SHOULD WE ATTEMPT GLOBAL (INLET-ENGINE-AIRFRAME) CONTROL DESIGN?

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SUMMARY

The Lewis-APL MultiVariable Control (MVC) program has demonstrated that MVC design techniques are applicable to engine control algorithm design. MVC has also been applied to other aircraft systems, flight control and functions, and energy management. The next major step is to consider the global problem - multivariable design of the entire airplane control system. An intermediate step in that direction is to design a control for an inlet-engine-augmentor system by using MVC techniques. Two valuable opportunities to do this and to exercise the results experimentally are available in the near future.

The Supersonic Cruise Research (SCR) large-scale-inlet research program will provide an interesting opportunity to develop, integrate, and wind tunnel test a control for a mixed-compression inlet and variable-cycle engine (VCE). The Integrated Propulsion Airframe Control (IPAC) program will introduce the problem of implementing MVC within a distributed processing avionics architecture, requiring real-time decomposition of the global design into independent modules in response to hardware-communication failures. As IPAC progresses beyond multivariable design of the propulsion system, it will provide a real-world environment in which to address more basic questions: Should we attempt global control design? Is it practical or desirable? What is the required methodology?

DISCUSSION

The Lewis-APL MVC program, figure 1, demonstrated that for an advanced engine, P&WA F100, multivariable control techniques can be used vigorously to design an engine control system. The quality of the resulting system was demonstrated by its test in the altitude cell at Lewis. Program documentation provides a basis for undertaking more complex multivariable design tools.

Current airplane control systems are designed, figure 2, with a minimum of interaction and integration, partially because of a historical lack of communications ability and partially because of a concern over failure propagation through integrated subsystems. Lack of integration penalizes the design of airplanes with strong aerodynamic-propulsion coupling - SST and V/STOL, for example. New technology and research programs, figure 3, provide the opportunity to design a highly integrated airplane control system. Ideally, this new "global" system will have fewer actuation and sensor components and superior performance and fault tolerance.

Substantial effort is required to reduce the global design concept to practice. Because the design process is configuration dependent, a specific airplane must be addressed. To ensure that the design and the testing of the design truly demonstrate reduction to practice, the selected airplane or propulsion system should be realizable and eventually be tested in the wind tunnel or preferably in flight. Two planned NASA programs, IPAC and the SCR inlet control program, provide appropriate opportunities to address the real-world problems, figure 4, of global design.

The NASA Lewis SCR inlet control program encompasses the design, development, and testing of a supersonic propulsion system that incorporates a mixed-compression inlet and a variable-cycle engine. The system interactions among the components and with the environment, figure 5, are complex; the typical propulsion control system will have six or more actuated variables and 10 or more sensed variables. Thus, the system represents an appropriate example on which to exercise multivariable control technology. The program schedule, figure 6, currently calls for a relatively long design and development cycle leading to closed-loop wind tunnel testing in 1983 and a flight inlet design in 1985.

The NASA DFRC IPAC program, figure 7, is intended to demonstrate the methodology and benefit of integrated flight and propulsion controls on a high-performance aircraft having variable-geometry external compression inlets. It is a multifaceted program that provides the opportunity to test multivariable control algorithms, advanced engine control hardware (FADEC), and data bus integration of avionics and control systems.

The elements of the IPAC system, figure 8, communicate via a MIL 1553 data bus that provides orders of magnitude greater communication potential than ever before available. Control system software will be structured to permit rapid system adaption in order to take advantage of control system concepts identified during flight testing and to implement new research tasks as they are identified.

Multivariable control technology has been applied to many aspects of the flight control problem, usually as one design tool among many, figure 9. Typically, the engine response has been highly simplified or neglected completely. This approach is acceptable for a conventional airplane, figure 10, in which each control affects one principal axis and coupling is deliberately minimized. In advanced aircraft, figure 11, frequently this is not economically practical and the active control system must provide the solution. In both research and practice limited solutions have been provided. Each starts from an existing limited base and fails to incorporate all the available technologies into a top-down design methodology. The IPCS program, figure 12, demonstrated full-authority digital propulsion system control but only demonstrated in a very limited way the potential for direct electronic integration of the autopilot and engine control. The conjunction of multivariable control algorithm development with the realities of hardware implementation, figure 13, must also be considered if a successful fault-tolerant design is to be created. The typical advanced control will probably have only 30 percent of its functions directly associated with control. The remainder will be related to communication, fault tolerance, maintenance (BIT), and propulsion system condition monitoring.

