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# Advanced Flight Deck/Crew System Simulator Functional Requirements

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# 1.0 INTRODUCTION AND SUMMARY

The National Aeronautics and Space Administration Langley Research Center Terminal Configured Vehicle Program is an intensive research and technology effort to provide improved capability for operating CTOL transport aircraft in future high-density terminal areas. This program is providing a direction and focal point for developing operating systems technology which, in combination with new ATC systems being developed by the FAA, could lead to more precise, efficient, and productive terminal-area operations.

The NASA Ames Research Center is beginning a program to develop a Man-Vehicle Systems Research Facility with advanced cockpit displays and technology representative of future aircraft. This facility will be used to address human factor issues pertaining to development and evaluation of information requirements using advanced display systems, distribution of responsibilities between air crews and ground controllers, and automation of air crew functions.

The United States Air Force Wright Aeronautical Laboratory is planning a program to develop crew systems technologies for advanced military/commercial transport aircraft operating in the Civil Reserve Aircraft Fleet of the 2000 AD time period.

The Lockheed-Georgia Company and the Lockheed-California Company are jointly involved in a multi-faceted and inter-related program to apply emerging electronics technology to development of their main product lines, military and commercial transport aircraft.

All of these programs involve the development of Advanced Concepts Research Simulators.

Recognizing that there might be some elements of commonality in facilities to support this research, NASA contracted Lockheed-Georgia Company to investigate methods of exploiting this commonality. This task investigated what issues industry planned to explore, and what others should be investigated by the NASA or by other government agencies. From this investigation, functional and basic design requirements for research and development simulator facilities necessary to conduct these research activities were developed, areas of commonality and similarity identified, and methods devised for exploiting this commonality. This report documents the results of that study.

During this study the technology research requirements necessary to develop an integrated flight station design for transport aircraft operating in the Advanced Air Traffic Management System envisioned for the 1990's were investigated. Industry, NASA and other government agency research needs and the resulting simulation requirements are documented in this report. Basic design and functional requirements for research and development simulator facilities with the capabilities to conduct these research activities are also included. Areas of commonality are discussed and specific recommendations of how to exploit this commonality to reduce the design and construction costs are presented.

## 2.0 LIST OF SYMBOLS AND ACRONYMS

| | |
|---|---|
| ACRS | Advanced Concepts Research Simulator |
| ADF | Automatic Direction Finder |
| AFCS | Automatic Flight Control System |
| AFWAL | Air Force Wright Aeronautical Laboratory |
| AIDS | Aircraft Integrated Data System |
| ALEC | Altitude Echo |
| APU | Auxiliary Power Unit |
| ARC | Ames Research Center |
| ARINC | Aeronautical Radio, Inc. |
| ATARS | Automatic Traffic Advisory and Resolution Service |
| ATC | Air Traffic Control |
| ATCS | Air Traffic Control System |
| ATIS | Air Terminal Information Service |
| ATS | Automated Traffic Service |
| AVE | Air Vehicle Equipment |
| A/C | Aircraft |
| A/D | Analog-to-Digital |
| BCAS | Beacon Collision Avoidance System |
| BIT | Built In Test |
| CA | Collision Avoidance |
| CADC | Central Air Data Computer |
| CAS | Collision Avoidance System |
| CAWS | Caution and Warning System |
| CDTI | Cockpit Display of Traffic Information |

| | |
|---|---|
| CDU | Control Display Unit |
| CGI | Computer Generated Image |
| CPU | Central Processing Unit |
| CRAF | Civil Reserve Air Fleet |
| CRT | Cathode Ray Tube |
| CTOL | Conventional Take Off and Landing |
| DABS | Discrete Address Beacon System |
| DADC | Digital Air Data Computer |
| DADS | Digital Air Data System |
| DME | Distance Measuring Equipment |
| DOF | Degrees of Freedom |
| D/A | Digital-to-Analog |
| D/S | Digital-to-Synchro |
| EADI | Electronic Attitude Director Indicator |
| EFIS | Electronic Flight Instrument System |
| EHSI | Electronic Horizontal Situation Indicator |
| EIA | Electronic Industry Association |
| EL | Electro-Luminescence |
| ELM | Extended Length Message |
| ETO | Estimated Time Overhead |
| FAA | Federal Aviation Administration |
| FMC | Flight Management Computer |
| FMS | Flight Management System |
| FORTRAN | Formula Translation |
| GPS | Global Positioning System |

| | |
|---|---|
| GPWS | Ground Proximity Warning System |
| HF | High Frequency |
| HOL | High Order Language |
| HUD | Head Up Display |
| ID | Identification |
| IEEE | Institute of Electrical and Electronics Engineers |
| IFR | Instrument Flight Rules |
| ILS | Instrument Landing System |
| INS | Inertial Navigation System |
| IPC | Intermittent Positive Control |
| IRS | Inertial Reference System |
| I/O | Input/Output |
| LaRC | Langley Research Center |
| LCD | Liquid Crystal Display |
| LED | Light Emitting Diode |
| MFD | Multifunction Display |
| MHRS | Magnetic Heading Reference System |
| MLS | Microwave Landing System |
| MOTAS | Mission Orientated Terminal Area Simulation |
| MSAW | Minimum Safe Altitude Warning |
| NASA | National Aeronautics and Space Administration |
| OMEGA | Low Frequency Navigation System |

| | |
|---|---|
| PA | Public Address |
| REL | Relative |
| RNAV | Area Navigation |
| RPM | Revolutions Per Minute |
| RTC | Real Time Clock |
| RVR | Runway Visual Range |
| SATCOM | Satellite Communication |
| SELCAL | Selective Calling System |
| SON | Statement of Operational Need |
| STOL | Short Takeoff and Landing |
| S/D | Synchro-to-Digital |
| TACS | Transport Advanced Crew Systems |
| TCV | Terminal Configured Vehicle |
| TI | Texas Instruments |
| UHF | Ultra High Frequency |
| USAF | United States Air Force |
| VASI | Visual Approach Slope Indicator |
| VFR | Visual Flight Rules |
| VHF | Very High Frequency |
| VMC | Visual Meteorological Conditions |
| VOR | VHF Omni Directional Range Navigation |
| 4-D NAV | Four Dimensional Navigation |

## 3.0 RESEARCH NEEDS

The establishment of the design requirements for a research facility, which includes a flight station and electronics complement representative of 1990's technology, initially entailed surveying various government agencies and industrial facilities for their anticipated research and development requirements, and to identify issues that must be resolved conjunctive to implementation of changes being considered in the ATC system. Both NASA LaRC and ARC submitted lists of their research requirements and ground rules for their respective facilities. These centers were visited to discuss the types of research planned and to obtain a better understanding of the problems involved in developing this capability at their facilities. The simulator requirements and ground rules for each of these centers is included in Appendix A.

The Boeing Commercial Airplane Company, the Douglas Aircraft Company and the Lockheed-California Company were visited to survey additional industry simulation requirements. These discussions helped to develop the types of issues concerning industry, and to present a more representative set of industry's research needs.

The U.S. Air Force Wright Aeronautical Laboratory's Crew Systems Development Branch, AFWAL/FIGR, has in its 5-year plan the development of crew station technology for military/commercial CRAF aircraft for 2000

AD. This program, TACS 2000, will ultimately involve construction of a research simulator. A visit with this agency revealed the simularity of issues that must be resolved and the functional similarity of the military and commercial flight station and systems. No formal set of research needs had been prepared, but some general requirements have been established through discussions with personnel involved in the development of a SON for the facility.

The following sections discuss in detail the research requirements that were identified in this investigation. Grouped into the following seven general categories, these discussions identify issues that must be resolved in each category.

a) Aircraft Operating Techniques

b) New Display Technology and Criteria

c) Flight Station Integration

d) Flying Qualities and Control Systems

e) Crew Performance

f) Research Tools

g) Flight Hardware Evaluation.

## 3.1 AIRCRAFT OPERATING TECHNIQUES

The studies concerned with aircraft operating techniques are investigations of the use of advanced equipment, both ground based and airborne, to obtain a higher degree of safety and more efficient aircraft operation. In addition, a primary goal of studying these techniques is to increase the utilization of airport facilities to accommodate the ever increasing traffic load.

Profile descent guidance studies will evaluate the operational benefits of straight flight path angle versus parabolic flight paths. This will require a definition of the display and flight guidance system requirements associated with both types of flight paths.

A study of curved path navigation techniques will define the types of complex trajectories that might be beneficial. Again the information display and guidance system requirements must be defined for each trajectory. This will require development of the guidance algorithms and the allowable tolerances.

One of the major areas of concern when considering simulation of 1990's aircraft is the role of the crew members in the future Air Traffic Control environment. The distribution of functions for flight crews and air traffic controllers must be investigated in 3-D and 4-D area navigation situations for aircraft with and without traffic information displayed in the cockpit.

A closely related area requiring research is the degree of automation that should be implemented in future aircraft. A study of this subject must not only determine the overall degree of improved performance of any automation and the anticipated level of acceptance in the aviation community, but foremost must determine the affect on the human crew member's failure detection ability and skill erosion.

A natural outgrowth of a 4-D RNAV system with metering and spacing is the development of an ATC environment that will allow more optimum operational procedures based on the performance characteristics of each aircraft. The area of integrated flight management needs to be expanded to operate in this improved environment.

The determination of the information criteria and the associated technology to transfer preflight planning data into the integrated flight management system are issues that require research. Voice characteristics, crew anthropometric data, and preferential data could be inserted into the aircraft at this time and should be investigated to determine the feasibility of using this type of information for flight station re-configuration. In addition, the possibility of recording inflight data for use in debriefing or training needs to be investigated.

There are several research needs that are uniquely military or industrial in the development of advanced military aircraft. The first of these concerns aerial refueling for both the tanker and receiver. This requirement, as far as unique simulation requirements are concerned, is the development of aerial refueling receiver capability. Visual scene generation is significantly impacted by this requirement.

Assault/STOL takeoff and landing studies must also be carried out for new military aircraft. New procedures and techniques must be developed using fully integrated flight stations with advanced avionics technology.

Development of air-drop and air-launch capabilities for multipurpose military transport aircraft is required. Techniques, procedures and development guidelines must be established for aircraft that will enter the military inventory in the 1990 to 2000 time frame.

## 3.2 NEW DISPLAY TECHNOLOGY AND CRITERIA

The rapid advances in electronics display technology will present the aviation industry with unprecedented potential and flexibility in aircraft display techniques. Instead of being limited to the decision of where to display data, the option is now expanded to require the designer to develop display formats that are optimized for each phase of aircraft operation, and to determine when and how these data should be presented in the manner most useful to each crew member.

One of the first areas of research in display technology concerns the use of color displays. The benefits of color versus monochromatic displays must be evaluated for various categories of application. The impact of implementation must be assessed and design criteria must be formulated.

The exposure of the displays to high ambient light levels will require research into the various contrast enhancement techniques. Design guidelines need to be formulated to improve contrast on various types of color displays, and near term research needs to be conducted to evaluate the effects of multi-color dot matrix display resolution on readability.

An area of increasing interest in display technology is the feasibility of applying holographic technology to HUD or to map displays. Research in this area would identify display problems that might be solved or simplified by employing holographics. In addition, steroscopic displays might be applied to some of these problem areas.

A potential problem area that requires investigation is the effect on landing performance of reduced field of view through a HUD under crosswind conditions. This study will require the development of a crosswind probability model.

### 3.3 FLIGHT STATION INTEGRATION

Advances in technology have traditionally generated new devices which are introduced into the flight station without adequate analysis of overall operational requirements. This often results in changes or additions to the flight station which adversely effect the overall operation, while improving the operation in specific areas. The primary reason that this problem developed is due to the use of discrete "standard" instruments, arranged in the best possible display format, and the inherent limitations of electro- mechanical devices. Until recent times it has been generally impractical or impossible to combine functions. This problem can be corrected in future aircraft with the proper integration of electronic display devices with highly researched display formats. Although various systems must be treated as separate systems, the integrated flight station must be evaluated as a total system.

