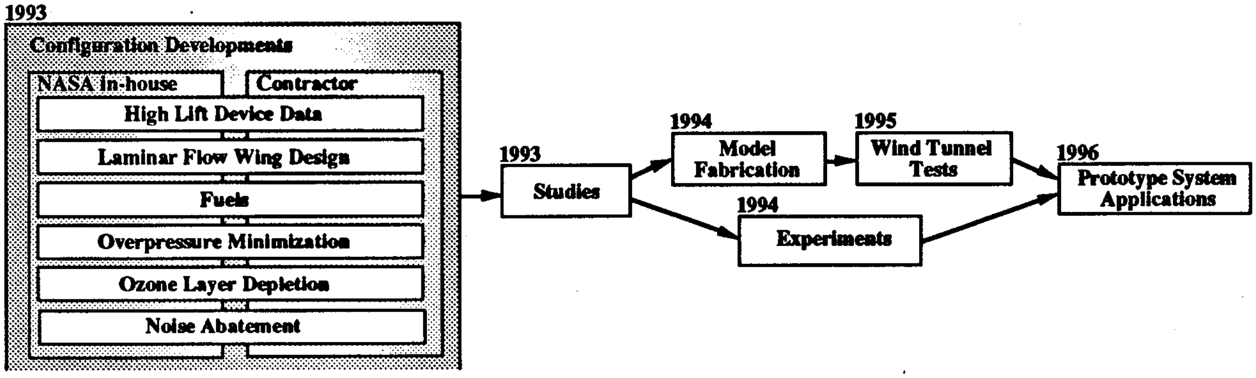

Figure 11 Configuration Development and Demonstration Plan

High Lift Device Data

We suggest that a program element be constructed to build wing models and conduct wind tunnel tests to obtain data on the performance of spoiler-slot-deflectors and inverted-spoiler-slot-deflectors for HSCT application.

Laminar Flow Wing Design

We suggest that a program element be constructed to build wing models and conduct supersonic wind tunnel tests to obtain data on the performance of laminar flow configurations for HSCT application using the results of the F-16XL laminar flow wing flight demonstration program.

Overpressure Minimization

We suggest that a program element be constructed to continue the work (ref. 53) in developing aerodynamic shapes which minimize sonic boom overpressure at the earth's surface from high altitude, high speed cruise.

Ozone Layer Depletion

We suggest that a program element be constructed to study the effects of operating many HSCT aircraft above 50,000 feet on ozone layer depletion. The SR-71 is well suited to this task. In addition, we urge the continued development of staged combustion concepts (ref. 61) for HSCT engines as a means of reducing Nitrogen Oxide emissions.

Noise Abatement

We suggest that a program element be constructed to continue the work in engine nozzle design to minimize noise (refs. 62, 63, 64, 65, 66, 67 and 68).

RECOMMENDATIONS AND CONCLUSIONS

The following conclusions were reached:

1. The aerospace industry is not likely to develop an HSCT unless NASA undertakes an aggressive, comprehensive multi-year technology development and demonstration program which addresses all the technical issues confronting an HSCT development.

2. The technical issues span many technical disciplines and are related to economics and environment. There are no technical barrier issues, per se. In other words all issues are technically soft, albeit serious enough in total to prevent a positive decision by the industry to proceed with a development unless solutions to all technical issues can be developed and successfully flight demonstrated.

3. NASA has the expertise to pursue solutions to all the technical issues through a combination of "in-house" and contracted R&D.

4. There are a number of flight demonstration alternatives which must be studied. They span a broad cost differential from a very high fidelity ground simulation to a dedicated technology flight demonstrator.

The following recommendations are made:

1. It is recommended that NASA construct an aggressive HSCT technology development and demonstration program to be pursued in the mid and late 1990s along the lines described in this report.

2. The technology development and demonstration program must be structured to address the stringent requirements to demonstrate reliability, maintainability and durability which commercial applications demand before technologies are included on a production airplane.

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Appendix A. TECHNOLOGY ISSUES

All of the technology issues are presented in this appendix. They are divided into six technology categories as follows:

1. flight and propulsion control issues,
2. hardware issues,
3. system engineering issues,
4. system architecture issues,
5. aerodynamics and performance issues,
6. environmental issues.

These issues have been compiled from references 1 and 2 plus inputs which we have obtained from a variety of other sources. In each category a cross-reference table is presented to references 1 and 2.

Flight and Propulsion Control Issues

This section describes technology issues related to flight and propulsion control. It includes:

1. flight control law issues,
2. inlet control law issues,
3. engine control law issues,
4. integrated control concepts and control law issues,

Table A-1 below shows a summary of technology issues related to flight and propulsion controls. The table shows cross-references to references 1 and 2. The priorities shown are also from references 1 and 2. These priorities are taken out of context. The reader should conduct the references to become familiar with the priority system used by the authors and to develop an understanding of the underlying reasoning. They are included in this report only to give a flavor of the relative importance attached to the issues by the authors.

Table A-1 Flight and Propulsion Control Issues Summary

Technical Issue	Reference 1 Paragraph	Priority*	Reference 2 Paragraph	Priority**
Augmented Manual Flight Control	4.1.1.1	M3	2.3.5	H/M
Automatic Flight Control	4.1.1.2	H11	2.3.5	H/M
Active Flight Envelope Protection	4.1.1.5	M4		
Trajectory Generation and Tracking	4.3.3.3	M6	2.3.5	L
Propulsion System Automation	4.2.2.1	M3	2.3.4	
Engine/Inlet Control Law Integration	4.2.2.2	H7	2.3.4	M
Inlet Sensor Fault Accommodation				
Unstart Avoidance/ Accommodation	4.3.3.2	H7	2.3.4	
Flight/Propulsion Control Integration	4.3.3.1	H7	2.3.4	
Gust and Maneuver Load Alleviation	4.1.1.4	M1		
Performance Seeking Control	4.3.3.4	M7		
Active Flutter Suppression	4.1.1.3	H10		
Active CG Management	4.1.1.6	M8	2.3.5	

* Priorities assigned in reference 1:
H = high (ranked 1 (highest) to x)
M = medium (ranked 1 (highest) to x)

** Priorities assigned in reference 2
H = high
M = medium
L = low

AUGMENTED MANUAL FLIGHT CONTROL

Issue Description

HSCT will be a very flexible, large aircraft with a long fuselage. It will be operated at very high altitude. The vehicle configuration, size and operating environment will provide unprecedented challenges to flight control system designers. HSCT will be a control-configured vehicle (CCV) (ref. 1). The design of the stability augmentation system (SAS) will be complicated by the uncertainty of predicted vehicle dynamics which will be highly influenced by aeroelastic modes: These modes will dominate the flight control system SAS (and, possibly, CAS) design to an extent previously unencountered in aircraft design. An extremely robust system will have to be designed because of the following uncertainties (ref. 1):

1. Initial control surface sizing based on rigid body wind tunnel testing will be in error.
2. Control surface effectiveness will depend strongly on aeroelastic vehicle deflections under maneuver loads.
3. Lift distributions, drag predictions and stability derivatives will be in error because of uncertainties in aeroelastic vehicle deflections under maneuver loads.

Control augmentation (CAS) may be required to provide adequate flight path control in high altitude cruise if not throughout the flight envelope. These flight control issues may require that HSCT be equipped with a full-authority, digital fly-by-wire/light flight control system with very robust digital logic (control laws) using either very extensive gain scheduling, or some form of real-time estimation and optimization.

The demands imposed on the flight control system designer must be reduced. Therefore, relatively high fidelity aerodynamic, structural, flight control system and atmospheric models must be developed and combined into a full flight envelope vehicle simulation for use very early in the design process (preliminary design) (ref. 1). The issue requires some rethinking of the entire preliminary control configuration development process to place proper emphasis on dealing with the uncertainties of vehicle dynamics for such a large, flexible vehicle operating in such an extreme environment and range of flight conditions.

Providing the HSCT with adequate handling qualities throughout the flight envelope will be a difficult task due to the following special considerations:

1. The vehicle will be statically unstable in pitch in at least a portion of the flight envelope.
2. Low speed flight control with and without automatic thrust control will pose special problems because of the configuration (long fuselage), poor (or artificial) visibility, high stall speed, backside approach, and high nose attitude.

3. The flight crew will be subjected to high rotational motions with pitch changes because of the location of the flight deck well forward of the center of gravity (CG).
4. High altitude precision flight path control for acceptable passenger ride quality will be difficult because of low static pressure changes with altitude, low dynamic pressure combined with high Mach number and significant changes in atmospheric conditions (density pockets, etc).

A highly augmented CAS design may be required to provide acceptable handling qualities throughout the flight envelope. The CAS design may differ significantly from existing designs employed primarily in tactical airplanes. It may provide decoupled responses to pilot inputs and emphasize position as opposed to rate control. For example, stick input could provide commanded attitude (pitch) control, angle-of-attack, or flight path angle as opposed to the more traditional CAS concept of commanded pitch rate, load factor or a blend of the two (C* control).

Technology Requirements and Benefits

Flight control system design methodology for HSCT requires development. The benefits involve reduced risk in the adequacy of the flight control system to control the airplane adequately and safely throughout its flight envelope particularly during initial flight testing and envelope expansion.

