NASA CONTROL RESEARCH OVERVIEW

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Washington, DC

First Annual NASA Aircraft Controls Workshop
NASA Langley Research Center
Hampton, Virginia
October 25-27, 1983

INTRODUCTION

The intent of this presentation is to provide an overview of NASA research activities related to the control of aeronautical vehicles. A groundwork is laid by showing the organization at NASA Headquarters for supporting programs and providing funding. Then a synopsis of many of the ongoing activities is presented, some of which will be presented in greater detail elsewhere. A major goal of the workshop is to provide a showcase of ongoing NASA-sponsored research. Then, through the panel sessions and conversations with workshop participants, it is hoped to glean a focus for future directions in aircraft controls research.

OFFICE OF AERONAUTICS AND SPACE TECHNOLOGY'S GOAL

The Office of Aeronautics and Space Technology, which sponsors most of the controls-oriented research for aircraft, publishes a long-range plan. The overall goal is stated in figure 1. Notice that the purpose of NASA's program in space and aeronautics is to continue to be long-term contributors toward the continued preeminence of the U. S. in civil and military aerospace activities.

STRENGTHEN THE AGENCY'S AERONAUTICS AND ADVANCED SPACE R&T PROGRAMS AS EFFECTIVE, PRODUCTIVE, AND LONG-TERM CONTRIBUTORS TOWARD THE CONTINUED PREEMINENCE OF U.S. IN CIVIL AND MILITARY AEROSPACE

Figure 1

HIGH-PRIORITY TECHNICAL GOALS/THRUST

Figure 2 shows the high-priority technical goals of OAST. It includes all the major thrusts proposed by OAST for the next 5 to 10 years. Ones of specific interest to the controls discipline are item 4, realize the full potential of advancing technologies for aircraft controls, guidance, and flight systems; item 7, provide technology to enhance flight management and crew effectiveness in aircraft operations and air traffic control systems; and, item 8, provide the technology base for exploitation of the use of modern computers in aeronautics. Other areas relate in terms of systems integration in an interdisciplinary nature. However, those three have generic and specific applications for aeronautical controls.

- BRING EXTERNAL AND INTERNAL COMPUTATIONAL FLUID DYNAMICS TO STATE OF PRACTICAL APPLICATION TO AIRCRAFT AND ENGINE DESIGN
- SIGNIFICANTLY REDUCE AIRCRAFT VISCOUS DRAG OVER THE FULL SPEED RANGE AND IMPROVE THE UNDERSTANDING OF REYNOLDS NUMBER EFFECTS AT TRANSONIC SPEEDS
- REALIZE THE FULL POTENTIAL OF COMPOSITE MATERIALS FOR PRIMARY STRUCTURES IN CIVIL AND MILITARY AIRCRAFT
- REALIZE THE FULL POTENTIAL OF ADVANCING TECHNOLOGIES FOR AIRCRAFT CONTROLS, GUIDANCE, AND FLIGHT SYSTEMS
- PROVIDE TECHNOLOGY ADVANCES TO EXPLOIT THE FULL POTENTIAL OF ROTORCRAFT FOR MILITARY AND CIVIL APPLICATION

Figure 2

HIGH-PRIORITY TECHNICAL GOALS

- PROVIDE TECHNOLOGY FOR AND FULLY SUPPORT THE DEVELOPMENT OF ADVANCED MILITARY AIRCRAFT AND MISSILE SYSTEMS
- PROVIDE TECHNOLOGY TO ENHANCE FLIGHT MANAGEMENT AND CREW EFFECTIVENESS IN AIRCRAFT OPERATIONS AND AIR TRAFFIC CONTROL SYSTEMS
- PROVIDE THE TECHNOLOGY BASE FOR EXPLOITATION OF THE USE OF MODERN COMPUTERS IN AERONAUTICS
- EXPLOIT THE FULL POTENTIAL OF HIGHLY INTEGRATED PROPULSION AIRFRAME SYSTEMS
- ADVANCE THE TECHNOLOGY FOR SMALL TURBINE ENGINES TO A LEVEL COMPARABLE WITH THAT OF LARGE TURBINE ENGINES
- ESTABLISH THE TECHNICAL FEASIBILITY OF HIGH-SPEED TURBOPROP PROPULSION
- PROVIDE COMPONENT TECHNOLOGY ADVANCES FOR FUEL-EFFICIENT SUBSONIC TRANSPORT ENGINES
- PROVIDE SAFETY TECHNOLOGY FOR IMPROVED DESIGN AND OPERATION OF CURRENT, ADVANCED CIVIL AND MILITARY AIRCRAFT AND SYSTEMS

Figure 2 (Concluded)

NASA ORGANIZATION

The overall organization of NASA is shown in figure 3. Most of the aircraft controls research is performed through the Office for Aeronautics and Space Technology (OAST). The three field centers supported by OAST's program are Ames, Langley, and Lewis. Although diverse activities occur at all three centers, each center is usually charged with a number of lead roles for specific research thrusts.

