NASA Conference Publication 2061

Avionics and Controls Research and Technology

Proceedings of a workshop sponsored by the NASA Office of Aeronautics and Space Technology and held at Hampton, Virginia, June 27-29, 1978

NASA

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Avionics and Controls Research and Technology

Editors

Herman A. Rediess, *NASA Headquarters*
Duncan E. McIver, *Langley Research Center*

Proceedings of a workshop
sponsored by the NASA Office of
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and hosted by the Langley Research
Center, Hampton, Virginia,
June 27-29, 1978

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PREFACE

A workshop on avionics and controls research and technology, sponsored by the National Aeronautics and Space Administration (NASA) Office of Aeronautics and Space Technology and hosted by the NASA Langley Research Center, was held in Hampton, Virginia on June 27-29, 1978.

This workshop provided a forum for industry and universities to discuss the state-of-the-art, identify the technology needs and opportunities, and describe the role of NASA in avionics and controls research. Approximately 110 individuals participated in the workshop, 74 from industry, 9 from universities, and the balance from NASA, the Federal Aviation Administration (FAA), and the U.S. Air Force (USAF).

The workshop was organized into two working sessions to consider vehicle-specific-technology and broadly-applicable-technology aspects of avionics and controls. This publication contains the recommendations developed during these sessions, along with other related observations.

August 1978

Duncan E. McIver
National Aeronautics
and Space Administration
Langley Research Center

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INTRODUCTION

In April 1978, a special planning team was established to make an across-the-board assessment of the NASA avionics and control program. The team charter as defined by Dr. James J. Kramer, NASA Headquarters, was to

(1) Develop a rationale for the NASA role in avionics and controls

(2) Assess NASA, DOT/FAA, and DOD avionics R&D programs and facilities

(3) Develop a major new NASA thrust in fiscal year 1981, if justified.

The planning team consisted of the following individuals:

From NASA,

Herman A. Rediess (chairman), Headquarters
Edward C. Buckley, Headquarters
Robert G. Chilton, Johnson Space Center
Kenneth E. Hodge, Headquarters
Calvin R. Jarvis, Dryden Flight Research Center
Norman S. Johnson, Ames Research Center
Gene E. Lyman, Headquarters
William D. Mace, Langley Research Center
John R. Zeller, Lewis Research Center

From FAA,

Colin Simpson, Systems Research and Development Services
Norm Solat, Systems Research and Development Services

The initial effort of the planning team was to conduct a detailed assessment of the NASA program; this included the development of written summaries of all related work and a visit to each NASA Center to review programs and facilities.

The following two sets of avionics and controls technology categories were established to facilitate the assessment:

VEHICLE SPECIFIC (AIRCRAFT TYPE)

- Conventional take-off and landing (CTOL)
- Vertical/short take-off and landing (V/STOL)
- Rotorcraft
- General aviation and short haul
- High performance/supersonic cruise

BROADLY APPLICABLE (GENERIC)

- Flight path management
- Aircraft control systems
- Crew Station
- Interfacing and integration
- Fundamental technology

A contract was also initiated with Dr. Richard K. Smythe, MILCO International, Inc., to provide the planning team with an independent assessment of the state-of-the-art in avionics and controls.

Following the review of NASA programs, the planning team was briefed on related programs ongoing at the Air Force Flight Dynamics Laboratory, Wright Patterson Air Force Base. The team also reviewed published data and made personal contacts regarding avionics and controls research in the Army, Navy, and other parts of the Air Force. In addition, a detailed briefing of DOT/FAA programs was provided in Washington, D.C.

Another key element of the overall planning process was to allow industry and universities to make inputs to the NASA plan. In late April, Dr. Rediess sent a letter to many industry and university personnel to inform them of the NASA team's activities, to invite them to contribute their views on what NASA's role should be, and to announce the plans for a workshop. A number of positive responses were received and an avionics and controls workshop was announced for June 27-29 in Hampton, Virginia to be hosted by the NASA Langley Research Center.

The workshop provided a forum for industry and universities to discuss the state-of-the-art, identify the technology needs and opportunities, and describe the role of NASA in avionics and controls research.

WORKSHOP PROCEDURES

The workshop attendees assembled in Hampton, Virginia, June 27-29, 1978. There were approximately 110 individuals, 74 from industry, 9 from universities, and the balance from FAA, USAF, and NASA.

Dr. Donald P. Hearth, Director, NASA Langley Research Center, welcomed the attendees and stressed the Langley commitment to avionics and controls as one of the Center's primary roles and missions. Dr. Herman Rediess, chairman of the workshop, followed Dr. Hearth's comments with a review of the NASA/OAST Avionics and Controls Planning Team activities, instructions on workshop procedures, and a discussion of what he hoped the workshop would accomplish during the three days.

As given in table I, the workshop was structured into two working sessions consisting of five teams each. Cochairmen, one from Industry/University and one from Government, had been previously selected. The Industry/University chairmen were to lead the discussion during the team sessions.

The Vehicle Specific Sessions were held first, beginning after lunch on the first day, and each attendee was assigned to one of the Vehicle Specific Teams. Each team met separately for almost 6 hours. The entire group then reassembled in a planning session for discussion and a report from each team. Following these reports, each attendee then reported to a Broadly Applicable Team, and on the second day a similar procedure was followed. The workshop closed with a brief wrap-up session on the third day.

The team cochairmen were asked to structure their own meetings; however, they were asked to consider, where appropriate, the following three questions:

(1) What should be the principal focus for research through about 1979-1984, through 1984-1990, and through the decade of 1990-2000?

(2) Considering where we are now, and the objectives identified in question (1), what are the principal research areas or technology deficiencies that should be addressed in these time periods?

(3) What role should NASA assume in the conduct of these research efforts, i.e., the nature of its output, the mechanism for disseminating new technology, and the nature of participation by industry and universities?

In addition to the verbal report and discussion, the cochairmen of each team were asked to provide a written version of their report. These inputs, with a list of the workshop attendees who were assigned to each team, are included as an appendix.

An additional question proposed by Dr. Rediess, during the discussion session, was whether attendees could identify any new facilities that NASA should develop.

Each attendee was asked to complete two tables to give their view of the relative importance of key technology drivers for the vehicle specific areas and the importance of these technology drivers in the broadly applicable research areas.

Before the teams began their working sessions, Dr. Richard K. Smythe presented a state-of-the-art survey of the avionics and controls area. This study had been initiated by Dr. Rediess and was structured along the broadly applicable research areas.

SUMMARY OBSERVATIONS

Team sessions were very lively and all points of view were discussed as fully as time permitted. The subsequent report provided an important set of guidelines to NASA for use in formulating the avionics and controls program. The following are some key observations and recommendations extracted from the team reports:

Team	Observations/Recommendations
Commercial Transport (CTOL)	o NASA should give high priority to research in: - Flight critical active controls - ATC/4D guidance - Systems integration o Research on lightning and all weather sensors important o Recommend strong liaison with NASA human factors program and FAA time referenced ATC efforts
V/STOL	o NASA is best agency to conduct V/STOL research since service funding is more subject to change o Research should include technology development in areas such as: - Integrated flight control/propulsion/ command display systems - High temperature electronics - Low speed sensors - Reliability/redundancy requirements o Recommend better technology interchange - seminars, personnel exchanges

Team	Observations/Recommendations
Rotorcraft	o 1979 to 1985 research should focus on: - Improving pilot's ability to control rotorcraft - Achieve IFR capability - Apply DFBW and redundant systems technology o 1985 to 2000 research should focus on: - Integrated avionics and control systems o Research specifics should include: - Investigation of GPS for navigation to remote sites - Improved crew station with electronic displays - Definition of propulsion/aerodynamics interaction
General Aviation/Short Haul	o Principal focus for research - Minimize requirements for pilot to communicate (talk) - Make future IFR flight easy as today's VFR flight o Specific research areas include: - Integrated flight and propulsion controls - System for navigation - guidance to remote sites (GPS?) - Information display requirements

Team	Observations/Recommendations
General Aviation/Short Haul (Continued)	o NASA Role - Management of overall programs plus in-house efforts - Demonstrator programs encouraged - More workshops/conferences for technology exchange
High Performance	o Principal focus for research - 1979 to 1984 - Digital-fly-by-wire multimode, direct lift, direct side force concepts - 1984 to 1990 - Advanced computers (optical) for improved reliability/ performance - 1990 to 2000 - More cost effective aircraft o Technology deficiencies include: - Date base for integration of aircraft systems - Software technology - validation and failure analysis - Crew station - controllers and displays o NASA's Role - Research and feasibility demonstration - Compliment DOD activities
Flight Path Management	o Most important research efforts for NASA to sponsor: - Time referenced (4D Nav) ATC system with airspace/fuel efficient route/ time profiles - System concepts for integrated navigation/ flight control instrumentation systems for flight critical operation

Team	Observations/Recommendations
Flight Path Management (Continued)	o Research specifics include: - Low cost GPS but some concern with high EMI in urban areas - Weather avoidance and traffic information by data link
	o Unanimous concensus that NASA significant role in flight management research and underscores a close working relationship with FAA
Aircraft Controls	o Recommend projects emphasizing flight demonstration - Advanced flight control system which fully exploits DFBW "Flight Control 2000" - Demonstrate active controls using research A/C - AFTI, HIMAT, F8 - Distributed/fault and damage tolerant architectures - Electronic control configured propulsion - Fly-by-wire transport demonstration
	o NASA should do work when: - NASA facilities required - NASA flight research resources required - Involves exploratory research having low industry motivation
Crew Station	o Critical need for human factors research
	o Cockpit needs to be designed as a system
	o NASA has unique status in crew station technology - Personnel - Facilities

Team	Observations/Recommendations
Crew Station (Continued)	- Funding potential - "No ax to grind" o Research program should include: - Crew information requirements - Display development - Workload measurement - Impact of automation
Systems Interface/Integration	o Driving factors for research in CTOL areas: - Safety (flight crucial systems) - Aircraft performance improvements (fuel economy, active controls) o Begin to develop avionics system compatible with evolving ATC system and air traffic expected by 2000 o Best accomplished by cooperative NASA/University/Industry effort o Research specifics include: - Integrated, fault tolerant system architectures - Intersystem communication (optical data bus?) - Lightning effects on digital systems
Fundamental	o Recommend increased funding in areas - Control analysis and synthesis - Flying qualities (especially relaxed static stability)

Team	Observations/Recommendations
Fundamental (Continued)	- Device technology (especially high temperature electronics, digital sensors) - Prediction/modeling/identification (especially aeroelastic modeling, unsteady aerodynamics) o Improved NASA/Industry/University relations - Team arrangements - "Cross fertilization" - More NASA personnel in research especially new, young engineers)

Response to the two questionnaires on technology drives and research and technology requirements are summarized in tables II and III. These results are based on responses from about half the attendees.

During the discussion period in the final day, support was given for additional NASA research facilities, especially in the areas of human factors and avionics integration research. The group also urged a continuing dialog and technical information exchange between government, industry, and the universities.

