NASA Conference Publication 3090

Aviation Safety/Automation Program Conference

Proceedings of a conference held in
Virginia Beach, Virginia
October 11–12, 1989

NASA

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Aviation Safety/Automation Program Conference

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PREFACE

The Aviation Safety/Automation Program Conference - 1989 was sponsored by the NASA Langley Research Center on 11-12 October 1989. The conference, held at the Sheraton Beach Inn and Conference Center, Virginia Beach, Virginia, was chaired by Samuel A. Morello and coordinated by the Science and Technology Corporation (STC) Meetings Division.

The primary objective of the conference was to ensure effective communication and technology transfer by providing a forum for technical interchange of current operational problems and program results to date. The Aviation Safety/Automation Program has as its primary goal to improve the safety of the national airspace system through the development and integration of human-centered automation technologies for aircraft crews and air traffic controllers. Specific objectives include the development of the basis (consisting of philosophies and guidelines) for applying human-centered automation to the flight deck and ATC controller station; human-centered automation concepts and methods for flight crews, which will ensure full situation awareness; and human-centered automation concepts and methods for ATC controllers which allow integration and management of information and air-ground communications. The effects of human error, the loss of situation awareness, the handling of system contingencies, and the capability of air and ground systems to cope with increasing traffic and schedule demands are technical issues being addressed in this effort.

This document has been compiled to record the conference presentations, which provided the stimulus for technical interchange. The presentation charts contained herein also document the status of on-going research and future plans of the Aviation Safety/Automation Program.

CONTENTS

KEYNOTE ADDRESS

HUMAN-CENTERED AUTOMATION OF COMPLEX SYSTEMS: PHILOSOPHY, METHODOLOGY, AND CASE STUDIES

William B. Rouse
Search Technology, Inc.

OVERVIEW

- o Design Philosophy
- o Design Process
- o Case Studies
- o Prerequisites for Success

DESIGN PHILOSOPHY

- o Roles of Humans
- o Design Objectives
- o Design Issues

ROLES OF HUMANS

- Operators, Maintainers, Managers
- Responsible for Operational Objectives
- Should be "In Charge"

DESIGN OBJECTIVES

Support humans to achieve operational objectives for which they are responsible

- Enhance Human Abilities
- Overcome Human Limitations
- Foster User Acceptance

DESIGN ISSUES

- o Formulating the Right Problem
- o Designing an Appropriate Solution
- o Developing It to Perform Well
- o Assuring User Satisfaction

DESIGN PROCESS

- o Measurement Issues
- o A Framework for Measurement
- o Typical Measurement Problems
- o Case Studies

MEASUREMENT ISSUES

Viability ——→ Are the Benefits of System Use Sufficiently Greater than its Costs?

Acceptance ——→ Do Organizations/Individuals Use the System?

Validation ——→ Does the System Solve the Problem?

Evaluation ——→ Does the System Meet Requirements?

Demonstration→How Do Observers React to System?

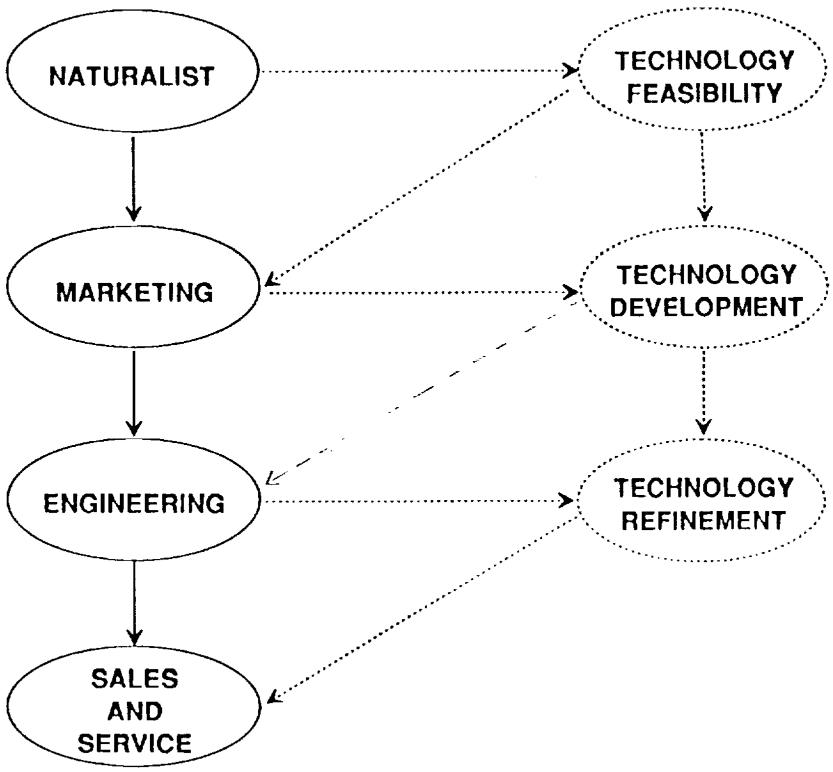
Verification ——→ Is the System Put Together as Planned?

Testing ——→ Does the System Run, Compute, Etc.?

OVERALL APPROACH

- o Plan Top-Down
- o Execute Bottom-Up

A FRAMEWORK FOR MEASUREMENT



TYPICAL MEASUREMENT PROBLEMS

- Planning Too Late
- Executing Too Early

NATURALIST PHASE

- Understanding Users' Domain and Tasks
- Assessing Roles of Individual, Organization, Environment
- Developing Formal Description of Users
- Identifying Barriers/Avenues for Change

METHODS AND TOOLS FOR MEASUREMENTS

- Magazines and Newspapers
- Databases
- Questionnaires
- Interviews
- Experts

EXAMPLES

- o Intelligent Cockpit
- o Design Information System
- o Design Tool

MARKETING PHASE

- o Introducing Product Concepts
- o Planning for Validity, Acceptability, Viability
- o Making Initial Measurements

BUYING INFLUENCES

- Economic Buyer
- Technical Buyer
- User
- Coach

INFLUENCES VS. MEASUREMENTS

	VIABILITY	ACCEPTABILITY	VALIDITY
ECONOMIC	●	◒	◒
TECHNICAL	◒	◒	●
USER	◒	●	◒
COACH	○	○	○

● PRIMARY

◒ SECONDARY

○ FACILITATING

METHODS AND TOOLS FOR MEASUREMENT

- Questionnaires
- Interviews
- Scenarios
- Mockups
- Prototypes

EXAMPLES

- Intelligent Cockpit
- Design Information System
- Design Tool

ENGINEERING PHASE

- o Trading Off Conceptual Functionality vs. Technological Reality
- o Application of Design Methodologies
- o Inherent Conflict Between Design and Evaluation
- o Efficient Choices of Methods and Measures

EVOLUTIONARY ARCHITECTURES

- o Level A: What you know you can do.
- o Level B: What you are willing to promise.
- o Level C: What you would like to do.
- o Principle: Conceptual architecture should be capable of potentially supporting all three levels.

SALES AND SERVICE PHASE

- Focusing on Validity, Acceptability, Viability
- Remediating Problems
- Recognizing Opportunities
- Maintaining Relationships

PREREQUISITES FOR SUCCESS

- Flexible Design Process
- Long-Term Perspective
- Sense of Accountability
- Cooperative User-Producer Relationship

PANEL SESSION

AUTOMATED FLIGHT DECKS AND CONTROLLER WORKSTATIONS: PHILOSOPHY AND ISSUES

Human-Centered Automation: Operational Experience

(Acknowledgment of Oral Presentations)

Vic Britt -- Northwest Airlines
Wayne Bundrick -- Delta Airlines
Cliff Lawson -- United Airlines Flight Center

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BOEING FLIGHT DECK DESIGN PHILOSOPHY

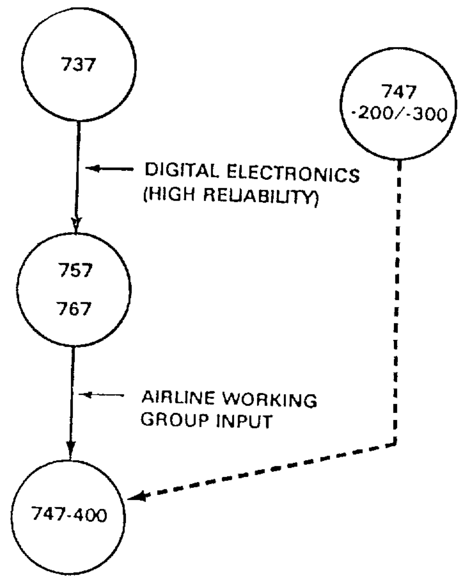
Harty Stoll
Boeing Commercial Airplane Company

FLIGHT DECK EVOLUTION

- EXTERNAL VISION
- WORKLOAD
- FAILURE MANAGEMENT
- PILOT INCAPACITATION

- FLIGHT MANAGEMENT COMPUTER & MAP
- AUTOMATED MONITORING
- INTEGRATED CAUTION AND WARNING
- QUIET DARK CONCEPT
- SIMPLIFIED CREW ACTION
- COLOR CRT DISPLAYS

- DEDICATED CREW REST AREA
- INCREASED REDUNDANCY
- CENTRALIZED MAINTENANCE COMPUTERS
- IMPROVED FLIGHT MANAGEMENT



FLIGHT DECK DESIGN GOALS

747-400

THE DESIGN OF THE 747 FLIGHT DECK IS BASED ON THE RECENT SUCCESSFUL 757/767 PROGRAMS AS WELL AS ON THE EXPERIENCE GAINED FROM MILLIONS OF FLIGHT HOURS ON BOEING COMMERCIAL JET TRANSPORTS. SPECIAL EMPHASIS IS PLACED ON THE LATEST DIGITAL TECHNOLOGY AND CONTROL/DISPLAY INTEGRATION TO PROVIDE UNCLUTTERED INSTRUMENT PANELS, IMPROVED REACH AND SCAN CAPABILITY, AND OPTIMIZED CREW WORKLOAD. THE RESULT IS ENHANCED SAFETY AND PRODUCTIVITY THROUGH IMPROVED CREW COMFORT, PERFORMANCE, AND WORKLOAD OPTIMIZATION.

GOALS

- ENHANCED SAFETY
- IMPROVED OPERATIONAL CAPABILITIES
- PERFORMANCE/WORKLOAD OPTIMIZATION
- INCREASED RELIABILITY/MAINTAINABILITY
- REDUCED OPERATING COST
- IMPROVED CREW COMFORT

TECHNOLOGY

- DIGITAL COMPUTERS/MICROPROCESSORS
- INTEGRATED DISPLAYS
- INTEGRATED FLIGHT MANAGEMENT
- CDU's
- LASER GYRO INERTIAL REFERENCE
- ADVANCED SYSTEM MONITORING
- CENTRAL MAINTENANCE SYSTEM WITH STANDARDIZED BITE

FLIGHT DECK DESIGN CONSIDERATIONS

INDUSTRY

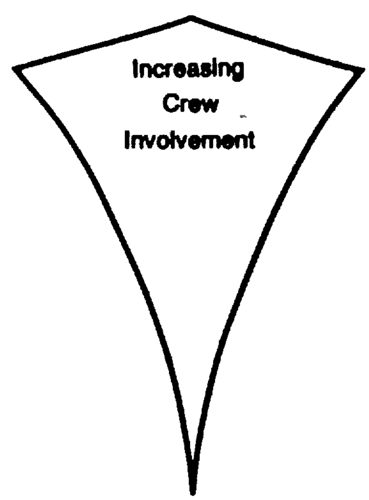
- AIRLINE INPUT
- FAA STUDIES
- NASA STUDIES
- NTSB
- SAE RECOMMENDATIONS
- ATA
- FLIGHT SAFETY FOUNDATION
- COMPETITIVE AIRFRAME MANUFACTURE
- SYMPOSIUMS
- WORKSHOPS
- AIAA
- ARINC
- RTCA
- ICAO
- ALPA, IFALPA, APA
- MISC. STUDIES (1969 UAL-ALPA)
- ASRS
- MILITARY - AIR FORCE, NAVY, ETC.
- HUMAN FACTOR ORGANIZATIONS

BOEING

- ACCIDENT/INCIDENT DATA
- BOEING FLIGHT TEST
- CREW TRAINING
- BOEING IR & D
- CUSTOMER SERVICE UNIT
- DATA ON EXISTING BOEING MODELS
- RELIABILITY AND MAINTAINABILITY
- QUESTIONNAIRES TO AIRLINES

Functions Allocated to Crew

- **Guidance**
- **Control**
- **Separation**
- **Navigation**
- **Systems Operation**



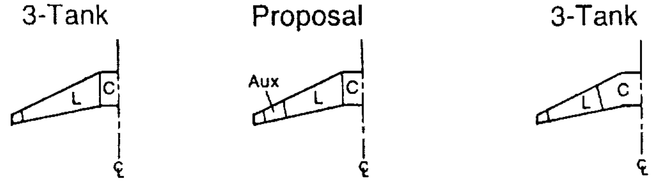
DESIGN PHILOSOPHY

- CREW OPERATION SIMPLICITY
- EQUIPMENT REDUNDANCY
- AUTOMATED FEATURES

Simplicity Through Design Refinement

Wing Fuel Tank Development–Example

	Original 3-Tank	5-Tank Proposal	Revised 3-Tank



	Jan '78	Jun '79	Jan '80
Wing Structure Weight	Base	Large Decrease	Large Decrease
Fuel System Weight	Base	Moderate Increase	Small Increase
Total Weight	Base	Moderate Decrease	Large Decrease
Crew Operation	Simple	More Complex	Simple

REDUNDANCY

(EXAMPLES)

- TRIPLEX
  - INERTIAL REFERENCE SYSTEMS
  - ELECTRONIC FLIGHT INSTRUMENT SYMBOL GENERATION
  - AUTOMATIC FLIGHT CONTROL AND FLIGHT DIRECTOR SYSTEM
  - ILS RECEIVERS
- DUAL
  - FLIGHT AND ENGINE INSTRUMENTS
  - FLIGHT MANAGEMENT COMPUTER
  - NAVIGATION RADIOS
  - COMMUNICATION RADIOS
  - AIR DATA SYSTEMS
  - WARNING AND CAUTION ALERTS

AUTOMATION

(WHAT DOES IT MEAN?)

- **SUBSYSTEM AUTOMATION**
  - REDUCE CREW WORKLOAD (3 TO 2 MAN CREW)
  - REDUCE CREW ERROR
- **GLASS COCKPITS**
  - REDUCE CREW ERROR AND ACCIDENTS
  - IMPROVE PILOT SCAN
  - REDUCES COST
- **FLIGHT MANAGEMENT COMPUTERS**
  - PROVIDE MAP INFORMATION
  - REDUCE FUEL BURN
  - REDUCE CREW ERROR
- **AUTOPILOT/AUTOTHROTTLE**
  - REDUCE WORKLOAD
  - REDUCE CREW ERROR

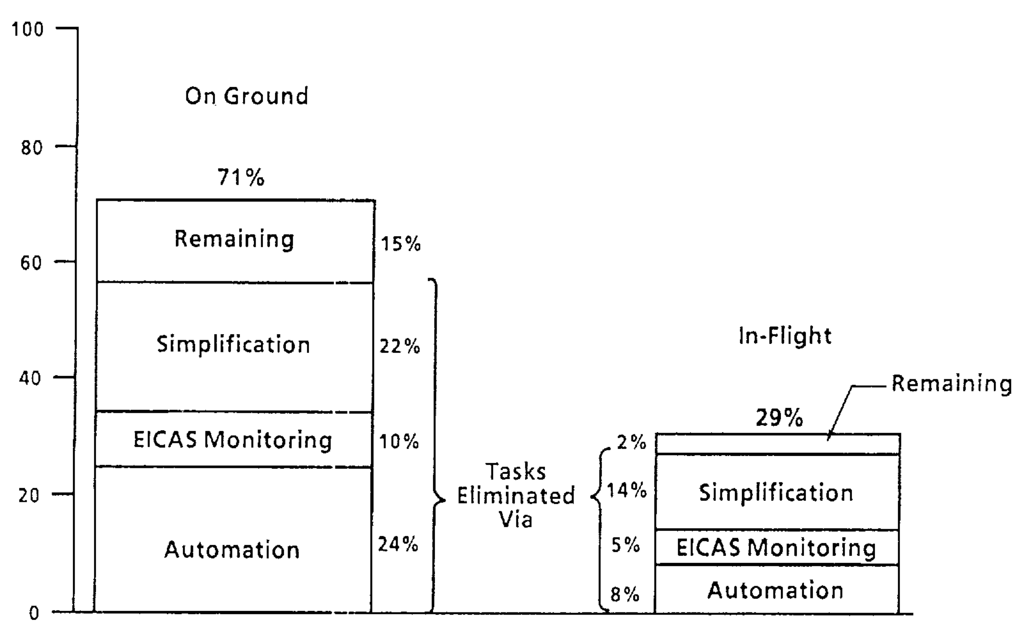
Boeing Flight Deck Design Committee

Examples of Accident Data Reviewed

- Subsystem management accidents—worldwide air carriers 1968-1980

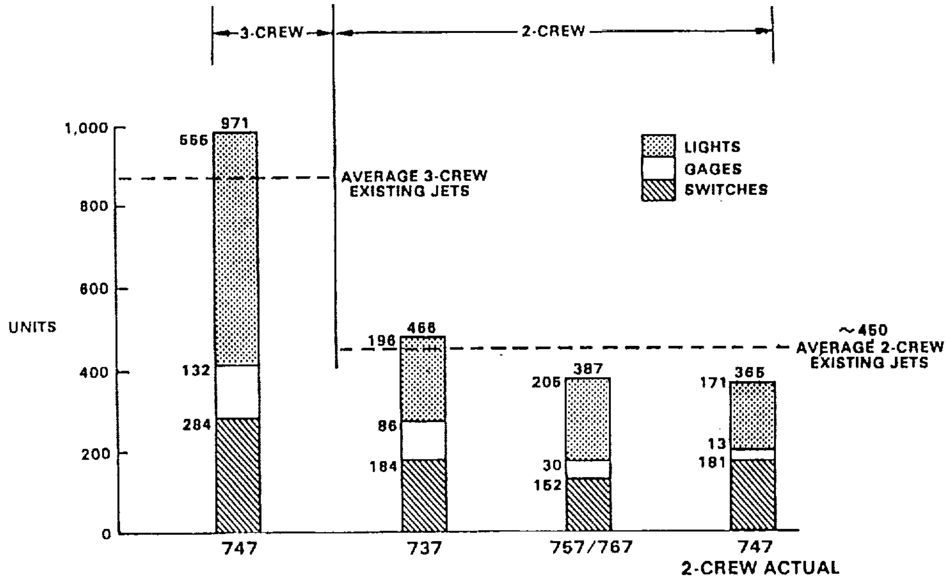
Accident Related Cause	Design
• Crew omitted pitot heat	• Auto on with engine start
• Wrong position of standby power switch	• Automated standby and essential power
• Flight engineer and captain conducted unauthorized troubleshooting	• Simplified systems delete maintenance functions
• Electrical power switching not coordinated with pilots	• Auto switching and load shedding—no crew action required
• Flight engineer shut off ground proximity	• Shut off on forward panel in full view of both pilots
• Faulty fuel management	• Auto fuel management with alert for low fuel, wrong configuration, and imbalance
• No leading edge flaps on takeoff	• Improved takeoff warning with digital computer
• Confusion over correct spoiler switch position	• Dual electric spoiler control
• Crewman did not follow pilot's instruction	• Full-time caution and warning system
• Mismanaged cabin pressure	• Dual auto system with auto switchover

Allocation of 747-200 Flight Engineer's Duties to 747-400 Flight Crew



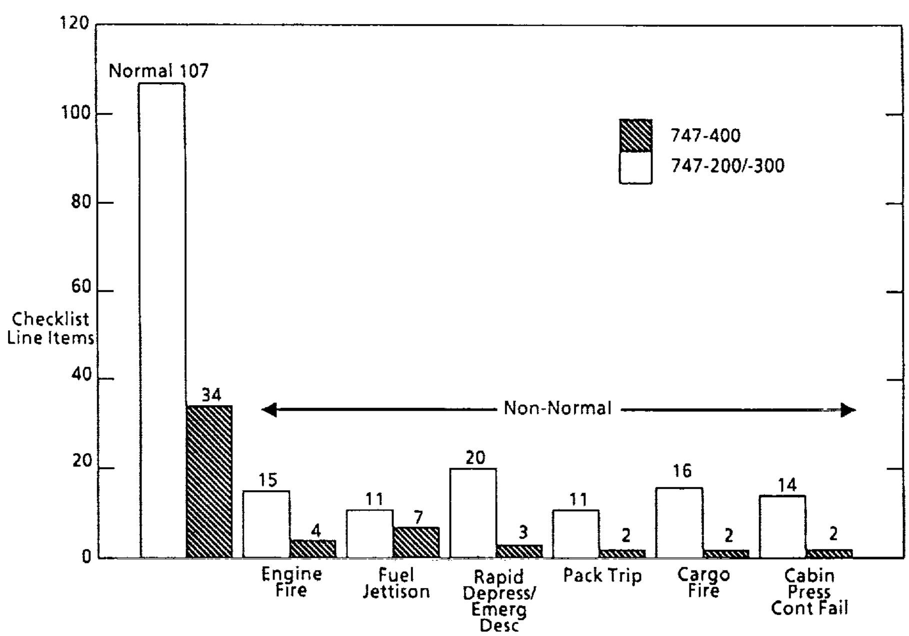
SUBSYSTEM CONTROLS & INDICATION COMPARISON

747-400

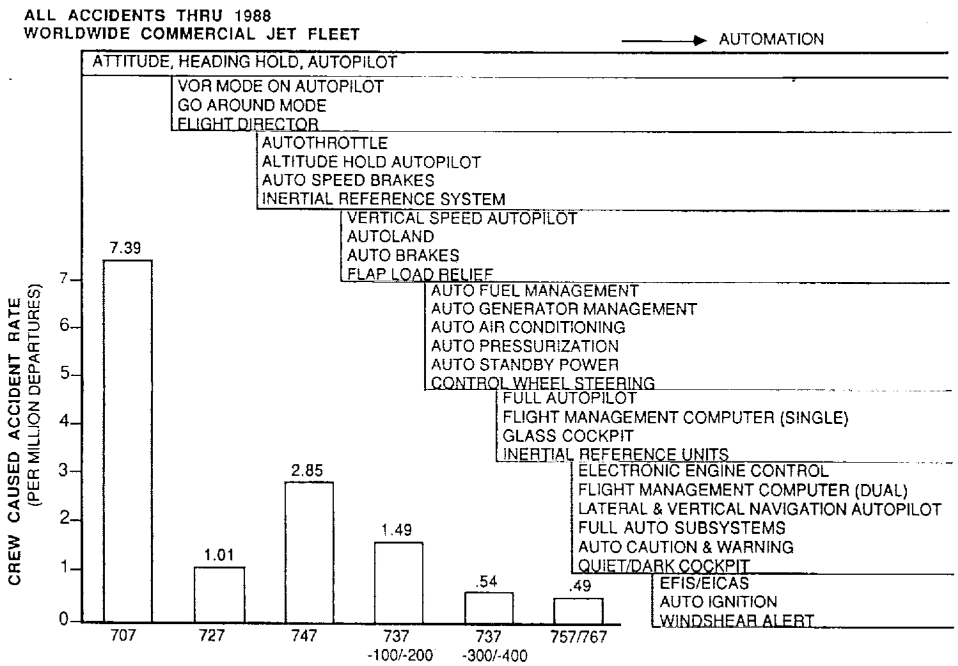


NOTE: NAV AND COMM PANELS NOT INCLUDED

747 Procedure Comparison



CREW CAUSED ACCIDENTS VS. AUTOMATION



AUTOMATION

(THE GOOD AND BAD)

- THE PLUSES
  - SAFETY
  - ERROR REDUCTION
  - WORKLOAD REDUCTION
  - SIMPLIFIED CREW OPERATION
  - COST SAVINGS
- THE PROBLEMS
  - REDUCE CREW UNDERSTANDING (AUTO-MANUAL)
  - CREW OVERUSE REDUCING CREW FALL-BACK CAPABILITY
  - PILOT TRANSITION IN AND OUT OF AUTOMATIC AIRPLANES
  - BOREDOM
  - DESIGNER's INTENT NOT TRANSMITTED TO PILOT

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COCKPIT AVIONICS INTEGRATION AND AUTOMATION

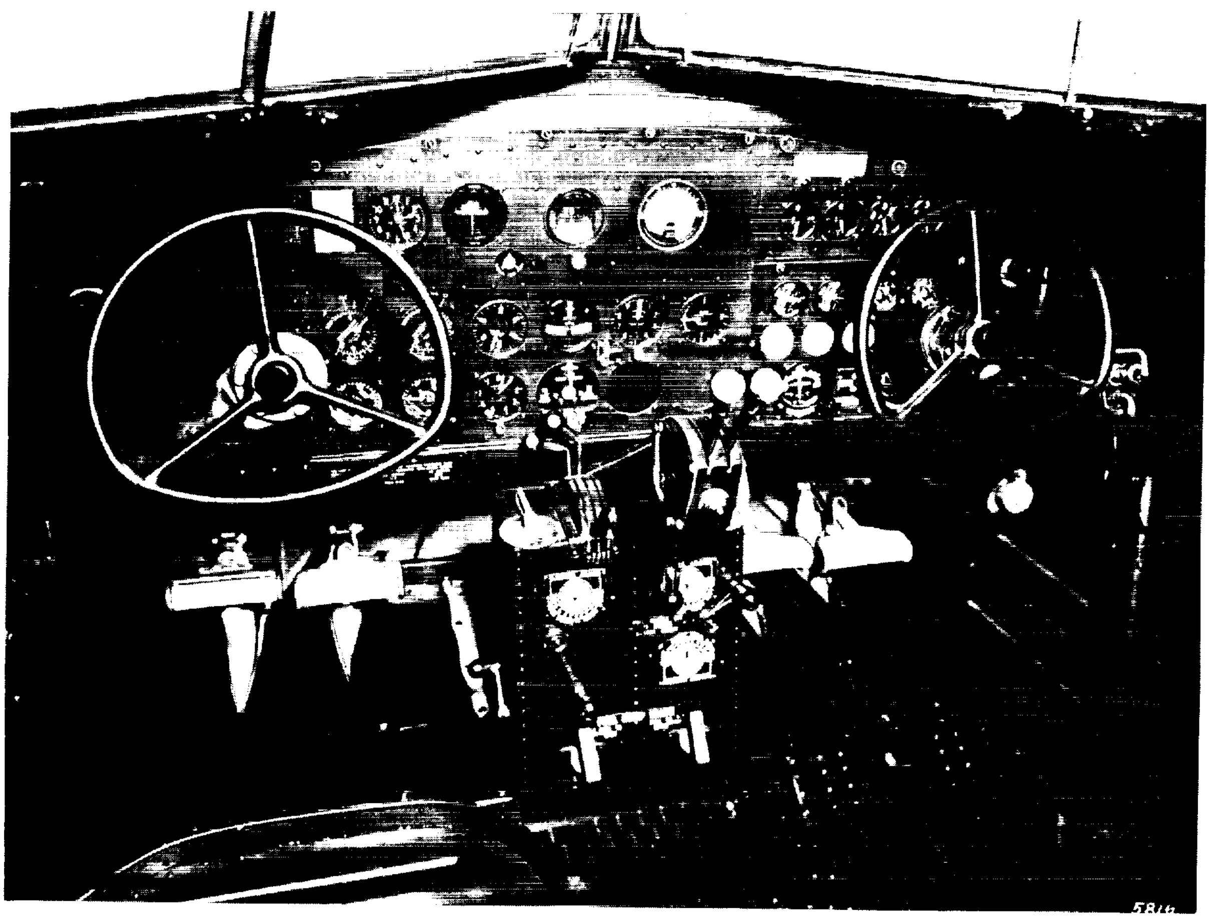
Keith M. Pischke
Honeywell Inc.

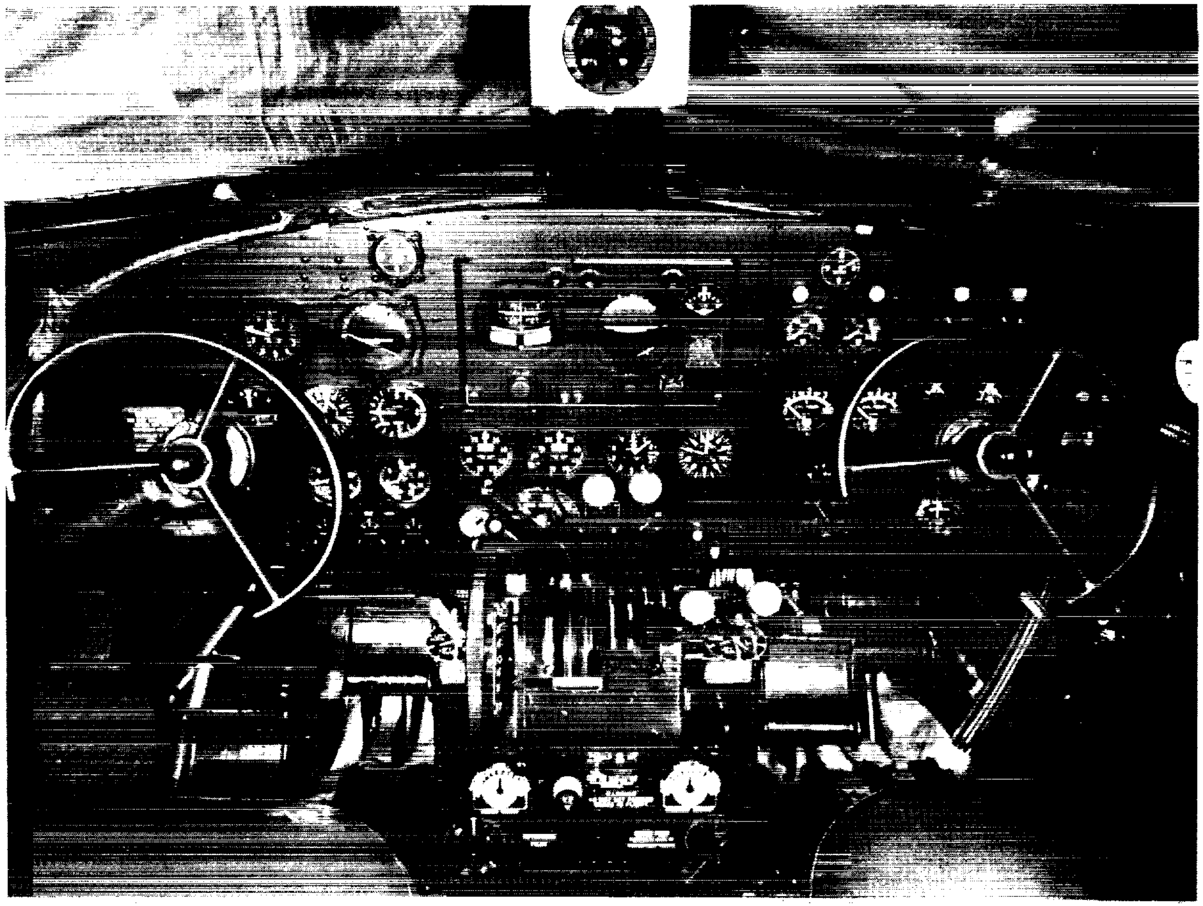
Integration
What is it Really?

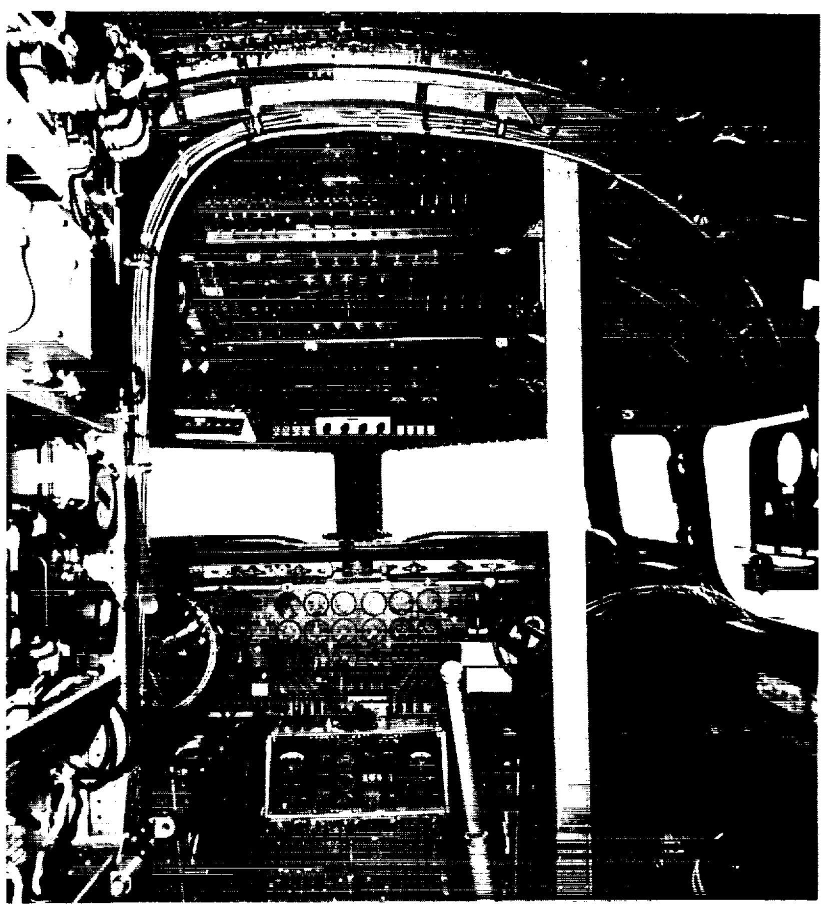
- The act of forming, coordinating, or blending into a functioning or unified whole.

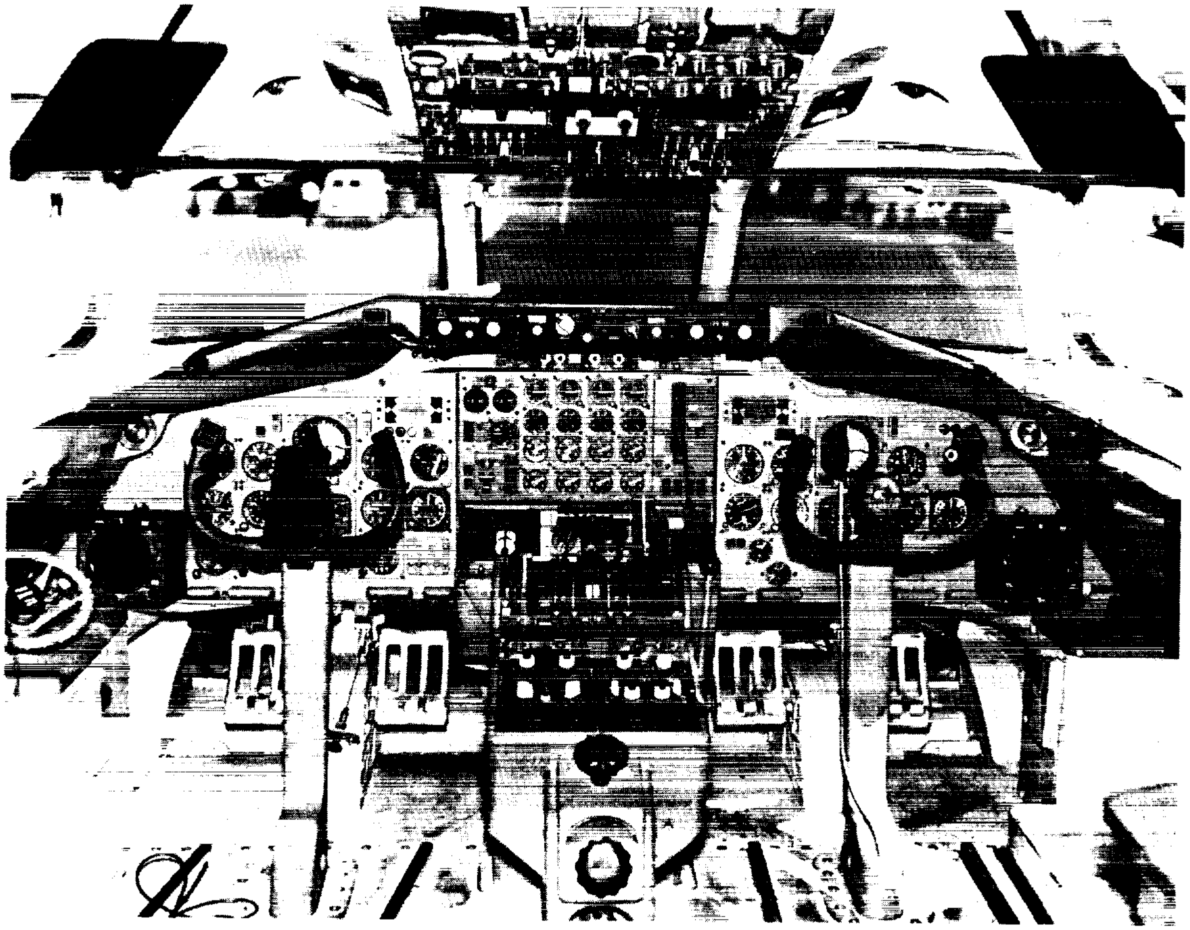
Merriam–Webster

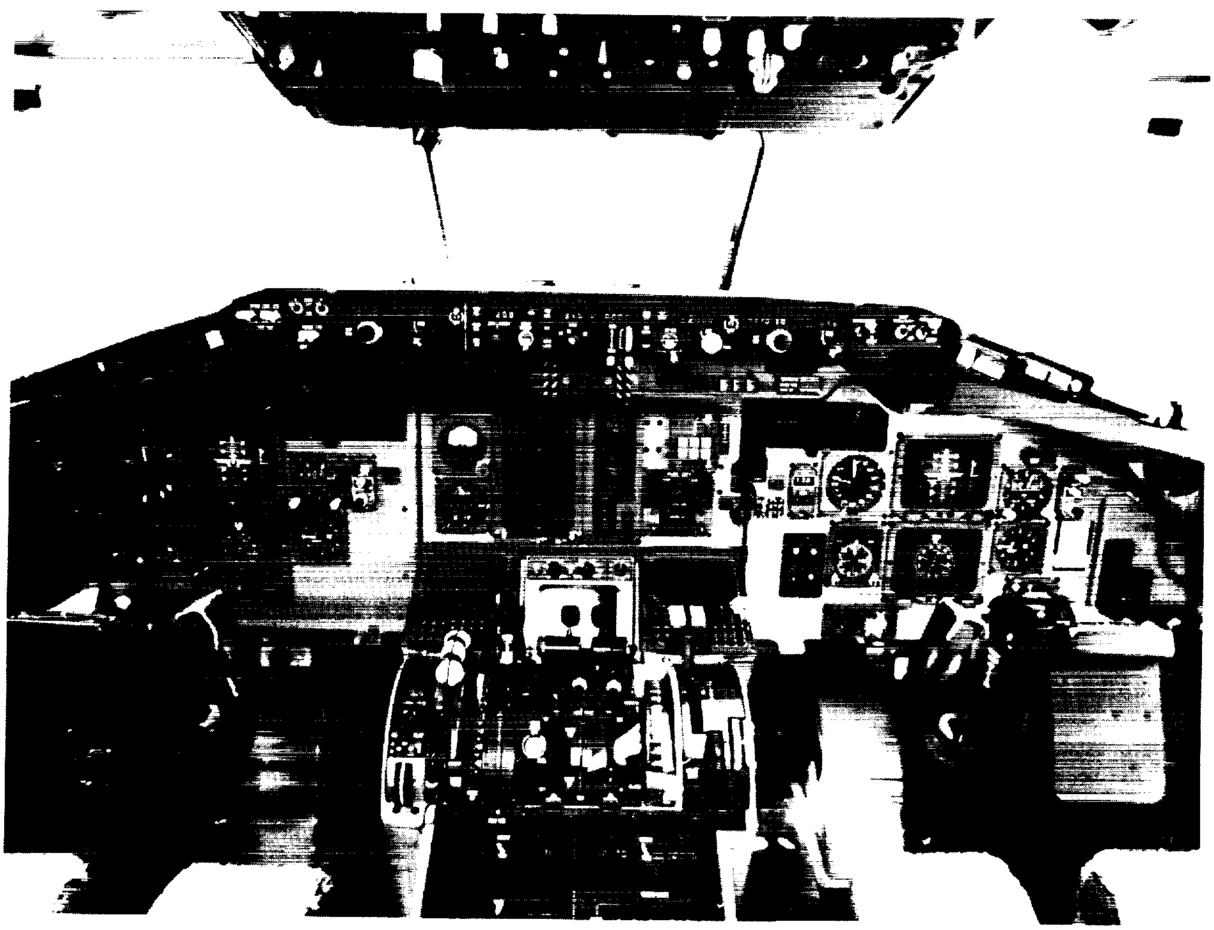
How does integration apply to Cockpit Avionics? . . . .

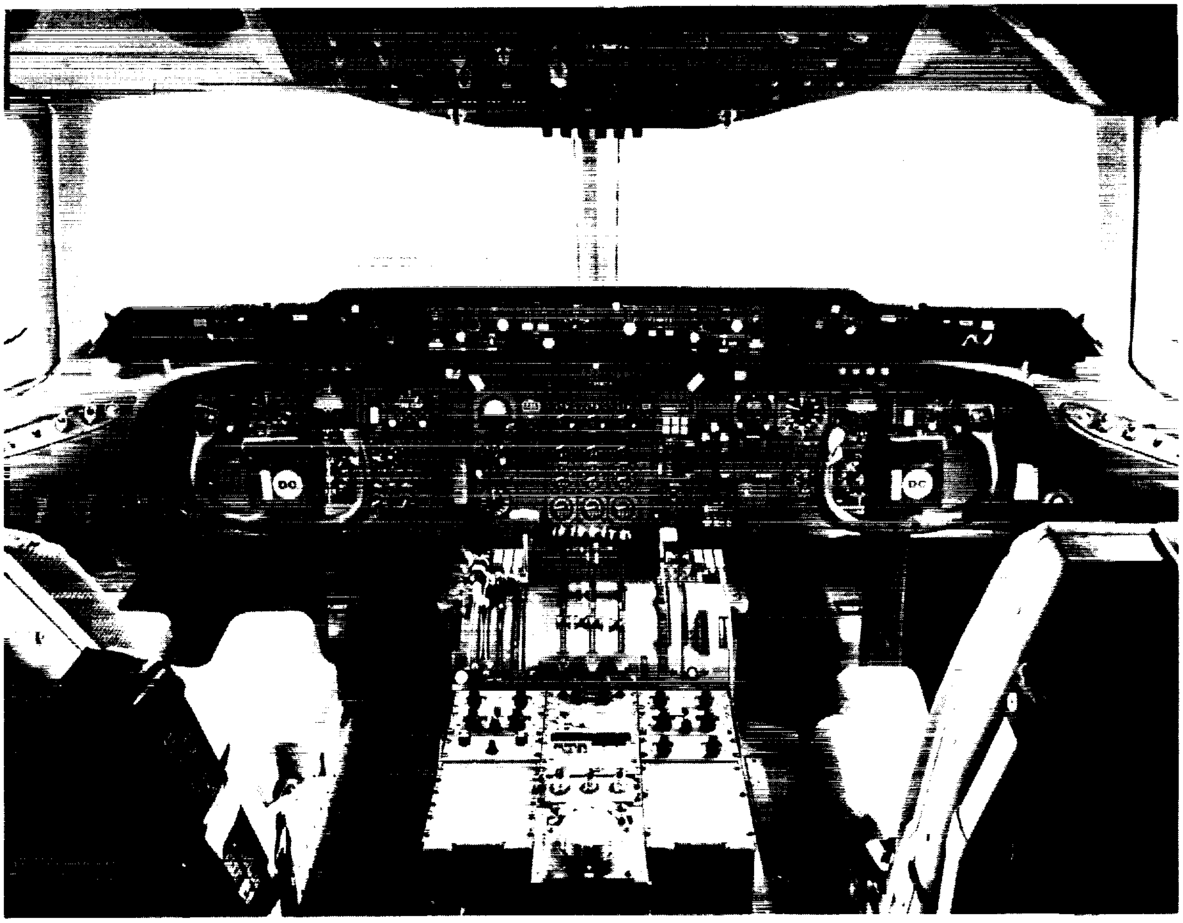


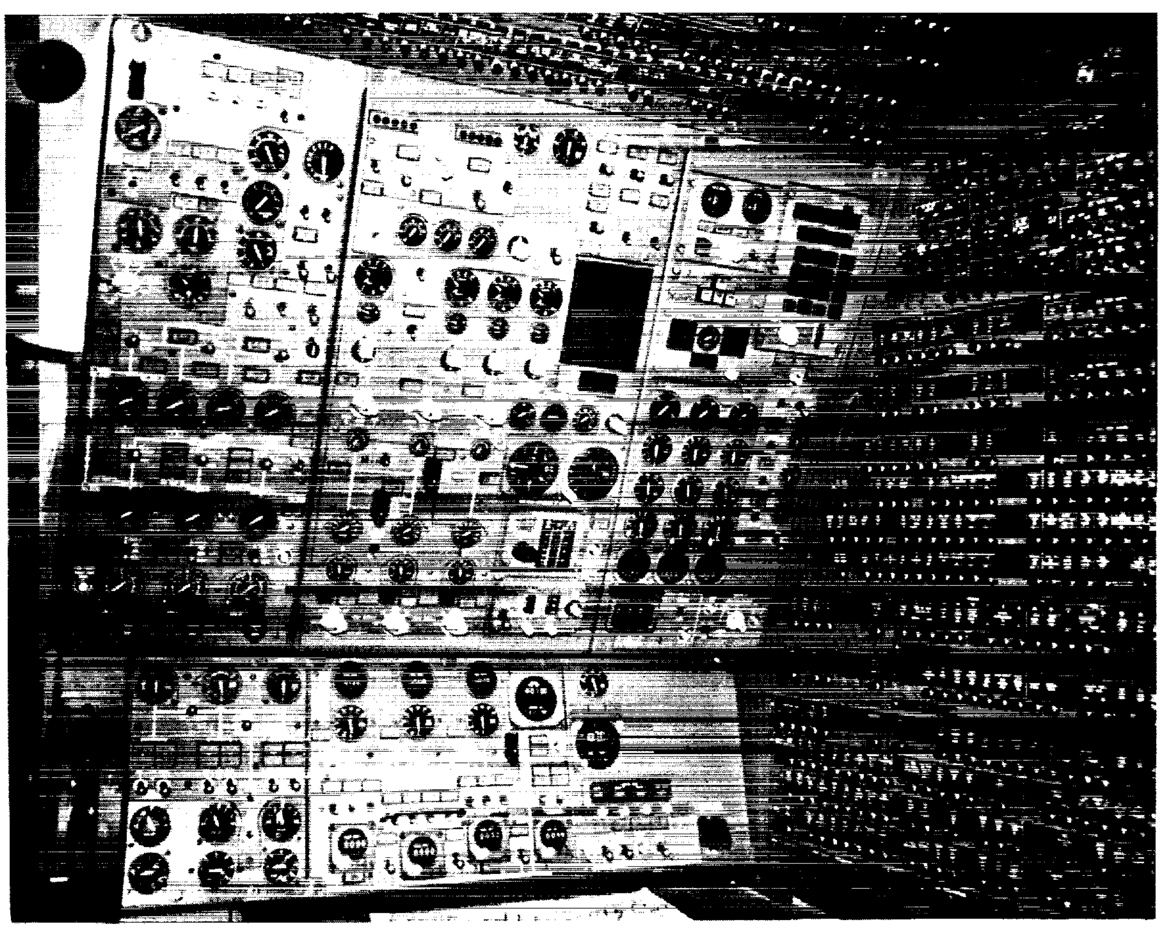


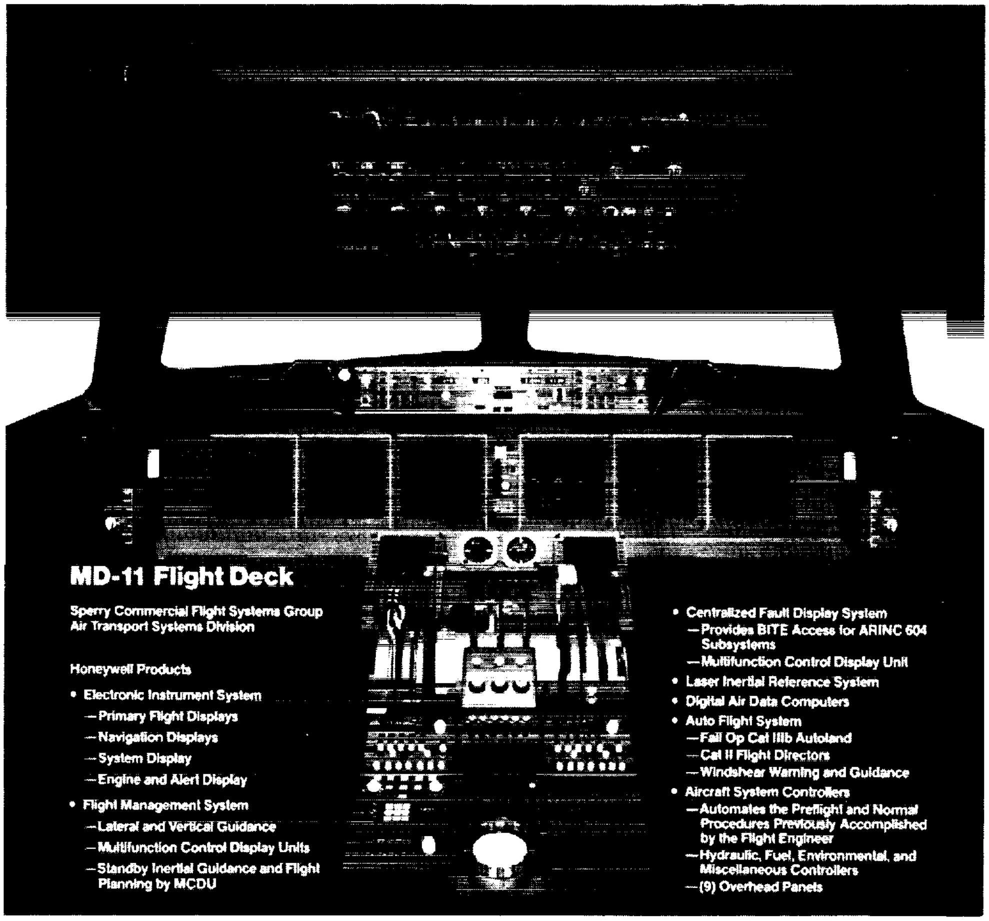












Benefits of Cockpit Integration

- Reduced pilot work load
- Increased system redundancy
- Increased maintainability
- Greater design flexibility for aircraft manufacturer
- Greater design flexibility for equipment manufacturer

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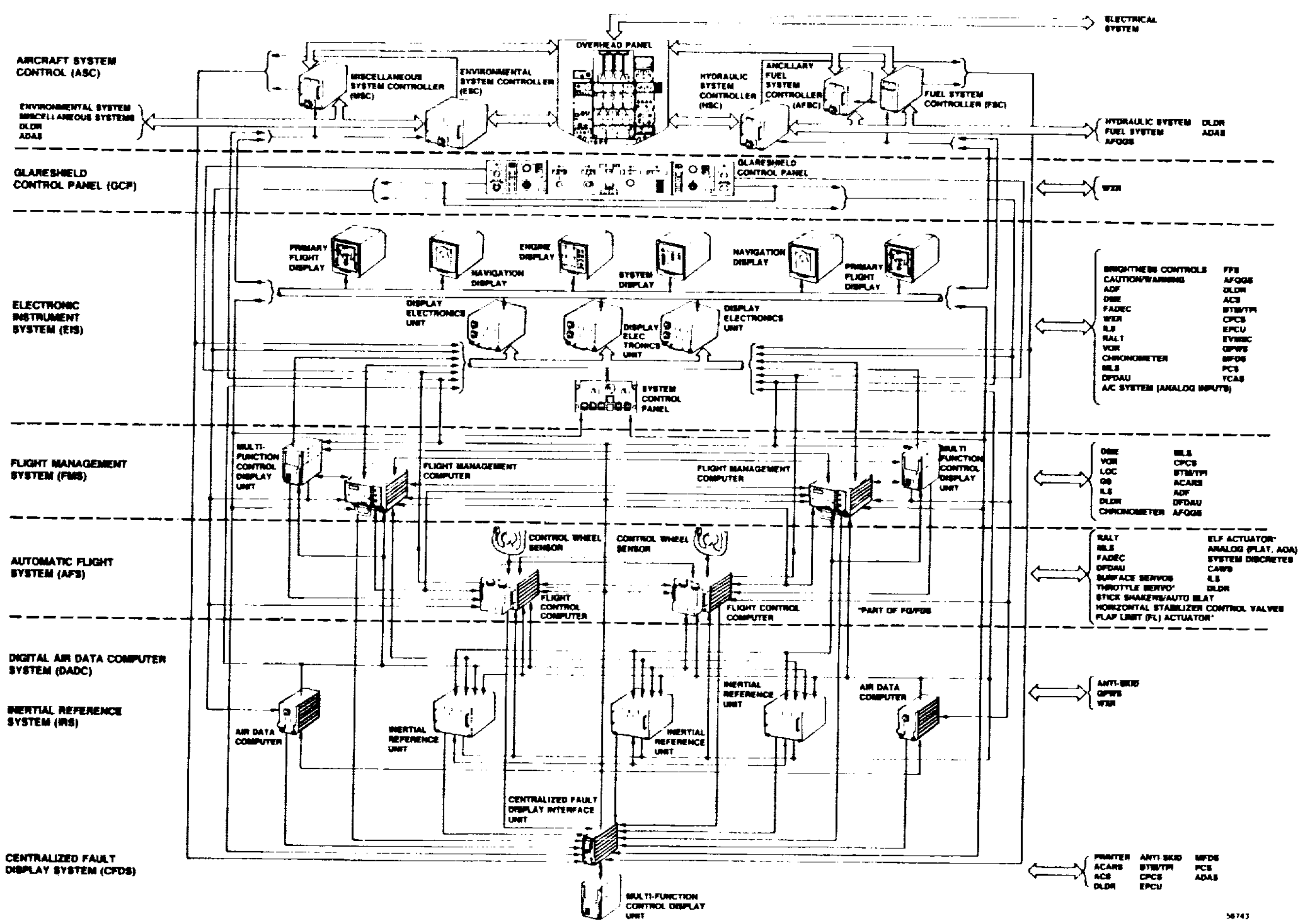
MD-11 Flight Guidance/ Flight Deck System (FG/FDS) Overview