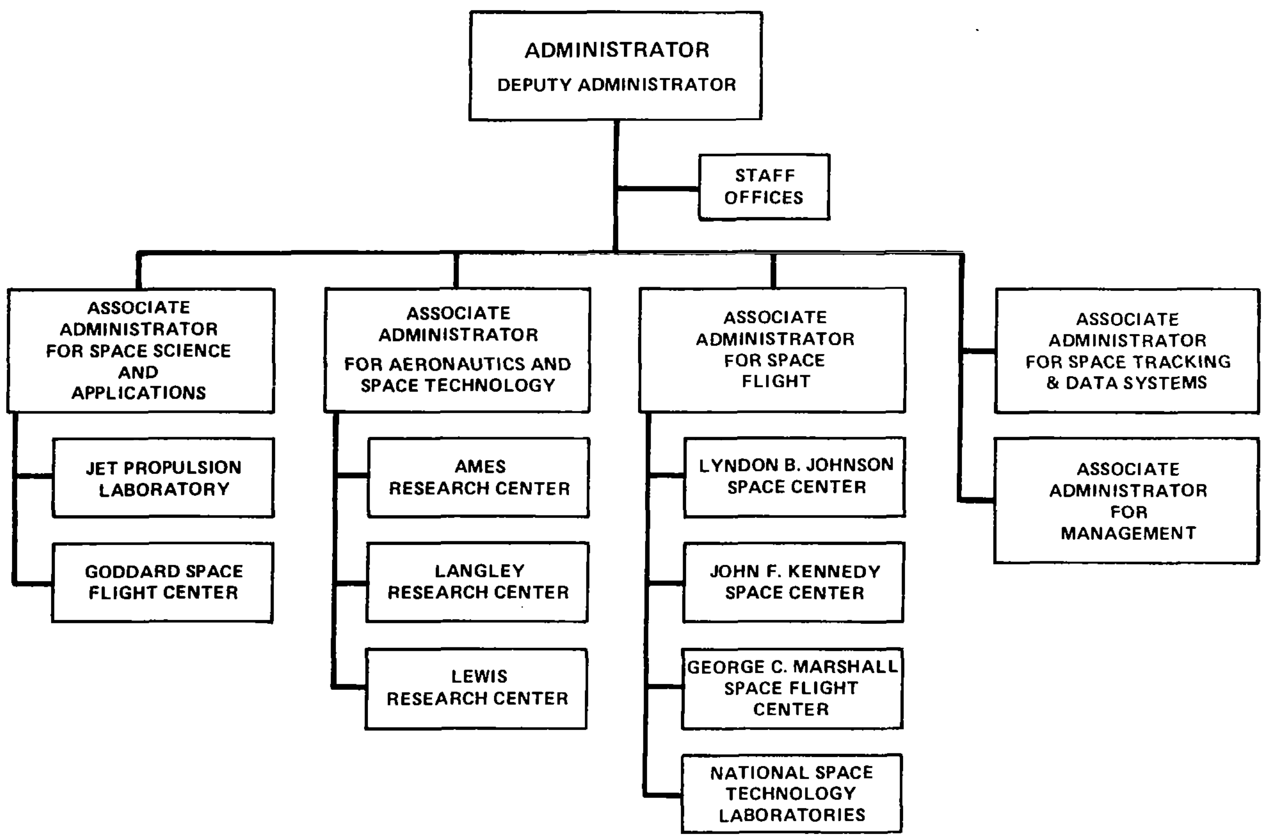

Figure 3

OAST ORGANIZATION

The OAST organization at NASA Headquarters is depicted in figure 4. Aircraft controls are sponsored in both the Aerospace Research Division (Code RT) and in the Aeronautical Systems Division (Code RJ). In code RT the research is usually of a general nature and could be applied to several vehicles or categories of vehicles. The Controls and Human Factors Branch administers research programs for Applied Control Theory and Analysis, Flight Crucial/Fault-Tolerant Controls and Guidance, Spacecraft Controls and Guidance, Flight Management, Flight Simulation Technology, and Space Human Factors. Code RJ sponsors vehicle specific research in each of the indicated areas. Code RJ research often results in a wind tunnel or flight research test of a specific configuration. One way of viewing the organization is that as the generic research of code RT matures it is picked up by code RJ-type programs for validation and fine tuning for specific applications. If fundamental problems are encountered during the vehicle specific research of code RJ, it identifies an area for more effort for code RT.

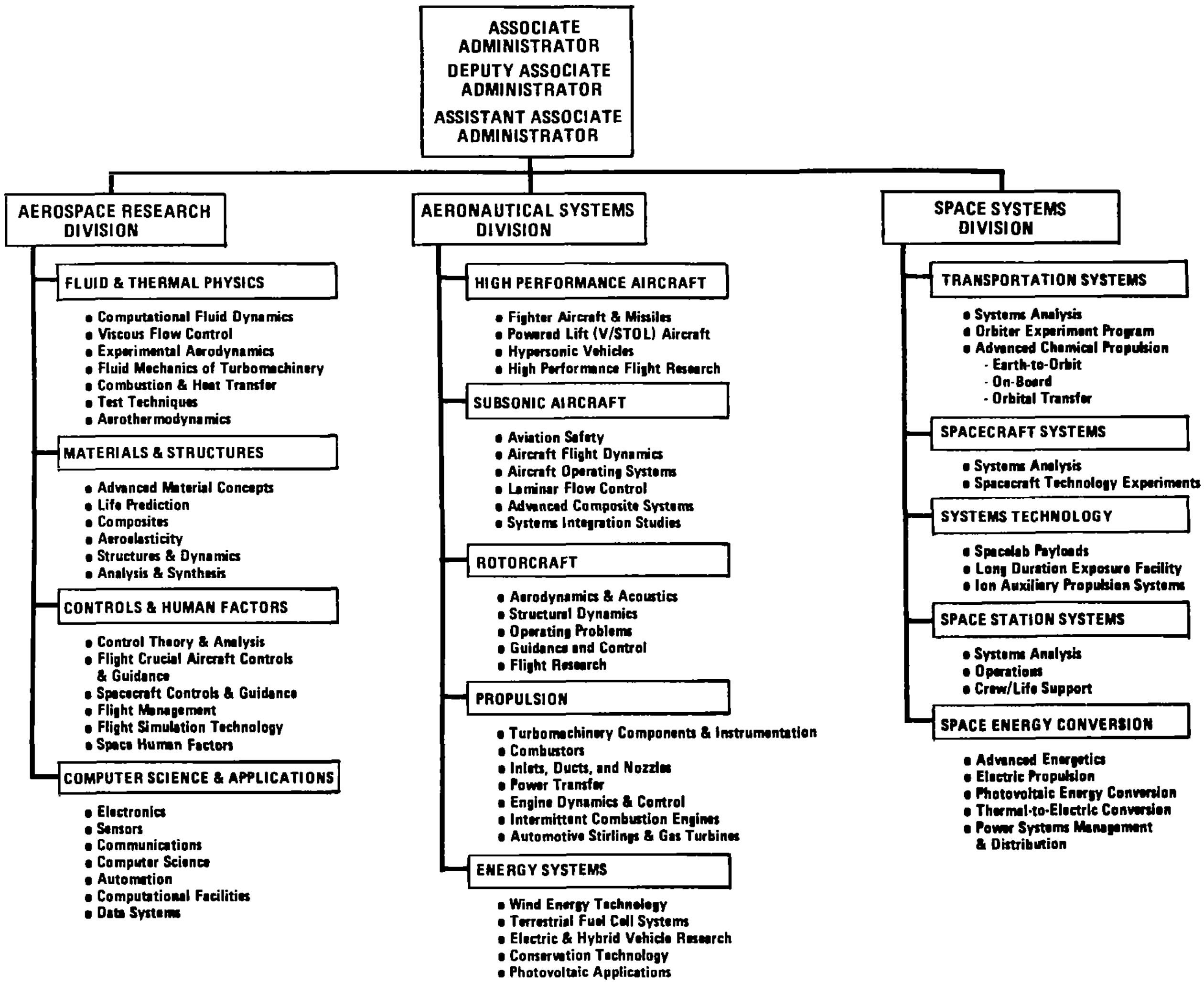

Figure 4

The three main areas of research sponsored by the Controls and Human Factors Office in the areas of aircraft controls and guidance are: applied control theory, flight-crucial systems, and flight path management and guidance (fig. 5). The goal of the applied control theory research is to provide the general tools for designing active control systems for many categories of aircraft. The flight-crucial systems research is attempting to develop analytical and mathematical models for ascertaining the validity and probability of failure of electronic active control systems and avionics in general. The overall goal is to provide a methodology for designing and verifying electronic active control systems which have the reliability of primary structural surfaces. The flight path guidance research program is aimed at providing fuel-efficient trajectories for commercial transports, time-optimal intercept guidance for tactical aircraft, and new enhanced display media for improving the cockpit environment.