Adequate handling qualities must be provided throughout the flight envelope in manual control modes and degraded modes. The benefits include improved safety margins, adequate passenger ride control and satisfactory approach and landing performance.

Technology Status and Readiness

Adequate flight control technology is available. Design tools are available. Work is required to develop and validate the appropriate design methodology and establish relationships between tolerable uncertainties in vehicle modal characteristics, control law robustness requirements and design methodology effectiveness.

There are no technology shortfalls in the area of handling qualities; however, the physical characteristics of the vehicle and its large flight envelope place unprecedented demands on flight control system design engineers to provide adequate handling qualities.

AUTOMATIC FLIGHT CONTROL

Issue Description

The traditional way of developing the automatic flight control system is to design each mode separately and independently. This results in design integration and performance problems that often appear late in the program resulting in design complexity and cost escalation (ref. 1). Problems typically include (ref. 57):

1. speed instability when using autopilot flight path control with a fixed throttle,
2. path instability when using autothrottle speed control with a fixed elevator,
3. high autothrottle activity in turbulence,
4. adverse control coupling, resulting in speed perturbations because of path control and vice versa,
5. inadequate anticipation of maneuvers and poor coordination of control between autopilot and autothrottle.

Technology Requirements and Benefits

A methodology is required which addresses an integrated approach to autopilot outer loop design. The potential benefits are improved path control in all flight phases.

Technology Status and Readiness

A Total Energy Control System Concept (TECS) (refs. 56, 57, 58 and 59) has been defined, evaluated in subsonic simulations and flight demonstrated on the NASA B-737 during the NASA Terminal Configured Vehicle Program. In this concept, outer loop flight path and speed control mode requirements are fully defined in point mass kinematic terms without regard to vehicle aerodynamic characteristics, while inner loops are custom designed for specific vehicle aerodynamic characteristics. The fundamental simplicity of the TECS concept makes it an attractive alternative for application to the HSCT autopilot development.

ACTIVE FLIGHT ENVELOPE PROTECTION

Issue Description

Active flight envelope protection is an extension of the typical separate systems found in both commercial and military airplane flight control systems such as stick shakers and pushers, oral stall warning, throttle control override based on angle-of-attack, etc. It is closer in concept to departure prevention systems found in a few advanced military airplanes such as the B-2 and the F-22. Active flight envelope protection provides control inputs which prevent envelope escape in all manual and automatic flight control modes. It can be thought of as a CAS system. It may provide control inputs (including propulsion inputs) which prevent aerodynamic stall; and prevent load factor limits, dynamic pressure limits, Mach limits and airspeed limits from being exceeded. It may actively prevent the deployment of devices such as flaps and landing gear if the aircraft flight condition is not within certain limits. It may go so far as to prevent the application of power for takeoff if the aircraft configuration (flaps, for example) is not correct for a given gross weight; or if runway length and density altitude are not compatible with a safe takeoff; or if sensed payload is not within safe limits from either a center-of-gravity or distribution viewpoint.

Technology Requirements and Benefits

With the introduction of relaxed static stability and FBW/FBL control, traditional warning systems may not be adequate (ref. 1). There is a need to develop more general flight envelope protection concepts and integrate their function into the basic manual and automatic control functions (ref. 1). Functions to be researched include:

1. angle-of-attack limiting,
2. minimum speed limiting,
3. maximum speed limiting,
4. dynamic pressure limiting,
5. Mach limiting,
6. bank angle limiting,
7. load factor limiting,
8. thrust command limiting,
9. configuration checking,
10. load distribution sensing and checking.

Many controversial issues related need to be addressed. Non-conflicting performance and system requirements need to be developed. Many of these issues have been dealt with in the military world, but they need to be addressed in the commercial world independently.

The potential benefits are in the area of increased safety margins. It may be possible to prevent the infrequent type of accident which occurs from flight crew distraction or inattention such as an incorrect flap setting for takeoff, an incorrect V1 and V2 calculation, or an incorrect (or outdated) density altitude calculation.

Conversely, it may also be possible to operate with smaller safety margins with these types of systems while meeting the same safety requirements. For example, if it were possible to rely on up-to-date (within seconds) density altitude calculations, sensed wind conditions at several points along the takeoff runway, individual engine thrust availability (automatically adjusted per engine for wear and condition), and accurately sensed payload weight and distribution, one could figure required takeoff roll and climbout performance very accurately (within tens of feet and feet/minute).

Technology Status and Readiness

The technology exists. Departure prevention systems have been implemented in some tactical military aircraft. The implementation of these types of systems is limited more by their acceptance by flight crews than by technology.

TRAJECTORY GENERATION AND TRACKING

Issue Description

The use of both ground-based preflight and on-board real-time optimal trajectory generation, and real-time tracking may provide significant range improvement and operational flexibility to operating HSCTs. Trajectory generation algorithms have the potential of providing minimum fuel profiles in the presence of many types of constraints including weather, winds and traffic control constraints. A significant portion of a flight crew's flight time on a typical flight consists of manual replanning in the presence of unforecasted winds to generate updated fuel and time estimates. Fuel replanning would be a particularly important issue in HSCT operations where many flight segments would be flown at maximum or close-to-maximum range.

This issue addresses preflight, ground-based optimal trajectory generation and tracking. On-board real-time applications are discussed in a follow-on issue. Developmental issues in preflight, ground-based optimal trajectory generation include (ref. 1):

1. pilot interface with off-line trajectory generation systems (ref. 1),
2. energy management computations and automatic configuration control to minimize fuel consumption (ref. 1),
3. timing of thrust cut-back, throttle closure, and speed commands based on prevailing wind to meet prescribed noise footprints on takeoff and landing (ref. 1),
4. flight path and gear/flap deployment command computation to meet a target position in a desired state, in spite of fluctuating wind profiles, aircraft weight and performance characteristics (ref. 1),
5. precision navigation and landing guidance in terminal areas using both ground based and satellite resources (ref. 1),
6. optimal takeoff, climb, cruise-climb, descent, approach and landing profiles in the presence of controller imposed limitations and instructions, wind profiles, weather restrictions, local area restrictions, standard instrument departure (SID) procedures and published approach procedures.

This issue also addresses on-board optimal trajectory generation and tracking. Trajectory generation algorithms have the potential of providing minimum fuel profiles in the presence of many types of constraints including weather, winds and traffic control constraints. A significant portion of a flight crew's flight time on a typical flight consists of manual replanning in the presence of unforecasted winds to generate updated fuel and time estimates. Fuel replanning would be a particularly important issue in HSCT operations where many flight segments would be flown at maximum or close-to-maximum range.

Technology Requirements and Benefits

The generation of optimal flight profiles in preflight planning to accommodate flight plan changes has the potential of improving range and operational flexibility for HSCTs.

The use of on-board real-time optimal trajectory generation, and real-time tracking may provide significant range improvement and operational flexibility to operating HSCTs. Developmental issues include (ref. 1):

1. pilot interface with on-board trajectory generation systems (ref. 1),
2. energy management computations and automatic configuration control to minimize fuel consumption (ref. 1),
3. timing of thrust cut-back, throttle closure, and speed commands based on prevailing wind to meet prescribed noise footprints on takeoff and landing (ref. 1),
4. flight path and gear/flap deployment command computation to meet a target position in a desired state, in spite of fluctuating wind profiles, aircraft weight and performance characteristics (ref. 1),
5. precision navigation and landing guidance in terminal areas using both ground based and satellite resources (ref. 1),
6. optimal takeoff, climb, cruise-climb, descent, approach and landing profiles in the presence of controller imposed limitations and instructions, wind profiles, weather restrictions, local area restrictions, standard instrument departure (SID) procedures and published approach procedures (ref. 7).

Technology Status and Readiness

The technology has been developed for tactical and strategic military airplanes. Its utility in a commercial operating scenario requires evaluation (ref. 1).

The generation of optimal flight profiles in on-board planning to accommodate flight plan changes requires considerable computational power. The computational intensity and solution time requirements push the throughput available from the current generation of airborne computers. It is possible that emerging technology in parallel processors will provide the solution to this problem. Computers composed of parallel architectures based on transputer processors seem to provide an answer for high-throughput airborne computation.

On-board generated optimal flight profiles have the potential of improving range and operational flexibility for HSCTs.

PROPULSION SYSTEM AUTOMATION

Issue Description

It may be desirable to provide a high degree of propulsion system automation to reduce pilot workload and insure that HSCTs can be designed to operate with a two man crew (ref. 1). It may be possible to limit the crew's mandatory propulsive system management tasks to requesting engine start, establishing desired thrust levels, maintaining thrust required to hold desired parameter set points in specific flight maneuvers (hold Mach, hold angle-of-attack, hold altitude, etc), and requesting engine shutdown (ref. 1). Flight crew manual override modes will probably be required along with extensive system health monitoring.

Technology Requirements and Benefits

Reduced flight crew workloads are possible. The safety and economic benefits of allowing the airplane to be operated safely with low crew workloads and a high degree of systems health awareness with a two man crew are significant. The benefits include additional time available for operational tasks such as weather monitoring and in-flight replanning.

Technology Status and Readiness

The technology is available to provide this degree of automation; however, significant work is required to research the computer resources required, the acceptability of this level of automation and Failure Modes and Effects Analysis (FMEA).