If the benefits of multivariable control research are to be achieved and demonstrated, an integrated cohesive research program, figure 14, supported by NASA and the DOD agencies is an absolute must. The problem of global design cannot be successfully approached on a piecemeal basis.

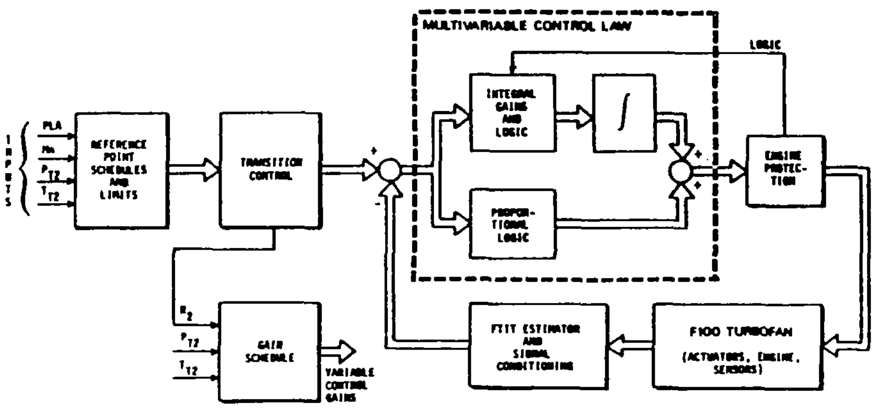
The problems associated with global control design, figure 15, are both technical and managerial. The technical areas are generally resolvable if sufficient time and effort are applied. The major managerial problem is that the real reward of integration does not lie in simple performance inprovement, another 5000 feet of altitude, for example. It lies in reliability, maintainability, pilot workload and skill level, and other things which are relatively intangible. Thus a control engineer concerned with inproving the product frequently finds it difficult to obtain the necessary resources. Organizational barriers also present a real but solvable problem to global control system design.

A major payoff from multivariable control design is the elegance of the resulting design, figure 16. The structure is clear and, to a degree, common from design to design. Component requirements are clearly developed as part of the design process, and standardized architectural elements should lead to standard hardware and software modules, thus reducing design cost and enhancing reliability.

CONCLUSIONS

The groundwork, figure 17, for global control design is provided by a prior research program. The need for it exists through the efforts of advanced airframe and engine cycle designers. A research program is required to carry out the design of the global control for a complex engine-airplane system and to flight test the resulting system in order to clearly demonstrate the utility of the existing technologies in addressing the problem of integrated control system design.