The display format for primary and secondary flight information will require research to develop and evaluate various concepts. The present flight instrument system is satisfactory during cruise and for instrument approaches under normal conditions. However, when terminal-area navigation, high traffic density, low visibility and/or turbulence are encountered, the workload and reaction times reach the point where the system is marginal at best. Since electronic displays provide almost unlimited format flexibility, they may be optimized to any situation. This information will depend on the phase of flight, the degree of automation and many other factors that must be investigated as a total flight system. The formulation of design criteria and an assessment of the impact of the implementation on the total system must be conducted.

Another area of major concern is the CAWS. Several advances in the electronics field in recent years have resulted in an unusual opportunity to research and establish design criteria for this type of system that did not exist previously. The electronic display units with their inherent flexibility of display formats, allow more levels of severity to be utilized. Coupled with computer generated voice and phase of flight logic, a highly sophisticated caution and warning system can be developed that can get the proper attention level and discriminate some level of urgency based on other activities that are taking place at the time.

The optimum use of electronic display units dictates their use for more than one display format or, as multi-function displays. Anything less relegates them to simply direct replacement for electro-mechanical instruments. Switching functions of multi-function display units need to be defined as a part of overall integration into the flight station and various design concepts must be evaluated. The impact of implementing this technique must be assessed and design criteria must be formulated.

Maintenance monitoring and systems monitoring display systems will require significant research to define the switching modes and format content requirements. Various methods of data output must be investigated and design criteria established. The impact of these systems on the total integration of the flight station and crew duties must be assessed.

The two/three person crew complement issue needs to be researched to obtain factual information in all phases of flight. Data on safety, aircraft performance, crew coordination, and fatigue must be compiled to assess the impact on overall systems design and crew station integration.

Extensive research is required in the area of CDTI. The issue of ground based versus airborne sensor information will require study, especially in failure modes; however, the design and evaluation of the display formats and the associated data requirements will require extensive research. This type of information can have a significant impact on total system integration due to the high level of concern of crew members for traffic separation.

The total impact of voice recognition and generation systems on crew duties, workload and coordination must be thoroughly studied. Various algorithms must be evaluated and design criteria formulated for the voice systems themselves. Next, system analysis studies should be conducted to assess the accuracy, speed and effectiveness of aural transmission of information.

An essential element of the integrated flight station must include new approaches to enhance pilot control of the aircraft. The use of center sticks or side-stick controllers, for example, affects the general arrangement of the flight station and must be a part of any integrated flight station research. The primary pilot controller, primary flight information display formats, and the pilot-in-the-loop for flying qualities research in the manual mode, must be considered as a part of the system.

Any research of an integrated flight station must investigate conflicts in information, regardless of the source. The capability to change display formats allows the flexibility to transfer information to other display units and will also allow input from other independent information sources. Recognition of any conflict and the resulting resolution will require extensive investigation.

### 3.4 FLYING QUALITIES AND CONTROL SYSTEMS

One of the traditional uses of flight simulators has been in the evaluation of flying qualities. Simulation techniques are still extensively used for this purpose and the totally integrated flight station and new control techniques require even greater emphasis in this area.

In the past, flying qualities, or control of flight, research has emphasized aircraft stability and control characteristics. Research results have largely been formulated in terms of vehicle responses to pilot control inputs or parameters related to aerodynamic stability such as frequency and damping. In recent years, however, the importance of other factors has resulted in an expanded concept of flying qualities as "those qualities or characteristics of an aircraft that govern the ease and precision with which a pilot is able to perform the tasks required in support of an aircraft role." In addition to stability and control characteristics, other factors such as the flight task, pilot's stress, cockpit interface, and aircraft environment also influence flying qualities. Also, the flight control characteristics have been taking on added influence as new aircraft configurations place larger requirements on the flight control system.

While theoretical analyses are important, flying qualities research is most effectively performed with the pilot-in-the-loop. Since flight testing is too costly for most research projects, flight simulation is the approach usually taken to obtain the necessary data. Closed-loop flying qualities with advanced primary/secondary controls, cockpit display formats, and automatic and active control systems must be evaluated. Failure modes or probability of failure on new systems must be assessed and design criteria formulated. The type of pilot input devices such as side stick, Brolly handles, or some other controller and fly-by-wire or fly-by-light systems will be areas of continued interest and research.

Digital flight control system requirements and criteria, optimal control theory, and fault tolerant digital control system concepts are areas requiring research and development. Active control system research and development for such items as relaxed static stability system requirements and criteria, load alleviation, and structural mode suspression will also be the subject of simulation studies. The emphasis of these studies will be to enhance man-machine effectiveness, minimize probability of pilot workload saturation conditions, increased flight safety, and improved aircraft operational capability.

Recent government studies have recognized that there are many new system design factors which have broad influences on flying qualities and pilot workload, which are not currently included in the existing documents on flying qualities. Environmental factors such as windshear, digital flight control processing capabilities, and the delineation of task-oriented piloted flight have all contributed to the need for an expanded view of flying qualities. The advent of advanced cockpit layouts with CRT displays also has potential implications to the flying qualities criteria. Economic considerations make it essential that the design criteria be structured to assure mission effectiveness, flight safety and acceptable pilot workload without penalizing cost effectiveness. Simulation studies involving closed loop flying qualities criteria will be performed on the advanced flight simulation facility.

## 3.5 CREW PERFORMANCE

In addition to the normal research on various flying characteristics and total system integration, a research simulator is a useful tool for human factors research, which can be conducted at two major levels. The basic level concerns individual elements of the flight station, such as a specific display format, and can be carried out initially in a part task simulator. The other level of research is concerned with the overall crew/vehicle system. This type of experimentation requires a very high degree of fidelity in the flight station and a full task simulation. The latter is the primary area of concern in developing functional requirements for the ACRS.

One specific area of research in this area is human error and aviation safety. Analysis of existing data bases can help develop experimental scenarios to study crew behavior as a function of specific accident scenarios or generic scenarios.

Another area of increasing concern, considering the rapid advances in technology, is the degree of automation. The major issue in this area is the degree to which automation is helpful or even desirable from the perspective of crew behavior, workload and performance. The two major issues that are apparent, and which require extensive research are skill errosion and failure detection.

Development of crew informaton requirements revolves about the question of the relative degree of responsibility between the air crews and ground controllers. The related issue of display format requirements must be derived from the responsibility distribution.

The greatest demands on configuration flexibility of flight station geometry will be exercised by studies of the human factors of advanced crew stations. Crew workload and safety considerations will to a great extent influence the design and use of many of the advanced systems in the 1990's aircraft. Problem solving and decision making will be an index of performance for these systems. Resolution of data conflicts and system failures is a major area of concern.

Air crew behavior studies of a generic nature will require the widest range of performance measuring equipment. These studies must concern themselves with training, crew workload, crew resource management, fatigue, and other areas of general significance including crew/vehicle performance.

### 3.6 RESEARCH TOOLS

The versatility of display devices will require some preliminary guidelines before the possible formats can be narrowed to a population practical to be investigated. This will require analytical studies possibily using an analysis tool such as the Optimal Control Model of the Human Operator. This type of analysis needs to be applied at the information level, display element level and the display format level. The comparative human performance at various levels of automation or with various display formats requires both workload and performance measurement capabilities. Performance measurement techniques in general have been refined, but additional research is required to develop improved workload measurement and prediction techniques.

Some areas of interest in workload measurement include the investigation of the correlation between various physiological parameters and workload. Methods of monitoring and interpreting these physiological parameters need to be developed. Full field-of-view oculometer systems will be required, and the correlation between these data and crew workload must be determined. Sensitivity analysis of various parameters concerning workload will be very useful in establishing design criteria or evaluating specific elements. This will establish the requirement for an integrated workload measurement system data reduction and analysis package.

A workload prediction technique that includes improved cognitive and visual factor representation should be developed. This will require the definition and validation of weighting functions for each workload factor.

## 3.7 FLIGHT HARDWARE EVALUATION

Flight hardware for future aircraft is usually mathematically modeled during the early stages of development or during research. As the designs begin to solidify, and as prototype hardware is developed or possible supplier hardware evaluations are required, actual hardware should be inserted into the simulation process.

The electronics or avionics interface to the simulation is easier to generalize without building a facility for each aircraft. The bus systems that are being used on the newer designs make this a very desirable approach. This capability can be used to validate and verify operational flight software. Redundancy management, backup modes and failure analysis, and sensor control development and evaluation should be performed in an electronics integration facility.

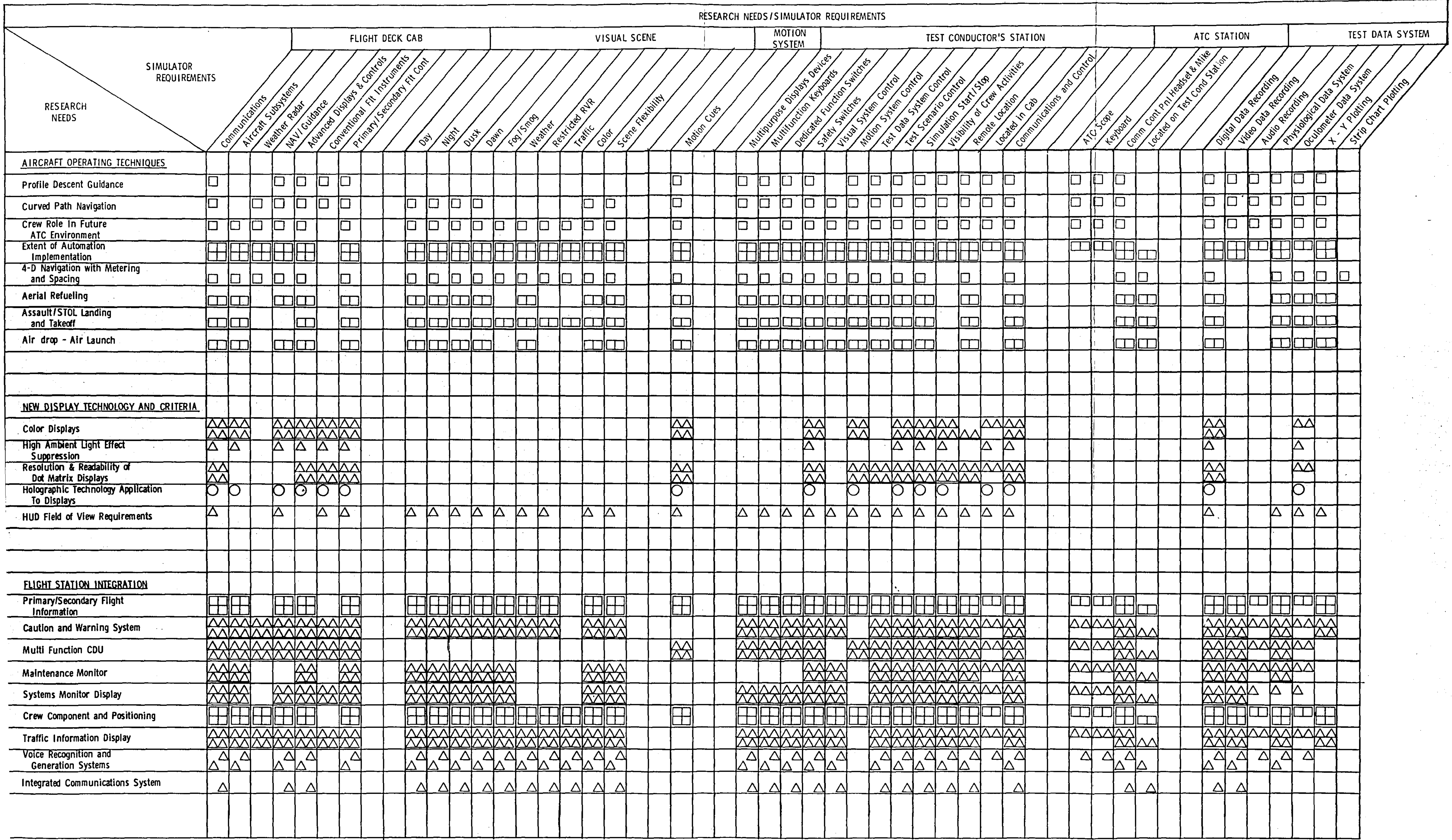
The mechanical, hydraulic and pneumatic simulation capability in general must replicate a specific aircraft. This capability is normally required during aircraft development, but should be considered during simulator design if the capability is desired.