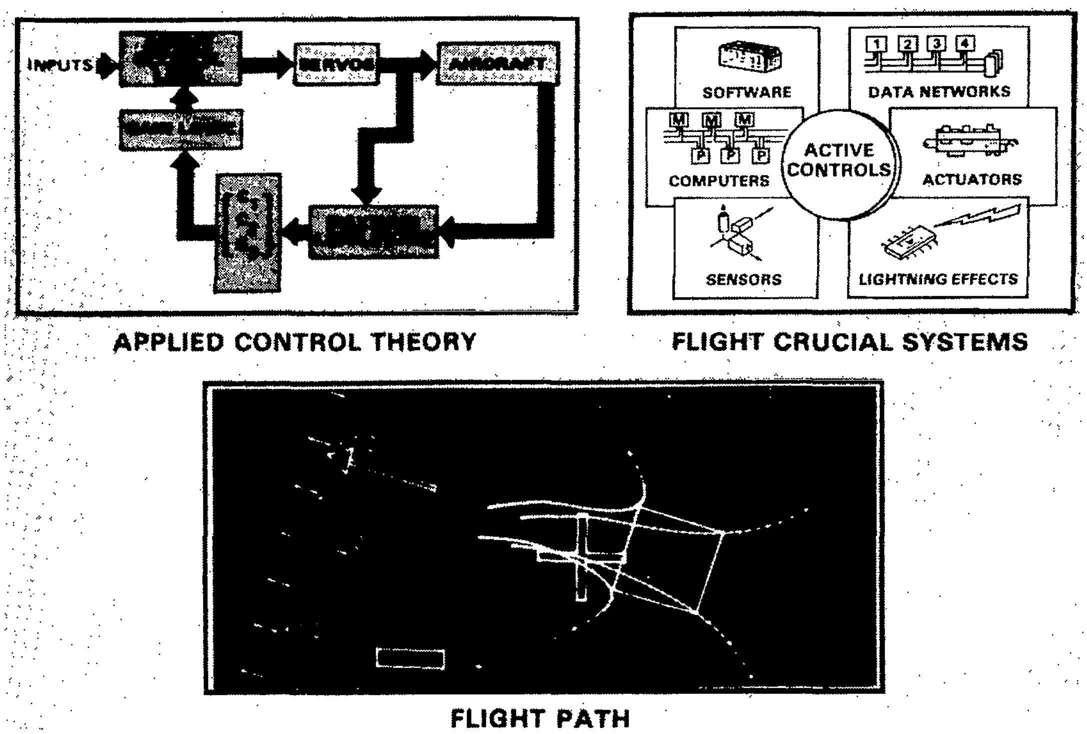

Figure 5

ACTIVE CONTROL TECHNOLOGY

Active control research at NASA embodies many important elements (fig. 6). There is a significant effort involved in the development of synthesis tools for control laws which account for structural flexibility. Several different approaches are being investigated. The control system designs are then evaluated using a variety of analysis tools. Successful candidates are then tested in the wind tunnel or in flight. This process provides a validation of synthesis techniques, analysis tools, and experimental facilities. The goal of active controls research is to improve mission effectiveness by reducing weight, increasing performance, and enhancing passenger acceptance.

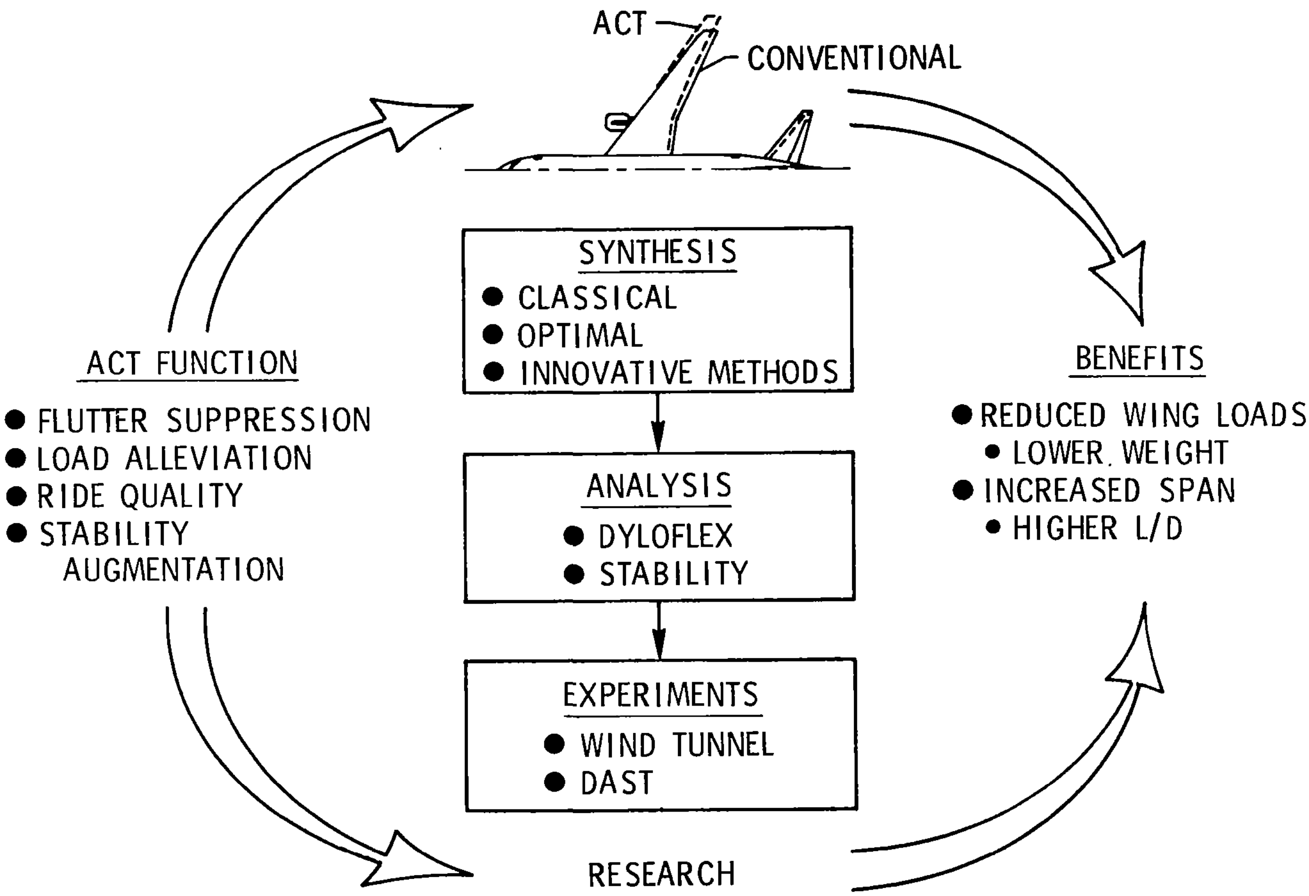

Figure 6

Parameter estimation is an important part of the control research program (fig. 7). Control system performance is greatly enhanced by having the most accurate model of the aircraft possible. Modelling work includes linear and nonlinear analysis of general aviation, commercial transport, and tactical aircraft. Recent cooperative agreements for exchange of data and information with Boeing and with Israel serve to illustrate the importance such work has in the eye of industry and the role that NASA plays in this area.

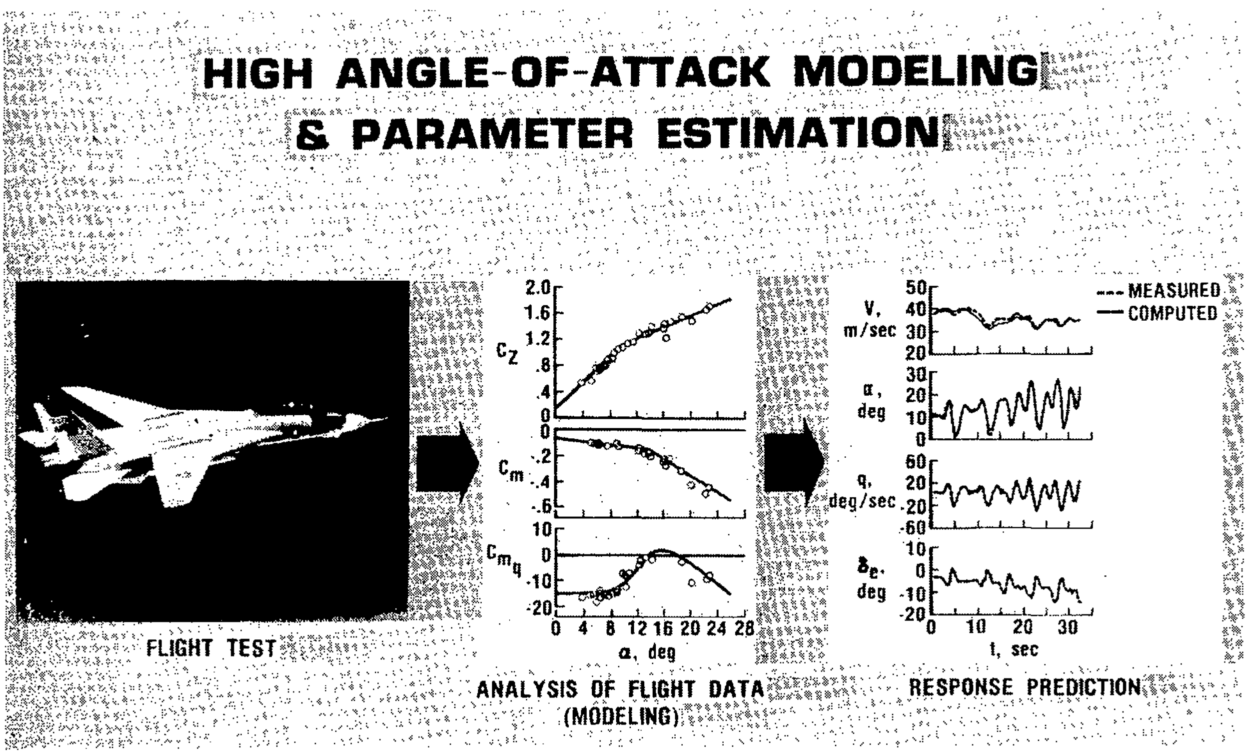

Figure 7

Research for fault-tolerant computers is the prime focus of the flight-crucial controls program (fig. 8). Two pioneering computer concepts have been constructed. The SIFT (Software Implemented Fault Tolerance) computer and the FTMP (Fault-Tolerant Multi-Processor) computer are currently undergoing evaluation in AIRLAB (Avionics Integration Research Laboratory). It is hoped that the experience gained with studying these concepts will provide an ultimate system reliability that has a probability of failure per flight hour of less than 10^{-9}.