TABLE I - WORKSHOP STRUCTURE

TEAM THEME	INDUSTRY/UNIVERSITY	GOVERNMENT
Vehicle Specific:		
Commercial Transport (CTOL)	Al F. Norwood, Boeing	William D. Mace, NASA
V/STOL	Jack B. Leonard, Grumman	Jack Franklin, NASA
Rotorcraft	Edmond Diamond, Sikorsky	Norman S. Johnson NASA
General Aviation and Short Haul	Jan Roskam, U. Kansas	Roger L. Winblade, NASA
High-Performance Aircraft	Chester Miller, McDonnel Douglas	Evard Flinn, AFFDL
Broadly Applicable:		
Flight-Path Management	Richard K. Smythe, MILCO	Colin Simpson, FAA
Aircraft Control Systems	Steve Osder, Sperry	Calvin R. Jarvis, NASA
Crew Station	Richard F. Gabriel, Douglas	Al B. Chambers, NASA
Interfacing and Integration	Rudy H. Cook, Lockheed	Billy L. Dove, NASA
Fundamental Technology	Edmund G. Rynaski, CALSPAN	Larry W. Taylor, NASA

TABLE II

AVIONICS & CONTROLS TECHNOLOGY DRIVERS

	CTOL	GENERAL AVIATION	ROTORCRAFT	V/STOL	HIGH PERFORMANCE	SUPERSONIC
HIGH SYSTEMS RELIABILITY	VI	VI	VI	VI	VI	VI
LOW COST SYSTEMS	CB	VI	VI	CB	CB	CB
HIGH DISPATCH RELIABILITY	VI	CB	CB	CB	CB	VI
LOW MAINTENANCE	VI	VI	VI	VI	CB	VI
IMPROVED OPERATIONAL SAFETY	VI	VI	VI	VI	VI	VI
REDUCED PILOT WORKLOAD	VI	VI	VI	VI	VI	VI
EFFICIENT FLIGHT PATHS	VI	CB	CB	VI	CB	VI
IMPROVED AIRCRAFT PERFORMANCE	VI	CB	CB	VI	VI	VI

VI - VERY IMPORTANT CB - CONDITIONAL BENEFIT

TABLE III

AVIONICS & CONTROLS R&T REQUIREMENTS

	RELIABILITY	LOW COST	DISPATCHABILITY	MAINTAINABILITY	OPERATIONAL SAFETY	PILOT WORKLOAD	EFFICIENT FLIGHT PATH	IMPROVED PERFORMANCE		
FLIGHT PATH MANAGEMENT	P	S	S	S	P	P	P	P		
AIRCRAFT CONTROL SYSTEMS	P	S	P	P	P	P	S	S		
CREW STATION	P	S	S	S	P	P	P	P		
INTERFACING & INTEGRATION	P	P	P	P	P	P	S	S		
FUNDAMENTAL	P	P	S	S	P	P	P	P		

P - PRIMARY

S - SECONDARY

APPENDIX A

ACRONYMS AND ABBREVIATIONS

ACARS	automatic communication and reporting system
A/D	analog to digital
AFCS	automatic flight-control system
AFFDL	Air Force Flight Dynamics Laboratory
AFTI	advanced fighter technology integration
AOA	angle of attack
ARCS	advanced reconfigured computer system
ARINC	Aeronautical Radio Incorporated
ATC	air traffic control
ATCRBS	air traffic control radio beacon system
BCAS	beacon-based collision avoidance
CCV	control configured vehicle
CDTI	cockpit display of traffic information
CRT	cathode ray tube
CTOL	conventional take-off and landing
D/A	digital to analog
DABS	discrete address beacon system
D/L	data link
DLC	direct lift control
DOC	direct operating cost
DOD	Department of Defense
DOT	Department of Transportation
EMI	electro magnetic interference

EMP	electro magnetic protection
FAA	Federal Aviation Administration
FBL	fly by light
FBW	fly by wire
FCS	flight-control system
FLEXSTAB	computer program for flexible body stability analysis
FTMP	fault-tolerant multi-processor
GA	general aviation
GPS	global position system
HIMAT	highly maneuverable aircraft technology
IFR	instrument flight rules
MIL-F	military flying qualities requirements
MLS	microwave landing system
NACA	National Advisory Committee for Aeronautics
NASA	National Aeronautics and Space Administration
NASTRAN	NASA structural analysis (computer program)
NAVSTAR	navigation system using time and ranging
OEW	operational empty weight
PFCS	primary flight-control system
PIO	pilot induced oscillator
R&D	research and development
RNAV	area navigation
RPRV	remotely piloted research vehicle
SFC	specific fuel consumption
SIFT	software implemental fault tolerance

TDMA	time division multiple access
USAF	U.S. Air Force
VFR	visual flight rules
V/STOL	vertical/short take-off and landing

APPENDIX B

TEAM REPORTS

1. Team 1: Vehicle Specific Technology Working Session

2. Team Theme: Commercial Transport (CTOL)

3. Team Members:

Al F. Norwood (cochairman), Boeing Commercial Airplane Company

William D. Mace (cochairman), NASA Langley Research Center

Larry Brock, Charles Stark Draper Laboratory
T. L. Cronley, Lockheed Georgia Company
Jerome Freedman, ARINC Research Corporation
Richard F. Gabriel, Douglas Aircraft
Jim Longshore, Douglas Aircraft
J. M. McCarty, Lockheed Georgia Company
Thomas Morgan, Federal Aviation Administration
Allen Mulally, Boeing Commercial Airplane Company
Steve Osder, Sperry Flight Systems
John E. Reed, Federal Aviation Administration
Edmund G. Rynaski, CALSPAN Corporation
Joseph Schwind, Airline Pilots Association
Colin Simpson, Federal Aviation Administration
Kenneth J. Szalai, NASA Dryden Flight Research Center
George Terhune, Airline Pilots Association
Wesley K. Tervo, Pratt & Whitney Aircraft
Harold N. Tobie, Boeing Commercial Airplane Company
Thomas M. Walsh, NASA Langley Research Center
John Wensley, Stanford Research Institute International
John R. Zeller, NASA Lewis Research Center

4. Team Observations, Issues, and Recommendations:

The objective of the Commercial Transport (CTOL) team was to identify critical needs for improvements in CTOL avionics and flight control systems and recommend NASA programs that, in conjunction with normal industry activities, will enable those needs to be fulfilled.

For each time period, the team attempted to

(1) Establish measures of effectiveness (criteria) of the air-transport system and identify those sensitive to avionics and controls improvements

(2) Provide an assessment of today's system for reference

(3) Develop a potential list of research items

(4) Determine the payoff of the proposed research

(5) Determine the reasons if and why NASA should support the proposed research

The effectiveness measures of the air-transport system which are sensitive to avionics and controls improvements are

(1) Safety

(2) Economics (payload, fuel, DOC, etc.)

(3) Reliability (of schedule)

(4) Ecology (noise)

(5) Comfort

(6) Capacity (of the ATC system, which included frequency of flight)

The review of the safety measure centered on the analysis of data (fig. 1) which highlighted the number of accidents occurring in the final approach and landing phases (4 percent of the flight exposure time with over 80 percent of final approach and landing accidents) and in the cockpit crew area.

The potential economic benefits were examined with respect to the impact of an improvement on direct operating cost. Figure 2 depicts for currently operational systems the percent change in direct operating cost caused by a 5 percent change in the cost of avionics maintenance (line and shop) will cause less than a 0.03 percent change in DOC. As with avionics maintenance, a 5 percent change in price (economic life) or weight of avionics has small leverage on the DOC. On the other hand, a 5 percent reduction in flight time (e.g., due to delay reduction) will reduce DOC by 3 percent. Estimated fuel savings (fig. 3) achievable with an airplane having the capability of the NASA terminal configured vehicle was cited as a further example of the potential leverage of improved avionics and controls upon direct operating costs.

A list of research items was developed and discussed. (See table I.) The detail of the research items is not intended to indicate that the team considered, for example, "active controls" to be a more urgent item for NASA research than "systems integration." The team addressed active controls in the beginning of the meeting (in part because of the background and interests of the majority of the team members), but the members were unable to complete the discussion of the other items in the same depth. It was noted that the improvements in systems integration offered potential enhancement in safety, reliability (of schedule), and adherence to noise profiles, as well as in economics. It was also noted that the lightning research was perceived to consist of data collection from in-flight strikes and the development and validation of a model of electromagnetic (including all potentially deleterious frequencies) and pressure effects. Further research should consider impact (if any) of new structural material. The reasons why the team felt the government should conduct the proposed research are coded on each item of table I: M for magnitude of the task, R for unique government requirement or resource, L for a low industry motivation, and E for exploratory. Note also the time periods in which the work should be done, with the periods in which the results should be available being marked within parentheses. No marked time period implies that a continuous effort is foreseen.

From their discussions, the team reached the following conclusions:

NASA should conduct research programs by giving highest priority to those activities in which the payoff is the greatest (e.g., in safety and economics) and where the NASA (or Government) role is unique.

Payoff is very high in areas of flight-path management and crew systems integration (safety and performance with fuel savings), delay reduction (ATC/4-D guidance), and airplane configuration (external, leading to drag and weight reductions). Payoff is relatively low however in reducing the costs of avionics and maintenance and in increasing the economic life (or decreasing the price) of the avionics and controls. (See figs. 2 and 3.) Therefore, avionics (even though relatively expensive) could be added to the aircraft if they provide operational configuration (or safety) advantages.

Without government sponsorship, industry will not be motivated to work on problems associated with time-referenced (4-D guidance) air-traffic control systems, nor will industry work on flight critical active controls because of their high program risk. Therefore, the highest priority should be given to NASA Research which concerns the following three items:

(1) Flight critical active controls

(2) ATC/4-D guidance

(3) Systems integration

This recommendation is rationalized on the basis that the first two items combine both a high payoff and a unique need for NASA research. The third item, which should be primarily concerned with "cockpit level" integration concepts, is rationalized on the basis of high payoff in safety improvements. Research on lightning and all-weather (atmospheric) sensors is considered important (especially to safety improvements) but is not as high a prioirty as the above three items.

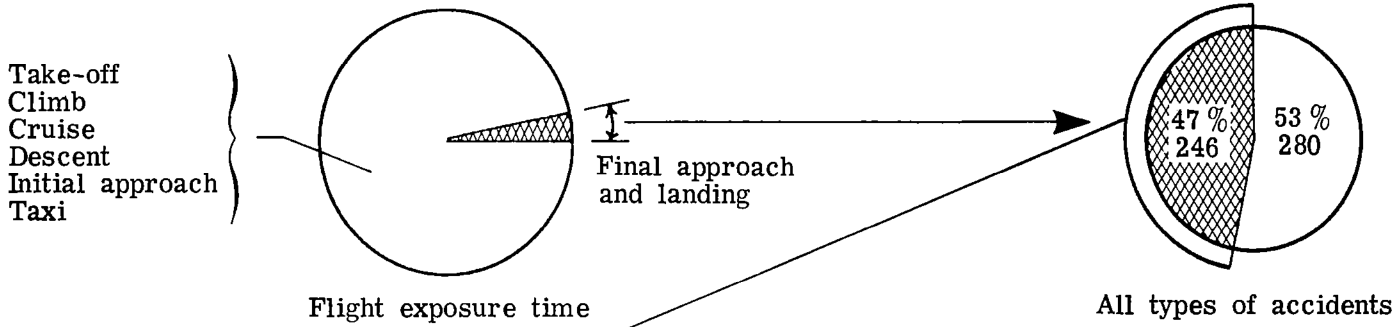
The team recommends that a strong liaison should be maintained between the avionics and controls research programs and the NASA human-factors research programs. Unless there is effective interaction, the avionics and control programs will, of necessity, repeat work in human-factors programs. A similar relationship exists with the FAA in regard to the evaluation of the time-referenced ATC system. However, again in the absence of credible scenarios from the FAA to support the avionics and controls developments, NASA should make their own projections with the best data from industry and government. No conclusions were reached on the specific facilities required. It was accepted that NASA should conduct theoretical and experimental research and that their facilities would be justified on the basis of their requirements to do that research.