## 3.8 RESEARCH NEEDS/SIMULATOR REQUIREMENTS

Figure 3-1 is a matrix that tabulates the research needs of industry and the various government agencies versus simulator requirements.

The shape of the symbol in each quadrant of the requirement blank indicates whether the requirement is near term only, far term, or required near term and used for an extended period of time.

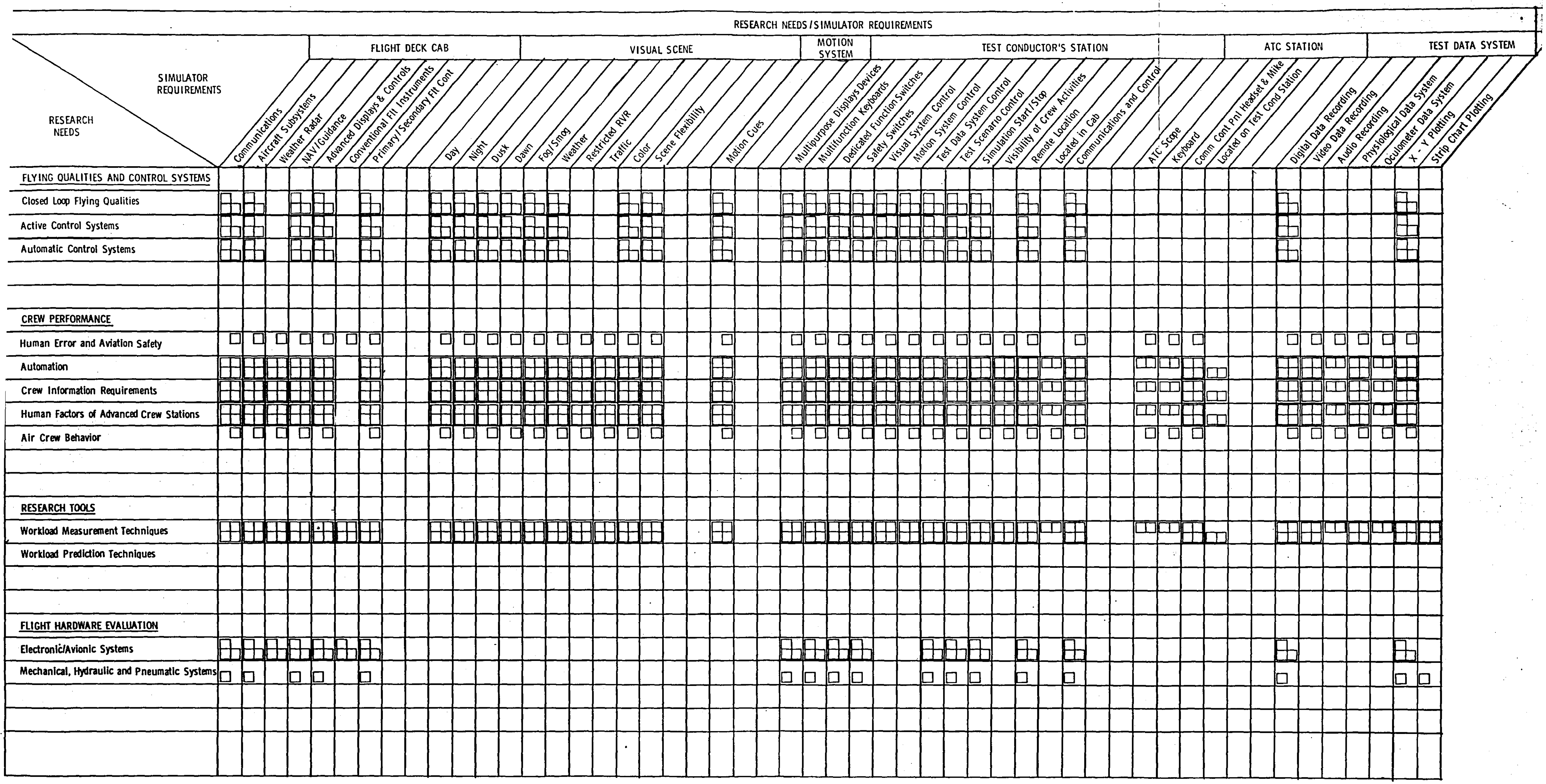
Inasmuch as the U. S. Air Force has not developed a complete set of research requirements at this time, those shown give some ideas of possible areas of similarity that were identified in discussions with knowledgeable individuals. Although several agencies may be shown as having the same requirements, the degree of the requirement is so different that it could be hypotheized that the requirements are indeed different. An example of this is the requirement for an ATC function. The NASA requirement is for extensive simulation, while the industry requirement is little more than communications and navigational aids.




REQUIREMENTS LEGEND

| | | |
|---|---|---|
| 1 2 / 3 4 | 1 NASA LaRC | △ Near Term |
| | 2 NASA ARC | ○ Far Term |
| | 3 Industry | □ Near Term - Long Range |
| | 4 Military | |

FIGURE 3-1 RESEARCH NEEDS/SIMULATOR REQUIREMENTS




REQUIREMENTS LEGEND

1 NASA LaRC
2 NASA ARC
3 Industry
4 Military

△ Near Term
○ Far Term
□ Near Term - Long Range

FIGURE 3-1 CONCLUDED

## 4.0 SIMULATOR REQUIREMENTS

This section addresses functional requirements and design criteria for those elements of the ACRS which are common to both government and industrial facilities devoted to advanced flight research. As such, they can be easily converted into a detailed design specification for an ACRS configured to satisfy the research goals of any particular agency or group.

The design requirements have been grouped into eight categories which address the common elements of the ACRS. These categories are as follows:

a) Hardware components

b) Flight Station

c) ATC interface

d) Computer complex

e) Environmental systems

f) Test conductor console

g) Computer control console

h) Data acquisition and recording system.

Specific design requirements applicable to each category are discussed in the following sections.

## 4.1 HARDWARE COMPONENTS

The basic elements of the ACRS are shown in block diagram form in Figure 4-1. One of the primary design goals of this study was to explore functional commonality among similar facilities located within industry and the various government agencies. Certain differences will inevitably exist, however, due to the unique research and development roles assigned to each simulator. In some implementations of the ACRS concept, for example, the host computer will drive a single cockpit as shown in Figure 4-1; in others, it will simultaneously drive multiple cockpits; in others, the host computer will be switched between multiple cockpits. Each version of the ACRS will, however, consist of the same basic functional elements configured to satisfy specific needs. A typical configuration in which multiple cockpits can be selectively driven by a single host computer is shown in Figure 4-2.

The computer complex is recognized to be the heart of any simulation facility, and includes the host computer, the I/O system and all peripherals necessary to support simulator operation and related software development activities. Flight station elements are connected to, and driven by the host computer through the I/O system. This provides the necessary physical interfaces among the test crew, the simulated aircraft, the aircraft systems and all external stimuli. The various consoles must allow test and maintenance personnel to exercise control over the ACRS and to monitor various aspects of its operation through links with the host computer.