ENGINE/INLET CONTROL LAW INTEGRATION

Issue Description

The use of variable geometry, mixed compression inlets allows for reductions in drag, increases in thrust-minus-drag, engine-inlet airflow demand matching, and other benefits which affect range, but also introduces the possibility of inlet unstarts. Integrating flight control, engine control and inlet control allows many potential advantageous features to be incorporated which can affect range, ride quality, engine operating efficiency, time between engine overhaul and a host of other associated advantages. The primary features which may be incorporated with such integration are (ref. 1):

1. programmable engine stall margin over the propulsive system operating range (either a constant stall margin can be maintained, or a reduced stall margin can be programmed with attendant thrust-drag improvements in steady state operation),
2. programmable inlet flow stability margin which is adjusted as a function of flight condition (sideslip, angle-of-attack) and air disturbances,
3. automatic stall and unstart recovery incorporating interlocks to prevent component damage and repeated stalls and unstarts,
4. automatic buzz suppression at minimum achievable thrust.

There is a significant issue in integrated system designs related to areas of responsibility among sub-contractors. For example, in an integrated flight propulsion control system, exactly what are the areas of responsibility of the engine manufacturer compared to flight control system manufacturer? To what degree is a component manufacturer responsible for the integrated system performance? Although it has always been the case that multiple sub-contractors share responsibilities in aircraft designs, the emergence of integrated control systems complicates the issue. The issue has considerable legal implications.

Technology Requirements and Benefits

The benefits of integrated flight/engine/inlet control are possible increases in range, improved ride quality, improved safety margins, and improved engine reliability (time between overhauls). Integration of the three control disciplines has not been developed or flight demonstrated on an aircraft which uses a mixed-compression inlet and a variable cycle engine.

Technology Status and Readiness

All of these concepts have been developed and evaluated in pieces. The NASA Digital Electronic Engine Control (DEEC) program (refs. 12, 13, 21, 22, 23, 24, 25, 26, 27 and 28) demonstrated the advantaged of integrated flight/propulsion control (IFPC). One of the concepts generated was the capability of performance gains using reduced stall margins made possible by IFPC control laws. The NASA YF-12 Cooperative Airframe/Propulsion Control System Program (COOP) (refs. 3, 4, 5 and 29) demonstrated that improved high altitude path control could be attained on an YF-12 using an integrated flight/inlet control concept.

Integration of the three control disciplines has not been developed or flight demonstrated on an aircraft which uses a mixed-compression inlet and a variable cycle engine. In addition, attention must be paid to the development methodology, certification difficulties and sub-contractor coordination and responsibility issues and problems associated with this degree of integration.

INLET SENSOR FAULT DETECTION AND ACCOMMODATION

Issue Description

The multiple pressure sensors used to define inlet flow conditions and shock position in mixed compression inlets are expensive, require extensive plumbing and considerable electronics support. Airframe air data should have sufficient information available to define the flow field in front of the inlet. This data combined with engine airflow from the engine, should make it possible to control the inlet geometry without using dedicated pressure sensors (ref. 1). The technology has never been developed or demonstrated.

Technology Requirements and Benefits

In external compression inlets, the technology would permit elimination of expensive high accuracy pressure transducers and their associated plumbing. In mixed compression inlets the concept would be used as a model based backup to the primary sensors (ref. 1). This would reduce the total number of sensors in a redundant high reliability application and substantially reduce the associated plumbing, electronics cost and complexity.

Technology Status and Readiness

Proof of concept in the flight environment is required. The primary issue is accuracy and repairability of the airframe and engine data used.

UNSTART AVOIDANCE/ACCOMMODATION

Issue Description

Inlet unstarts in the mixed compression inlet of the HSCT must be avoided. Unstarts can be caused by flow disturbances, atmospheric anomalies, changes in flight conditions (angle-of-attack, sideslip), changing engine demands and incorrect inlet geometry adjustments resulting from component failures. Unstarts can cause abrupt changes in thrust-drag producing both undesirable longitudinal forces and directional moments. The resulting aircraft motions can be very annoying and possibly injurious to unseated passengers especially if they are frequent. In addition, the total time spent in the unstart condition at supersonic cruise can significantly reduce range available. Finally, it is desirable to operate the inlet with the terminal shock as close to the throat as possible for best thrust-minus-drag performance. Low flow stability margin exacerbates the unstart problem in direct proportion.

Technology Requirements and Benefits

The solution to providing unstart avoidance especially at low flow stability margins requires (ref. 1):

1. improved definition of free stream disturbance environment,
2. improved prediction of free stream disturbances,
3. improved normal shock position measurement (direct or indirect) capability,
4. improved analytical estimates of inlet characteristics and performance,
5. improved estimates via wind tunnel or analysis of the unstart generated forces and moments on the aircraft.

Technology Status and Readiness

The physics involved are well understood. Accurate understanding of the detailed aerodynamics involved for specific configurations is lacking. Direct measurement of shock position is possible but not developed. It is covered in another issue. The use of forward-looking sensors based on LASER technology to provide air disturbance warning is also covered in another issue.

FLIGHT/PROPULSION CONTROL INTEGRATION

Issue Description

Flight propulsion control integration on the HSCT raises a number of issues (ref. 1). One is the interchange between and use of flight critical data by conventionally isolated systems. Some examples of data interchange are:

1. the use of air data, and flight control command and feedback data to provide dissimilar redundancy and feed-forward information within the inlet control system;
2. the use by the flight control system of propulsion system model data such as actual thrust and minimum and maximum thrust limits;
3. the use of the propulsion system as a force generator both symmetrically and asymmetrically within the flight control laws.

Another issue is the definition of the thrust command interface between propulsion and flight control. For example:

1. what should the interface parameter be: total thrust, net thrust, installed thrust or something less obvious;
2. what should throttle lever characteristics be in terms of linearity and sensitivity;
3. what discretes and interlocks are required;

4. what is the propulsion system dynamic response and accuracy performance 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 propulsion/airframe/control system sensitivities to disturbances,
2. what should control priorities be when limit conditions are reached,
3. what is the inlet unstart effect on hydraulic/electric power and vehicle dynamics.

Technology Requirements and Benefits

The dynamic response and accuracy requirements for each piece of proposed interchanged data between flight control and propulsion control systems must be established. Because of the size, structural flexibility, and speed of the aircraft and the potentially large number of interchanged variables contemplated, the design of the data interchange is a significant task.

The benefits to an integrated system are significant. The integration requires study and flight demonstration of a prototype system before implementation on an HSCT is possible.

Technology Status and Readiness

The concepts and tools to develop the control laws for an integrated flight/ inlet/ propulsion control system exist. Flight demonstrations of a demonstration prototype are required before an integrated system design will be accepted in an HSCT.

GUST AND MANEUVER LOAD ALLEVIATION

Issue Description

Active gust and maneuver load alleviation has the potential for reducing design weight. Design weight reduction is particularly important in the HSCT because the airplane must meet very specific and difficult range and operating cost requirements. In addition, gust prediction, which is a part of a gust load alleviation system, may be required to prevent inlet unstart especially if the inlet system is designed to operate at a low flow stability margin.

Technology Requirements and Benefits

A successful gust load alleviation system design depends on (ref. 1):

1. identification of flight and engine control requirements for gust load alleviation,
2. identification of sensor technology requirements for gust prediction,
3. determination of the performance penalty (increased drag and thrust required) associated with the use of active gust and maneuver load alleviation,
4. formulation of the appropriate aeroelastic modes in simulation models for gust and maneuver load alleviation system design and a real-time simulation validation of a design including its effect on handling qualities.

The potential benefit is reduced design weight. The potential drawbacks are increased drag integrated over a flight resulting in reduced range. The added drag is created by constantly moving control surfaces which provide the gust and maneuver alleviation aerodynamic moments.

Gust load alleviation requires a tradeoff in design between actuator bandwidth and gust warning time. It is current believed that gust detection between 50 to 300 meters in front of the wing root leading edge is required at cruise Mach number.

Technology Status and Readiness

Flight worthy LASER based (LIDAR) forward looking sensors are planned for demonstration in 1993 that are sufficient for airspeed, sideslip and angle-of-attack measurements (ref. 1). Actuator and control technology can support the development of these systems now.

PERFORMANCE SEEKING CONTROL

Issue Description

The control laws of the integrated flight/engine/inlet system of the HSCT will be designed for optimum performance at a number of operating (design) conditions. The number of operating conditions included in the control law design is limited by engineering design labor costs, and the control law implementation complexity. The system's performance depends on how well the control laws handle off-design conditions. Off-design conditions include not only the normal conditions away from a very limited set of design operating points, but also, degraded modes and changes in component characteristics because of normal wear and tear. Off-design performance is often referred to as the robustness of the system.

Performance Seeking Control (PSC) consists of a control law implementation strategy which allows adjustments to be made to control variables on-line to obtain near optimal performance in the presence of off-design conditions. PSC has been flight demonstrated in a propulsion control system for a modified F-100 engine in a specially configured F-15 (the HiDEC F-15 at DFRF); however, the technology has not been employed in any production military or commercial airplanes.

Technology Requirements and Benefits

The large flight envelope of the HSCT and the complexity of the integrated flight/engine/inlet control system will place a severe burden on the control system designers to produce a sufficiently robust design to meet performance requirements. PSC has the potential for allowing design engineers to implement a set of control laws which provides the best possible system performance throughout the flight envelope.