TABLE I.- RECOMMENDED RESEARCH ITEMS

Time period (a)	Research item	Effectiveness measures						Reason for NASA to support research (b)
		Safety	Economics	Reliability	Noise	Comfort	Capacity	
	Active Controls:		X					
	Aeroelastic control							
1,(2),(3)	- Modeling							M, R, E
1,(2),(3)	- Criteria							L, R
1,(2),(3)	- Benefits							E
1,(2),(3)	- Control law synthesis							E
1,(2),(3)	- Flight critical implementation							M, L, E
	Static stability relaxation							
1,(2),(3)	- Handling quality criteria							R, M
1,(2),(3)	- Implementation							M
(1),2,3	Lightning	X						M, L
1,2,3	Time-Based ATC System Operation: Procedures (fuel; capacity sensitivity) Functions		X				X	R, L, M, E
1,2,3	Systems Integration (controls; displays; processors; crew functions; man/machine interface)	X	X	X	X			R, M, E
1,2,3	Digital Avionics (fault-tolerant concepts; flight critical systems		X					M, E
(1)	All-Weather Operations (weather — atmospheric — sensors)	X		X		X		E

a.
1 1979 - 1984
2 1984 - 1990
3 1990 - 2000

b.
M magnitude of task
R unique resource
L low industry motivation
E exploratory



Probable cause factor	Number of accidents	Percent of 221 accidents with known causes
Cockpit crew	180	81.4%
Airplane	20	9.1%
Maintenance	6	2.7%
Weather	7	3.2%
Airport/ATC	6	2.7%
Other	2	0.9%
Unknown or awaiting reports	25	
Total	246	

Figure 1.- Critical time and probable cause factors (47 percent of all accidents (246 out of 526) occur during 4 percent of the flight exposure time).

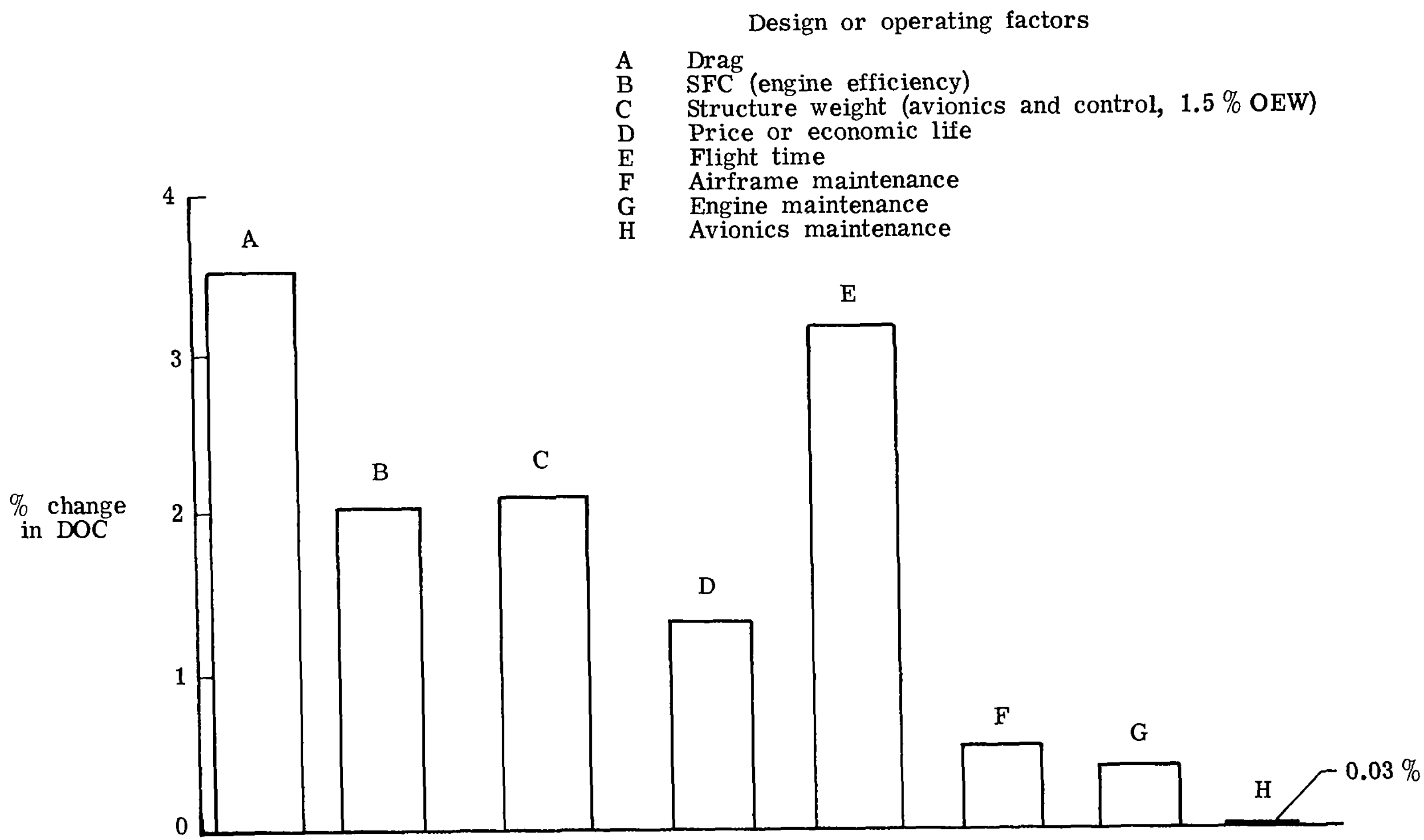


Figure 2.- Percent change in direct operating cost (DOC) caused by 5 percent change in various design or operating factors.

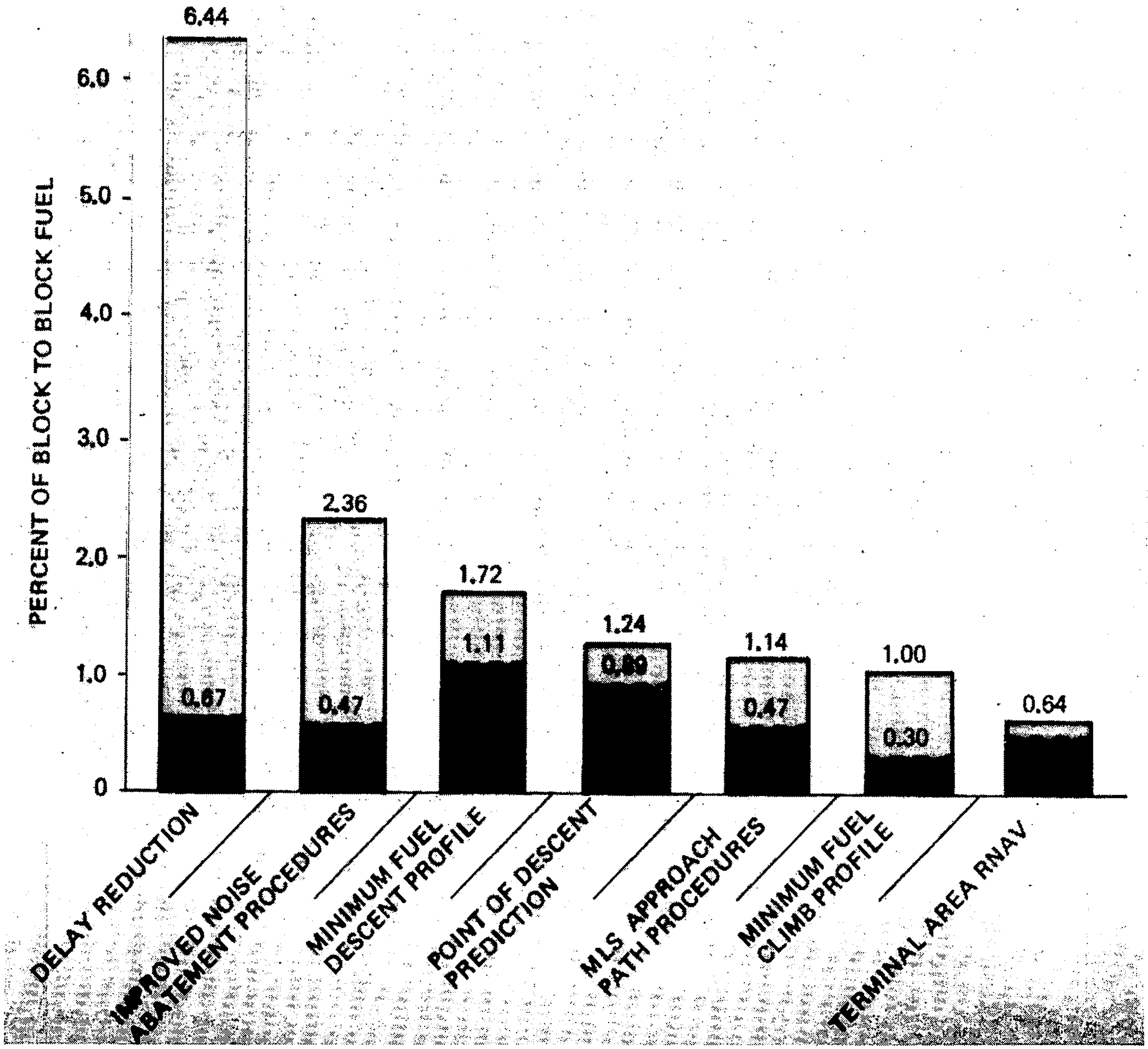


Figure 3.- Estimated fuel savings.

1. Team 2: Vehicle Specific Technology Working Session

2. Team Theme: V/STOL

3. Team Members:

Jack B. Leonard (cochairman), Grumman Aerospace Corporation

Jack Franklin (cochairman), NASA Ames Research Center

Billy L. Dove, NASA Langley Research Center
Donald C. Fraser, Charles Stark Draper Laboratory
William Herring, Honeywell, Inc.
J. A. Hauge, Honeywell, Inc.
Fred M. Krachmalnick, McDonnell Douglas Corporation
Craig B. Kunkle, Pratt & Whitney Aircraft
Gene E. Lyman, NASA Headquarters
M. F. Marx, General Electric Company
Joe Redan, Avionics Products Company
Duane B. Schoelerman, Vought Corporation
Richard K. Smythe, MILCO International, Inc.
Wallace E. Vander Velde, Massachusetts Institute of Technology
Robert P. Wanger, General Electric Company

4. Team Observations, Issues, and Recommendations:

The V/STOL team addressed the three questions posed by NASA. The consensus of the team is presented with minority viewpoints on some critical issues.

Principal Focus for Research

For the 1979-84 time period, the team recommended a program to establish generic design guidelines and a credible data base to provide the background, information, and recommendations of content to be used in the preparation of specifications. The program should address performance and handling qualities requirements, representative mission vehicle and operational requirements, and subsystem definition and requirements. It is not recommended that NASA prepare the specifications. The workshop team felt that this should be done by the procuring agency.

The research recommended in the time frame 1985 and following is a program to improve system reliability and maintainability. The entire team was dedicated to the basic program defined, but the subgoals and means of achieving the goal was controversial. The consensus was that the keynote was simplicity and reduction in the parts count. Others felt that a goal should be a reduction in the effective redundancy, with a near-term goal of a three-channel system and a long-term (1990-2000) goal of a two-channel system. The term "effective redundancy" is used to allow for consideration of skewed sensors, analytic redundancy, and sophisticated redundancy management techniques.

A third principal area recommended for on-going research is the exploration of new missions and V/STOL vehicle configurations.

Principal Research Areas To Be Addressed

The principal research areas recommended for study in the time periods defined are

(1) Establish design guidelines and data base

(2) Investigate techniques for reliability and maintainability improvement

(3) Technology support programs

V/STOL flight-control systems overlap into, and are mutually dependent upon, other vehicle systems. For instance, flight-path control demands sensors that support the concept and are dedicated to the presentation of cues and information quite different from those required in the past. Since the control system is controlling attitude independent of pilot inputs, attitude information is not only useless to the pilot but is probably dangerous because of the confusion it would create. The following systems must be included in the studies:

(1) Flight-control system

(2) Propulsion system

(3) Displays

(4) Navigation and guidance systems

(5) Crew stations

The study to improve reliability and maintainability should include consideration for improved fault tolerance, simpler systems with a lower parts count, reduced effective redundancy, and high temperature electronics. There was considerable exchange of opinions within the team regarding the sometimes conflicting goals of improved fault tolerance, reduced redundancy, and improved reliability. For instance, it was pointed out that an ultra-high reliability system requires less redundancy and perhaps eliminates the need for consideration of fault tolerance. In the extreme case, there is no need to consider fault tolerance if there are no failures.