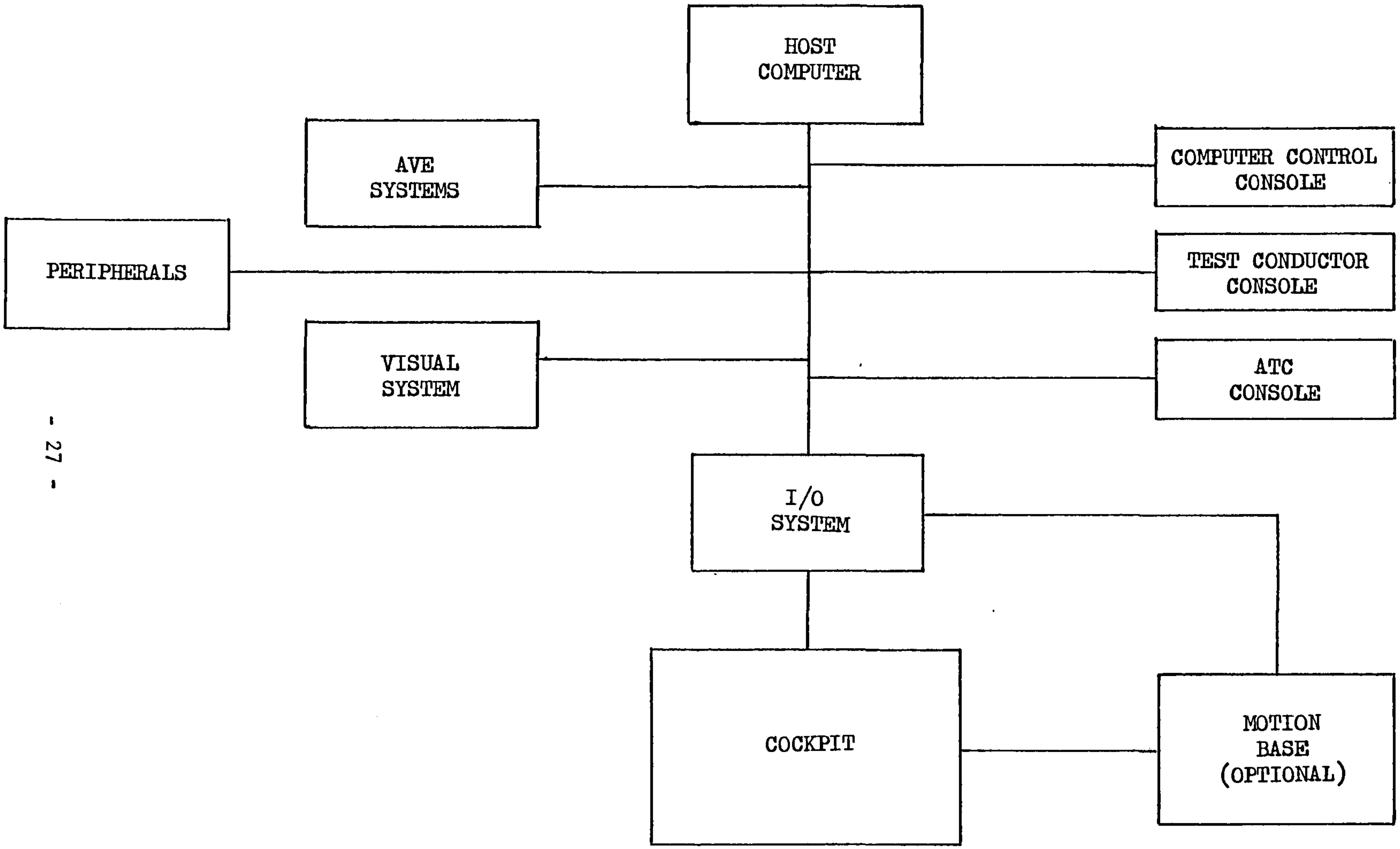



FIGURE 4-1 . ADVANCED CONCEPTS RESEARCH SIMULATOR

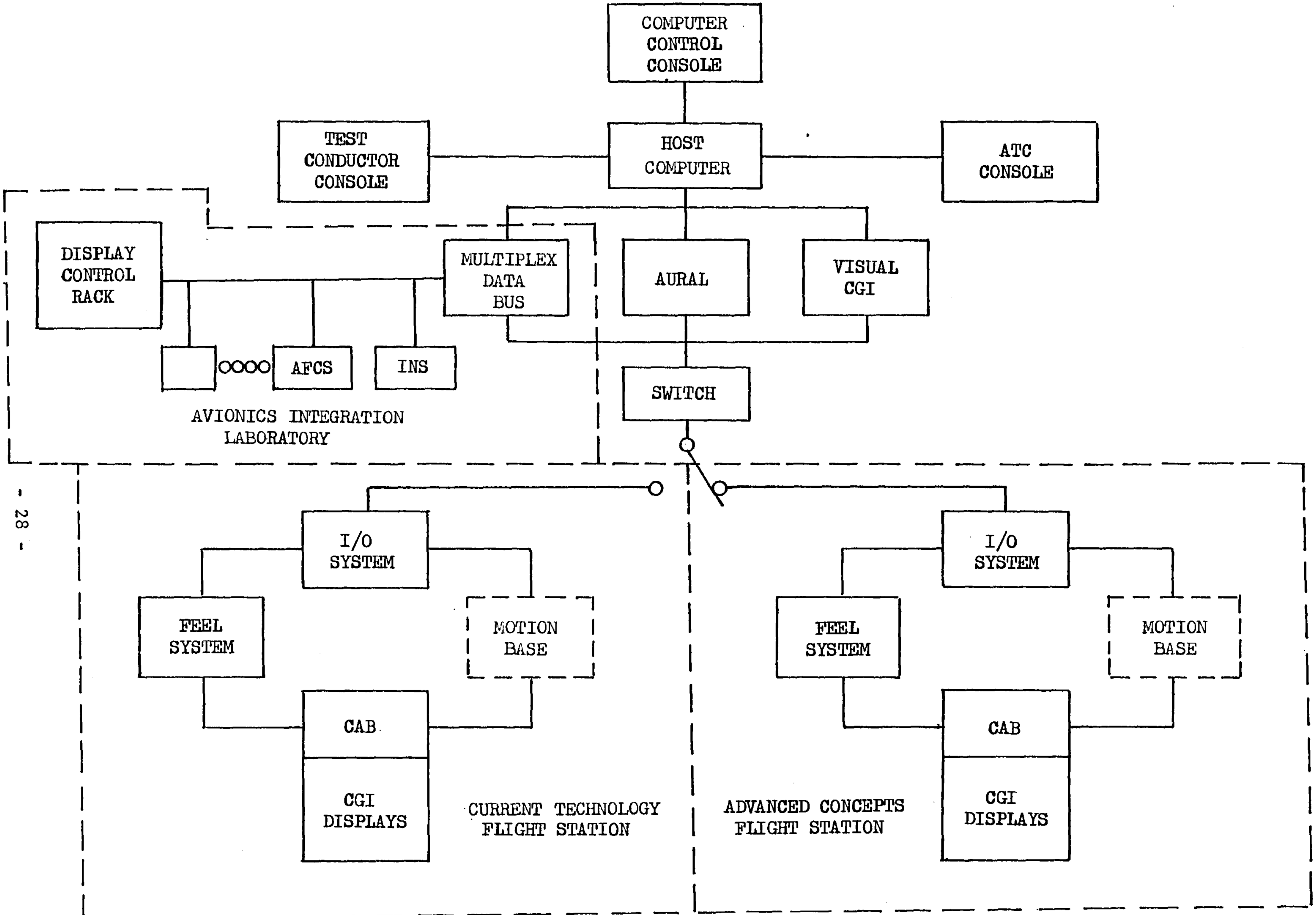



FIGURE 4-2. TYPICAL ACRS CONFIGURATION

While the computer complex must be fully capable of simulating an aircraft, its systems, and any desired external effects with a high degree of fidelity, provisions must be made for replacing the software simulation of any given system with corresponding AVE. Additional realism must be provided via the external scene presented by the visual system. Multiplex data bus techniques should be used to the extent practicable to interconnect the various elements into a functioning simulator. If physical motion cues are considered pertinent to the research tasks to be accomplished within a particular ACRS, the cockpit should be mounted on an appropriate motion base or g-seats should be utilized.

A number of significant physical factors must be considered during design of the ACRS. Some of these factors directly affect the degree to which the facility would ultimately satisfy its design goals. Others address the manner in which the facility could be operated, and the ease with which it could be reconfigured or expanded to satisfy changing research requirements. Others concern the level of safety provided to the physical facility itself, to its operating personnel and to the test subjects.

While not exhaustive, the following discussion is intended to summarize some of the more significant considerations affecting the design and physical implementation of the ACRS:

a) One of the first considerations must obviously be the amount of physical space available, and its configuration. Each of the basic functional elements identified in Figure 4-1 impose certain unique physical space requirements. Overall, however, the elements should be physically located as close together as possible both to minimize the length of physical cable runs, and to facilitate coordination during simulator operation and maintenance. Due to the dynamic nature of the research environment, space must be provided to accommodate future expansion. Particular attention must be given to the space requirements of candidate visual and motion systems.

b) Sufficient electrical power, for future expansion as well as for current operation, must be available. As a minimum, the computer complex should be provided with a non-interruptible power source.

c) Adequate cooling air must be provided. Use of modern digital systems employing solid state technology tends to lessen this problem somewhat. The potential heat problem inherent in the operation of a large amount of electronic equipment in a somewhat confined area must be recognized, however, and the facility design must include measures to provide sufficient cooling to ensure proper operation and to maximize equipment life. An alarm system must be provided to sense the occurrence of any potential over-temperature situation and to annunciate this fact to facility personnel so that immediate corrective action can be taken.

d) Potential problems related to electromagnetic interference must be anticipated and eliminated insofar as possible within the facility design. Provision of an adequate electrical grounding scheme for the ACRS is mandatory, and it should be designed to absolutely minimize the level of ground noise. Particular care must be taken to ensure that no noise signals of any type can enter the computer complex through the grounding system. In extreme cases, the computer complex may have to be electrically isolated from the remainder of the simulation facility.

e) To the extent possible, electrical interconnection of the basic functional elements should be accomplished via multiplex data buses. In addition to providing improved flexibility, use of data bus techniques will significantly reduce the amount of physical wiring required within the facility. This will dramatically reduce the costs associated with initial fabrication of the ACRS and will aid in keeping recurring maintenance costs at an acceptable level.

f) Accessibility of all hardware components and wiring must be stressed throughout the design. This will greatly facilitate later implementation of facility improvements in addition to providing easy access by facility personnel to components during both normal simulator operation and maintenance actions.

g) Adequate lighting must be provided in all areas of the ACRS. Particular attention must be given to the need for lighting in all confined areas such as equipment racks and underfloor wiring troughs.

h) A comprehensive intercom system linking all areas of the ACRS must be provided. This system should serve at least two basic functions. During normal simulator operation, it should provide for the audible coordination required among research personnel, and during maintenance periods it should allow facility personnel to communicate among the various simulator stations as an aid in the necessary troubleshooting and repair operations.

i) RS232-type data connectors should be installed at strategic locations throughout the ACRS. These connectors should be interfaced to the computer complex through standard RS232 buses to allow interactive access to the various computers, and to the I/O system via CRT-type or portable data terminals. As such, these terminals can be used to control the operation of certain portions of the ACRS in order to implement temporary software changes or to perform various maintenance actions. The availability of these data connectors at sites throughout the facility will prove to be quite useful in normal day- to-day simulator operations.

j) All other factors aside, the overriding consideration in the design of the ACRS must be the physical safety of those who work within it. All design decisions must be made with due consideration to their ultimate impact upon the safety aspects of the facility. Specific areas of concern include provision of fire alarm/protection systems in all areas, with particular emphasis upon the cockpit; availablity of emergency shutdown switches throughout the facility; provisions to ensure that all electrical and/or hydraulic systems have been deactivated as appropriate during maintenance operations; and provision of protective systems to prevent injury to personnel in the event of failure of hydraulically-driven hardware such as the control loading system or the motion system. The specific areas just mentioned are intended merely to indicate the types of safety considerations which must be included within the design. They do not constitute an all-inclusive list. Every area must be carefully examined during the design phase to determine any factors which might ultimately compromise the safety of the operators and users of the ACRS.

## 4.2 FLIGHT STATION

### 4.2.1 DEVELOPMENT PROCESS

Development of a 1990's flight station configuration for an advanced concepts research facility requires the orderly systems engineering approach set forth in the following paragraphs.

The initial phase of this activity must consist of obtaining, forecasting, and determining information on 1990's user needs, operating environment and procedures, and aircraft systems and electronics technology. Operational scenarios must be developed using this information, and then validated by the users. Detailed time lines can be developed from these and used to generate aircraft functional requirements, and to determine aircrew information and control requirements.

Following a conceptual description of the aircraft functions required to satisfy the mission and environment, those functions and the tasks to perform them must then be allocated to either the crew or the machine and the input/output relationship between them established. To establish a baseline, an initial selection of crew size and complement must be made, which will be refined throughout the analysis until a final determination can be made. Through the process of time lines, task loading, trade-off analyses, and reallocation of functions between crew members, and between the crew and the machine, an equalized and logical task loading for the crew members can be derived. A feedback of design solutions through the system will determine by a functional analysis if the information/action requirements are met.

Aircraft subsystems such as fuel, electrical, and hydraulics must be designed and configured to reflect 1990's technology, and requirements for display and control devices for these as well as the communications, guidance, and navigation functions determined. These designs must consider and be responsive to the facility functional requirements and research needs identified previously. Technology forecasts developed earlier in the program for displays and system operating controls must guide the selection of the technologies which will be available in the 1990's time period. When this is accomplished, functional layouts of the various crew stations can then be made. These should consider primarily the categorization of each information/action item as to its importance from the standpoint of reach, vision, or other sensory perception. Conceptual/actual candidate crew systems will be the result of this effort.

Upon incorporation of these designs in a mockup, critical segments of the scenarios developed earlier can be "flown" by proficient test subjects to evaluate and validate the various design options. The testing must be iterative, and must examine all candidate designs. Subjective performance data must be collected during and following mockup flying sessions through questionnaires and debriefings. These and additional objective and subjective workload data must be collected, reduced, and the results evaluated.

From these iterations, simulator design and fabrication can begin. This process starts with refining the features of the mockup design found necessary during the mockup tests. As with the mockup, components must be sized and constructed, crew systems must be designed/selected, and control/display layouts made. Hardware must be fabricated, installed, integrated with software to operate as systems, and then be thoroughly checked against the mission scenario requirements.

Completion of this process is mandatory to provide an authentic baseline configuration that is representative of both projected developments in aircraft subsystems technology, as well as displays, controls, and systems compatible with the airways and ATC system improvements projected for the future. Flexibility and versatility in developing and evaluating various display and control hardware, display formats, equipment arrangement and location, crew complements, etc. is the key to providing a useful research tool. All of these factors, plus providing ease of rapid reconfiguration to accommodate efficient conduct of experiments must heavily influence the design process.

4.2.2 DESIGN CRITERIA

In analyzing the research needs and issues to be addressed in the various facilities being contemplated, the following factors were determined to be common basic design requirements:

a) Ease of changing functional layout of equipment. This implies both change of individual equipment within an area and also shifting of entire modules to different locations in the simulator.

b) Changes to seating arrangements such as location and spacing whereby various crew complements can be easily accommodated within the cab.

c) Cooling required for high density electronics regardless of the individual units or clusters of units.

d) Electrical power for basic equipment needs as well as panel lighting.

e) Both ARINC 429 and MIL-STD-1553B data buses for computer interface to various displays and controls.

f) Maximum safety of occupants in the event of a smoke or fire emergency or malfunction of motion base system including smoke detectors, temperature warning and satisfactory egress methods. Automatic release of a fire retardant gas into an area where a warning has been detected should be included.

g) Environmental conditioning that provides clean, filtered, and temperature controlled air.

h) Easy access to the rear of equipment through combination of hinged panels and removable shell panels. Maximum maintenance capability and minimum down time because of basic equipment malfunctions must be provided.

i) Special considerations must be given to items not normally found in a cab such as television cameras and devices for accepting physiological inputs such as heart rate, breathing rate, eye point-of-regard and other physiological measures.

j) Voice communications including ATC interface, crew intercom, test conductor private line to other observers, and maintenance intercom.

k) Emergency system cutoffs located where access is unrestricted in the event of a major electrical or hydraulic failure. Automatic activation of separately wired emergency lighting.

l) Consideration must be given to including auxiliary hardware for overall realism such as coffee cup holders, trays, map lights, oxygen masks, trim detail, carpets.