Technology Status and Readiness

PSC has been flight demonstrated in the HiDEC F-15 for Digital Electronic Engine Control (DEEC) (refs. 12, 21, 22, 23, 24, 25, 26, 27 and 28). PSC has not been applied to or implemented in a broader integrated flight/engine/inlet control system. PSC has not been implemented in any production system. The technology must be applied to a demonstration system closer in application to the HSCT and flight demonstrated before it could be considered as a technology to be included in the HSCT development.

ACTIVE FLUTTER SUPPRESSION

Issue Description

The use of an active flutter suppression system can cause a designer to save considerable structural weight in aerodynamic surfaces such as wings and tails. The science of structural dynamics is sufficiently inexact in predicting structural mode frequencies and flutter that considerable over design is required to provide a safe margin without active suppression. The higher the design Mach number and dynamic pressure at cruise, the more serious the problem becomes. Even if all structural modes are adequately damped by themselves, active mode stabilization may become necessary if structural mode frequencies are too close to, or overlap rigid body modal frequencies (ref. 1).

Technology Requirements and Benefits

Successful active flutter suppression design depends on:

1. accurate knowledge of the in-flight vehicle state in terms of mass distribution, static and dynamic pressure and Mach number;
2. correct design and analysis methods, tools and procedures;
3. correlation of models used in servo-elastic control synthesis and active flutter suppression design to production airplane;
4. accurate modeling of the vehicle structural dynamics, aerodynamics and system components (sensors and actuators);
5. knowledge of interactive effects of flutter suppression on primary controls; in particular, to determine the requirements and effects of special flutter control surfaces;
6. provision for backups and/or redundancy to support flight critical operation;
7. availability of reliable hardware (actuators, processors) to handle the duty cycle and the environmental requirements of the system.

The benefits are enormous in structural weight savings in the tail area in particular and in the wing design secondarily. The weight savings could translate significantly to range and payload increases which could mean the difference between marginal commercial performance and spectacular performance in HSCT operation.

Technology Status and Readiness

No production aircraft, military or commercial, have used active flutter suppression, nor has such a system ever been flight demonstrated in a critical application; that is, where flutter would have occurred naturally without it. It has been flight demonstrated in an experiment in which flutter was induced by the movement of a mass within an aerodynamic surface to change the surface's inertia properties in flight. Wind tunnel demonstrations of active flutter suppression systems installed in a wing designed to flutter under given conditions have been conducted successfully.

Currently confidence in active flutter suppression to replace structural damping is low. Extensive validation efforts are required to allow the technology to be considered in the HSCT design as a means of generating weight savings: that is, to be relied on as a flight critical system. These efforts must include (ref. 1):

1. repeated, successful, first time prediction of various open loop flutter modes on a flutter wind tunnel model, over a range of dynamic pressures, densities and mass distributions;
2. repeated, successful, first attempt, stabilization of these flutter modes by an active flutter suppression system;
3. demonstration of satisfactory design robustness in all cases in terms of gain and phase margin as well as misprediction of the open loop flutter characteristics.

4. successful in-flight demonstration of an active flutter suppression functional design on a representative free flying model or research aircraft;
5. satisfactory demonstration of flutter suppression hardware and software reliability and safety through analysis and supporting appropriate testing.

ACTIVE CG MANAGEMENT

Issue Description

Active center-of-gravity management has the potential of improving HSCT performance by reducing trim drag, providing active static margin control during all phases of flight (especially in subsonic to supersonic transitions and vice-versa) and improving safety margins by automatic determination of optimum stabilizer position for takeoff and as an input to gain scheduling for active flutter suppression and CAS.

Active center-of-gravity management is most easily realized by automatic, high flow rate, fuel transfer. It is particularly important in a vehicle that cruises at supersonic speed because of the shift in aerodynamic center-of-pressure from approximately the quarter-chord position subsonic (25% mean aerodynamic chord (MAC)) to the half-chord position supersonic (50% MAC). If a center-of-gravity shift is not implemented to accommodate this transition, very high trim drag can result from the requirement to generate the offsetting trim pitching moment with an aerodynamic surface.

Technology Requirements and Benefits

Technology requirements include (ref. 1):

1. use of nose and main gear sensed pressure/position to compute takeoff trim settings,
2. integration of CG control with the primary flight control system to provide optimal flight configuration in every flight phase,
3. accurate, reliable fuel gaging systems capable of operation in the HSCT environment,
4. fuel transfer for CG control,
5. payload load sensors for computed CG calculation.

The benefits are improved performance through automated CG control (reduced drag). Improved safety margins through automated CG calculation and takeoff stabilizer setting.

Technology Status and Readiness

The necessary hardware technology is developed. Fuel transfer for CG control has been operational in imlitary airplanes for three decades. The B-58, in particular, employed automatic fuel transfer to shift CG position when the aircraft transitioned from subsonic to supersonic flight and vice-versa.

Hardware Issues.

This section describes technology issues related to hardware. It includes:

1. actuation technology issues,
2. sensor technology issues,
3. digital computation hardware issues.

Table A-2 below shows a summary of technology issues related to hardware. The table shows cross-references to references 1 and 2. These priorities are taken out of context. The reader should review the references to become familiar with the priority system used by the authors and to develop an understanding of the underlying reasoning. They are included in this report only to give a flavor of the relative importance attached to the issues by the authors.

Table A-2 Hardware Issues Summary

Technical	Reference 1	
Issue	Paragraph	Priority*
Actuation Technology	4.2.1	H1
Fiber Optic Sensors	4.2.2.1	M10
Vision Enhancement Technology	4.2.2.2	H6
High Altitude Air Data	4.2.2.3	M2
Forward Looking Sensors	4.2.2.3	H7
Multi-function Sensor Technology	4.2.2.4	
Shock Position Sensing	4.2.2.5	H7
High Temperature	4.2.2.6	H7
Electronics/Sensors	4.2.3.1	M9

Computational Hardware Improvements	4.2.3.2	M5
Single Event Upset Phenomena	4.2.3.3	M5
HIRV/EMI Immunity	4.2.3.4	M11
Flight System Data Bus Technology	4.2.3.5	H8

* Priorities assigned in reference 1:
H = high (ranked 1 (highest) to x)
M = medium (tanked 1 (highest) to x)

ACTUATION TECHNOLOGY

Issue Description

There are many actuation system technology improvements in various stages of CRAD and IRAD research and development which may provide significant cost reduction and weight savings to the HSCT. Several specific technologies need to be studied for possible inclusion on the HSCT as follows:

1. high temperature hydraulic fluids,
2. high pressure hydraulic systems,
3. composite actuators,
4. thin profile actuators,
5. high bandwidth actuators,
6. high bandwidth electric actuators,
7. fiber optic - mechanical transducers.

Several architectural design philosophies involving actuation require study with respect to possible application to the HSCT design as follows:

1. redundancy management,
2. remote vs. local actuator loop closure,
3. time-division multiplexed busses vs. dedicated wiring for actuator electronics.

The HSCT will likely include more actuators than any previously built airplane.

Technology Requirements and Benefits

Hydraulic fluids which can retain their properties at high temperatures and promote long seal life are required to satisfy the high temperature environment which hydraulic lines will be subjected to on the HSCT.

The use of high pressure hydraulics and composite actuators has the potential benefit of very significant weight savings. Although the composite actuator may be larger than its conventional counterpart, the savings in weight and cost may outweigh the increase in size. Thin profile (hinge line) actuators may be required to minimize aerodynamic drag in the wing and tail sections.

Very high bandwidth actuators will be required if active flutter suppression is employed. High bandwidth actuators will be required to support active gust load alleviation and ride improvement systems. Also, if low flow stability margins are used in the engine inlet system, spike and bypass door motion will have to be swift in response to air disturbance detection.

Samarium cobalt technology has made it possible to build light weight, electric power, high bandwidth actuators. The technology could reduce the dependence on hydraulics for control power.

Fiber optics technology could provide further reductions in weight over conventional wiring for control signals. There is a requirement to produce reliable, high performance, low cost transducers to convert optical signals to electronic and mechanical signals and vice-versa.

Local actuator loop closure with local electronics reduces the requirement for extensive electronic communication with centrally located electronics (a flight control computer, for example). The weight savings in wiring bundles are considerable. A second philosophy to save wiring is the use of time-division multiplexed busses as opposed to dedicated wiring even for actuator loop closure.

Technology Status and Readiness

High pressure hydraulic systems and high temperature hydraulic fluids have been in R&D for a number of years. Both technologies require flight demonstration before an airframe manufacturer will include them on an HSCT design.

Thin profile actuators have shown a propensity for lockup failures. An improved system must be developed and flight demonstrated.

Very high bandwidth actuator technology is available for flutter suppression systems and has been demonstrated in wind tunnel tests of proof-of-concept designs.

DC motors have not been used in high bandwidth primary flight control. The application requires study.

Fiber optics control signal communication for flight control application has been demonstrated in laboratory systems. Transducer technology is still the weak link. A flight demonstration of a flight control system using a fiber optic communication link is required.

Local actuator loop closure requires high temperature electronics which are in development, but are not yet ready for application. They will require flight demonstration before an airframer will consider them for an HSCT. To date bus technology has not been used for inner loop flight control applications (actuator loop closure). A flight demonstration will be required. The technology is well developed.