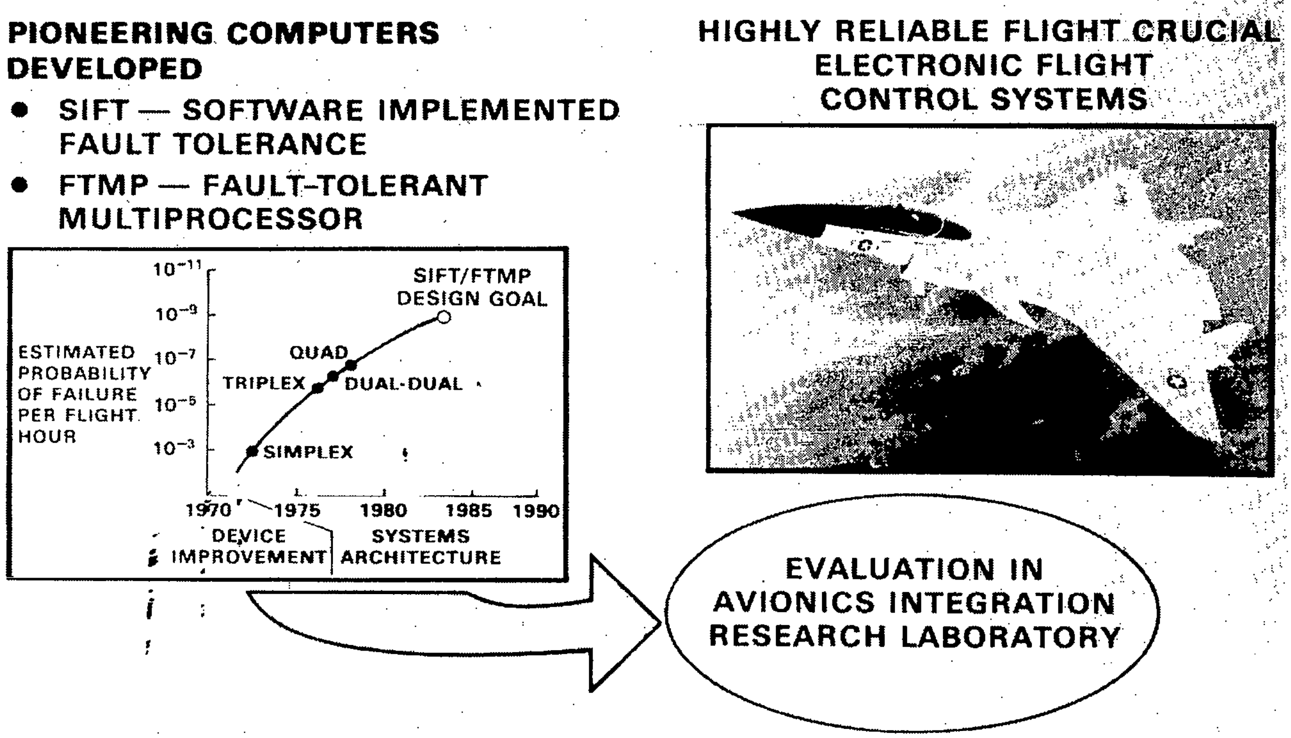

Figure 8

AIRLAB

AIRLAB (fig. 9) is a new facility which brings online an impressive set of capabilities for performing fault-tolerant research. System transient response and recovery rates are investigated during the injection of artificial faults at the gate, component, and functional levels. Through the study of actual state-of-the-art concepts physically located at AIRLAB, the development of analytical models and emulation methods are a near-term objective. With tools available for analyzing architectures and hardware component selection, design methodologies can be developed. Additionally, new efforts are underway to model and understand software reliability.

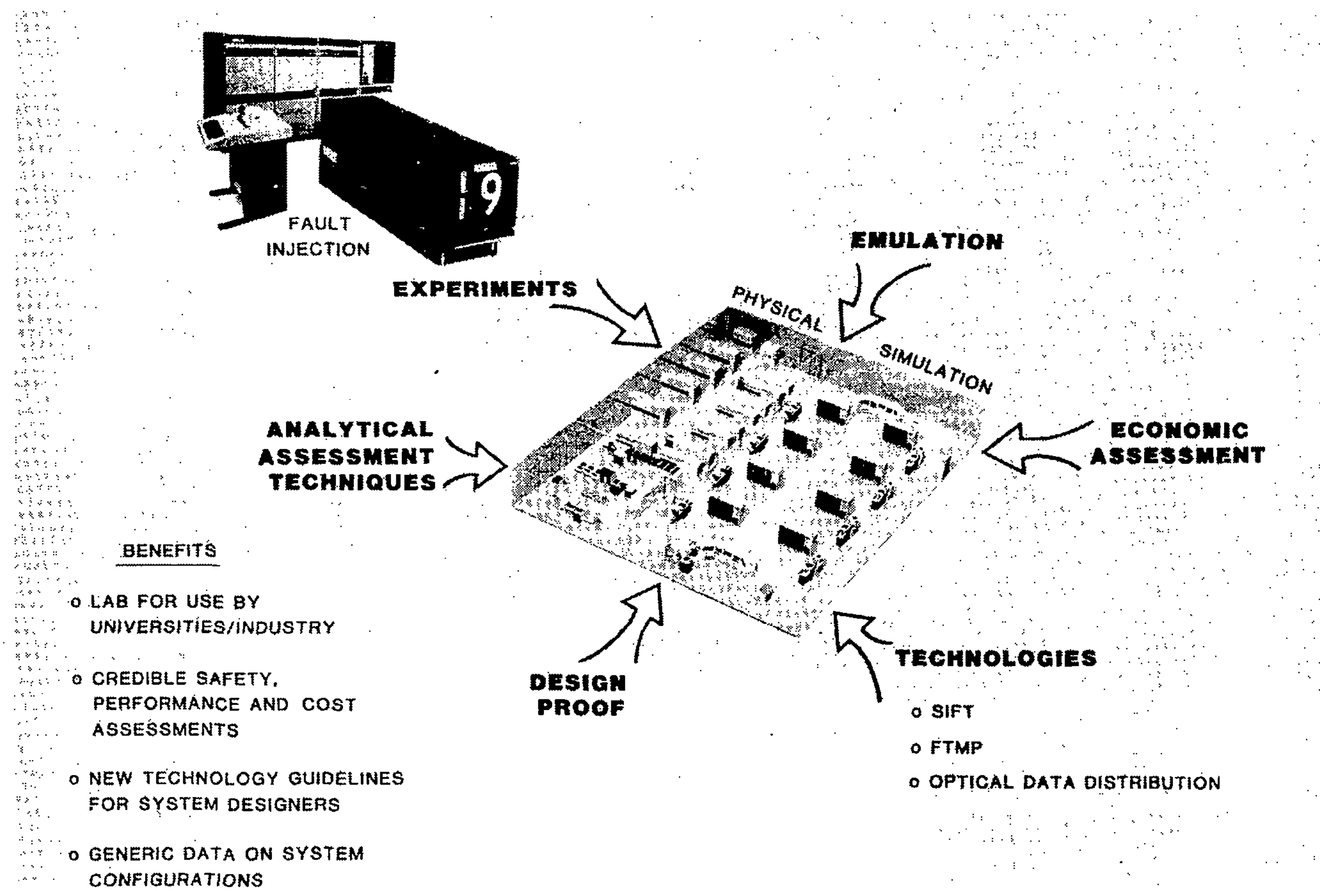

Figure 9

In the area of flight path guidance (fig. 10) there is research in three major segments underway. Tools for computing optimal guidance laws for transport, V/STOL, rotorcraft, and tactical aircraft are being refined. Current emphasis is on trying to integrate such concepts into the air traffic control (ATC) system and provide 4-D traffic flow management. Additionally, there is an effort to develop advanced display media concepts for cockpits of the future.