The technology development programs recommended for NASA support are:

- Suitable sensors
- Reliability, redundancy requirements
- Mux bus transmission requirements
- Blending of force and moment producing elements
- Integrated flight-control, propulsion, command display systems
- Aerodynamic and propulsion interactions in transition and hover
- All-weather landing capability
- Curved-path approach for vertical landings
- High-temperature electronics
- Analytical techniques
- Flight-path control and velocity control concepts

The all-weather landing, curved-path approach, and flight-path control studies are interrelated. Since there was some confusion regarding flight-path control, it was pointed out that the pilot's objective is determination and control of flight path and that his normal tasks are sensing of actual flight path, estimating the attitude change required to achieve the desired path, and estimating the final attitude required to stay on the flight path. Direct flight-path control eliminates the two estimation processes, reduces the work load, and allows the pilot to fly the desired flight path directly. The concept requires advanced technology sensors, fly-by-wire FCS and integrated FCS/displays, both dedicated to the flight-path control concept.

There was considerable dialog on the desirability of improved analytical techniques and the use of direct digital design. The consensus was that direct digital design is beneficial and needs further investigation and development.

Sophisticated V/STOL flight-control systems in the past were based on the traditional angular rate and attitude feedbacks required for stability and control augmentation functions. Availability of three-axis inertial velocity information, low airspeed magnitude and direction, and side-force control capability in future V/STOL aircraft will enable formulation of new concepts in flight control to enhance V/STOL control precision and flight safety. Effort should be directed towards development of these sensor concepts and the associated control laws. Sensor technology requirements, levels of redundancy, and signal quality should be identified, and criteria for design should be established.

Research and development effort is currently being expended to develop accurate and reliable low-airspeed sensors for applications in V/STOL aircraft, with some promising concepts reaching the flight-test stage. The major problem, however, is with installation of such equipment on an aircraft which at low speeds is usually enveloped in propulsion generated or induced airflows. The need for further research and development in this area is readily evident.

Research and development for integrated redundant inertial velocity and low-airspeed sensors and their implementation in V/STOL aircraft flight-control systems is required to provide all-weather operational capability. Implementation of propulsive side-force control will further enhance control precision during the difficult task of a vertical landing in small space areas in the presence of crosswinds and air turbulence. The V/STOL control concepts based on the use of these sensors and side-force control are well suited for piloted evaluations using six-degree-of-freedom motion base simulators. Research and development on criteria for V/STOL aircraft control power requirements is needed because of the impact of these requirements on airframe weight, size, and cost.

Outer loop control is necessary to provide guidance functions and pilot assistance in reducing workload to within acceptable levels. Research and development is needed in the area of range and range-rate sensors, flight-director control laws, command display functions, display formats, and display devices. Development of various levels of outer-loop automatic control designed to function reliably with available equipment aboard the aircraft and on the ground is also required.

Role of NASA

It was recommended that NASA should support the following research efforts listed in the approximate order of priority:

(1) Studies, manned simulation, and flight validation of all-weather landing capability

(2) Definition studies of reliability/redundancy requirements

(3) Studies of integrated flight-control, propulsion, command, display systems

(4) Development of

- Piloting techniques for curved-path approaches to landing
- Flight-director command functions
- Display methods and formats
- Research and development of redundant inertial velocity and low-airspeed sensors
- Criteria for control power requirements
- High-temperature electronics
- Analytical techniques

(5) Studies to determine jet-induced interference effects

- Prediction techniques for hover and transition aerodynamics in ground effect
- Engine performance and re-injection
- "Suck down" and "fountain" effects

The consensus of the team was that general V/STOL research is important, that NASA is the agency best able to conduct such research, and that service funding is often subject to policy and funding changes. It was recommended that NASA assume a more traditional role in V/STOL research and that NASA expand its V/STOL avionic and flight-control programs to include as many of the recommended studies as possible.

Technology Dissemination

The team was concerned about the dissemination of information resulting from NASA programs. The conventional publications are good and well distributed, but few people, and the proper people, do not take advantage of them. The team agreed that seminars, workshops, and interchange of personnel between NASA and industry were the more effective means of disseminating information. It is recommended that more workshops, seminars, and symposiums be held and that on major programs there be an exchange of personnel between prime contractors and NASA.

1. Team 3: Vehicle Specific Technology Working Session

2. Team Theme: Rotorcraft

3. Team Members:

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4. Team Observations, Issues, and Recommendations:

A research program in avionics and flight controls for rotorcraft should focus on technology that increases rotorcraft performance (range, payload, etc.), safety, reliability, and maintainability; but it should be recognized that application of technology advances to achieve these must be cost effective. A recommended focus for 1985 is to improve, through application of avionics and flight-control technology, the ability of the pilot to control the rotorcraft and to achieve an IFR operational capability for rotorcraft. In the same time period, work should be initiated on the application of FBW/FBL technology to derive criteria for a redundant systems architecture for rotorcraft which gives increased performance with reduced vibration and noise and permits the use of active controls for design efficiency. The recommended focus for 1985 to 2000 and beyond is the definition of criteria for integrated system architecture for rotorcraft which is fault tolerant, integrates redundancy management, flight control, flight-path control, and propulsion control, and provides a quantum jump in performance and reliability. Line replacable units and automatic diagnostics are advocated for maintainability.

In order to achieve the focus in the three time periods, a continuing program must be carried out to advance technology in avionics and flight control for rotorcraft. This program is divided into the following four disciplines:

(1) Flight-path management

(2) Aircraft control systems

(3) Crew station

(4) Interfacing and integration

Flight-Path Management

Research is needed to establish design and operational criteria for rotorcraft IFR operations. This includes all operations from take-off to landing in congested areas and at remote sites (both prepared and unprepared).

Digital computer technology, which is advancing rapidly to provide increased capability at reduced cost, should be utilized, and algorithms and logic should be developed to provide improved flight-path control and improved fuel management. Mathematical models are needed to simulate the operational environment (particularly low-altitude turbulence, etc.) for rotorcraft.

Research is needed to define concepts for self-contained navigation (inertial, weather radar, etc.) for rotorcraft operations to remote sides; research is also needed to provide design criteria for actual hardware. These concepts should be investigated for operation into congested areas. For rotorcraft operation into remote sites, NAVSTAR/GPS should be investigated for use as a primary navigation aid. There is a need for a recording system for helicopter operations similar to that now being carried out for commercial transports. Also, a program should be initiated to derive sensing techniques that would prevent wire strikes by helicopters in civil operations which apply military technology where appropriate.

Research is needed to derive low-cost concepts for sensing information on rotorcraft control and guidance systems. Computational techniques should be explored to reduce the number and sophistication of the sensing elements. Strap-down inertial guidance concepts should be investigated to achieve redundancy with sensing elements rather than redundant platforms.

Research is needed to provide operational criteria and procedures for departing from any cruise condition and arriving at a hover at any desired position while traveling along an optimum flight path (fuel, noise, etc.) and arriving at an assigned time. Airspace requirements for this operation should be defined by taking into consideration the requirement to fly in congested areas to a helipad or to a remote site.

Aircraft Control Systems

Many rotorcraft accidents are caused by pilot error and highlight the need to improve helicopter flying qualities with application of avionics systems technology. This includes an emphases on preciseness of control in hover and low-speed conditions. Desperately needed is research to define a low-velocity omnidirectional airspeed sensor to inform the pilot of the aircraft situation relative to envelope constraints.

Improved pilot training can reduce rotorcraft accidents, and simulators are recommended as a means of achieving this. A program is needed to provide the technology which could result in the development of a low-cost simulator affordable to all operators of rotorcraft.

Research is needed to define the propulsion-aerodynamic interaction and to develop criteria for integration of rotorcraft propulsion and flight-control systems. Concepts are needed for using avionics and flight-control systems to improve the ride qualities of rotorcraft by improving its responses to gusts, reducing rotor vibration and noise, and expanding the operational envelope.

Criteria are needed to design control-system configurations which provide increased reliability through redundancy management. In addition, research is needed to derive a design criteria for high reliability actuators for use in digital control systems as a key element in increasing reliability.

Research is needed to exploit the feasibility of twin lift in which two or more helicopters are simultaneously used to transport an external load. Such a development would effectively increase the overall effectiveness of a given helicopter size and would be of use to both civil and military needs.

Research is needed to derive rotorcraft control-system configurations which meet the reliability requirements for active control of flight critical systems; research is needed to provide concepts for using active control of the tail rotor, main rotor, and/or aerodynamic control surfaces to achieve improved performance while reducing control-surface size and weight.

A program is needed to demonstrate the feasibility and benefits of active control for rotorcraft, including a demonstration which meets the reliability requirements of fly-by-wire systems. Research is needed to define criteria for redundant system architecture for rotorcraft control systems. This includes consideration of fault detection, isolation, and repair, as well as redundancy management.

Crew-Station Technology

Research is needed to relieve the over-crowded condition of instruments in rotorcraft cockpits. Initially, consideration should be given to combining information from several instruments into one integrated display wherever feasible. In the long term, research is needed to define a cockpit in which information which was formerly presented to the pilot in a series of instruments is integrated into one or more electronic displays. This would include not only information on aircraft situations but also information on pilot action to be taken in emergency situations.

Research is needed to optimize the controls for manual tasks to reduce pilot workload. For example, with appropriate control logic, a remote control stick could be used. Research is needed to define a head-up display for helicopter operations. The display should be flexible enough to allow the pilot freedom of head movement for precision hover operations.

In the far term, research is needed to derive criteria for a cockpit which optimizes information flow to the pilot and his control of the rotorcraft. It is envisioned that his cockpit would have all electronic displays with functions selected and displayed automatically as required and called by the pilot. The use of voice commands should be considered, as well as auditory and optical displays.

Interfacing and Integration

In interfacing systems with data bus technology, research will be needed for rotorcraft on the effects of EMI, static discharge, and multiplexing. These factors, as well as the weight and cost requirements, are unique for the short transmission lines.

Research is needed to define criteria for the system architecture for integrating all of the avionics systems onboard rotorcraft. This includes systems for guidance and navigation, flight control, propulsion control, rotor control, redundancy management, fault detection, and isolation and integrated pilot command and display.

1. Team 4: Vehicle Specific Technology Working Session

2. Team Theme: General Aviation and Short Haul

3. Team Members:

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4. Team Observations, Issues, and Recommendations:

The following is the General Aviation and Short Haul team response to the three NASA questions. (It should be noted that in the team recommendations "develop" means to develop technology. Also, activities related to the crew station will involve a significant amount of human-factors research. Finally, the research areas listed are considered as high risk but have high potential payoff in general-aviation and short-haul applications.)

Principal Focus for Research

The team observed that today's general-aviation and short-haul pilots are required to aviate, navigate, and communicate. The team felt that an unnecessary burden on the pilot is the talking and listening associated with communication required during mostly enroute flight and the frequently required switching of frequencies. The team also felt that ideally IFR flight should be as easy to conduct as VFR flight.

Principal focus for research is therefore suggested in terms of the two following broad research objectives:

(1) Minimize or eliminate as much as possible the requirement for communication (talk).

(2) Allow conduct of IFR flight in the future to be as easy as VFR flight is today.

These objectives should be achieved as soon as possible in the 1984-90 time slot. The team felt that such objectives cannot be realistically reached before 1984 and would be undesirably late if reached beyond 1990.

Technology Deficiencies To Be Addressed

The two principal research areas to be addressed are:

(1) Pilot + PFCS + Displays

(2) Pilot + AFCS + Displays

In both areas, reliability and cost maintainability are important considerations. Also, the display activity should focus on careful selection of information for the pilot to achieve easier single pilot operation.

Pilot + PFCS + Displays.- The technology deficiencies in the first research area are listed as follows:

(1) Handling qualities research: Define

- Level 1
- Level 2
- Level 3

as function of failure state, more or less like MIL-F-8785B. This is needed so that aircraft and systems designers can work with the specifications.

(2) Systems research: Identify best types of PFCS for the time period

- 1984 to 1990
- 1990 to 2000

(3) Advanced (low-cost) sensor packages for sensing

- Attitude
- Altitude
- Speed
- Acceleration

on a modular basis and with plug-in and self-check capability.