FIBER OPTIC SENSORS

Issue Description

Fiber optic transducers provide potentially significant advantages over conventional electro-mechanical transducers for temperature, pressure, displacement and speed sensing. They are potentially more forgiving of high temperatures and are inherently immune to electromagnetic interference. Conventional transducers require special design and development to operate in high temperature environments. They typically require some form of local electronics with connecting wires to some central avionic component which promotes susceptibility to electromagnetic interference.

Technology Requirements and Benefits

HSCT sensors must be able to withstand high temperature environments and demonstrate immunity from radiation and EMI.

Technology Status and Readiness

There is significant CRAD and IRAD work ongoing in fiber optic sensor development. The FOCSI program will provide open loop demonstration of most necessary sensor operation (ref. 1).

VISION ENHANCEMENT TECHNOLOGY

Issue Description

HSCT configurations make it very difficult to provide normal vision ahead to the flight crew in any flight phase. The problem was solved in Concorde with a nose which was drooped for landing and takeoff. The problem in the HSCT is even more severe due to the higher speed requirement and the necessity to reduce overpressures (sonic booms) at the earth's surface. Platypus nose designs provide this reduction but are not amenable to droopable nose designs. Thus, synthetic vision is being considered for all phases of flight to compensate for the fact that (ref. 1):

1. cockpit vision will probably not be adequate either forward or down.
2. the extreme length of the vehicle will make it difficult to see obstructions near the wings and landing gear,
3. the position of the flight deck relative to the front gear could interfere with steering on the ground.

Technology Requirements and Benefits

Synthetic vision must provide not only views of the scene ahead and to the sides of the airplane but the scenery must include all threatening obstacles and other airplanes without exception.

If the technology is reliable, considerable cost savings in design can be realized by eliminating any requirement to shape the fuselage to provide natural vision.

Technology Status and Readiness

There are two approaches being considered for the HSCT application (ref. 1):

1. computer generated imagery (CGI),
2. sensor imaging (SI).

CGI involves reconstructing a scene from maps and data on board the airplane. SI senses and displays images on the obstacles in its field of view. A third approach combines the two. Sensor vision technology must address the following current shortfalls:

1. perspective generation technology,
2. sensor performance in weather or other atmospheric conditions,
3. pilot acceptance,
4. backup architecture,
5. certification requirements.

CGI and SI have been demonstrated separately in dome simulations and other very high performance computing and display systems. A demonstration has been undertaken in industry of full image fusion, where a sensor package and a CGI are processed and combined into one image at this time (ref. 1). No existing vision enhancement system is presently sufficient to meet HSCT requirements (ref. 1).

HIGH ALTITUDE AIR DATA

Issue Description

Static pressure is extremely low at HSCT cruise altitudes. In addition, the change in static pressure with altitude is also very low. Determining pressure altitude with the resolution required to support satisfactory operation of certain CAS and autopilots modes such as altitude hold will be difficult. In addition, there is significant evidence from the U-2, SR-71 and Condor programs (ref. 1) that large atmospheric disturbances occur at high altitude which create pressure variations which are much greater than the nominal pressure lapse rate over several hundred feet.

These issues cause several related problems:

1. ride control may be unsatisfactory because of motions resembling those of a high amplitude, poorly damped phugoid mode;
2. ride control may be so compromised as to be a passenger safety issue;
3. HSCTs may not be able to meet current ATC vertical traffic separation requirements (2000 feet above FL240);
4. control law design will be extremely challenging for even the simplest pitch axis control modes.

Technology Requirements and Benefits

The HSCT integrated flight control system must be able to provide cruise control augmentation (CAS) in manual control and autopilot control which yields safe, satisfactory ride control and meets ATC vertical separation requirements. Control activity must be minimized to the extent that range does not suffer from the integrated effect of control activity on drag (a problem on the highly augmented B-2 in the directional axis) and to the extent that fatigue life is not a factor in control actuation components reliability and maintenance.

The aerodynamic performance requirements of the HSCT may require the development of flush mounted air data probes that meet the more stringent resolution requirements of the supersonic flight envelope. The choice of air data configuration depends both on the characteristics of the air data concept and the requirements of the control laws (ref. 1). Early in preliminary design engineers must address:

1. what range of control laws are required for airspeed, altitude and flight path stabilization, augmentation and automatic control;
2. what range of control laws are required for inlet control and engine control;
3. what are the air data system performance requirements for each control law;
4. what candidate air data concepts meet HSCT configuration requirements;
5. to what extent does each concept meet the most stringent control law performance requirements.

Technology Status and Readiness

Control law design tools and methodology exist, although some of the newer methods involving multiple-input, multiple-output modern control based techniques (DMICS (LQG-LTR) and PSC) (refs. 17, 34, 38, 39, 41 and 42) require flight validation.

Proof of concept optical and flush air data systems have or are being demonstrated by DARPA, DFRF and at least two commercial vendors (ref. 1). These systems operate between 45,000 and 80,000 feet.

FORWARD LOOKING SENSORS

Issue Description

Requirements have been identified for the HSCT for sensors to improve the detection of obstructions and air disturbances ahead of the airplane in cruise (ref. 1) such as:

1. clear air turbulence,
2. windshear and microburst,
3. obstacles, terrain and other airplanes in terminal operations (takeoff, climb-out, approach and landing).
4. taxiways, runways and ground obstacles in ground operations.

In high speed cruise it may be highly desirable or even required to detect air disturbances ahead of the airplane to momentarily increase inlet air flow stability margin (move the terminal shock position aft) to prevent inlet unstart. In addition, it may be desirable to employ the same advanced detection sensor to temporarily increase engine stall margin to get through the turbulence/disturbance. These features become critical if the inlet and engine have been specifically tuned to operate with low stability margins for improved steady state thrust-drag performance.

In terminal operations the detection of windshear and microbursts is important. In addition, it is possible that the HSCT will be designed to operate without forward vision from the flight deck, or any natural vision whatsoever. Sensors are required to generate the visual scene, provide obstacle detection and mapping including ground detection ahead of the airplane, and provide airplane detection and collision avoidance in all terminal area operations including ground operations.

Technology Requirements and Benefits

Sensor technology must be developed to support the requirements discussed above, namely:

1. air disturbances in high speed cruise,
2. wind shear and microburst in terminal operations,
3. obstacles, terrain, airplanes, runways, taxiways and ground vehicles in terminal operations.

Technology Status and Readiness

Forward looking sensors using LASER technology are under development from multiple sources including commercial vendors and government agencies. To date the driving requirement has been wind shear and microburst detection in terminal operations. There are unknowns with respect to the use of LASER based forward looking sensors at high altitude. The problem involves the availability of aerosol at HSCT cruise altitudes.

MULTI-FUNCTION SENSOR TECHNOLOGY

Issue Description

Traditionally, air data, obstacle and airplane sensors have generally been developed for specific functions, operated independently, and provided to the pilot or control system through a unique interface or display.

There is a need to develop a system approach to sensor suite design and integration; that is; there is a need to automatically process data from diverse sensors (data fusion) and distribute the information to sub-systems (including the flight crew) in an optimum fashion. The information presented to the flight crew on displays must not increase flight crew workload, but rather, must contribute to overall system performance. Certain information will be used in control law loop closures. Certain information will be used in flight crew decision aids. Certain information will be displayed in some higher order form to the flight crew. Finally, certain information may best be presented raw to the flight crew.

Technology Requirements and Benefits

Properly designed data fusion has the potential for providing best estimates of required data for automatic system control loop closures, for flight crew displays of appropriately processed information, and for raw data output from a given sensor suite.

A system approach to sensor integration and data fusion can reduce overall sensor design costs.

Multi-function sensor fusion technology addresses these requirements from two angles (ref. 1):

1. data fusion from several sensors can be used to estimate unsensed states and improve the estimates of measured states,
2. distribution of data from a single sensor to all functions which require it can reduce the compliment of sensors required.

Technology Status and Readiness

Data fusion has been addressed in a number of military R&D programs. Optimization and estimation theory are well understood and have been employed in production military vehicles. Data fusion has not been widely applied to commercial vehicles.

SHOCK POSITION SENSING

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 measurements (ref. 1). Such measurements require multiple high accuracy pressure transducers. Significant calibration and computation are required to extract the desired feedback signal. 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 (ref. 1).

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 (ref. 1).

Technology Requirements and Benefits

There are significant benefits to be gained in simplicity of design, cost and maintainability by developing a system of direct shock position sensing.

Such a system should show improved reliability, reduced complexity, improved dynamic response, reduced testing time and improved maintainability.

Technology Status and Readiness

Shadow-graph and Schlieren photography have been used for years in wind tunnels to directly measure shock position. It appears possible to develop an optical method to accomplish the same purpose in a mixed compression inlet on an airplane.

HIGH TEMPERATURE ELECTRONICS AND SENSORS

Issue Description

Ambient temperatures are expected to be between 10 and 450 degrees Fahrenheit in high speed cruise. Engine nacelle temperatures are expected to be substantially higher. If electronics could operate with a 400 degree cold-plate, remotely located modules could be used to reduce system weight and improve reliability by eliminating long, heavy, high count, wire bundles (ref. 1).

Sensors are not currently available which will withstand the extreme ambient temperatures to which they will be subjected on the HSCT.