F100 MULTIVARIABLE CONTROL



- ENGINE ONLY
- TESTED IN ALTITUDE CELL
- WELL DOCUMENTED
- CLEARLY DEMONSTRATES UTILITY OF MVC

Figure 1

CURRENT AIRPLANE CONTROL SYSTEM, DESIGN

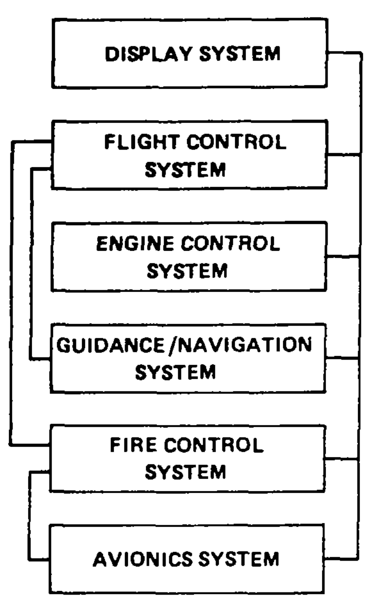


Figure 2

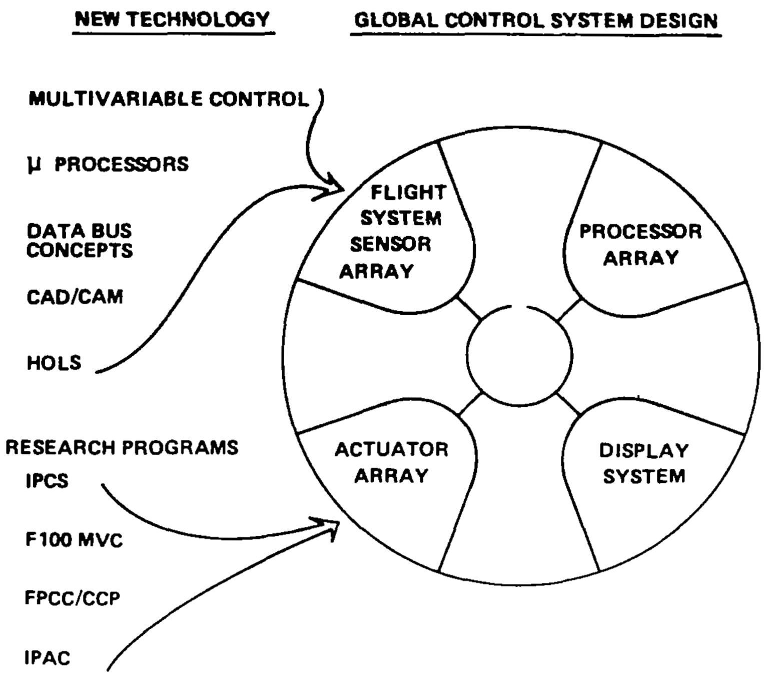


Figure 3

MVC EXTENSION TO PROPULSION SYSTEMS

- CANDIDATE SYSTEM REQUIREMENTS
  - REAL
  - SIGNIFICANT INLET/ENGINE/AUGMENTOR INTERACTION
  - FULL SCALE TEST PROGRAM PLANNED
- POSSIBLE SYSTEMS
  - INTEGRATED PROPULSION AIRFRAME CONTROL (IPAC)
  - SUPERSONIC CRUISE RESEARCH (SCR) INLET CONTROL PROGRAM
- ADDRESS REAL WORLD PROBLEMS
  - SENSOR LOCATION
  - AVIONICS ARCHITECTURE
  - RELIABILITY
  - REDUNDANCY
  - FAULT TOLERANCE
  - DISTRIBUTED SYSTEMS
  - AIRFRAME INTERACTION

Figure 4

VSCE PROPULSION SYSTEM INTERACTIONS

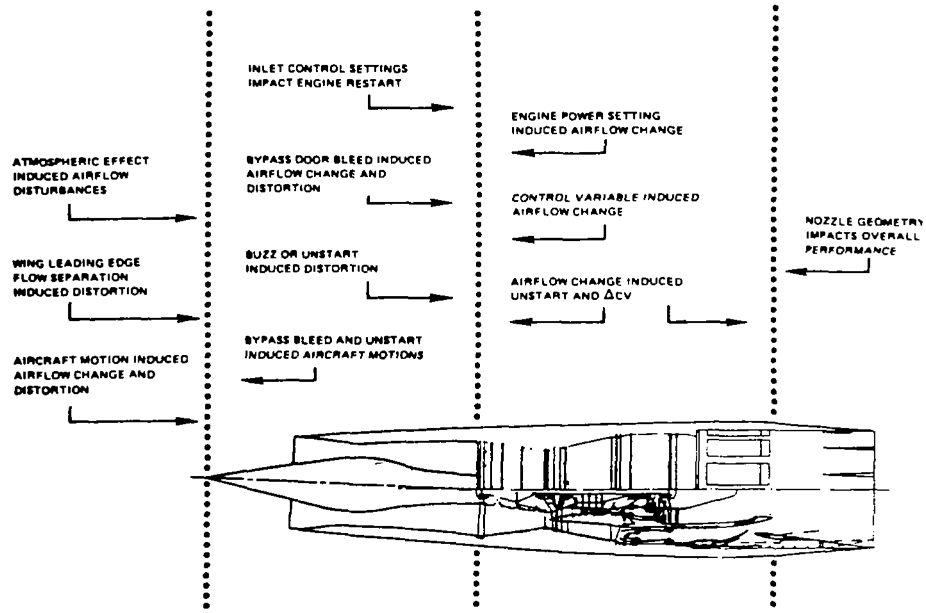


Figure 5

SCR SUPERSONIC PROPULSION SYSTEM CONTROLS RESEARCH

- SYSTEM
  - MIXED COMPRESSION INLET
  - VARIABLE CYCLE ENGINE
  - AIRFRAME AERODYNAMIC COUPLING
- SST CONTROLS CHARACTERISTICS
  - HIGH BAND PASS INLET ACTUATION
  - AD HOC FCS PROPULSION INTERFACE
- MODERN CONTROL PAYOFF
  - REDUCED ACTUATION REQUIREMENTS
  - IMPROVED SENSOR SELECTION
  - ACHIEVE REDUNDANCY THROUGH MULTIVARIABLE ANALYSIS OF AERO COUPLING