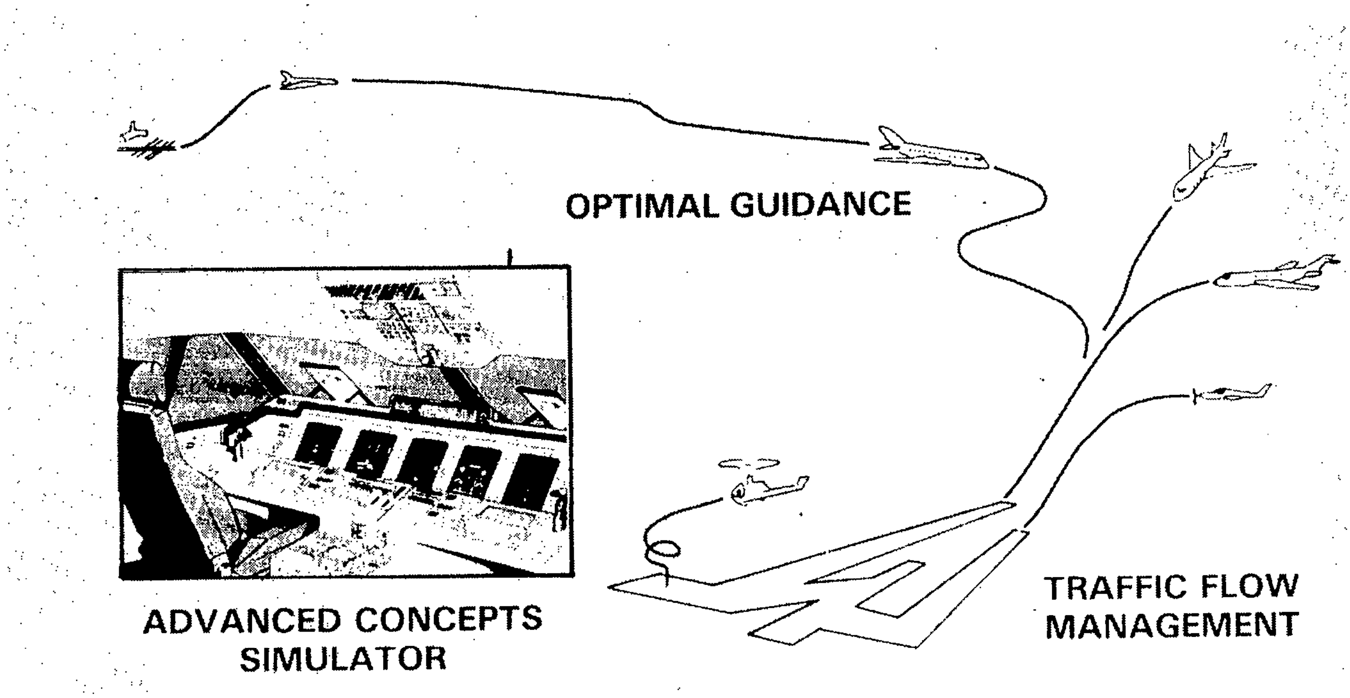

Figure 10

COCKPIT AVIONICS PROGRAM

Cockpit avionics research (fig. 11) in the controls and guidance program emphasizes the development of advanced display concepts. The prime users of this research will be the avionics manufacturers. Active areas of research include advanced display media, display generation techniques, data input/output technology, and cockpit systems integration. The goal of most research is toward thin panels which are required for the "All-Glass Cockpit" concept where electro-mechanical display devices are replaced by computer-generated images. It should be noted that the human factors research program at NASA is cooperating with industry in developing fundamental guidelines for deciding what should be displayed to the pilots.

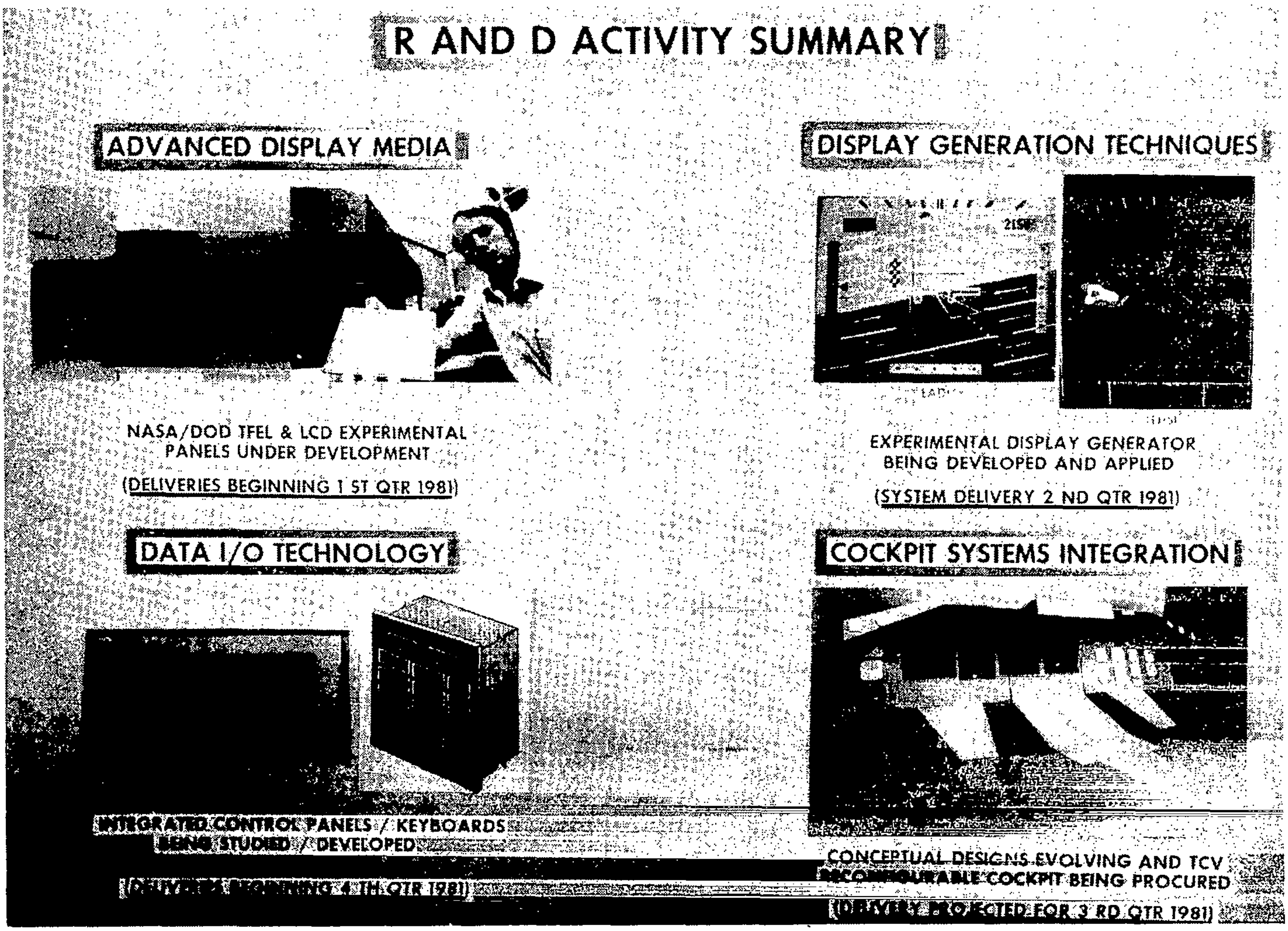

Figure 11

VEHICLE SPECIFIC CONTROLS AND GUIDANCE TECHNOLOGY

Up to now, most of the research that was described was sponsored by the Aerospace Research Division at NASA Headquarters and represents vehicle independent or generic developments. Figure 12 shows some of the vehicle specific research that is sponsored by the Aeronautical Systems Division at NASA Headquarters. Active controls research is performed in transport, general aviation, high-performance, V/STOL, and rotorcraft classes of airplanes. A natural development process would be the development of general design tools which are then used to synthesize control systems for a specific vehicle. The direct application to a particular problem and the experience gained can be used to refocus research in control theory as new challenges are presented.