### 4.2.3 HARDWARE INTERFACE

The use of the digital data bus concept will provide maximum flexibility and best growth potential for new and advanced systems. This concept is based upon the serial transmission of data between different subsystems using a digital data transmission means. Adding or deleting systems becomes more of a software modification task rather than an extensive hardware change. There are, however, two standards ARINC 429 (or ARINC 453) and MIL-STD-1553B, both of which should be available for use by components of the simulator. Except for the flight station control panel, certain complex functions such as inertial navigation or automatic flight controls may be entirely software simulated.

To achieve this maximum flexibility, the simulator should be able to accommodate four possible configurations:

a) Functional simulation of flight station control units having discretes, A/D, D/A, S/D, D/S input/output capability. The avionics system itself would be entirely simulated by a detailed model within the host computer, or possibly by a microprocessor.

b) Interface of an entire avionics subsystem consisting of front control panels plus actual avionics equipment with the host computer through the use of a TI 990/101 special purpose I/O system. The TI interface would provide all processing and conversion of data between the host computer and the desired format and form of data to the avionics subsystem.

c) The avionics controls and systems must be designed with an ARINC 429 bus input/output capability. This would necessitate a special interface unit which could convert ARINC 429 serial digital data into properly formatted parallel data suitable for connection to the host computer.

Control, sync and data words, would be generated within the special interface.

d) The avionics front panel controls and associated avionics designed with MIL-STD-1553B bus input/output capability. Another interface unit would be required here to tie the host computer together with the avionics subsystem.

In the case of the instruments which are bus-compatible, the interface hardware can be located outside the flight deck. This is not the case for AVE hardware located on the flight deck which requires the various discrete, analog and synchro interfaces. Here, the interface hardware would best be located in the cab so the number of wires coming from the flight deck can be minimized. Also, shorter AVE to interface wiring helps to minimize noise pickup and cross coupling to other wiring.

Not all functions, controls, and switches in the flight station have to be fully functional. Minor functions such as "No Smoking" and "Fasten Seat Belts" are insignificant electrical loads and would not have to actually be a discrete input to the computer. In this case, the switch could be present and not wired. Other systems must be carefully analyzed to assess the impact of the absence of specific electrical system inputs.

Since the simulator cab must be designed to allow easy and frequent changes in the functional and physical characteristics of the systems, those systems and functions used over and over again must be ruggedly constructed, whereas other experimental system which are used rarely can be significantly less durable.

## 4.3 ATC FUNCTION REQUIREMENTS

Resolution of aircraft/ATC interface issues requires that the ATC function include a high degree of fidelity such as the following:

a) Aircraft Communications (oral and data bus)

b) Area model - navigation aids, etc.

c) Pseudo - pilot function

d) ATC controller station(s)

### 4.3.1 AIRCRAFT COMMUNICATIONS

In addition to the standard aircraft communications requirement for all normal air/ground modes of voice communications, an additional requirement exists for simulation of the air/ground data link such as provided by the DABS system. This type of data link will require both input from the controller and output to the controller's console. A discussion of the projected data that will flow over the DABS system is given in reference 1. The following data are excerpted from that report.

#### 4.3.1.1 DABS Downlink Data

Figure 4-3 details the aircraft systems which send data to the DABS transponder for downlink transmission. Most of these data are required once every four seconds (one ATC ground station scan time).

From the figure it can be seen that the total data transfer required on a once-per-scan basis amounts to less than 160 bits. Actually 136 bits will suffice if the proper data arrangement is used. This will require two data reply words per scan (one comm B, 56 bit reply, and one comm D, 112 bit reply). The data transfer can also be handled by one ELM comm D reply.

#### 4.3.1.2 DABS Uplink Data

The uplink data from the ground system has a wide variation in data rates, some data occurring only once or twice during the entire terminal phase while other data occurs once per scan, as shown in Figure 4-4.

#### 4.3.1.3 Intra-Aircraft Data Requirements

Figure 4-5 lists the intra-aircraft flow of data and its origins and destinations. Examination of ARINC 429 and other ARINC specifications reveals that most applications can be accommodated by the low speed ARINC bus with very few needing the high speed ARINC version.

| PARAMETER | ORIGIN | DESTINATION | UPDATE RATE | WORD LENGTH | TYPE MESSAGE | REMARKS |
|---|---|---|---|---|---|---|
| Altitude | DADS | ATC Display, Conflict Cmptr. | 1/SCAN | 16 bit | Surveillance | |
| Ident. | Acft. Wiring | ATC Display, ATC Cmptr. | 1/SCAN | 24 bit | Surveillance | |
| Pilot Acknowledge | Pilot Action | ATC Display, ATC Cmptr. | 1/SCAN | 1 bit | Surveillance | |
| Sys. Status | BIT | Info. Display, ATC Cmptr. | 1/SCAN | 3 bit | Comm. B | |
| A/C Capability | Acft. Wiring | Info. Display, ATC Cmptr. | 1/Initial Contact | 7-10 bit | Comm. B | Includes RNAV 4-D NAV, CDTI BCAS notation |
| Baroset | Inst. Sys. | ATC Cmptr. | 4/Min. | 9 bit | Comm. B | |
| Position | Flt. Mgmt. Sys. | ATC Cmptr., Conflict Cmptr. | 1/SCAN | 38 bit | Comm. B | |
| Airspeed | DADS | ATC, ATC Display | 1/SCAN | 7 bit | Part of Comm. B | |
| Track | INS/FMC | Conflict Cmptr. | 1/SCAN | 7 bit | Part of Comm. B | |
| Heading | INS (IRS) | Conflict Cmptr. | 1/SCAN | 7 bit | Part of Comm. B | |
| Roll | IRS | Conflict Cmptr. | 1/SCAN | 6 bit | Part of Comm. B | |
| Wind | IRS/FMC | Windshear Cmptr., ATIS | 1/SCAN | 10 bit | Part of Comm. B | |
| Flt. Plan Data | FMC | Info. Display, Traffic Sequence | 1 (On Req.) | 0-250 bit | ELM, Comm. D | Includes waypoints, ETO, and vertical profile for 4D NAV |
| Route Change Req. | Pilot Action | Info. Display | 1/Req. | 0-250 bit | ELM, Comm. D | |
| Clearance Req. | Pilot Action | Info. Display | 1/Req. | 2 bit | Comm. B | |
| Trk. Change | FMC | Conflict Cmptr. | 1/SCAN | 9 bit | Comm. B | |
| Emerg. Declare | Pilot Action | Info. Display, Traffic Sequence, ATC Display | 1/Req. | 5-10 bit | Surveillance | Includes description of emergency, aircraft, medical, etc. |
| IFR/VFR | Pilot Action | | 1 Initial Contact | 1 bit | Surveillance | |
| Climb Rate | DADS | Conflict Cmptr. | 1/SCAN | 10 bit | Comm. B | |
| Ground Speed | IRS | Conflict Cmptr., ATIS | 1/SCAN | 9 bit | Comm. B | |
| Unreported or Unusual Weather | Pilot Action | ATC Cmptr., ATIS | 1/Event | 5-20 bit | Comm. B | As events occur. |

Note: All Comm. B replies required on a once/scan basis could be condensed into one, two-segment ELM Comm. D reply or one Comm. B and one Comm. D reply.

FIGURE 4-3 DABS DOWNLINK DATA

| PARAMETER | DESTINATION/USE | WHEN TRANSMITTED |
|---|---|---|
| Altitude Echo (ALEC) | Cross Check Alt. Rpting | Each Surv. Interr. |
| Master Time | Synchronization | Initial Contact |
| A/C Position Est. with Variance | FMC - Cross Check A/C Navigation | |
| Comm. Freq. Assign. | Int. Comm. - Set Comm. Freq. | On Contact/Freq. Chng. |
| ATIS & Terminal Info. | | |
| Flight Rules | Info. Display (ATIS) | Initial Contact/Prior to Final Appr. |
| Ceiling | Info. Display (ATIS) | Initial Contact/Prior to Final Appr. |
| Visibility | Info. Display (ATIS) | Initial Contact/Prior to Final Appr. |
| Altimeter Setting | Info. Display (ATIS) | Initial Contact/Prior to Final Appr. |
| Active Runway/Rnwy. Assign | Info. Display (ATIS) | Initial Contact/Prior to Final Appr. |
| Runway Conditions | Info. Display (ATIS) | Initial Contact/Prior to Final Appr. |
| Surface Winds (At Several Locations Including Rwy. Threshold) | ATIS & Shear Computation & Display | Initial Contact/Prior to & During Final Appr. |
| Wind at Approach Alt. | Shear Comp. & Display | Prior to Final Appr. |
| Wind Profile @ 3000 Ft. Intervals with Time of Data Collection | FMC (4-D NAV Planning) | Initial Contact - Entrances to Term Area, Start of Descent |
| RVR & Landing Rules in Effect | Info. Display | Initial Contact/At Start of Final Appr. |
| Vortex Advisory | Info. Display | Prior to Final Appr. |
| Windshear Description | Windshear Comp/Display | On Final Appr. |
| MSAW Warning | EHSI Display | On Initial Contact |
| T.O. & Landing Clearance | Pilot Display | As Appropriate |
| Rwy. Turnoff Assignment | Info. Display | On Landing |
| Route Info./Control | | |
| Route Assignment, Up to Seven Waypoints with T.O.A. for Each | FMC - Info. Display | On Initial Contact |
| Course Assignment (If Different from Star) | FMC, Pilot Display | On Contact |
| Metering Fix Time | FMC - Info. Display | On Initial Contact |
| Route Changes | FMC - Info. Display | As Needed or Req. by Pilot |
| Approach to T.O. or Approach to Final | FMC - Info. Display | Prior to Final or T.O. |
| Threshold Time | | On Final Approach |
| Weather on Route | Info. Display | After Route is Established or Changed. |
| Visibility | | |
| Clouds | | |
| Wind at Each Waypoint or Each Leg | | |
| Severe Weather | FMC - Pilot Display | As occurance, and Updated as Storms Move. |
| Location | | |
| Extent | | |
| Gradients | | |
| Severity | | |
| Special Hazards | | |
| Traffic & CDTI | | |
| Expected Traffic in Flow | Info. Display | After Initial Contact or When Change Occurs. |
| ID's | Info. Display | After Initial Contact or When Change Occurs. |
| Landing Sequence | Info. Display | After initial Contact or When Change Occurs |

FIGURE 4-4 DABS UPLINK DATA

| PARAMETER | DESTINATION/USE | WHEN TRANSMITTED |
|---|---|---|
| Traffic & CDTI (Cont'd.) | | |
| Position of Each | CDTI | 1/SCAN/Aircraft |
| Altitude of Each | CDTI | 1/SCAN/Aircraft |
| Speed & Direction of Flight for Each | CDTI | 1/SCAN/Aircraft |
| Vertical Speed | CDTI | 1/SCAN/Aircraft |
| Roll Angle | CDTI | 1/SCAN/Aircraft |
| VFR Traffic | CDTI & Info. Display | 1/SCAN/Aircraft |
| Position | CDTI & Info. Display | 1/SCAN/Aircraft |
| Altitude | CDTI & Info. Display | 1/SCAN/Aircraft |
| Direction of Flight | CDTI & Info. Display | 1/SCAN/Aircraft |
| Intentions (If Known) | Info. Display | 1/Aircraft |
| Projected Encounter Aircraft | Collision Avoidance Warning and Display | On Occurance, then 1/SCAN |
| ID | Info. Display | On Occurance |
| Time to Encounter | C A Display & FMC | 1/SCAN |
| REL Direction | C A Display & FMC | 1/SCAN |
| REL Alt. Assigned | CA Display & FMC | 1/SCAN |
| Range to A/C | CA Display & FMC | 1/SCAN |
| Response Assign. | CA Display & FMC | 1/SCAN |
| Position, etc. (CDTI Info.) If Not Already Sent | CA Display & FMC | 1/SCAN |
| Conflict Alert | C A Display | On Occurance |
| Projected Best Action | Pilot EADI or EHSI or C A Display | As Determined |
| IPC | | As Required by ATCS |
| Ground Speed or Airspeed | Pilot Display & FMC | As Chng. needed. |
| Altitude | Pilot Display & FMC | As Chng. needed. |
| Direction (Hdg. & Track) | Pilot Display & FMC | As Chng. needed. |
| Next Leg on Release | Pilot Display & FMC | As Chng. needed. |
| Airport Surface Display Information | Pilot Display, Info. Display | Prior to final approach or during final approach. |
| Taxi Instructions: Taxiway route, hold short, proceed, other aircraft direction, location, gate assignment | Pilot Display, Info. Display | During landing, during taxi as required. |