(4) Low-cost parameter identification package to establish math model of airplane (also needed for Pilot + AFCS + Displays).

Pilot + AFCS + Displays.- The technology deficiencies in the second research area are listed as follows:

(1) Define type and content of primary and secondary information needed by pilot in flight.

(2) Develop best type (dedicated!) display(s) for primary information.

(3) Develop time shared (prompting) display(s) for secondary information.

(4) Develop autocheck (Go/No-Go) display(s).

(5) Develop "Now-Here" weather information available on demand by pilot.

(6) Develop "Where" display for

- Altitude
- Terrain
- Flight path and separation information

Other Considerations.- The research in both areas should be focused separately on the four airplane categories:

- Single engine and light twins
- Heavy twins, business props, and jets
- Short haul
- Agricultural and other special purpose

Note that, in particular, the first two categories suffer from lack of cockpit real estate. All important for each category is reduction of pilot workload!

The team recommended the need for specific systems research in the 1979-90 time frame as follows:

(1) Systems architectural research and development (busing)

(2) Approach plate recall system

(3) Collision avoidance plus recommended pilot action system

(4) System to allow (pilot or automatic) following of geometric beam GPS (no field-based systems)

(5) Integrated flight and propulsion controls

(6) Monitoring systems

- Associated sensors
- Associated displays
- Associated warnings

(7) Functional standardization in cockpit design

(8) Human factors

(9) Packaging of avionics

(10) Avionics testing techniques

(11) Lighter and smaller power generation systems through the use of

- Samarium cobalt (or similar) technology
- Electronic commutation plus regulation

(12) Circuit protection plus switching systems

In these twelve research areas, attention should be given to:

- Reliability
- Maintainability
- Cost
- Information displayed to the pilot

Role of NASA in Research

The team made the following recommendations:

(1) NASA should have management of overall programs plus significant in-house efforts in most of the areas listed.

(2) Research and development programs should continue in which NASA, universities, industry, and the user coordinate efforts.

(3) Demonstrator (research integration) programs are encouraged.

(4) More workshops and NASA conferences are needed to help spread the research results faster.

1. Team 5: Vehicle Specific Technology Working Session

2. Team Theme: High-Performance Aircraft

3. Team Members:

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John Kishel, Teledyne Systems Company
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4. Team Observation, Issues, and Recommendations:

The High-Performance Aircraft team considered the three questions:

(1) What should be the principal focus of research, (2) what are the technology deficiencies, and (3) what should be the role of NASA in the technological deficient areas.

Principal Focus

In the 1979-84 time period, the focus should be on the currently emerging technologies such as the digital fly-by-wire, multimode direct lift-direct side-force concepts, a feasibility demonstration of microwave landing system (MLS), etc. In the more distant 1984-90 time period, the focus should be on the high-performance aircraft with emphasis on new sensors, simplified systems with possibly two-channel redundancy, advanced computer technology (optical) to achieve improved reliability, and control techniques that enable high maneuverability and other high-performance objectives. In the 1990-2000 time period, advanced techniques should strive for more cost-effective aircraft applying newly developed analytical tools to obtain confident configuration design of the aircraft and its control system.

Technology Deficiencies

The data base is not adequate to proceed with the quantitative integration of the pilot with the aircraft system. Additional information is needed in the areas of

- Man-machine communications and display

- Optimum control laws

- Analytical design tools for the crew station

The following research tools need to be improved:

(1) Simulation for criteria development, for example, certification criteria by the FAA and failure modes and effects analysis. In addition, better techniques are needed for control-system modeling and verification.

(2) Flight testing, especially in the area of generalized variable stability work. A new variable stability fighter airplane is needed to replace the NT33A. Flight test methods (quantitative) need to be defined for task oriented testing.

(3) Control system analyses, by developing criteria for reduced order models.

In the area of software technology, research is needed in validation and analysis techniques, standardization, and failure analysis. As a result of the new technology in microprocessors, the trade-off between a central versus distributed processing should be studied. Research is needed on solid-state electronics for use in a high-temperature vibration environment. Clock technology needs improvement to avoid long warm-up-time; the use of lasers is a possibility. Research is required on integrated communications-navigations systems. More reliable digital avionics are required for fly-by-wire applications. Additional research is needed in computational aerodynamics for application to the design of control configured vehicle (CCV) flight-control systems.

Research in flying qualities/flight dynamics should be focused on

(1) Task oriented criteria (as a function of specific tasks and possibly as a function of control mode)

(2) High angle-of-attack departure prevention

(3) Criteria for relaxed static stability design (especially limiting conditions)

(4) Display and controller effects.

In the control-system hardware area, the emphasis should be placed on

(1) Criteria for microprocessor system architecture for dispersed and reconfigureable concepts

(2) Criteria for aeroelastic effects

(3) Criteria to accommodate an all-electric aircraft

(4) Criteria for electrical hazard protection, especially for composite structures

(5) Failure transients associated with advanced sensors, sensor skewing, and dispersion concepts.

Research is needed in the following areas:

(1) Crew station, including controllers and displays with emphasis on

- the pilot as a mission manager

- criteria for control/display of decoupled six degrees of freedom.

(2) Studies of an integrated control system including

- combining sensor information from other systems

- criteria for the use of vectored thrust as a moment producer

- criteria for direct force control as a function of task

- criteria for vectored thrust in combat.

(3) Development of reliable and redundant angle-of-attack and sideslip sensors. (This area is considered very important).

(4) Development of a configuration data base for designing optimum direct lift and direct side-force control concepts.

(5) Development of a high angle-of-attack data base for confident post stall control design and validation of analytical high angle-of-attack data.

(6) Validation of direct digital design techniques by simulation and flight.

Role of NASA

It is believed that the role of NASA in the technology deficient areas should involve the following:

(1) Basic research.

(2) Feasibility demonstrations.

(3) Development of component technology including sensors.

(4) Specific efforts to capitalize on advances in electronics to develop better data instrumentation of ground and flight tests.

(5) Complementary programs with the Department of Defense - with NASA emphasizing basic disciplinary research and DOD being concerned with integration, for example, the advanced fighter technology integration (AFTI) program. An exception is when NASA has an existing facility and/or test capability, for example, early Remotely Piloted Research Vehicle (RPRV) testing.

(6) Development of a data base for handling qualities and aeronautical design data, including advanced computational methods, etc.

1. Team 6: Broadly Applicable Technology Working Session

2. Team Theme: Flight-Path Management

3. Team Members:

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4. Team Observations, Issues, and Recommendations:

The Flight-Path Management team summarized its recommendations in the following list of topics.

Priority Research for Sponsorship

The Flight-Path Management team recommended NASA sponsorship of two candidates for avionics research which would be most beneficial to the national aviation system within the next five years.

Candidate 1.- The first candidate is a time-referenced (4-D NAV) ATC system with airspace/fuel-efficient, route time profiles. This candidate addresses the key problem of increasing the ATC capacity and, at the same time, of making adequate free airspace available to other users, such as rotorcraft and general aviation which do not have the need for additional ATC capacity. A key avionic deficiency identified for this candidate is a reliable, low-cost, accurate, position-fixing technique for general aviation in the high-density ATC areas.

Candidate 2.- The second candidate is the development of system concepts for integrated-navigation flight-control instrumentation systems with adequate reliability for flight critical operation, including development of testing and validation concepts. This effort includes development of satisfactory position update methods and emphasizes the need to utilize redundancy and fault-tolerant concepts necessary during flight critical operations.

Focus of Research in Navigation and Guidance

The team felt that it was important that NASA and its contractors understand the doctrines of emerging and future ATC techniques and their interactions with the requirements for avionics and controls. Furthermore, it was considered necessary to support the research in technologies required for the avionics to operate within the future ATC system. This research area emphasizes the terminal-area navigation phase of flight.

ATC Compatible Avionics.- The team recommended the development of a scenario for the interaction of commercial aviation, general aviation, and rotorcraft in ATC areas which would benefit the general economy; i.e., it would not discourage general aviation growth by being too costly or too onerous and it would not excessively penalize commercial aviation operations. Systems studies should be performed to help develop this plan; also, equipments or techniques should be identified or specified which would be used in implementing this plan. These could form the basis of "standards" promulgated to industry by the regulatory bodies. The thrust of the research in this area should be to develop and evaluate avionic systems concepts compatible with scenarios for commercial/general aviation/helicopter interaction in ATC areas beneficial to national economy.

Utilization of high-production commercial electronics.- The team believed a deficiency exists in not capitalizing upon technology developments occurring in commercial fields (automotive, TV, CB, etc.) which could be adapted to lead to low cost, reliable avionics for general aviation. The team did recognize the efforts of the NASA Ames Research Center in the general-aviation advanced avionics program in this area. However, the team felt that even more emphasis is required.

High-density-area navigation receivers.- The team recommended that NASA develop technology/experimental data base on near-future navigation receivers to aid in planning and developing ATC system (examine useability of GPS in high-density urban areas with the high EMI). The team had a concern that because of the low signal level of GPS and the high degree of unwanted L-band radiation in urban areas that an analysis of GPS vulnerability is warranted.

Low-cost GPS receivers.- Even though the team was concerned with the possible EMI threat to GPS in urban areas, the feeling was strong that NASA should stimulate development of a low-cost GPS receiver for civil users.

4-D Guidance.- The time-referenced ATC recommended for priority research support in the preceding section requires the following supporting research elements:

- Algorithms for the ground and airborne elements of the ATC system
- Study to establish the data link requirements
- Establishment of airborne avionic element requirements, including sensors and display types (The requirement for CDTI is cited as an example.)

Mixed vehicle operation.- A study should be made of 4-D guidance for mixed vehicle operations, including the integration of the guidance techniques with the ATC system.

Fuel-efficient approach and landing.- Development of 4-D fuel efficient approach and landing techniques should be made for V/STOL with special emphasis on defining the airborne and ground-based sensor needs.

Remote-site guidance techniques.- The team would encourage continued FAA and NASA involvement in the sponsorship of guidance techniques to remote sites, such as oil rigs, and guidance of rotorcraft to disaster areas. For example, a significant public-safety problem arises in the case of traffic accidents on traffic clogged freeways which prevent ambulances from access to the accident site. An accurate rotorcraft guidance system to the accident site is an example application cited by the team.

Navigation and guidance blunders.- The team felt that as the complexity of navigation and guidance systems increases in response to the growth in functional requirements, an important issue is the study of human factors relevant to such systems to avoid serious blunders in navigation. Consequently, the team recommended that human-factors studies should be initiated to examine techniques for the purpose of reducing blunders, particularly in the environment of multifunction-mode selection systems such as the multilevel menu selection techniques being proposed and implemented in avionics systems.

Air-Traffic-Control Capacity Increase

Demonstration program for mix of equipment and aircraft.- The team perceived that the emerging ATC system would result in aircraft with varying types of airborne equipment, such as both the ATCRBS and DABS aircraft with and without BCAS and 4-D navigation equipment having varying degrees of capability and accuracy. Consequently, the team recommended that NASA should sponsor a demonstration program which would examine the implications of equipment mix as well as aircraft type mix, all operating in the emerging ATC environment.

Closely spaced parallel runways.- The team observed that the microwave landing system (MLS), coupled with the emerging ATC environment, may permit increase in capacity through the use of closely spaced parallel runway operation. The team recommended that NASA should initiate studies to determine the interaction between MLS and the ATC system in closely spaced runway operations.

IFR Operations Like VFR. The team felt that the ATC service for VFR aircraft should be expanded. The general-aviation representatives on the panel emphasized the potential benefits in ATC capacity expansion if techniques and avionics equipments would permit the conduct of IFR flight in nondense sectors of the airspace in a manner emulating the freedom of routing characteristic of VFR flight. NASA should sponsor studies to determine the avionic requirements to permit "VFR-like" IFR flight, including the equipment characteristics and the degree of collision protection required.

