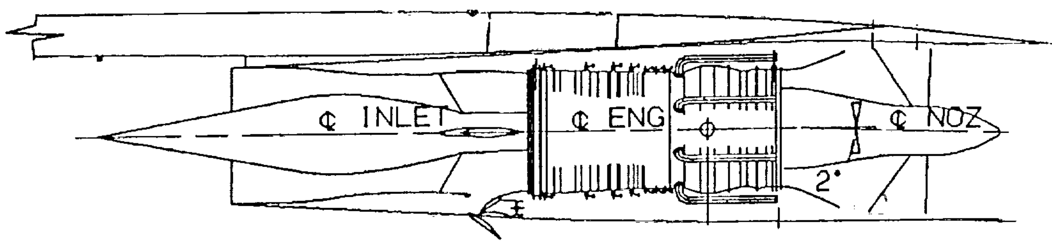
HSCT INTEGRATED PROPULSION CONTROL ISSUES



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OVERVIEW

The propulsion control system affects the economics of the HSCT through the mechanisms indicated. Weight reduction is paramount in aircraft of this type. Significant reductions are possible relative to SST or even current technology if improvements are made in areas such as high temperature electronics. Dependability is an increasingly important parameter in all aircraft, but the higher capital cost of the HSCT makes it doubly important. Conversely the more difficult HSCT design problem makes it more difficult to achieve. Integration of propulsion controls will make it possible to improve both the static and dynamic performance of the HSCT propulsion system. Noise and emissions requirements may introduce novel control system requirements such as automatically programmed takeoff thrust for noise abatement. Control system development technology is evolving. For HSCT, highly automated and thoroughly validated tools will be required to reliably achieve desired system performance at introduction, and to reduce development costs.

A technology plan has been developed to prepare for HSCT development. This presentation addresses the portion of the plan required to demonstrate technology readiness for the HSCT in the late 1990's rather than the technology development currently in progress.

OVERVIEW

- **Technical Issues**
  - **Weight**
  - **Dependability**
  - **Performance**
  - **Noise/Emissions**
  - **Control System Development**

- **Technology Plan**
  - **Simulation**
  - **Control Laws**
  - **Architecture**
  - **Component Development**
  - **Technology Demonstration**

PROPULSION CONTROL AIRPLANE LEVEL ISSUES

The weight of the SST control system was concentrated in long wire runs from fuselage mounted electronics to nacelle mounted actuators and sensors, and in the actuators themselves. Dependability will be improved through accurate knowledge of disturbances, validated simulations, highly reliable components operating in a well understood environment, and reducing system parts count. Performance improvements are available either through reduced component operating margins or by improving system off design performance through integration and optimization. Noise abatement introduces requirements for automatic thrust profile management, and relatively complex nozzle configuration management. Control system development is currently a complex, labor intensive, and costly process. The tools used need to be improved, validated, and integrated to permit reliable automated analysis, design, build, and test. The propulsion control development process also needs to become more analytical to reduce dependence on the wind tunnel and test cell.

PROPULSION CONTROL AIRPLANE LEVEL ISSUES

- **Weight**
  SST Total Intake Control System - 4442 Lbs
  1782 Lbs of Wire
  2066 Lbs of Actuation Equipment

- **Dependability**
  Unstarts,Stalls,and Flameouts are unacceptable

- **Performance**
  Reduced Control Margins
  Integrated & Optimizing Controls

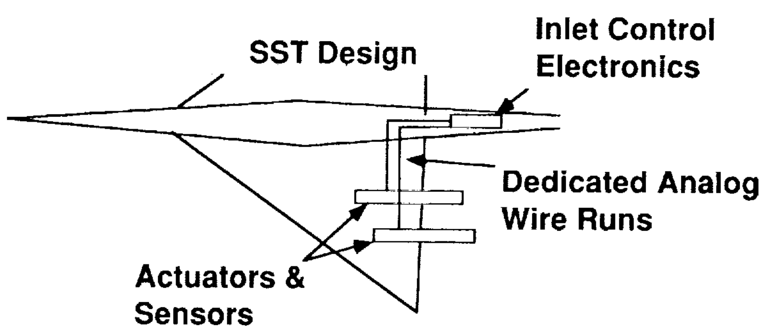
- **Noise & Emissions may introduce novel control requirements**

- **Control System Development**
  Reduce development cost through automation
  Minimize interdependence between controls
  and machinery development

INLET CONTROL SYSTEM WEIGHT

SST control system weight was largely caused by long wire runs and actuation requirements. High temperature electronics, if available, would permit mounting multiplex/control units in the nacelles, eliminating long multiwire bundles. Fiberoptic sensors would permit reductions in the size, and weight of long wire runs by eliminating HERF/EMI considerations. Depending on the development of the technologies some combination of them should significantly reduce the wire weight of the propulsion control system. In the event none of the advanced technologies become available air or fuel cooling of nacelle mounted electronics is a practical but less than desirable solution to the problem. Light weight, probably composite, actuation along with relatively high pressure hydraulics are required to reduce actuation weight. Actuation weight may also be reduced by reducing actuation dynamic response requirements. This may be achieved by coordination of airframe,inlet,engine, and nozzle operation and by anticipation of system disturbances.