FIGURE 4-4 CONCLUDED

| SYSTEM | DATA IN | ORIGIN | DATA OUT | DESTINATION | SIMULATOR BUS NEED |
|---|---|---|---|---|---|
| VHF Comm | Desired Freq. | Integrated Comm. Control | Freq Tuned | 1. Integrated Comm. Control<br>2. Multifunction Display | Input/Output |
| HF Comm | Desired Freq. | Integrated Comm. Control | Freq Tuned | 1. Integrated Comm. Control<br>2. Multifunction Display | Input/Output |
| SELCAL | | | Call Annunciation | Integrated Comm. Control | Output |
| Autoflight System | Attitude, Hdg.<br>Air Data<br>Steering Data | IRS<br>DADC<br>FMS<br>MLS<br>GPS | Status<br>Failures<br>Sys Warn | 1. Multifunction Display<br>2. AIDS | Output Only |
| MLS | | | Deviation, Distance | Auto Flight Sys<br>FMS | None |
| Laser IRS (ARINC 704) | Initial Pos.<br>Air Data | FMC<br>DADC | Present Pos.<br>Attitude<br>Heading<br>Gnd Track<br>Gnd Speed | FMS, DABS<br>Autoflt Sys,<br>EFIS, DABS<br>FMS | Output to EFIS Only |
| Radar Altimeter | | | Altitude, Validity | FMS, EFIS, Autoflt System | Output to EFIS Only |
| Wx Radar | Tilt, Rng<br>Attitude | Integrated Control<br>IRS | Digitized<br>Video | EFIS,<br>Radar Ind(Option) | Input/Output |
| DADC | | | Air Data Validity | FMS<br>EFIS<br>IRS<br>DABS<br>Autoflt Sys<br>Aids | Output to EFIS Only |
| FMS (ARINC 702) | Position Velocities, Validity<br>Air Data<br>Altitude<br>Waypoints,etc.<br>Approach Deviation<br>Position Est., Alt., etc. | IRS, GPS<br>DADC<br>Radio Alt.<br>Integrated Control Sys., DABS<br>MLS<br>DABS | Steering Data<br>Steering Data Dev., Desired Flt Path, etc.<br>Waypoint Data<br>Nav Data, Etc.<br>Initial Pos,Time<br>Position, Flt Path, Speed,etc.<br>Status | Autoflt Sys<br>EFIS<br>Multifunction Display<br>GPS, IRS<br>DABS<br>AIDS | Input from Int. Cont. Sys.<br>Output to EFIS & MFD |
| EFIS (ARINC 600) | Display Information (See Source System) | DADC<br>FMS<br>IRS<br>MLS<br>Autoflt Sys<br>Radio Alt | Status | AIDS | Input |
| CAS Computer | Traffic Data<br>A/C Velocity, Position,<br>Planned Flt Path | DABS<br>FMS<br>IRS<br>GPS | Conflict Alert, Avoidance Commands, Traffic Display Information | EFIS, Multifunction Display | Output |
| Multifunction Display | See Originating Systems | | Status | AIDS | Input |
| DABS | See DABS Downlink Data | | See DABS Uplink Data | | None |
| GPS | | | Position (3 Axis)<br>Velocity (3 Axis) | FMS,<br>EFIS, DABS | Output to EFIS Only |

FIGURE 4-5 INTRA-AIRCRAFT DATA FLOW

### 4.3.2 AREA MODEL

The area model must provide all of the necessary ATC environmental elements in the area of interest. The advanced ATC computer/communications network that includes systems that will be in place in the future should be considered as functions that must be included in this model. This would include a system such as ATARS for traffic control and fully coordinated BCAS and DABS. An ATS system will probably monitor and advise transponder equipped aircraft at some low density airports. Many other communication, control and navigation systems will remain in use or be in development and must be integrated into a coordinated model.

The MOTAS model that is being developed at NASA LaRC is an example of a flexible and totally integrated system that will provide the capability to support operating system research in the terminal area.

### 4.3.3 PSEUDO - PILOT FUNCTION

The full traffic load for the controller must be provided by pseudo-pilot functions. These functions must be capable of flying a designated flight plan that can be altered by ATC controller input. The controllers should not be able to detect any difference between simulated cockpits and the pseudo-pilot functions. This will require that the pseudo-pilot functions be capable of responding to verbal instructions from the controller and initiate required verbal transmissions.

#### 4.3.4 ATC CONTROLLER STATION

The ATC controller station must have a computer graphics system with the capability to operate in all modes that will be required by the controller to perform the procedures under investigation. In addition, the ATARS system may require additional input/output devices for the console. Both hardware and software must have a high degree of flexibility to adapt to the developing concept of the functional responsibilities of the ATC controller in the 1990s.

The minimum ATC function must have full aircraft communications capability as described previously; however, the mechanization of the function may be reduced to a function of the test conductor's console. Any navigation aids required for the simulation must be supported. Traffic can be totally under computer control, if required, and there would be no requirement for pseudo-pilot functions that would extend beyond data required for the CDTI display or the visual system. The controller's station and display function would not be required.

### 4.4 COMPUTER COMPLEX

#### 4.4.1 HARDWARE SYSTEM

Functionally, the computer complex is the heart of the ACRS since it provides the means by which overall operation of the facility is implemented and controlled. As the term is used here, the computer complex includes all computers employed within the ACRS, their peripherals, the software system and the I/O system. An overview of the computer complex and its interface with the remaining elements of the ACRS was shown earlier in Figure 4-1.

#### 4.4.1.1 Utilization

Utilization of the computer complex falls into two primary categories -- simulation and software development. Additional secondary applications may be identified at a later date. While the primary uses will be common to all versions of the ACRS, secondary applications of the computer complex, if any, may well be peculiar to each facility. Reduction of special-purpose test data is an example of a unique requirement at one facility that would represent a secondary, though important, function of its computer complex. Another example might be the storage of research, training or maintenance records using the computer complex resources at another facility.

In its role of supporting flight research and training activities, the computer complex must generate the basic aircraft/systems simulation and must provide the means by which facility personnel can exercise control over simulator operation. It must be recognized, of course, that the configuration of the ACRS will never be finalized but will continue to change to satisfy new requirements. In its software development role, the computer complex must therefore provide all tools necessary to develop the operational software and firmware required to satisfy both current and future research goals.

4.4.1.2 Design Criteria

The ACRS must be configured to satisfy a variety of research and development needs while taking full advantage, where possible, of common design concepts and techniques. Functional commonality does not, however, require the use of identical hardware or software components. In specifying common design parameters for the computer complex, it must be realized that different physical machines or networks of machines may satisfy the stated requirements. Any one of several acceptable hardware implementations may thus be selected for use in a particular ACRS without violating the common design concept and without eliminating the many advantages inherent in such an approach.

A number of basic requirements must be satisfied by the computer complex, regardless of the specific physical implementation chosen. These include the following:

a) The computer complex must be capable of providing a high fidelity simulation of the desired aircraft configuration (the airframe plus its systems) along with any appropriate external effects.

b) It must provide the hardware and software necessary to allow facility personnel to specify a given test situation, control its execution and evaluate the results.

c) It must include all hardware and software components required to support efficient software development activities. In some versions of the ACRS, the computer complex must be capable of supporting simultaneous flight simulation and software development operations.

d) Sufficient computational power and speed must be available to allow the necessary simulation and testing tasks to be accomplished in real-time.

e) It must implement an architecture which provides the flexibility necessary to allow the ACRS to be easily configured to satisfy a wide variety of current investigative needs.

f) Sufficient computer resources must be available to accommodate future expansion in response to changing research requirements.

g) It must allow the transfer of experiments and simulation packages (both hardware and software) between facilities.

h) Its design must include consideration of features to minimize life cycle cost associated with the implementation, operation and maintenance of the facility.

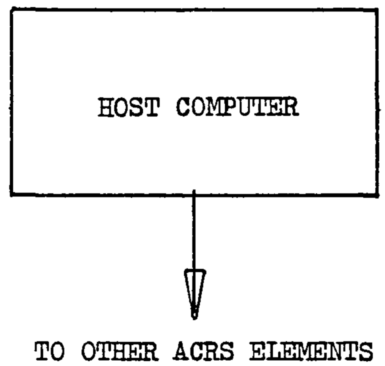
i) Its design must be highly modularized to allow portions of the design to be added, deleted, modified or otherwise utilized as required without adversely affecting overall operation of the ACRS.

4.4.1.3 System Architecture

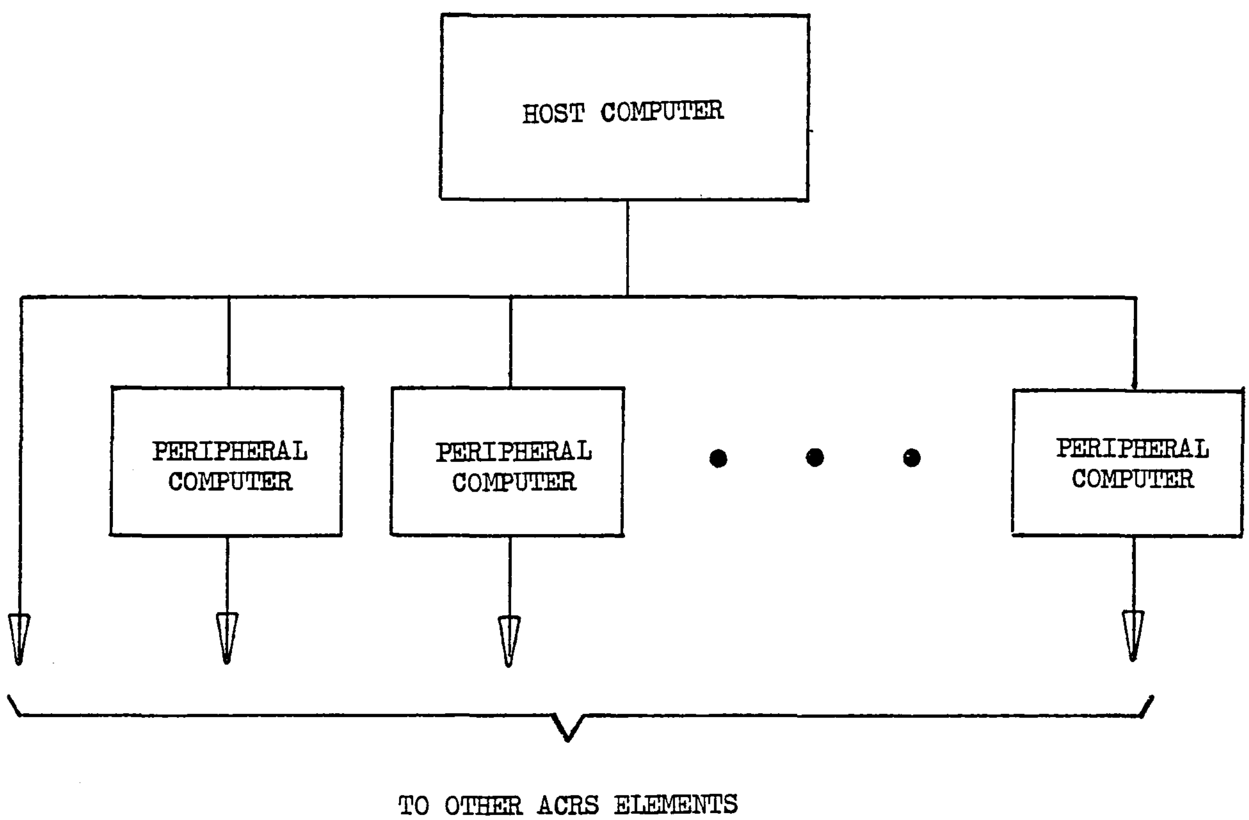
While a number of basic design decisions affecting the overall flexibility and power of the ACRS must be made, few have the potential impact of the one concerning definition of the computer complex architecture. Selection of a non-optimum architecture initially would have serious implications on the flexibility of the facility and its ability to respond to changing needs and research goals.