Flight Guidance/ Flight Deck System



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MD-11 Flight Guidance/Flight Deck System

Honeywell System Summary

- 44 Line replaceable units (LRUs) per shipset
- 28 Different LRU types
- 48 Microprocessors per shipset
- 8 Different types of processors
- 1.5 Million total words of software
- 175 ARINC 429 type buses
- 8 Different ARINC data protocols
- 14 Other signal types

Honeywell Approach to Avionics Systems Integration

- Goals
- Tools and techniques

Honeywell Approach

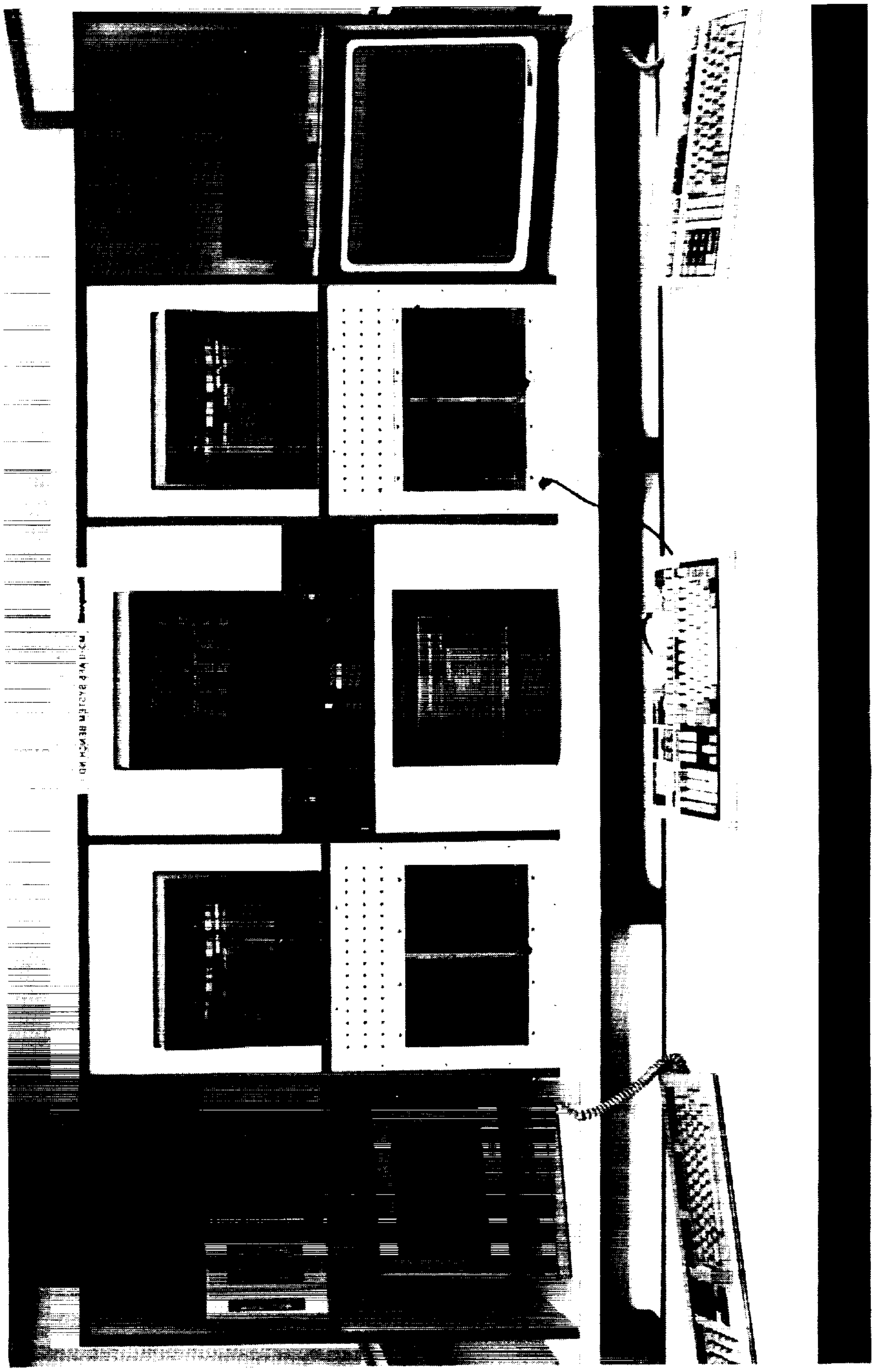
Goals

- Develop systems that are safe and meet regulatory agency requirements
- Develop systems that optimize the operation of the aircraft
  - For the pilots – Passengers – Operators – Mechanics
- Develop, test, and certify systems on schedule at a reasonable cost
  - Minimize interface problems
  - Reduce on-aircraft development, test, and demonstration time
  - Identify and correct system problems early

Tools and Techniques

- Team approach with airframe manufacturer
  - Joint development of system architecture and system analyses
  - Use of combined systems experience-airframe/avionics
- Systems integration organization
  - Coordinate top level system design
  - Enhance communication internal/external
  - Coordinate solutions to common design problems
  - Coordinate solutions to problems involving multiple systems
  - Perform top level system testing
  - Provide flight test and flight operations support
- System level test facilities
  - Subsystem test benches
  - Subsystem validation facilties (VALFAC)
  - Integration validation facility (VALFAC)

MD-11 AFS System Bench



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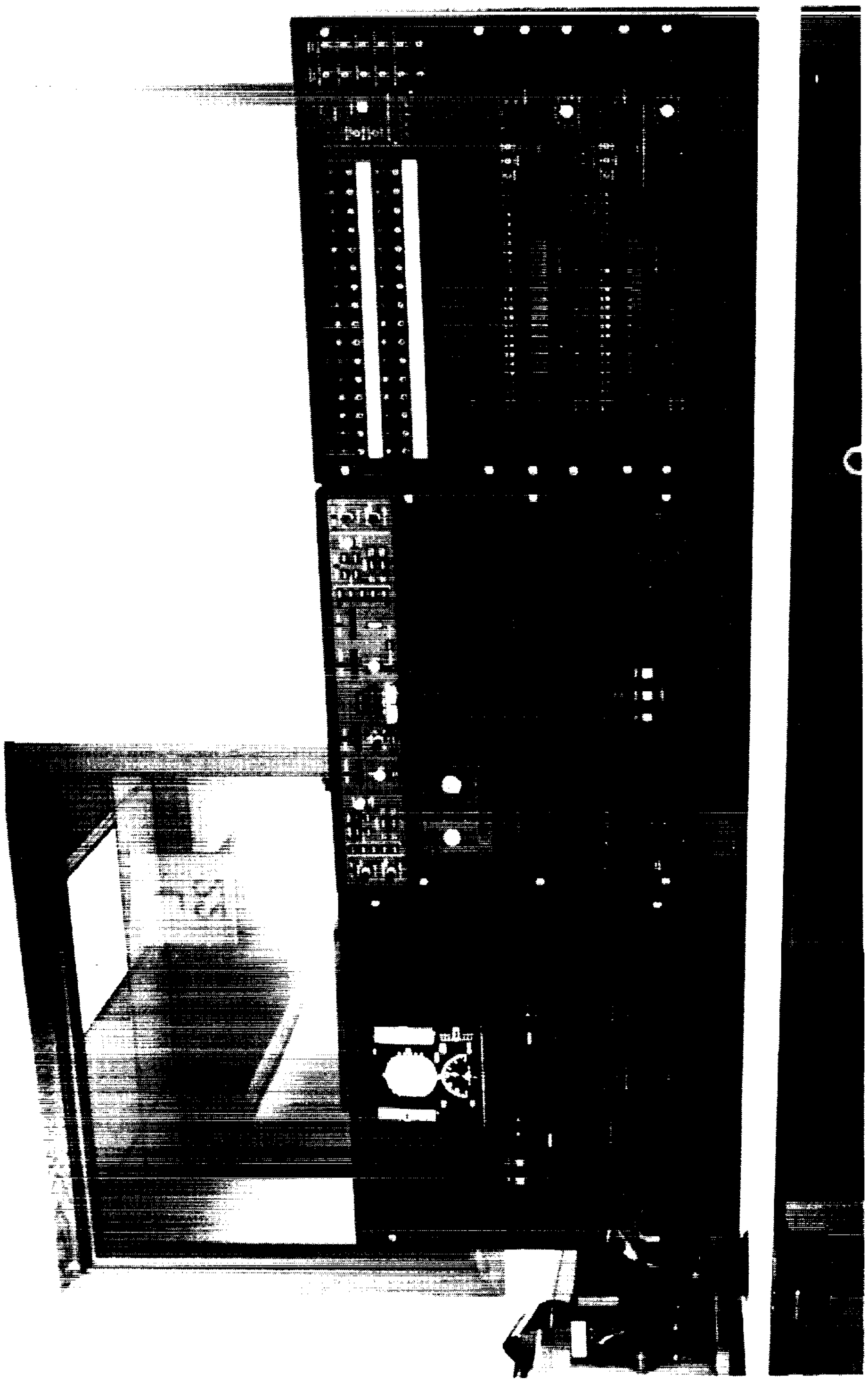
MD-11 AFS Subsystem VALFAC



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MD-11 Integration VALFAC

Cockpit Avionics Integration
Conclusions

- Level of integration in cockpit avionics has increased significantly in recent years
- Benefits of integration are readily apparent in modern aircraft cockpits
- Approach to avionics system design must change in order to take full advantage of system integration
- Different types of test facilities/test procedures are required for integrated systems
- Changes in aircraft manufacturer/avionics system supplier relationship likely

Cockpit Avionics Integration

What are the effects on Cockpit Automation? . . . .

Automation

What is it Really?

- Automatically controlled operation of an apparatus, process, or system by mechanical or electronic devices that take the place of human operators.

Merriam–Webster

- How does this apply to Cockpit Avionics? . . . .

MD–11 Cockpit Automation

Typical Aircraft System	MD–11 System
Autopilot Flight Director Auto Throttle	Auto Flight System
Compass System (slaved) Auto Nav – Lateral Auto Nav – Vertical Performance (Auto Speed)	Flight Management System
Attitude Director Indicator Horizontal Situation Indicator Engine Instruments Aircraft Alerts	Electronic Flight Instrument System
Fuel System Hydraulic System Environmental System Electrical System	Aircraft System Controllers

MD–11 ASC Hydraulic System Functions

- Pre–flight
  - –Pressure test (manually initiated)
  - –Engine–driven pumps test
- Normal
  - –System operation monitor
- Abnormal
  - –Fault isolation and system reconfiguration

MD-11 ASC Fuel System Functions

- Pre-flight
  - Test
- Normal
  - Fuel schedule
  - Tail fuel management/CG control
  - Fuel circulation to prevent freezing
  - Wing fuel balance
  - Forward pump control
  - Ballast fuel management
- Abnormal
  - Fuel dump monitor
  - Manifold drain
  - Outboard tank monitoring (trapped/premature transfer)
  - Tank overfill
  - Component failure accommodation

MD-11 ASC
Environmental System Functions

- Pre-flight
  - Test
- Normal
  - Engine start configuration
  - Bleed air limit
  - Manifold pressurization
  - Take-off mode control
  - Economy mode
- Abnormal
  - Failure reconfiguration
  - Manifold failure

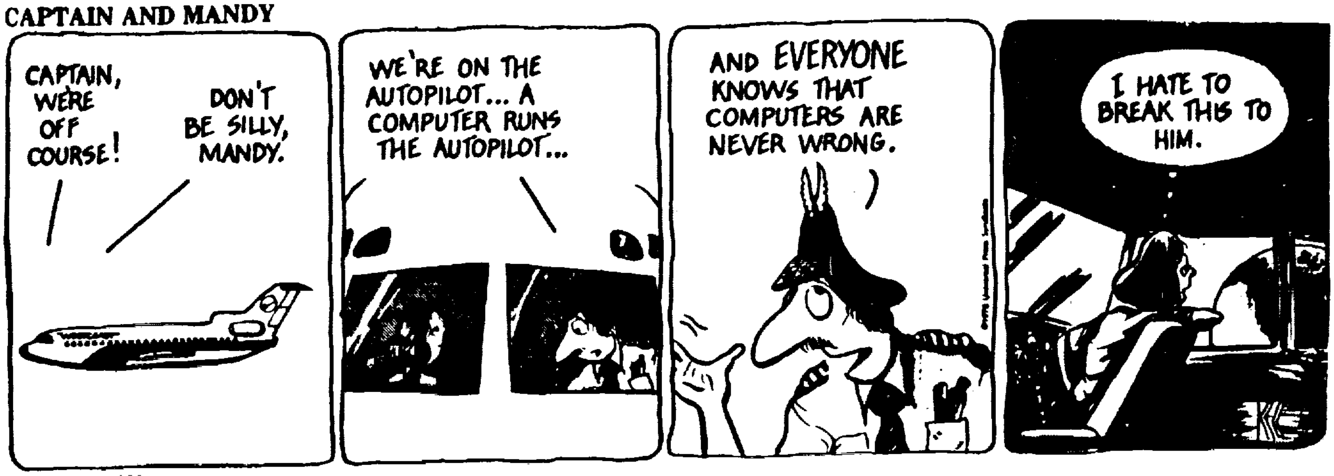
MD-11 ASC
Miscellaneous System Functions

- Pre-flight
  - -Cargo fire test
  - -Cargo doors test
  - -Air data heaters test
  - -Emergency lights battery test
- Normal
  - -Engine start control
  - -Auto ignition
  - -Cargo fire agent timing
  - -APU/CFDS interface
  - -APU shut down, on/off control
- Abnormal
  - -Pilot heat fault recovery

Cockpit Automation Concerns

- Crew awareness - does pilot need to know
- Crew work load
- Fail safe design
- Compatibility with existing operational environment
- Certificability

CAPTAIN AND MANDY



Cockpit Automation Conclusions

- Automation is unavoidable
- Automation is beneficial
- Cockpit designs must address operational/ human factors concerns
- Pilot is ultimately responsible for aircraft/ passenger safety. He must be able to do his job.

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DOUGLAS FLIGHT DECK DESIGN PHILOSOPHY

Paul Oldale
Douglas Aircraft Company

AIRCRAFT SYSTEMS

The systems experience gained from 17 years of DC-10 operation was used during the design of the MD-11 to automate system operation and reduce crew workload. All functions, from preflight to shutdown at the termination of flight, require little input from the crew.

The MD-11 aircraft systems are monitored for proper operation by the Aircraft Systems Controllers (ASC). In most cases, system reconfiguration as a result of a malfunction is automated. Manual input is required for irreversible actions such as engine shutdown, fuel dump, fire agent discharge, or Integrated Drive Generator (IDG) disconnect. During normal operations, when the cockpit is configured for flight, all annunciators on the overhead panel will be extinguished. This "Dark Cockpit" immediately confirms to the crew that the panels are correctly configured and that no abnormalities are present. Primary systems annunciations are shown in text on the Alert Area of the Engine and Alert Display (EAD). This eliminates the need to scan the overhead.

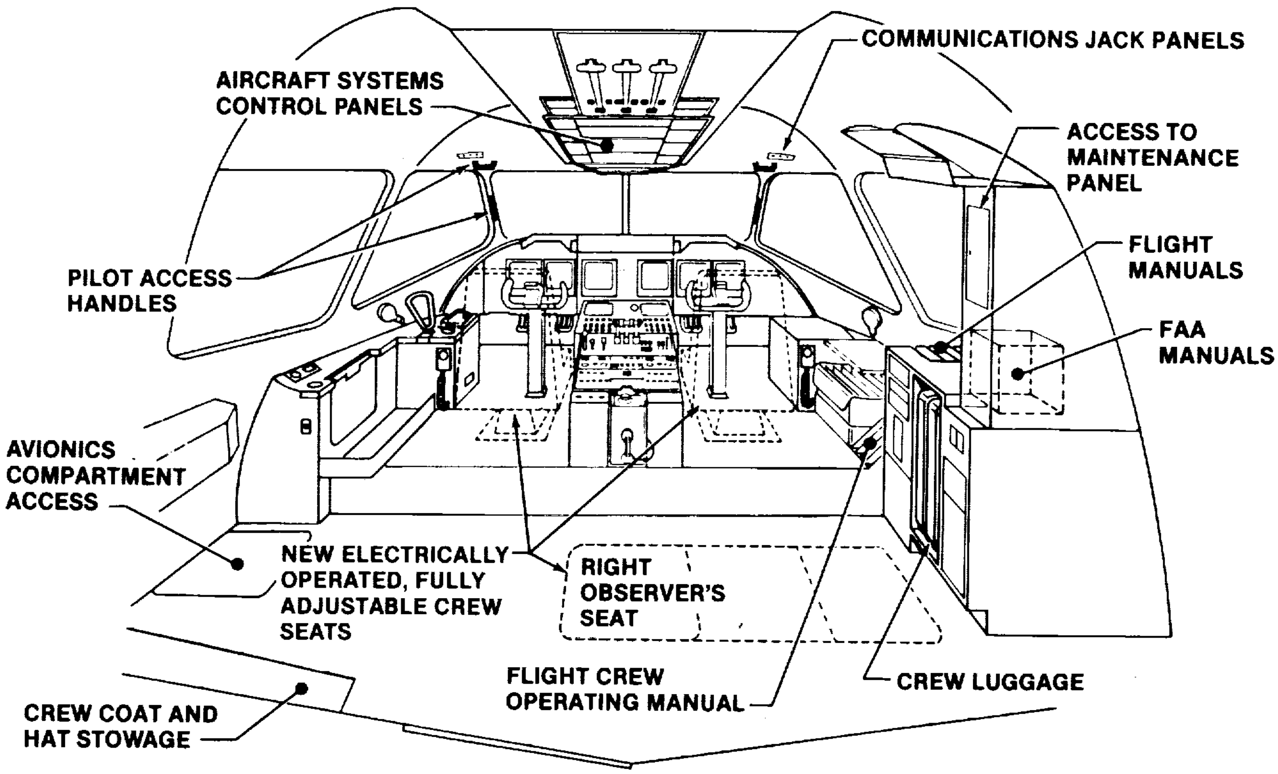
The MD-11 aircraft systems can be manually controlled from the overhead area of the cockpit. The center portion of the overhead panel is composed of the primary aircraft systems panels, which include FUEL, AIR, Electrical (ELEC) and Hydraulic (HYD) systems, which are easily accessible from both flight crew positions. Each aircraft system panel is designed in such a way that the left third of the panel controls the No. 1 system, the center portion controls the No. 2 system, and the right side controls the No. 3 system. For quick reference, they are lined up directly with the No. 1, No. 2 and No. 3 engine fire handles. The most used panels are located in the lower forward area of the overhead; the lesser used panels are in the upper aft area. Each aircraft system panel has a pictorial schematic of that system on the light plate that symbolically connects the various systems and controls on that panel. This schematic closely resembles the System Synoptic shown on the Systems Display (SD).

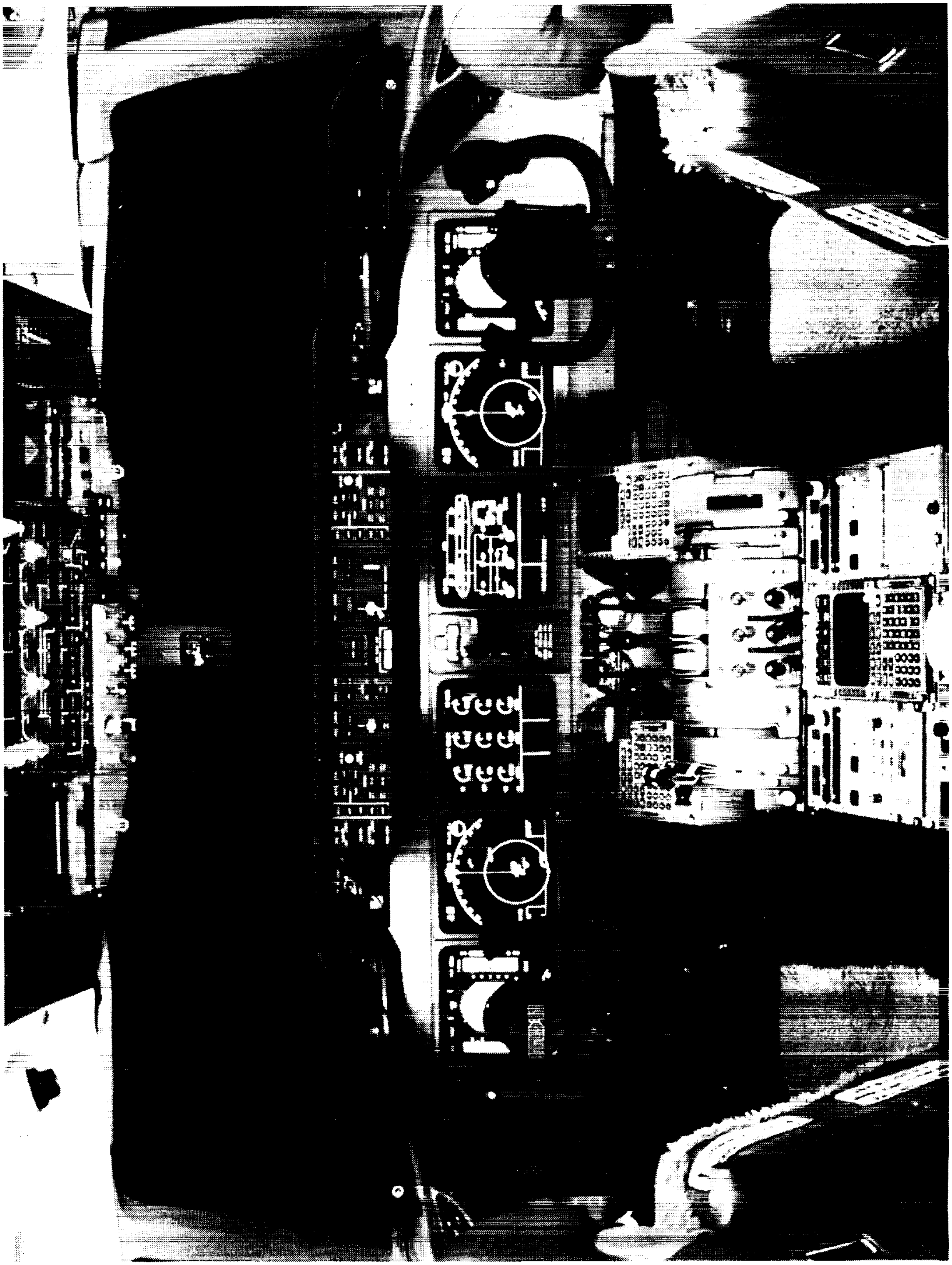
Each Aircraft Systems Controller (ASC) has two automatic channels and a manual mode. Should the operating automatic channel fail or be shut off by its protection devices, the ASC will automatically select the alternate automatic channel and continue to operate automatically as required for that particular flight condition (manual selection of the alternate channel is also possible). Should both automatic channels fail, the controller will revert to manual operation and reconfigure the aircraft to a safe condition. The crew would then employ simplified manual procedures for the remainder of the flight for that system only.

All rectangular lights are annunciators. All square lights are combined switches and annunciators called switch/lights. Red switch/lights on the overhead (Level 3 alerts) are for conditions requiring immediate crew action. Amber (Level 2 or Level 1 alerts) indicates a fault or switch out of position requiring awarness or crew interaction. Overhead switches used in normal operating conditions will illuminate blue when in use (Level 0 alerts) such as WING ANTI-ICE — ON.

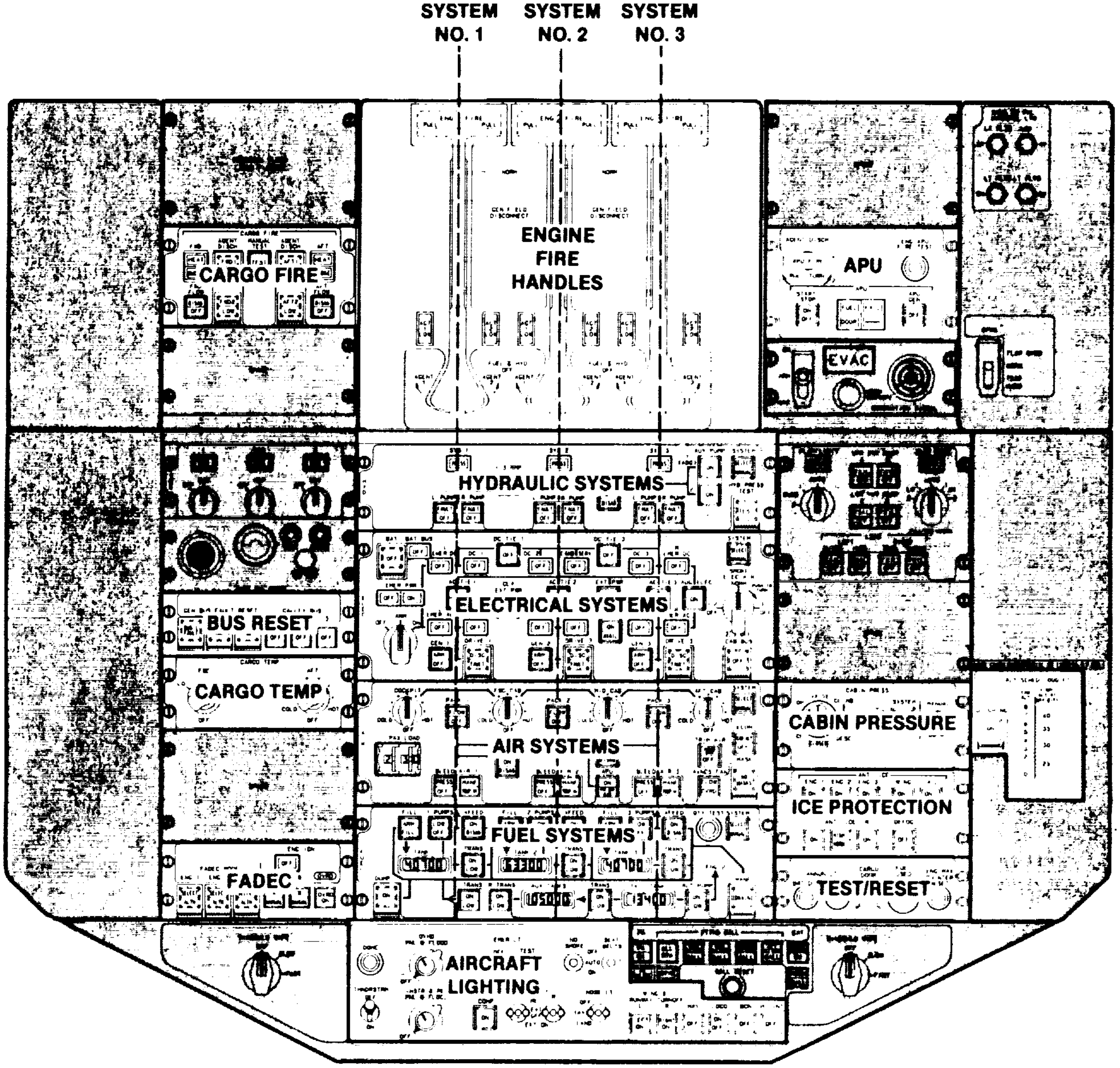
An overhead switch/light with BLACK LETTERING on an amber or red background indicates a system failure and that crew interaction is required. A switch/light with blue or amber lettering and a BLACK BACKGROUND indicates a switch out of normal position and that crew action is necessary only if the system is in manual operation.

MD-11 FLIGHT COMPARTMENT





MD-11
AIRCRAFT SYSTEMS



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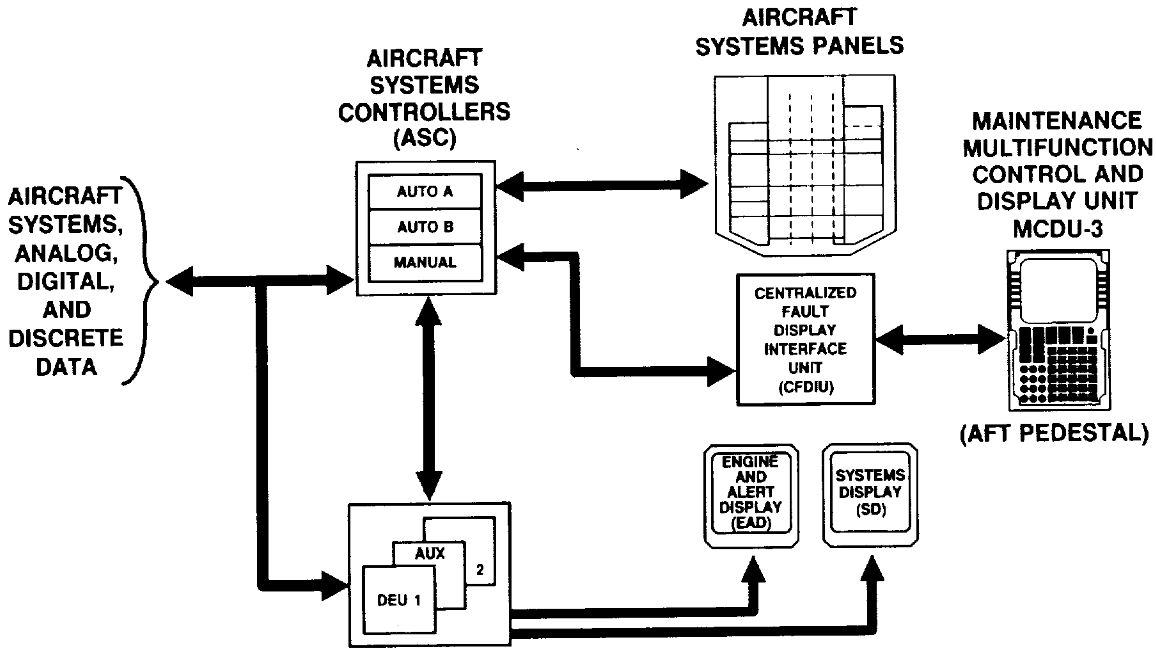
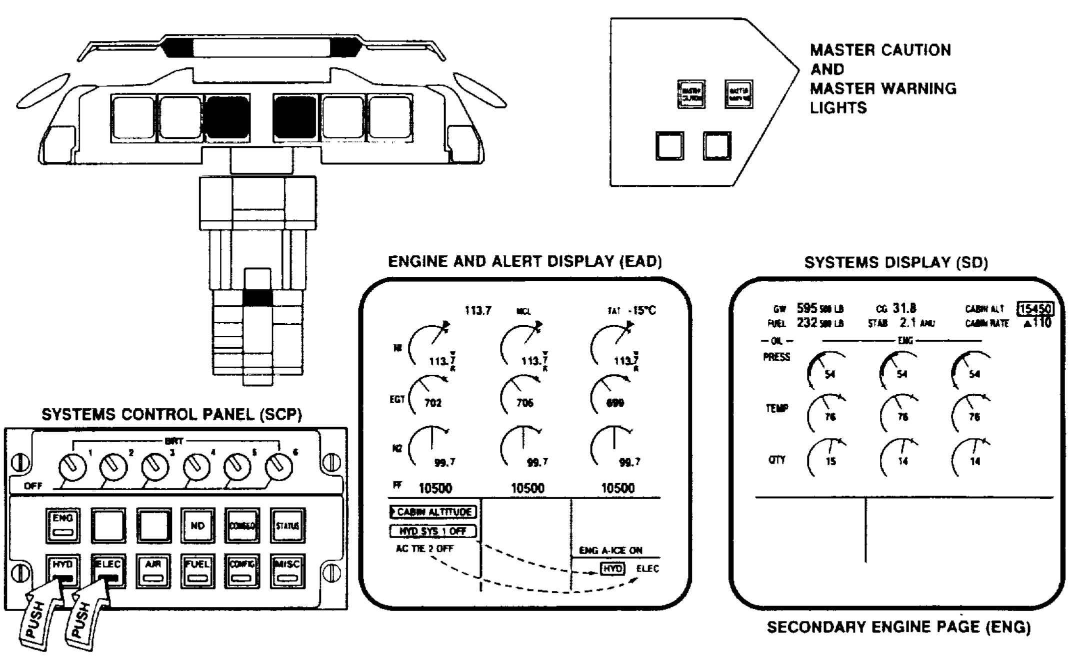
ASC SYSTEM



ALERTING SYSTEM COMPONENTS



SUMMARIZED FAULT DATA
(GENERATOR BUS FAULT CONDITION ILLUSTRATED)

DC-10 CONTROL PANEL
ANNUNCIATOR LIGHTS

R EMER AC BUS OFF	FUEL PMP 1 PRESS LO
R EMER DC BUS OFF	UPR R AUX PMP PRESS LO
DC BUS 3 OFF	ENG 3 ANTI ICE DISAG
AC BUS TIE 3 ISOL	
AC BUS 3 OFF	
GEN 3 OFF	
GALLEY POWER OFF	

DC-10 CONCEPT REQUIRED INTERPRETATION
OF SEVERAL ANNUNCIATIONS TO DETERMINE
"ROOT" CAUSE OF THE PROBLEM

▼

AC BUS TIE ISOL + AC BUS OFF +
GEN OFF LIGHT ON = GEN BUS FAULT

MD-11 PROVIDES SPECIFIC
ANNUNCIATION OF THE
PROBLEM

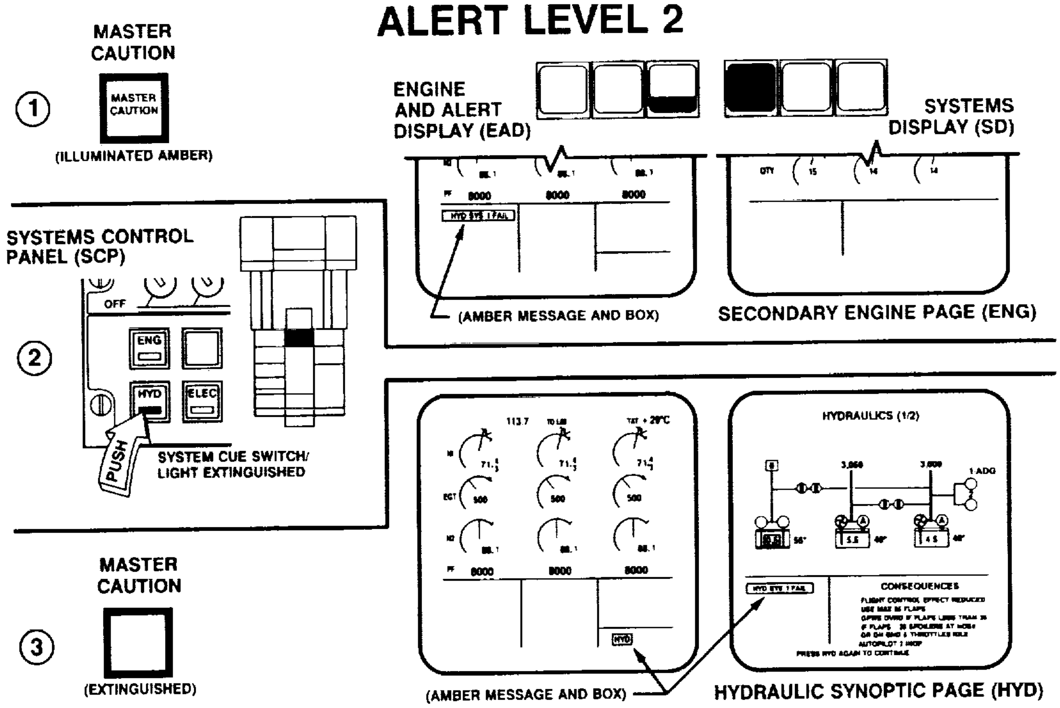
GEN BUS 3 FAULT

ENGINE AND
ALERT DISPLAY (EAD)

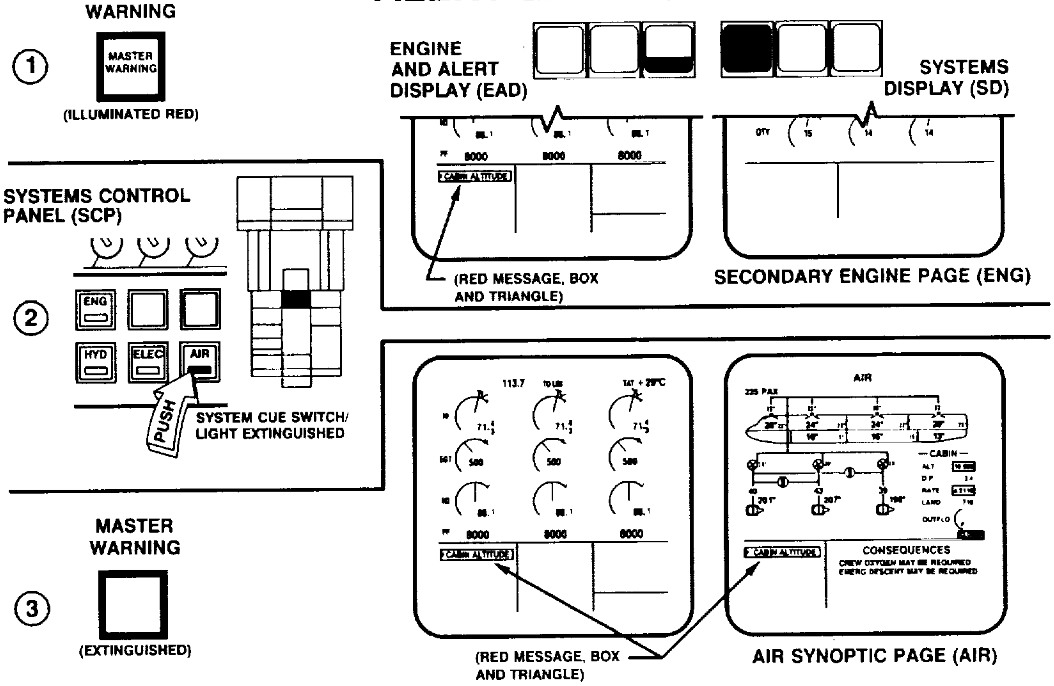
PROCEDURAL STEPS REQUIRED TO EXECUTE THE PROCEDURE (MD-11 AUTO MODE)

DC-10 = 13-16 **MD-11 = 0**

ALERT LEVEL 2



ALERT LEVEL 3



N91-10940

NATIONAL PLAN TO ENHANCE AVIATION SAFETY THROUGH HUMAN FACTORS IMPROVEMENTS

Clay Foushee
FAA

CONTROLLER

PURPOSE

The purpose of this section of the Plan is to establish a development and implementation strategy plan for improving safety and efficiency in the Air Traffic Control (ATC) system. These improvements will be achieved through the proper applications of human factors considerations to the present and future systems.

The program will have four basic goals:

- -prepare for the future system through proper hiring and training.
- -develop controller work station team concept (managing human errors).
- -understand and address the human factors implications of negative system results (NMACs, incursions, etc.).
- -define the proper division of responsibilities and interactions between the human and the machine in ATC systems.

PROGRAM ELEMENTS

This plan addresses six program elements which together address the overall purpose. The six program elements are

1. Determine principles of human-centered automation that will enhance aviation safety and the efficiency of the air traffic controller.

2. Provide new and/or enhanced methods and techniques to measure, assess, and improve human performance in the ATC environment.

3. Determine system needs and methods for information transfer between and within controller teams and between controller teams and the cockpit.

4. Determine how new controller work station technology can optimally be applied and integrated to enhance safety and efficiency.

5. Assess training needs and develop improved techniques and strategies for selection, training, and evaluation of controllers.

6. Develop standards, methods, and procedures for the certification and validation of human engineering in the design, testing, and implementation of any hardware or software system element which affects information flow to or from the human.

PROGRAM MANAGEMENT

(Details of program management are yet to be worked out but it appears obvious that to be effective, the program must be managed in such a way as to cross all organizational lines. Attached is a paper entitled "Configuration of the Mind: a concept of Human Factors" which may contain the basic requirements for the management of this program.)

PROGRAM DESCRIPTIONS

1. AUTOMATION

Program Element. - Determine principles of human-centered automation that will enhance aviation safety and the efficiency of the air traffic controller.

Problem. - The proposed introduction of advanced computer-based technology into the controller work environment will be associated with a dramatic change in both the role and expertise expected of the controller. To an increasing degree, the computer will be working from a self generated "plan" to make recommendations to the controller. The controllers ability and willingness to accept these decisions while maintaining responsibility for the separation of aircraft will present major challenges to system designers.

Approach

1. Develop a human centered philosophy of automation by evaluating levels and degrees of automation as well as alternative automation strategies. The human as monitor is one extreme while the machine as monitor is the other.

2. Define the limits to automation tasks. This should include a determination of when an automated system should be limited due to the human's inability to comprehend its actions or to take over where procedures require.

3. In keeping with the proposed level of human responsibility, evaluate the human functions dynamically as automated system planning evolves.

4. Define function allocation and more explicit criteria for assigning tasks, and develop quantitative measures.

5. Conduct scientifically valid simulation studies which measure human performance using various automation philosophies (i.e., kind and level of automation).

Results/Products

1. A methodology for evaluating the effect of alternative levels of automation on overall human/system performance in a real time simulated and real time operational environment

2. Guidelines for determining the optimal role of both the controller and the automation under various conditions

3. Guidelines for warning devices/alerting systems which notify the human of the failure or partial failure of an automated system

2. HUMAN PERFORMANCE

Program Element. - Provide new and/or enhanced methods and techniques to measure, assess, and improve human performance in the ATC environment.

Problem. - The existing body of human factors knowledge, data and methods for assessing and predicting human performance needs to be expanded. Easy to use and predictive workload measurers are not available.

Approach

1. Investigate and identify the human performance limitations at the ATC work station. Realistic human performance expectations (including what can designers realistically expect in human performance, e.g., what is the required time to respond to an external stimulus?) should be developed.

2. Develop improved methods of measuring controller mental state and workload criteria.

3. Define the effects on performance of fatigue, disruptive rest/work cycles, and drugs.

4. Develop fundamental understanding of decision making and means to aid or improve it in aviation.

5. Define team building methodologies for improved ATC work station resource management, including means to support or enhance the decision making process.

Results/Product

1. Provision of basic tools needed to assess potential problem areas and evaluate design.

2. Guidelines for work station design, certification, and operating procedures.

3. Plan for an ATC work station resource management (team building) program.

3. INFORMATION TRANSFER/CONTROLLER-PILOT INTERFACE

Program Element. - Determine system needs and methods for information transfer between and within controller teams and between controller teams and the cockpit.

Problem. - The information requirements of controllers and flight crews in an increasingly complex aviation system must be specified, and methods developed for the transfer, management, and integration of this information in ways which reduce the chance of accident due to human error.

Approach. - The sources and types of information available to and needed by the controller and flight crew will be identified, classified and prioritized. Various data entry and display methods will be evaluated in part-task studies prior to being integrated and validated in full mission simulations and/or operational evaluations.

Results/Product

1. Prioritized inventory of total information available at the work station

2. Guidelines for information management

4. CONTROLS AND DISPLAYS

Program Element. - Determine how new controller work station technology can optimally be applied and integrated to enhance safety and efficiency.

Problem. - Continued engineering development has, and will continue to provide a technological base to enhance system safety and increase productivity. Methods of displaying, controlling, and integrating data for input to and to accept output from the controller must be further developed to assure proper application.

Approach. - On an ongoing basis, assess the ability of new technology displays and input devices to enhance the man-machine relationship. As appropriate, develop projects to

1. Develop new display technology. This includes new methods (e.g. 3D displays), new materials and color enhancements.

2. Improve and standardize ATC display formats, symbology, and annunciations.

3. Develop data transfer systems that can exchange data between the aircraft and ground in a timely manner.

4. Explore the use of touch panel inputs as well as voice recognition.

5. Apply Artificial Intelligence and expert systems into the ATC work station. Fault analysis and appropriate display to controller should be included.

Results/Product

1. Fundamental understanding of displays for information transfer

2. Guidelines for design and certification of ATC automation and display systems

3. Systems to improve the decision making process

5. SELECTION AND TRAINING

Program Element. - Assess training needs and develop improved techniques and strategies for selection, training, and evaluation of controllers.

Problem. - Current hiring, training, and qualification requirements do not necessarily take into account the operational environment with new automation capabilities in the ATC work station and the new training techniques available. For example, concern has been expressed about the effects of automation on the controller's traditional skills.

Approach

1. Review fundamental training requirements and assess their effectiveness in today's and tomorrow's ATC system.

2. Assess the efficacy of ATC work station resource management training from the perspectives of the present and future needs.

3. Study the types of training programs which can be developed and/or utilized to reduce the causal factors in instances of negative system results.

4. Review controller selection criteria with a view towards appropriate staffing for future systems.

6. Consider the advantages and disadvantages of ab-initio training.

Results/Product

1. Specific human factors audio/visual and CBI training criteria.
2. Human factors training programs for ATC work station resource management (team building).

3. Specifications of training program characteristics which lead to enhanced safety and productivity in the present system and future systems.

4. Definition of a "potential controller" profile and techniques for ascertaining its degree in an applicant.

6.CERTIFICATION

Program Element. - Develop standards, methods, and procedures for the certification and validation of human engineering in the design, testing, and implementation of any hardware or software system element which affects information flow to or from the human.

Problem. - The current FAA process does not adequately stress the importance of and the corresponding need for well founded human factors technology to be applied throughout the initial design stage of new or modified ATC system elements. Nor does the current process provide sufficient procedures for certification of the appropriateness of the input/output of data to/from the human. Nor are there procedures for certifying task assignments and the associated information requirements relative to the human.

Approach

1. Develop new certification standards and the means to assess the human interface with the ATC work stations. Means will be developed to allow evaluation of the effects of the introduction of new systems in the controller work station. Standards will include issues relating to the intermixing of old and new systems as well as transition strategies.

2. Develop standards which assure that human factors considerations are properly incorporated in the existing configuration management process.

Results/Product. - Recommended additions to the existing configuration management system which require appropriate human factors consideration for any new or changed system element which affects the human input, output, or data processing.

CONFIGURATION MANAGEMENT OF THE MIND:

A Concept of Human Factors

We in the FAA have been wrestling for a long time with the concept of Human Factors. We write about it; we study it; we agonize over it, but we can't quite seem to come to grips with it. I submit that while all that has been done, is being done, and will be done is important and necessary, it is all for naught because we continually overlook one key element - application. There exists in the FAA no vehicle whereby the knowledge and experience of the experts in the fields (truly there is a multiplicity of disciplines involved) are brought to bear on the requirements definition, acquisition and implementation process.

This paper proposes a concept which, if implemented as an element of a total FAA Human Factors program, would insure the delivery of far superior products to the controller in the field.

BASIC ASSUMPTIONS

The concept under discussion here makes several basic assumptions. It would be impossible for the concept to be understood, much less accepted, without an acceptance of these assumptions:

-the human is one element in a very complex ATC system of many elements
-a major consideration in controller Human Factors is one of information flow - from the machine to the controller and from the controller to the machine
-the controller has two input sources - ears and eyes
-the controller has two output sources - voice and touch
-each I/O source is unique in its capabilities and its limitations (sight requires direction, touch requires proximity, etc.)
-the human mind processes different data types in different ways; ergo, the form in which a datum type is presented is of extreme importance (properly design allows for pre-processing external to the human.

CURRENT FALLACY

The time honored approach to human factors within the FAA has been: "Ask the user what he wants; he knows best." Often a preliminary step is taken in which a computer display expert or an engineering expert will offer a choice of two or three options for the user to select from. These choices are usually very sound <u>computer display or engineering</u> options, but are they sound <u>human factors</u> options? Another common preliminary step in the name of human factors is to study the new hardware from an ergonomics perspective. These studies will lead to either recommendations or a report (or both) but never to <u>requirements</u>.

The bottom line is that all elements of the system conform to requirements developed and approved by experts in the field except for the most complex system element - the human. And why is this? Simply because all other elements of the system are under configuration management <u>except the human</u>. Also, the transfer of data between elements is designed and controlled by Interface Control Documents (ICDs) but no such vehicle exists for data transfer to or from the human.

THE SOLUTION

A system must be created along with the enabling support structure which will configuration manage the human mind. As is the case with any other configuration managed system element, the supporting structure must have the capability <u>and authority</u> to influence the design, acquisition and implementation of any new or modified hardware, software or procedure which causes a change in the data flow to or from the human. Equally important is the capability and authority over anything which would change the way in which the human processes data.