Weather Avoidance

The team felt there is an important requirement for the real-time exchange of current flight critical weather conditions, such as the region of icing conditions, thunderstorm cell locations, and the existence of severe wind-shear conditions for aircraft landing and taking off. NASA should initiate a study to determine the data link requirements, the sources of weather data, and the cost effective means for dissemination of the real-time weather data.

Communications

The team felt that research on data link capacity requirements must be conducted for all data exchange functions, including cockpit display of traffic information (CDTI), weather data, ATC clearances and acknowledgements, and other flight relevant data exchanges. The team felt that such studies should emphasize the use of DABS data link capacity because DABS is the primary data link capability for the emerging ATC environment. However, the studies should also consider the possibility of using satellite data link and possibly even VHF data link (such as the ARINC ACARS D/L) to relieve channel capacity problems which may develop with the DABS system.

The team acknowledged the proposed TDMA data link but did not forsee the requirement for implementation in the 1979 - 1990 time period, provided DABS and the DABS channel capacity augmentation techniques suggested above prove adequate. The team expressed a concern regarding DABS data link capacity in such high-density ATC areas as the Los Angeles basin.

NASA Role in Flight-Path Management Technology Research

In its deliberations, the team recognized the significant degree of interaction between the aircraft flight-path management avionics and the national ATC system. This strong interaction imposes the requirements for close cooperation between NASA and the FAA in the establishment of research efforts to resolve problems and conflicts that result from this interaction. The fact that the team included representatives from both NASA and FAA, as well as the user groups, concerned industry representatives, and university researchers, indicated that this cooperation is taking place and working satisfactorily.

The team had a unanimous consensus that NASA has a significant role in sponsoring research in the flight-path management areas. Specifically, the team recommended that NASA provide funding and support to the flight-path management research areas identified by the team. The NASA support should continue to be a mix of contract and in-house work.

Information Dissemination

The team recommended an increase in the use of workshops and interactive conferences to disseminate the results of R&D to the interested parties in industry, Government, and universities. The team felt strongly that both in-house and contract research results should be distributed sooner than in the time now required to issue the formal, approved, final report. Specifically, the team felt that resurrecting the old NACA "MEMO" (orange sheet) should be considered by NASA management as a cost effective technique.

1. Team 7: Broadly Applicable Technology Working Session

2. Team Theme: Aircraft Control Systems

3. Team Members:

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4. Team Observations, Issues, and Recommendations:

The Aircraft Control Systems team acknowledged the profound possibilities for flight-control advances that can be derived from the new computer/electronic technologies. Fly-by-wire, control configured vehicles, active controls, and new system integration architectures offer improvements in performance/economics, safety, reliability, etc. Much of this progress is already taking place independently of NASA research efforts. However, most of the current efforts are geared toward near term applications. Therefore, the thrust of the team's deliberations and recommendations does not reiterate the many new technology possibilities but does attempt to define a constructive NASA participation. It was concluded that, in many of the flight-control areas, the theoretical/conceptual work has been done but the practicality or validity of the concepts has not been adequately demonstrated in realistic applications. In those areas where the theory or analytical tools need improvement, realistic flight research would also provide the desired advancement. Consequently, the team approached the recommendations to NASA from the standpoint of defining projects emphasizing flight-research demonstrations. The intent of these projects would be to provide a foundation about which the new analytical/synthesis tools, computer and system architectures, advanced vehicle/aerodynamic concepts, and testing/validation techniques could be evaluated and demonstrated.

In order to guide the recommendations, a perspective of the role shared by industry, universities, and NASA was established. The intent of this perspective was to help identify a rationale for NASA sponsorship. In general, the justification for NASA participation had to be its unique facility resources, flight-research capability, organization, and expertise which enables its sponsorship of research tasks having low industry motivation because of cost and capability in the way of facilities. The NASA capability required for the suggested research activity is primarily the existing and projected NASA simulation and flight-research resources. Other considerations which enter into scoping NASA programs must be the establishment of a clear state-of-the-art perspective being achieved in DOD programs and in the normal process of commercial transport systems development. NASA should avoid undertaking developments that duplicate the efforts provided by the competitive market place.

Five programs were defined by the team and are outlined in tables I to V. No priority is implied by the numbering. Each program has an objective which encompasses important issues associated with advanced flight control. Specific technology tasks which allow these objectives to be achieved are identified, and approximate time frames are suggested. All of these efforts culminate in flight demonstrations. It is these demonstrations which make the work significant; therefore, it is recommended that the program planning should avoid extensive hypothetical studies and move rapidly to evaluate concepts in realistic contexts. The recommended programs are envisioned as having major industry participation with appropriate support by universities and NASA management. In this regard, the team expressed some concern over the difficulty in achieving broad technology transfer, as opposed to the accrual of all the technical advantages by the major contractors. Also, there was some concern over the difficulty in assuring that demonstration efforts do not become excessively diverted toward the solution of narrow, specific problems — rather, generic problem areas should be addressed. No solutions were offered for these problems.

The recommended programs do not carry the universal endorsement of the team. There was some dissent or scepticism associated with each program. Also, the make-up of the team may not have been sufficiently representative of industry. The lack of representation by the major commercial-transport producers and the airlines is perhaps reflected in the military orientation of the active controls program and in the very ambitious recommendation of an operational transport aircraft fly-by-wire demonstration under NASA sponsorship. One final observation: In every discussion of fly-by-wire technology there are two recurring but related themes. First, there is the call for more flying systems in order to build confidence regarding safety. Second, there is the concern regarding survivability in a lightning strike encounter. Analytical and extrapolation derived conclusions do not satisfy the sceptics, and flight experiments that avoid lightning risks do not provide a satisfactory data base. Perhaps a full scale lightning test program should be considered employing a "hardened" fly-by-wire equipped aircraft. One approach suggested would be to expose the aircraft, with all systems operational, while on the ground, to an actual thunderstorm environment and attempt to excite an actual lightning "hit" through laser excitation or an extended lightning rod device. Such a test program would provide valuable data in allowing assessment of extrapolation test validity and system response to an actual strike.

TABLE I

PROGRAM 1 - FLIGHT CONTROL 2000

OBJECTIVE: DEVELOP AN ADVANCED AND INNOVATIVE FLIGHT CONTROL CONCEPT WHICH FULLY EXPLOITS DIGITAL FBW TECHNOLOGY

- o ABANDON TRADITIONAL FLIGHT CONTROLS WHICH RELATE CONTROLLER (STICK) TO CONTROL SURFACE OR ATTITUDE MANEUVERS
- o CONTROLLER COMMANDS MANEUVERS THROUGH SPACE ... FOR EXAMPLE, A DELTA VELOCITY CONTROL STICK WHICH COMMANDS THE VELOCITY COMPONENTS $\dot{X}$, $\dot{Z}$, AND SOME FORM OF $\dot{Y}$ (OR TURN RATE)
- o MULTIMODE FUNCTIONS OBTAINABLE BY ROTATING VELOCITY REFERENCE AXES IN CONTROL ALGORITHM
- o CONTROL CAN BE LARGELY UNIVERSAL FOR ALL AIRCRAFT
- o MAY PROVIDE BETTER SOLUTIONS TO HANDLING QUALITY PROBLEMS
- o PROVIDES INHERENT FLIGHT CONTROL/PROPULSION INTEGRATION
- o THE DEVELOPMENT EFFORT DEFINES TECHNOLOGY NEEDS IN SUCH AREAS AS COMPUTER HARDWARE AND SOFTWARE, SYSTEM ARCHITECTURES, FAULT TOLERANCE AND ANALYSIS/SYNTHESIS TOOLS

TABLE I.- CONTINUED

SHORT TERM TECHNOLOGY TASKS

o STUDY APPLICABILITY TO VARIOUS AIRCRAFT TYPES

... CONTEMPORARY AND FUTURE CTOL, V/STOL AND MILITARY VEHICLES

o CONTROLLER DESIGN CONCEPTS

... HUMAN FACTORS

... DEFINE CANDIDATE SOLUTIONS

... SIMULATOR EVALUATIONS

... DEVELOPMENTAL MODELS

... SELECT BEST CONCEPTS

o CONTROL SYSTEM SYNTHESIS

... DECOUPLING CONTROL LAWS

... VEHICLE RELATED MANEUVER BOUNDS

... ACTUATION REQUIREMENTS

... DEFINE PERFORMANCE CRITERIA

o DEFINE TEST VEHICLE PROGRAM

... USE SINGLE CHANNEL MECHANIZATIONS WITH CONVENTIONAL FLIGHT CONTROL BACK-UP

... DEFINE VEHICLE MODIFICATIONS FOR DLC AND/OR SFC MECHANIZATIONS

o TEST VEHICLE EVALUATIONS

o FBW TECHNOLOGY SUPPORT AS REQUIRED

... REDUNDANCY MANAGEMENT/FAULT TOLERANCE

... SOFTWARE/HARDWARE TESTING

... LIGHTNING SUSCEPTIBILITY EVALUATIONS

TABLE I.- CONCLUDED

LONG TERM TECHNOLOGY TASKS

MID 1980's	o	SIMULATOR EVALUATIONS USING ADVANCED VEHICLE CONCEPTS
		... V/STOL AIRCRAFT
		... FUEL EFFICIENT AERODYNAMIC CONCEPTS
LATE 1980's	o	SELECT ADVANCED RESEARCH FLIGHT VEHICLE
		... MECHANIZE FLIGHT CONTROL 2000 SYSTEM CONCEPT USING BEST AVAILABLE COMPUTER TECHNOLOGY/REDUNDANCY ARCHITECTURE/FAULT TOLERANT CONCEPTS
1990's	o	FLIGHT RESEARCH PROGRAM
		... CONTRIBUTE RESULTS TO INDUSTRY REGARDING:
		A) HANDLING QUALITY DEFINITION
		B) CONTROLLER CONCEPT
		C) SYNTHESIS TECHNIQUES
		D) TEST AND VALIDATION TECHNIQUES

TABLE II

PROGRAM 2 - ACTIVE CONTROL INVESTIGATION AND DEMONSTRATIONS

OBJECTIVE: DEMONSTRATE ACTIVE CONTROL TECHNOLOGY CAPABILITY AND DESIGN TECHNIQUES USING REPRESENTATIVE RESEARCH AIRCRAFT (AFTI, HIMAT, F-8

GENERAL:

- o DEMONSTRATE SYNTHESIS TECHNIQUES
- o DEFINE REALISTIC MECHANIZATION REQUIREMENTS
  - ... BANDWIDTH OF SENSORS AND ACTUATORS
  - ... COMPUTATION REQUIREMENTS
- o DEMONSTRATE/VERIFY EFFECTIVENESS
- o COMPARE THEORETICAL AND ACTUAL RESULTS AND IMPROVE MODELING TECHNIQUES FOR AEROELASTIC EFFECTS WITH UNSTEADY AERODYNAMICS

RESEARCH AREAS:

- o ACTIVE FLUTTER SUPPRESSION
- o RIDE QUALITIES IMPROVEMENT LOAD ALLEVIATION INCLUDING CRITERIA
- o CONTROLLABILITY AT HIGH ANGLE OF ATTACK FOR AIRCRAFT WITH RELAXED STATIC STABILITY
- o DEPARTURE CRITERIA FOR HIGHLY AUGMENTED AIRCRAFT
- o POST STALL CONTROL TECHNIQUES

} JOINT NASA DOD SPONSORSHIP

TABLE II.- CONCLUDED

TECHNOLOGY TASKS:

- o SUITABLE SENSORS (ANGLES OF ATTACK AND SIDESLIP)
- o CONTROL LAW DEVELOPMENT
- o AERODYNAMIC MODELING AT HIGH ANGLE OF ATTACK
- o AEROELASTIC/UNSTEADY AERODYNAMIC MODELING AND HIGH FREQUENCY SURFACE EFFECTIVENESS TECHNIQUES
- o HIGH BANDWIDTH ACTUATORS
- o ANALYTICAL PREDICTION OF DEPARTURES
- o POST STALL CONTROL TECHNIQUES