Technology Requirements and Benefits

To locate modules in engine nacelles and other areas external to the fuselage in unconditioned air requires electronics which will operate at 400 degree Fahrenheit. Air data sensors used on the HSCT will have to provide reliable, maintenance free service in ambient temperatures of up to 400 degree Fahrenheit.

Technology Status and Readiness

There are a number of governmental and commercial activities pursuing high temperature electronics developments. Most commercial developments are proprietary. In sensor technology, there is work required in temperature varnishes, sealants, solder, and improved thermal compensation.

COMPUTATIONAL HARDWARE IMPROVEMENTS

Issue Description

The airborne computational load required to support HSCT avionics will be higher than any airplane built to date including the Space Shuttle. Many of the issues raised in this report suggest solutions which are computationally intensive and, thus, require airborne digital computers with significant on-board computational throughput.

Technology Requirements and Benefits

Significant performance improvements and cost and size reductions have occurred in many computational products including airborne computers. Available throughput is approximately doubling every year for a fixed cost and component size in all computer markets. We have observed this trend now for ten years and despite the threats of encountering miniaturization boundaries imposed by particle physics, the trend continues. Recent advances include (ref. 1):

1. Reduced Instruction Set Computing (RISC),
2. solid state mass memory,
3. graphic geometry processors,
4. parallel processors,
5. optical data processing or logic.

Technology Status and Readiness

Much work needs to be done to qualify these products for the temperature, vibration and radiation environments which will be encountered in the HSCT application (ref. 1).

Furthermore experience has shown that the value of a new, raw technology is limited until components are engineered and integrated into a reliable system for the specific application (ref. 1).

SINGLE EVENT UPSET PHENOMENA

Issue Description

It has been observed that high density, low power memory devices such as static RAMs, dynamic RAMs, and EPROMs, operating in space or a high altitudes, are subject to upsets due to cosmic radiation. It must be determined to what extent HSCT avionics will be susceptible to such effects.

Technology Requirements and Benefits

HSCT avionics must be designed to compensate for upsets which cause memory faults due to cosmic radiation.

Technology Status and Readiness

Redundant, self-detecting and repair strategies have been developed, demonstrated in the laboratory and some have been implemented in production systems.

Scientific/engineering studies are being conducted in industry on Single Event Upset (SEU) effects and in developing hardening strategies for high altitude avionics (ref. 1). No HSCT focused research is being conducted or contemplated.

HIRF/EMI IMMUNITY

Issue Description

The HSCT may be more vulnerable to High Intensity RF interference than previous aircraft which operate at high altitude (SR-71, U-2, Space Shuttle) in two ways. First, the nonmetalic airframe exposes the electronics and the associated wire paths to the full effects of any RF radiation fields through which the airplane might pass. Second, radio functions on the airplane generate EMI which can interfere with other electronic functions. This becomes a concern when RF generating equipments are collocated in a modular cabinet, and it is a concern in protecting the contents of a modular LRU from other RF contamination (ref. 1).

Technology Requirements and Benefits

Protection from EMI from both external and internal sources or radiation will be more of an issue in HSCT aircraft that any other ever built. Adequate protection is important to equipment reliability and operational flight safety.

Technology Status and Readiness

HIRF shielding research and testing are being provided for the B-777 to meet stringent FAA requirements. B-777 solutions may be difficult to apply to the HSCT because of structure and size differences. Photonic sensors, datalinks and busses may be required to meet weight budgets for the HSCT. An accepted strategy for protecting LRUs from EMI has not been developed.

FLIGHT SYSTEM DATA BUS TECHNOLOGY

Issue Description

The integrated flight/propulsion/inlet control system envisioned for the HSCT will require the use of time division multiplexed data busses. These busses will likely run through and contain remote terminals in environmentally non-protected areas external to the fuselage.

Several sub-issues can be listed:

1. what are the tradeoffs between copper wire cable and various fiber optic high speed data bus technologies;
2. what is the reliability of copper wire and photonic connectors in extreme environments;
3. what are the effects of HIRF/EMI on bus lines routed outside avionics bays;
4. what are the data bus requirements for integrated flight/ propulsion/ inlet systems;
5. what are the data bus redundancy levels required for safe engine operation;
6. what is the impact of engine bus traffic on flight critical flight control in an integrated system.

Technology Requirements and Benefits

Integrated propulsion and flight control laws will require shared airplane/engine states, data bases and multi-function sensor data. It will be necessary to connect the flight system data bus to propulsion units in engine nacelles. This means that the bus extends into a severe environment subject to high temperature, low pressure, electromagnetic radiation and RF interference.

Technology Status and Readiness

Copper wire flight data system bus technology (DATAC in the commercial world) is just now being accepted in flight critical service (ref. 1). Photonic DATAC offers no throughput advantages. Other high speed fiber optic data bus technologies have not yet met certification/standardization requirements for use in flight critical applications (ref. 1).

Systems Engineering Issues.

This section describes technology issues related to systems engineering methodology and design tools. It includes:

1. certification issues,
2. multidisciplinary system engineering issues,
3. control law design issues.

Table A-3 below shows a summary of technology issues related to hardware. The table shows cross-references to references 1 and 2. These priorities are taken out of context. The reader should review the references to become familiar with the priority system used by the authors and to develop an understanding of the underlying reasoning. They are included in this report only to give a flavor of the relative importance attached to the issues by the authors.

Table A-3 Systems Engineering Issues Summary

Technical Issue	Reference 1		Reference 2	
	Paragraph	Priority*	Paragraph	Priority**
Certification Requirements	4.3.1.1	H9		H
Integrated Eng. Design Methods & Tools	4.3.1.2	H5	2.3.1	M
Doc/Spec/Programming Methods & Tools	4.3.1.2	H5	2.3.1	M
Verification/Validation Methods & Tools	4.3.1.2	H5	2.3.1	M
Controls Design Methods & Tools	4.3.1.2	H5	2.3.1	M
Simulations & Models				
Structural Analysis Methods & Tools			2.3.1	M
Aerodynamic Analysis Methods & Tools			2.3.1	M

* Priorities assigned in reference 1:
H = high (ranked 1 (highest) to x)
M = medium (tanked 1 (highest) to x)

** Priorities assigned in reference 2:
H = high
M = medium
L = low

CERTIFICATION REQUIREMENTS

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 (ref. 1). The following areas contain requirements which may have to be relaxed or rewritten:

1. FAR 91.121 high altitude vertical traffic separation (2000 ft beginning at flight level (FL) 290),
2. FAR 91.70 aircraft speed restrictions (less than 250 kn below 10,000 ft, and 200 kn within an airport traffic area),

3. FAA Instrument Flight Rules (IFR) approach time separations,
4. FAR 36, Stage 3 noise requirements,
5. FAR 91 Appendix B ATC supersonic flight restrictions (special authorization required with no measurable sonic boom overpressure at the surface),
6. large transport flying qualities criteria.

Technology Requirements and Benefits

Applicable technology requirements include:

1. the development of aerodynamic shapes which will absolutely minimize sonic boom surface overpressures,
2. the development of a SAS/CAS system which will minimize altitude excursions required to hold Mach number in supersonic cruise thereby reducing the requirement to expand vertical traffic separation,
3. the development of engine nozzles which will meet FAR noise requirements on takeoff for the class of engines required.

Certification requirements need to be updated to allow HSCT to be certified; and to reduce development costs, weight and complexity.

Technology Status and Readiness

Certification requirements were suggested for SST and established for Concorde. They need to be updated for the HSCT development (ref. 1).

INTEGRATED ENGINEERING DESIGN METHODS AND TOOLS

Issue Description

Most software design/analysis tools do not provide data that can be transferred transparently to other tools in use on a project (ref. 1). Most tools are proprietary with protected source code and data formats. Some tool developers protect data formats for the sole purpose of forcing his customers to buy their associated tools. Inter-operability standards for system analysis and simulation tools are needed now to avoid expensive and unnecessary duplication of engineering effort (ref. 1). The duplication and manual transfer/translation of data from tool to tool and department to department is a major generator of wasted engineering hours and man-power.

Many design and analysis tools use outdated graphical user interfaces (GUI) which are difficult to learn, meet no standard, impose very limiting serial sequences of operations (menu-driven), are based on character graphics and are functional only on specific machines. It is very time consuming, frustrating and depressing to learn and use these interfaces to software tools. In addition, the cost to a company for the training time necessary to learn and use many GUIs each using a different look (what you see on the screen)-and-feel (what you do with the keyboard and mouse), is very high.

Technology Requirements and Benefits

Data from engineering documents and objects should be electronic file transfer accessible and readable by all design and analysis tools which require the data by all activities from early concept definition through flight testing and certification. There should be no case in which data available from one source should have to be recreated or manually transferred to a tool which requires it or some transformation of it.

As an example, an appropriate CAD/CASE environment is required to efficiently develop an integrated propulsion control system for HSCT. Moreover the propulsion development environment must be an integral part of the environment used for airframe development. At the moment individual tools suitable for various functions with the development process exist within various organizations and companies. However, these tools are not seamlessly integrated into one functional entity. The ideal environment would consist of a data base for the entire air vehicle driven by designer inputs, and accessible by simulation/analysis programs.