INLET CONTROL SYSTEM WEIGHT

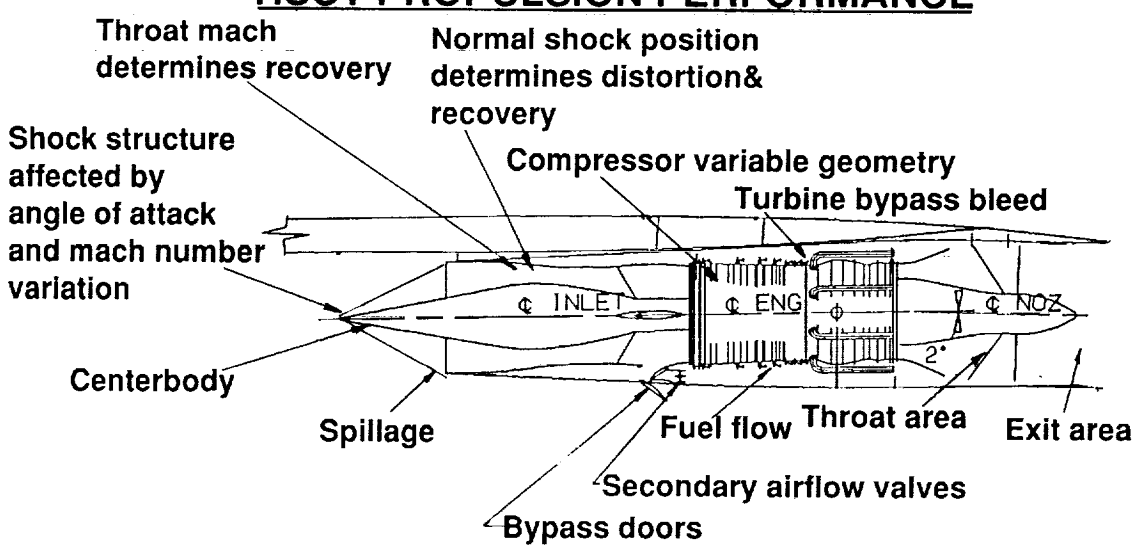


- Weight reduction requires technology advances
  - High temperature electronics
  - Severe environment fiberoptic sensors and data buses
  - Reduced sensor set
  - Lightweight actuation
- Without technology advances actively cooled electronics will be required

HSCT PROPULSION PERFORMANCE

The turbine bypass engine/mixed compression inlet propulsion system depicted is probably the simplest HSCT propulsion system configuration under study. It presents a multivariable control problem in both the steady state and dynamic sense. When operating on design at steady state the desired operating position for each element of the system is well defined. Bypass doors are shut, turbine and compressor operate at their design match points, etc. However as the system operates off design, either due to deviations from the optimum flight path, temperature variations, or during climb and descent a non trivial optimum selection process is required to distribute captured airflow to achieve the best (thrust-drag)/fuel flow possible while satisfying stability margin requirements on various elements of the system. The fact that each effector from the centerbody to the exhaust nozzle has an effect on the set of states which define engine operating condition makes the control design problem inherently multivariable. There is significant coupling between the airframe and propulsion system not only through thrust commands, but also through angle of attack and Mach number influences on the inlet and inlet bypass contributions to yawing and rolling moments. Application of multivariable design techniques is expected to permit reduction of actuator bandwidth requirements and control margins, thus improving weight and performance. Development of a control system for this system will require an accurate, relatively high bandwidth, propulsion/airframe simulation including representation of major non-linear phenomena such as unstart and surge.

HSCT PROPULSION PERFORMANCE



- Propulsion system is physically coupled both internally and externally
- Integrated propulsion/airframe control
  Best performance for given control margins,sensors,and actuation capability
  Self optimising for off design conditions
- Analysis requires integrated high fidelity simulation

ADVANCED INLET INSTRUMENTATION

The critical measurement in a mixed compression inlet is normal shock position. Historically this has been measured by sensing the static pressure rise associated with the normal shock. This approach, although workable, suffers from deficiencies including complex plumbing, relatively low bandwidth, high precision requirements and sensitivity to angle of attack, inlet geometry variations, and minor inlet design changes. More direct approaches to normal shock sensing, suited to the low terminal shock mach numbers of the HSCT inlet, could benefit both system performance, by reducing supercritical margin, and dependability, by eliminating plumbing and fragile pressure transducers.