TIMING:

ANALYSES, STUDIES, VEHICLE SELECTION ... 1980-1982

MANNED SIMULATION PROGRAM ... 1982-1985

WIND TUNNEL, GROUND TESTS ... 1983-1985

FLIGHT TEST VALIDATION ... 1983-1990

TABLE III

PROGRAM 3 - ADVANCED FLIGHT CRITICAL SYSTEM ARCHITECTURES

OBJECTIVE: FLIGHT DEMONSTRATION OF ADVANCED, DISTRIBUTED/FAULT AND DAMAGE TOLERANCE SYSTEM ARCHITECTURES

- o SELECT CANDIDATE SCHEMES FROM WORK NOW UNDERWAY
- o PROTOTYPE SYSTEM DEVELOPMENT
- o HARDWARE/SOFTWARE VALIDATION TESTING
- o DEFINE FLIGHT VEHICLE AND AIRCRAFT MODIFICATION REQUIREMENTS ...
  F-8 POSSIBLE CANDIDATE
- o FLIGHT EVALUATION

TABLE IV

PROGRAM 4 - ELECTRONIC CONTROL CONFIGURED PROPULSION SYSTEM

OBJECTIVE: INVESTIGATE PROPULSION SYSTEM CONCEPTS WHICH EXPLOIT ELECTRONIC CONTROL CAPABILITIES

- o SUPERIOR FUEL EFFICIENCIES
- o LIFE CYCLE COST REDUCTIONS
- o OPERATIONAL ADAPTABILITY

SHORT TERM TECHNOLOGY TASKS:

- o EVALUATE ENGINE DESIGN PROCEDURES AND INVESTIGATE ALTERNATIVE CONCEPTS MADE POSSIBLE BY COMPUTER CONTROL
- o DEFINE PROPULSION/AIRCRAFT INTEGRATION AND UTILIZATION CONCEPTS WHICH EXPLOIT IMPROVED CAPABILITY
- o DEVELOP ADVANCED AIRCRAFT AND PROPULSION SYSTEM ... TEST VEHICLE

LONG TERM TECHNOLOGY TASKS:

- o SIMULATOR STUDIES TO QUANTIFY BENEFITS IN SELECTED APPLICATION AIRCRAFT
- o SYSTEM DEVELOPMENT
- o FLIGHT TEST

TABLE V

PROGRAM 5 - FLY-BY-WIRE TRANSPORT DEMONSTRATION

OBJECTIVE: DEVELOP CONFIDENCE IN THE CONCEPT OF DIGITAL FLY BY WIRE FOR TRANSPORT AIRCRAFT BY IMPLEMENTING AND TESTING A SYSTEM ON A CONTEMPORARY TRANSPORT

- o EVALUATE ENVIRONMENTAL SUSCEPTIBILITY
  - ... EMI, LIGHTNING ETC.
  - ... MISCELLANEOUS OTHER VULNERABILITIES
- o EVALUATE CREW/CONTROLS INTEGRATION
  - ... 2-INTERCONNECTED OR NONINTERCONNECTED CONTROL SIDE STICKS
- o ONE AXIS OPTION TO BOUND COSTS
- o DEFINE MAINTENANCE CONSIDERATIONS WHICH ARE UNIQUE TO FBW OPERATIONAL DEPLOYMENT

TECHNOLOGY TASKS:

- o STUDY FEASIBILITY CONSIDERING THE MODIFICATIONS REQUIRED FOR FAIL-OP, FAIL-OP ACTUATOR DEVELOPMENT AND INSTALLATION IN SELECTED VEHICLE
- o SELECT SYSTEM ARCHITECTURE
- o DEVELOPMENT
- o VALIDATION TESTING
- o FLIGHT TESTS

1. Team 8: Broadly Applicable Technology Working Session

2. Team Theme: Crew Station

3. Team Members:

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George Terhune, Airline Pilots Association

4. Team Observation, Issues, and Recommendations:

Principal Focus of Research

In the opinion of the Crew-Station team, human factors is an area which needs major emphasis. The majority of accidents have human error as, at least, a contributing factor. Automation may accentuate the problem since it may tend to emphasize the monitoring role for the crew which available research indicates man does poorly and is bored and unhappy while doing.

The current approach, because of the traditional hardware orientation of design teams, frequently results in the submerging of human-factors considerations.The major current and future issue is not how to mechanize, but what and why!

A major deficiency exists in terms of sufficiently relevant information. This deficiency is not inherent. Human-factors research simply needs to be emphasized. It seems incongruous to devote great effort to assuring the integrity of structure, weather, etc., but very little to crew issues when accident data indicate the vast majority of accidents are crew related. Gains in economy, efficiency, etc. resulting from aerodynamics, improved avionics, propulsion, and structure may not fully compensate for ineffective crew utilization.

In the judgment of the team, NASA has a unique potential for furthering human-factors knowledge. Reasons for this unique position include:

- An established reputation for technical competence

- An unbiased position with "no axe to grind"

- A cadre of qualified personnel

- Unequaled facilities

- Significant funding potential

- Relative freedom from the short-term market-place pressures which can facilitate the required dedication of staff to satisfying long-term research goals.

Role of NASA

The role of NASA was judged to be in the following areas: research, information assessment and dissemination, data bank for relevant information, support of facility definition, and facility resource. Descriptors of NASA involvement for each of these areas are provided in table 1.

Suggested Areas of Investigation

The following areas were viewed as being within NASA's purview and of high priority. Attempts to prioritize or schedule emphases were not successful since it was believed information and guidance in all areas are required now.

Definition of capabilities and limitations of human as operator. - Much of the existing information has been gathered in academic settings. Seldom can a designer turn to a handbook and obtain readily useful information. Little is known about performance trade-offs in applied settings. For example, the time required for a pilot to initiate action to abort a take-off has probably been underestimated because of lack of realistic data. Moreover, the effects of the interaction of relevant operational variables has been largely untested. Effects of fatigue, sleeplessness, and information processing-decision making methods and effects are poorly understood. Even up-to-date useful anthropometric data are lacking.

Human-error research is considered a subset of this topic. Frequency, types, and factors which may contribute to or mitigate human error are understood only at a very fundamental level, and available knowledge is difficult to apply in pratical design of equipment or operational procedures.

Crew role/function/composition guidelines.- The role of the crew has envolved without systematic consideration of man's inherent capabilities and limitations. Changes have occurred generally as a result of the tradition as modified by available technology. The recent advances in computer technology are likely to result in a major change in crew role. This role should be defined to match system requirements and human characteristics. Crew selection, training, and procedures, as well as hardware design, are greatly dependent on the role assigned to the crew. An additional change is the changes in mission such as the interaction with air-traffic control, all-weather landings, etc. A systematic program to help establish guidelines is needed. Certainly, the role is central to information requirements which, in turn, is central to avionics design.

Crew information requirements.- Avionics systems are defined partly by information requirements. Information requirements have not been systematically defined. As new requirements become recognized, the new information is "squeezed in". Current examples of this are the ground proximity warning system, windshear displays, and, possibly, the cockpit display of traffic information. The result is apt to be a nonoptimum integration of the new data with existing cockpit displays. It may be assumed that the incorporation of electronic display will help solve this problem since multimode, flexible formats will be under software control, but formatting the integrated displays may be more difficult than assumed. Moreover, some types of information are desirable today and are not incorporated; but had it been available, it could have resulted in fewer accidents. For example, improved take-off performance data to facilitate crew decision making before/at V1 (stall speed with aircraft in cruise configuration) could reduce the probability of aborted take-off accidents. Improved cockpit VFR landing cues may be required. Only if a comprehensive, systematic investigation is performed will cockpit displays encompass all of the information of value to the crew. Of course, these requirements must be specific to the mission/vehicle, but guidelines and methods could be developed and demonstrated to facilitate the manufactures and users for the specific application.

Crew procedures.- Each airline develops its own crew procedures for a specific aircraft. Some of these procedures differ significantly from other airlines. An example is first-officer callouts and functions during the approach. Another is the "quiet cockpit" during approach and landing and take-off which some airlines have incorporated to minimize distractions during these critical flight phases. A study is recommended to define crew-procedure issues and problems (including cabin crew during evacuation), define alternatives, and evaluate promising alternatives.

Workload measurement.- The ability to quantify workload, particularly mental workload, is essential in determining crew size, identifying equipment areas which need improvement, and evaluating alternative concepts in equipment and procedures. Current methods are inadequate. While some research is currently underway, the significance of this problem area, particularly for military aircraft, warrants intensive effort.

Impact of automation.- Automation is one of the key drivers of the emerging change in pilot role. To be effectively implemented, automation must be carefully designed to satisfy human characteristics. It has been demonstrated that some automated systems result in poorer overall performance than the system they replaced, at least in some military systems. Moreover, operation requiring pilot intervention in a degraded mode will be required for the foreseeable future. Key to the incorporation of automation is the allocation of functions between man and machine. The trade-offs need to be studied to provide realistic guidelines for the allocation of these functions.

Decision-making research.- Academic work has been performed in the area of decision making (e.g., signal-detection theory). The relevance of this work is somewhat limited. Orientation toward decisions representative of those required in man-machine systems is needed. One recent research paper, for example, pointed out the anecdotal evidence of the difficulty pilots have in an all-weather landing situation of reversing a decision (at decision height) to proceed with the landing, even if the condition deteriorated because of moving or nonhomogeneous for. A related area is the potential value of computer-aided decision making; most new aircraft will have processors on board which could be used to assist the decision process.

Improved methods and techniques.- NASA can be of great service to manufacturers and operators by developing improved analytical and test methods. An authoritative and comprehensive design guide for cockpit crew-station design, which recognizes and treats realistic design problems and recommends step-by-step techniques and procedures, would be of significant value. Improved math models, or other models of human performance or behavior for use in early analyses, would have particular merit. Development of improved validation methods and criteria would also be beneficial.

Information transfer.- Both input and output design characteristics need to be improved and defined. Many of these issues are already defined, but seldom have they been systematically and intensively evaluated at the conceptual level. A program in this area could result in very useful guidelines that would minimize duplicative efforts to a large degree. Specific issues include

Displays:

- Guidelines for application of visual and auditory displays
- Definition of required characteristics for each mode
- Guidelines for format development
- Multimode/transition definition
- Remote viewing systems (including stereo)
- System status displays
- Thresholds and parametric values for display characteristics (brightness, loudness, resolution, refresh rate, etc.)

Controls:

- Trades between yoke, center stick, side stick

- Isometric versus displacement

- Data entry-callup (dedicated keyboard versus programmable versus alternative methods such as voice actuated)

- Communication displays (synthetic speech)

- Status reporting/recording

Air-traffic control-system development.- The team believed that NASA should perform a research and evaluation service for the ATC system. No other agency seems to have the resources to perform the in-depth, systematic studies required for the development of a system of this size and complexity. For instance, FAA was viewed as being limited in terms of the research and development know-how and in need of NASA in-depth assistance.

Scheduling

Insufficient time was devoted to determining the emphases for the respective time frames. The team believed that all of the information would be immediately useful. No definition of criteria upon which to base priorities was achieved. Certainly, a list and weighting of such criteria was deemed an essential first step in scheduling.

Budgeting

It is believed that insufficient budget has been allocated in the past to achieve the level of effort required to satisfactorily resolve issues such as those outlined above. Unless human-factors issues are addressed with sufficient resources and dedication, advances in understanding and useful data will not be available in time to have a significant impact in the next generation of aircraft.