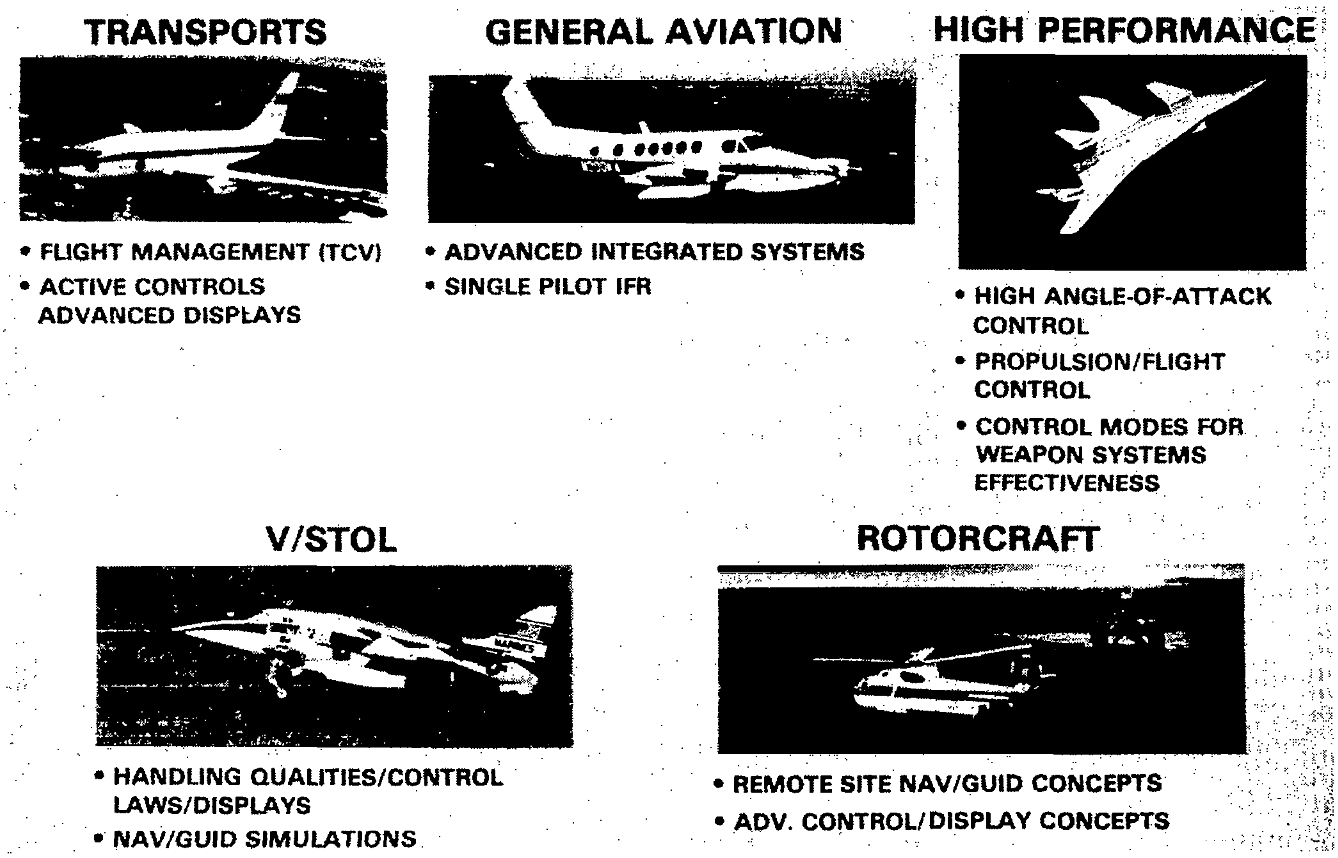

Figure 12

FLIGHT TEST OF ACTIVE CONTROLS TECHNOLOGY

NASA has had an aggressive program in cooperation with industry to investigate and demonstrate the application of active controls technology to commercial transports. One aspect of the program was a flight test demonstration of maneuver load alleviation and relaxed static stability on a Lockheed L-1011 (fig. 13). Analysis and piloted simulations of the technology were validated using the flight test results.