Considerable training time could be saved and engineering time more productively spent if all design and analysis tools used the same GUI design philosophy (the same look-and-feel). The technology is available. The standards exist. Two look-and-feel specifications have emerged and dominate the workstation software world: Open Look and Motif. The graphical support libraries for various workstations are becoming more and more available at a rapid pace. They are available now for all of the major workstations on the market, although some workstations are still not supported with both Open Look and Motif based graphics libraries. What is required is the construction of GUIs built to the Open Look or Motif specification for all design and analysis tools in general use.

Technology Status and Readiness

The methods and tools exist. Their integration and communication is a standards problem, and a proprietary issue with tool developers.

State-of-the-art GUIs support multiple path choices of operations (event-driven), use bit-mapped graphics, are portable to a variety of machines, and are easy to learn (some to the extent that User Manuals are not required). These GUIs were born out of the Macintosh software design philosophy and development guidelines. Two look-and-feel specifications have emerged and dominate the workstation software world: Open Look and Motif.

DOCUMENTATION/SPECIFICATION/PROGRAMMING METHODS AND TOOLS

Issue Description

Programming-oriented documentation and development tools are abundantly available, but some advances and methodologies must be improved. Tools that support graphic oriented programming or reuse of simulation code in operational flight programs do not typically provide sufficient programming power to meet all integration requirements of multi-function systems within the tool (ref. 1).

Technology Requirements and Benefits

Standards for the vendor community must be established that provide for delivery of software. Software that can be maintained by vendor, airplane manufacturer or customer, with full access to documentation and firm protection from installation errors that could damage other software. Programming oriented tools should support the following activities with seamless, inter-operable tools (ref. 1):

1. software documentation publication management,
2. method oriented specification,
3. program editing, compilation and debugging,
4. program installation, configuration management and maintenance.

Technology Status and Readiness

Graphic programming, program specification, compilation, debug and maintenance tools exist and are improving with maturity. Inter-operability is a problem at this time. Safe methods for multi-programming flight critical programs are not yet fully accepted (ref. 1).

VERIFICATION/VALIDATION METHODS AND TOOLS

Issue Description

Flight test engineers require tools to support the following activities with seamless, inter-operable tools (ref. 1):

1. requirements and specifications traceability,
2. automated test planning, conduction, data analysis and data archiving,
3. automated management of test points, test data, and flight plans,
4. automated configuration management to include aircraft configuration, avionic configuration, instrumentation requirements, support requirements, weather requirements, etc.

Technology Requirements and Benefits

Standard test planning is wasteful of flight time and expensive. Automated planning has the potential of reducing the cost of flight test for major new aircraft significantly.

Technology Status and Readiness

A tool exists which meets all of the requirements of this issue. Its initial development was sponsored by DFRF and was known as the Automated Flight Test Management System (ATMS). It has been improved significantly since government support ended in 1988.

ATMS runs on all UNIX based workstations which support X-Windows and the Open Look Graphical toolkit (XView). Its is currently being translated to support MOTIF. ATMS requires an interface with a Relational Data Management System (RDBMS).

CONTROLS DESIGN METHODS AND TOOLS

Issue Description

Design methods for integrated controls systems have been refined in recent years (refs. 33, 34, 35, 39, 40 and 43). The Air Force sponsored DMICS program resulted in the development of a methodology based on the linear quadratic modern control theory. The methodology address the fundamental shortcomings of LQG design which is the generation of nonimplementable full-state feedback designs. The methodology requires validation on real-world designs.

Technology Requirements and Benefits

Integrated systems are inherently multiple-input, multiple-output (MIMO) systems. These systems are amenable to design using methods based on modern control theory. The trick is in the translation of the resulting full-state feedback design into something which is implementable with available sensors without losing the features of the original design, and possesses the robustness necessary to cope with nonlinearities and uncertainties associated with off-design conditions.

Technology Status and Readiness

The DMICS program and others have provided the methodology, but to date the methodology has been validated only on paper designs.

C-2

SIMULATIONS AND MODELS

Issue Description

There are several issues with respect to the development of an HSCT which will require very high fidelity simulation to support HSCT development. They are:

1. what are the effects of a mixed compression, variable geometry inlet propulsion system on airplane dynamics, particularly at high speed,
2. what is the effect of high altitude air disturbances on autopilot and augmentation system performance,
3. what is the aeroelastic effects on autopilot, augmentation and flutter suppression systems.

Technology Requirements and Benefits

A very high fidelity simulation is required to support an HSCT development effort. The modeling must include accurate:

1. atmospheric modeling,
2. propulsion modeling,
3. inlet flow modeling,
4. aerodynamic modeling,
5. sensor modeling,
6. control system component modeling,
7. aeroelastic mode modeling.

Technology Status and Readiness

In many areas the modeling required will push the technology.

STRUCTURAL ANALYSIS METHODS AND TOOLS

Issue Description

Shortcomings exist in the state-of-the-art of aeroelastic analysis which must be corrected before a highly flexible HSCT can be designed. Traditional responsibility for an aircraft's rigid body behavior resides with a stability and control group, while responsibility for flexible body behavior resides with a dynamics group. The rigid body portion of the flexible body model attempts to predict the stability and control specified rigid body behavior. The methodology to adequately blend the rigid body and flexible body models together into one unified aeroelastic plant model needs improvement (ref. 2).

If a sub-scale technology demonstrator is to be built, it is critical that the aeroelastic characteristics of a sub-scale aircraft be relatable to the full-scale vehicle. The sub-scale aircraft must possess relatable rigid-body and aeroelastic dynamic interaction with the full-scale vehicle. The problem, of course, is that the HSCT is envisioned to be a very flexible aircraft with relatively low frequency first structural modes. These modal frequencies may be relatively close to rigid-body stability and control modal frequencies. One can conceive of a dimensionless similarity number (such as Reynolds number for viscous fluid flows) comprised of rigid-body and structural modal characteristics, structural material characteristics, and relative scales which, if matched, would permit an extension of sub-scale results to full-scale predictions with respect to vehicle stability, control, and handling qualities.

Technology Requirements and Benefits

The HSCT is envisioned to be a very flexible aircraft with first structural modal frequencies which may be uncomfortably close (from a controls design viewpoint) to rigid body modal frequencies. In addition, before any attempt is made to develop a sub-scale demonstrator, the structural similarity to a full-scale vehicle must be predictable.

Technology Status and Readiness

Generalized coordinates consisting of a reduced set of flexible, natural mode shapes are derived from simple bean stick models or more complex finite element models. The analytically derived mode shapes, natural frequencies and damping are validated through full-scale ground vibration testing. Modern finite element methods for structural analysis are also available: these permit application of time varying loads to a deforming structure (ref. 2).

AERODYNAMIC ANALYSIS METHODS AND TOOLS

Issue Description

Very little steady and unsteady aerodynamic data and analysis capability is available for spoilers, spoiler-slot-deflectors (SSD) and inverted-spoiler-slot-deflectors (ISSD). Wind tunnel tests and enhanced analysis capabilities are needed to obtain this information. Also, the role of viscous effects must be assessed in transonic flow conditions using more advanced CFD methods (ref. 2).

Technology Requirements and Benefits

The enhanced aerodynamic analysis capability is particularly important for predicting the performance of advanced high lift systems and low sonic boom planforms.

Technology Status and Readiness

Traditional unsteady lifting surface theories determine the frequency dependent magnitude and phase of the aerodynamic force over a lifting surface element due to the motion of another element. These forces are generally weighed to match wind tunnel data at the steady state condition. More modern computational fluid dynamics (CFD) methods perform numerical integration to solve the governing equations in time. CFD methods are usually more computationally intensive compared to lifting surface analysis and are not widely used for production work.

System Architecture Issues.

This section describes technology issues related to system architecture. It includes:

1. Flight critical systems architecture issues,
2. Integrated system architecture issues,
3. Built in test issues.

Table A-4 shows a summary of technology issues related to system architecture. The table shows cross-references to references 1 and 2. These priorities are taken out of context. The reader should conduct the references to become familiar with the priority system used by the authors and to develop an understand of the underlying reasoning. They are included in this report only to give a flavor of the relative importance attached to the issues by the authors.

Technical Issue	Reference 1	
	Paragraph	Priority*
Flight Critical Arch. Strategy	4.3.1.2	H2
General Flight & Propulsion Arch.	4.3.1.1	M5
Built-in Test & Maintenance	4.1.4	H4

* Priorities assigned in reference 1:
H = high (ranked 1 (highest) to x)
M = medium (tanked 1 (highest) to x)

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FLIGHT CRITICAL ARCHITECTURAL STRATEGY

Issue Description

There are many possible architectural issues concerning flight control system design which must be considered for the HSCT. They include:

1. digital/analog fly-by-wire/light,
2. mechanical/ hydraulic with digital/ analog SAS/CAS,
3. mechanical/hydraulic (no SAS),
4. hydraulic/electric power,
5. backup control modes.

The most important concerns are flight safety oriented. Common mode failures which may cause the loss of an airplane are of concern to both manufacturers and certifiers. They are reluctant to rely on any system no matter how reliable it is without some limit to its control authority and without some backup capability which provides the capability of recovering the airplane when everything else fails. Fly-by-wire technology has been accepted by the military and even commercial airplanes are being certified with the technology incorporated; however, the DFBW systems in production are complex and expensive. They contain highly redundant control paths (triplex and even quadruplex) to multiple control input (three or four channel - very expensive), multiple power channel (usually dual tandem) flight control actuators, backup mechanical or direct electrical systems and high count wiring cables to centrally located avionics.