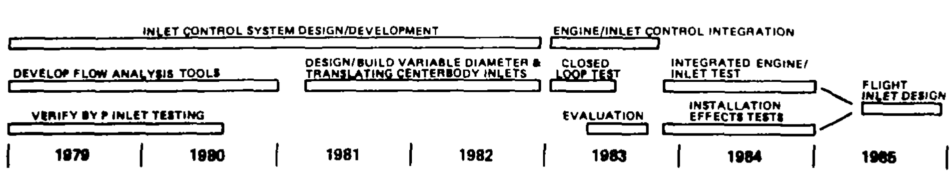


Figure 6

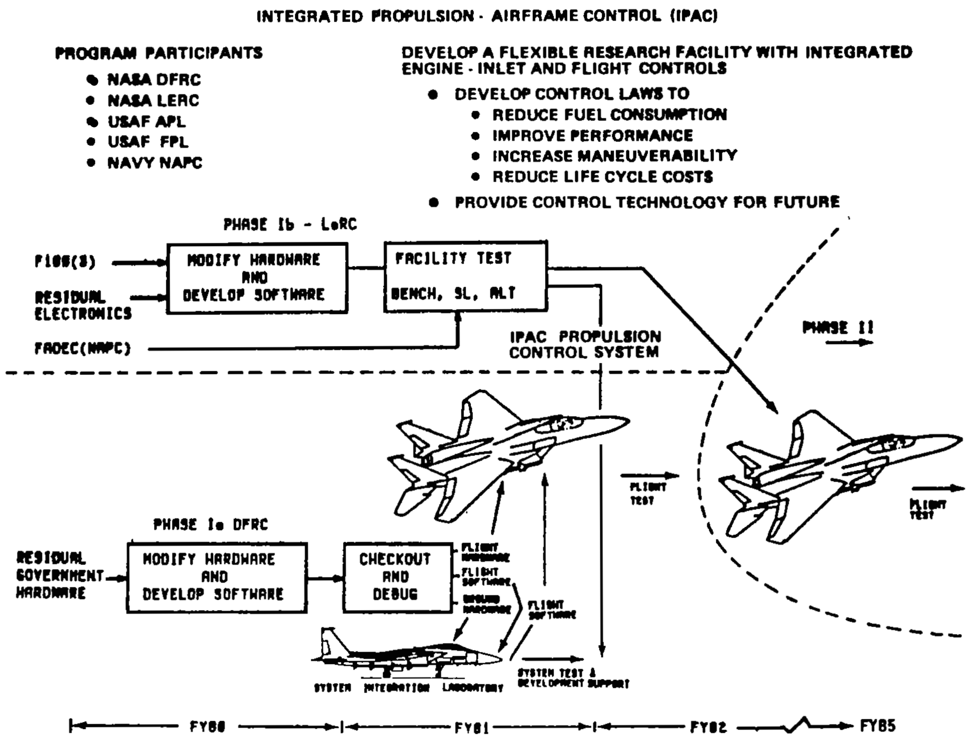


Figure 7

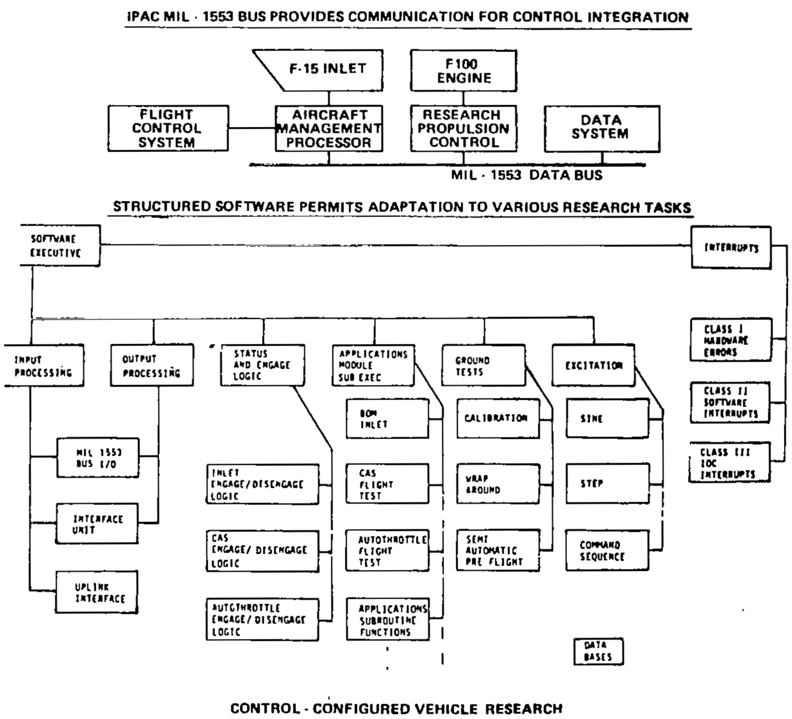


Figure 8

MULTIVARIABLE CONTROL TECHNOLOGY IS WIDELY APPLIED IN FLIGHT CONTROLS

- OVERALL DESIGN TOOL
  - SYSTEM IDENTIFICATION
  - STATE REDUCTION
  - CONTROL DECOUPLING
  - SENSOR SELECTION
  - MODE OPTIMIZATION
  - SAMPLING EFFECTS
    - DIRECT DIGITAL
    - CONTINUOUS TRANSLATED

- APPLICATIONS
  - F - 8C NASA (LRC / DFRC) DFBW
  - DAST II
  - L - 1011
  - 757
  - 767
  - B - 1, B - 52 OPTIMAL TERRAIN FOLLOWING

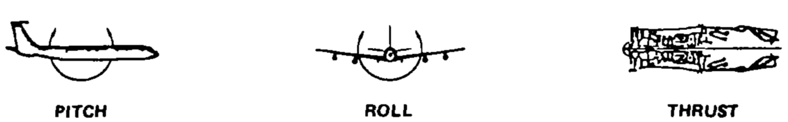
ALL APPLICATIONS HAVE MINIMUM TREATMENT OF PROPULSION SYSTEM

- PILOT SELECTED THRUST
- THRUST IS A SIMPLE LAG ON PLA

Figure 9

CONTROL - CONFIGURED VEHICLE RESEARCH

- CONVENTIONAL APPROACH - DECOUPLED DESIGN



- CONTROL - CONFIGURED VEHICLE RESEARCH
  - IMPROVED HANDLING QUALITIES (NUMEROUS)
  - FLIGHT ENVELOPE LIMITING (F - 101, F - 103)
  - REDUCED STATIC STABILITY (C - 5A, F - 4, YF - 16)
  - GUST ACCELERATION REDUCTION (B-52, XB - 70, B - 1, C - 5A, YF - 12)
  - MANEUVER LOAD CONTROL (MLC)
    - FIGHTER TYPE – MINIMUM DRAG DURING MANEUVERS (F - 4, YF - 16)
    - TRANSPORT TYPE – MINIMUM STRUCTURAL FATIGUE (B-52, C-5A)
  - ACTIVE CONTROL OF STRUCTURAL MODES (B-52, YF-12)
  - PROPULSION / DIRECTIONAL CONTROL MODES (YF-12)
  - AUTOMATIC TERRAIN FOLLOWING (B-1, B-52, F-111)
  - ADVANCED FIGHTER TECHNOLOGY INTEGRATION (AFTI) (F-111)