N91-10941

AVIATION SAFETY/AUTOMATION PROGRAM OVERVIEW

Samuel A. Morello
NASA Langley Research Center

Aviation Safety/Automation

NATIONAL AERONAUTICS & SPACE ADMINISTRATION

FY89 BASE AUGMENTATION

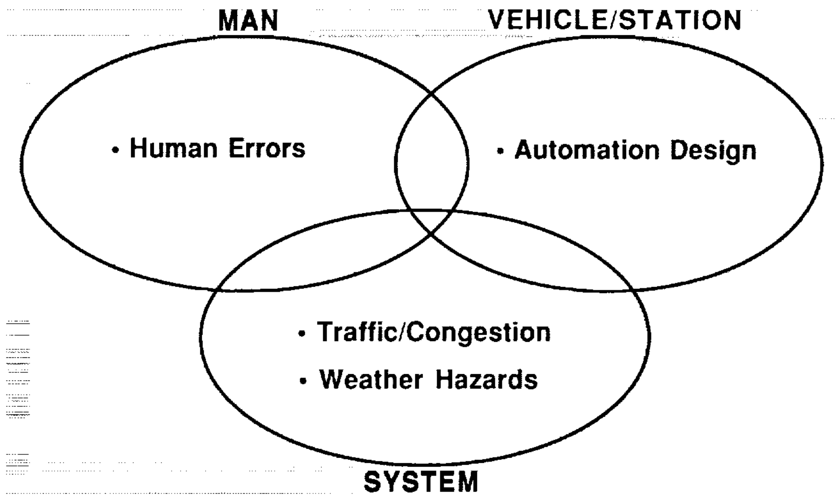
NASA Ames Research Center • NASA Langley Research Center

GOAL

PROVIDE THE TECHNOLOGY BASE LEADING TO IMPROVED SAFETY OF THE NATIONAL AIRSPACE SYSTEM THROUGH DEVELOPMENT AND INTEGRATION OF HUMAN-CENTERED AUTOMATION TECHNOLOGIES FOR AIRCRAFT CREWS AND AIR TRAFFIC CONTROLLERS

AVIATION SAFETY/AUTOMATION

The Problems



Perspective

- Automation can improve the efficiency, capacity and dependability of the national aviation system

— BUT —

- Humans will manage, operate and assure the safety of the next generation system

— THEREFORE —

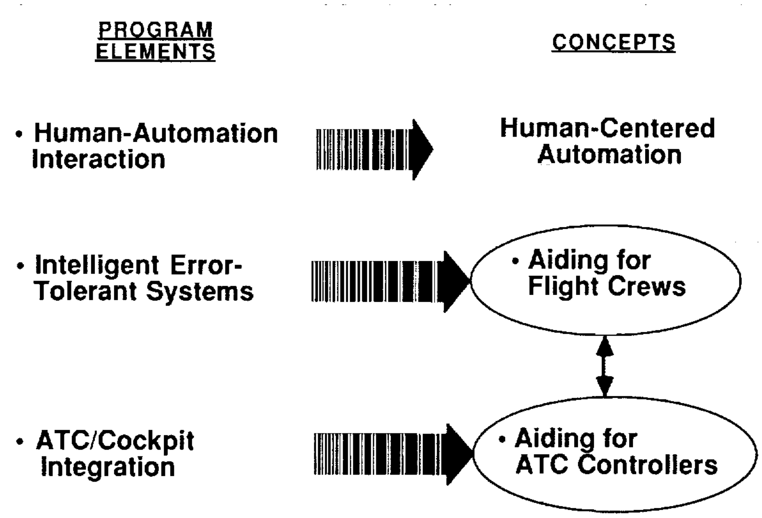
- Human-centered automation is the key to system effectiveness

AVIATION SAFETY/AUTOMATION

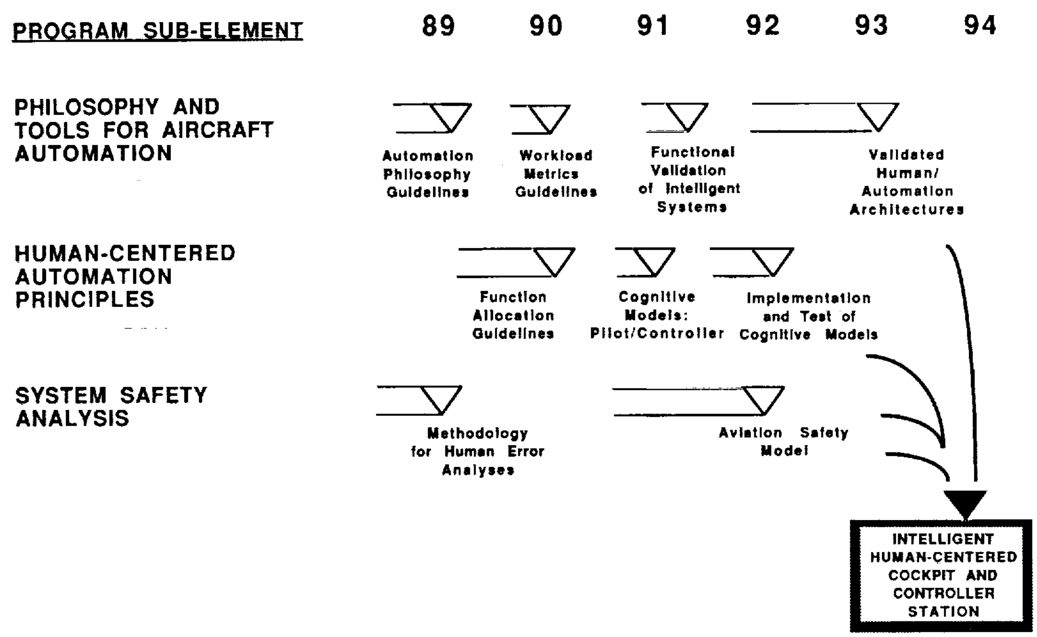
Specific Objectives

- To develop the basis, consisting of philosophies and guidelines, for applying human-centered automation to the flight deck and ATC controller station
- To provide human-centered automation concepts and methods to the flight crew which ensure full situation awareness
- To provide human-centered automation concepts and methods for ATC controllers which allow integration and management of information and air-ground communications

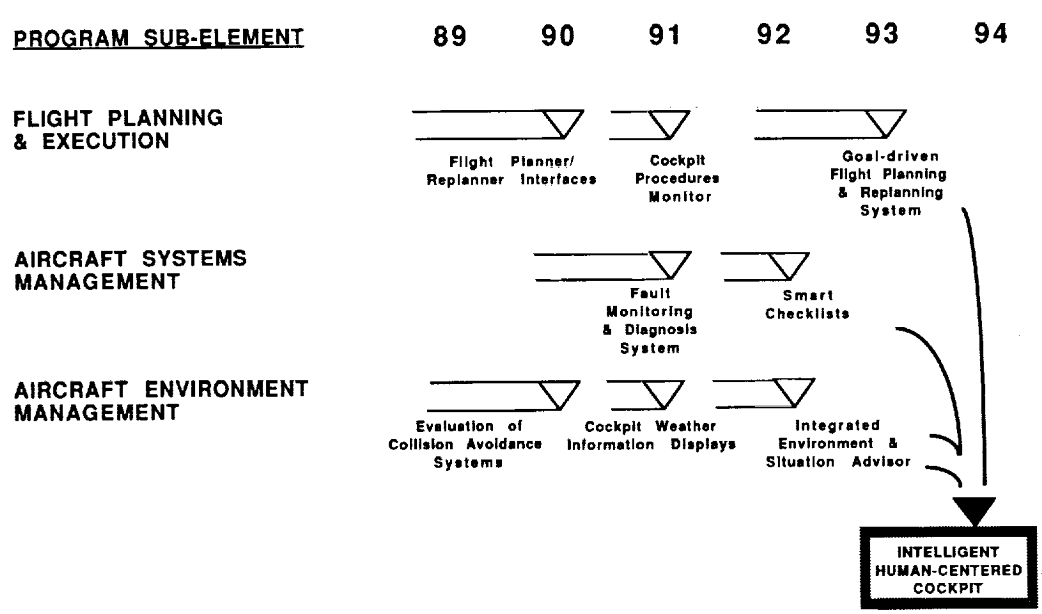
Overview



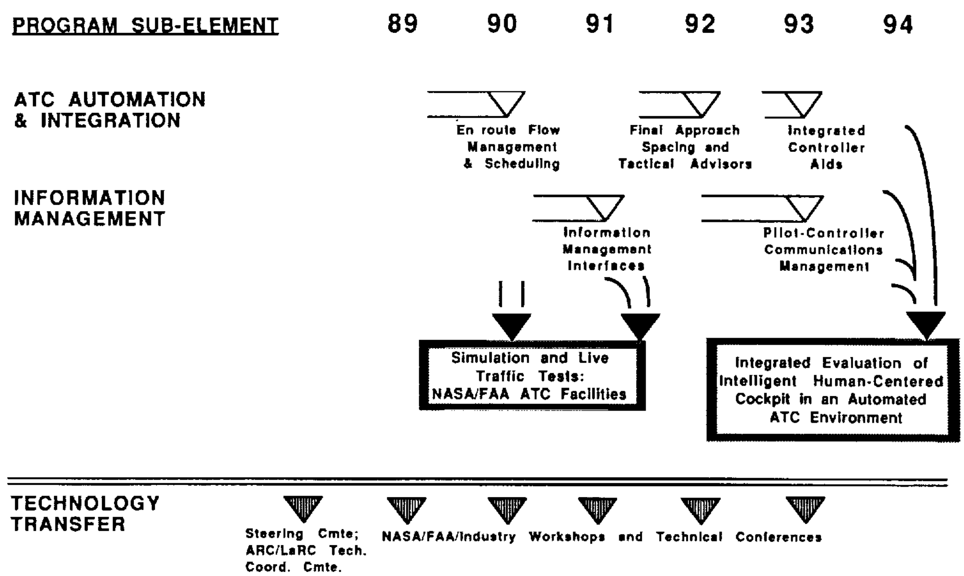
HUMAN-AUTOMATION INTERACTION



INTELLIGENT ERROR-TOLERANT SYSTEMS



ATC/COCKPIT INTEGRATION



PROGRAM ELEMENT I

HUMAN/AUTOMATION INTERACTION

N91-10942

SUMMARY OF THE INDUSTRY/NASA/FAA WORKSHOP ON PHILOSOPHY OF AUTOMATION: PROMISES AND REALITIES

Susan D. Norman
NASA Ames Research Center

ABSTRACT

Issues of flight deck automation are multi-faceted and complex. The rapid introduction of advanced computer based technology on to the flight deck of transport category aircraft has had considerable impact on both aircraft operations and the flight crew. As part of NASA's responsibility to facilitate an active exchange of ideas and information between members of the aviation community, an Industry/NASA/FAA workshop was conducted in August 1988. This paper summarized the major conclusions of that workshop.

One of the most important conclusions to emerge from the workshop was that the introduction of automation has clearly benefited aviation and has substantially improved the operational safety and efficiency of our air transport system. For example, one carrier stated that they have been flying the Boeing 767 (one of the first aircraft to employ substantial automation) since 1982, and they have never had an accident or incident resulting in damage to the aircraft.

Notwithstanding its benefits, many issues associated with the design, certification, and operation of automated aircraft were identified. For example two key conceptual issues were the need for the crew to have a thorough understanding of the system and the importance of defining the pilot's role. With respect to certification, a fundamental issue is the lack of comprehensive human factors requirements in the current regulations. Operational considerations, which have been a factor in incidents involving automation, were also cited.

Copies of the final report, *NASA Conference Publication 10036,* may be obtained by requesting a copy from

Susan Norman
Aerospace Human Factors Division
NASA Ames Research Center
Moffett Field, California 94035

AUTOMATION IS A CLEAR BENEFIT

DESIGN PHILOSOPHIES

(From Boeing Commercial Airplane Company)

Effective Systems Design

1) Simplicity

2) Redundancy

3) Automation

OPERATIONAL LESSONS LEARNED

TRAINING/ OPERATIONAL PROCEDURES

- Crews need to understand HOW the system works

MODE MISAPPLICATION

- Crew assumption that the aircraft is operating in one mode when it is actually in another

OPERATIONAL CRUTCHES

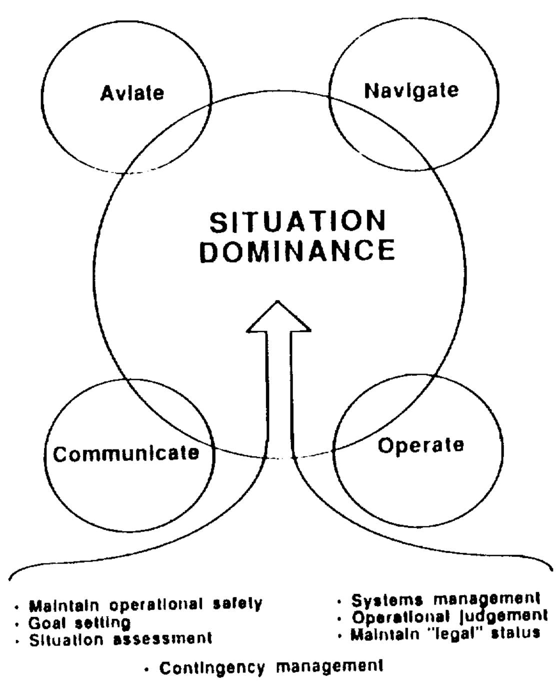
- Changing an operational procedure to get around an improper design

SOFT FAILURES

- When an automated system is not indicating a failure yet something is clearly wrong

ISSUES IN AUTOMATION

DESIGN/
ROLE of the PILOT



TECHNICAL SUMMARY

1) UNDERSTANDING NORMAL versus IRREGULAR OPERATIONS

Irregular operations are "UNANTICIPATED" deviations from intended flight operations

2) DEFINE the ROLE of the PILOT

Distinguish between the Pilot's GOAL and ROLE

Develop a Philosophy of Automation

3) AIR-GROUND COMMUNICATION INTERFACE

A SYSTEMS Perspective is needed

4) CERTIFICATION of AUTOMATED SYSTEMS

Need to develop HUMAN FACTORS criteria/guidelines

N91-10943

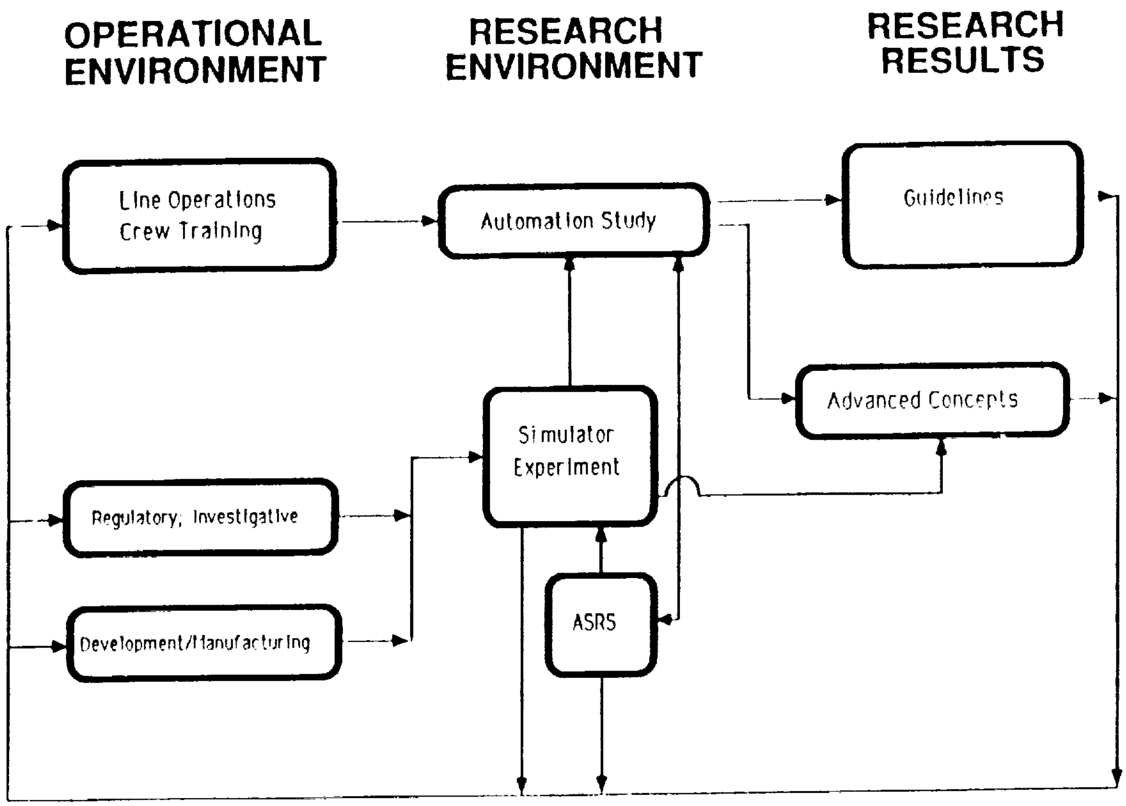
HUMAN FACTORS OF THE HIGH TECHNOLOGY COCKPIT

Earl L. Wiener
University of Miami

ABSTRACT

The rapid advance of cockpit automation in the last decade has outstripped the ability of the human factors profession to understand the changes in human functions required. High technology cockpits require less physical (observable) workload, but are highly demanding of cognitive functions such as planning, alternative selection, and monitoring. Furthermore, automation creates opportunity for new and more serious forms of human error, and many pilots are concerned about the possibility of complacency affecting their performance.

On the positive side, the equipment works ''as advertised'' with high reliability, offering highly efficient, computer-based flight. These findings from the cockpit studies probably apply equally to other industries, such as nuclear power production, other modes of transportation, medicine, and manufacturing, all of which traditionally have looked to aviation for technological leadership. The challenge to the human factors profession is to aid designers, operators, and training departments in exploiting the positive side of automation, while seeking solutions to the negative side.



INCIDENTS AND ACCIDENTS

MARINE
- Herald of Free Enterprise
- Exxon Valdez

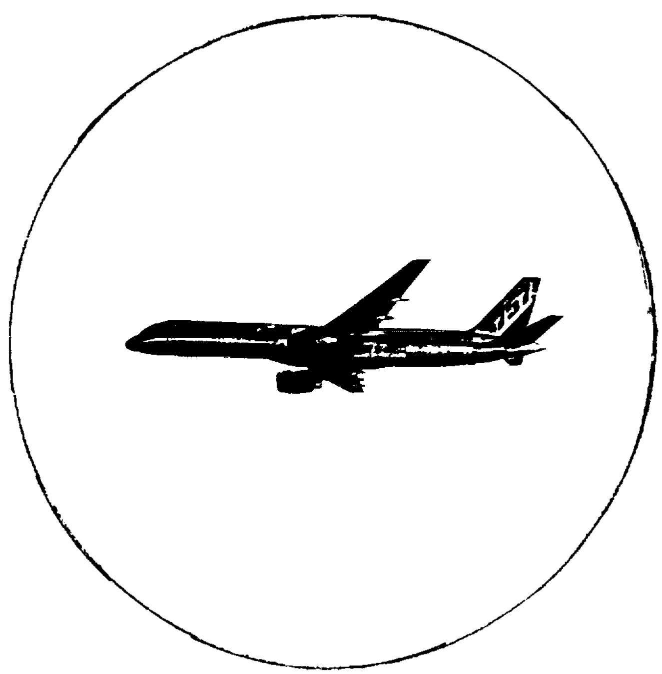
PRODUCTION
- Three Mile Island
- Chernobyl
- Bhopal

MILITARY
- U.S.S. Vincennes/Iran Air 655

CRM ISSUES

- Who does what (SOPA)
- Supervision
- Shift of authority
- Independence of crew members
- Failure to coordinate more critical
- Automation requires more CRM, not less

THE ELECTRONIC COCOON



FINDINGS

- High enthusiasm for 757, but reservations about safety
- Workload may be increased or decreased
- Less time head-up in terminal area
- Two vs. three pilots still at issue
- Training overall good, but too much emphasis on automation rather than basics
- ATC limits exploitation of 757 features especially VNAV
- Crew coordination critical in glass cockpit

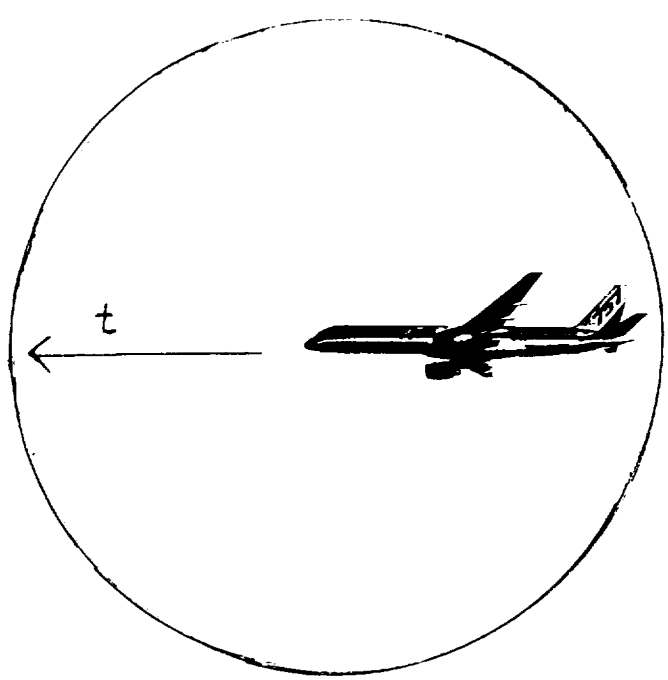
INTERVENTION STRATEGIES

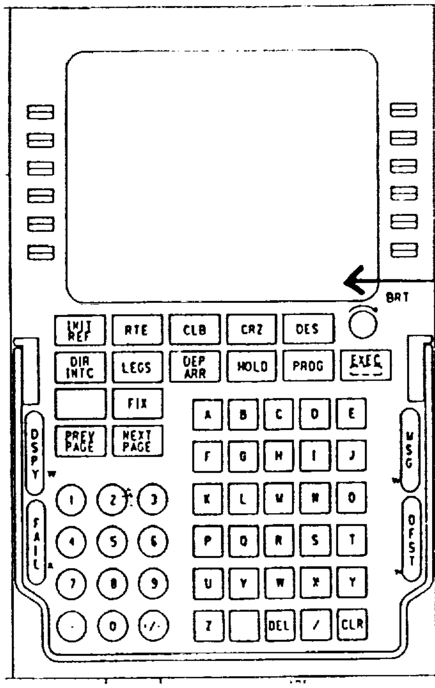
- **BASIC HUMAN ENGINEERING**
- **CREW COORDINATION TRAINING**
- **INTELLIGENT WARNING AND ALERTING**
- **ERROR-EVIDENT DISPLAYS**
- **PREDICTIVE WARNING SYSTEMS**
- **INTENT-DRIVEN SYSTEMS**

CONCLUSIONS

- Equipment
- Errors
- Training
- Workload
- ATC

THE ELECTRONIC COCOON





"INSUFFICIENT FUEL"

N91-10944

HUMAN-CENTERED AUTOMATION: DEVELOPMENT OF A PHILOSOPHY

Curtis Graeber
and
Charles E. Billings
NASA Ames Research Center

AVIATION SAFETY/AUTOMATION PROGRAM CONFERENCE
11-12 October 1989

HUMAN-CENTERED AUTOMATION PHILOSOPHY

ATA National Plan, April 1989; pg. 5:

- The **fundamental concern** is the lack of a scientifically based **philosophy of automation** which describes the circumstances under which tasks are appropriately allocated to the machine and/or to the pilot.
  - **Humans** will continue to **manage and direct the NAS** through 2010.
  - Automation should be designed to **assist** and **augment** the capabilities of the human managers.
  - It is vitally important to develop **human-centered automation** for the piloted cockpit and controller work station.
- NASA's Aviation Safety/Automation Program is founded in large part on these precepts.

IMPLICATIONS OF THE PRECEPTS IN THE NATIONAL PLAN

- An explicit philosophy of automation, and the explicit allocation of functions between humans and machines in the system, are **inextricable**.
  - Both must be approached as **fundamental design issues**.
- By implication, automation can be designed to fulfill any task necessary for effective system functioning.
  - This is not true yet, but we believe it will be within a decade or so, perhaps sooner.
- Despite this automation capability, **humans** are to continue to manage and control the system, for a variety of social and political as well as technical (and probably economic) reasons.
  - Automation should therefore function to **supplement, not to supplant**, the human management and control function in civil air transport.

HUMAN-CENTERED AUTOMATION PHILOSOPHY

• Automation implementation to date has been largely **technology-driven**

highly capable solid-state avionics	⟹	highly automated flight and performance management systems (B747-400)
highly reliable redundant distributed microprocessors	⟹	automatic, reconfigurable aircraft subsystem management systems (MD-11)
highly sophisticated fly-by-wire control and guidance systems	⟹	simplified flight control with comprehensive envelope protection (A-320)

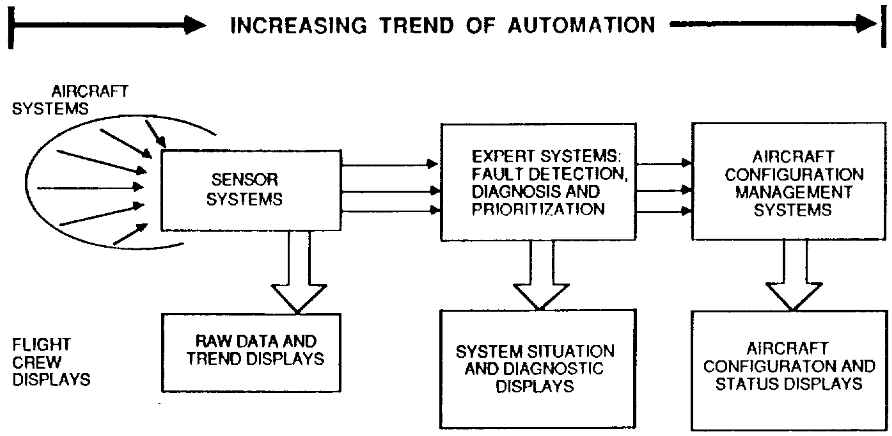
• *Do these systems, as implemented to date, **supplement**, or tend to **supplant**, the flight crew as manager and controller of its aircraft?*

• *Do they perform the functions that a **human-centered** automation philosophy would allocate to the machine, or to the human?*

• To answer these questions, we must be more explicit. What do we mean by "human-centered automation"? Is it merely a catchy phrase, or a concept that can be defined and evaluated rigorously?

• Because of the central importance of this question, we have given it considerable attention from the genesis of the Aviation Safety/Automation concept and program in 1987, though our work leading up to this program has been in progress for nearly a decade.

HUMAN-CENTERED AUTOMATION PHILOSOPHY



- What does the flight crew need to know?
- The answer depends on the automation philosophy embodied in the aircraft:
  - Why is the flight crew informed?
  - What are they expected to do about the information?
  - Are they informed before, or after, action has been taken?
  - Are they expected to diagnose the problem, choose a course of action, concur with such a choice, carry out the action, or simply to be aware of altered aircraft configuration or status?

- These and other similar questions about increasingly competent and autonomous automated systems have led to a search for a set of irreducible first principles for human-centered aircraft automation.

- Our present construct is shown in the following viewgraph, in the hope that we shall receive constructive criticism from the experts at this workshop.

HUMAN CENTERED AUTOMATION: FIRST PRINCIPLES

PREMISE:	The pilot bears the ultimate responsibility for the safety of any flight operation.
AXIOM:	The human operator must be in command.
COROLLARIES:	The human operator must be involved. To be involved, the human operator must be informed.

Because systems are fallible, and in order to remain informed,

The human operator must monitor the system.

Because humans are likewise fallible,

The system should also monitor the human operator.

If monitoring is to be effective,

Each component must have knowledge of the other's intent.

HUMAN-CENTERED AUTOMATION: APPLICATIONS OF CONSTRUCT

We have examined a number of mishaps and proposed systems in terms of this construct:

- China Airlines descent into SFO
  - Needed A/P status information not immediately obvious
  - Flight crew not sufficiently involved
  - Was system effectively in command?
- Air Canada fuel exhaustion
  - FMC system knew flight crew intent
  - But aircraft was unable to inform crew of insufficient fuel
- A proposed system with automatic reconfiguration
  - Should operator be informed of problem, or solution?
  - Should operator be involved in decision to reconfigure?

HUMAN-CENTERED AUTOMATION PHILOSOPHY

We have used this construct to evaluate a limited number of automated systems in current aircraft.

- It points out certain known shortcomings in these systems, especially with respect to information management
- It also suggests ways in which information transfer between humans and systems might be improved

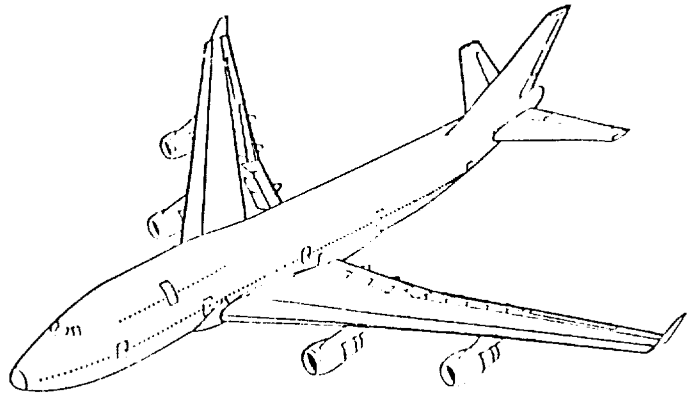
We are using this construct in the design of automated checklists for a series of experiments which will begin this fall

- To determine whether the construct is viable
- To determine how it must be modified or extended to serve as the basis for human-centered automation guidelines in our studies:
    - automated procedures monitoring
    - smart checklists
    - automated diagnostics systems

SUMMARY

- Objectives of this Element of the Program
    - Development of concepts and guidelines
    - Evaluation of competing philosophies
    - Integration of program elements in an intelligent, human-centered automated cockpit
    - Functional validation of these concepts and systems
- Cooperative research with industry in pursuit of these goals
- Hopefully, incorporation of validated concepts into automated interactive cockpit design tools.

WHY DOES THE 747-400 HAVE NASA-DEVELOPED WINGLETS BUT NO NASA-DEVELOPED TAKE-OFF MONITOR?



OR, WHY IS TECHNOLOGY TRANSFER HARDER IN FLIGHT DECK THAN IN AERO, STRUCTURES, AND PROPULSION

TECHNOLOGY TRANSFER

OUTLINE

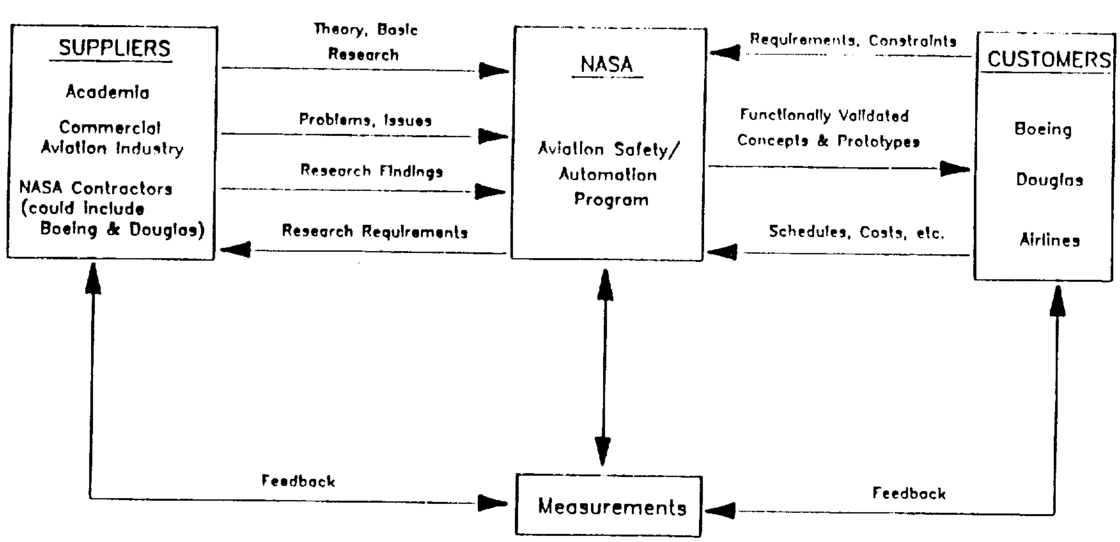
- Goal
- Who
- What
- How
    - Preconditions
    - Impediments
    - Solutions

TECHNOLOGY TRANSFER

GOAL

What is the most effective means for accomplishing the transfer of the program's research products?

ORGANIZATIONAL FRAMEWORK FOR
SUCCESSFUL TECHNOLOGY TRANSFER FROM
NASA PROGRAMS TO COMMERCIAL TRANSPORT AIRCRAFT



TECHNOLOGY TRANSFER

TO WHOM

- Transport Aircraft Manufacturers
- Business Aircraft Manufacturers
- Avionics Manufacturers
- Airlines
- Pilots
- Controllers
- FAA (Standards, Regulations)
- Research Community (Academic & Industrial Standards)
- Military
- NTSB

AND FROM WHOM

WHAT (OUTPUT)

- Information (Tools, Measures)
- Technology (Systems, Designs, Hardware)
- Methods - Measures
- Guidelines (Training, Operational Design)
- Candidate Designs (Early Prototypes)
- Technical Support

C-2

TECHNOLOGY TRANSFER

HOW (APPROACH)

- Preconditions
- Impediments
- Solutions/Suggestions

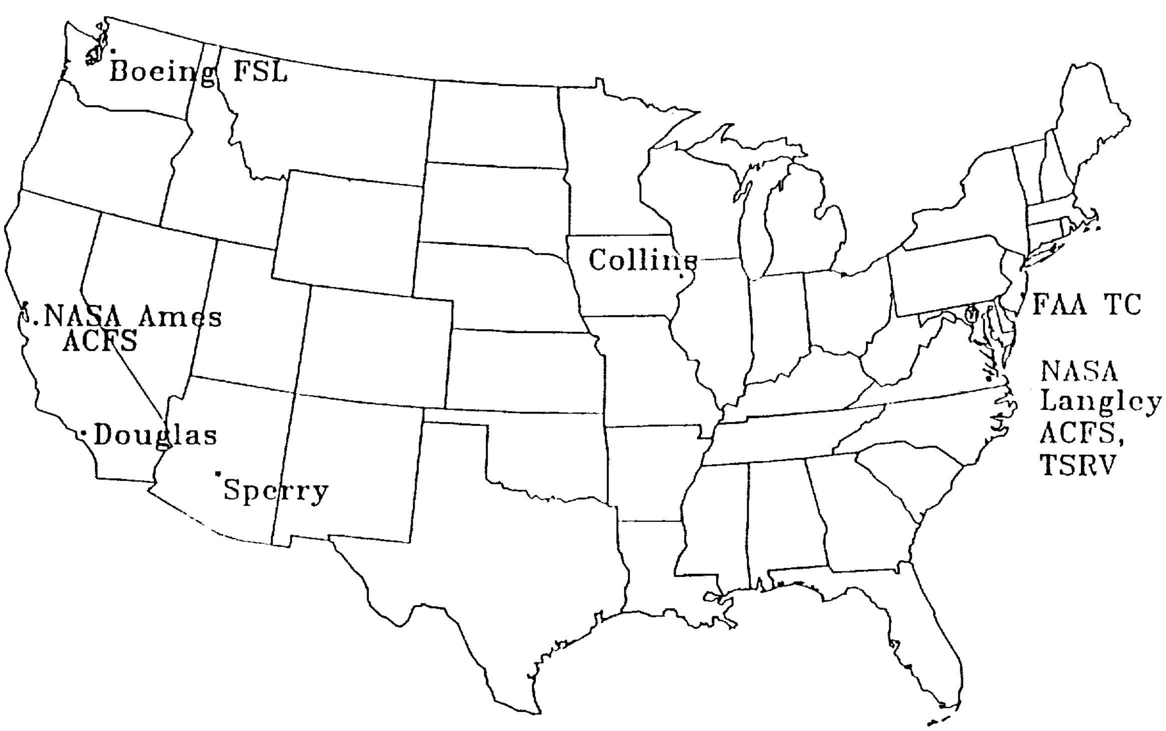
PRECONDITIONS/PROPER ENVIRONMENT

- Clear Goal Statement (Shared Goals)
- Economic Incentives
- Measurement Technology
- Ease of Interaction
- Stable Funding

TECHNOLOGY TRANSFER

IMPEDIMENTS

- Poor Customer Interface
- Geography
- Human Factors Domain (Soft Science)
- NAS Incompatibility
- Type Rating Schemes
- Measurement Techniques
- Lack of Standardization/Cross Feeding Simulation Scenarios Methodology
- Foreign Competition
- Proprietory Rights
- Allocation of Resources
- Limited Market Place



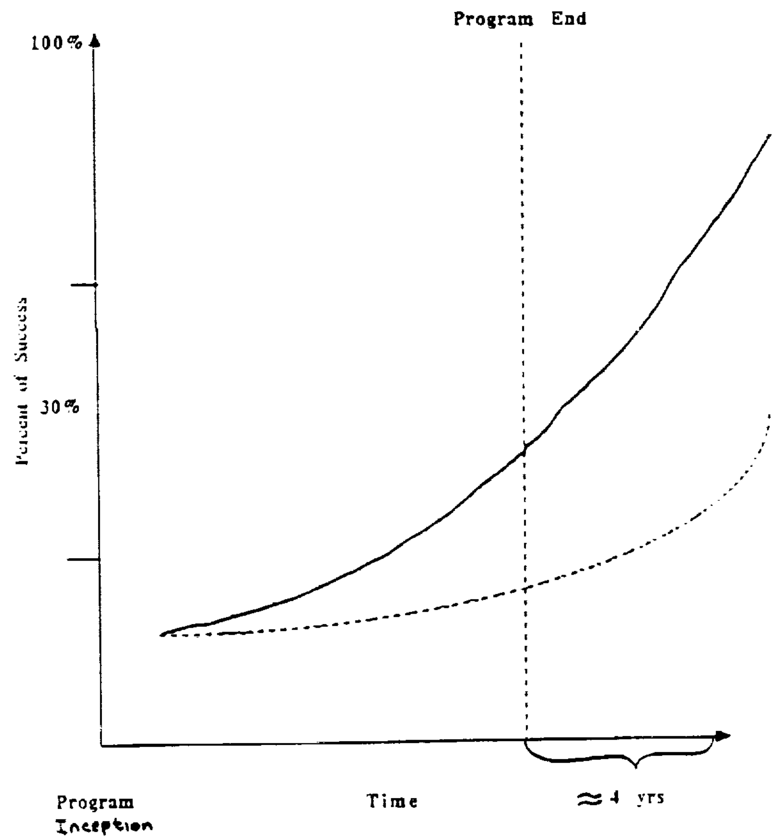
TECHNOLOGY TRANSFER

SOLUTIONS/SUGGESTIONS

- Living Program Plans
- Workshops
- Newsletters (Electronic, Multi-Media, Hyper-Media)
- Networking Technologies - Support Structure
- Temporary Personnel Exchanges
- Cooperative Teams
- Consortium Contracts (Novel Contracting)
- Portability/Compatibility
  - Methods and Scenarios
  - Hardware and Software
- Demonstrations

PROCESS FOR
NAS TECHNOLOGY DEVELOPMENT AND TRANSFER

		PARTICIPANTS		
	PROCESS STEP	OPEN TO ALL	INDIVIDUAL CONTRACTORS	INDUSTRY CONSORTIUM (LED BY PROPOSAL) WINNER
NASA + INDUSTRY	Problem Definition	•		
	Propose Solutions		•	
	Implement Prototype Solutions and Test			•
	Lessons Learned/ Technical Support			•
INDUSTRY	Application of Solution		•	



REALIZATION OF SUCCESS

1. User/Peer Review
   - Demonstrations
   - Simulations
2. Inclusion in Product Definitions
3. Citation Frequency

---

4. Implementation
   - FAA Certification
   - Training
   - ATC
   - Aircraft Design
5. Improved Aviation Safety and Efficiency

N91-10945

CREW WORKLOAD STRATEGIES IN ADVANCED COCKPITS

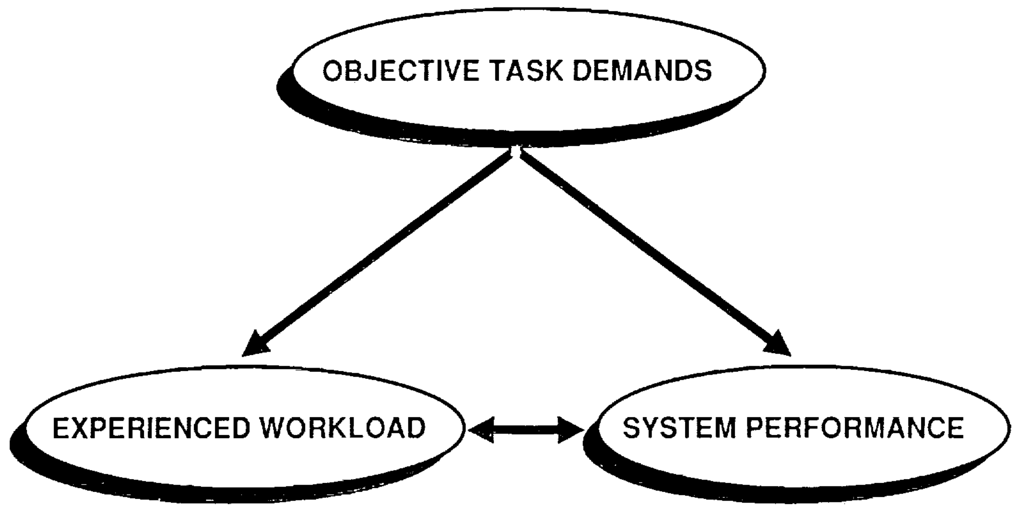
Sandra G. Hart
NASA Ames Research Center

ABSTRACT

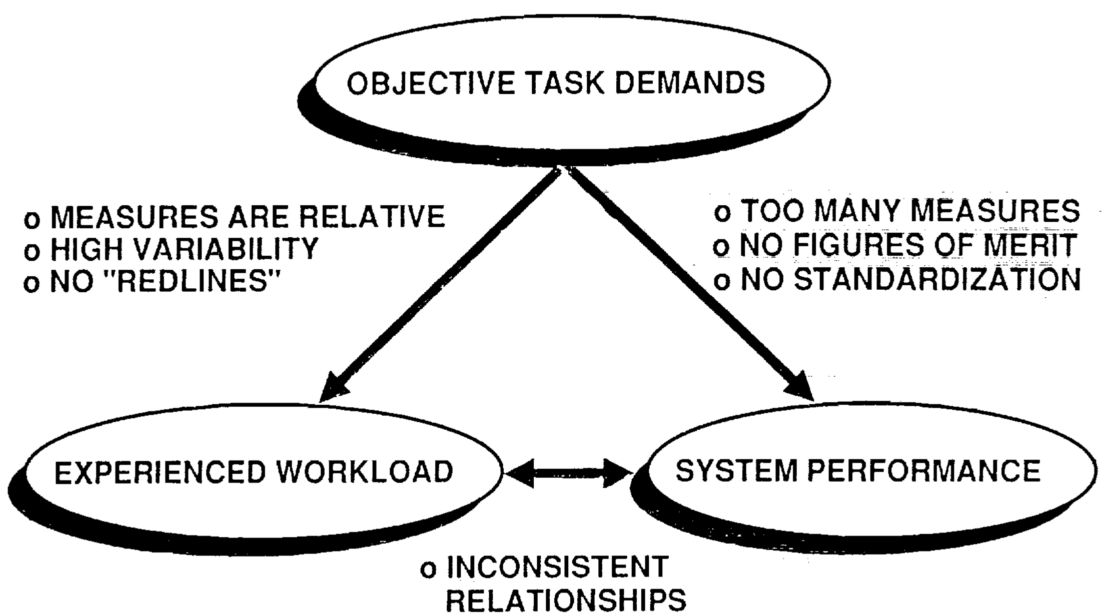
Many methods of measuring and predicting operator workload have been developed that provide useful information in the design, evaluation, and operation of complex systems and which aid in developing models of human attention and performance. However, the relationships between such measures, imposed task demands, and measures of performance remain complex and even contradictory. It appears that we have ignored an important factor: people do not passively translate task demands into performance. Rather, they actively manage their time, resources, and effort to achieve an acceptable level of performance while maintaining a comfortable level of workload. While such adaptive, creative, and strategic behaviors are the primary reason that human operators remain an essential component of all advanced man-machine systems, they also result in individual differences in the way people respond to the same task demands and inconsistent relationships among measures. Finally, we are able to measure workload and performance, but interpreting such measures remains difficult; it is still not clear how much workload is "too much" or "too little" nor the consequences of suboptimal workload on system performance and the mental, physical, and emotional well-being of the human operators. The rationale and philosophy of a program of research developed to address these issues will be reviewed and contrasted to traditional methods of defining, measuring, and predicting human operator workload.

PREVIOUS RESEARCH GOALS

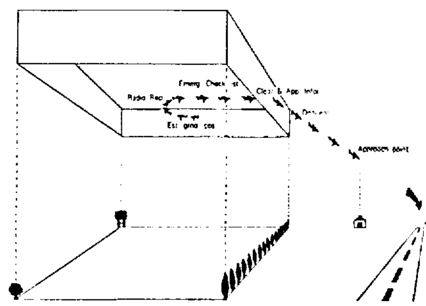
TO EXPLAIN, QUANTIFY, AND PREDICT RELATIONSHIPS AMONG:

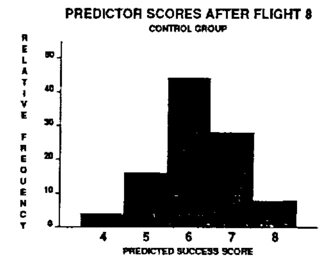


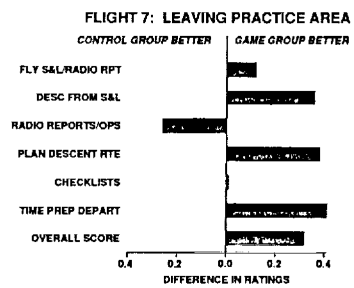
LESSONS LEARNED

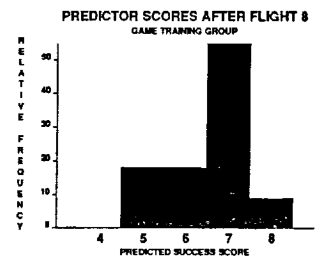


EFFECTIVENESS OF COMPUTER-GAME TRAINER IN IMPROVING WORKLOAD MANGEMENT SKILLS

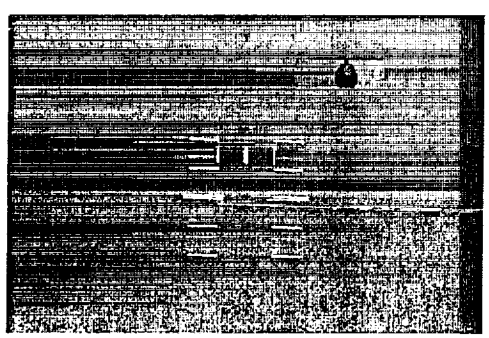


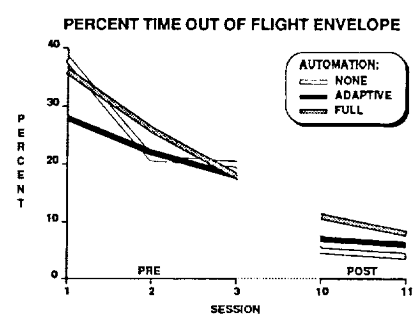


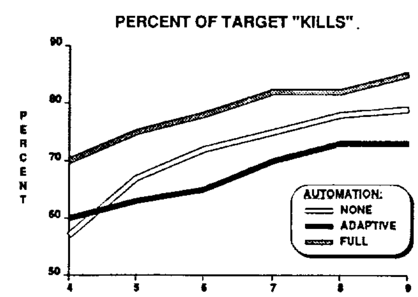




EFFECTIVENESS OF AUTOMATION IN RELEASING RESOURCES TO PERFORM OTHER TASKS







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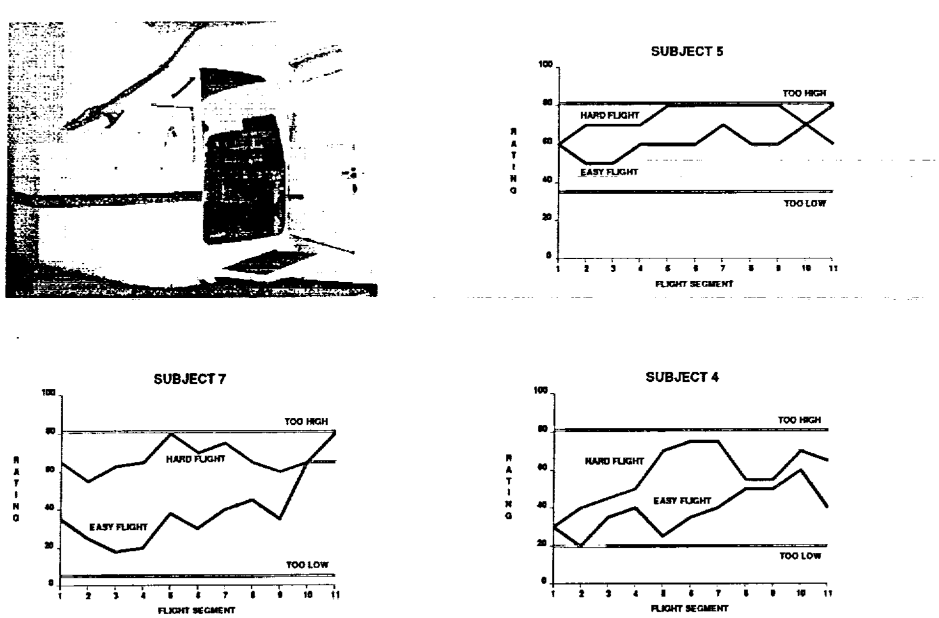
ELEMENT 4: METHODS OF IMPROVING STRATEGIES

	FY89	FY90	FY91	FY92	FY93
MILESTONES:					
IDENTIFY OPTIMAL STRATEGIES FOR TYPICAL FLIGHT TASKS AND SITUATIONS					
DEVELOP TRAINING PROCEDURES TO IMPROVE PILOTS' MANAGEMENT OF TIME/RESOURCES, STRATEGY SHIFTS APPROPRIATE FOR STATE					
DEVELOP CONCEPTUAL DESIGNS FOR COMPUTER AIDS TO IMPROVE PILOTS' ABILITIES TO SELECT APPROPRIATE PLANS, STRATEGIES AND TACTICS					
TEST CONCEPTUAL DESIGNS FOR INFLIGHT ADAPTIVE SYSTEMS FOR DYNAMIC TASK ALLOCATION					

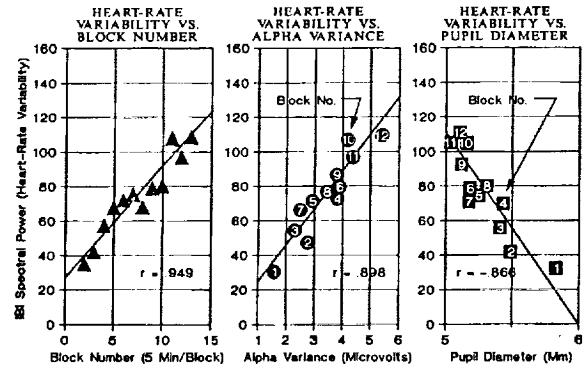
INDIVIDUAL DIFFERENCES IN SUBJECTIVE WORKLOAD "REDLINES"

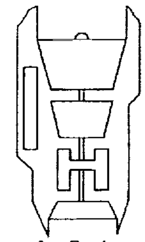


BOREDOM: PERFORMANCE/PHYSIOLOGICALCORRELATES

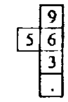
PHYSIOLOGICAL MEASURES

AVERAGED DATA FROM 11 SUBJECTS SHOWS
CORRELATION OF 3 PHYSIOLOGICAL MEASURES





Jet Engine
"Fault" Pictorial

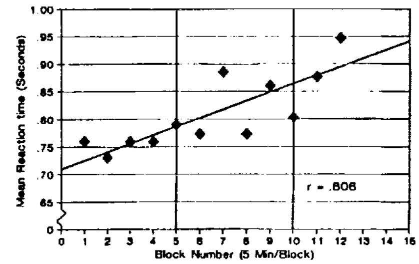


Computer Keypad
Responses

TASK PERFORMANCE

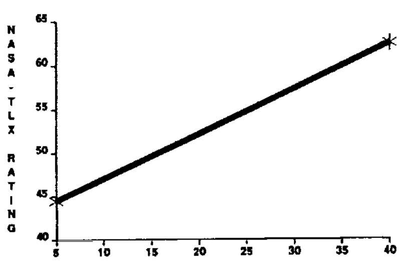
AVERAGED DATA FROM 11 SUBJECTS SHOWS
DECREMENT IN "UNDERLOAD" TASK PERFORMANCE

MEAN REACTION TIME VS. BLOCK NUMBER

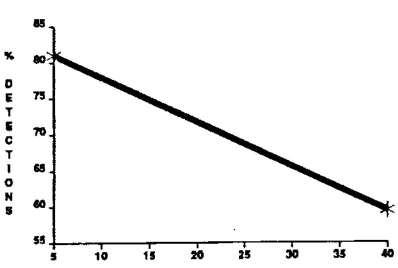


EFFECT OF BOREDOM ON PERFORMANCE , WORKLOAD

INFLUENCE OF BOREDOM ON RATED WORKLOAD



INFLUENCE OF BOREDOM ON PERFORMANCE



SYMPTOMS OF UNDER/OVERLOAD STATES

WORKLOAD	SUBJECTIVE EXPERIENCE:	PHYSIOLOGICAL INDICES:	STRATEGIES	PERFORMANCE:
UNACCEPTABLE (TOO HIGH)	OVER-WHELMED	SIGNIFICANT CHANGE	NONE	UNACCEP-TABLE
SUBOPTIMAL	STRESSED	SOME CHANGE	COMPEN-SATION: - SHED - DEFER	ACCEPTABLE
OPTIMAL	COMFORT-ABLE	"NORMAL"	MANAGE TASK DEMANDS	GOOD
SUBOPTIMAL	BORED	SOME CHANGE	COMPEN-SATION: TRIES TO MAINTAIN AROUSAL	ACCEPTABLE
UNACCEPTABLE (TOO LOW)	DROWSY	SIGNIFICANT CHANGE	UNPREPARED	POOR

ELEMENT 3: WORKLOAD "RED-LINES"

MILESTONES:

IDENTIFY VARIABLES ASSOCIATED WITH UNDER/OVERLOAD

IDENTIFY PERFORMANCE /PHYSIO-LOGICAL CORRELATES OF SUB-JECTIVE OVER/UNDERLOAD STATES

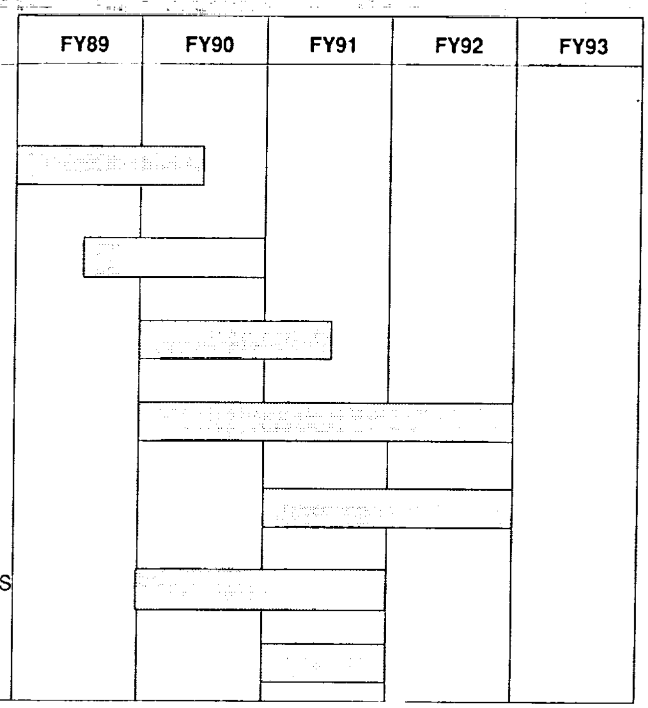
INVESTIGATE ROLE OF INDIVIDUAL DIFFERENCES IN PERSONAL WORKLOAD CRITERIA

QUANTIFY IMPACT OF STRATEGIES IN DYNAMIC WORKLOAD/PERFOR-MANCE TRADEOFFS

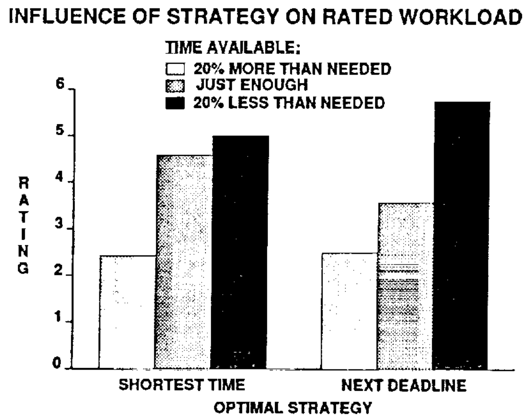
MODEL WORKLOAD/PERFORMANCE TRADEOFFS

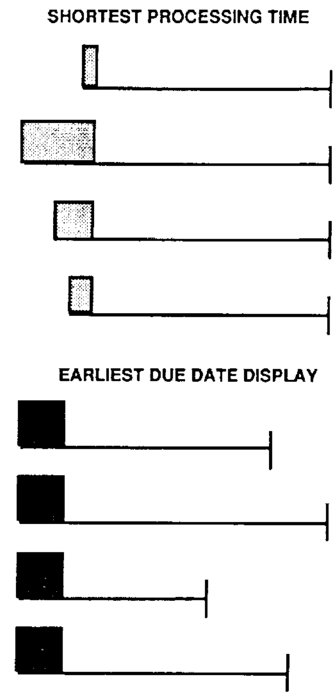
QUANTIFY OVER/UNDERLOAD REGIONS FOR WORKLOAD MEASURES

DEVELOP STANDARD PROCEDURES FOR AIRCRAFT CERTIFICATION

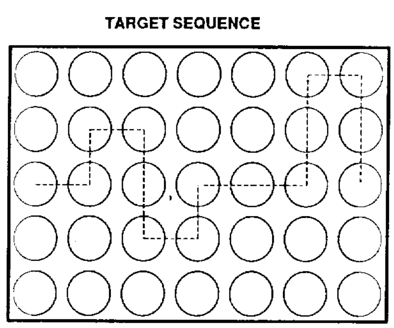


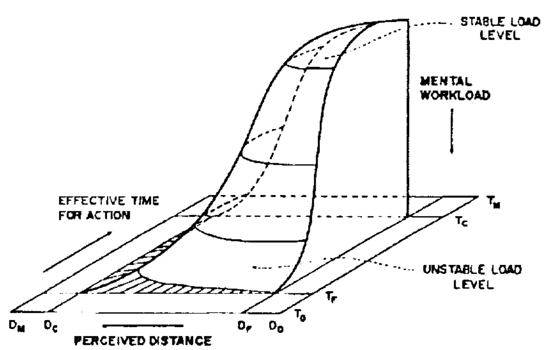
SCHEDULING THEORY MODELS OF WORKLOAD

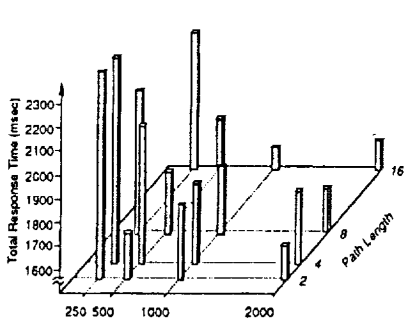


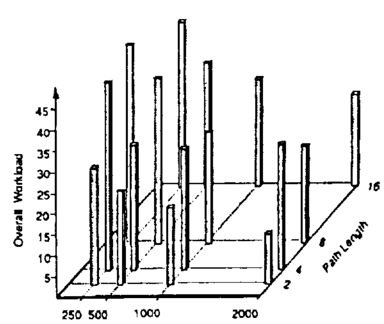


TEMPORAL DYNAMICS OF MENTAL WORKLOAD

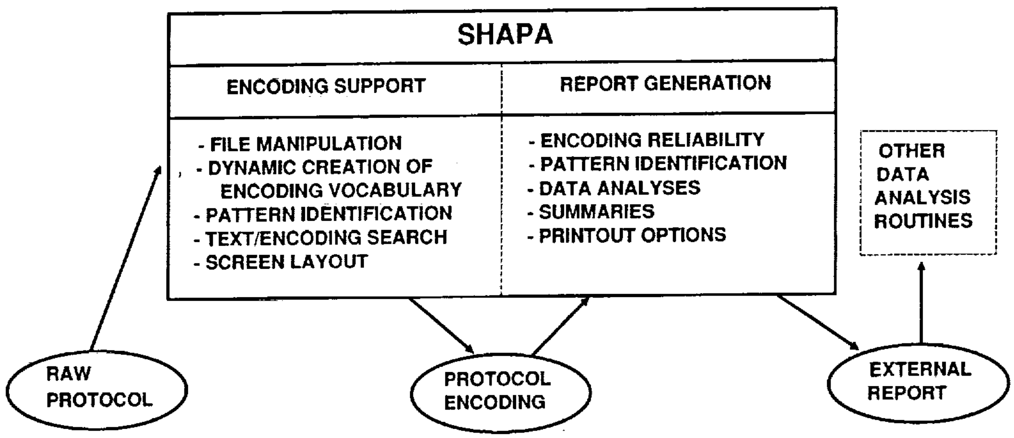








SHAPA: VERBAL/NONVERBAL PROTOCOL ANALYSIS TOOL



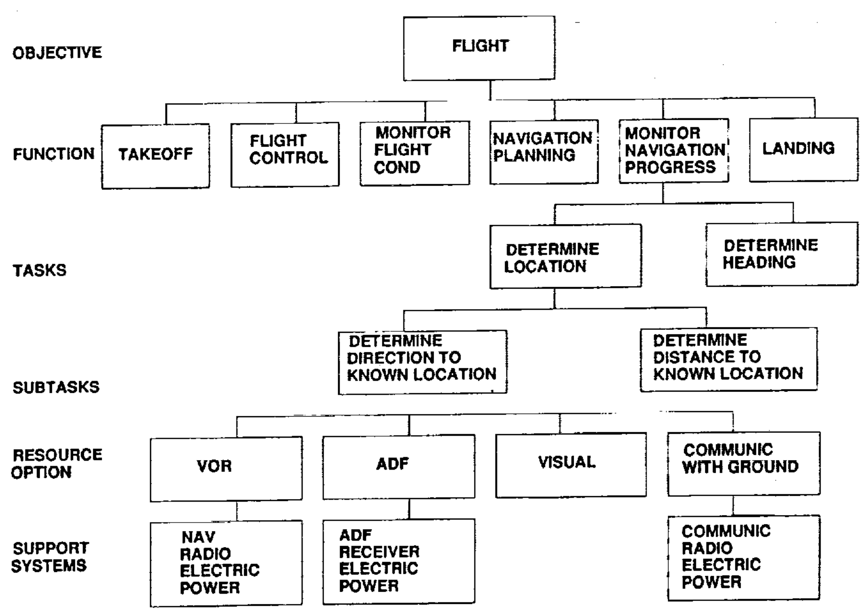
FEATURES:

- RUNS ON IBM-AT WITH EGA
- FULLY INTERACTIVE
- ENCODER DETERMINES ENCODING MODEL/THEORY
- FASTER ENCODING
- CHOICE OF DATA ANALYSIS TECHNIQUES
- DIRECT ENGAGEMENT WITH DATA

UNDER DEVELOPMENT: MacSHAPA

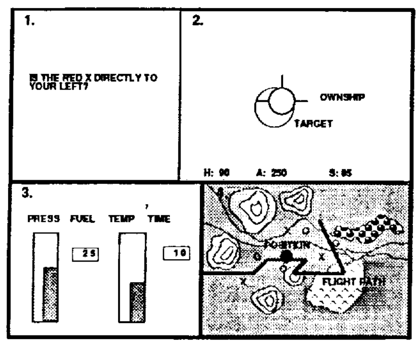
- MULTIPLE INTERACTING AGENTS
- MULTIPLE STREAMS OF VERBAL AND NON-VERBAL BEHAVIORS
- MULTIPLE ENCODERS/RESEARCHERS
- VISUALIZATION TOOLS

MODEL FOR CODING VERBAL PROTOCOLS TO ASSESS PILOT STRATEGIES

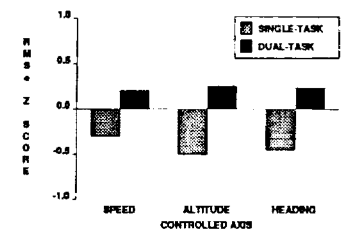


WORKLOAD /PERFORMANCE FOR COMPONENT TASKS

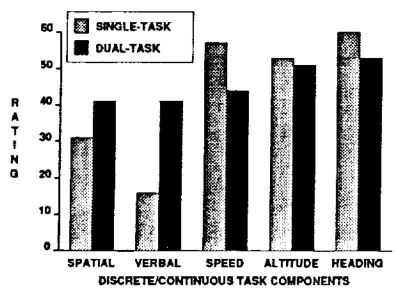
WINDOWS DISPLAY



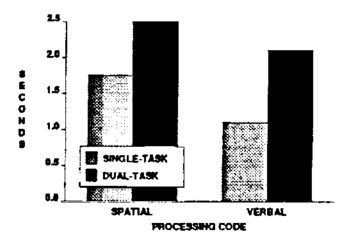
TRACKING ERROR FOR CONTROL TASK



RATED WORKLOAD OF TASK COMPONENTS

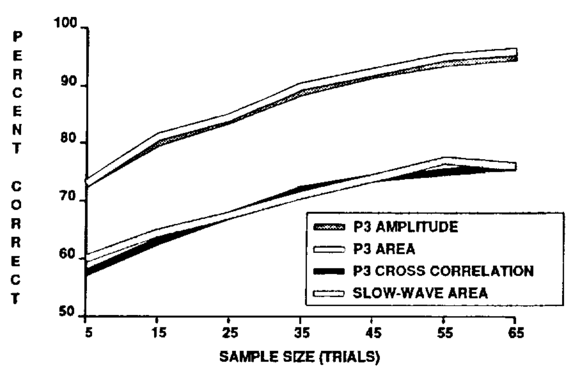


RESPONSE LATENCY FOR DISCRETE TASKS

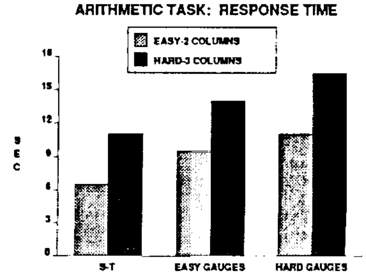


REAL-TIME MEASUREMENT OF MENTAL WORKLOAD

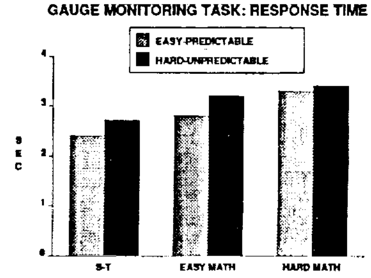
PERCENT CORRECTLY CLASSIFIED TRIALS: ERP MEASURES



ARITHMETIC TASK: RESPONSE TIME



GAUGE MONITORING TASK: RESPONSE TIME



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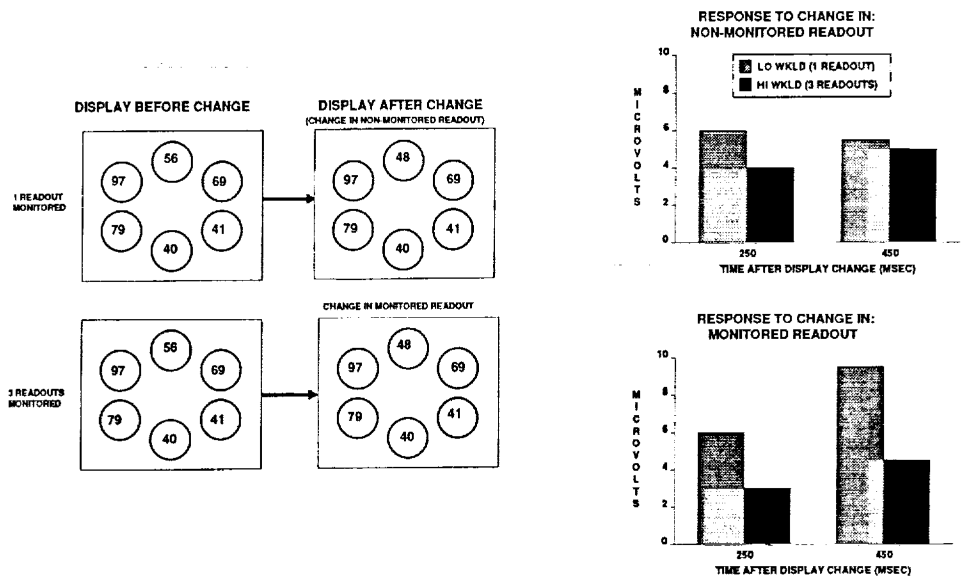
APPLICATION OF EVOKED POTENTIAL MEASURES IN COCKPIT SIMULATOR

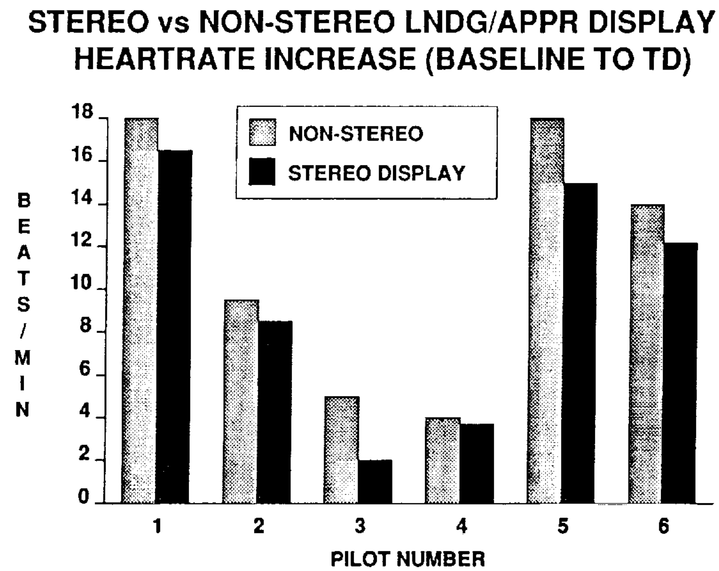


SENSITIVITY OF CARDIOVASCULAR MEASURES

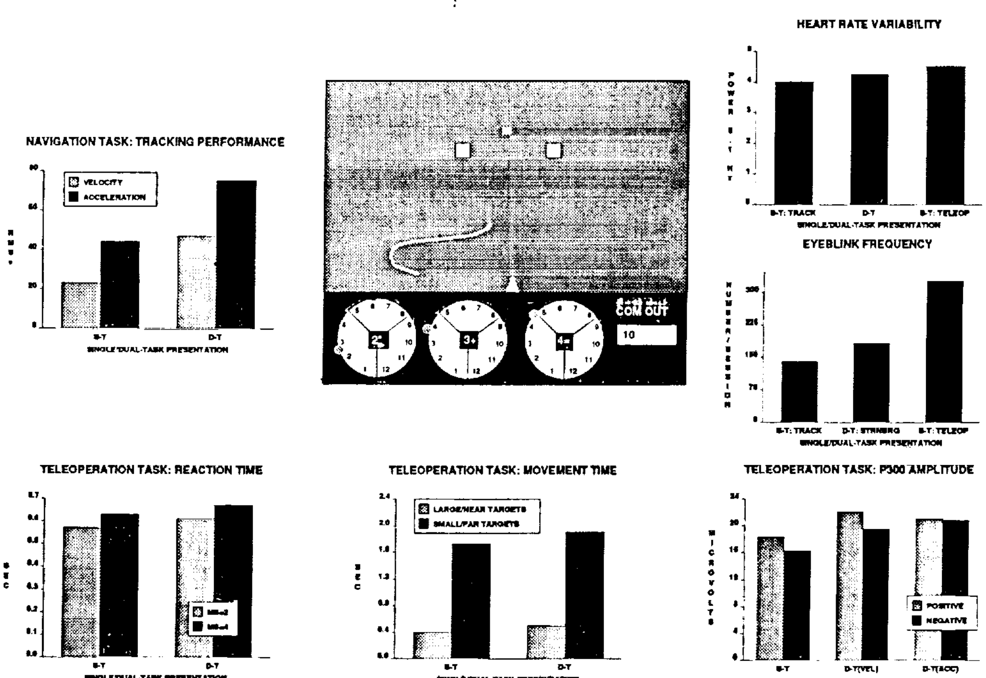
	FLIGHT PATH	CONTROL GUIDANCE	DISPLAY FORMAT	TIME ON TASK (UNDERLOAD)	TASK PACING
AVERAGE HEART RATE	+	+			
HEART RATE CHANGE	++	++	++		
HEART RATE VARIABILITY	+	+		++	+
BLOOD PRESURE COMPONENT HRV (0.1Hz)	+	+		++	

NOT USEFUL
+ SHOWS TRENDS
++ STATISTICALLY SIGNIFICANT

INFLUENCE OF DISPLAY DESIGN ON PILOT'S HEART RATE



COMPARISON AMONG MEASURES



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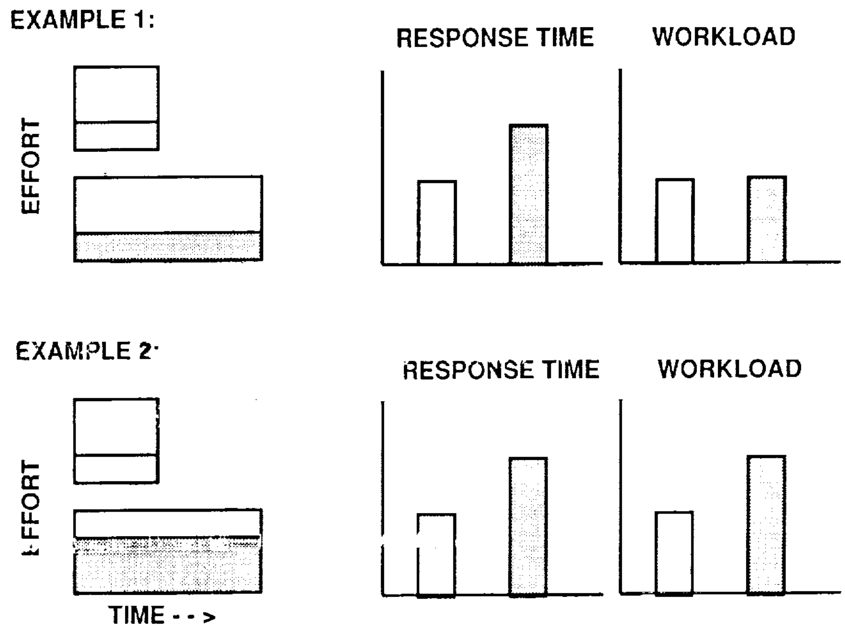
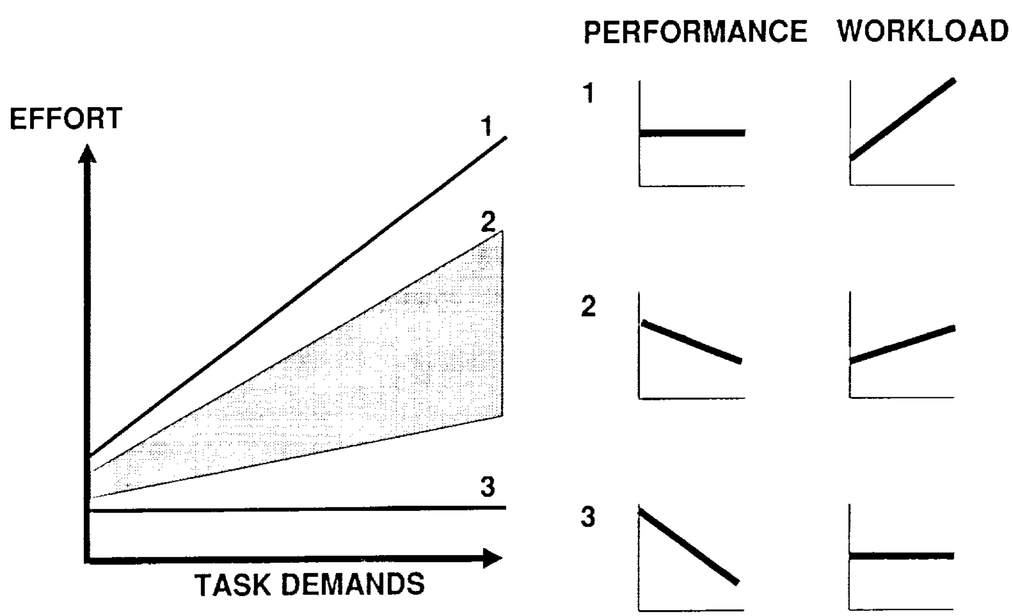
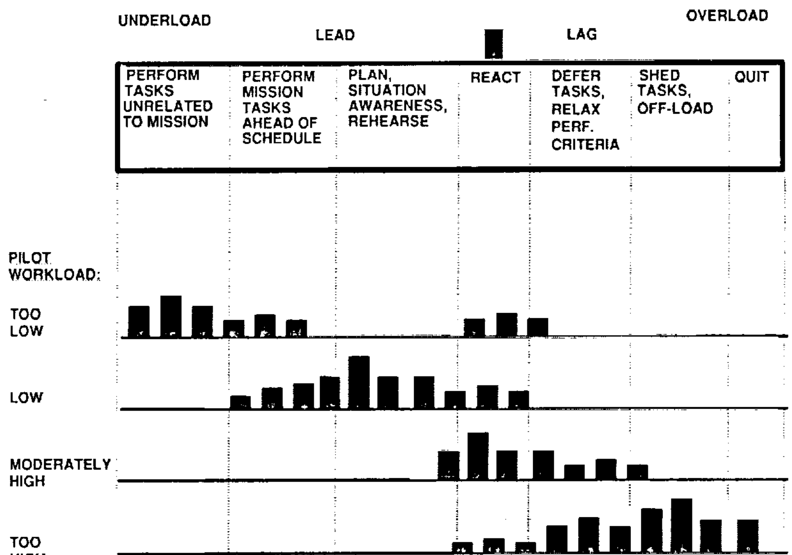
INFERENCES ABOUT "EFFORT" AND WORKLOAD CANNOT BE DRAWN FROM MEASURES OF REACTION TIME



HYPOTHETICAL RELATIONSHIPS BETWEEN TASK DEMANDS, EFFORT, MEASURES OF PERFORMANCE, AND WORKLOAD

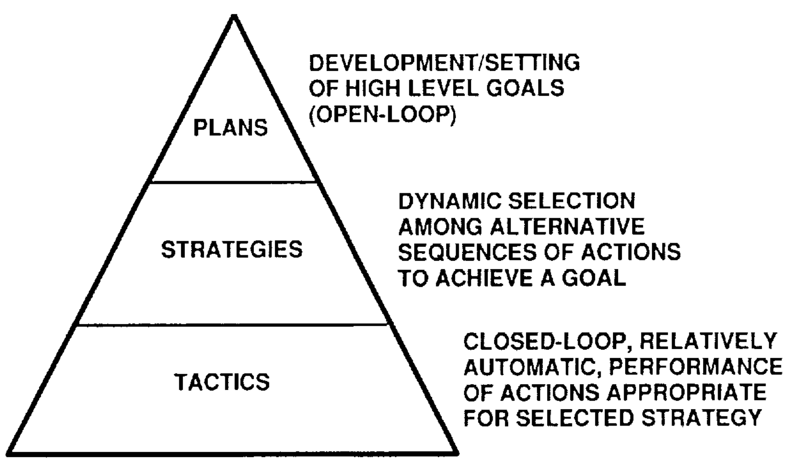


PILOTS ADOPT DIFFERENT STRATEGIES WITHIN A FLIGHT

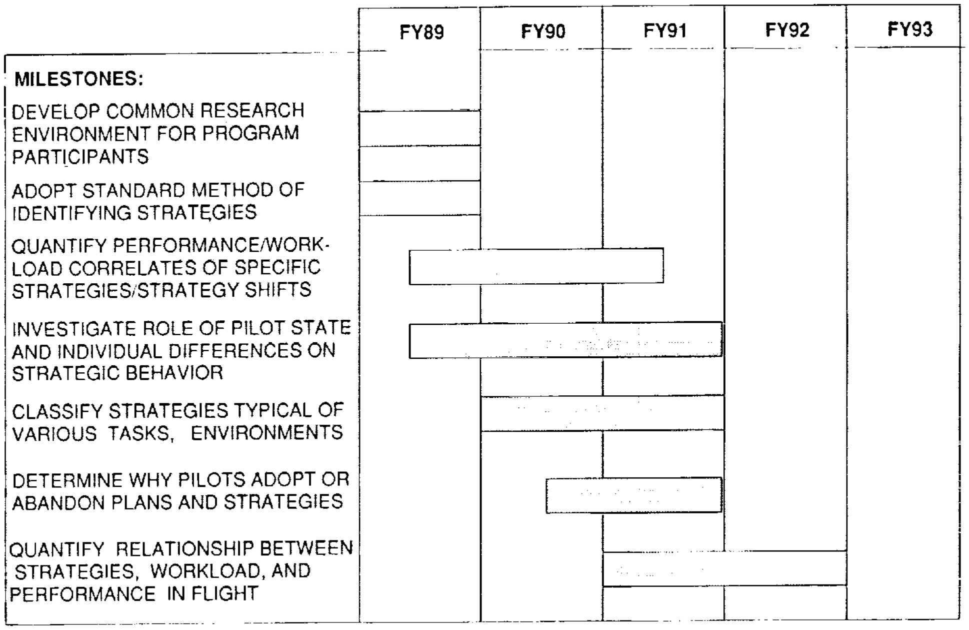


HYPOTHETICAL DISTRIBUTIONS OF STRATEGIES

CHARACTERISTICS OF STRATEGIC BEHAVIORS



ELEMENT 2: STRATEGIC BEHAVIOR



FIGURES OF MERIT - II

GOAL:

IDENTIFY A PARSIMONIOUS SET OF VARIABLES WHICH, IN COMBINATION, ARE DESCRIPTIVE OF THE INFLUENCE OF THE PILOT/VEHICLE INTERFACE DESIGN AND PILOT'S INTENT ON SYSTEM PERFORMANCE

APPROACH:

- **SELECT 50 VARIABLES FROM THOSE ALREADY AVAILABLE**
- **MONITOR PERFORMANCE OF NOVICE AND EXPERT PILOTS IN AFTI F-16 DURING:**
  - **AIR-TO-AIR MISSION**
  - **TERRAIN-FOLOWING MISSION**
- **MEASURE PILOT WORKLOAD USING SWAT**
- **SELECT PARSIMONIOUS SET OF VARIABLES USING MULTI-DIMENSIONAL SCALING, CLUSTER ANALYSIS, ETC**
  - **IDENTIFY REDUNDANT MEASURES**
  - **IDENTIFY MEASURES THAT PROVIDE UNIQUE INFORMATION**
  - **COMBINE SOME MEASURES TO CHARACTERIZE A PARTICULAR ASPECT OF PERFORMANCE**

FIGURES OF MERIT - I

GOAL:

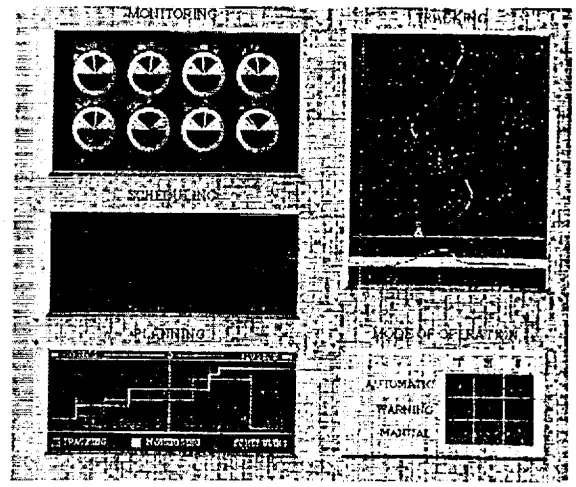
DEVELOP COMPOSITE FIGURE OF MERIT FOR PERFORMANCE

APPROACH:

- EXPERIMENTAL TASK (SCORE):
  - 10-MIN TRIALS
  - 2nd-ORDER, 1-AXIS PURSUIT TRACKING
  - MONITOR 8 DIALS
  - ONLINE SUBTASK PERFORMANCE FEEDBACK
- FIGURE OF MERIT
  - EQUALLY WEIGHTED AVERAGE OF:
    - TRACKING (% MAX ERROR; 1-10)
    - MONITORING (% MAX ERROR; 1-10)
  - SELF EVALUATION (ONCE PER MIN)

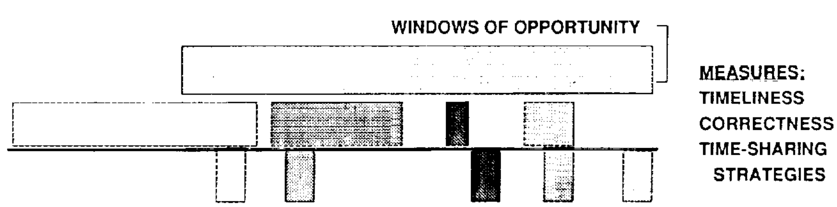
RESULTS:

- Ss FOCUSED ON TRACKING (BASED ON PERFORMANCE STRATEGY, SELF RATING)
- EQUAL WEIGHTING INAPPROPRIATE

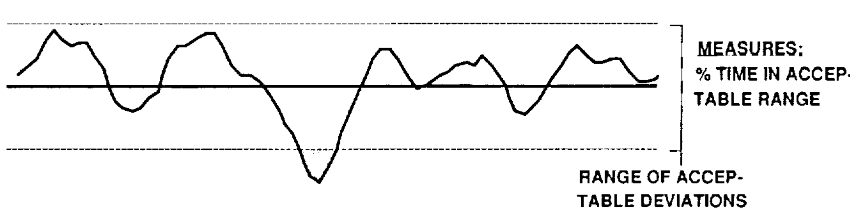


FIGURES OF MERIT ARE NEEDED THAT CAPTURE THE QUALITY OF OVERALL PERFORMANCE

DISCRETE TASKS



CONTINUOUS TASKS



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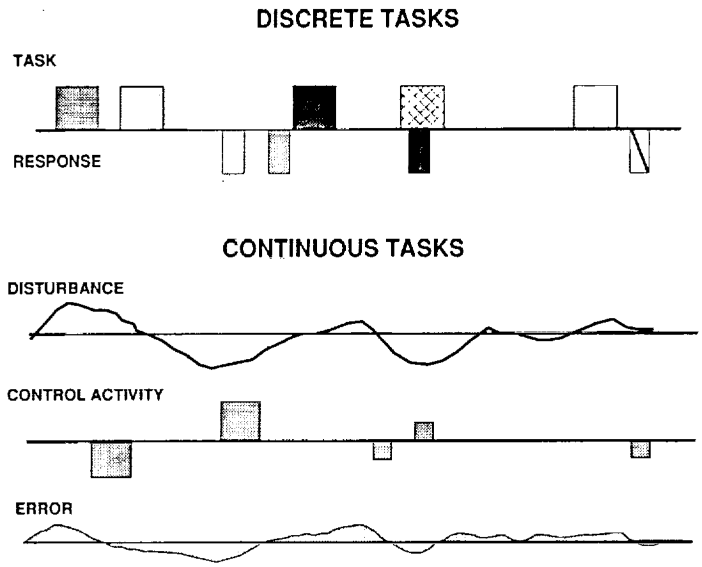
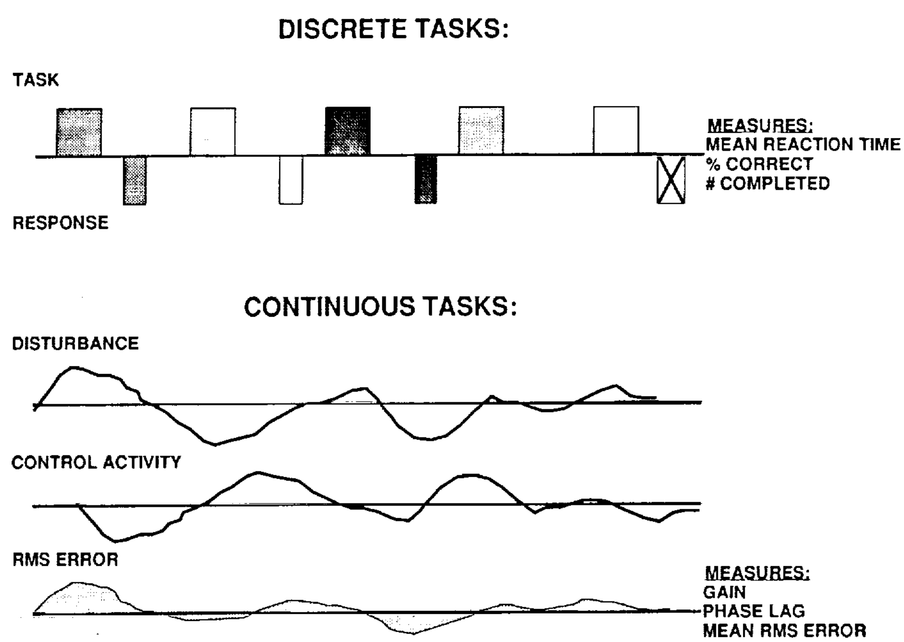
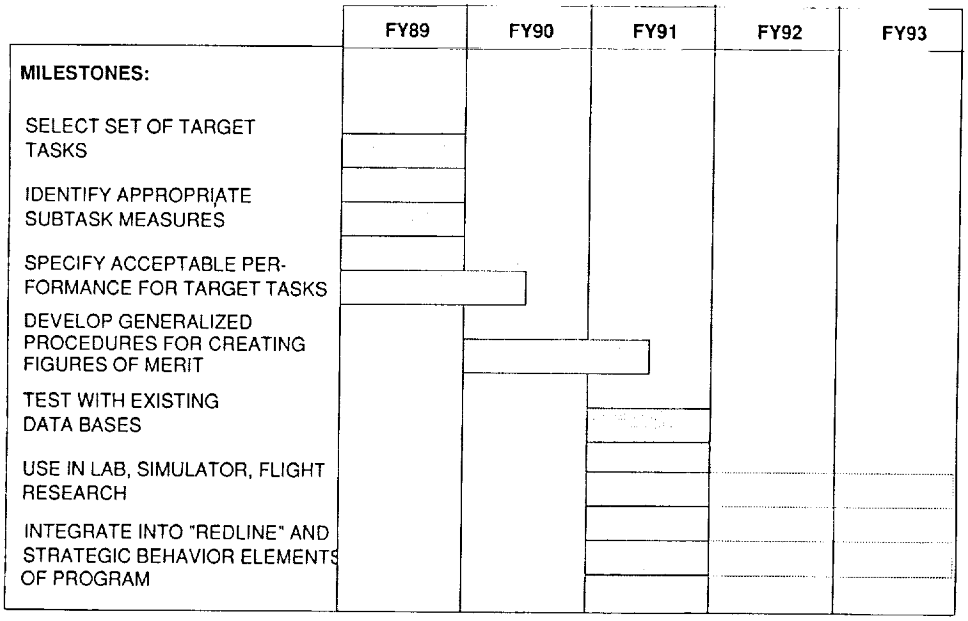
TRADITIONAL MEASURES LOSE THEIR MEANING IF OPERATORS DO NOT TRY TO RESPOND: (1) IMMEDIATELY AND (2) PERFECTLY



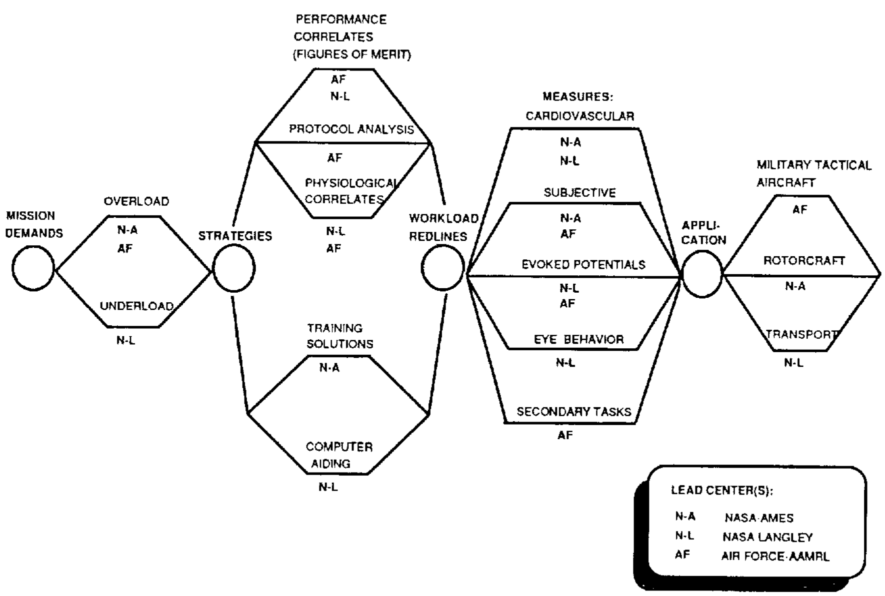
TRADITIONAL MEASURES OF PERFORMANCE



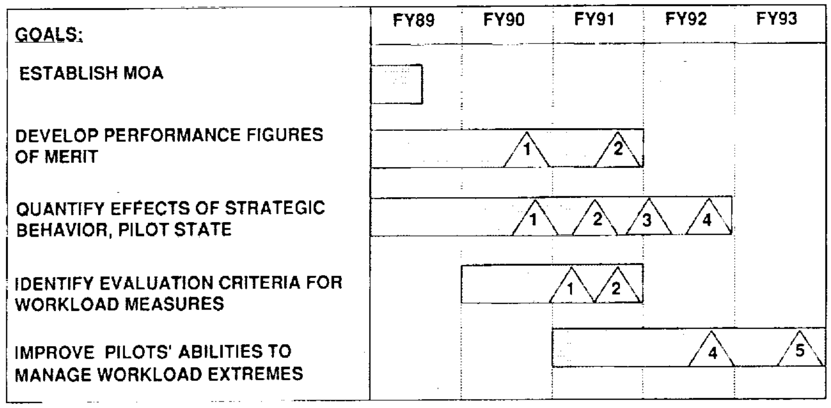
ELEMENT 1: FIGURES OF MERIT (FoM)



PROGRAM ORGANIZATION: LEAD ROLES



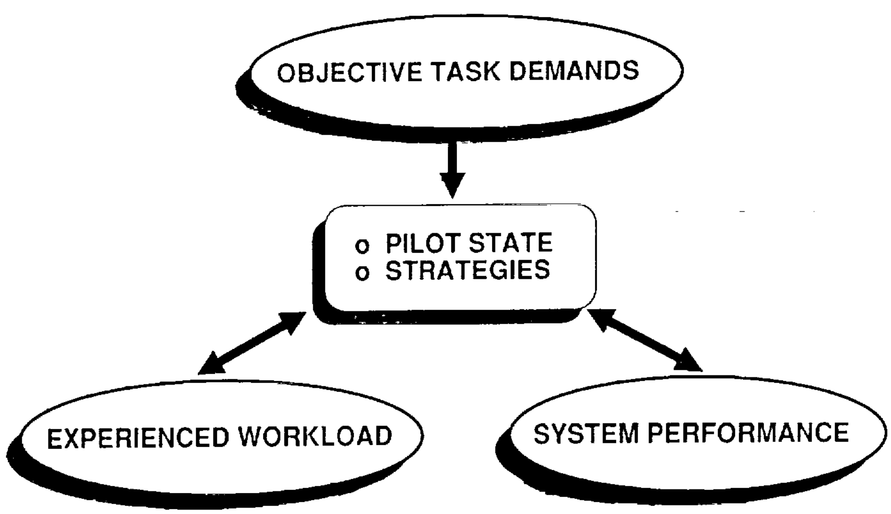
PROGRAM ELEMENTS/MAJOR MILESTONES



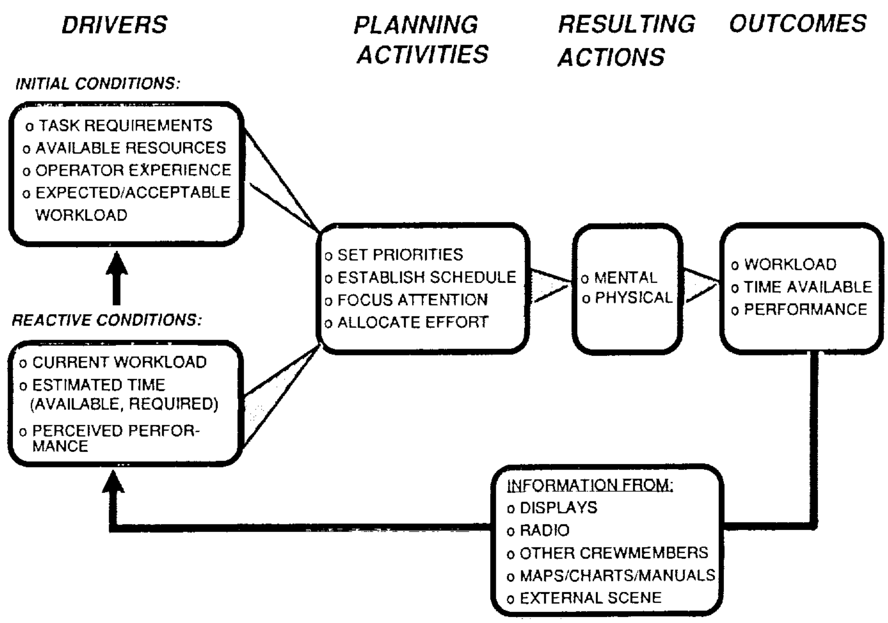
PRODUCTS:

1. PREDICTIVE TOOLS FOR SYSTEM DESIGNERS
2. STANDARD EVALUATION PROCEDURES FOR AIRCRAFT CERTIFICATION
3. IMPROVED THEORETICAL MODEL OF WORKLOAD
4. WORKLOAD-MANAGEMENT TRAINING CONCEPTS
5. ADAPTIVE COMPUTER AIDS TO IMPROVE TASK ALLOCATION

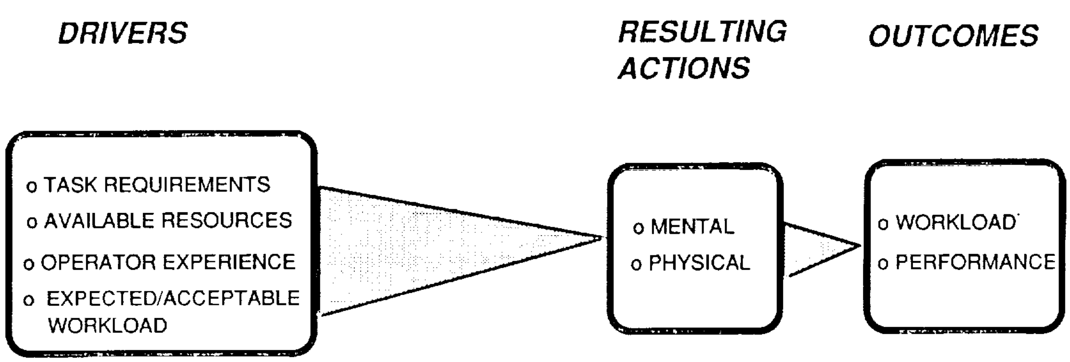
PROPOSED EXPLANATION



PROPOSED DYNAMIC CONCEPT OF WORKLOAD



CURRENT CONCEPTUALIZATIONS OF WORKLOAD GENERALLY IGNORE THE DYNAMIC, ADAPTIVE, CREATIVE BEHAVIOR OF HUMAN OPERATORS



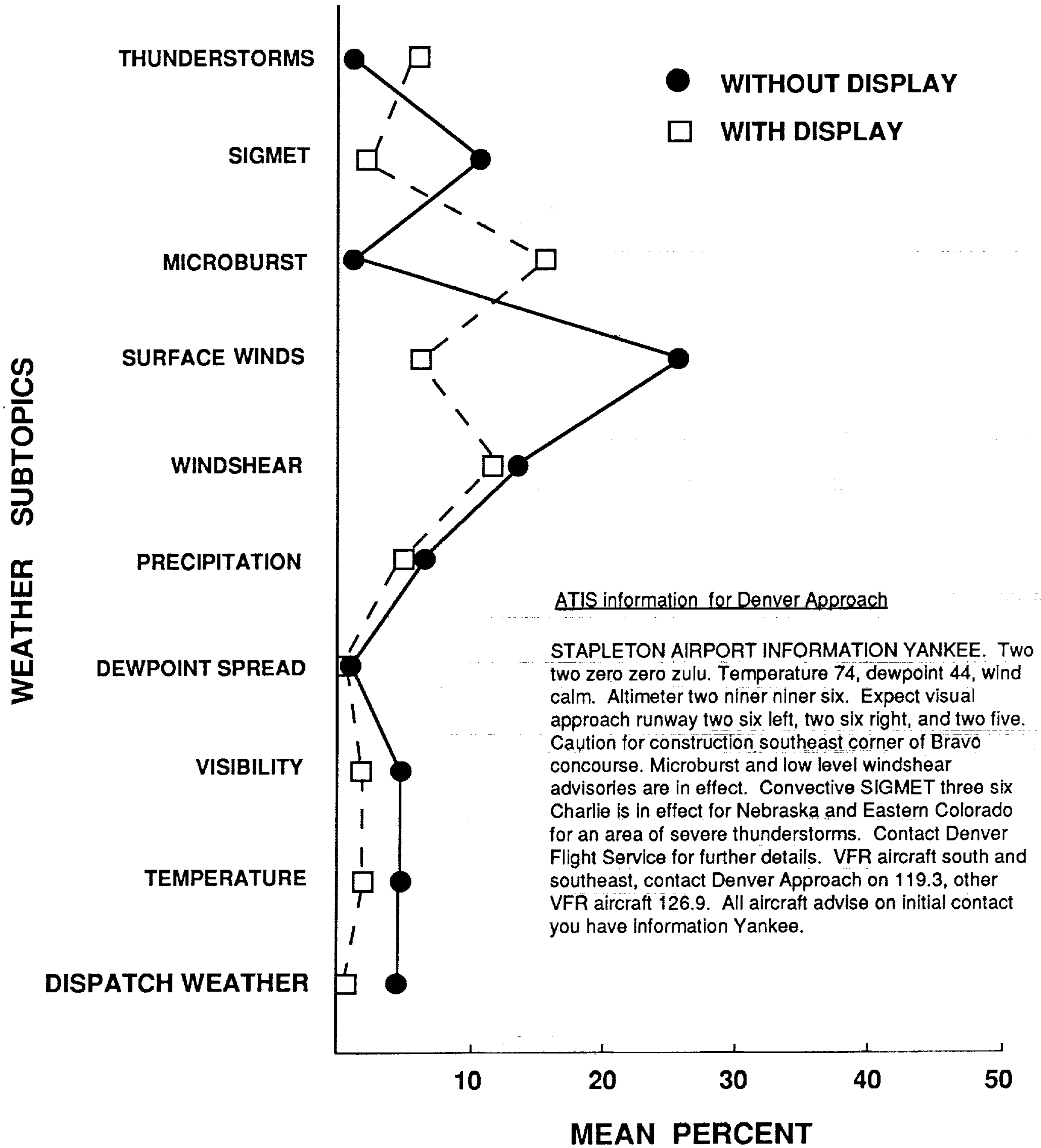
N91-10946

ASSESSING INFORMATION TRANSFER IN FULL MISSION FLIGHT SIMULATIONS

Alfred T. Lee
NASA Ames Research Center

ABSTRACT

Considerable attention must be given to the important topic of aircrew situation awareness in any discussion of aviation safety and flight deck design. Reliable means of assessing this important aspect of crew behavior without simultaneously interfering with that behavior are difficult to develop. Unobtrusive measurement of crew situation awareness is particularly important in the conduct of full mission simulations where considerable effort and cost is expended to achieve a high degree of operational fidelity. An unobtrusive method of assessing situational awareness is described in this paper which employs a topical analysis of intra-crew communications. The communications were taken from videotapes of crew behavior prior to, during, and following an encounter with a microburst/windshear event. The simulation scenario re-created an actual encounter with an event during an approach into Denver Stapleton Airport. The analyses were conducted on twelve experienced airline crews with the objective of determining the effect on situation awareness of uplinking ground-based information of the crew during the approach. The topical analysis of crew communication was conducted on all references to weather or weather-related topics. The general weather topic was further divided into weather subtopical references such as surface winds, windshear, precipitation, etc., thereby allowing for an assessment of the relative frequency of subtopic reference during the scenario. Reliable differences were found between the relative frequency of subtopical references when comparing the communications of crews receiving a cockpit display of ground-based information to the communications of a control group. The findings support the utility of this method of assessing situation awareness and information value in full mission simulations. A limiting factor in the use of this measure is that crews vary in the amount of intra-crew communications that may take place due to individual differences and other factors associated with crew coordination. This factor must be taken into consideration when employing this measure.



GROUP COCKPIT COMMUNICATION EVENTS WITH AND WITHOUT GROUND-BASED WEATHER DISPLAY FOR PERIOD FROM ATIS TO MICROBURST ALERT (N=12 AIRCREWS)

N91-10947

TECHNOLOGICAL ADVANCES FOR STUDYING HUMAN BEHAVIOR

Renate J. Roske-Hofstrand
NASA Ames Research Center

Requirement/Justification

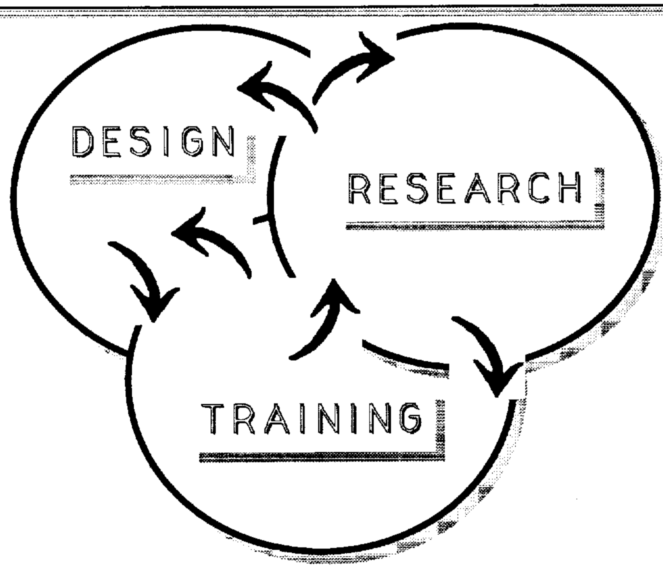
GOAL: To conduct principled human-systems interaction research:

- Develop Significant Design Principles
- Develop Timely Design Alternatives
- Develop Appropriate Design Tools
- Develop Meaningful Evaluation Instruments

JUSTIFICATION:

Performance-Aiding Systems are proliferating without a fundamental understanding of how they should interact with the humans who must control them.