Mixed compression inlet throat mach number margin is set by the anticipated magnitude and rate of change of freestream mach number variations and the bandwidth of the centerbody actuator. If techniques can be developed which allow us to detect freestream variations substantially ahead of the airplane we can reduce throat mach number margin and the dynamic response requirements on the centerbody actuation system. Optical techniques show promise for providing this kind of prediction capability. Unfortunately current systems are heavy and are dependent on aerosols which may not have adequate density to assure a continuous signal. If available such system would also benefit flight control system performance.

ADVANCED INLET INSTRUMENTATION

- **NORMAL SHOCK SENSOR**
  High bandwidth
  Eliminate plumbing & manifolds
  Minimize signal sensitivity to inlet design changes

- **FREESTREAM DISTURBANCE DETECTION**
  Throat mach tolerance dictated by:
  disturbance frequency content
  actuator bandwidth
  anticipation available

  Approach
  Temperature - infrared imaging
  Wind shear - laser backscattering

  Issues
  Complexity/weight & aerosol availability

  Other potential benefits
  Clear air turbulence avoidance
  Improved autopilot performance

CONTROL SYSTEM DEVELOPMENT OBJECTIVES

For the most part adequate control simulation and analysis tools exist to perform the propulsion control system design, analysis, build, test task. Unfortunately, although the individual tools exist, they are not integrated into a system that permits automation of the control system development process starting from the CAD data base for the propulsion plant. Furthermore many of the tools are proprietary and individuals in a given organization are familiar only with their own tools. In order to efficiently develop an HSCT control system an integrated package available across corporate boundaries must be created. Such a system will reduce development costs and produce a more reliable high quality product.

Current propulsion system development practice is strongly dependent on test results to establish component performance, pneumatic signal characteristics used for airflow and normal shock measurements, and to confirm system dynamics. Significant development economies can be achieved by using CFD to predict these characteristics and using the wind tunnel/test cell only as a final confirmation tool.

CONTROL SYSTEM DEVELOPMENT OBJECTIVES

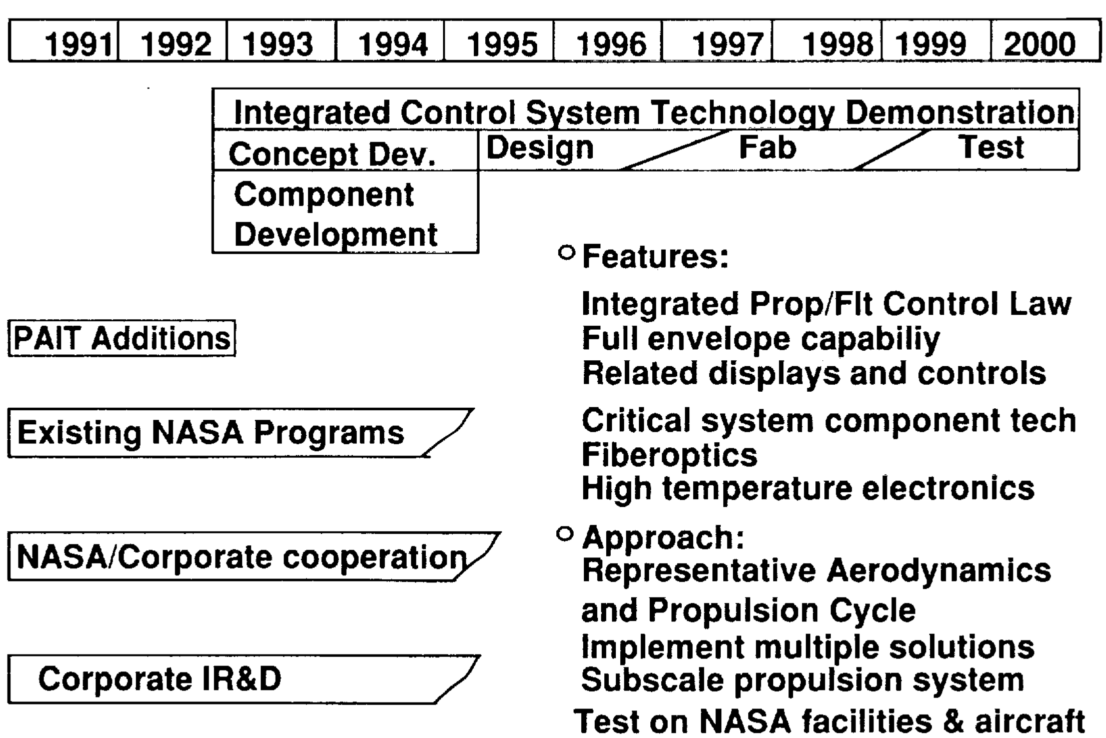
- **Automate the design/analysis/build/test process**
  Integrate and validate existing tools
  Modify or develop tools if required
  Benefits cost and reliability/quality