Figure 10

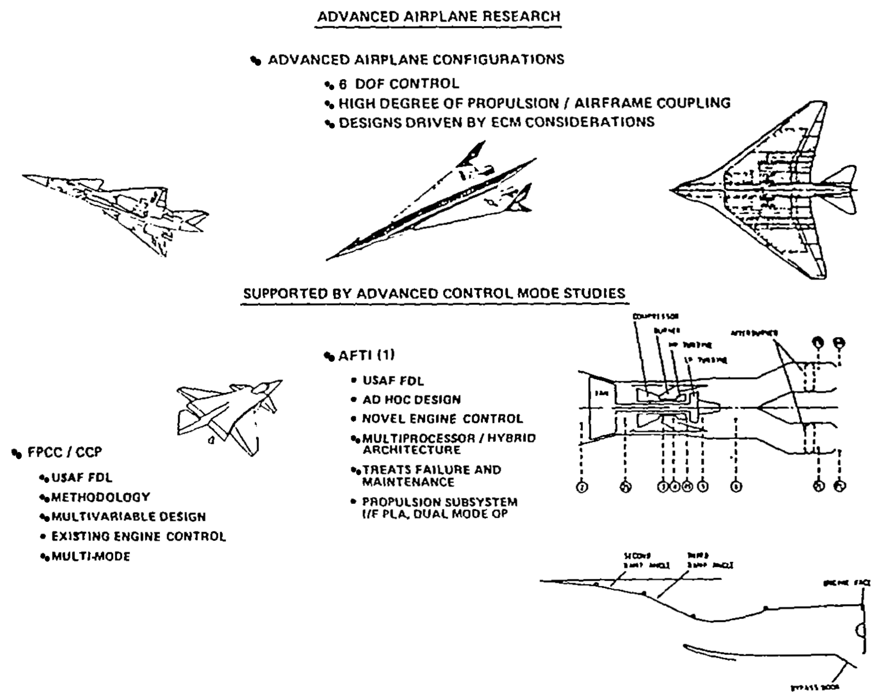


Figure 11

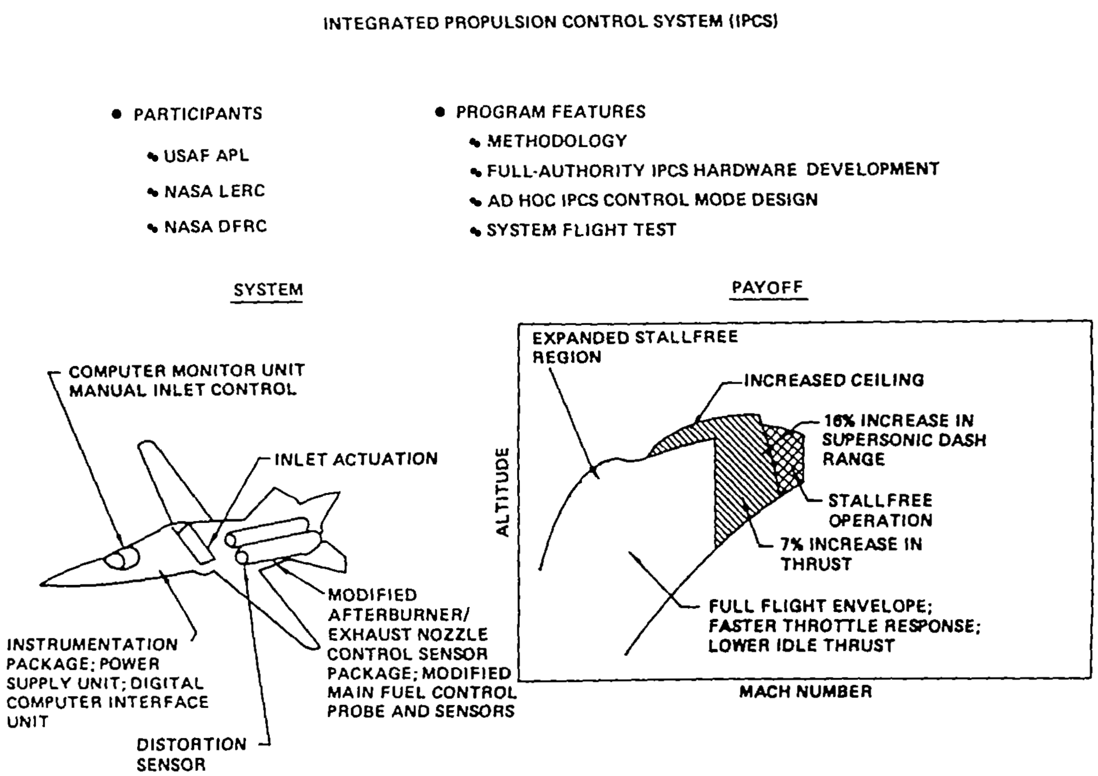


Figure 12

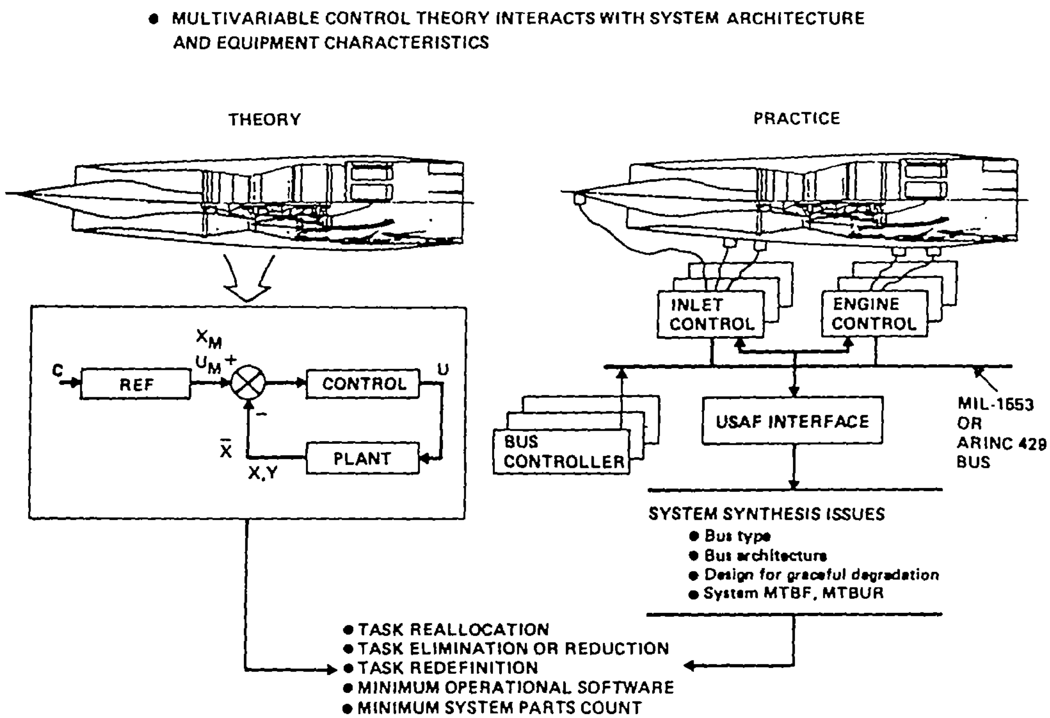


Figure 13

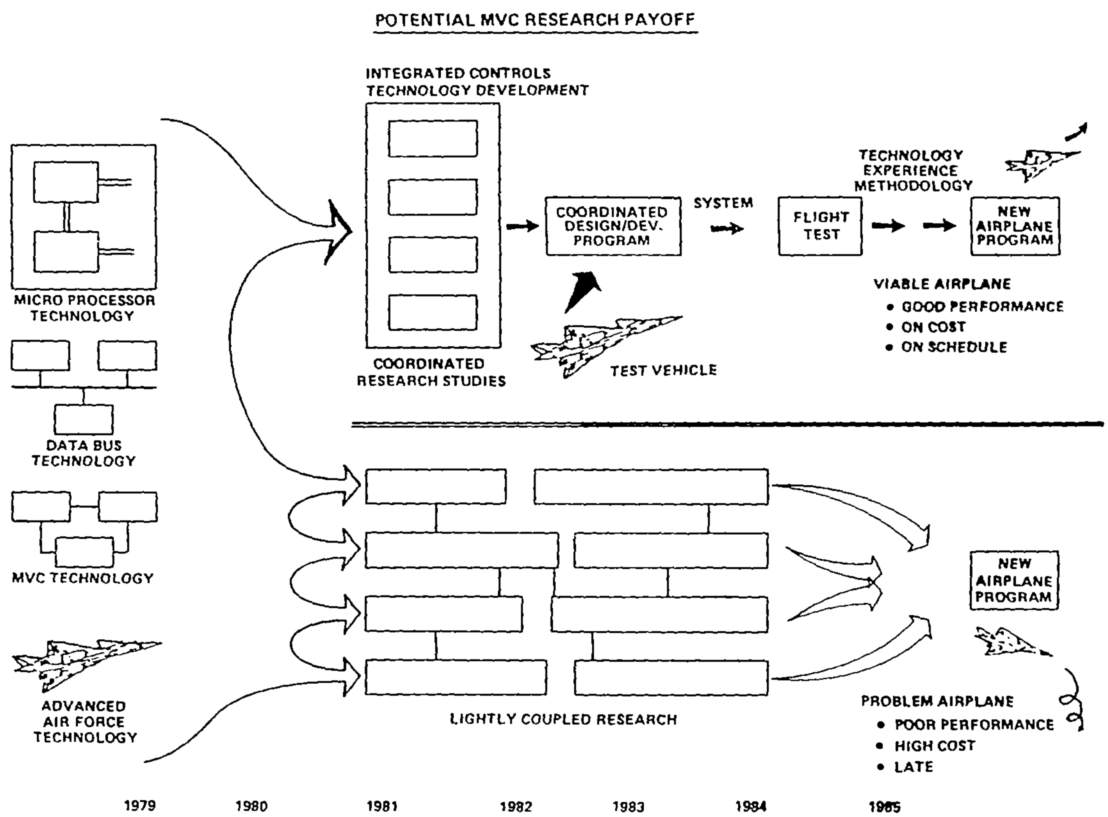
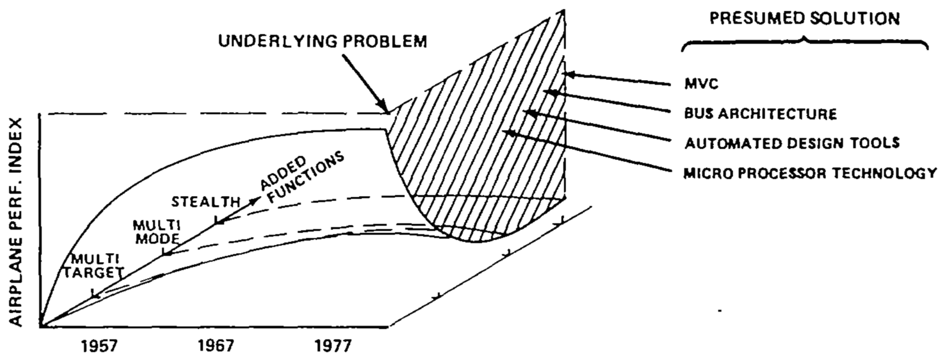


Figure 14

PROBLEMS OF GLOBAL APPROACH TO MVC



IMPLEMENTATION PROBLEMS

TECHNICAL

- SIZE OF PROBLEM
- INTERFACE TO STRUCTURED PROGRAM
- AUTOMATED DESIGN EXECUTION
- GRACEFUL DEGRADATION IN AUTOMATED SYSTEM
- SUBSYSTEM I/F ARE NO LONGER SIMPLE