HUMAN-CENTERED AUTOMATION INVOLVES INTERACTION IN ALL THREE DOMAINS



THE EVOLUTIONARY RESEARCH PROCESS (adapted from W. Rouse, 1989)

- What you know you can do
- What you are willing to promise you can do
- What you would like to do

Two Views of Automation Research

HARDWARE VIEW:

- Focus on Hardware Capability
- Focus on Hardware Performance
- Focus on Hardware Testing
- Focus on Sensing Criteria & Logic

HUMAN-CENTERED VIEW:

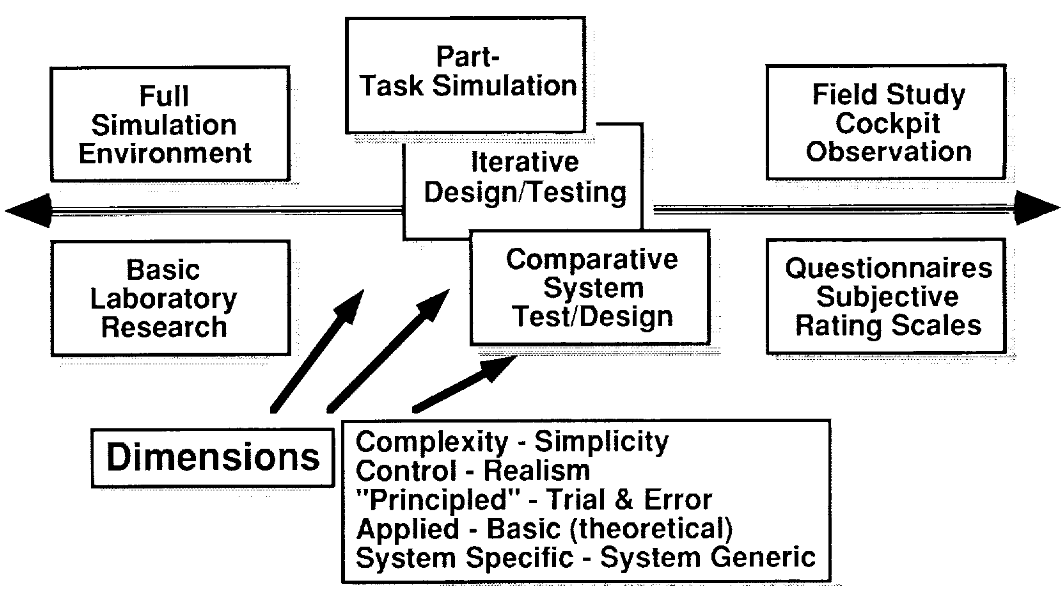
- Focus on the User
- Focus on User Performance
- Focus on Human Performance Testing
- Focus on Matching Information to user need and current context

PERFORMANCE-AIDING SYSTEMS (just as any technological systems) WILL SUCCEED IN THEIR PURPOSE TO THE EXTENT THAT THEY EFFECTIVELY DELIVER THEIR CAPABILITIES TO THEIR USERS !!!

VITAL ELEMENTS FOR HUMAN-CENTERED RESEARCH

• DOMAIN MODEL	Event-Driven Task and Performance Constraints Scenario Specification
• BEHAVIORAL MODEL	User goal / intent structure User Understanding Performance Predictions
• PERFORMANCE TRACE	Measurement Technology Testing Environment Analysis Technology

A Continuum of the Research Process



Available Technologies

- Personal Computer Work Stations
- Local Area Network (LAN) connection
- Interactive Digital Video
- Sophisticated Hyper-Type Software
- Integrated Input/Output devices :
  keyboards, mice, track-balls,joy sticks, microphones, touch-screens, speakers, printers, telephones, video tape recorders/players, cameras, scanners, sound digitizers etc.

NEW TECHNOLOGIES FOR PERSISTENT PROBLEMS

PROBLEMS:

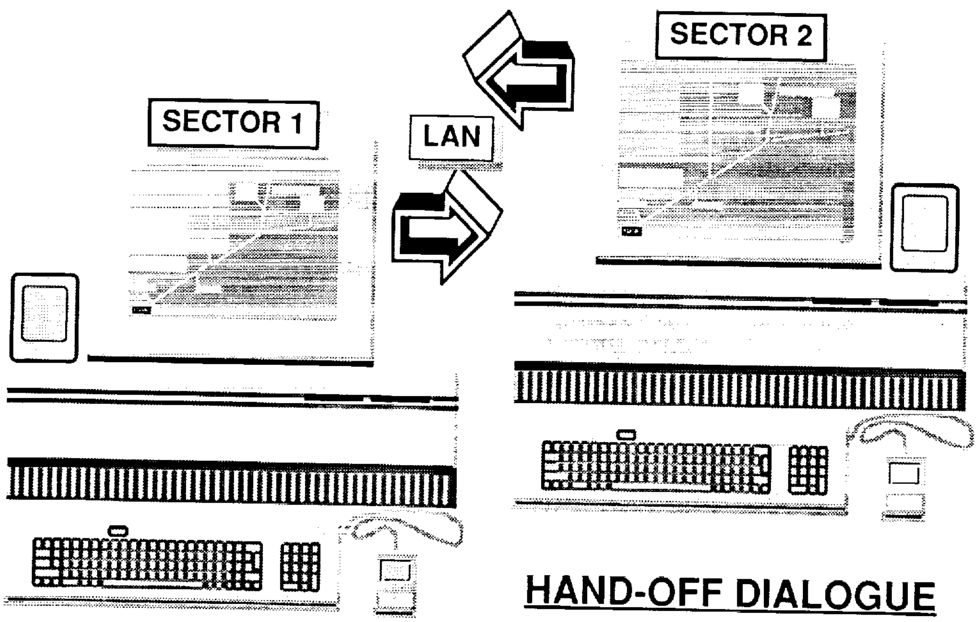
- Access to Expert subjects (potential users)
- Limited time frame
- Cost & scheduling of Full Simulation
- Data translation / lack of comprehensive analysis

SOLUTIONS:

- Portability
- Rapid Dynamic Prototyping
- Coarse-Grain Simulation
- Integrated Measurement

Example: PASS = Portable Air traffic control Simulation System

THE "PASS" SYSTEM



Sample Research Infrastructure

• Scenario Specification

-Dynamic Scenario Generator
-Simulation Event Editor
-Scenario Bank

• Rapid Dynamic Prototyping

- Easy to Use Object Behavior Specification
- Reusable & Copyable Code
- Quick to Adjust/Change Feature Specification
- Alternative Design Concepts Specification

• Simulation in the Field

- Quick set-up
- More subjects
- Automatic collection of data
- On-line Evaluation

Sample Research Infrastructure (continued)

- **Integrated Data Collection**
  - Time-Stamped Event Protocol Files
  - Screen - Configuration
  - Summary Files (Action Breakdown)
- **Integrated Data Analysis**
  - Statistical Software Packages
- **Design Documentation and Training Module**
  - Concept Communication
  - Criterion Practice and Testing

Popular Statements based on Misconceptions about Human Factors and Interface Design

"The system will use a mouse and icons and will have multiple windows - therefore it will be easy to use."

"The new interface, using color coding, command echoing, text editing, and a variety of input modes, has resulted in a substantial improvement in operation over the old system."

"AVIATION-SAFETY GENERAL'S WARNING:

USING THIS TECHNOLOGY CAUSES OPERATIONAL ERRORS, PANIC, INCREASED WORKLOAD, AND MAY COMPLICATE YOUR JOB"

NEED FOR METRICS

- What constitutes safe and efficient performance ?
- How can and should we measure the impact of new devices ?
- How can we translate system capacity improvement goals into standards for acceptable human performance ?

Example metric for Performance Analysis with new Interfaces (after Whiteside, Wixon, and Jones, 1988):

$$S = \frac{1}{T} PC$$

A rate measure that expresses percentage of the task completed per unit of time - the higher the score, the better, the more efficient the performance

S= Performance Score
T= Time spend in task
P= Percentage of task completed
C= A constant (example 5 minutes)

FACT: SYSTEM TYPE MAKES LITTLE DIFFERENCE IN USABILITY!

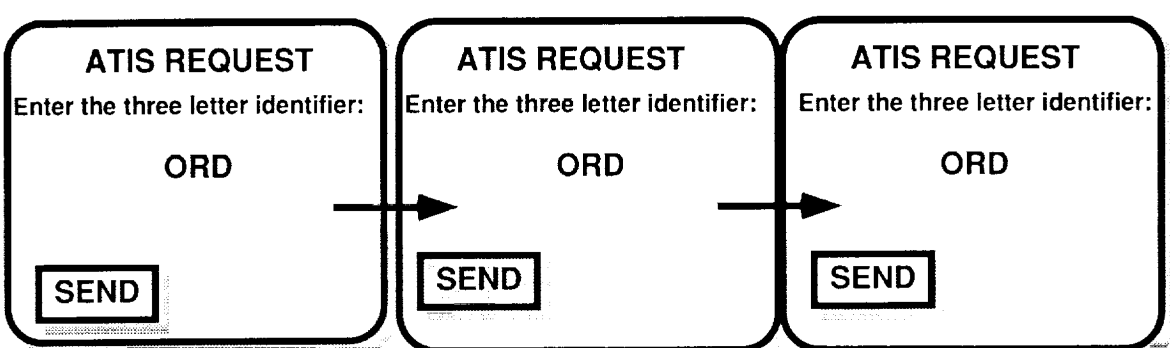
New problems are found in the
"new and improved" systems
which renders them ineffective

TYPICAL Predictable Problems:

- Lack of feedback....what is the system doing ?
- Unanticipated Interdependencies....why is it not accepting this ?
- Lack of "impedance matching"....why does it take 3 steps when I think of it as just one step ?
- Lack of consistency of input forms (and labelling) ....which do I use "cancel" or "delete"?
- Lack of proper information management.....where is the information ?

Examples for Data-Link Technology

"THE FEEDBACK PROBLEM"



A CONFIRMATION MESSAGE IS NEEDED ESPECIALLY WHEN SENDING INFORMATION FROM ONE STATION TO THE NEXT !

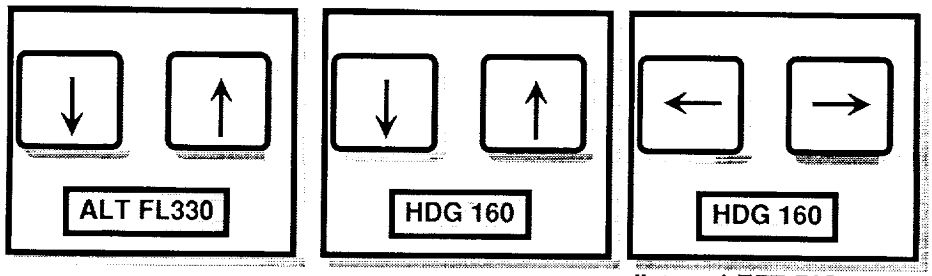
Examples for Data-Link Technology (continued)

"THE LABELLING PROBLEM"

A. CLEAR | CANCEL | DELETE

? clear the current display, message, paragraph, line, word ?
? cancel the current selection, this message, the last request ?
? delete WHAT FROM WHERE ?

B.



OK ??? "..turn LEFT/RIGHT ..."

FACT: "MATURE" SYSTEMS ARE BETTER

A HUMAN-CENTERED APPROACH MEANS CRAFTSMANSHIP AND ATTENTION TO DETAILS !

- stress clear system and performance goals
- involve users at all phases of design
- conduct empirical tests

DESIGNERS MUST BE PREPARED TO REEVALUATE THEIR ASSUMPTIONS>>>WE NEED A FLEXIBLE AND HOLISTIC APPROACH TO USABILITY OF NEW AUTOMATION !

N91-10948

ASSESSING THE FEASIBILITY, COST, AND UTILITY OF DEVELOPING MODELS OF HUMAN PERFORMANCE IN AVIATION

William Stillwell
Battelle-Pacific Northwest Laboratories

ABSTRACT

Substantial change is expected in aviation in the United States, both commercial and private, over the next decade and beyond. New aviation tools (TCAS, innovative CDTI display concepts, and "cockpit weather management") are now being developed that will change the essential nature of aviation. There is also the expectation that the system itself will change; load will increase; more "high flight" will occur, and more capable and efficient aircraft will become available, along with many other fundamental changes. Changes will also occur in areas separate from, but that will impact on aviation. For example, new methods will be developed for selection and training of pilot and ground personnel, and flight procedures will continue to evolve.

Decisions regarding the development of new technologies, such as those mentioned above, or related implementation issues (training requirements of new technologies) are usually difficult to make prior to the testing and/or fielding phase of a system development effort. A primary reason for the difficulty is the unavailability of data useful for evaluating the system's effectiveness. In some situations, models of various types (simulation, statistical, or mathematical) provide data that can be used for such evaluation.

The purpose of the effort outlined in this briefing will be to determine whether models exist or can be developed that can be used to address aviation automation issues. A multidisciplinary team has been assembled to undertake this effort, including experts in human performance, team/crew, and aviation system modeling, and aviation data used as input to such models. The project consists of two phases, a requirements assessment phase that is designed to determine the feasibility and utility of alternative modeling efforts, and a model development and evaluation phase that will seek to implement the plan (if a feasible cost effective development effort is found) that results from the first phase.

HUMAN PERFORMANCE MODELS TO ASSESS AUTOMATION IMPACTS IN AVIATION

GOAL:
- Determine impacts of automation on Aviation performance

OBJECTIVES:
- Assess feasibility of modeling key aspects of the Aviation System
- Determine value and cost of adding human performance to existing aviation system models
- Develop a research plan
- Implement developmental efforts

Interdisciplinary Team

- Human Performance
- Team/Crew Performance
- Large Scale System Modeling
- Aviation Information

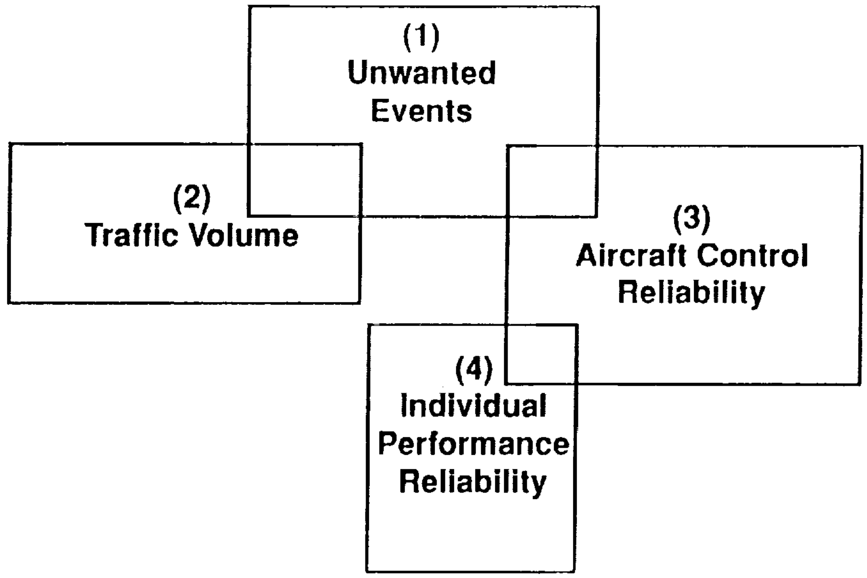
Project Phases

- Phase I - Requirements Assessment
- Phase II - Model Development and Evaluation

Phase I

- Determine Needs/Requirements
- Inventory and Evaluate Existing Models
- Detail Additional Modeling Requirements
- Determine Feasibility and Cost of Developmental Efforts
- Develop Model Portfolios
- Assess NASA Tradeoffs
- Establish Modeling Plan

Modeling Areas



INPUTS

- ❑ Intelligent Actors
  - ✔ Pilots
  - ✔ Aircraft Computers
- ❑ Individual Task Loadings
- ❑ Performance Shapers
  - ✔ Training
  - ✔ Experience
  - ✔ Duty Cycles
  - ✔ Work Loads
  - ✔ Noise
  - ✔ Discomfort
  - ✔ Fatigue
  - ✔ Etc.

(4)
Individual
Reliability

OUTPUTS

- ❑ Individual Performance Reliabilities
  - ✔ Expected Error Rates

Models of Individual Performance

- THERP (Technique for Human Error Rate Prediction)
- OAT (Operator Action Tree)
- HCR (Human Cognitive Reliability)
- SLIM-MAUD (Success Likelihood Index Methodology--MultiAttribute Utility Decomposition)
- STAHR (Socio-Technical Assessment of Human Reliability)
- CES (Cognitive Environmental Simulation)
- HOS (Human Operator Simulation)
- Norman's Model of Action Slips
- Reason's Model of Action Lapses
- Rasmussen's Model of Skill, Knowledge and Rule-Based Behavior

Phase II

- Development Efforts
- Kludge
- Nothing

PROGRAM ELEMENT II

INTELLIGENT ERROR-TOLERANT SYSTEMS

OVERVIEW OF ERROR-TOLERANT COCKPIT RESEARCH

Kathy Abbott
NASA Langley Research Center

INTELLIGENT COCKPIT AIDS

OBJECTIVE

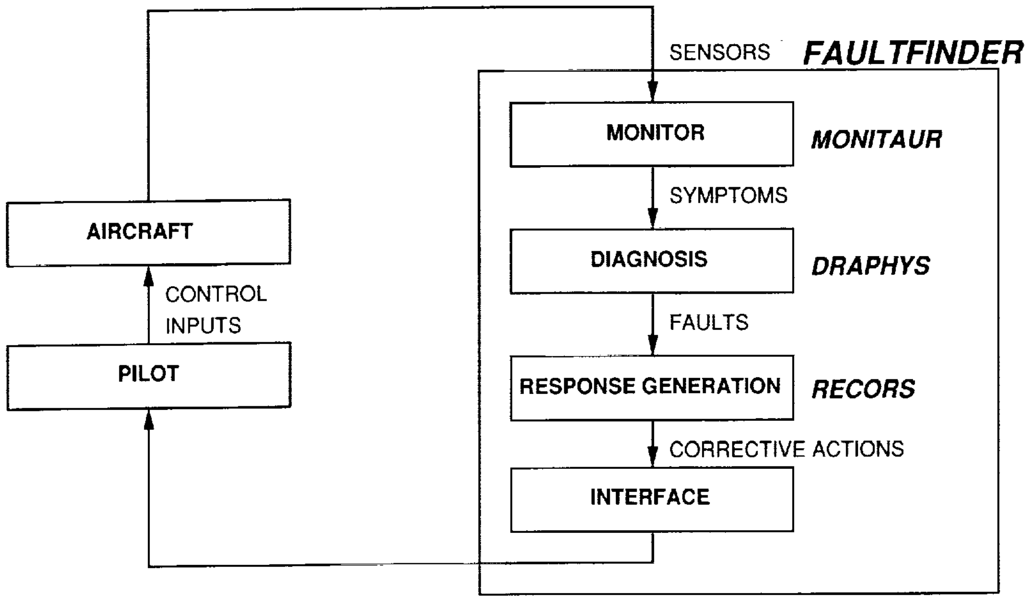
To provide increased aid and support to the flight crew of civil transport aircraft through the use of artificial intelligence techniques combined with traditional automation.

INTELLIGENT ERROR-TOLERANT SYSTEMS

OBJECTIVE

Develop And Evaluate Cockpit Systems That Provide Flight Crews With Safe And Effective Ways And Means To Manage Aircraft Systems, Plan And Replan Flights, And Respond To Contingencies

SUBSYSTEMS FAULT MANAGEMENT FUNCTIONAL DIAGRAM



N91-10950

FAULT MONITORING

Paul Schutte
NASA Langley Research Center

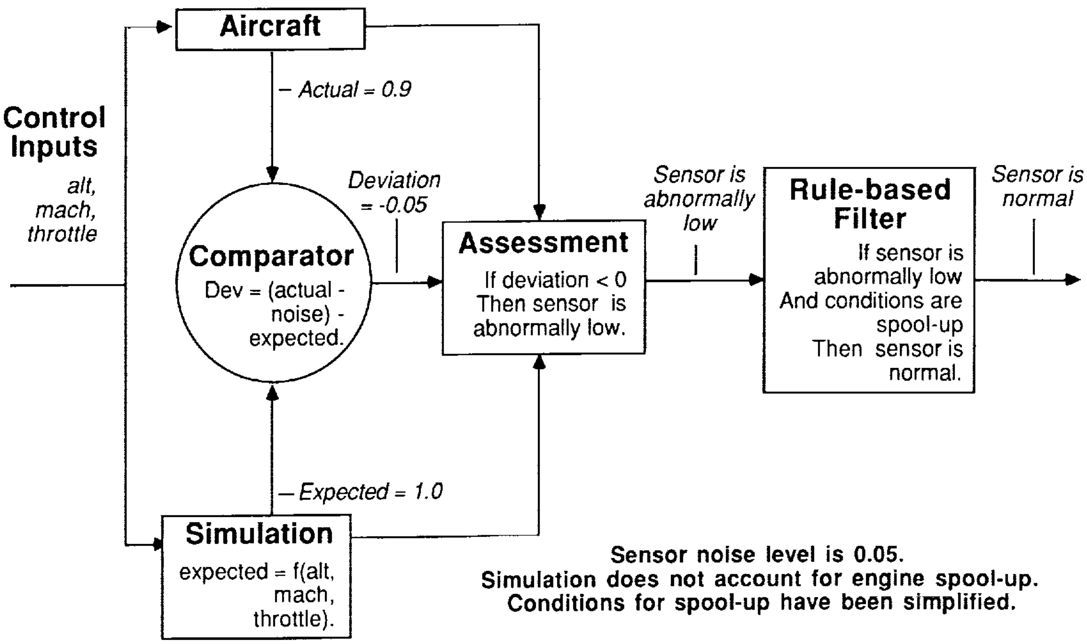
FAULT MONITORING IN THE AIRCRAFT DOMAIN

- - Develops behavioral expectations
  - Collects relevant data
  - Makes appropriate comparisons
  - Interprets data into information
- Provides subsystem information which either directly or indirectly leads to an appropriate response.
- "Acts like a flight engineer"

Information Requirements

- Caution and warning exceedances
- Degradations (abnomal but within range)
- Data interpretation
- Dynamic information (derivatives)
- Relative parameter information
- Low level of false alarms

MONITAUR ARCHITECTURE



Sensor noise level is 0.05.
Simulation does not account for engine spool-up.
Conditions for spool-up have been simplified.

IMPLEMENTATION

Characteristics

- Monitors turbofan engine
- Separate device data base
- Sensor-centered object oriented design
- Written in Common Lisp

Anticipated Benefits of MONITAUR Concept

- Early detection of abnormalities
- Minimal interpretation of data
- Quality system state description
- Low number of false alarms
- Relatively low implementation expense

REMAINING WORK

- **Determine false alarm rate**
  - **- on Symbolics using aircraft data**
  - **- on a PC in an LaRC test aircraft**
- **Implement for other subsystems (e.g. electrical, hydraulic)**
- **Implement on other test aircraft**

REMAINING ISSUES

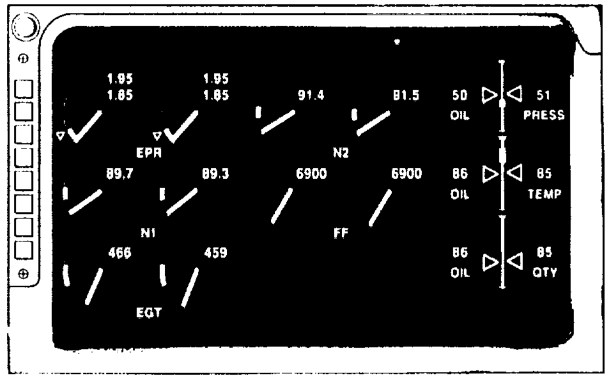
- Prioritize monitoring tasks
- Develop guidelines for knowledge acquisition of rules and noise levels
- Evaluate effects of faulty inputs to the model
- Assess the risk of false alarms

E-MACS

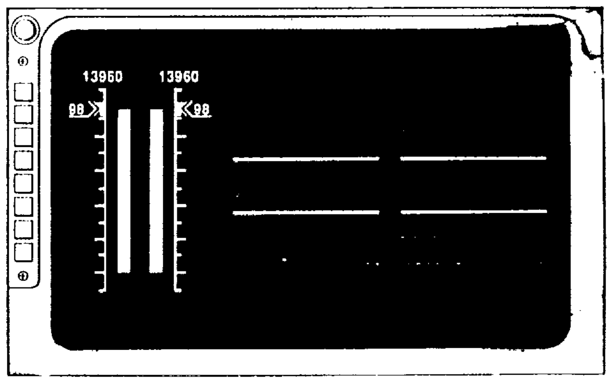
Engine Monitoring and Control System

Situation: *Normal engine power-up for takeoff.*

Traditional

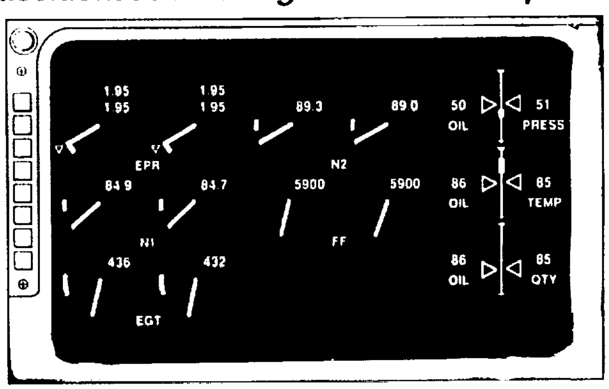


E-MACS

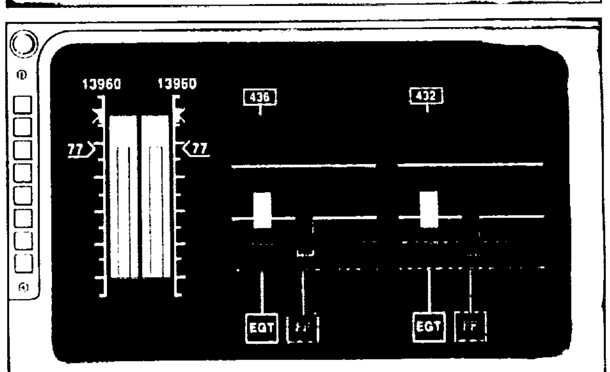


Situation: *Incorrect sensor (EPR). Similar to the 1982 Air Florida accident at Washington National Airport.*

Traditional



E-MACS



N91-10951

FAULT DIAGNOSIS

Kathy Abbott
NASA Langley Research Center

FAULT DIAGNOSIS

The objective of the research in this area of fault management is to develop and implement a decision aiding concept for diagnosing faults, especially faults which are difficult for pilots to identify, and to develop methods for presenting the diagnosis information to the flight crew in a timely and comprehensible manner.

The requirements for the diagnosis concept were identified by interviewing pilots, analyzing actual incident and accident cases, and examining psychology literature on how humans perform diagnosis. The diagnosis decision aiding concept developed based on those requirements takes abnormal sensor readings as input, as identified by a fault monitor. Based on these abnormal sensor readings, the diagnosis concept identifies the cause or source of the fault and all components affected by the fault. This concept was implemented for diagnosis of aircraft propulsion and hydraulic subsystems in a computer program called Draphys (Diagnostic Reasoning About Physical Systems).

Draphys is unique in two important ways. First, it uses models of both functional and physical relationships in the subsystems. Using both models enables the diagnostic reasoning to identify the fault propagation as the faulted system continues to operate, and to diagnose physical damage. Draphys also reasons about behavior of the faulted system over time, to eliminate possibilities as more information becomes available, and to update the system status as more components are affected by the fault.

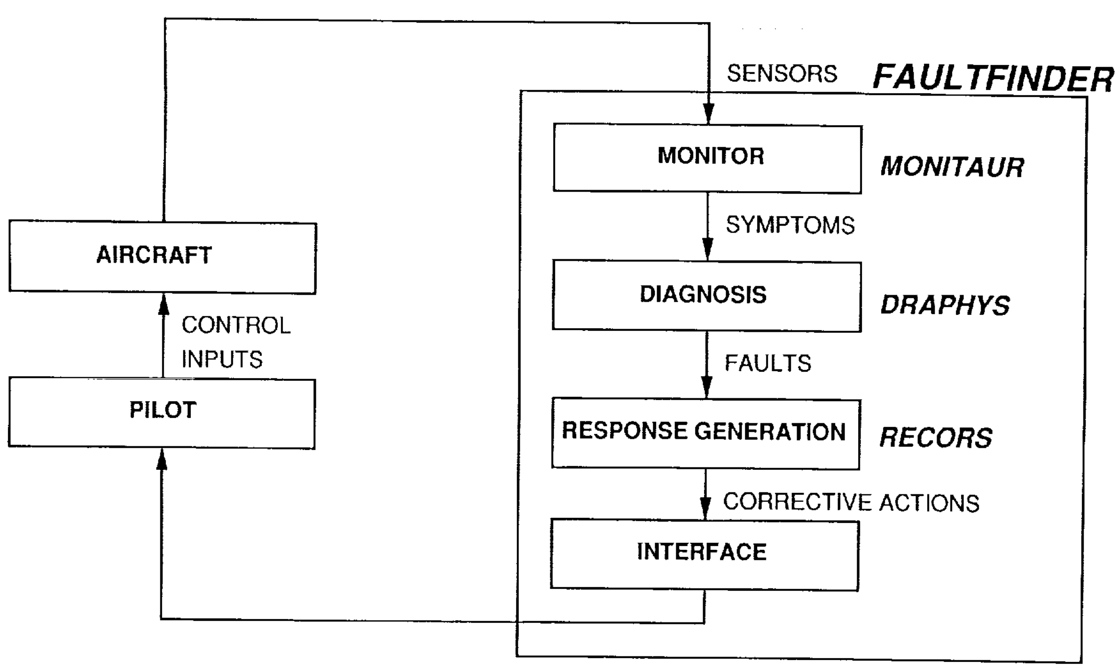
The crew interface research is examining display issues associated with presenting diagnosis information to the flight crew. One study examined issues for presenting system status information. One lesson learned from that study was that pilots found fault situations to be more complex if they involved multiple subsystems. Another was pilots could identify the faulted systems more quickly if the system status was presented in pictorial or text format. Another study is currently under way to examine pilot mental models of the aircraft subsystems and their use in diagnosis tasks.

Future research plans include piloted simulation evaluation of the diagnosis decision aiding concepts and crew interface issues.

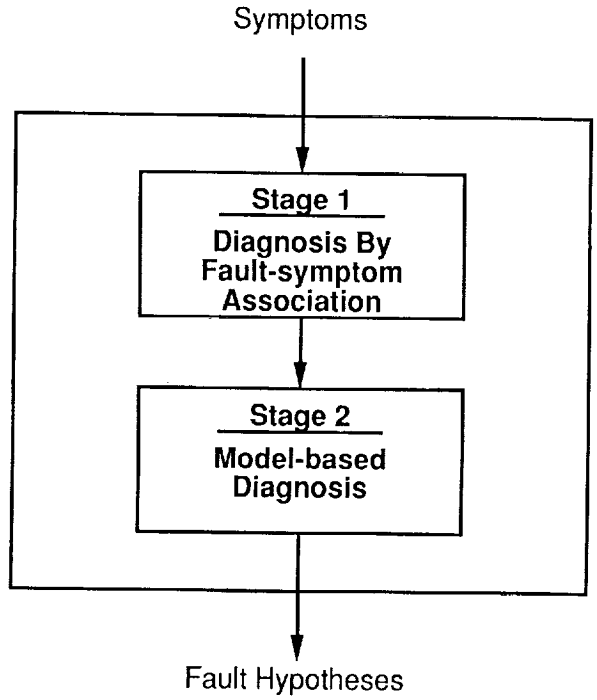
OUTLINE

- Decision Aiding Concepts for Diagnosis
- Crew Interfaces

SUBSYSTEM FAULT MANAGEMENT FUNCTIONAL DIAGRAM



SUBSYSTEM FAULT DIAGNOSIS



INFORMATION CONTAINED IN A FAULT HYPOTHESIS

- Cause Or Source Of The Problem
- Propagation Path
- System Status

UNIQUENESS OF DIAGNOSTIC REASONING

- Uses Models Of Both Functional And Physical Relationships
  - *Identify Fault Propagation*
  - *Diagnose Physical Damage*
- Reasons About Behavior Over Time
  - *Eliminate Possibilities*
  - *Update System Status*

DIAGNOSTIC REASONING CONCEPTS
Current Status

- Single Faults
- Propulsion and Hydraulic Subsystems
- Workstation Implementation
- Evaluated on Accident Cases

DIAGNOSTIC REASONING CONCEPTS
Future Directions

- Multiple Faults
- Electrical and Pneumatic Subsystems
- Real Time Implementation

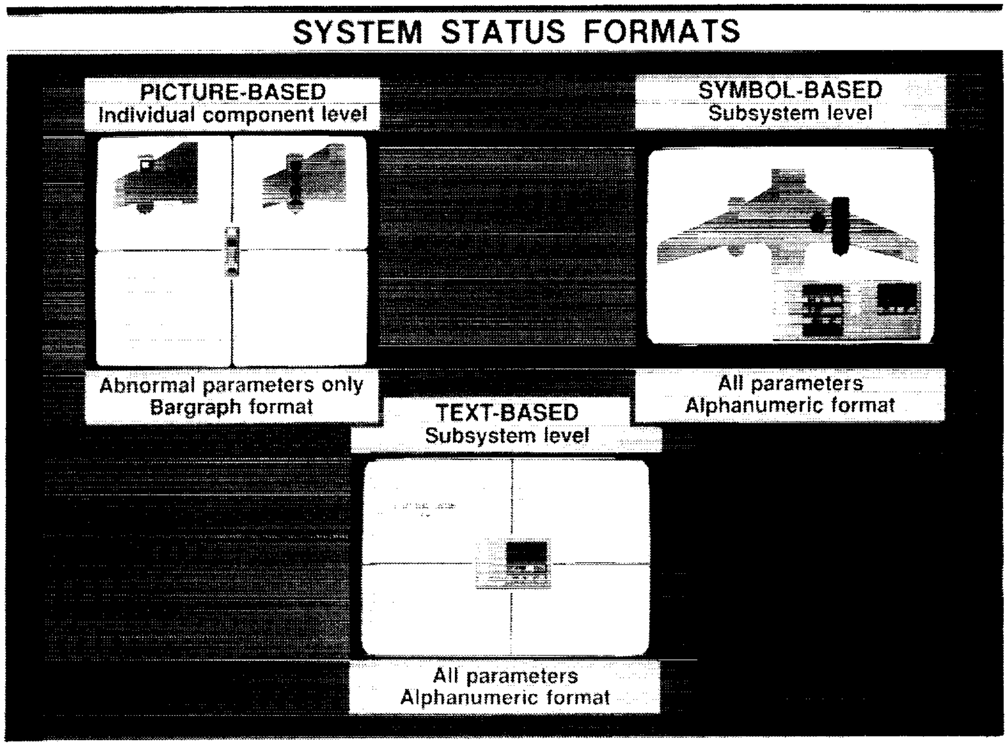
INITIAL CREW INTERFACE RESEARCH STUDY

Objective:

Provide display format guidelines for presenting system status information to improve situational awareness

Technical Issues Addressed:

- Display style (pictorial vs symbolic vs text)
- Hypothesis presentation style (composite vs multiple)
- Information density (all relevant vs out-of-tolerance only)



RESULTS

- Response time increased with display complexity
- Response time decreased with:
  - Pictorial and text display styles
  - Composite hypothesis presentation style
  - Out-of-tolerance only
- Errors of omission noted when multiple subsystems involved

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PILOT DIAGNOSTIC REASONING STUDY

Objective:

Determine pilot mental models of aircraft subsystems and their use in diagnostic problem solving tasks

Technical Issues Addressed:

- Can Diagnosis Behavior Be Predicted Based On Knowledge Of Mental Models?

- Do Pilots Misdiagnose Because They Lack Knowledge Or Because They Apply Knowledge Improperly?

PILOT DIAGNOSTIC REASONING STUDY

Two Experiments

One Generic, One Application Specific

Results Of First Experiment

A Person's Fault Diagnosis Behavior Can Be Predicted Based On That Person's Mental Model

CREW INTERFACES FOR DIAGNOSIS
Future Directions

- Displaying Multiple Faults
- Displaying Fault Propagation Behavior
- When To Present Diagnostic Information

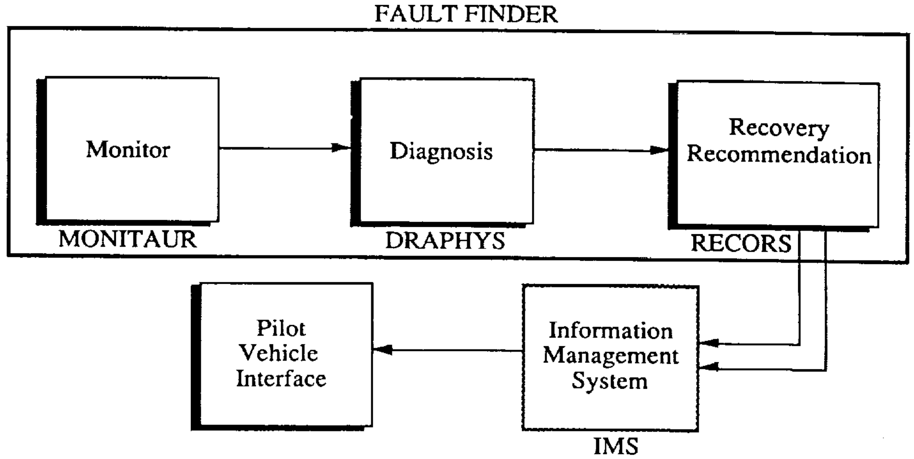
N91-10952

FAULT RECOVERY RECOMMENDATION

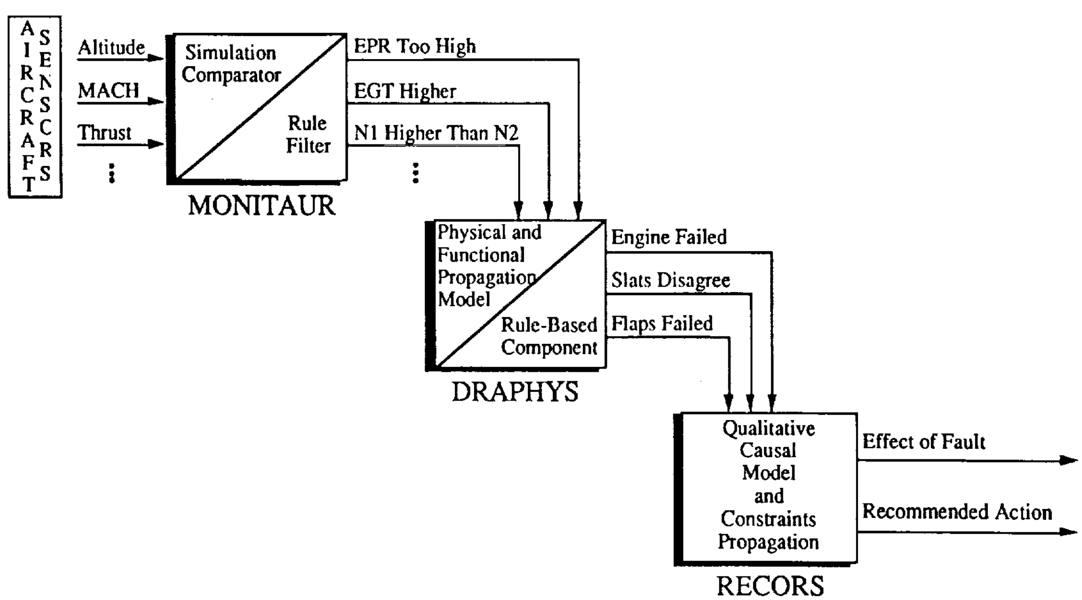
Eva Hudlicka
and
Kevin Corker
BBN Systems and Technologies Corporation

SYSTEM INTEGRATION CONTEXT FOR THE RECOVERY RECOMMENDATION SYSTEM (RECORS)

System Goal: To provide intelligent aiding for monitoring, diagnosis and response to aircraft system failures.



DATA FLOW CONTEXT FOR RECORS



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GOALS OF RECOVERY RECOMMENDATION SYSTEM (RECORS) ARE SITUATION ASSESSMENT AND RESPONSE AIDING DURING EMERGENCIES

Method:

- Predict effects of faults on future system behavior

- Perform reasoning to aid the time-stressed and/or capacity limited flight-crew to suggest response to faults

- Predict consequences of recommended actions and advise crew

RECORS:
MODEL-BASED
SITUATION ASSESSMENT/RESPONSE AIDING

Current Status:

- Functions in a help mode, rather than autonomous mode
  - pilot is in the Loop
  - pilot has Final Authority
  - explanation of Reasoning and Displays are Important
- Uses a causal model of the aircraft and the flight domain
- Reasons at multiple levels of abstraction
- Predicts the effects of aircraft system failures on flight profile
- Suggests responses in emergencies

. . . RECORS

Planned Development:

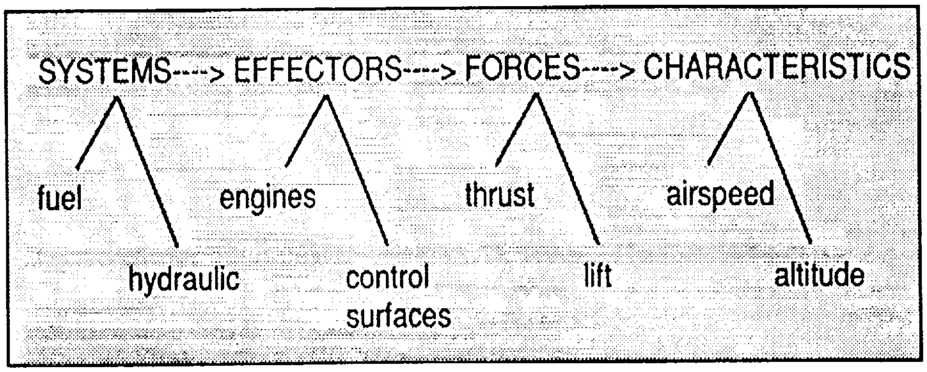
- Help identify faults based on their effects on the system
- Help make up for lack of sensor data by inferencing
- Predict long-term effects of actions to help in response selection

RECORS: CAUSAL MODEL

- Model implemented within Object-Oriented, Frame-Based representation formalism
- Model consists of objects representing:
    - aircraft sub-systems
    - effectors
    - forces acting on the aircraft
    - flight characteristics

CAUSAL MODEL (cont)

- Represents both the taxonomic and the causal relationships among the objects



RECORS:
MULTIPLE LEVELS OF ABSTRACTION

- Two orthogonal types of abstraction exist in the model: taxonomic and causal

  - Taxonomic ("IS-A" relationship)

    Taxonomic abstraction consist of the different levels of the model hierarchy

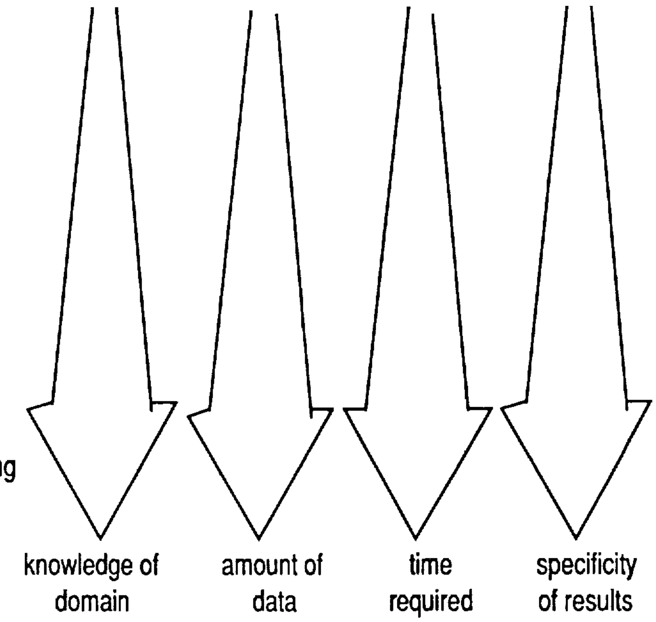
  - Causal: causal relationships among model objects expressed at binary and qualitative levels (AFFECTS and AFFECTED-BY relationships)

    Causal relationships are represented at both binary and qualitative levels at each level in the object taxonomy

- Other planned abstractions include partonomy and physical location relations

MULTIPLE LEVELS OF ABSTRACTION

BINARY	normal/abnormal
QUALITATIVE	low/normal/high decreasing/stable/increasing
QUANTITATIVE	differential equations



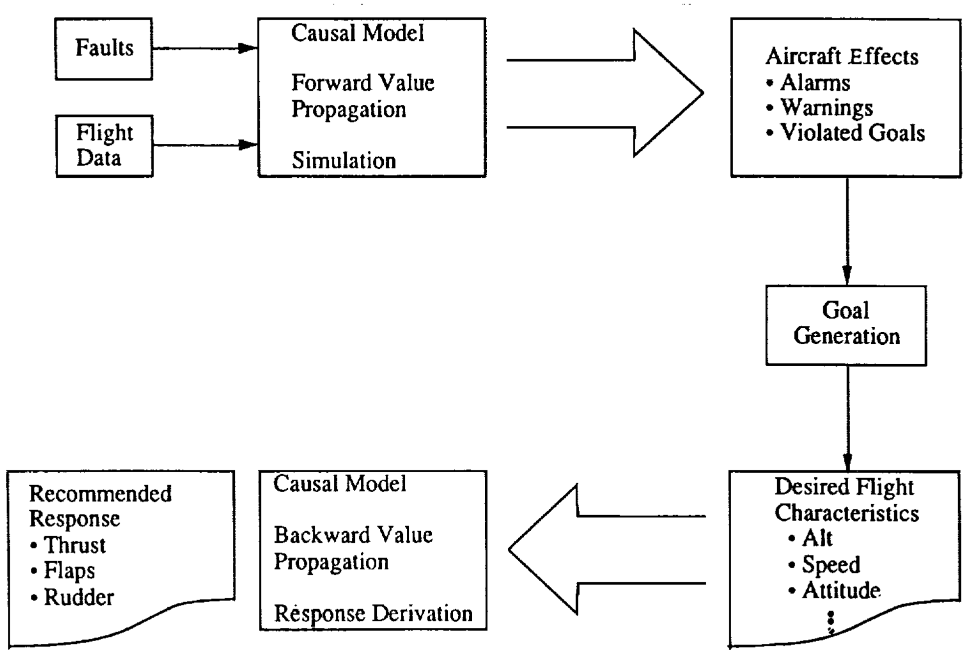
RECENT DEVELOPMENTS

- **Causal Model Editor**
- **Subsystem Modeling**
  - **Requires the Representation of various types of Causal Relations**
  - **Different Temporal Propagation Delays Exist Along the Causal Links**
  - **Requires Use of Different Causal Contexts**
  - **Specialized "Device" Models**
- **Representational Formalism Modified to Reflect these Requirements**
- **Simulation Algorithm Modified to Reflect These Requirements**
- **Time Representation Included in terms of Delays Along Causal Links**
- **Reconfigurable Interface**

FUTURE DIRECTIONS

- Explanation
  - Display Format for Recommendations and Aircraft Effects
  - Visual and Textual Explanation of RECORS' Reasoning
- Verification and Validation
  - Determine How System Effectiveness Varies with
    - fault type
    - emergency type
    - display design
    - crew experience
  - Verify Model Function
  - Validate Against Known Accident Responses
- Evaluation
  - Test Pilot Acceptance in Cockpit Simulation

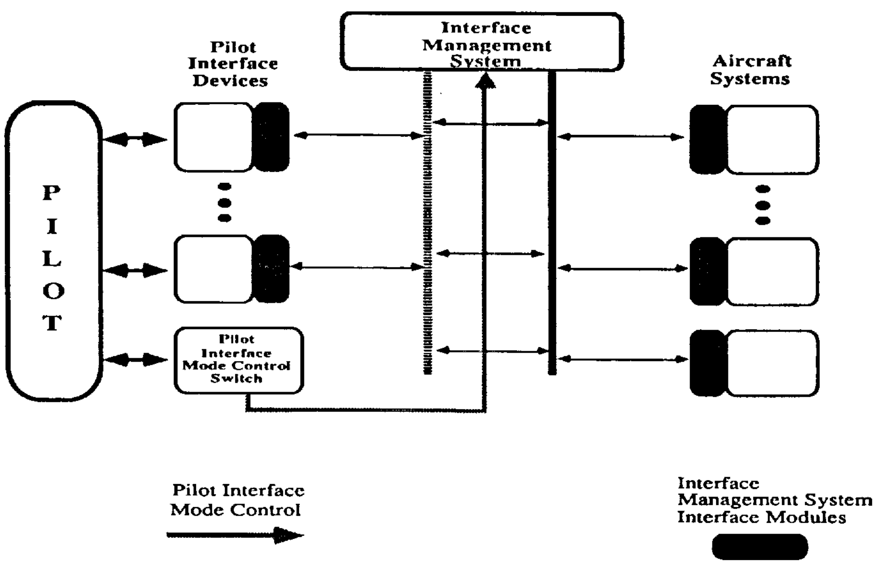
RECORS INFERENCING CYCLE



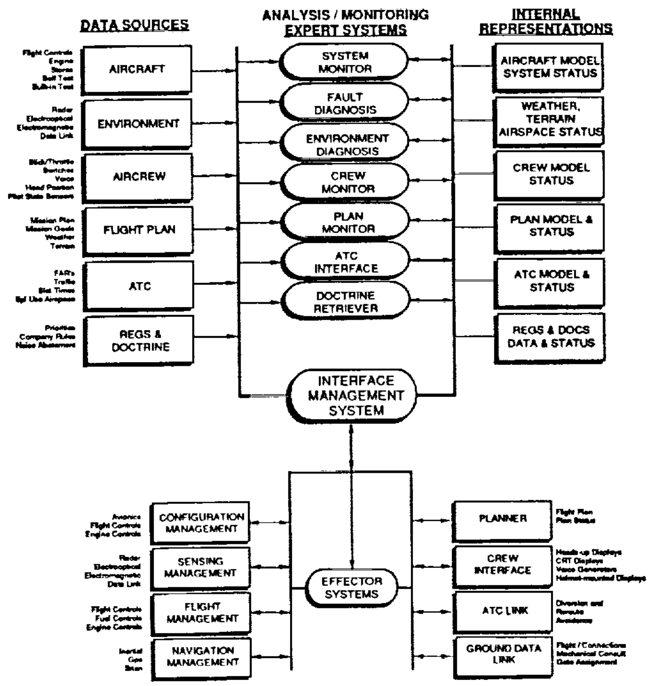
RECORS IMPLEMENTATION

- Version I: Implemented in the KEE development environment on a Symbolics 3600
- Version II: Implemented in Zeta LISP Using an Object-Oriented, Frame-Based Language on a Symbolics XL400

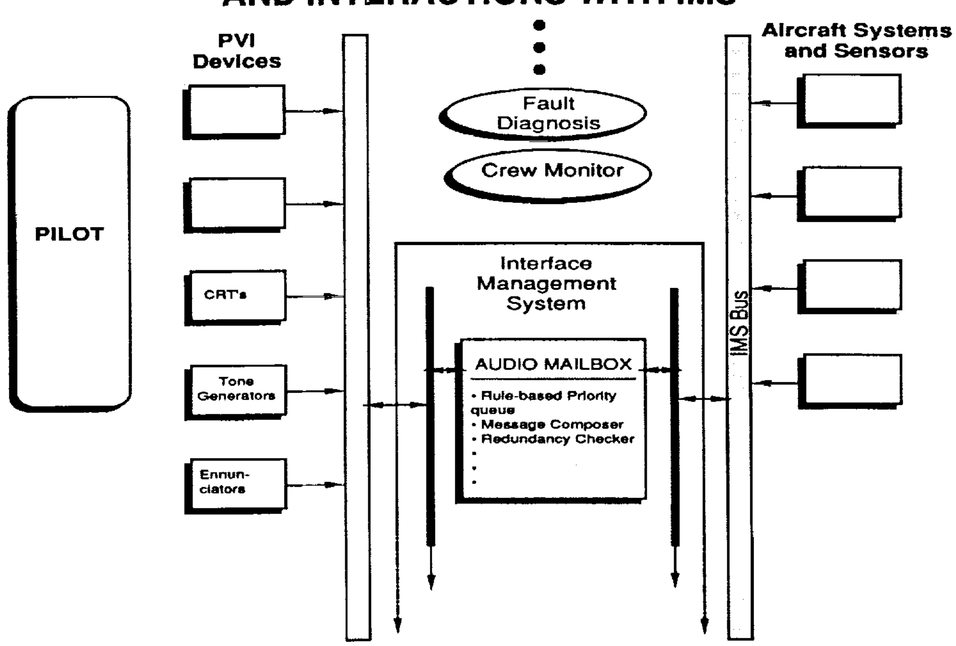
THE INTERFACE MANAGEMENT SYSTEM MANAGES THE FLOW OF INFORMATION AND THE DIALOGS BETWEEN THE SYSTEMS AND THE PILOT

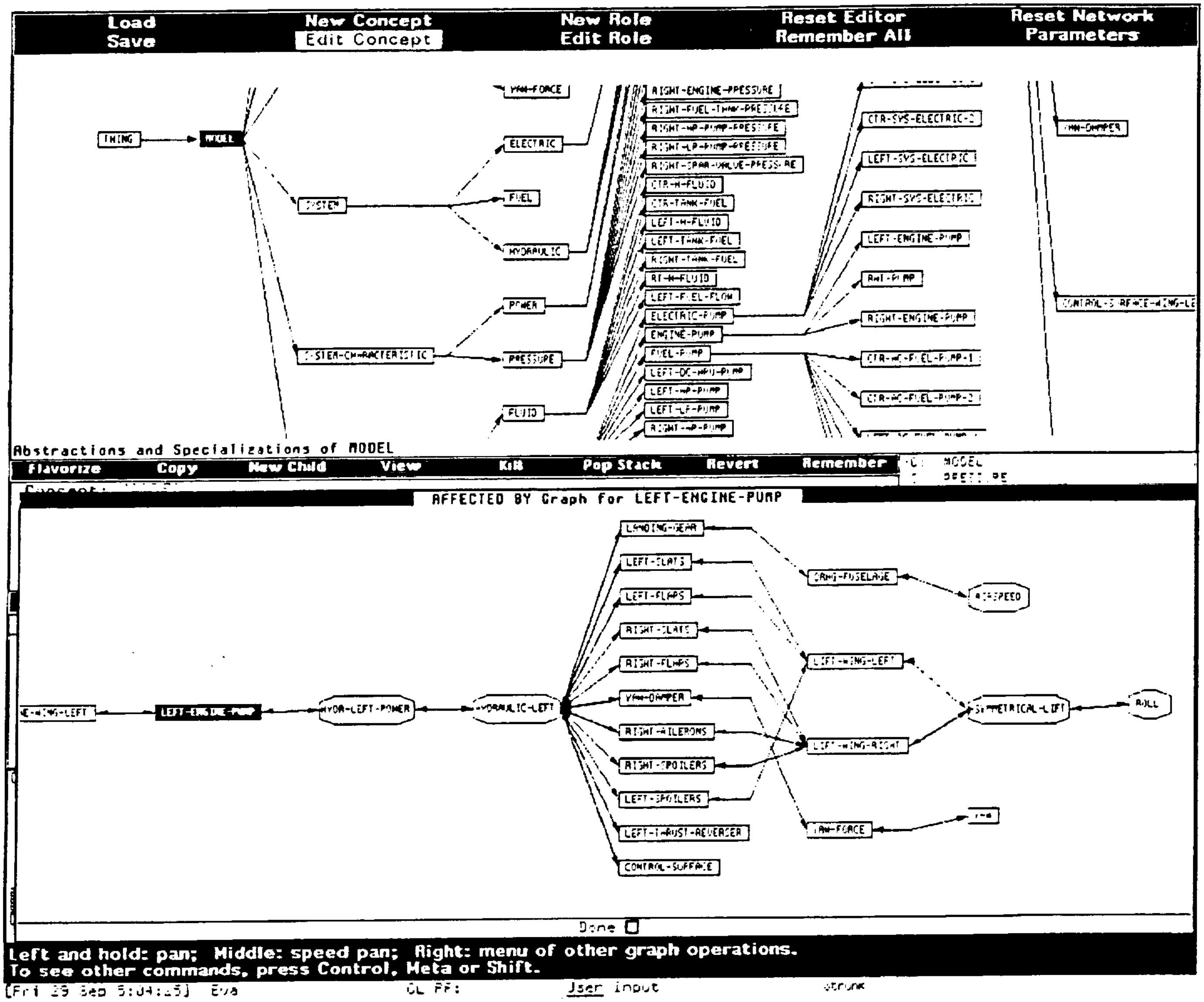


OVERALL A3 ARCHITECTURE



AUDIO MAILBOX ARCHITECTURE AND INTERACTIONS WITH IMS





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A FUNCTION-BASED APPROACH TO COCKPIT PROCEDURE AIDS

Anil V. Phatak and Parveen Jain
EXPERT-EASE

and

Everett Palmer
NASA Ames Research Center

ABSTRACT

The objective of this research is to develop and test a cockpit procedural aid that can compose and present procedures that are appropriate for the given flight situation; described by the current phase of flight, the status of the aircraft engineering systems, and the environmental conditions. Prescribed procedures already exist for normal as well as for a number of non-normal and emergency situations, and can be presented to the crew using an interactive cockpit display. However, no procedures are prescribed or recommended for a host of plausible flight situations involving multiple malfunctions compounded by adverse environmental conditions. Under these circumstances, the cockpit procedural aid must review the prescribed procedures for the individual malfunction (when available), evaluate the alternatives or options, and present one or more composite procedures (prioritized or unprioritized) in response to the given situation.