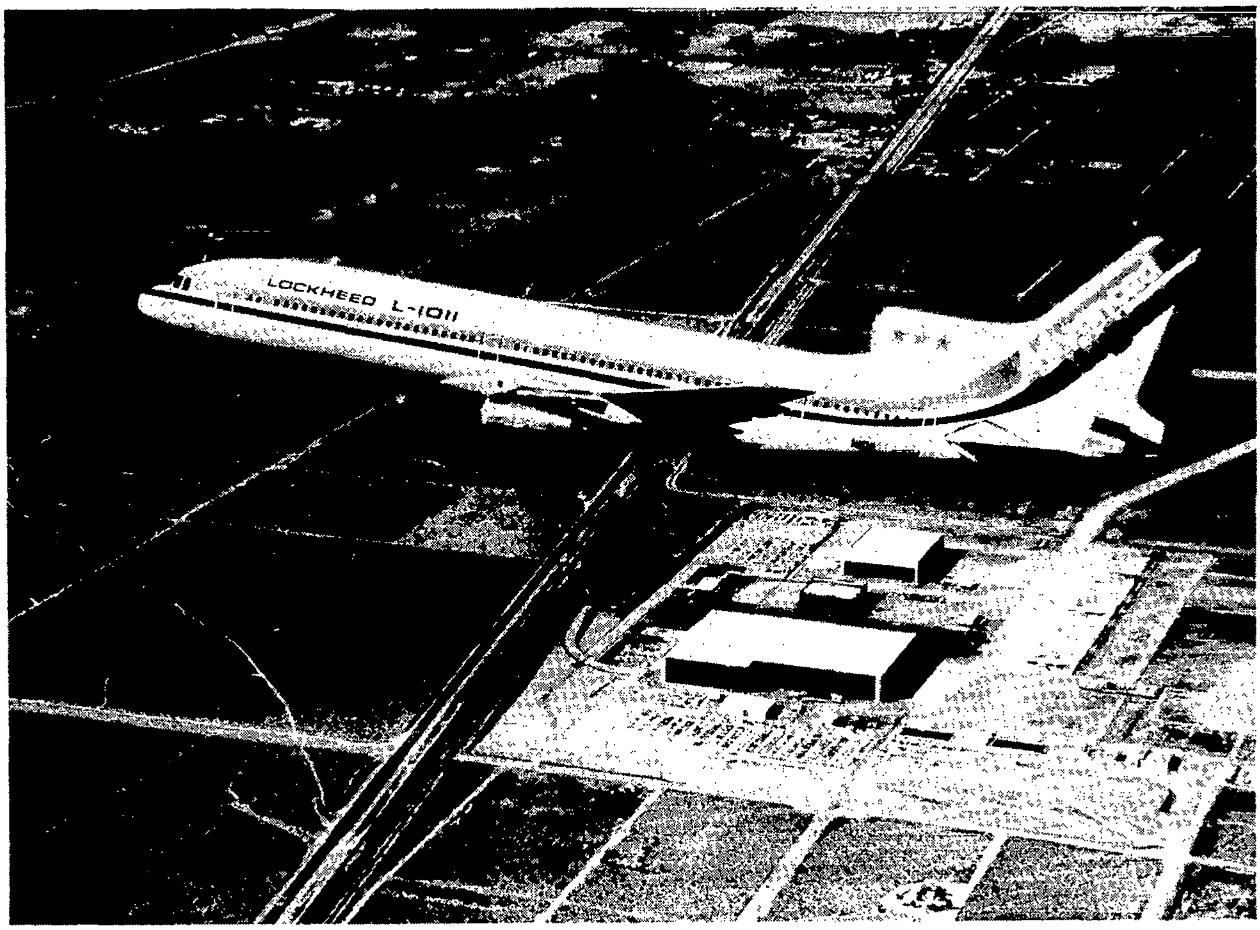

Figure 13

ROTORCRAFT CONTROLS RESEARCH

A number of controls activities are being focused upon V/STOL aircraft and rotorcraft (fig. 14). The nonlinear, inverse control theory presented in this conference was sponsored with generic controls research money. Now the tools that have been developed are being used to design control laws which are being flown on the NASA Ames UH-1H. This is a good example of the ideal flow of NASA research in controls: theory enhancement; tool development; simulation and analysis; followed by verification and validation through flight test.

UH-IH IROQUOIS

AMES RESEARCH CENTER

PRIMARY PURPOSE:

- FLIGHT CONTROLS & AVIONICS
- FLIGHT CONTROL LAWS
- INVESTIGATE FLIGHT RELATED PROBLEMS
- INVESTIGATE ROTOR FLIGHT PROBLEMS
- UTILITY SUPPORT HELICOPTER

KEY CHARACTERISTICS:

- TWO HELICOPTERS
  - ONE WITH VSTOLAND EQUIPMENT
  - ONE USED FOR ROTOR FLIGHT STUDIES
- MEDIUM UTILITY HELICOPTER

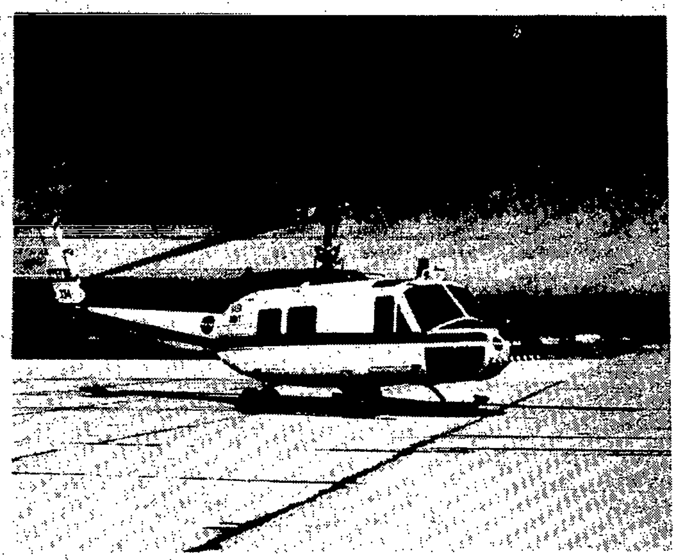

Figure 14

The AFTI/F-16 program (fig. 15) has joint military and NASA funding. It has been a tremendous success in terms of demonstrating what can be accomplished through the aggressive use of integrated controls technologies. The addition of vertical canards and multi-purpose trailing-edge flaps allowed the addition of new control modes including translational flight, nose pointing, and flat turns. Other systems concepts have been evaluated including voice command, heads-up displays, and multi-purpose advanced panel displays. Work is continuing with the evaluation of advanced combat and maneuvering systems taking advantage of the new operational control modes.

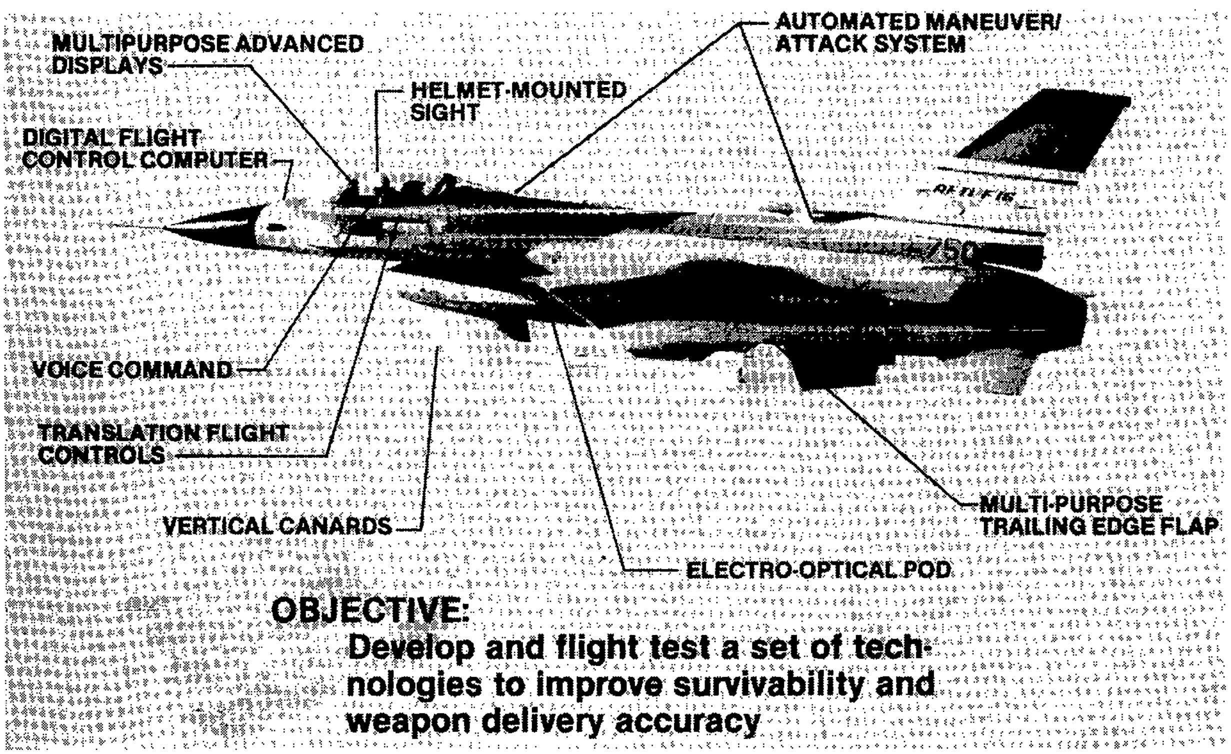

Figure 15

HIGHLY MANEUVERABLE AIRCRAFT TECHNOLOGY (HiMAT)

The HiMAT technology demonstration program (fig. 16) has recently been completed and was jointly funded by the USAF and NASA. It was used to assess the effectiveness of integrated aircraft design with an emphasis on maximizing transonic maneuvering without compromising supersonic performance. Additionally, composites were used to aeroelastically tailor the lifting surfaces to allow deflection into optimal aerodynamic shape under any load. HiMAT is an RPV (Remotely Piloted Vehicle) which permitted the use of risky and advanced technologies in a flight vehicle at greatly reduced cost.