This decision involves selection of one of the two basic architectural approaches outlined in Figure 4-6. The first of these, the centralized architecture, makes use of a single, relatively large host computer to provide all computational functions for the ACRS. The second, generally referred to as a distributed architecture, uses one or more mid-sized host computers in a network with a number of smaller computers (minicomputers and microcomputers) distributed throughout the facility.

Analysis of the requirements indicates that the computer complex for the ACRS should be configured as a network of distributed computers. This decision is based upon consideration of the following factors:




a. CENTRALIZED ARCHITURE




b. DISTRIBUTED ARCHITECTURE

Figure 4-6. ARCHITECTURAL APPROACHES TO THE COMPUTER COMPLEX

a) Computational power and flexibility - The computer complex must obviously possess the basic characteristics necessary to perform in real-time the multitude of computations involved in providing the simulation, control and evaluation functions basic to its use as a research and development tool. In addition, it must be capable of simultaneous use for software development purposes. While various large computer systems may be capable of satisfying the ACRS requirements insofar as computational power is concerned, a network of smaller machines provides a much more flexible approach. With a network, the distribution of the computational burden among the various computers can easily be modified in response to changing requirements.

b) Operational efficiency - Every effort must be made to ensure that the functions required for proper operation of the ACRS are accomplished in the most efficient manner possible. This implies that the physical flow of information within the facility must be minimized. The use of a network of computers allows the computational power to be distributed throughout the facility so that data can be operated upon near its source (or its destination, as appropriate). The result can be a reduction in the number of internal data transfers required with a corresponding increase in overall operational efficiency.

c) Expansion of computational capability - While closely related to the question of overall flexibility, this factor more specifically addresses the potential for expansion of the computer complex to satisfy future requirements which cannot be fully anticipated at the present time. A properly structured network of computers is, by its very nature, easily expandable to provide additional computational capability. Expansion of a centralized complex, once the large machine has been saturated, can be very expensive in terms of both time and money.

d) Life cycle costs - A network of medium and small-sized computers can, if structured correctly, provide overall capability equivalent to that of a single large machine at a fraction of the cost. Additional savings can be realized as a result of the low level of maintenance normally required by these smaller machines as opposed to that involved in the day-to-day operation of a large computer system.

e) System reliability - The medium and small-sized computers available today are extremely reliable devices, as are their peripherals. Aside from considerations of the reliability of individual system modules, however, operational reliability and availability of the ACRS as a whole is the important concern. The relatively small cost at which computing power can be purchased today in the form of midi-, mini- and microcomputers implies that a network of these machines can be economically configured to possess a considerable amount of spare processing capability. In some cases, the additional capability available may be such that, in the event of failure of one of the network members, its vital processing tasks can be distributed among the remaining members in a predetermined fashion such that normal operation of the ACRS can continue while the failed unit is being repaired.

All factors considered, implementation of a network of computers offers the most efficient and cost effective solution to the processing needs of the ACRS. Again, it should be stressed that sufficient latitude exists within the overall concept to allow any of several hardware/software configurations to be selected for implementation within the various ACRS's while still retaining the many advantages of functional commonality.

4.4.1.4 System Characteristics

Bearing in mind that the desired goal is functional commonality, the primary concern at this time is to identify the characteristics which the computer complex must possess in order to provide the required operational capability. As stated earlier, actual physical implementation can assume a number of forms without compromising the overall concept of functional commonality and interchangeability. This initial effort is thus directed toward specification of overall design requirements and is not intended to identify specific hardware and software components.

Specification of the design requirements for the computer complex obviously involves many considerations, some of which may tend to be incompatible. While definition of certain non-controversial parameters may be easily accomplished, the establishment of others will involve detailed analysis of design trade-offs. When design conflicts do occur, the decision criteria must be prioritized as 1) the capability to satisfy specific operational requirements for a given ACRS, 2) flexibility to respond to new and expanded tasks and, 3) functional commonality among similar facilities.

The following discussion identifies some of the more significant design considerations relative to the computer complex hardware:

a) A network architecture has been specified in which the total computational burden of the ACRS is distributed among one or more host computers and a number of smaller peripheral computers. For a number of reasons (reduction of life cycle costs and achievement of functional commonality being the primary ones), the majority of the software included within the host computer will be written in an HOL. The host computer must therefore be one which possesses the operational characteristics consistent with execution of a large volume of HOL code in real-time. This requires features which go far beyond pure computational speed and implies an internal computer architecture designed primarily to achieve efficient execution of HOL software. A corollary implication is that the support software used to develop the applications programs must have been designed to generate extremely efficient machine language code from the HOL statements. A highly desirable feature is the capability to mix HOL and assembly language code when appropriate.

The peripheral computers used within the ACRS should include both minicomputers and microcomputers. The minicomputers deemed suitable for the ACRS must be capable of executing at least modest amounts of HOL code in real-time and thus must be primarily programmed in an HOL for this application. Microcomputers, on the other hand, are generally not designed to execute HOL code in real-time. As a result, the majority of the software provided for these machines should be written in assembly language form. The architecture of the microcomputers selected for the ACRS must allow for extremely efficient execution of assembly language code in order to satisfy the real-time operational requirements.

b) The host computer should have a word length of at least 24 bits. While many simulation tasks can be adequately accomplished using a machine with a shorter word length, simulation of certain types of systems or effects demands the longer word in order to efficiently achieve the required accuracy and precision. A specific example is the simulation of an inertial navigation system in which more than 16 bits are necessary in order to provide a sufficiently accurate simulation of operational performance.

c) The ability to efficiently operate upon individual bits and bytes within words, as well as upon the words themselves is a requirement. Operational efficiency demands that the amount of data flow among the computers within the network and between the computers and the remaining elements of the ACRS be minimized. In this context, bit manipulation capability is vital in order to accommodate the relatively large number of discrete signals which must be processed during operation of the facility. Similarly, the ability to efficiently handle information in byte form must facilitate accomplishment of the required digital communication tasks.

d) All machines within the computer complex must be capable of extremely efficient I/O transfers. The ability to accomplish both program-controlled and direct memory access-type I/O operations is desirable so that the appropriate mode can be selected for each specific application, the primary criteria being efficiency. The impact of I/O operations upon normal software execution must be considered along with the requirements of pure transfer speed.

e) Closely related to the need for efficient I/O capability is the requirement that each computer possess a flexible interrupt structure. Many functions within the ACRS must be accomplished on an as-needed basis using interrupt-driven software. Even the scheduled repetitive tasks must be initiated as a result of various levels of system interrupts. Operational efficiency thus demands that the computers respond to and service these interrupts quickly and with as little software overhead as possible.

f) While not a requirement, a number of significant advantages can be realized if at least some of the machines included within the computer complex belong to a family of processors. Ideally, the peripheral computers should possess a certain level of hardware and software compatibility, if for no reason other than to reduce the investment in the necessary support systems. As a practical example of the application of this concept, the following possible computer complex implementation plan should be considered. The host computer is a VAX-11/780. The peripheral computers all belong to the family of software-compatible

TI-990 processors and include 990/12 and 990/10 minicomputers along with 990/4, 990/5 and 990/101 microcomputers. If required, special-purpose computers can be designed around the TMS/9900 microprocessor. Development of software for any of the peripheral computers can thus be accomplished using a single software development system.

g) The computer complex should include all peripherals required to support both simulator operation and software development activites. Specific peripherals provided will include magnetic disc units, magnetic tape units, line printers, card readers and CRT display terminals.

4.4.1.5 Life Cycle Cost Considerations

While the initial design, procurement and installation of the computer complex represents a significant investment, it is in reality only a relatively minor portion of the total life cycle cost. Decisions made during this initial phase can, however, dramatically affect the ultimate cost, either favorably or unfavorably. Design of the computer complex should thus be accomplished with due regard to all factors which contribute to life cycle cost and should incorporate features to reduce this to the lowest level consistent with achievement of the research goals.

Specific areas which must be addressed during the design phase include:

a) Fabrication, installation and checkout -- Modular design techniques, coupled with a distributed architecture, must be exploited to minimize the effort involved in fabricating the system modules and integrating them into a functioning ACRS.

b) Reliability -- State-of-the-art digital components and systems must be used throughout to ensure maximum operational reliability.

c) Maintainability -- The ease with which maintenance can be accomplished at both the module and the facility level must be stressed. Adequate documentation must be provided to aid required maintenance actions. Comprehensive diagnostics must be provided as appropriate, with emphasis upon use of test features built into the various modules and systems. The objective must be to configure a simulator which can be maintained with minimum reliance upon outside vendor service. An adequate level of spares must be identified so that failed items critical to operation of the ACRS can be quickly replaced to return the simulator to operational status.

d) Expansion -- The ACRS must be designed with expansion in mind. The flexibility to satisfy unanticipated near-term changes must be provided along with the ability to easily accommodate major expansion in the future.

4.4.1.6 Hardware System Design Tasks

The following tasks must be accomplished in order to design the computer complex hardware system:

a) Establish overall design requirements for the computer complex hardware system.

b) Identify the physical requirements imposed by the computer complex hardware on the ACRS facility, including consideration of related safety aspects.

c) Design the computer complex hardware architecture.

d) For each ACRS, identify the computers to be used as the host and peripheral processors. Specify the manner in which they are to be interfaced with the remaining functional elements of the ACRS.

e) Identify the peripherals required to support both simulation and software development activities and provide interfaces with the appropriate computers.

f) Provide for installation of AVE components as appropriate to the research goals of a given ACRS.

g) Generate the documentation required to establish configuration control of the computer complex hardware and to facilitate its maintenance.

### 4.4.2 SOFTWARE SYSTEM

As noted earlier, the ACRS should be driven by a multi-processor computer complex. The total software system should be distributed among the host and the various peripheral computers. An overview of the distribution of the software is shown in Figure 4-7.