A top-down function-based conceptual approach towards composing and presenting cockpit procedures is being investigated. This approach is based upon the thought process that an operating crew must go through while attempting to meet the flight objectives given the current flight situation. In order to accomplish the flight objectives, certain critical functions must be maintained during each phase of the flight, using the appropriate procedures or success paths. The viability of these procedures depends upon the availability of required resources. If resources available are not sufficient to meet the requirements, alternative procedures (success paths) using the available resources must be constructed to maintain the critical functions and the corresponding objectives. If no success path exists that can satisfy the critical functions/objectives, then the next level of critical functions/objectives must be selected and the process repeated.

Thus, at any given time during a flight, a function-based cockpit procedure performs the following operations:

* Situation Assessment
  - Phase of flight
  - Aircraft engineering systems status (malfunction)
  - Environmental conditions

* Procedure Selection
  - Present prescribed procedures (when available)
  - Perform critical functions/success path analysis
  - Present alternative procedures/consequences

This function-based approach to cockpit procedural aids is demonstrated through application to flight scenarios where multiple malfunctions occur during the course of the flight.

Problem Description

OVERALL OBJECTIVE OF A FLIGHT:

- MOVE PASSENGERS FROM ORIGIN TO DESTINATION WHILE CONSIDERING THE FOLLOWING FACTORS
  - SAFETY
  - SCHEDULE
  - EFFICIENCY
  - COMFORT

- CREW MUST CONTINUALLY PERFORM THE FOLLOWING FUNCTIONS:
  - SITUATION MONITORING
  - SITUATION ASSESSMENT
  - EVALUATE ALTERNATIVES
  - SELECT PROCEDURES

- COCKPIT PROCEDURAL AID CAN ASSIST THE CREW IN EVALUATING ALTERNATIVES AND SELECTING PROCEDURES

Project Objectives

TO DEVELOP A COCKPIT PROCEDURAL AID (CPA) TO

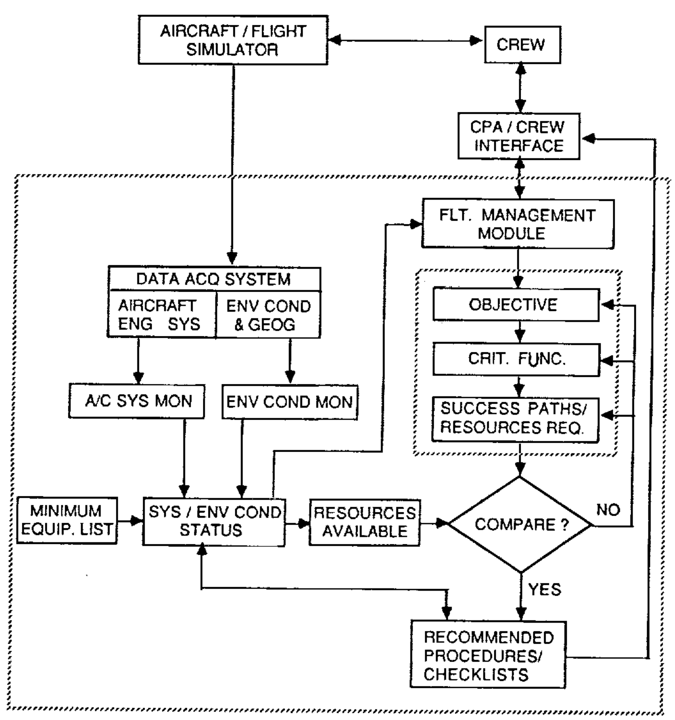
- PRESENT THE PRESCRIBED PROCEDURES UNDER
  - NORMAL CONDITIONS
  - NON-NORMAL CONDITIONS
  - EMERGENCY CONDITIONS

- DEVELOP/PROVIDE RECOMMENDATIONS FOR MULTIPLE MALFUNCTIONS
  - PRESENT PRESCRIBED PROCEDURES CORRESPONDING TO EACH MALFUNCTION AND THEIR CONSEQUENCES
  - PRESENT COMPOSITE PROCEDURES BY AGGREGATING THE INDIVIDUAL PRESCRIBED PROCEDURES
  - WHERE NO PRESCRIBED PROCEDURES ARE AVAILABLE, RECOMMEND ALTERNATIVES AND PRESENT CONSEQUENCES
- PRESENT CONSEQUENCES OF CREW INITIATED DECISIONS AND ACTIONS

Characteristics of Flight

- EVERY FLIGHT CAN BE HIERARCHICALLY DECOMPOSED INTO A NUMBER OF PHASES, SEGMENTS, AND SUB-SEGMENTS
- OVERALL FLIGHT AND ITS INDIVIDUAL PHASES, SEGMENTS, AND SUB-SEGMENTS HAVE
  - -- OBJECTIVES
  - -- CRITICAL FUNCTIONS
  - -- SUCCESS PATHS
- OBJECTIVE IS TO FOLLOW A PRESCRIBED FLIGHT PROFILE
- A CRITICAL FUNCTION IS A FUNCTION THAT MUST BE MAINTAINED TO FOLLOW A FLIGHT PROFILE
- CRITICAL FUNCTION ACCOMPLISHED BY ONE OF SEVERAL SUCCESS PATHS
- A SUCCESS PATH IS A SET OF RECOMMENDED ACTIONS (PROCEDURES) FOR MAINTAINING THE CRITICAL FUNCTION
- EACH SUCCESS PATH (PROCEDURES) HAS A DEFINITE SET OF RESOURCE REQUIREMENTS
- PATH CHOSEN BY MATCHING REQUIREMENTS WITH AVAILABLE RESOURCES
  - -- ENGINEERING SYSTEMS
  - -- ENVIRONMENT

COCKPIT PROCEDURAL AID - CPA

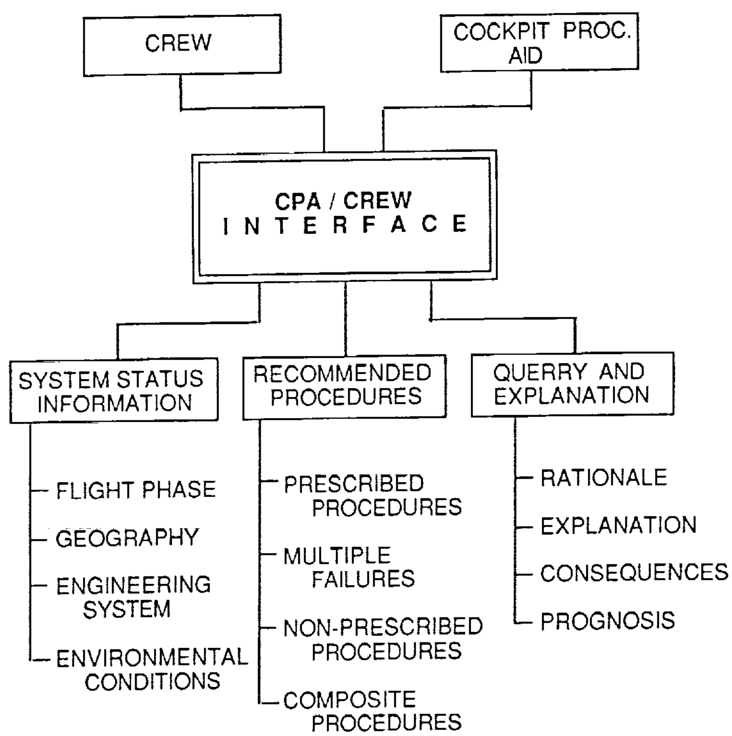


Flight Management Module

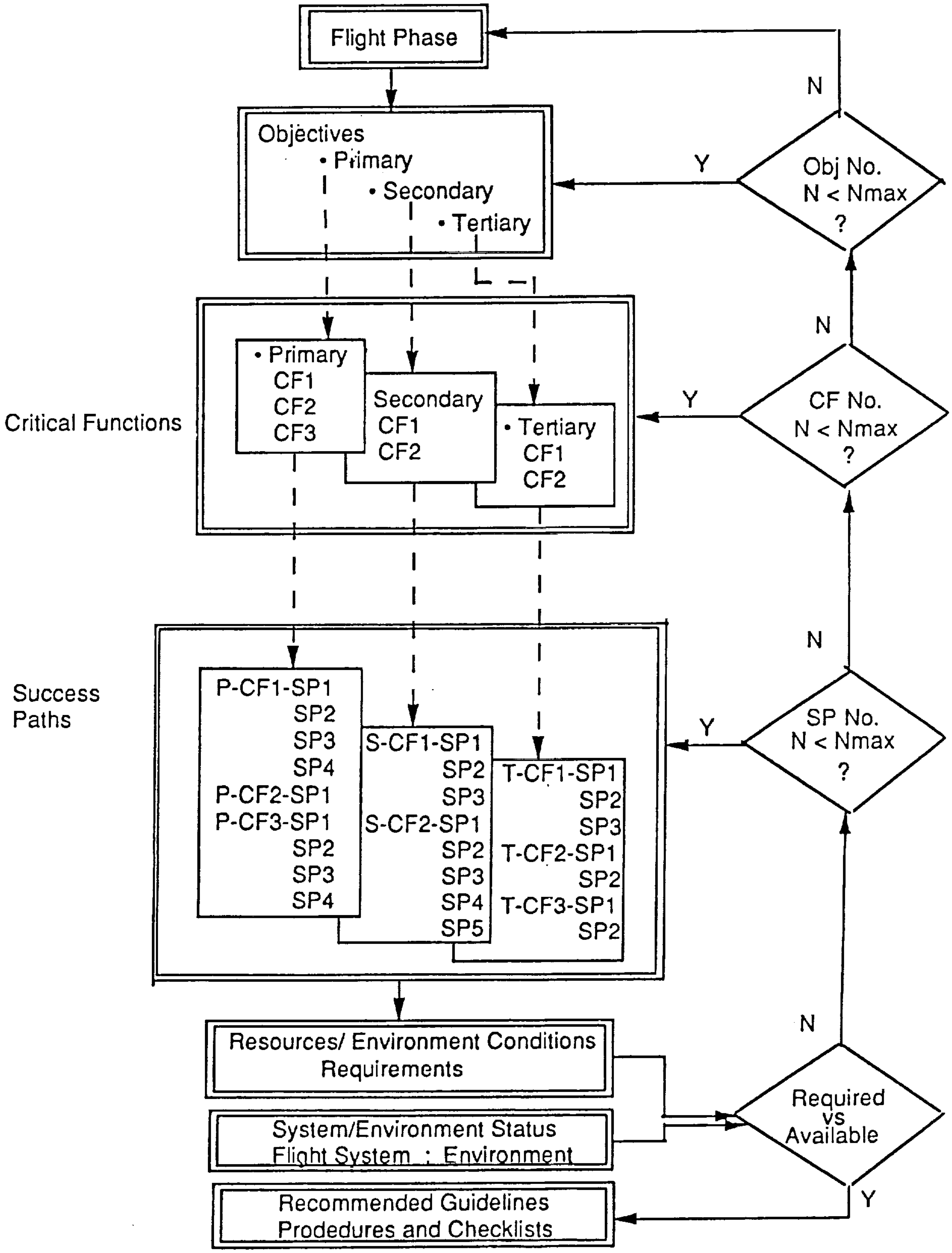
MONITORS THE GLOBAL FLIGHT OBJECTIVES

PERFORMS THE FOLLOWING FUNCTIONS:

- MONITOR THE SITUATION
  - -- PHASE OF FLIGHT
  - -- GEOGRAPHICAL LOCATION
  - -- FUEL STATUS
- MONITOR VEHICLE CONTROL AND STABILITY
- INTERFACE WITH FLIGHT MANAGEMENT COMPUTATIONS
  - -- TIME ELAPSED / TIME TO DESTINATION
  - -- DISTANCE FROM DESTINATION
  - -- FUEL REMAINING / BUDGET CALCULATIONS



Critical Function/Success Path Logic



Examples

- OVERALL FLIGHT
  - OBJECTIVES: FLY TO DESTINATION USING A SAFE AND FUEL EFFICIENT FLIGHT PROFILE
  - CRITICAL FUNCTIONS:
    - VEHICLE STABILITY / CONTROLLABILITY
    - FUEL REMAINING
  - SUCCESS PATHS:
    - FUEL MANAGEMENT METHODS
    - ALTERNATE VEHICLE CONFIGURATIONS
  - RESOURCES REQUIRED:
    - FUEL SYSTEM
    - AIRCRAFT ENGINEERING SYSTEMS
    - ENVIRONMENTAL CONDITIONS

- LANDING PHASE
  - OBJECTIVES: LAND WITH PRESCRIBED SPEED
  - CRITICAL FUNCTIONS: THRUST AND LIFT
  - SUCCESS PATH: HIGH LIFT DEVICES, CONTROL SURFACES, THROTTLE, WEIGHT (FUEL)
  - RESOURCES REQUIRED: AIRCRAFT ENGINEERING SYSTEM, ENVIRONMENTAL CONDITIONS

Candidate Scenario #1

FLIGHT: SACRAMENTO TO LOS ANGELES

FLIGHT PLAN:
SMF.FOGGO5.FRA.J7.DERBB.FIM4.LAX FL 330

MALFUNCTIONS:
- DURING CRUISE GEN #1 TRIPS
- AT TOD ENG #3 OP DEC. TO 36 PSI, OT INC

QUICK SITUATION ASSESSMENT BY CREW AND CPA
- GEN-1 CIRCUIT LIGHT ON
- PRESCRIBED IRREGULAR PROCEDURE
  - CHECK BUS TIE CIRCUIT OPEN LIGHTS (NO)
  - FIELD LIGHTS ON (NO)
  - VOLT AND FREQ NORMAL (YES)
  - CHECK GEN CIRCUIT OPEN LIGHTS OFF (NO)
  - PRESCRIBED ACTION ITEMS:FOLLOW 2-GEN OPER IRR PROC TO DROP ELEC LOAD BELOW 54 KW

Candidate Scenario #1 (cont)

- ENG-3 LOW OIL PRESS LIGHT ON
- PRESCRIBED IRREGULAR PROCEDURE
  - -- OIL PRESS BELOW 35 PSI (NO)
  - -- REDUCE THRUST
  - -- LOW OIL PRESS LIGHT ON (YES)
  - -- ACCOMPLISH IRR PROC FOR ENG-3 SHUTDOWN, OR REDUCE THRUST TO MIN REQUIRED

OPTION 1: SHUTDOWN ENG-3

- CONSEQUENCE: 2 ENG AND 1 GEN OPERATING
  - -- LOAD < 36 KW, POSSIBLE CABIN PRESS PROBLEMS AND HIGH RISK UNDER NIGHT CONDITIONS, POSSIBLE FUEL UNBALANCE PROBLEM

OPTION 2: REDUCED MIN THRUST ENG-3

- CONSEQUENCE: 2 ENG AND 2 GEN OPERATING
  - -- LOAD < 54 KW, MAX 20 MIN FLYING TIME

Candidate Scenario #2

FLIGHT: LOS ANGELES TO SACRAMENTO

FLIGHT PLAN:
LAX.GMN6.EHF.365.CZQ.WRAPS4.SMF FL 310

MALFUNCTIONS:

- NEAR TOD FUEL LEAK IN TANK #3 (APPROX. 500 LB/MIN), STOPS BELOW 1800 LBS OF FUEL
- #7 LEADING EDGE SLAT DOES NOT EXTEND

QUICK SITUATION ASSESSMENT BY CREW AND CPA

- 1000 LB FUEL TANKS 1 AND 3 DIFF (POSSIBLE EARLIER DETECTION BY CPA)
- PRESCRIBED IRREGULAR PROCEDURE
  - -- NONE
  - -- VIOLATION OF FUEL UNBALANCE SPECIFICATIONS/LIMITATIONS

FLIGHT MANAGEMENT OBJECTIVES:

- VEHICLE STABILITY / CONTROLLABILITY
- LAND AT THE INTENDED DESTINATION
- POSSIBLE CONFLICT DEPENDING ON PRIORITY

Candidate Scenario #2 (cont)

OPTION 1: PRIORITY ON VEHICLE STABILITY ONLY

- BALANCE TANK FUEL BY DUMPING FROM TANK #1
- MANAGE FUEL FLOW CONFIGURATION TO PREVENT ENG-3 FLAMEOUT
- EVALUATE AND RECOMMEND LANDING SITE

OPTION 2: REACH DESTINATION WITH ACCEPTABLE VEHICLE STABILITY

- PRESENT ALTERNATIVE FUEL FLOW CONFIGURATIONS TO OPTIMIZE FUEL COMSUMPTION
- EVALUATE CONSEQUENCES OF EACH CONFIGURATION OPTION
- RECOMMEND LANDING SITE OPTIONS

Implementation

- IMPLEMENTED ON PERSONAL COMPUTER AND VAX WORKSTATION
- CUSTOM APPLICATION BUILT FROM GENERIC TOOLS
- OBJECT-ORIENTED REPRESENTATION:
  - AIRCRAFT ENGINEERING SYSTEMS
  - ENVIRONMENTAL CONDITIONS
  - FLIGHT MANAGEMENT MODULE
  - CRITICAL FUNCTION
  - SUCCESS PATHS (PROCEDURES/CHECKLISTS)
- FRAME-BASED INFERENCING (FLIGHT MANAGEMENT/ CRITICAL FUNCTION/SUCCESS PATH EVALUATION)
  - LOGIC FLOW INFERENCE ENGINE
  - FRAMES REPRESENTED IN TERMS OF OBJECTS
  - REASONING USING FORWARD AND/OR BACKWARD CHAINED RULES
- INTERFACE TO AIRCRAFT OR FLIGHT SIMULATOR
- MAN-MACHINE INTERFACE:
  - EASE+ - A GRAPHICAL DATA BASE MANAGEMENT ENVIRONMENT
  - PROVIDES ENVIRONMENT FOR INTERACTION BETWEEN USER, DATABASE, FLIGHT MANAGEMENT MODULE AND SIMULATOR
  - GRAPHICAL AND SYNOPTIC PRESENTATION OF ALL RELEVANT INFORMATION

Remaining Work

- COMPLETE PROTOTYPE IMPLEMENTATION OF COCKPIT PROCEDURAL AIDS METHODOLOGY

- DEVELOP AND TEST COCKPIT PROCEDURAL AIDS METHODOLOGY USING 2 OR 3 FLIGHT SCENARIOS AS EXAMPLES

N91-10954

PROCEDURAL ERROR MONITORING AND SMART CHECKLISTS

Everett Palmer
NASA Ames Research Center

Error Detection and Correction: Self and Automatic

• **Human beings make and usually detect errors routinely. The same mental processes that allow humans to cope with novel problems can also lead to error. Bill Rouse has argued that errors are not inherently bad but their consequences may be. He proposes the development of "error-tolerant" systems that detect errors and take steps to prevent the consequences of the error from occurring. Research should be done on self and automatic detection of random and unanticipated errors.** For self detection, displays should be developed that make the consequences of errors immediately apparent. For example, electronic map displays graphically show the consequences of horizontal flight plan entry errors. Vertical profile displays should be developed to make apparent vertical flight planning errors. Other concepts such as "energy circles" could also help the crew detect gross flight planning errors. **For automatic detection, systems should be developed that can track pilot activity, infer pilot intent and inform the crew of potential errors before their consequences are realized.** Systems that perform a reasonableness check on flight plan modifications by checking route length and magnitude of course changes are simple examples. Another example would be a system that checked the aircraft's planned altitude against a data base of world terrain elevations.

From: Flight Deck Automation: Promises and Realities

PROCEDURAL ERROR MONITORING AND SMART CHECKLISTS

Error Detection & Correction: Self and Automatic

- Humans make and usually detect errors routinely.
- The same mental processes that allow humans to cope with novel problems can also lead to error.
- Errors are not inherently bad but their consequences may be.
- "Error-Tolerant" Systems should be developed that can track pilot activity, infer pilot intent and inform the crew of potential errors.

From: ***Flight Deck Automation: Promises and Realities***

Research Goal

- To design systems that can infer the crew's current plan, form expectations about future crew actions and warn the crew of possible errors.

Approach:

- Base the system on script based AI programs that understand human actions in stories.
- Develop a hierarchical script based program to detect procedural errors in data form our B-727 simulator.
- Incorporate the program concepts into a "SMART CHECKLIST" for the Advanced Cockpit Flight Simulator".
- Support Related Grant and Contract Research.

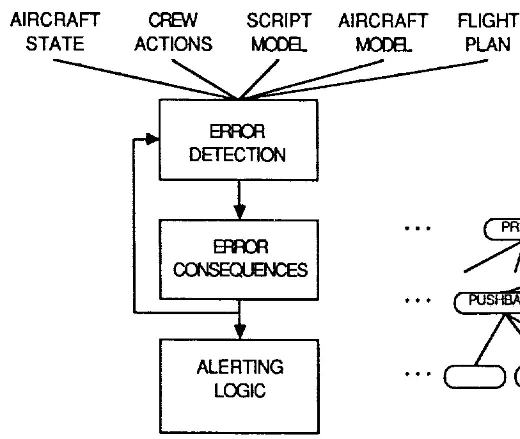
PROCEDURAL ERROR MONITORING & SMART CHECKLISTS

OBJECTIVE

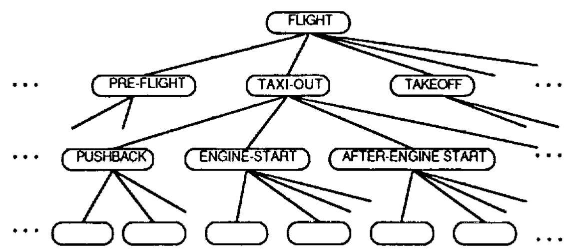
- AVIONIC SYSTEMS THAT "UNDERSTAND" THE ACTIONS OF CREW AND CAN INFORM CREW OF POSSIBLE ERRORS

APPROACH

- SCRIPT BASED MODEL
- TRACK CREW ACTIONS
- DETECT ERRORS IN B-727 SIMULATOR
- DETERMINE ERROR CONSEQUENCES
- REAL-TIME FEEDBACK
- SMART CHECKLISTS FOR THE ACFS



SYSTEM ARCHITECTURE



SCRIPT OF CREW ACTIVITIES

Status

- B-727 flights analysed with Version 1 of the script based activity tracking program.
- Difficulty in dealing with actions from procedures done in an unexpected order.
- Version 2 of the script based activity tracking program "explains" observed actions by linking them to expected actions in the procedure script.
- Gathered data on procedure execution in two full mission experiments in our 727 simulator.

Plans

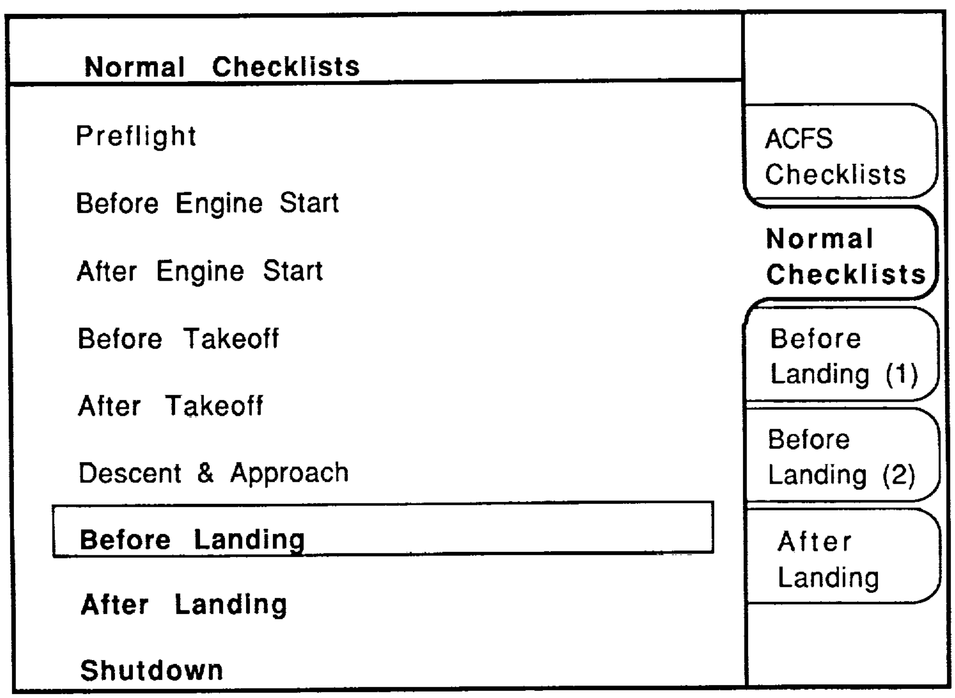
- Analyze 727 data from the "ATC FLOW" and "PNPS" Experiments.
- Compare program to pilot understanding of crew activity.
- Compare program to "OFMspert" developed at Georgia Tech.
- Develop and test Smart Checklists in the ACFS.

Two Problems with Conventional Checklists

- External Memory.
- Task Automization.

Smart Checklists Designs

- Designs are based on the Script Based Procedure Tree Architecture.
- Phase of Flight and Procedure Selection will be done Manually.
- Designs differ in the **Level of Automation** of procedural tasks.
- Designs differ in the **Level of Involvement** of the crew in the execution and monitoring of procedural tasks.



Before Landing - Page 2 of 2

Seat Belt Light	On
No Smoking Light	On
Spoilers	**Armed**
Landing Gear	**Down**
Flaps	**Down**
Landing Clearance	**Received**

ACFS Checklists

Normal Checklists

Before Landing (1)

Before Landing (2)

After Landing

Engine Overheat

Engine Bleed Air Switch..Off

Thrust Lever...Retard
Retard slowly until ENG OVHT light extinguishes.

Is ENG OVH light still illuminated? YES NO
- **Engine Failure / Shutdown Checklist.....................................Accomplish**

Is wing anti-ice required? YES NO
- **One Pack Control Selector..........................Off**
- **Isolation Switch (Affected Side) ....On**
  Return to OFF when anti-ice is no longer required.

***** End of Engine Overheat Checklist *****

Normal Checklists

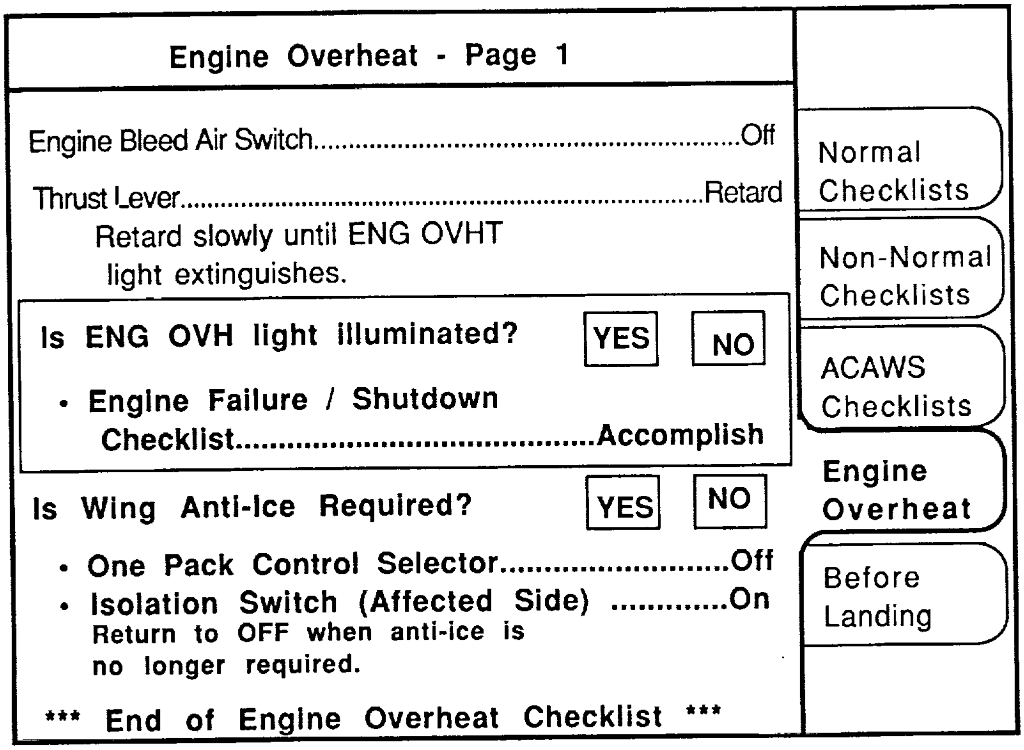
Non-Normal Checklists

ACAWS Checklists

Engine Overheat

Before Landing

PROCEDURAL ERROR MONITORING & SMART CHECKLISTS



Checklist Features - Experimental Conditions

- A Passive Electronic Checklist -> External Memory of completed steps.
- A Monitored Electronic Checklist -> Machine Monitoring of crew actions
- An Automatic Checklist Control -> Lower Workload
- An Automatic Execution Checklist -> Still Lower Workload

PROCEDURAL ERROR MONITORING AND SMART CHECKLISTS

Expected Results of Research

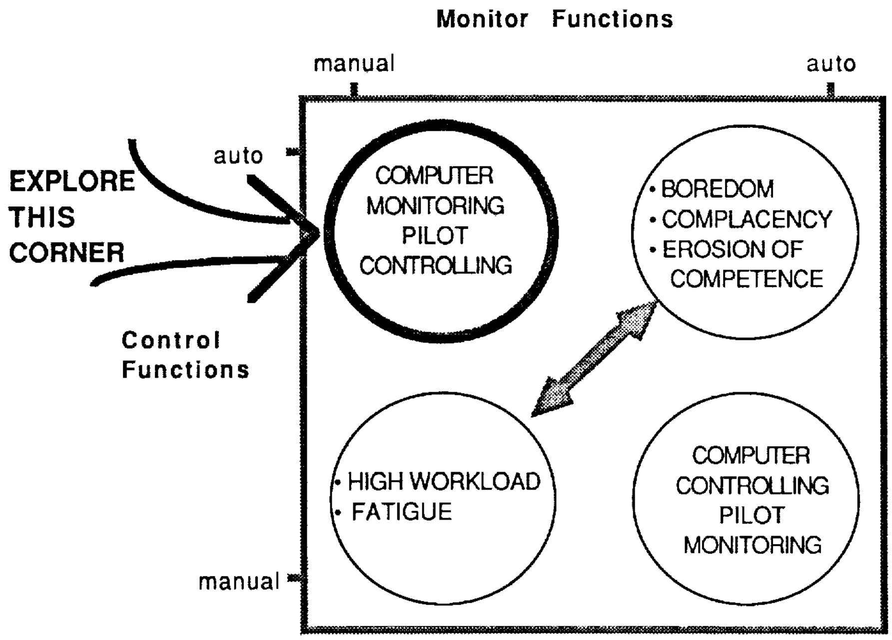
- Reduce consequences of pilot error.
- A model of the pilot for the avionic system.
- Avionic systems that "understand" pilot intent.
- Avionic systems that knows the current context.
- A framework for electronic checklists.
- Data on human error.

Related Grants and Contracts

- "Bayesian Temporal Reasoning"
  - Curry, Cooper & Horvitz at Search Technology Inc.
- "Operator Function Modeling & OFMspert"
  - Mitchell at Georgia Institute of Technology
- "Expert Flight Systems Monitor"
  - Frogner, Jain & Phatac at Expert Ease Systems Inc.
- "Distributed Cognition in Aviation"
  - Norman & Hutchins at University of California, San Diego
- "Human Factors of Flight Deck Checklists"
  - Degani at University of Miami.

PROCEDURAL ERROR MONITORING & SMART CHECKLISTS

Two Dimensions of Automation: Control & Monitoring



The objective of this research is to develop the technology necessary for the design of error tolerant cockpits. A key feature of error-tolerant systems is that they incorporate a model of pilot behavior. The system uses this model to track pilot actions, infer pilot intent, detect unexpected actions, and alert the crew to potential errors. In some sense, the goal is to develop an "electronic check pilot" that can intelligently monitor pilot activities.

We are pursuing a number of alternative ways to track operator activity and infer operator intent. We are investigating techniques based on 1) a rule based script of flight phases and procedural actions, 2) operator function models, and 3) Bayesian temporal reasoning. The first version of the script based program was tested against protocol data from four 727 simulator flights. The program could detect procedural errors but its ability to account for pilot actions from procedures done out of the normal sequence was inadequate. A capability to explain unexpected actions by linking them to procedures that are nominally done or unstarted is being added to the program to remedy this problem. Under a grant to Georgia Tech, an intent inferencing system based on an operator function model was developed and tested on data from a satellite communications system with good results. Under a contract to Search Technology, a prototype for an intent inferencing system based on Baysian reasoning was developed. We plan to compare these methods against data from our 727 simulator. We also plan to initiate an empirical study designed to better understand how check pilots detect procedural errors and infer pilot intent.

The technology developed for the "Procedural Error Monitor" will be used to develop an interactive cockpit display to aid pilots in executing procedures. Modes of checklist operation will include both passively monitoring pilot execution of procedures and automatically executing procedures. Under a related SBIR contract, we will develop and test a procedure execution aid that can compose procedures that are appropriate for the current flight situation and equipment configuration.

Everett A. Palmer

N91-10955

INFLIGHT REPLANNING FOR DIVERSIONS

Michael Palmer
NASA Langley Research Center

INFLIGHT REPLANNING FOR DIVERSIONS

Current procedures for handling flight plan diversions can require too much of the crew's resources. This increases workload and may compromise safety and cause delays in modifying the flight plan. The goal of NASA Langley Research Center's Diverter research program is to develop guidelines for a prototype pilot decision aid for diversions that will reduce cognitive workload, improve safety, increase capacity and traffic flow, and increase aircraft efficiency. The Diverter program has been partitioned into five phases, the first three of which were performed under contract by Lockheed Aeronautical Systems Company, Marietta, GA. In the first two phases, which have been completed, the system requirements and desired functions were defined and a prototype decision-making aid was implemented and demonstrated on a workstation. In phase three, which is currently under way, the pilot/vehicle interface is being defined and the capability of the prototype is being improved. In the last two phases, which will be performed at NASA Langley Research Center, the interface will be implemented, tied into the prototype aiding software, and installed in an advanced simulation facility for testing. In addition, significant implementation issues may be addressed through flight testing on NASA research aircraft.

PROBLEM

Current procedures for handling diversions can require too much of the crew's resources. This increases workload, and may compromise safety and cause delays in modifying the flight plan.

DIVERTER PROGRAM GOAL

Develop guidelines for and implement a prototype pilot decision aid for diversions which will:

- Reduce cognitive workload
- Improve safety
- Increase capacity & traffic flow
- Increase aircraft efficiency (time & fuel)

DIVERTER ISSUES

- What aspects of diversion planning would benefit the most from intelligent aiding?
- Where should diversion information be displayed?
- How should the crew interact with the system?
- How should a diversion system interact with other aircraft systems?
- How should the system interact with existing ATC?

DIVERTER PROGRAM OBJECTIVES

- ● Phase 1 - Define requirements and desired functions
- ● Phase 2 - Develop prototype decision-making aid, and demonstrate "stand-alone" capability
- ○ Phase 3 - Define pilot/vehicle interface, and improve Diverter's functional capability
- ○ Phase 4 - Install and evaluate the aid in a realistic flight simulation environment
- ○ Phase 5 - Examine human-centered automation issues through simulation, and investigate implementation issues by flight testing on TSRV aircraft

PHASE 1 ACCOMPLISHMENTS

- Determined Diverter system requirements
  - Identified causes of diversions
  - Identified different types of diversions

- Determined desired system functions
  - Identified functions to be performed
  - Identified information required to make the necessary decisions for those functions
    - > Destination selection decision factors
    - > Route planning/replanning decision factors
    - > Other information sources

CAUSES FOR DIVERSIONS

- Destination traffic
- En route traffic
- Weather
- Runway or airfield closure
- Aircraft malfunction
- Passenger problem

TYPES OF DIVERSIONS

- Different departure route
- En route change to same destination
- Delaying vectors
- Holding
- Different arrival route
- Alternate destination

DIVERTER FUNCTIONS

- Perform situation assessment
  - Position, heading, airspeed, etc.
- Evaluate influences on rerouting
  - FAR's, weather, traffic, priorities, company rules, airspace restrictions, noise abatement, slot times
- Consider system status constraints
  - Aircraft systems, avionics, fuel, etc.
- Perform flight planning/replanning
  - Destination, route, fuel, time
- Perform manuever planning
  - Performance, terrain, traffic, weather

DESTINATION DECISION FACTORS

- Safety
- Airfield condition and facilities
- Passenger comfort
- Schedule constraints
- Economy

ROUTE DECISION FACTORS

- Available routes
- Obstacles & terrain
- Min & max altitudes
- Distance from destination
- Aircraft status
- Current weather conditions

PHASE 2 ACCOMPLISHMENTS

- Developed prototype decision-making aid
  - Selected subset of Diverter functions for implementation
  - Designed prototype decision aid using applicable AI technology
  - Implemented in Lisp on Symbolics
  - Incorporated engineering interface and explanation capability
- Demonstrated "stand-alone" capability
  - Demo 1: Included alternate airfield selection
  - Demo 2: Added route replanning & Adage display

PHASE 3 APPROACH

- Define pilot/vehicle interface
  - Identify pilot information needs, and display locations and hardware interactions
  - Define specs for all required display formats
    - > Appearance of information on display
    - > Exact source, content, and organization of required information
- Improve Diverter's functional capability
  - Integrate airfield selection/route replanning
  - Redesign database I/O procedures to read and write to independent data streams

PHASE 4 APPROACH

- Install Diverter in NASA Langley Advanced Concepts Simulator (ACS)
  - Adapt interface design as necessary
  - Tie in appropriate data streams
- Evaluate aiding capability during realistic flight scenarios

PHASE 5 APPROACH

- Examine human-centered automation issues through simulation
  - Evaluate existing interface, identify necessary changes, implement those changes
  - Examine sensitivity to decision factor weight changes, and to inaccurate or incomplete data
- Examine implementation issues through flight test on TSRV aircraft

GRAPHICAL INTERFACES FOR COOPERATIVE PLANNING SYSTEMS

Philip J. Smith and Chuck Layton
Ohio State University

and

C. Elaine McCoy
San Jose State University

ABSTRACT

Based on a cognitive task analysis of 5 airline flight crews in a simulator study, we have designed a testbed for studying computer aids for en route flight path planning. This testbed runs on a Mac II controlling three color monitors, and is being used to study the design of aids for both dispatchers and flight crews.

Specifically, our research focuses on design concepts for developing cooperative problem-solving systems. We use en route flight planning (selecting alternate routes or destinations due to unanticipated weather, traffic, malfunctions, etc.) as the context for studying the design of such systems. Flight planning provides an interesting context because

1. Decisions must be made based on multiple competing or complementary goals.
2. Decisions are made in an information-rich environment.
3. Some of the information is available only to the flight crew (e.g., visual data or verbal reports from other planes and air traffic control). Other information is most easily accessed or processed by the computer.
4. Decisions must be made in a stochastic world. There is a great deal of uncertainty about future events.
5. There is the potential to apply both knowledge-based systems and optimization approaches in the design of computer aids.
6. Much (but not all) of the data is very graphic in nature.

We are currently exploring three questions in this test environment:

1. When interacting with a flight planning aid, how does the role of the pilot influence overall system performance? (Should the computer aid generate and recommend full flight plans; and should it respond to "what if" explorations by the pilot, etc.?)
2. Can the architecture for a cooperative planning system be built around Sacerdoti's (1983) concept of an abstraction hierarchy, where the pilot can interact with the system at many different levels of detail (but where the computer aid by default handles lower level details that the pilot has chosen not to deal with)?
3. Can graphical displays and direct manipulation of these displays provide perceptual enhancements (Larkin and Simon, 1987) of the pilot's problem-solving activities?

Motivation

Use "aiding/automation only at those points in time when human performance in a system needs support to meet operational requirements - in the absence of such needs, human performance remains unaided/manual, and thereby humans remain very much "in the loop", (Rouse, 1988).

"Users will not accept an aiding system that appears to usurp their authority or unduly restricts their options", (Madni, 1988).

"The improvement of cooperative problem solving...increases proportionately as the degree of overlap between the user's and the expert system's problem-solving processes decreases; that is, with decreasing cognitive consistency," (Lehner and Zirk, 1987).

"The user must have an accurate model of how that machine operates," (Lehner and Zirk, 1987).

Questions

- When should we provide computerized decisions aids?
- How should these aids function?
- How should the computer's functioning be represented in the displays and controls that the user interacts with?

Goal

- To study possible answers to these questions in the context of en route flight planning.

Context: En route Flight Planning

- Planning must take into consideration multiple competing and/or complementary goals (Wilensky, 1983).
- Decisions must be made in an information rich environment (Rouse, 1983).
- The flight crew and the computer must share data and inferences with each other.
- Such planning involves decision making under uncertainty.
- Decision making is really a group activity, involving ATC and Dispatch as well.

GOALS

*Study issues in the design of cooperative problem-solving systems

*Develop and evaluate design concepts for aiding real-time planning of flights

Approach

*Study human performance in existing environments

*Build a test-bed for empirically studying alternative design concepts and principles (part-task simulation)

*Evaluate promising concepts in full-task simulations

Flight Planning Testbed

* Calculation of optimal altitudes
* Feedback on the implications of a plan
* Ability to explore "what-if" questions
* Spreadsheet-like computations and displays
* Integration of text and graphics displays
* Graphics-based exploration of flight plans
* Easy text-based editing of plans
* Alerting functions
* Accurate map projections for the whole world
* Shared plan generation

Flight Planning Testbed

* For studying flight crews and dispatchers
* Part-Task Simulation
* Mac II
* Up to 6 Color Monitors
* Mouse and Keyboard Entry
* Real-Time and Simulation-Time Clocks
* Updating of Weather and Airport Statuses Over
* Automatic Recording of all Actions for Replay or Computer Analysis
* Trend Information

Design Concepts

* Personalized displays to accommodate particular circumstances and preferences
* Carefully designed functional groupings
  (visual displays, menus, text displays)
* Compact displays
* Alternative methods of interaction (direct manipulation with mouse or trackball vs. keyboard entry)
* Develop intelligent "alarms" to focus attention on critical data and inferences (allow the pilot to "alarm" the computer as well?)

Design Concepts

* Monitor for clearly questionable plans
  (a critiquing system)

* Allow the pilot and the computer to exchange hypotheses, data, and inferences

* Take advantage of graphics-based planning aids to provide perceptual enhancement of problem solving
  (Larkin and Simon, 1987)

* Design cooperative problem-solving systems rather than "autonomous" expert systems

* Allow pilots to ask "what if" questions

* To make it easy to ask "what if" questions, structure the architecture of the cooperative system around Sacerdoti's notion of an abstraction hierarchy

* To make it easy to ask "what if" questions, have the system infer the intentions of the pilot

Summary

- Testbed
- Initial design concepts and implementations
- Methods for studying alternative designs

PROGRAM ELEMENT III

ATC AUTOMATION AND A/C-ATC INTEGRATION

N91-10957

ATC AUTOMATION CONCEPTS

Heinz Erzberger
NASA Ames Research Center

RESEARCH PROGRAM IN ATC AUTOMATION

OBJECTIVE:

DESIGN OF HUMAN -CENTERED AUTOMATION TOOLS FOR TERMINAL AREA AIR TRAFFIC CONTROL

SCOPE:

- AUTOMATION CONCEPTS
- TRAJECTORY PREDICTION AND CONTROL ALGORITHMS
- SCHEDULING AND SEQUENCING ALGORITHMS
- HUMAN-SYSTEM INTERFACE DESIGN
- TEST AND EVALUATION OF CANDIDATE CONCEPTS
- TECHNOLOGY TRANSFER

PAYOFFS AND PRODUCTS

PAYOFFS

- INCREASED FUEL EFFICIENCY
- REDUCED DELAYS
- EFFECTIVE RESPONSE TO CONTINGENCIES
- IMPROVED WORK ENVIRONMENT FOR CONTROLLERS

PRODUCTS

- CONCEPTS AND DESIGN METHODS FOR AUTOMATED ATC SYSTEMS
- AUTOMATION SOFTWARE
- CONTROLLER SYSTEM INTERFACE AND CONTROLLER PROCEDURES
- TESTS AND EVALUATIONS OF KEY CONCEPTS AT OPERATIONAL SITE

OUTLINE

- DESIGN PHILOSPHY
- AUTOMATION CONCEPT
- CONTROLLER SYSTEM INTERFACES
- TESTS & EVALUATIONS

BROAD GUIDELINES

- CONTROLLER RESPONSIBILITIES UNCHANGED
- AUTOMATION TOOLS ASSIST BUT DO NOT REPLACE CONTROLLER FUNCTIONS
- PROVIDE ADVISORIES FOR BOTH NORMAL AS WELL AS ABNORMAL SITUATIONS
- CONTROLLERS DECIDE WHETHER TO USE OR IGNORE ADVISORIES
- NO ADDITIONAL SENSORS REQUIRED ON THE GROUND OR ONBOARD
- PROVIDE A BASIS FOR DESIGN OF FUTURE AUTONOMOUS ATC SYSTEMS

OBSERVATIONS AND APPROACH

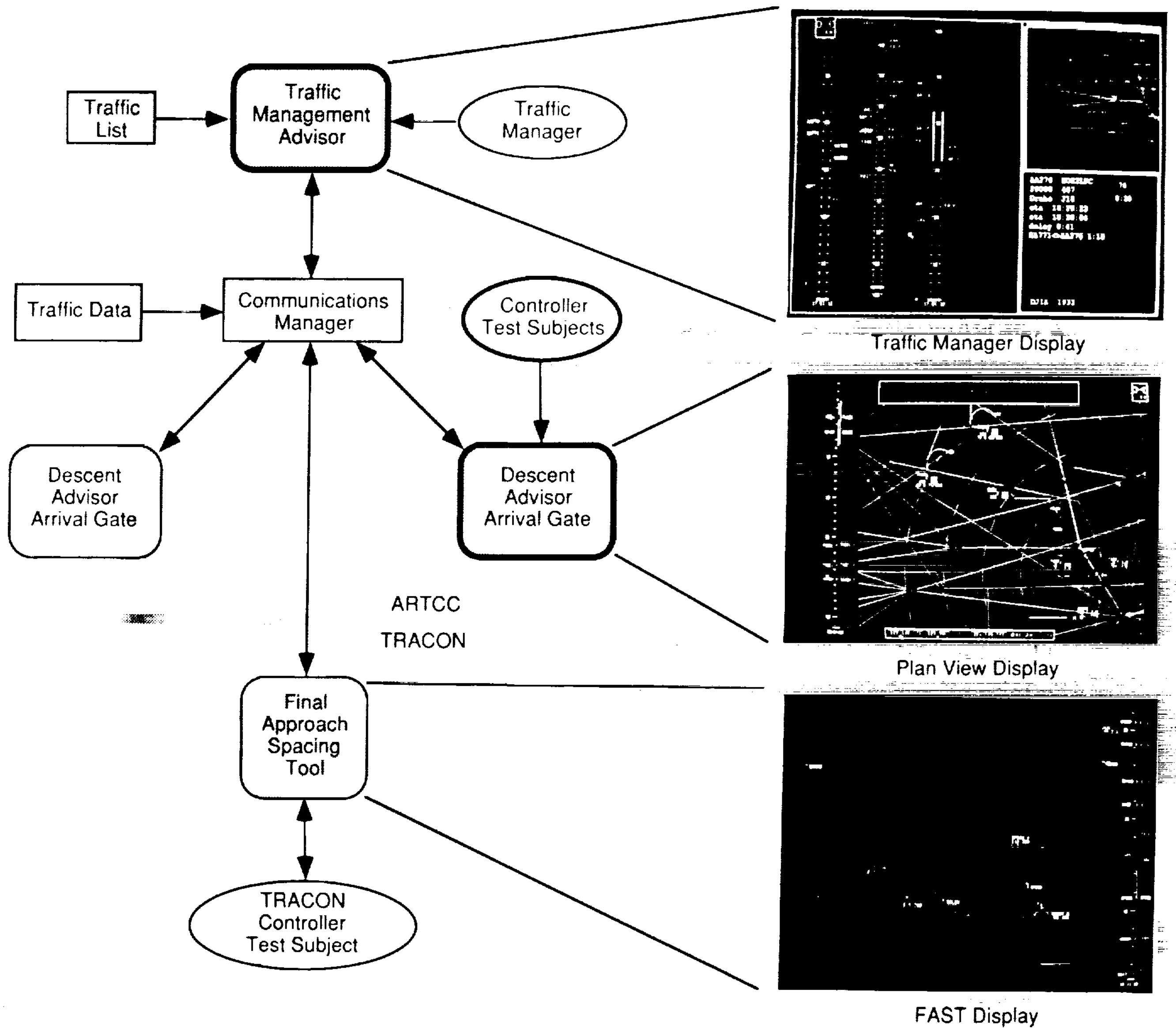
AIR TRAFFIC CONTROL IS A TEAM PROCESS

- EACH TEAM MEMBER IS AN EXPERT IN HIS POSITION; BUT WORKS CLOSELY WITH OTHER TEAM MEMBERS
- COMMUNICATIONS AND COORDINATION BETWEEN TEAM MEMBERS IS A DOMINANT FEATURE

DESIGN OF AUTOMATION SYSTEM IMITATES STRUCTURE OF MANUAL CONTROL PROCESS

- HIERARCHY OF SUPERVISION AND CONTROL
- EXPERT ADVISORS DESIGNED FOR EACH CONTROLLER POSITION
- COMPLEX COMMUNICATION PROTOCOLS BETWEEN EXPERT ADVISORS

ATC AUTOMATION TOOLS



TRAFFIC MANAGEMENT ADVISOR: WHAT IS IT?