- **Reduce dependence on tests involving propulsion machinery**
  Integrated tests of developmental machinery
  and developmental controls are costly and risky
  Use CFD to reduce dependence on wind tunnel
  and flight test results

RECOMMENDED HSR PROGRAM

As indicated in the early charts significant technology improvements are anticipated in the next 5 years to improve the development and operating economics of the HSCT. Before these technologies can be applied in a production program a demonstration program to validate them is required. The recommended HSR program consists of four to five years of technology development, and a five year technology demonstration program. Some of the technology development efforts are already under way in programs such as the NASA/NAVY FOCSI program and the NASA HIDEC/PSC program. Other technology development efforts in areas such as high temperature electronics and improved normal shock sensing need to be initiated rapidly if they are to be useful to the HSCT on the planned schedule. The technology demonstration program would be based on a complete supersonic propulsion system, and its integrated control including examples of all desirable advanced technology components. The system would be exercised through a complete test cycle starting with a control hardware in the loop bench test, and culminating in a flight test on an appropriate aircraft. The design, development, and test activity would provide the necessary validation of the integrated control development tool, the design methodology, and component technologies.

RECOMMENDED HSR PROGRAM



FLIGHT TEST DEMONSTRATION OBJECTIVES(I)

A flight test demonstration provides the opportunity to confirm a large number of propulsion system issues which are not specifically control related. These include validation of the analytical techniques use to design the cycle and propulsion components and predict thrust minus drag. An opportunity is also provided to confirm noise prediction techniques for impingement on the aircraft and the ground. The opportunity is provided to see the complete system in operation and identify any unexpected environmental effects on components and to understand the real world maintenance situation.

FLIGHT TEST DEMONSTRATION OBJECTIVES(I)

DEMONSTRATE INSTALLED PROPULSION SYSTEM PERFORMANCE

- o **Validate analytical techniques**
- o **Confirm wind tunnel results**
- o **Confirm engine/inlet compatability**
- o **Operation in real world environment**
- o **Acoustic impingement on adjacent structure**
- o **Noise prediction**
- o **Thrust - drag accounting verification**

FLIGHT TEST DEMONSTRATION OBJECTIVES(II)

From a control standpoint there are a number of flight test objectives. Confirmation of analytical techniques, in particular those involved in predicting the installation effects both on the inlet flow field and installed thrust - drag, is critical to reducing risk in the production program. Demonstration of the integrated control system with the pilot in the loop in the flight environment is also extremely critical since the system will have a number of novel pilot interface features and control modes relative to current commercial practice. Finally the demonstrator is critical to demonstrating the practicality of advanced hardware components in the supersonic environment on a closed loop basis.

FLIGHT TEST DEMONSTRATION OBJECTIVES(2)

PROPULSION CONTROLS

- **Confirm analytical techniques**
- **Demonstrate integrated inlet/engine/nozzle/flight control system**
- **Demonstrate system automation &display features**
- **Obtain pilot evaluation of integrated system**
- **Demonstrate system operability**
- **Demonstrate advanced component technology**
  - **High pressure hydraulics**
  - **Fiberoptics**
  - **Light weight actuators**
  - **Normal shock sensor**
  - **High temperature electronics**
  - **Advanced data bus**
  - **High temperature connectors & wiring**
  - **Freestream disturbance detection**

CONCLUSIONS

Substantial component development effort is required if HSCT control system weight and performance are to be significantly improved over that of the SST. An integrated control system development package including simulation, analysis, and autocode tools is required to reduce development costs and improve system reliability. This development package must be shared among all participants in HSCT control system development. A controls demonstration program is required to confirm both the advanced component technologies and the control system development methodology prior to undertaking a full scale commercial development program. Further NASA and industry planning of the next ten years research effort in this area is required.

CONCLUSIONS

COMPONENT DEVELOPMENT IS REQUIRED

- **Fiberoptic sensors**
- **High temperature electronics**
- **Direct shock sensing**
- **Freestream disturbance detection**
- **Lightweight actuation**
- **Fiberoptically signalled actuation**
- **Advanced data buses**

SIMULATION,ANALYSIS, AND DEVELOPMENT TOOLS

- **Integration,improvement, and validation are required**

CONTROLS DEMONSTRATION PROGRAM REQUIRED

- **Prove methodology & design/analysis tools**
- **Demonstrate advanced hardware technology in realistic environment**
- **Validate HSCT economic factors related to propulsion control**
- **Flight test required for complete demonstration**

FURTHER PLANNING IS REQUIRED

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Session XI. Airframe and Engine Materials

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