TABLE 1. - DESCRIPTORS OF NASA ROLE

- RESEARCH
  - LONG-TERM PAYOFF
  - HIGH RISK
  - METHODS DEVELOPMENT
    - ANALYSIS
    - SYNTHESIS
    - EVALUATION
  - UNIQUE FACILITY
  - FUNDAMENTAL, AIMED AT PROVIDING GUIDELINES
  - POSTULIZATION, CONCEPTUALIZATION, EVALUATION } NEEDS, REQUIREMENTS OF
  - CONTROVERSIAL
  - BROADLY APPLICABLE, GENERIC
  - STIMULATING OTHER ACTIVITY
  - BASIC
  - ATC (UNIQUE SITUATION)
  - PUBLIC INTEREST PROTECTION
- INFORMATION ASSESSMENT AND DISSEMINATION
  - COLLECTION
  - COLLATION
  - ORGANIZATION
  - DISSEMINATION
  - FOREIGN AND DOMESTIC
  - NASA RESEARCH
    - STANDARD METHODS (FINAL REPORTS, SYMPOSIA, etc.)
    - STATUS REPORTS
    - COMPETITOR PARTICIPATION IN MAJOR NASA RESEARCH CONTRACTS
- DATA BANK FOR RELEVANT INFORMATION
- FACILITY DEFINITION
  - SIMULATOR FIDELITY
- FACILITY "LOAN" TO OUTSIDE AGENCIES
  - SIMULATORS
  - LABORATORIES

1. Team 9: Broadly Applicable Technology Working Session

2. Team Theme: Interfacing and Integration

3. Team Members:

Rudy H. Cook (cochairman), Lockheed California Co.
Billy L. Dove (cochairman), NASA Langley Research Center
Harold Alsberg, ARINC Research
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4. Team Observation, Issues, and Recommendations:

The Interfacing and Integration team addressed problems in the five major areas outlined in the meeting guide. These included:

(1) Functional integration

(2) Information processing

(3) Intersystem communications

(4) External interference effects

(5) Power supply and other systems

It was agreed that technology drivers for CTOL research were primarily in safety and improved aircraft performance. In the safety area, most concern was expressed for flight safety in the airspace and for flight crucial systems operation. In the area of performance improvements, fuel economy and optimum utilization of the aircraft were paramount. Both of these lead to economic payoffs which contribute to DOC reductions, as well as cost avoidance.

In general, the consensus was that existing and forseeable problems through about 1985 are in hand or are being worked out satisfactorily; for the longer range problems, however, further activity is required and should be initiated soon if the needs are to be met in time.

These tasks involve high-risk, high payoff technology which industry is reluctant to address alone because the requirement is relatively far in the future and the payoff is not that certain. The work also involves, in many cases, cooperative effort with other agencies or already established facilities, such as the ATC system operated by the FAA. Many of the tasks involve study and development in areas in which the required methodology is not presently available.

One of the major tasks determined was the great need to begin now the development of an airborne data system compatible with the evolving ATC system which could meet the increased air traffic expected by 2000. This will best be accomplished by cooperative NASA/universities/industry effort to establish a working pool of knowledge in generic subject areas, with NASA directing contracts to industry and with the universities creating "engineering model-design example systems" for in-house investigation and the establishment of required design criteria. This will require expanding effort in:

- Analytical Methods
- Simulation/Emulation
- Physical Simulation
- Flight Testing

In addition, there were a number of other specific areas which should receive similar attention because they are the components necessary to support the solution of the problems. This effort would include studies in:

- Crew Interface/Human Factors
- System Architecture
    - Integrated Design
    - Partitioning
    - Fault-Tolerant Computers
    - Redundancy/Fault Tolerance
      (Examine SIFT/FTMP/ARCS/Hardened Systems)

- Intersystem Communication
- Reliability Assessment Techniques
- Software Reliability - Verification - Validation
- Lightning/EMI/EMP - Composite Effects
- Maintainability/Availability (including automatic maintenance aids)
- Fiber Optics
- Data Bus Standardization (Multiplexing)
- Sensors (Digital Hardware)

In summary, it was recommended that a flight vehicle be made available and be fitted with avionics and computer systems which could meet the study requirements necessary to permit in-flight testing and evaluation of these unknown quantities for the purpose of providing data base to support knowledgeable design of the avionic system needed in the 1985-2000 time frame.

1. Team 10: Broadly Applicable Technology Session

2. Team Theme: Fundamental Technology

3. Team Members:

Edmund G. Rynaski (cochairman), CALSPAN Corporation

Larry W. Taylor (cochairman), NASA Headquarters

Nicholas Albion, Boeing Vertol Company
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J. A. Hauge, Honeywell, Inc.
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Jack B. Leonard, Grumman Aerospace Corporation
J. M. McCarty, Lockheed Georgia Company
Kurt Moses, Bendix Corporation
Clark M. Neily, Jr., Intermetrics, Inc.
Jan Roskam, University of Kansas
Duane B. Schoelerman, Vought Corporation
Robert P. Wanger, General Electric Company

4. Team Observations, Issues, and Recommendations:

The Fundamental Technology team report is intended to summarize the results of the workshop session on fundamental technologies. The report not only tries to illuminate those areas of significant interest and importance to both NASA and industry but also tries to order or to indicate priorities in particular areas. Because the team concentrated on areas of a primary research nature, no particular time frame could be spelled out.

The evolution of technology proceeds at a definable pace. The areas of research indicated in this report are those that should be given increased emphasis in order for the technology development to proceed at an even pace. Theoretical bottleneck areas need to be overcome in order for the theory to be fully developed and to be available for application to specific vehicle-oriented problems and objectives. For instance, it seems highly likely that active control technology will be extensively adapted for future CTOL aircraft in the 1990's time period. Control theory which would fully realize the objectives of active control is not yet available or adapted from the pure theoretical results now being generated by the academic community.

The recommendations of the team fall into the following six general categories:

(1) Control analysis and synthesis

(2) Flying qualities research

(3) Device technology or development

(4) Prediction/modeling/system identification

(5) System configuration development

(6) NASA/industry/universities relations

Each of these categories are summarized in the following paragraphs, and the likelihood of near-term need for the specific research is identified when possible.

Control Analysis and Synthesis

Multicontroller system analysis and synthesis techniques development was felt to be an area of most importance, perhaps urgently needed in order to properly exploit the active control technology objectives of industry. Much research is needed, not only to efficiently analyze and synthesize multicontroller linear systems but also to adapt these ideas to the needs and objectives of active control. Among the areas of particular interest are:

(1) Applications of optimal control theory to realistic and difficult flight control problems.

(2) Specification or the development of control criteria related directly to the objectives of a control system design. (For instance, how does one define a performance index to optimize flying qualities as defined by MIL-F-8785B?)

(3) Realization of optimal systems. (It is felt that techniques involving only output feedback should be investigated in more detail.)

A second area that was given primary emphasis by a large majority of the team was in the area of direct digital design methods and techniques. It was felt that significant computational efficiency may result by using direct methods rather than by digitializing a control system configuration obtained initially by analog methods.

Other areas of significant need in control analysis and synthesis include:

(1) Control configurations at high angles of attack.

(2) Nonlinear control theory investigations involving the specific effects of control surface saturation and rate limits with particular emphasis on stability, both in automatic control and PIO situations.

(3) Most effective and most simple methods of control system design for a wide flight range.

(4) Distributed parameter systems investigations.

(5) Insensitive control system design methods.

Flying Qualities

The general consensus was that there is an urgent need for flying-qualities investigations relating to the phenomena of relaxed static stability. In case of a feedback failure, manual control of an airplane having an unstable short period mode of response may be necessary. In this case, the minimum controllability requirements in terms of frequency and damping ratios, control power, and rate requirements need to be defined.

Control power requirements related to the V/STOL task was a second area of emphasis in the flying qualities areas. Both automatic and manual control were areas of concern. Lesser, but still significant, interest was expressed in the following areas:

(1) Criteria for direct force control, both direct lift control and direct side-force control are needed.

(2) Flying qualities criteria related to higher order systems, including compensation networks, washout filters, feedforward compensation, and the like are needed. This work should be formulated in such a way that the particular configuration is not restricted or specified in terms of system structure. It was felt that this must be the prerogative of the control-system design engineer.

(3) A continued effort directed towards the efficient specification of pilot-in-the-loop configurations is needed, particularly with respect to multivariable and multicontroller systems.

It was felt by the majority of the team that the systematic investigations of flying qualities could not be supported by any one government agency. As a result, no agency is supporting research in the area of flying qualities in a systematic way, and some areas are neglected while others are unnecessarily duplicated. The team strongly urge a cooperative effort by the USAF/Navy/Army/NASA/FAA, and other interested parties, to share the sponsorship load in a coordinated effort.

Device Technology

Members of the team expressed a strong desire to have NASA continue research and development in several areas of device technology, with particular emphasis on actuator design, sensor design, and high-temperature electronics.

It was felt that increased emphasis was needed in all areas of actuator design, including electro-mechanical, electro-hydraulic, and pneumatic. A users guide may be quite useful in trying to specify those areas of application that seem particularly suited to specific types of actuators. It was felt that a continuous, steady level of research should be sponsored rather than attempting to specify particular performance objectives within particular time frames.

Several members of the team expressed the need of trying to develop an all-digital control system, including digital sensors and actuators. It was felt that the elimination of the A/D and D/A conversion could result in a superior system configuration.

Too little is known about the effects of prolonged elevated temperatures on solid-state devices and methods of design for operation in high-temperature environments. Consequently, the team members who have an interest in power-plant control expressed a strong desire for more basic research associated with high-temperature electronics.

Prediction, Modeling, and Identification

A continued need exists in being able to predict model systems by analytical methods; consequently, the team felt that NASTRAN should be extended to include nonlinear systems and that FLEXSTAB should be further developed. All elements of the system, including airframe, pilot, and control elements such as actuators, sensors, etc. should be included in the prediction methodology.

Team members are aware that analytic methods of prediction cannot proceed without the accompanying experimental research necessary to validate and verify the analytic predictions. Wind-tunnel testing, flight simulation, and flight testing should keep pace with the analytical developments to help verify the accuracy of the predictions. Development of in-flight identification techniques should be continued to cover the area of aeroelastic vehicles and the development of aerodynamic modeling techniques at high angles of attack.

Increased emphasis is needed in the areas of

(1) Higher order systems such as aeroelastic modeling and unsteady aerodynamic effects.

(2) Nonlinear characteristics as at high angles of attack.

(3) Low-altitude environmental effects and better mathematical models of low-altitude turbulence and shear effects.

System Configuration

Because a continued effort in the area of system configuration was considered important, a desire was expressed by the team members to see continued research in the following four areas (not in priority order):

(1) Crew/display integration (Human factors continue to be important).

(2) Integrated panel design (It was felt that the need for improvements in this area was obvious).

(3) Avionics systems architecture.

(4) Redundancy management.

NASA/Industry/Universities Relations

It appeared that everyone in attendance had strong opinions about NASA/industry/universities relations. Some of these concerns are briefly documented as follows:

(1) A more meaningful arrangement is needed that would result in extended NASA/industry/universities exchange of ideas and technology transfer. Also, a need for more effective "cross fertilization" is becoming increasingly apparent.

(2) More and more closely integrated NASA/industry/universities team arrangements are needed.

(3) Closely related to the preceding two items is a concern that NASA needs more personnel directly involved in research activities. The fact that NASA is apparently not training new, young engineers will lead to obvious problems in the not too distant future. As a result, the team members felt that at the present time NASA has an obvious imbalance between personnel involved in research and contract monitoring and that no alleviation of this undesirable situation appears to be forthcoming in the near future.

There was no question at all as to which of these three concerns is the most acute: the shortcomings in NASA/industry/universities relations. The lack of new, young engineers within NASA will mean an eventual drying up of new ideas, initiatives, and leadership by NASA. This trend, if allowed to continue much longer will adversely affect industry and the academic community. The responsibility for continued American leadership in the area of aeronautics depends heavily on the effectiveness and foresight of the National Aeronautics and Space Administration.

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16. Abstract

A workshop on Avionics and Controls Research and Technology sponsored by the NASA Office of Aeronautics and Space Technology, was hosted by the NASA Langley Research Center at Hampton, Virginia on June 27-29, 1978.

The workshop provided a forum for industry and universities to discuss the state-of-the-art, identify the technology needs and opportunities, and describe the role of NASA in avionics and controls research.

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