OPTIMUM SCHEDULING ALGORITHMS

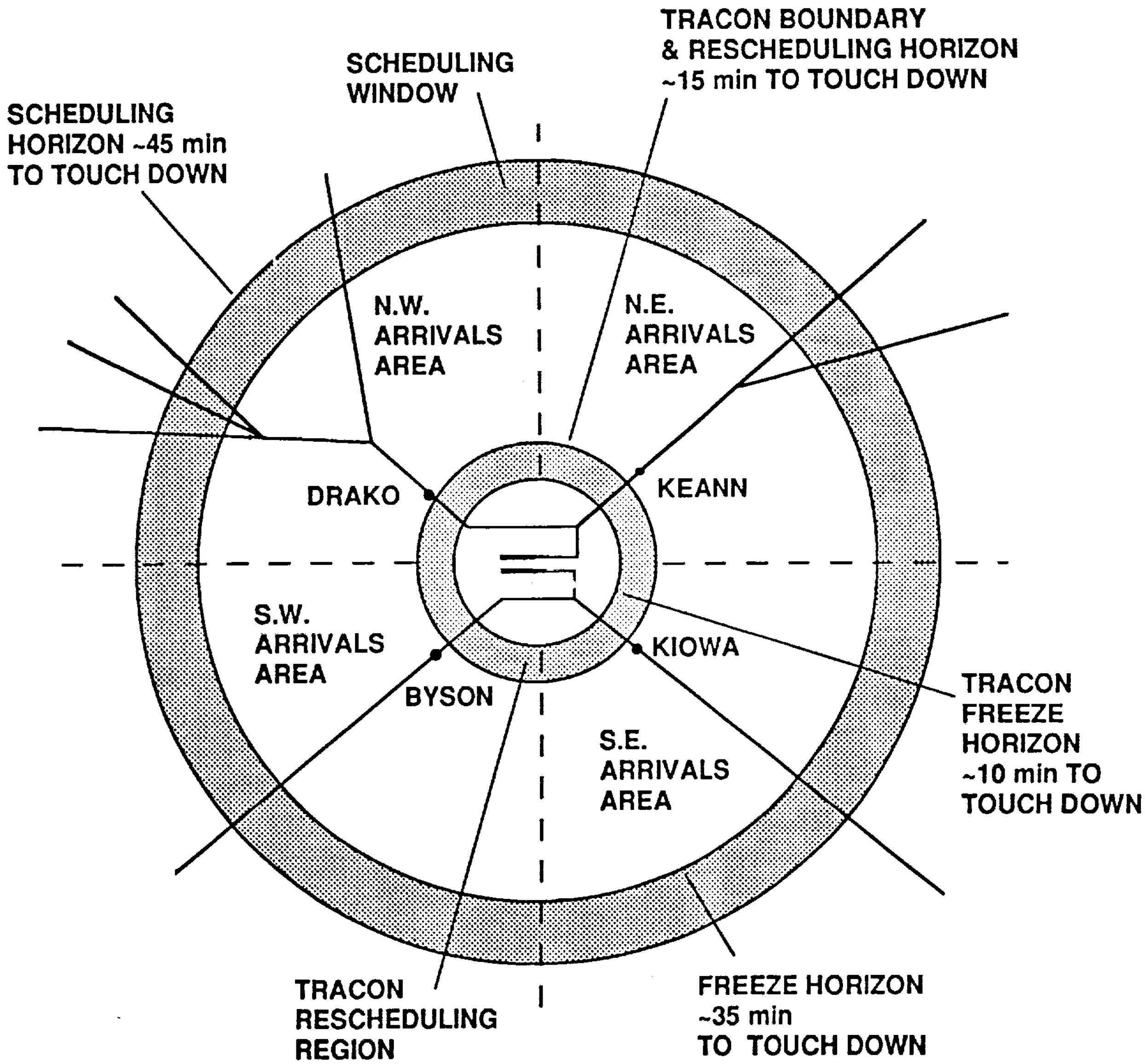
- COORDINATE AND MERGE TRAFFIC, CONFLICT FREE
- MINIMIZE AVERAGE DELAY, FCFS, ETC.
- MEET SEPARATION STANDARDS

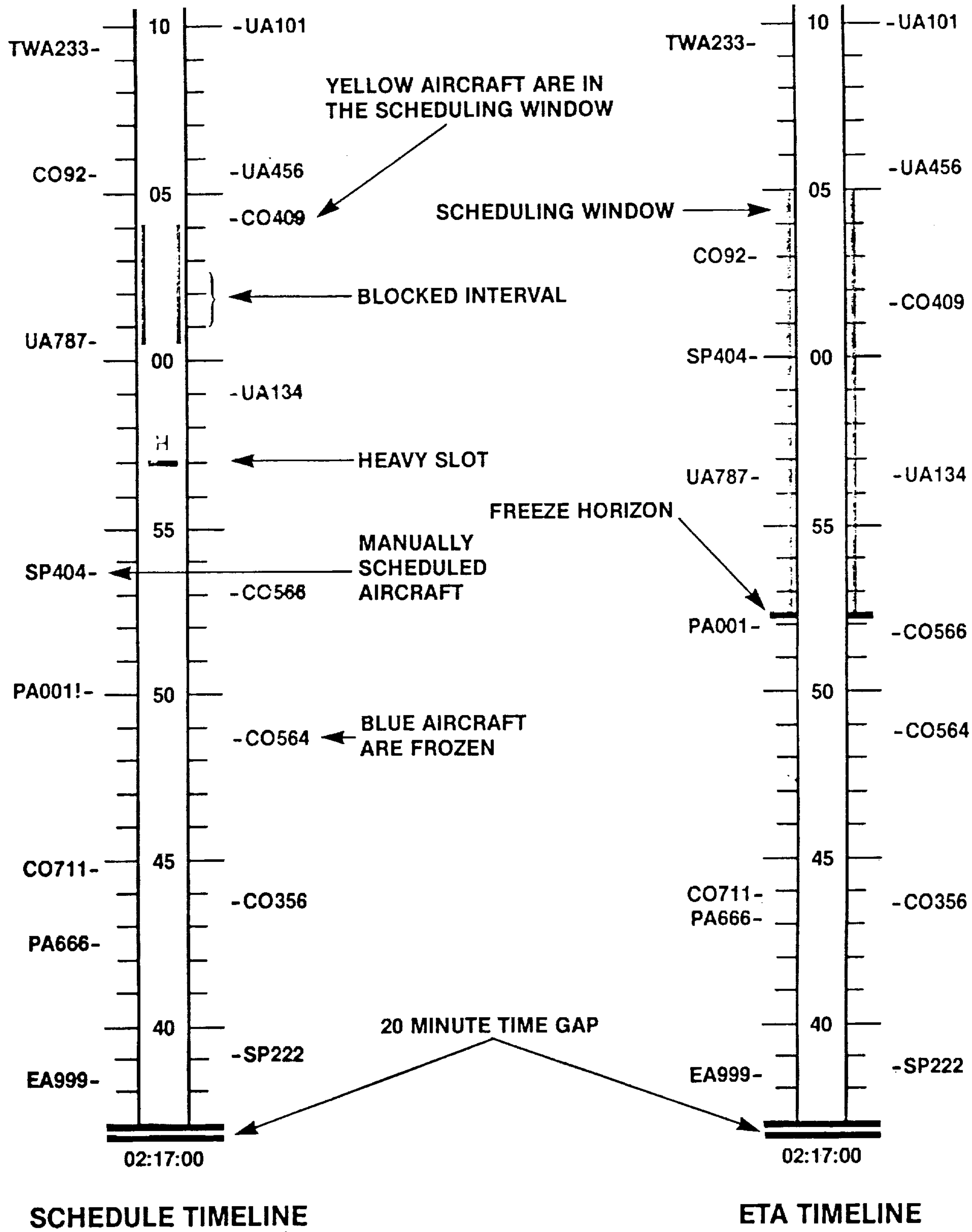
FLOW CONTROL ALGORITHMS

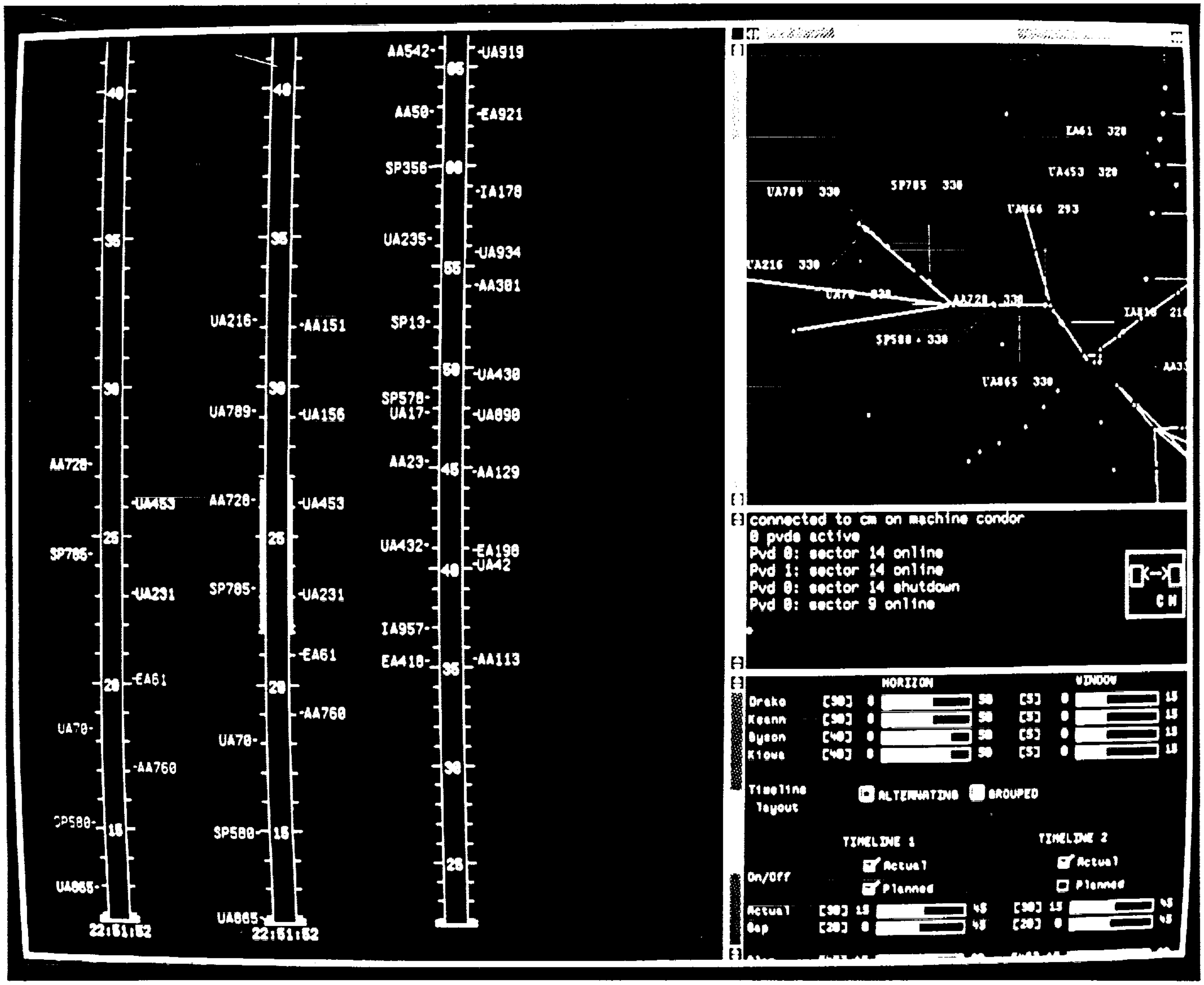
- CAPACITY MANAGEMENT
- REROUTING: GATE BALANCING, FRONTAL SYSTEM AVOIDANCE, RUNWAY CHANGE
- FLOW MONITORING

INTERACTIVE GRAPHICAL TOOLS FOR MANAGING ALGORITHMS IN REAL TIME

COMMAND AND COMMUNICATIONS INTERFACE FOR DA'S AND FAST


TRACON BOUNDARY
& RESCHEDULING HORIZON
~15 min TO TOUCH DOWN
SCHEDULING
WINDOW
SCHEDULING
HORIZON ~45 min
TO TOUCH DOWN
N.W.
ARRIVALS
AREA
N.E.
ARRIVALS
AREA
DRAKO
KEANN
S.W.
ARRIVALS
AREA
KIOWA
BYSON
S.E.
ARRIVALS
AREA
TRACON
FREEZE
HORIZON
~10 min TO
TOUCH DOWN
TRACON
RESCHEDULING
REGION
FREEZE HORIZON
~35 min
TO TOUCH DOWN


YELLOW AIRCRAFT ARE IN THE SCHEDULING WINDOW
SCHEDULING WINDOW
BLOCKED INTERVAL
HEAVY SLOT
FREEZE HORIZON
MANUALLY SCHEDULED AIRCRAFT
BLUE AIRCRAFT ARE FROZEN
20 MINUTE TIME GAP
TWA233-
CO92-
UA787-
SP404-
PA001!-
CO711-
PA666-
EA999-
-UA101
-UA456
-CO409
-UA134
-CO566
-CO564
-CO356
-SP222
PA001-
02:17:00
SCHEDULE TIMELINE
ETA TIMELINE



Screen photograph of Traffic Management Advisor display.

DESCENT ADVISOR: WHAT IS IT?

A SET OF INTERACTIVE TOOLS FOR ASSISTING CONTROLLERS IN MANAGING ARRIVAL TRAFFIC EFFICIENTLY UNDER DIVERSE CONDITIONS, FROM CRUISE TO FINAL APPROACH.

- FUEL OPTIMAL DESCENT ADVISORIES ADAPTED TO AIRCRAFT TYPE, AIRLINE PREFERENCE AND WIND PROFILE.
- ACCURATE TIME CONTROL AT FEEDER GATE AND ON FINAL APPROACH:
  - TOP OF DESCENT, MACH/IAS, SPEED ADVISORIES
  - ON-ROUTE AND OFF-ROUTE HORIZONTAL GUIDANCE ADVISORIES
- LONG LEAD TIME CONFLICT PREDICTION AND RESOLUTION ALONG COMPLEX DESCENT/APPROACH TRAJECTORIES

DESCENT ADVISOR TOOLS

TRAFFIC MANAGEMENT

- DISTANCE SPACING MARKERS AND ADVISORIES
- TIME AT METERING FIX MARKERS AND ADVISORIES
- CONFLICT PREDICTION MARKERS AND ADVISORIES

HORIZONTAL TRAJECTORY MANAGEMENT

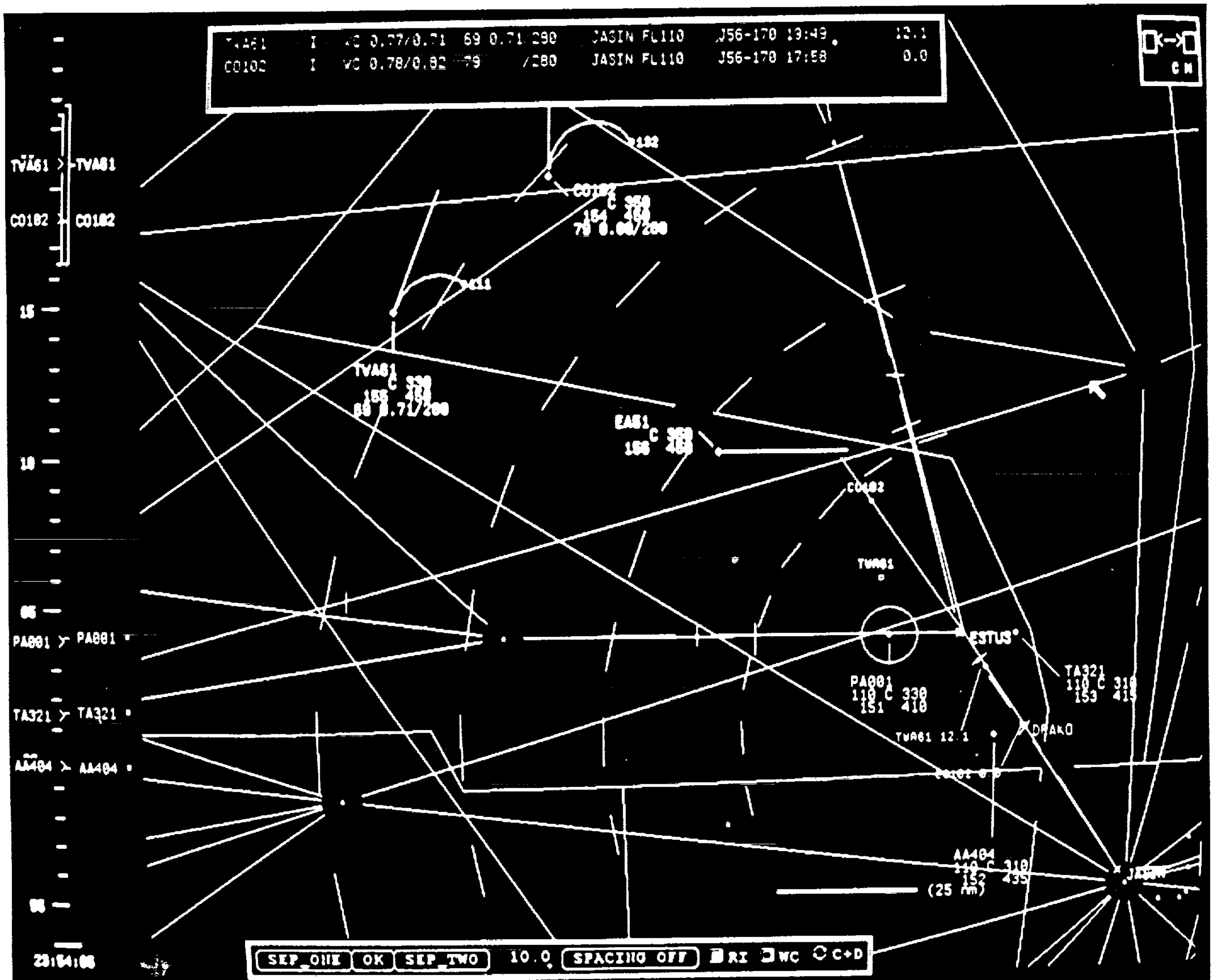
- ON-ROUTE ADVISORIES
- DIRECT-TO-WAYPOINT ADVISORIES
- ROUTE INTERCEPT ADVISORIES

SPEED AND ALTITUDE PROFILE MANAGEMENT

- DESCENT SPEED (MACH/IAS PROFILE), RANGE TO TOP OF DESCENT
- CRUISE SPEED, STANDARD AIRLINE DESCENT PROFILE
- CRUISE + DESCENT

TRAJECTORY TRACKING INFORMATION

- ACCUMULATED TIME ERRORS OF "CLEARED" AIRCRAFT
- BROKEN CLEARANCE INDICATOR



Integrated controller display illustrating waypoint capture guidance to Drako and STAs on the time line.

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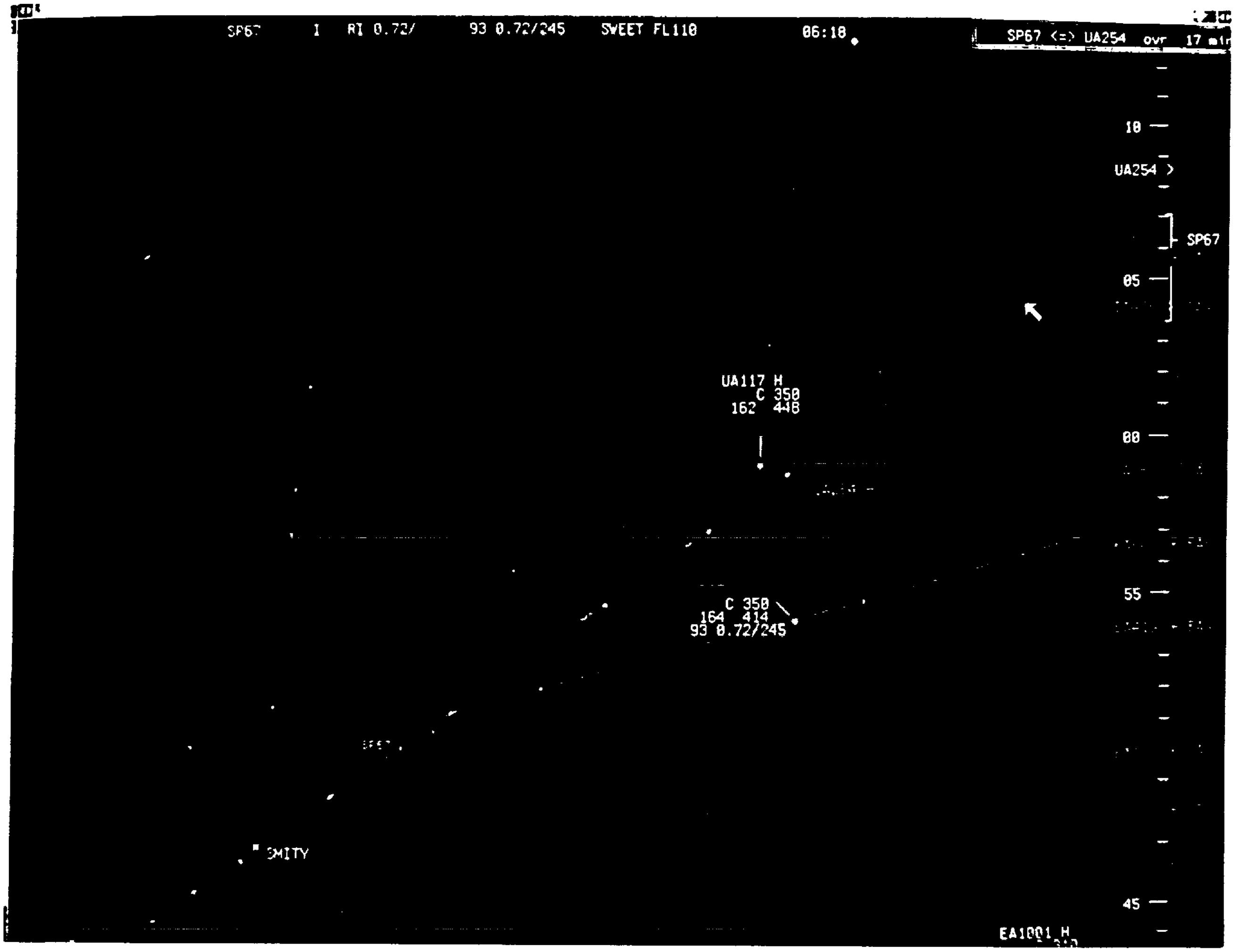
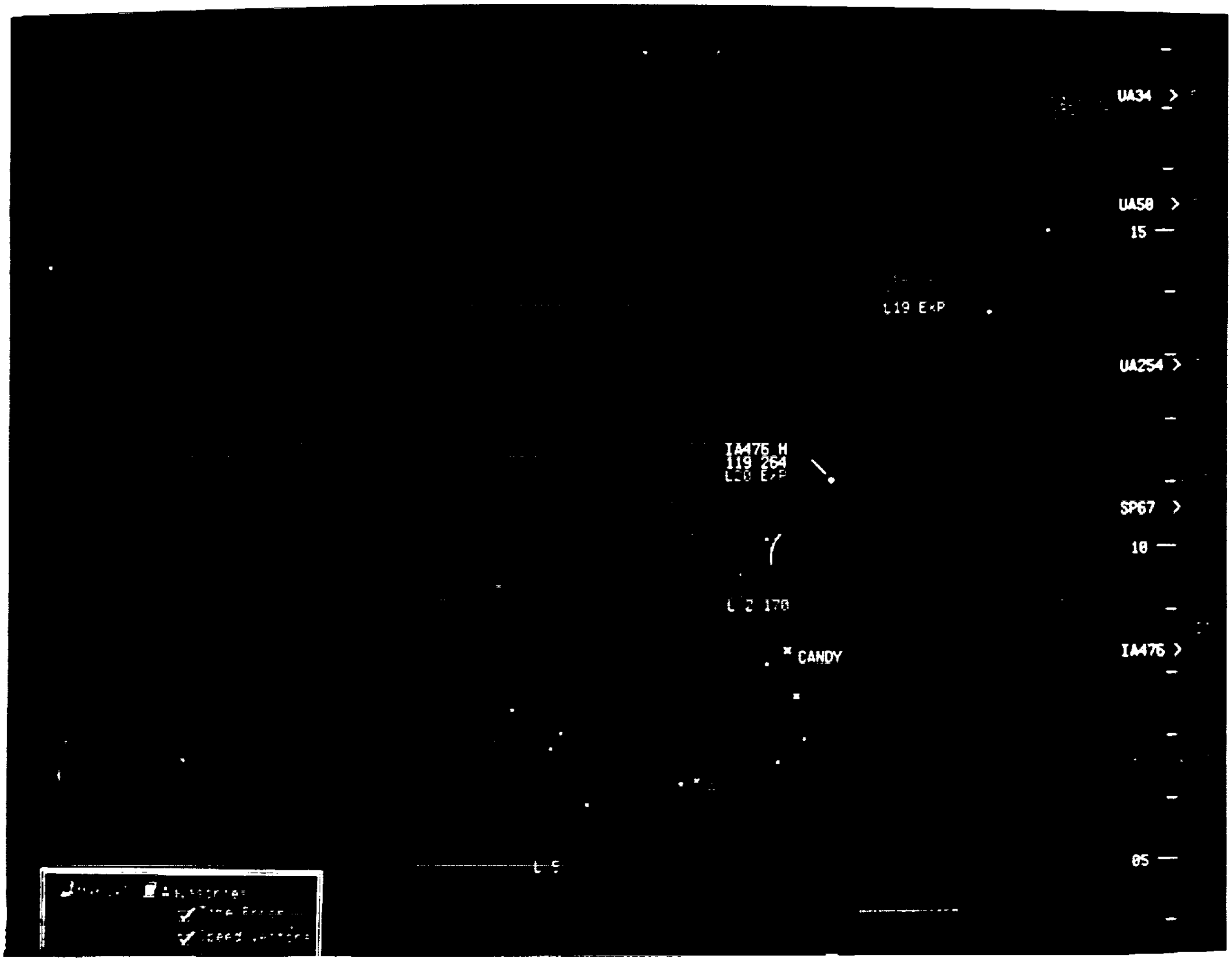


FINAL APPROACH SPACING TOOL (FAST): WHAT IS IT?

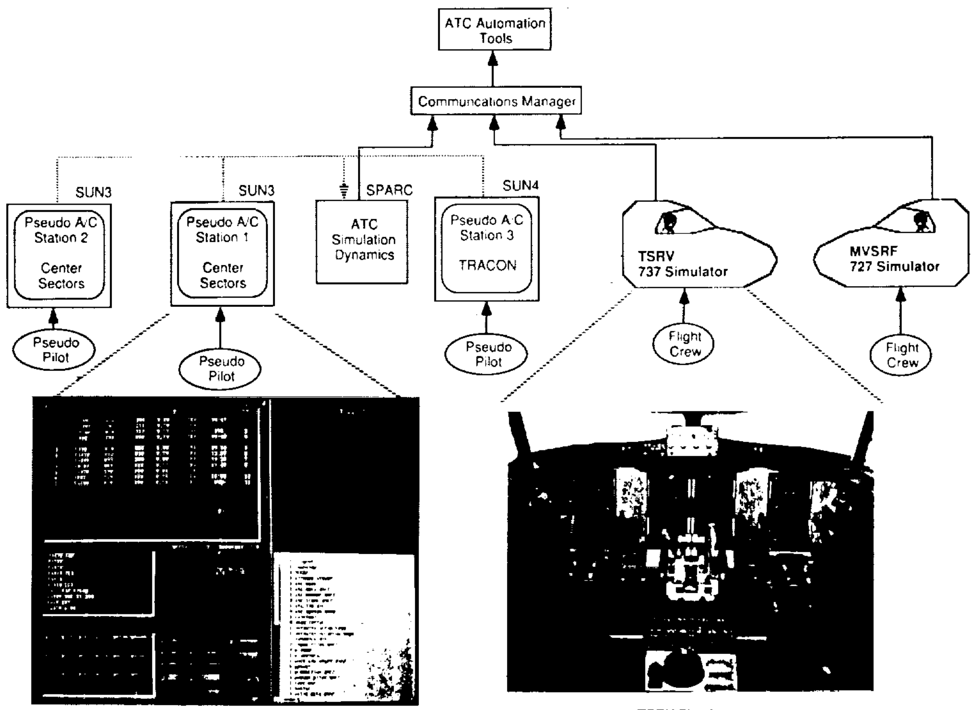
A TOOLBOX OF GRAPHICAL ADVISORIES AND CONTROLLER SELECTABLE OPTIONS TO ASSIST TRACON CONTROLLERS IN SEQUENCING AND SPACING ARRIVAL TRAFFIC ON FINAL APPROACH

- ADVISORIES PROVIDED FOR ON-ROUTE AND OFF-ROUTE AIRCRAFT
- DYNAMIC RESCHEDULING AND ADVISORIES FOR ON SCHEDULE AND OFF SCHEDULE AIRCRAFT SUCH AS MISSED APPROACH AND POP-UP



Fast Display

AIR TRAFFIC SIMULATION



Pseudo-Pilot Display

TSRV Simulator

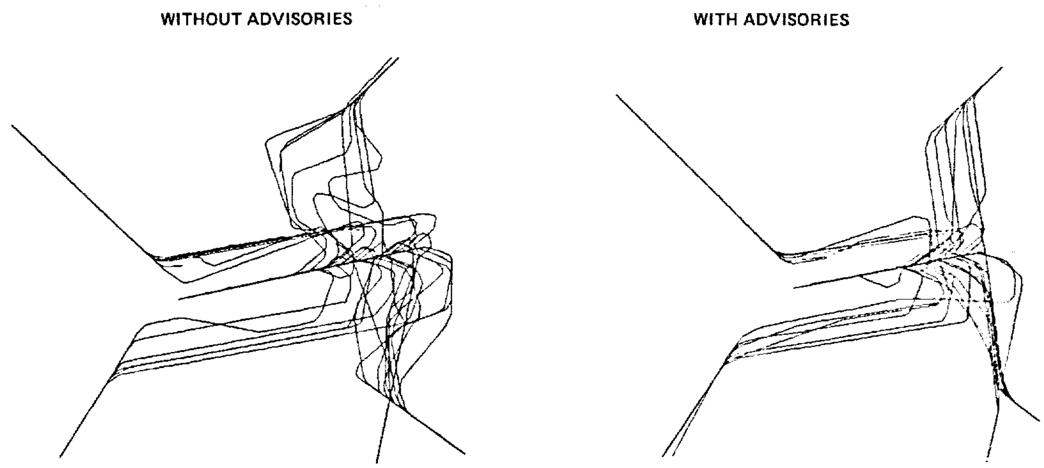
SIMULATION EVALUATIONS

EVALUATION DATE (DURATION)	CONTROLLER SUBJECTS	TEST CHARACTERISTICS
MAY 1988 (3 WEEKS)	9, RETIRED OAKLAND CENTER	INTRAIL SPACING MODE MVSRF-727, LINE PILOTS
MARCH 1989 (3 WEEKS)	2, ACTIVE DENVER CENTER 4, RETIRED OAKLAND CENTER 3, RETIRED BAY TRACON	TIME CONTROL MODE; INTEGRATION OF TRAFFIC MANAGEMENT ADVISOR (TMA), DA, AND FINAL APPROACH SPACING TOOL (FAST); MVSRF-727, LINE PILOTS
JULY 1989 (3 WEEKS)	6, ACTIVE OAKLAND CENTER 2, RETIRED BAY TRACON	TIME CONTROL MODE; INTEGRATION OF 4D EQU. AIRCRAFT; TMA + DA + FAST; TSRV-737, LINE PILOTS
JAN - JUNE 1990?	ACTIVE CENTER AND TRACON CONTROLLERS	SHADOW CONTROL OF LIVE DENVER ARRIVAL TRAFFIC

EFFECTIVENESS OF DESCENT ADVISORIES

COMPOSITE TRAJECTORIES FROM ATC SIMULATION OF DENVER AREA

- ALL ARRIVALS INITIALLY SCHEDULED CONFLICT-FREE TO TOUCHDOWN AT TOP OF DESCENT
- TRAFFIC LOAD AT RUNWAY CAPACITY



CONCLUDING REMARKS

- PRIMARY BASIS FOR AUTOMATION TOOLS IS AN ACCURATE AND VERSATILE TECHNIQUE FOR PREDICTING TRAJECTORIES AT LEAST 30 MINUTES INTO THE FUTURE
- ACCURATE PREDICTION TECHNIQUE IS ESSENTIAL FOR EFFECTIVE PLANNING AND CONTROL
- COMPUTER GENERATED PLANS AND ADVISORIES SHOULD NOT BE INCOMPATIBLE WITH ACCEPTED CONTROLLER TECHNIQUES.
- TOOLS FOR ESSENTIAL CONTROLLER NEEDS TAKE PRECEDENCE OVER TOOLS FOR FLOW OPTIMIZATION.
- AFTER MEETING ESSENTIAL NEEDS, TOOLS SHOULD HELP MINIMIZE DELAYS AND FUEL CONSUMPTION.
- WELL DESIGNED TOOLS OFFER INTELLIGENT ADVISORIES UNDER ABNORMAL AS WELL AS NORMAL SITUATIONS.

CONCLUDING REMARKS
(continued)

- DESIGN OF GRAPHICAL AND OTHER INTERFACES POSES THE MOST DIFFICULT DESIGN CHALLENGE.

- TO BE EFFECTIVE TOOLS MUST BE CUSTOM-DESIGNED FOR EACH TYPE OF CONTROL POSITION.

- ADVISORY TOOLS ARE A NECESSARY TRANSITONAL STEP TOWARD A FUTURE AUTOMATED ATC SYSTEM.

N91-10958

TIME-BASED OPERATIONS IN AN ADVANCED ATC ENVIRONMENT

Steven Green
NASA Ames Research Center

OUTLINE

- OBJECTIVES
- EXPERIMENT DESCRIPTION
- RESULTS
- SUMMARY

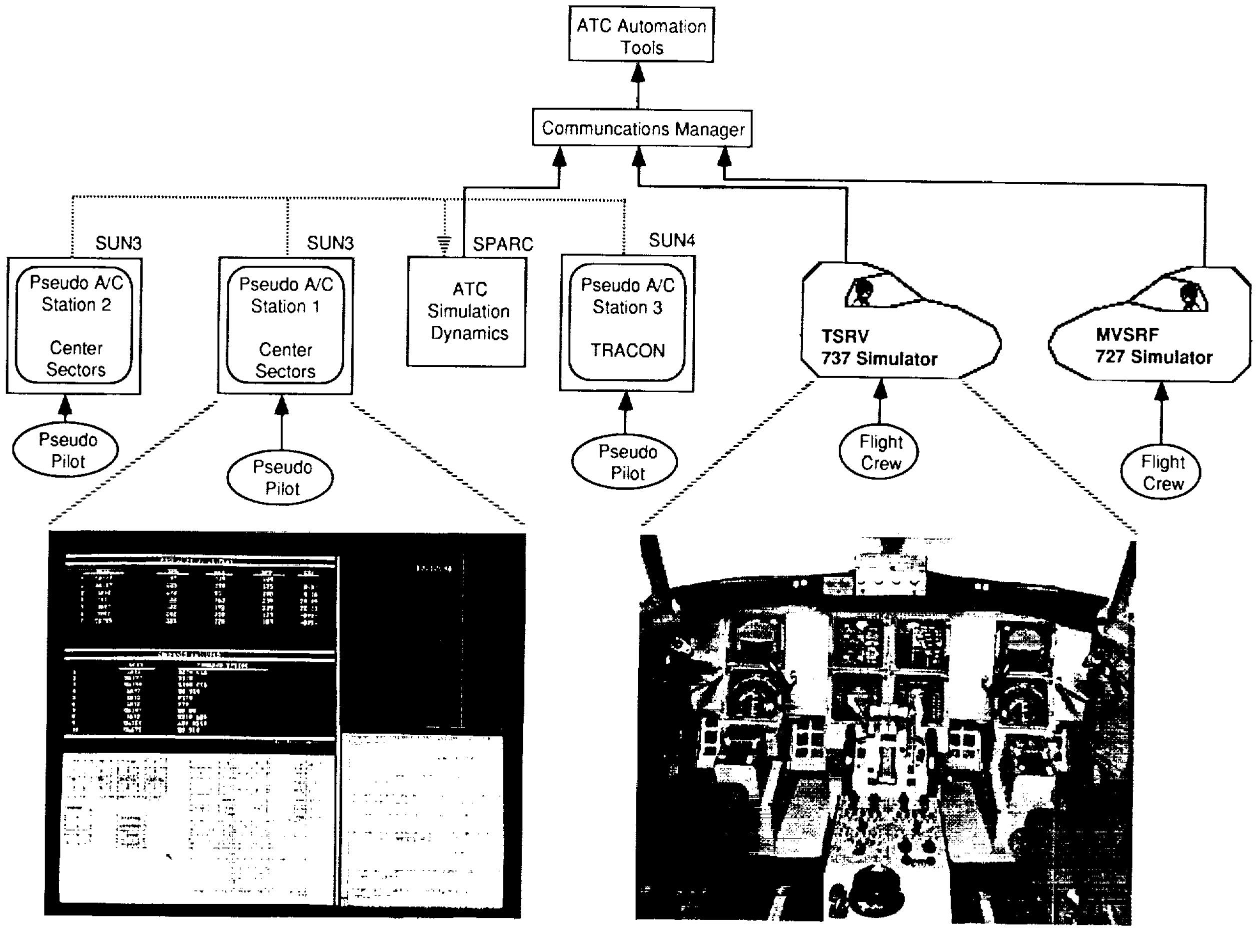
OBJECTIVES

- DEVELOP AND EVALUATE PROCEDURES AND CLEARANCES FOR 4D EQUIPPED AIRCRAFT
- STUDY THE EFFECT OF DISSIMILAR AIRBORNE AND GROUND-BASED SPEED STRATEGIES
- EVALUATE THE EFFECTIVENESS AND ACCEPTABILITY OF ATC AUTOMATION TOOLS

EXPERIMENT SET-UP

- **TEST SUBJECTS**
  - 6 ACTIVE ARTCC CONTROLLERS
  - 3 AIRLINE PILOTS
- **SIMULATION FACILITY**
  - AIR TRAFFIC SIMULATION
  - ATC AUTOMATION AIDS
- **DENVER ARRIVAL AIRSPACE**
- **TIME-BASED PROCEDURES**

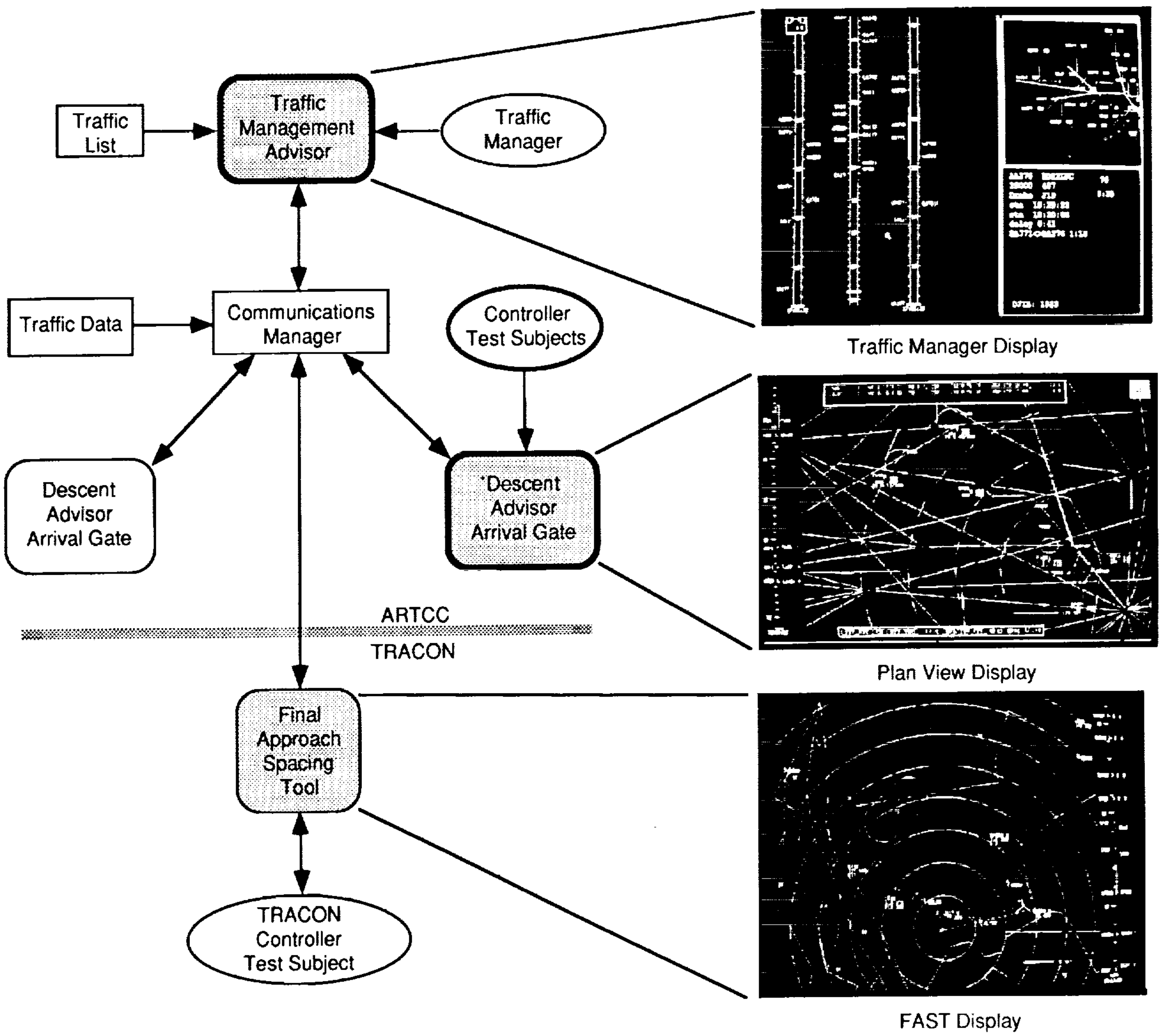
AIR TRAFFIC SIMULATION



Pseudo-Pilot Display

TSRV Simulator

ATC AUTOMATION TOOLS



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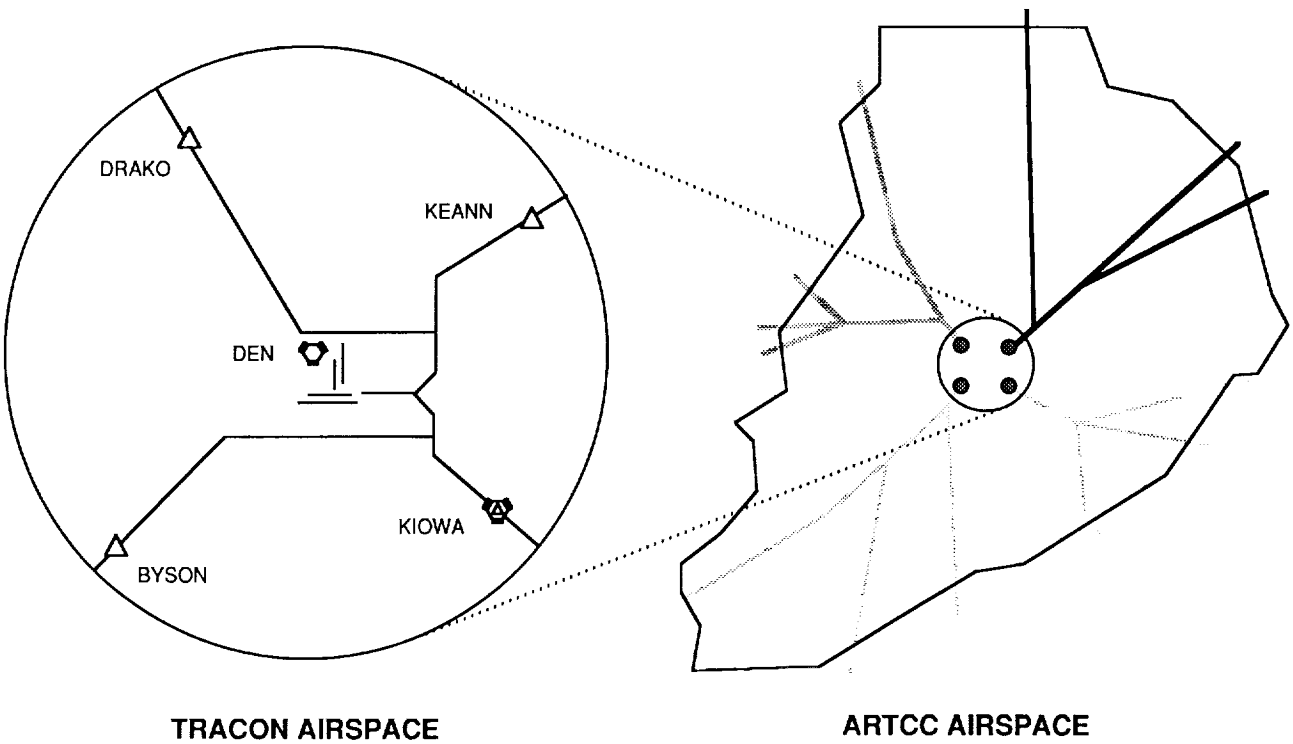
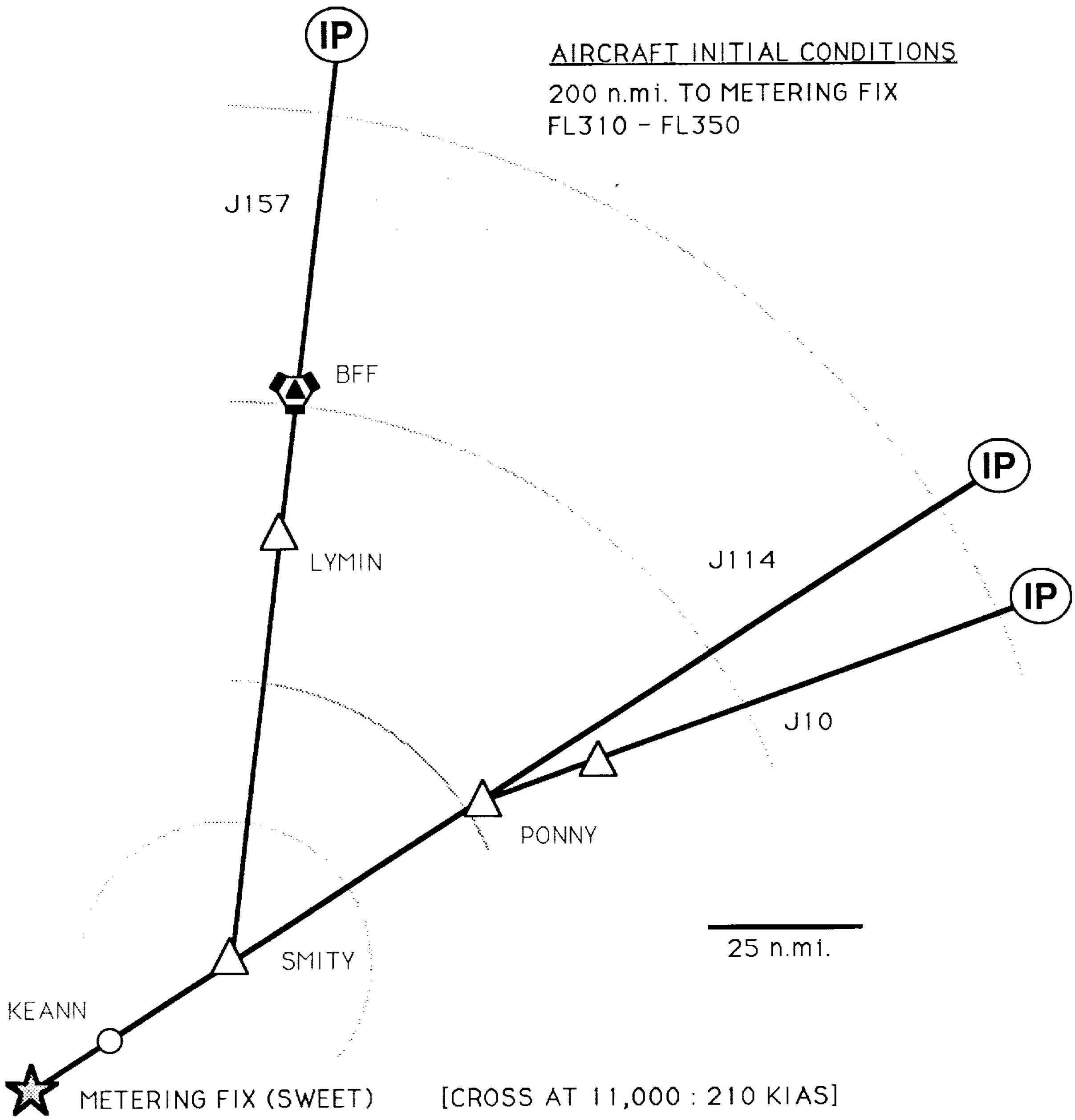
DENVER ARRIVAL AIRSPACE

(4 CORNER POSTS)



DENVER'S NORTHEAST ARRIVAL AIRSPACE (KEANN GATE)



TIME-BASED ATC PROCEDURES

- **UNEQUIPPED AIRCRAFT**
  - **CRUISE/DESCENT CLEARANCE**

    CRUISE SPEED ADJUSTMENT

    TOP OF DESCENT

    DESCENT SPEED PROFILE

- **4D EQUIPPED AIRCRAFT**
  - **TIME CLEARANCE**

    METERING FIX TIME

    PILOT DISCRETION DESCENT

    PILOT DISCRETION CRUISE/DESCENT SPEED PROFILES

  - **TIME DELAY VECTOR CLEARANCE**

    NAVIGATION RESTRICTIONS

    TIME CLEARANCE

TRAFFIC

- 100 % OF SINGLE RUNWAY CAPACITY (APPROX. 40 A/C PER HOUR)

- TRAFFIC "RUSH" (80% OF ALL ARRIVALS) THROUGH KEANN (NORTHEAST GATE)

- TRAFFIC THROUGH TWO ARRIVAL GATES MERGED FOR LANDING
  (BASED UPON FAA REGULATIONS FOR INTERARRIVAL SPACING)

- DELAY CONDITIONS

  - MODERATE (3 MINUTE DELAYS, SPEED CONTROL)
  - HEAVY (8 MINUTE DELAYS, PATHSTRETCHING REQUIRED)

- SINGLE 4D EQUIPPED A/C INJECTED INTO EACH RUSH

  - COMPATIBLE ALGORITHMS
  - INCOMPATIBLE ALGORITHMS
  - INCOMPATIBLE ALGORITHMS / OFFSET ROUTING

RESULTS SUMMARY

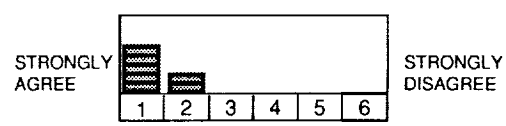
- **TRAFFIC DATA**
  - 30 EXPERIMENT RUNS
  - 28 HOURS OF AIR TRAFFIC SIMULATION

- **PRELIMINARY RESULTS**
  - EXPERIMENTAL OBSERVATIONS

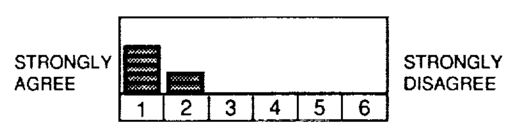
    EXAMPLE: SIMILARITY / DISSIMILARITY
  - CONTROLLER QUESTIONNAIRES

"EVALUATION OF PROCEDURES/CLEARANCES FOR 4D AIRCRAFT"

THE TIME CLEARANCES AND PROCEDURES WERE EXPLICIT AND UNDERSTANDABLE.