- SOLUTIONS AND PAYOFFS ARE SENSITIVE TO PLANT

MANAGEMENT

- CROSSING STAFF LINES
- CROSSING CORPORATE LINES
- DEFINING ORGANIZATIONAL RESPONSIBILITIES

Figure 15

MULTIVARIABLE CONTROL SHOULD LEAD TO ELEGANT DESIGN

- STRUCTURE
  - STRUCTURED IDENTIFIABLE ARCHITECTURE VERSUS RANDOM LOGIC
- COMPUTATION REQUIREMENTS
  - IDENTIFIABLE ITERATION RATE REQUIREMENTS VERSUS EMPIRICAL SELECTION
  - IDENTIFIABLE PRECISION REQUIREMENTS VERSUS EMPIRICAL SELECTION
- HARDWARE
  - STANDARD CONTROL PROCESSOR AND LANGUAGE VERSUS DIVERSE TYPES

Figure 16

CONCLUSIONS

- RESEARCH PROGRAMS HAVE PROVIDED GOOD GROUNDWORK FOR GLOBAL CONTROL DEVELOPMENT
- AIRPLANE DESIGNERS / ENGINE CYCLE DESIGNERS ARE IMPOSING A HIGHER LEVEL OF INTEGRATION
- A PROGRAM(S) IS REQUIRED TO –
  - SHOW BENEFITS / COSTS
  - EXERCISE AUTOMATED DESIGN PROCESSES
  - VERIFY TECHNOLOGY READINESS
- DEMONSTRATION OF READINESS REQUIRES REALISTIC ENVIRONMENT –
  - ARCHITECTURE
  - INTERFACES
  - RELIABILITY
  - REDUNDANCY

Figure 17