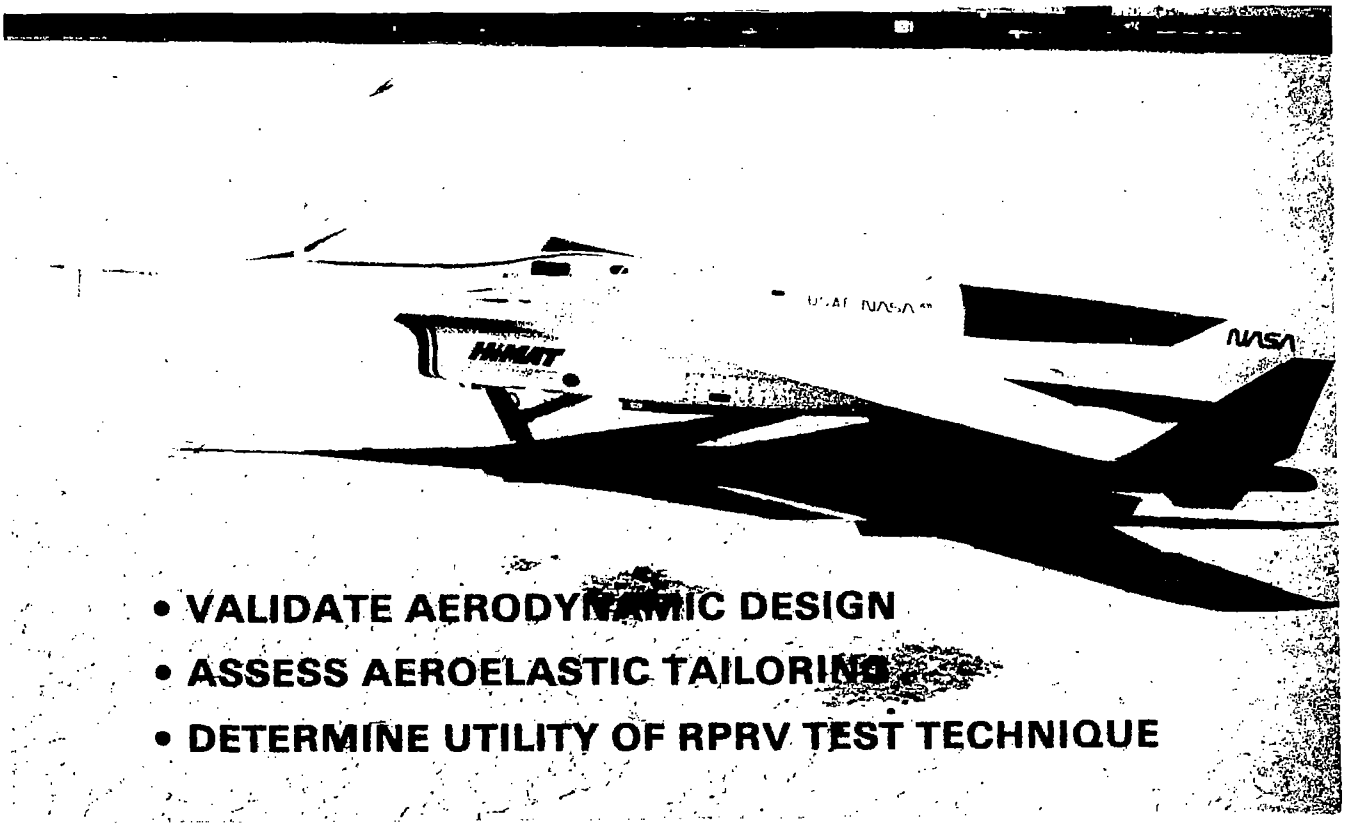

Figure 16

X-29A RESEARCH PROGRAM

Another joint program between DARPA, USAF, and NASA is the X-29A Flight Research Vehicle (fig. 17). It is being used to investigate aeroelastically tailored, forward-swept-wing technology. It features a closely coupled canard, multiple longitudinal control surfaces, and a static margin of 35 percent unstable. Because of these features, it has become a major technical challenge for the controls specialists. When the joint military/NASA flight tests have been completed, the aircraft will be retained by NASA and will be used for continuing flight research with respect to integrated control systems.

Figure 17

SUPERAUGMENTED AIRCRAFT CRITERIA

The X-29 and Shuttle (fig. 18) are prime examples of highly augmented aircraft. This level of what is sometimes termed "superaugmentation" results from the requirements for low observables, ultra-high maneuverability, and the extended flight envelope. However, since the dynamic response of these vehicles is dominated by the control system characteristics, as opposed to conventional airplane dynamics, the interfacing with pilots becomes an issue. Early results indicate that flying qualities criteria need to be reconsidered for this category of aircraft. Such criteria are important for being able to design effective controls for piloted vehicles. Significant research envisioned for the future will undoubtedly be aimed at developing design guidelines through expanding the data base and constructing handling quality criteria for application superaugmented aircraft.

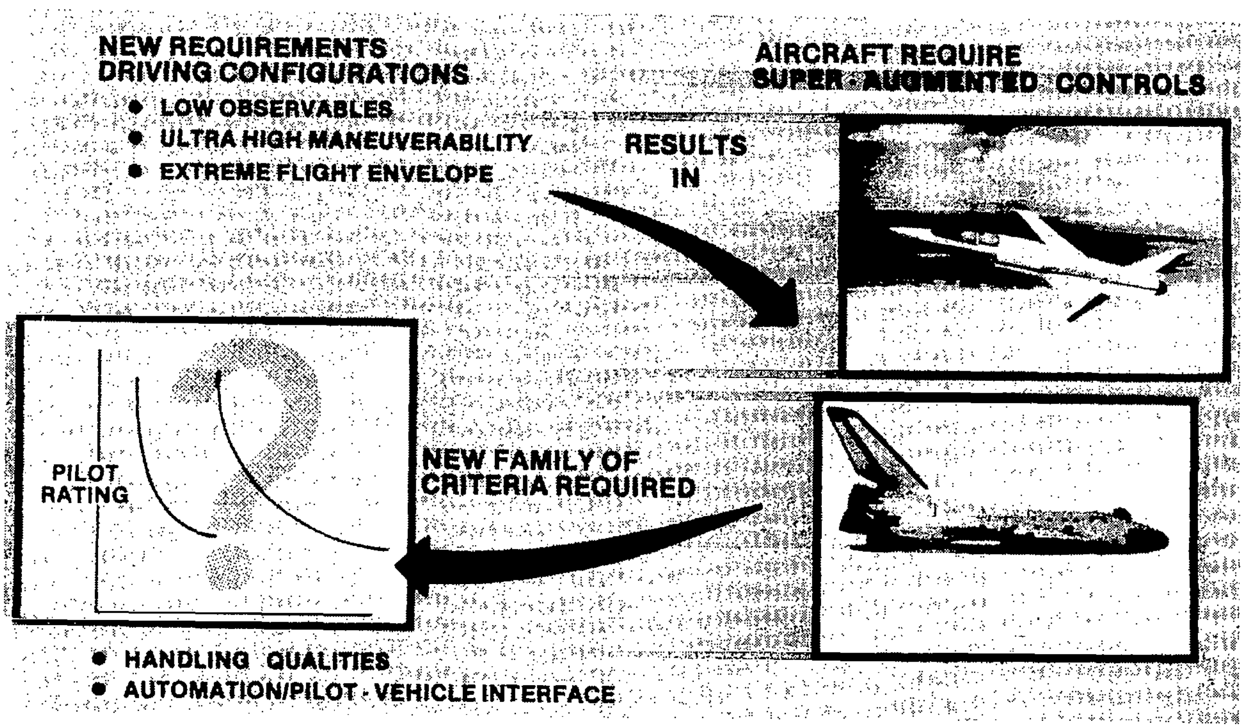

Figure 18

RESEARCH OPPORTUNITIES FOR THE FUTURE

What NASA research will be performed in the future? The answer to this question is a major goal of this workshop. The papers presented should yield a good scope of what the current NASA-sponsored aeronautical controls program is. The panel discussions and interactions with participants will hopefully serve to guide the future directions. Because of this, active participation by all attending the workshop is encouraged and is, in fact, essential for the continued United States preeminence in the area of aircraft controls.