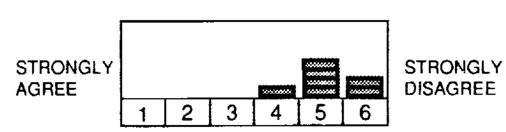


IT IS IMPORTANT TO KNOW THE 4D AIRCRAFT'S PLANNED DESCENT STRATEGY (i.e., final cruise speed, descent speed, and top of descent).



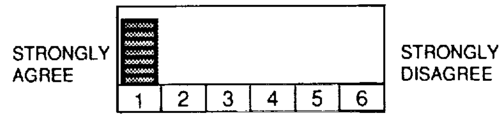
"EFFECT OF DISSIMILARITY BETWEEN AIR AND GROUND SYSTEMS"

NO DIFFICULT TRAFFIC SITUATIONS AROSE WITH THE 4D AIRCRAFT AFTER A TIME CLEARANCE WAS ISSUED.

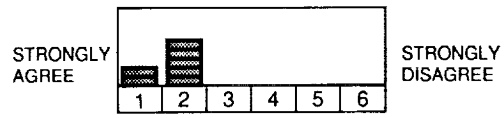


"EFFECTIVENESS/ACCEPTABILITY OF ATC AUTOMATION TOOLS"

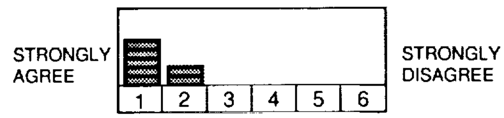
THE VERTICAL TIMELINE PROVIDED USEFUL INFORMATION ON THE SEQUENCE AND SCHEDULE.



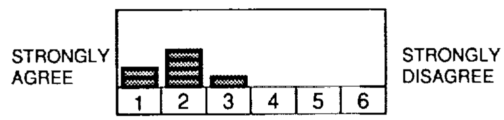
THE AUTOMATION PROVIDED REASONABLE INFORMATION UPON WHICH ONE CAN RELY.



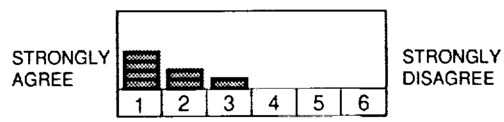
THE AUTOMATION PROVIDES A BETTER AND EARLIER IDEA ABOUT FUTURE CONFLICTS AND SEPARATION AT THE METERING FIX.



IT WAS EASY TO COMBINE MY OWN SPEED, ALTITUDE, AND VECTOR CLEARANCES WITH THE AUTOMATION'S ADVISORIES.



OVERALL, THE AUTOMATION REDUCED WORKLOAD.



CONCLUDING REMARKS

- TIME CLEARANCES AND PROCEDURES WERE USED EFFECTIVELY BY THE CONTROLLERS
- CONTROLLERS WANT TO KNOW THE PLANNED DESCENT STRATEGY OF 4D AIRCRAFT (SEPARATION)
- DISSIMILARITY IN SPEED STRATEGIES MAINLY AFFECT CONTROLLER WORKLOAD AND TRAFFIC FLOW EFFICIENCY
- ATC AUTOMATION TOOLS PROVIDE AN EFFECTIVE AID FOR THE SEQUENCING OF ARRIVAL FLOWS
- ATC AUTOMATION TOOLS WERE WELL RECEIVED BY THE CONTROLLER SUBJECTS

FUTURE PLANS

- TEST SOLUTIONS TO IMPROVE SYSTEM EFFICIENCY AND REDUCE WORKLOAD FOR DISSIMILARITY CASES :

    - CONFLICT DETECTION / RESOLUTION AIDS

    - SEPARATION PROCEDURES / CRITERIA FOR 4D

- EXPLORE DATA LINK APPLICATIONS TO REDUCE COMMUNICATIONS WORKLOAD FOR TIME-BASED OP'S.

- DETERMINE ATMOSPHERIC AND PERFORMANCE MODELLING REQUIREMENTS

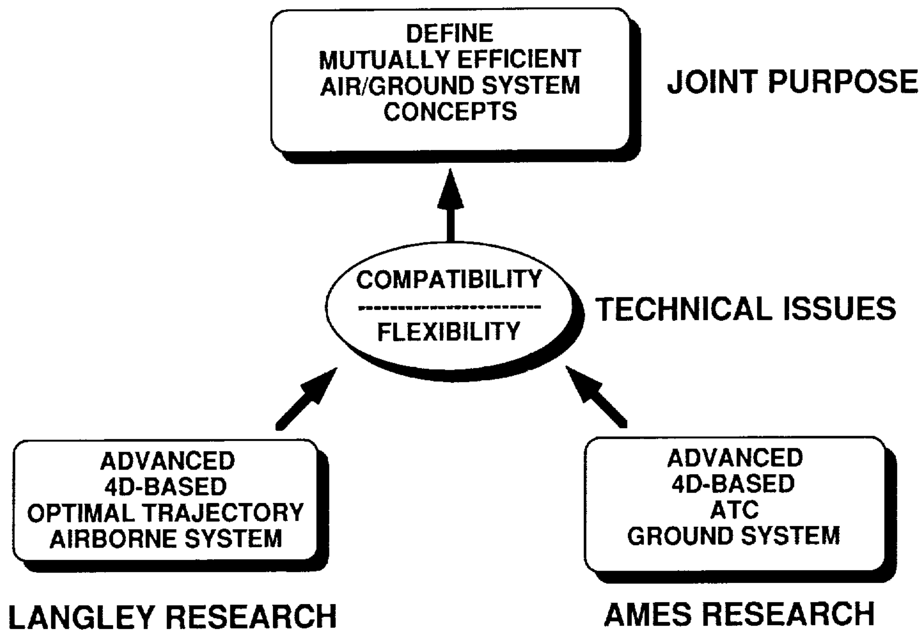
- TEST SCENERIOS WITH MULTIPLE 4D EQUIPPED AIRCRAFT

N91-10959

TIME-BASED AIRCRAFT/ATC OPERATIONS STUDY

David H. Williams
NASA Langley Research Center

TIME-BASED AIRCRAFT/ATC OPERATIONS STUDY
(JOINT LaRC /ARC SIMULATION)



STUDY OBJECTIVES

- DEVELOP AND EVALUATE PROCEDURES FOR INCORPORATING 4D-EQUIPPED AIRCRAFT INTO A 4D ATC SYSTEM
- DETERMINE IMPACT ON THE SYSTEM OF DISSIMILAR AIRBORNE AND GROUND 4D SPEED STRATEGIES
- EVALUATE EFFECTIVENESS OF AIRBORNE TIME GUIDANCE

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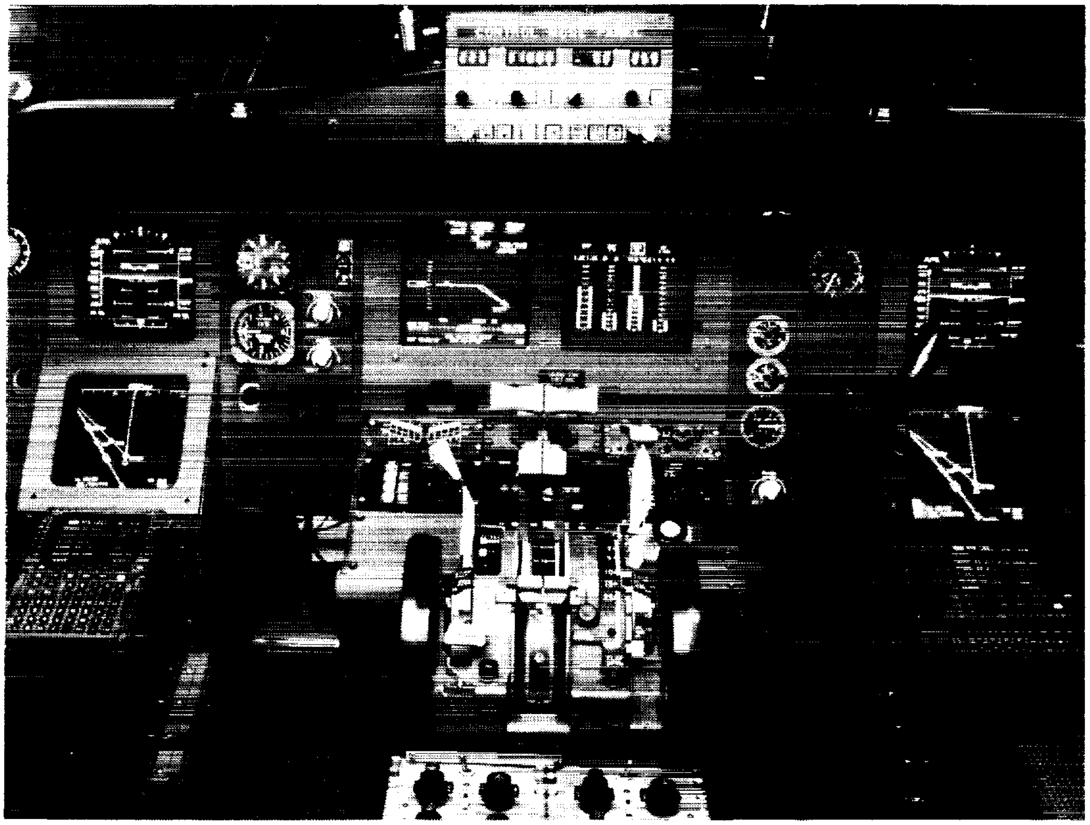


NASA TSRV 4D FMS CAPABILITIES

TRAJECTORY GENERATION

HORIZONTAL ROUTE DEFINED THROUGH FLEXIBLE CDU OPERATIONS.
(COMPARABLE TO B-737-400)

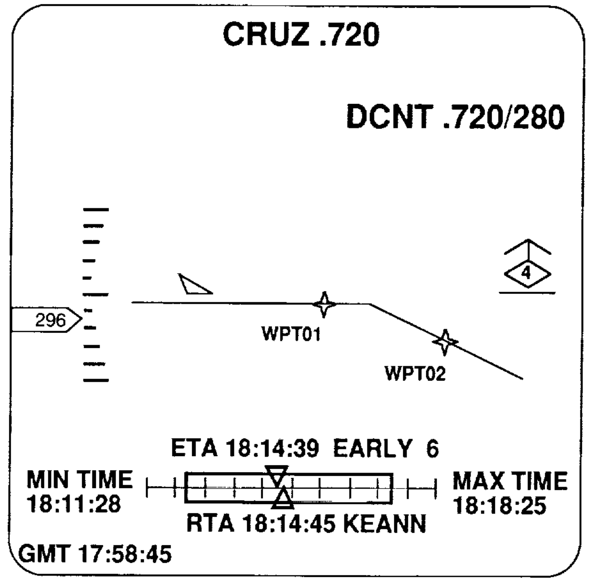
VERTICAL TRAJECTORY GENERATION WITH ARRIVAL TIME CONSTRAINT.
- MINIMUM FUEL
- ATC DESCENT ADVISOR

AUTOMATIC RECALCULATION CAPABILITY.

4D GUIDANCE

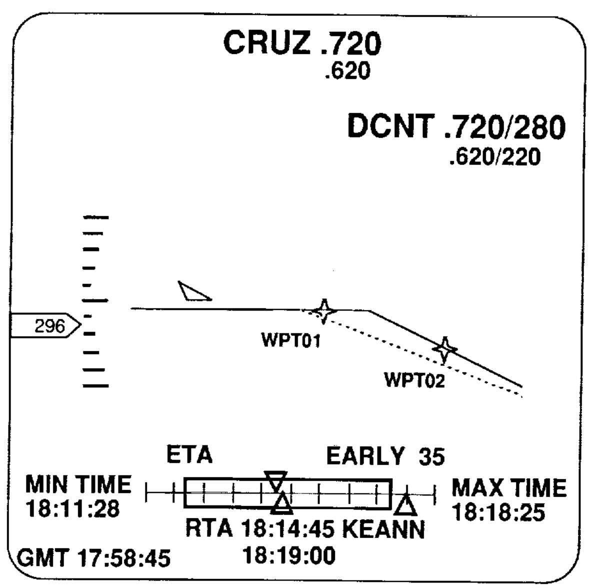
VERTICAL SITUATION DISPLAY WITH TIME CAPABILITIES SHOWN AT ARRIVAL FIX.
TIME-BASED ENERGY ERROR DISPLAY.

TSRV VERTICAL SITUATION DISPLAY



ACTIVE GUIDANCE MODE

TSRV VERTICAL SITUATION DISPLAY



PROVISIONAL MODE

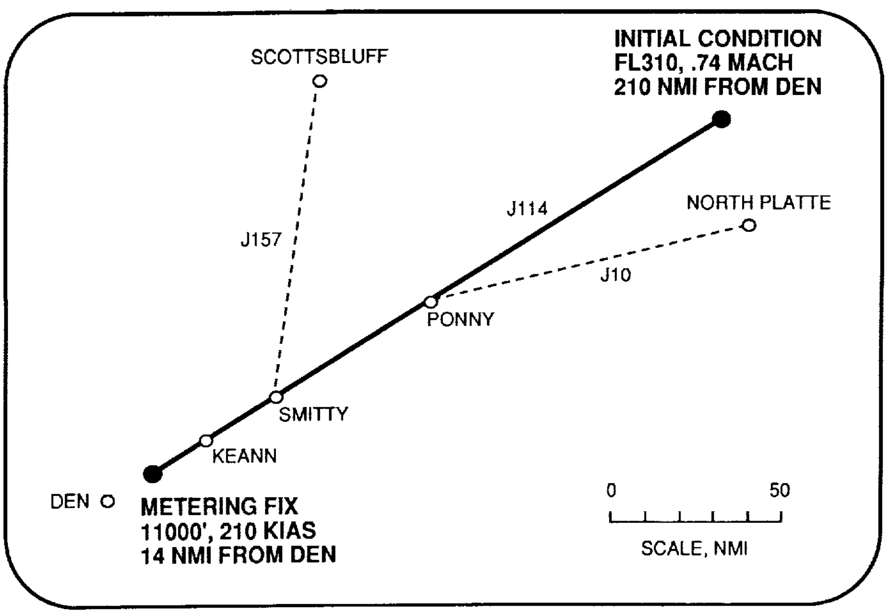
AIRBORNE 4D PROCEDURES

- **TIME CLEARANCE**
  - ACKNOWLEDGE ATC
  - ENTER ARRIVAL TIME
  - EXECUTE NEW VERTICAL PROFILE
  - ADVISE ATC OF SPEED CHANGE

- **TIME DELAY VECTOR**
  - ACKNOWLEDGE ATC
  - FLY ATC-SPECIFIED VECTOR AT MINIMUM SPEED
  - ADVISE ATC OF SPEED CHANGE
  - ENTER ARRIVAL TIME
  - SELECT DIRECT INTERCEPT OF ATC-SPECIFIED WAYPOINT

    << AUTOMATIC PROFILE RECALCULATION >>
  - EXECUTE NEW PROFILE WHEN TIME DELAY COMPLETE
  - ADVISE ATC WHEN TURNING BACK

TEST SCENARIO



TEST CONDITIONS

	CONDITION NUMBER 1	2	3	4	5
TRAFFIC LEVEL					
MODERATE	X	X	X		
HEAVY				X	X
SPEED STRATEGY					
MINIMUM FUEL		X	X		X
DESCENT ADVISOR	X			X	
HORIZONTAL ROUTE					
NORMAL	X	X		X	X
OFFSET			X		
total number of runs (3 pilots)	6	9	4	7	2

RESULTS

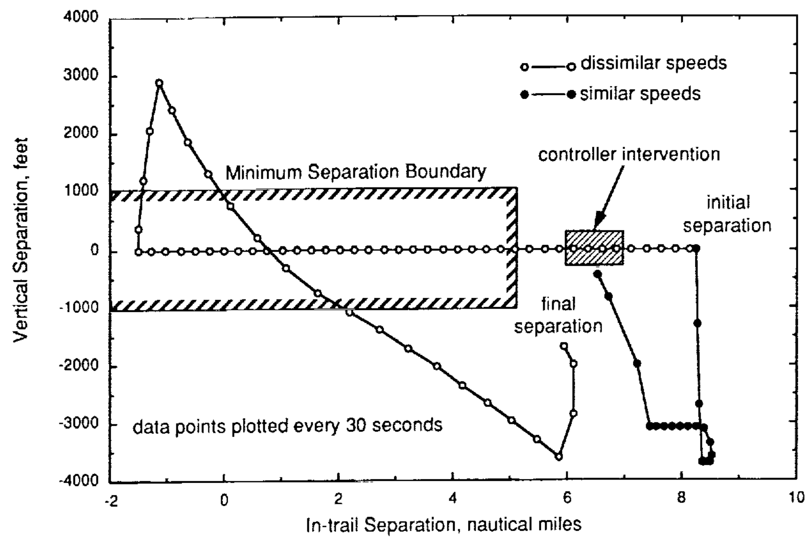
- **TIME CLEARANCES, PROCEDURES AND DISPLAYS WELL RECEIVED BY PILOTS**

- **DISSIMILAR AIR AND GROUND SPEED STRATEGIES PRODUCED POTENTIAL TRAFFIC CONFLICTS DURING MODERATE TRAFFIC**
  - ATC VECTORS AND ROUTE-OFFSET PROVED LESS EFFICIENT
  - CRUISE SPEED RESTRICTION COULD ALLEVIATE THE PROBLEM

- **TIME DELAY VECTOR USEFUL DURING HEAVY TRAFFIC**
  - POTENTIAL FOR RELIEVING CONTROLLER WORKLOAD
  - ALLOWS AIRCRAFT TO MINIMIZE DELAY RANGE
  - DISSIMILAR SPEEDS NOT A PROBLEM

- **TIME GUIDANCE PROVED VERY EFFECTIVE**
  - ARRIVAL TIME ERROR OF 2.9 SECONDS (STANDARD DEVIATION)

SEPARATION CONFLICT INDUCED BY DISSIMILAR SPEED SCHEDULES



En route separation for 32 minute flight time with 80 seconds in-trail separation at initial and final conditions

FUEL USAGE OF TSRV SIMULATOR

Aircraft Speed Strategy	Route	ATC Interruption	Number of runs	Average Fuel Used
Descent Advisor	normal	no	6	1779 (reference)
Minimum fuel	normal	no	6	1740 (-2.2%)
Minimum fuel	normal	yes	3	1891 (+6.3%)
Minimum fuel	offset	no	3	1800 (+1.2%)
Minimum fuel	offset	yes	1	1916 (+7.7%)

FUTURE PLANS

- TEST PROCEDURAL SOLUTIONS TO COMPATIBILITY PROBLEMS OF DISSIMILAR SPEED STRATEGIES
- EXPLORE DATA LINK APPLICATIONS
  - UPLINK OF CLEARANCES AND SPEED CONSTRAINTS
  - DOWNLINK OF PLANNED SPEED SCHEDULE AND TOP OF DESCENT
- INTEGRATE TIME GUIDANCE INTO PRIMARY DISPLAYS
- DETERMINE WIND AND TEMPERATURE MODELING REQUIREMENTS
- TEST SCENARIOS WITH MULTIPLE 4D AIRCRAFT

SUMMARY

- **AIRBORNE 4D CAN BE EFFECTIVELY INTEGRATED INTO AN ADVANCED 4D ATC SYSTEM**
- **DIFFERENCES IN 4D SPEED STRATEGIES CAN BE MANAGED WITH PROCEDURAL SOLUTIONS**
- **TIME GUIDANCE CONCEPTS VERY EFFECTIVE**
  - MUST NOW BE INTEGRATED INTO AIRLINE COCKPIT

N91-10960

TERMINAL WEATHER INFORMATION MANAGEMENT

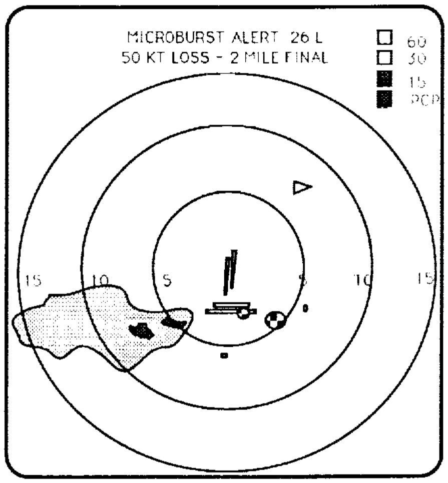
Alfred T. Lee
NASA Ames Research Center

ABSTRACT

Since the mid-1960's, microburst/windshear events have caused at least 30 aircraft accidents and incidents and have killed more than 600 people in the United States alone. This study evaluated alternative means of alerting an airline crew to the presence of microburst/windshear events in the terminal area. Of particular interest was the relative effectiveness of conventional and data link ground-to-air transmissions of ground-based radar and low-level windshear sensing information on microburst/windshear avoidance. The Advanced Concepts Flight Simulator located at Ames Research Center was employed in a line oriented simulation of a scheduled round-trip airline flight from Salt Lake City to Denver Stapleton Airport. Actual weather en route and in the terminal area was simulated using recorded data. The microburst/windshear incident of July 11, 1988 was re-created for the Denver area operations. Six experienced airline crews currently flying scheduled routes were employed as test subjects for each of three groups: a) A baseline group which received alerts via conventional ATC tower transmissions, b) An experimental group which received alerts/events displayed visually and aurally in the cockpit six miles (approx. 2 min.) from the microburst event, and c) An additional experimental group received displayed alerts/events 23 linear miles (approx. 7 min.) from the microburst event. Analyses of crew communications and decision times showed a marked improvement in both situation awareness and decision-making with visually displayed ground-based radar information. Substantial reductions in the variability of decision times among crews in the visual display groups were also found. These findings suggest that crew performance will be enhanced and individual differences among crews due to differences in training and prior experience are significantly reduced by providing real-time, graphic display of terminal weather hazards.

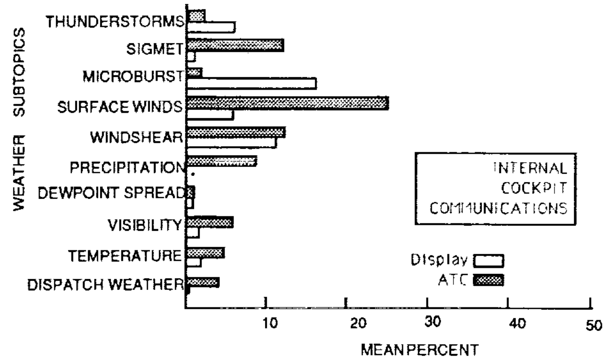
TERMINAL WEATHER INFORMATION MANAGEMENT

TWIM COCKPIT DISPLAY

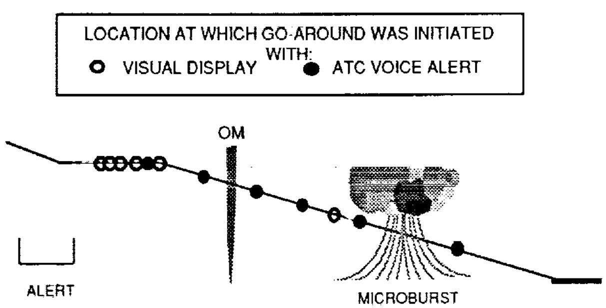


DENVER STAPLETON TERMINAL AREA

ENHANCED AIRCREW SITUATION AWARENESS



ENHANCED AIRCREW DECISION-MAKING



CONCLUSION: **Displays of ground-based terminal weather data enhance crew avoidance of microburst/ windshear events.**

IMPACT: **Relatively low-cost technology offers potential to significantly decrease microburst/windshear encounters.**

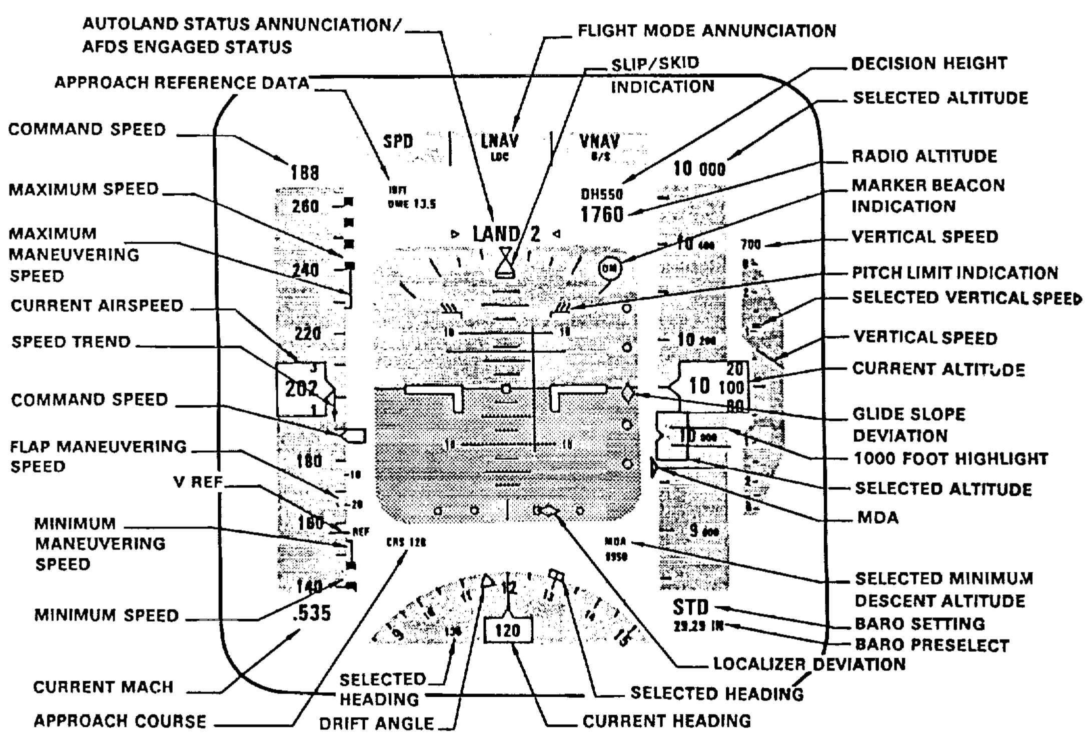
N91-10961

INFORMATION MANAGEMENT

Wendell Ricks
NASA Langley Research Center
and
Kevin Corker
BBN Systems and Technologies Corporation

Outline

- PFD Information Management
  - Problem
  - TTFIM Approach
  - Status
- Cockpit Information Management
  - Problem
  - Information Management Objective
  - System Characteristics
  - Issues
  - Approach



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Information Management Problem with the PFD

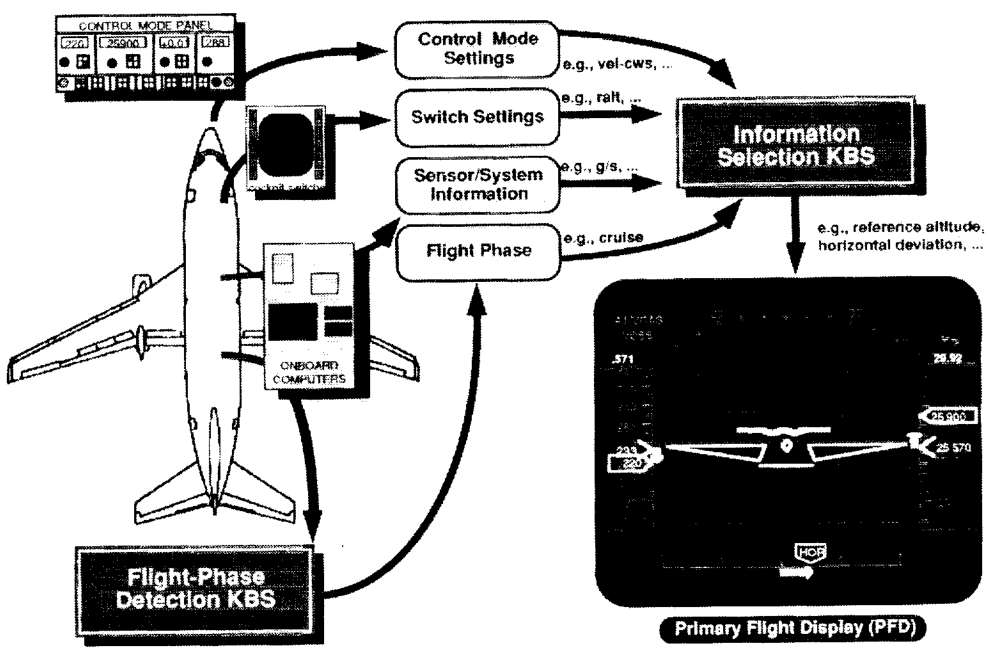
Increased amounts of information on the PFD increases the burden of interpretation

Target PFD Format

TTFIM Approach

Decrease the quantity of information on the PFD by presenting only the information pertinent to the current tasks

PFD Information Management



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Status of the PFD Information Management Work

- Validated the implementation and integration of TTFIM during June 1989 flight tests
- Completed implementation of automatic flight phase detection KBS and scheduled for validation during November 1989 flight tests
- Evaluation of the functional and operational utility of TTFIM will begin with the 1989 flight tests

Outline

- PFD Information Management
  - Problem
  - TTFIM Approach
  - Status
- Cockpit Information Management
  - Problem
  - Information Management Objective
  - System Characteristics
  - Issues
  - Approach

Information Management Problem in the Cockpit

Large quantities of information currently compete for the attention of flight crews, and the amount of information is expected to increase

Information Management Burdens

Auditory
- ground control communications
- aircraft-to-aircraft communications
- intercrew dialogues
- electronically generated speech and tone signals

Visual
- radar signatures
- multiple display configurations
- number of displays

Cognitive
- control mode configurations
- cooperative action of independent, interactive agents
- periods of situation monitoring with little or no action, and periods of extensive action

Information Management Objective

Explore techniques that present information in a manner that exploits the capabilities the flight crew brings to the cockpit

Key Characteristics of an Information Manager

- Manage several media/formats
- Integrate across several programs and data sources
- Consider both pilot workload and tasking
- Factor in the information demands of the systems
- Account for the interactions among human performance variables, equipment characteristics, and mission/environment imposed demands

Technical Issues

- How do we prioritize information?
- How should new information be melded with old information?
- How will the content of each possible piece of information and its potential impact be evaluated?
- How are priorities ranked relative to goals (mission, tactical, safety)?
- How are the priorities of old messages changed?
- What information sources should be included?
- What hardware and software architectures are suited for supporting information management?
- What kind of feedback from the aircrew is necessary?
- How will it support multimember crews?

COCKPIT INFORMATION MANAGEMENT APPROACH

- Survey the Current State-of-Cockpit Information Environment
  - Identify Management Principles to be Invoiced Near/Long Term
- Abstract Current Information Flow for Designated Flight Phases
- Provide Functional Decomposition for Communication Management
- Design Architecture for Expert Assistance
  1. Prioritize
  2. Compose
  3. Format and Display
- Evaluate Effectiveness

COCKPIT INFORMATION MANAGEMENT: FUNCTIONAL REQUIREMENTS

- Flight Phase and Aircraft Situation Responsiveness
- Flight Crew Responsive Display Configuration
- Prioritization and Composition of Information
- Facility for Storage, Retrieval, Review and Repetition of Information

COCKPIT INFORMATION MANAGEMENT SYSTEM: FUNCTION

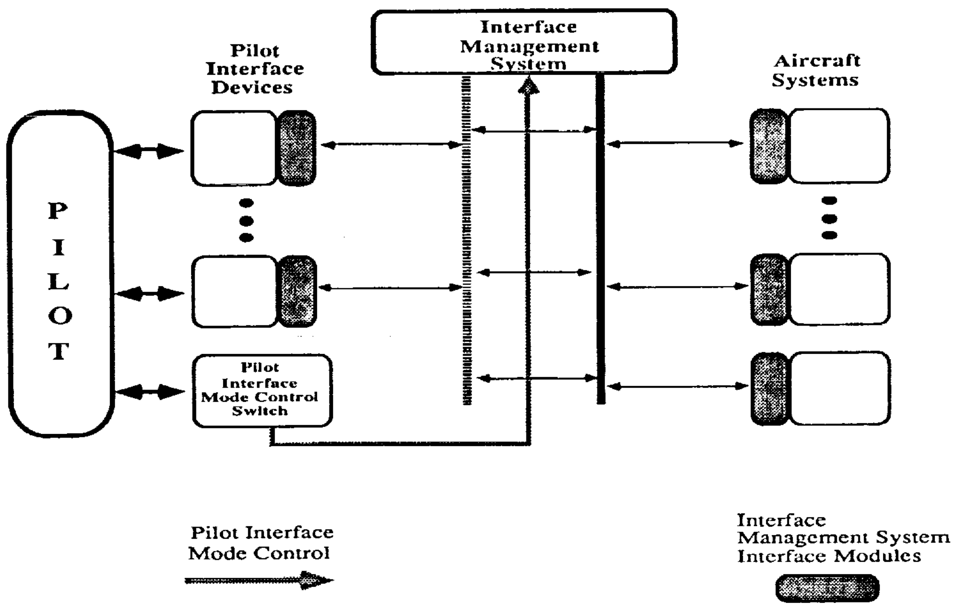
Integrate Information Across Avionics Devices and Data Sources so that One Interface Provides Full Access to Systems

Integrate Presentation Across Display Modalities so that the System Can Manage Several Formats for Information Display

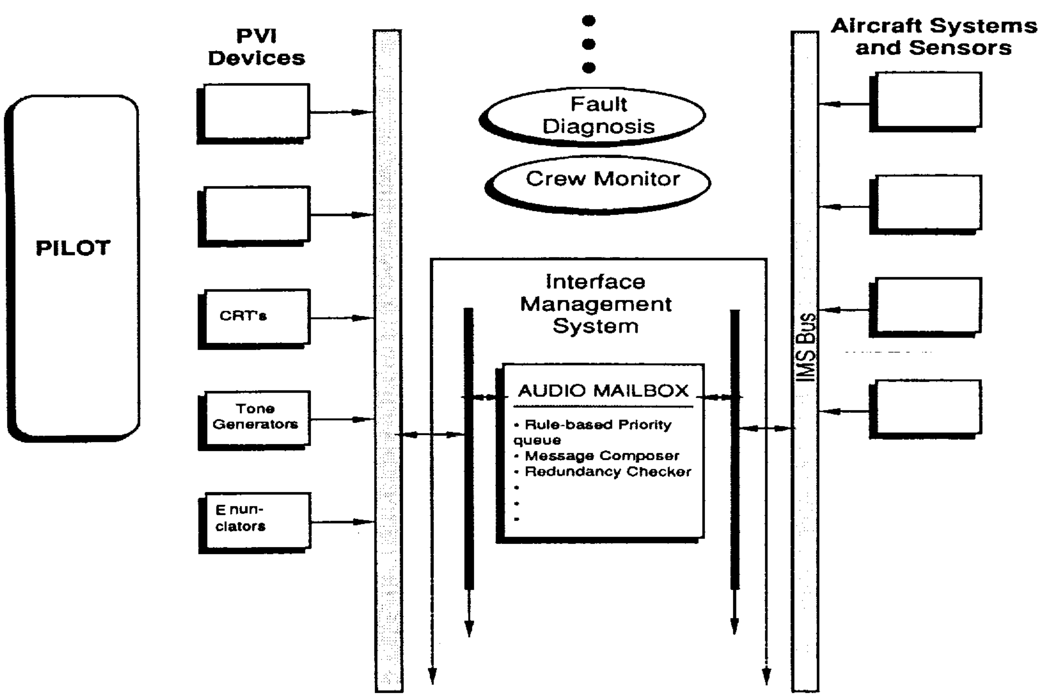
COCKPIT INFORMATION MANAGEMENT SYSTEM IMPLEMENTATION STAGES

- Specification of Message Interactions that is Format Independent
- Develop Functional Knowledge Base of Information Exchange Requirements and Dialogue Structures
- Abstract Characterization of Data Types, Sensor Systems, and Communications Links
- Develop Methodology for Controlling Media Interaction:
  - Format
  - Timing
  - Consistency/Error Checking
  - Storage

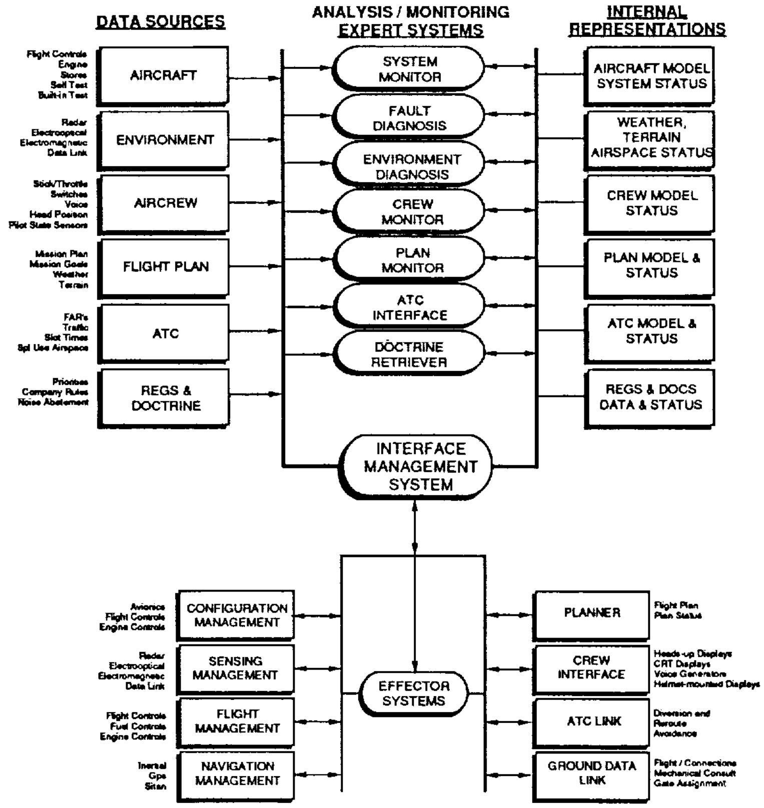
THE INTERFACE MANAGEMENT SYSTEM MANAGES THE FLOW OF INFORMATION AND THE DIALOGS BETWEEN THE SYSTEMS AND THE PILOT



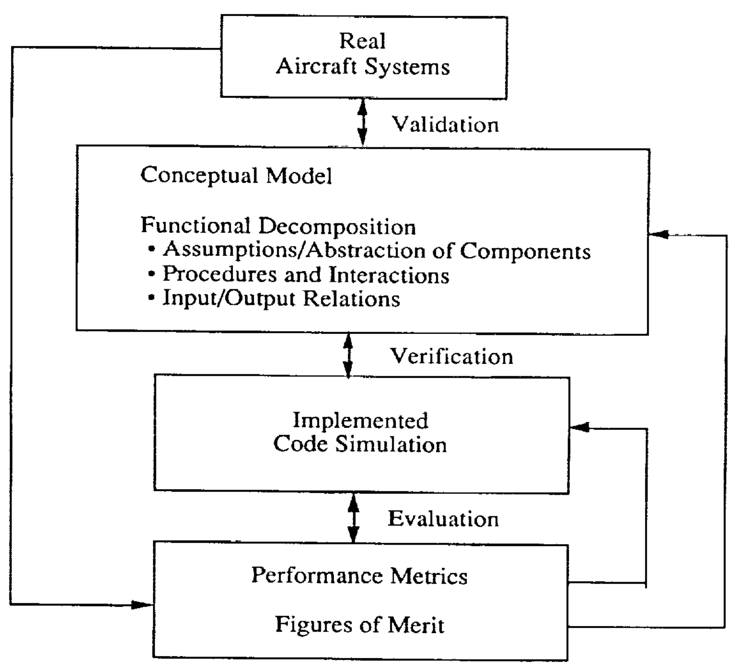
AUDIO MAILBOX ARCHITECTURE AND INTERACTIONS WITH IMS



OVERALL A3 ARCHITECTURE



MODEL/IMPLEMENTATION ASSESSMENT PROCESS



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FUNCTIONAL VALIDATION (SOME DEFINITIONS)

VERIFICATION: Comparison of the Conceptual Model or System Design to the Software that Implements that Design

VALIDATION: Determination of the Accuracy with Which the Model or System Captures the Function of the Real World Operation

EVALUATION: Comparison of the Target System's Operation to Current or Alternative Systems

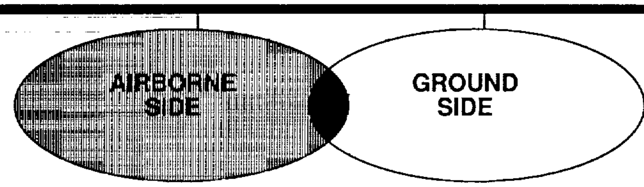
N91-10962

A FLIGHT TEST FACILITY DESIGN FOR EXAMINING DIGITAL INFORMATION TRANSFER

Charles E. Knox
NASA Langley Research Center

AIRCRAFT / GROUND INFORMATION EXCHANGE

OBJECTIVE: EXPLORE AND DEFINE INTERFACE / MESSAGE CONCEPTS FOR EFFECTIVE INFORMATION EXCHANGE THROUGH DATA LINK SYSTEMS



SYSTEMS CHALLENGES:
- USER-CENTERED AUTOMATION
- DATA BASE COMPATIBILITY
- OPERATIONAL PROCEDURES

NASA LaRC

DATA LINK RESEARCH ACTIVITIES

PRIMARY DIRECTION: ATC/WEATHER COMMUNICATIONS

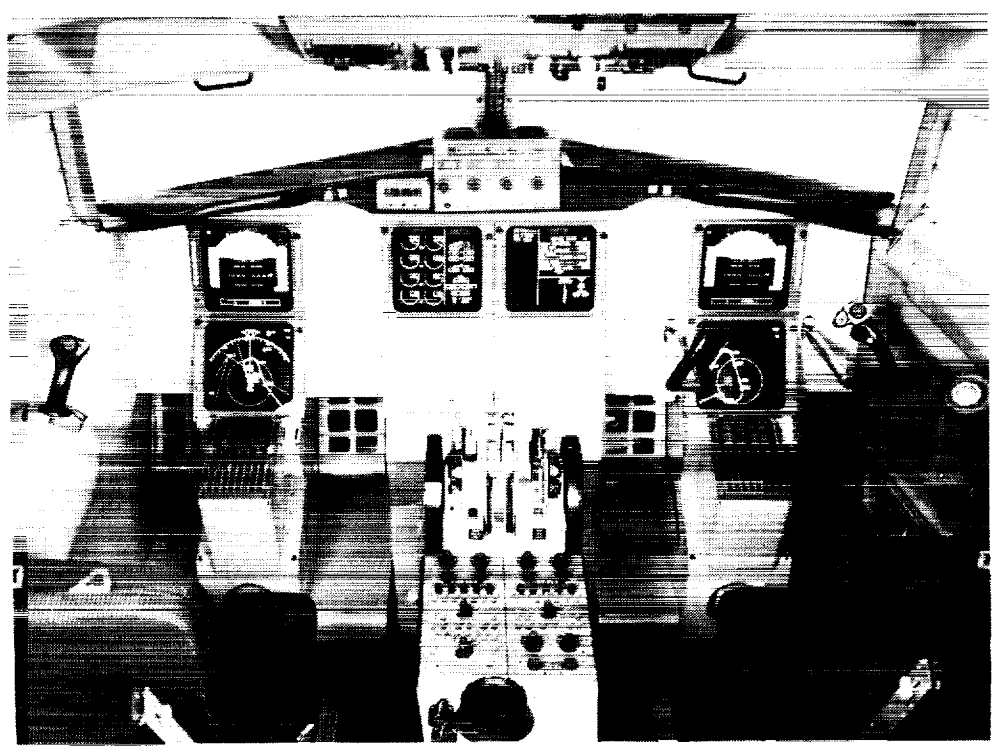
- SINGLE PILOT IFR PROGRAM
  - o FLIGHT EVALUATION -- CR-3461 / CR-3653
  - o SIMULATOR INVESTIGATION -- TP-2837

- DEVELOPMENT OF AN AIR GROUND DATA EXCHANGE CONCEPT:
  - o FLIGHT DECK PERSPECTIVE -- CR-4074
  - o ATC GROUND PERSPECTIVE -- BEING DRAFTED

- NASA ATOPS COMMERCIAL JET TRANSPORT OPERATIONS
  - o INITIAL PILOTED SIMULATION -- TP-2859
  - o TOUCH PANEL/COMPUTERIZED VOICE INTERFACE -- PILOTED SIMULATION -- COMPLETED
  - o TYPICAL AIRLINE MISSION FLIGHT PROFILE -- FLIGHT TEST -- NOV '89

NASA Transport System Research Vehicle (TSRV)

TSRV Research Cockpit



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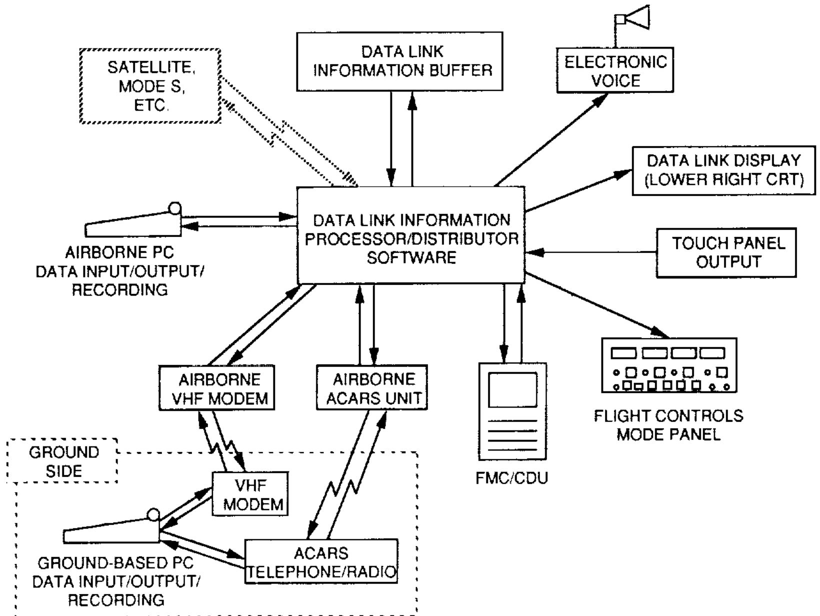
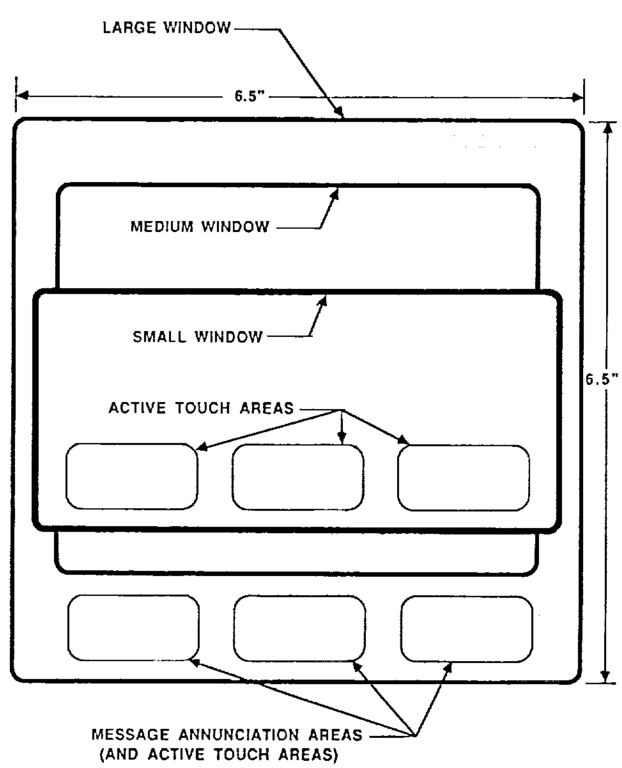
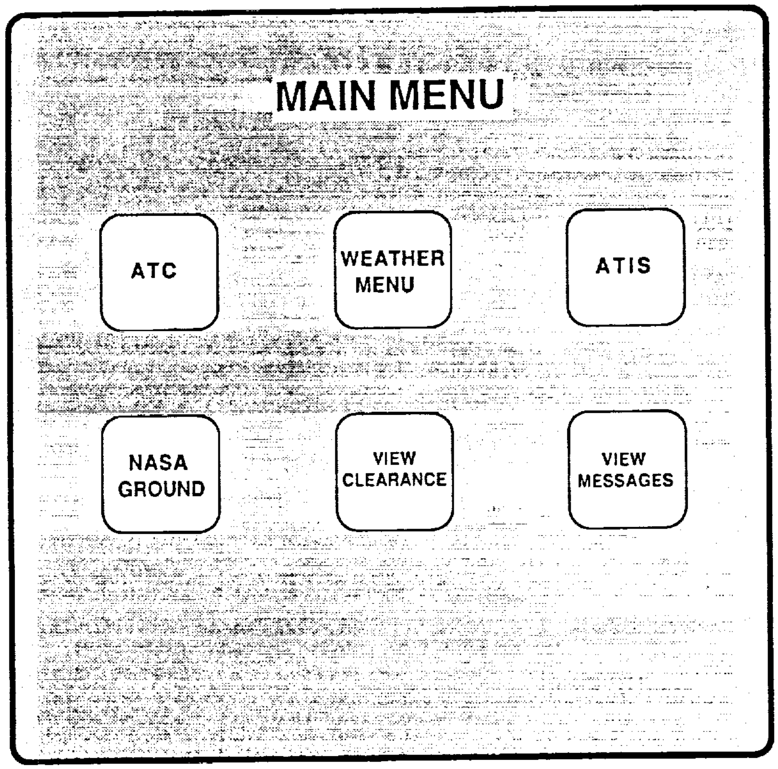
DATA LINK RESEARCH SETUP



Data Link Display Format




MAIN MENU
ATC
WEATHER MENU
ATIS
NASA GROUND
VIEW CLEARANCE
VIEW MESSAGES


MAIN MENU
ATC 164215:
NASA 515, TURN LEFT TO 350,
DESCEND AND MAINTAIN FL310
ROGER
ROGER
ENTER
UNABLE
WCP MSG

INITIAL TSRV DATA LINK FLIGHT TEST

TEST OBJECTIVE: COMPARISON OF CURRENT VOICE COMMUNICATIONS TO DIGITAL INFORMATION TRANSFER FOR AN EFIS-EQUIPPED TRANSPORT AIRPLANE DURING FULL MISSION SCENARIO TYPICAL OF COMMERCIAL AIRLINE FLIGHT OPERATIONS

SPECIFIC FOCUS:

- ADVANCED DATA LINK/CREW INTERFACE DESIGN
- CREW ACCEPTANCE AND PERCEIVED WORKLOAD
- ROUND-TRIP COMMUNICATION RESPONSE TIME
- AUTO-ENTRY OF DATA (PILOT APPROVED) INTO AIRCRAFT SYSTEMS

FLIGHT TEST SETUP

COMMUNICATIONS CAPABILITY COMPARISON:

- VOICE RADIO ONLY
- DATA LINK WITH CRT DISPLAY
  + VOICE RADIO BACKUP
- DATA LINK WITH CRT DISPLAY
  + COMPUTERIZED VOICE OF DATA LINK MESSAGE
  + VOICE RADIO BACKUP

TYPE OF COMMUNICATIONS MESSAGES:

VOICE TRANSMISSIONS

- ATC SIGN-ON
- TRAFFIC CALLS
- URGENT
- NEGOTIATIONS

DIGITAL COMMUNICATIONS

- ATC TACTICAL
- ATC STRATEGIC
- INFORMATION (ATC, WEATHER, ATIS, NASA GROUND)

FLIGHT TEST SETUP - (CONC)

FLIGHT PROFILE:

- o TAKEOFF AND LANDING AT NASA WALLOPS FLIGHT FACILITY
- o THREE PHASE FLIGHT PATH (~250 NM)
  - TAKEOFF AND CLIMB
  - ABBREVIATED CRUISE
  - DESCENT AND LANDING

TEST SUBJECTS:

- o COMMERCIAL LINE PILOTS

DATA COLLECTION:

- o PILOT COMMENTS, QUESTIONNAIRE, DEBRIEFING
- o SWAT
- o MESSAGE AND TRANSMISSION/RESPONSE TIMES
- o AIRPLANE STATE AND FMS AND FLIGHT CONTROL SYSTEM CONFIGURATION

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16. Abstract

The Aviation Safety/Automation Program Conference—1989 was sponsored by the NASA Langley Research Center on October 11–12, 1989. The conference, held at the Sheraton Beach Inn and Conference Center, Virginia Beach, Virginia, was chaired by Samuel A. Morello. The primary objective of the conference was to ensure effective communication and technology transfer by providing a forum for technical interchange of current operational problems and program results to date. The Aviation Safety/Automation Program has as its primary goal to improve the safety of the national airspace system through the development and integration of human-centered automation technologies for aircraft crews and air traffic controllers. This document has been compiled to record the conference presentations, which provided the stimulus for technical interchange. The presentation charts contained herein also document the status of on-going research and future plans of the Aviation Safety/Automation Program.

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