The redundancy concepts developed in the USAF Reconfiguration Control program need to be studied for possible commercial application to the HSCT. The germane concept is that of aerodynamic redundancy: the idea is to build a primary flight control system which features multiple panels individually controlled by single channel control and power actuators, each actuator using its own hydraulic power supply. If a system fails, the panel is aligned with the airstream. Redundancy is provided aerodynamically through the remaining panels with adjusted gains albeit some control authority may be lost: a concept which is readily accepted in propulsion (its easy to argue that you can't get the same thrust out of three engines after a flame-out than you can with four), but which has never been accepted in flight control (people want the same control effectiveness after a channel failure as they had before).

Technology Requirements and Benefits

A set of philosophical ground rules that will dictate the range of flight control system designs that are acceptable to the manufacturer and the FAA must be determined. Analysis, simulation, prototype demonstrations and experience with airplanes with these advanced flight control systems are not yet in a data base that is acceptable by the design and certification communities (ref. 1).

The potential benefits in simplicity, cost, reliability and safety are significant if these advanced concepts can be flight demonstrated and accepted.

Technology Status and Readiness

The technologies are in place. Their application to an HSCT requires flight demonstrations of proof-of-concept and prototype demonstration systems.

GENERAL FLIGHT AND PROPULSION ARCHITECTURES

Issue Description

Current flight control system designs feature separate Line Replacement Units (LRU) for every control surface on an airplane, each LRU manufactured and warranted by a different vendor. Cost savings could be realized and reliability may be improved by employing more integrated, simpler designs with fewer LRUs.

Technology Requirements and Benefits

In order for the HSCT to be competitive, operational availability must be significantly higher than conventional airliners. HSCT flight and propulsion control systems must be composed of fewer, more reliable LRUs and fewer, more reliable, connectors than competing airplanes.

Technology Status and Readiness

One design strategy is to physically integrate numerous vehicle, flight and engine controllers, but several issues must be addressed (ref. 1):

1. the hardware should be packaged so that interface connectors are minimized;
2. the LRUs should be packaged so that replaceable modules can be swapped without compromising EMI barriers;
3. the hardware should tolerate some internal degradation before the LRU needs to be replaced, and the amount of degradation must be available to flight and ground crews;
4. manufacturers should be able to produce and warrant software modules that are functionally equivalent to LRUs in 1990 airplanes;
5. airplane system integrators should be able to verify algorithms and validate system performance when flight and propulsion controllers are developed by different vendors;
6. certification agencies must be able to inspect and validate multi vendor/ multiprogram LRUs and recently updated software with no more expense than the cost of swapping LRUs.

BUILT-IN TEST AND MAINTENANCE

Issue Description

The economic viability of the HSCT is critically dependent on aircraft availability and thus on reliability and maintenance. The objective is to achieve 30% higher availability than currently prevails on long range subsonic aircraft on a vehicle which is substantially more complex and operates in a much more severe environment (ref. 1).

Technology Requirements and Benefits

Built-in test and maintenance systems must be able to automatically detect and isolate down to the Line Replacement Unit (LRU) level virtually 100% of faults in real time. The system must be able to sort these faults into categories for in-flight attention, correction during the next turn-around or correction during scheduled maintenance periods (ref. 1). Due to the flight critical nature of some of these faults, the system must also provide decision aiding or, possibly, automated decision activation particularly with respect to dispatch criteria (ref. 1).

Technology Status and Readiness

Monitoring system technology exists. Decision aiding is an active area of research in artificial intelligence particularly in the military. The Pilot's Associate program has addressed this and related issues, and developed simulation demonstrations of concepts.

Aerodynamics and Performance Issues.

This section describes technology issues related to aerodynamics and performance. Table A-5 below shows a summary of technology issues. The table shows cross-references to references 1 and 2. These priorities are taken out of context. The reader should review the references to become familiar with the priority system used by the authors and to develop an understanding of the underlying reasoning. They are included in this report only to give a flavor of the relative importance attached to the issues by the authors.

Table A-5 Aerodynamics Issues Summary

Technical Issue	Reference 2 Paragraph	Priority**
High Lift Device Data	2.2.3	M
Laminar Flow Wing Design	2.2.3	M

** Priorities assigned in reference 2
H = high
M = medium
L = low

HIGH LIFT DEVICE DATA

Issue Description

Spoiler-slot-deflectors (SSF) and inverted-spoiler-slot-deflectors (ISSD) are being considered for the HSCT along with conventional trailing edge control surfaces. The SSD and ISDD will be used for roll control and possibly for gust and maneuver load alleviation. The unsteady aerodynamic forces because of spoilers are generally not well known: even less is known about the unsteady effects of the SSD and ISSD (ref. 2).

Technology Requirements and Benefits

A significant wind tunnel test program is required to generate the required data.

Technology Status and Readiness

The techniques exist to obtain the required data.

LAMINAR FLOW WING DESIGN

Issue Description

Laminar flow control is currently planned for HSCT operation at cruise and possibly upper level climb. Including this effect in the aeroelastic plant model will reduce the uncertainty of the model. Laminar flow control reduces viscosity effects on the aerodynamics of the system. This will make current inviscid analysis methods of unsteady aerodynamics more acceptable (ref. 2).

Technology Requirements and Benefits

Supersonic wind tunnel testing of laminar flow wing models is required.

Technology Status and Readiness

Design work and wind tunnel testing are required to arrive at the best aerodynamic shape.

Environmental Issues.

This section describes technology issues related to the environment.

OVERPRESSURE MINIMIZATION

Issue Description

Overpressures from sonic booms at the surface of the earth from supersonic flight have been an environmental issue since the advent of supersonic aircraft. Currently, supersonic flight is prohibited over the continental United States except in designated restricted areas with supersonic corridors, in connection with military air shows by special arrangement on an air show-to-air show approval basis with the FAA, or in connection with Concorde flights by special agreement with the FAA. In point of fact, none of the route segments approved for supersonic flight for the Concorde are over land.

Technology Requirements and Benefits

An airframe design is required which minimizes sonic boom overpressures. The benefits are improved acceptance by the public of overland supersonic flights of HSCTs and a relaxation of current FAA policy.

Technology Status and Readiness

Several design studies have addressed configurations which minimize sonic boom overpressure (refs. 34 and 53). LaRC has wind tunnel tested a platypus nose shaped Mach 3.0 cruise vehicle with good results (ref. 53). Further design work, wind tunnel testing and flight experiments using sub-scale, unmanned models are required to arrive at the best aerodynamic shape.

OZONE LAYER DEPLETION

Issue Description

Large numbers of HSCT aircraft cruising above 50,000 feet pose a significant threat to the destruction of the earth's ozone layer. Nitrogen oxides (NOx) are especially damaging the ozone layer when then enter the atmosphere above 50,000 feet. These and other products of combustion from HSCT engines must be minimized. A 90% decrease in NOx emissions from current engines is required to keep the emissions from damaging the ozone layer at HSCT cruise altitudes (ref. 45).

Technology Requirements and Benefits

Until the extent of the ozone layer depletion problem is well understood and technology solutions are available to solve the problem, the development of an HSCT is out of the question.

Technology Status and Readiness

Combustor concepts have been developed which show promise. The work is sponsored by LeRC (ref. 45). Both very rich and very lean combustion produce low molecule counts of Nitrogen oxides per unit volume. Stoichiometric combustion produces high molecule counts of Nitrogen oxides per unit volume. A multi-stage combustion engine may be possible which features a very rich combustion zone followed by a very lean combustion zone produced by the injection of bypass air. This rich burn/ quick quench/lean burn combustion concept may provide a partial answer to the ozone depletion problem.

NOISE ABATEMENT

Issue Description

The large, high thrust HSCT will produce significant noise. Noise levels in airport areas may exceed FAR regulations.

Technology Requirements and Benefits

Engine nozzle configurations are required which minimize noise levels in airport areas.

Technology Status and Readiness

There have been many studies in this area (refs. 62, 63, 64, 65, 66, 67 and 68).

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13. ABSTRACT ***(Maximum 200 words)***

This report presents a strawman program plan consisting of technology developments and demonstrations required to support the construction of a high-speed civil transport. The plan includes a compilation of technology issues related to the development of a transport. The issues represent technical areas in which research and development are required to allow airframe manufacturers to pursue an HSCT development. The vast majority of technical issues presented require flight demonstrated and validated solutions before a transport develpment will be undertaken by the industry. The author believes that NASA is the agency best suited to address flight demonstration issues in a concentrated effort. The new Integrated Test Facility at NASA Dryden Flight Research Facility is considered ideally suited to the task of supporting ground validations of proof-of-concept and prototype system demonstrations before night demonstrations. An elaborate ground hardware-in-the-loop (iron bird) simulation supported in this facility provides a viable alternative to developing an expensive full-scale prototype transport technology demonstrator. Dryden's SR-71 assets, modified appropriately, are a suitable test-bed for supporting flight demonstrations and validations of certain transport technology solutions. A subscale, manned or unmanned flight demonstrator is suitable for flight validation of transport technology solutions, if appropriate structural simularity relationships can be established. The author contends that developing a full-scale prototype transport technology demonstrator is the best alternative to ensuring that a positive decision to develop a transport is reached by the United States aerospace industry.

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