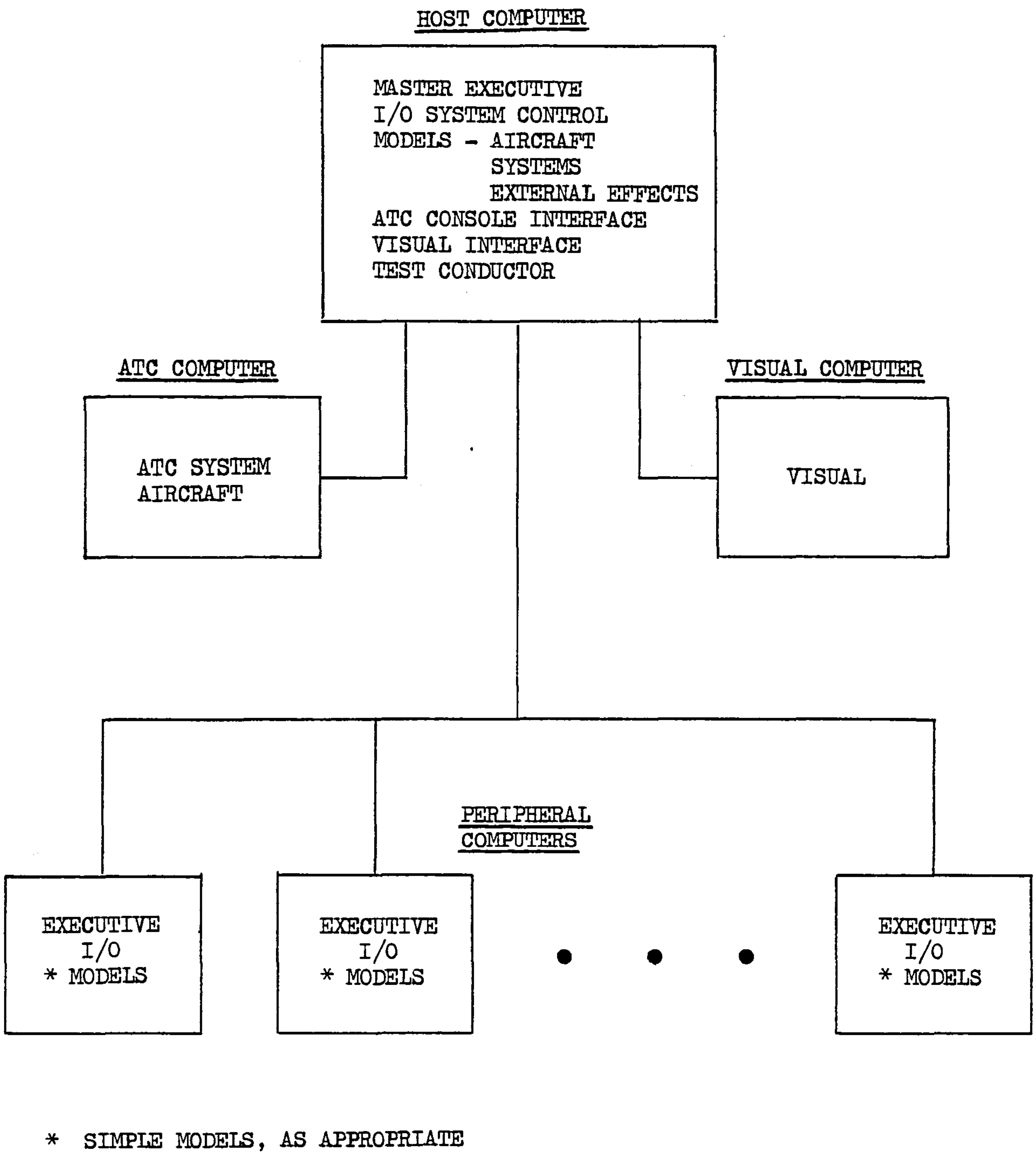



FIGURE 4-7. SOFTWARE DISTRIBUTION WITHIN THE ACRS

Overall operation of the facility should be under control of the host computer which should contain the master Executive, the majority of the software models and the master I/O control software. Most of the peripheral computers should serve primarily as intelligent I/O controllers and should contain their own Executive, the necessary I/O control and processing routines and, where appropriate, individual software models. Transfer of data between each of these peripheral computers and the host should occur as necessary. While each peripheral computer should function in a semi-autonomous fashion under control of its internal software, ultimate control must be exercised by the host.

In addition to the I/O system, certain types of auxiliary systems should contain internal computers. A specific example shown in Figure 4-7 is that of the visual system which would generally be purchased as an off-the-shelf entity complete with its own dedicated computer and software system.

Perhaps no area of the overall design task is more critical to the ultimate capability of the ACRS than that which addresses the detailed structure of the software system. While all elements must obviously be present and properly integrated in order for the facity to function properly, the software system must be recognized as the single element which ultimately determines the flexibility and overall utility of the ACRS as a research, development and training tool.

Given the impact of the software system, extreme care must be exercised to ensure that its structure provides both the desired level of simulation fidelity and the flexibility to allow the simulation to be easily reconfigured and expanded in response to changing requirements. Of particular importance, in view of the real-time nature of the problem, is assurance that the two basic computer resources -- memory and processor time -- be utilized as efficiently as possible.

#### 4.4.2.1 Software System Language

One of the more fundamental questions which must be addressed during the design of the ACRS concerns the particular software language to be used. The overriding consideration is obviously the need for real-time operation to allow the desired degree of simulation fidelity to be achieved. In a simulator dedicated to a particular task (crew training for a specific aircraft type, for example), assembly language might well be chosen so as to attain maximum efficiency in the execution of the resulting software code. In configuring an ACRS for general-purpose research use, however, factors beyond mere execution efficiency must be taken into account.

Specific factors which affect selection of the simulation software language include:

a) The need for real-time operation, which implies a high level of software execution efficiency.

b) The goal of minimum life cycle cost, which requires efficiency of software development, documentation and maintenance.

c) The desire to be able to transport the software from one ACRS to another (and thus possibly from one computer to another) with minimum rework of the code.

All factors considered, the desire to achieve maximum commonality among various advanced research simulators demands that the simulation software be written in a common HOL to the extent practicable. Of the HOL's, FORTRAN is the most likely candidate for this common language due to the fact that it is supported by essentially every computer system available today, including all large mainframe machines, midicomputers and minicomputers.

The evolution of other HOL's should be closely monitored and evaluated for possible future simulation applications. Of particular interest are the HOL's being considered for possible airborne applications, since the use of a language compatible with advanced AVE computers would obviously be advantageous to the ACRS. At present, however, no language can rival FORTRAN for general availabiity or applicability.

While the vast majority of the simulation software should be written in a common HOL, certain modules should be coded in assembly language. In particular, certain I/O routines should be written in assembly language so as to maximize the efficiency with which the necessary I/O operations can be accomplished by the peripheral computers. As will be discussed later, the I/O system should employ distributed microprocessors to perform many of the computational tasks associated with the actual scaling, formatting and transfer of the simulator data. Microprocessors are not, in general, efficient HOL machines and are usually programmed at the assembly language level.

The simulation software system should thus be written, for the most part, in a common HOL so as to maximize flexibility while minimizing life cycle costs. Where appropriate, however, assembly language routines should be used to achieve the desired operational efficiency, the objective being an optimum mix of HOL and assembly language code that produces the most efficient and flexible simulation possible, while retaining the highest possible level of software commonality and transportability.

4.4.2.2 Host Computer Software Structure

The host computer software should execute under control of an Executive routine which will:

a) Perform all required initialization functions.

b) Issue calls to the various simulation models.

c) Perform all necessary software system bookkeeping.

d) Control the I/O system.

A simple flowchart of a typical Executive is shown in Figure 4-8. Upon start-up, this routine issues the commands necessary to initialize the simulator, including the software, the I/O system, all test/control consoles and any other peripheral devices or systems. Once initialization has been completed, the Executive waits for the first interrupt from the RTC. Periodic receipt of the RTC interrupt triggers the Executive to issue commands to control the I/O system and to execute the appropriate foreground and background models. Once all scheduled tasks have been accomplished, the software sits in a loop awaiting the next RTC interrupt.

The simulation software system should include a number of individual routines (models) designed to simulate the functioning of various aircraft systems as well as the effects of the external environment.

Each of the models must be repetitively executed at a rate which will cause the simulated system or effect to appear to be occurring in real-time analog fashion. The rate at which each model must be executed so as to achieve this desired effect is obviously a function of many factors, and not all models will require execution at the same rate. A critical phase of the design of the overall software system thus involves determining the optimum iteration rate for each model and structuring the Executive to call each one correctly.

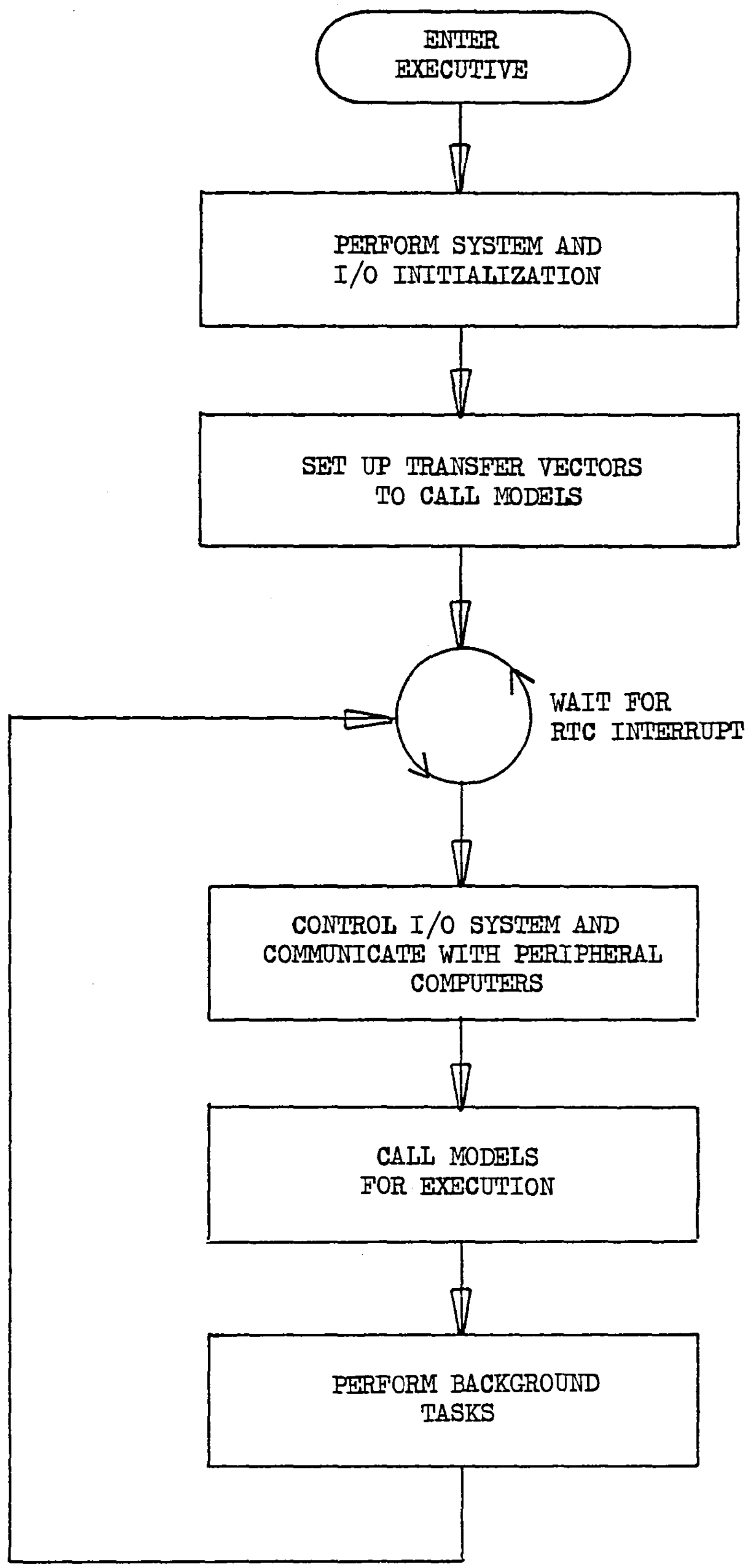



FIGURE 4-8. TYPICAL SIMULATION EXECUTIVE ROUTINE

An extremely flexible way to accomplish the scheduled execution of the various models is to set up a calling structure similar to the one shown in Figure 4-9. At each level, a table of pointers exists into which the transfer vectors (addresses) of individual models can be placed. These pointers thus determine the rate at which each model is iterated.

In the specific example shown, the RTC interrupt is assumed to occur every 16.7 msec, such that an individual software model can be executed at a maximum rate of 60 times per second. This basic iteration rate is sub-divided into 20/sec, 10/sec, 5/sec and 1/sec slots. During each RTC interval all 60/sec models are executed as are the models from one each of the 20/sec, 10/sec, 5/sec and 1/sec slots. During the typical RTC interval illustrated by means of the arrows in Figure 4-9, for example, the execution of models would proceed as follows:

a) All 60/sec models in leg 60S1.

b) All 20/sec models in leg 20S3.

c) All 10/sec models in leg 10S5.

d) All 5/sec models in leg 5S10.

e) All 1/sec models in leg 1S49.

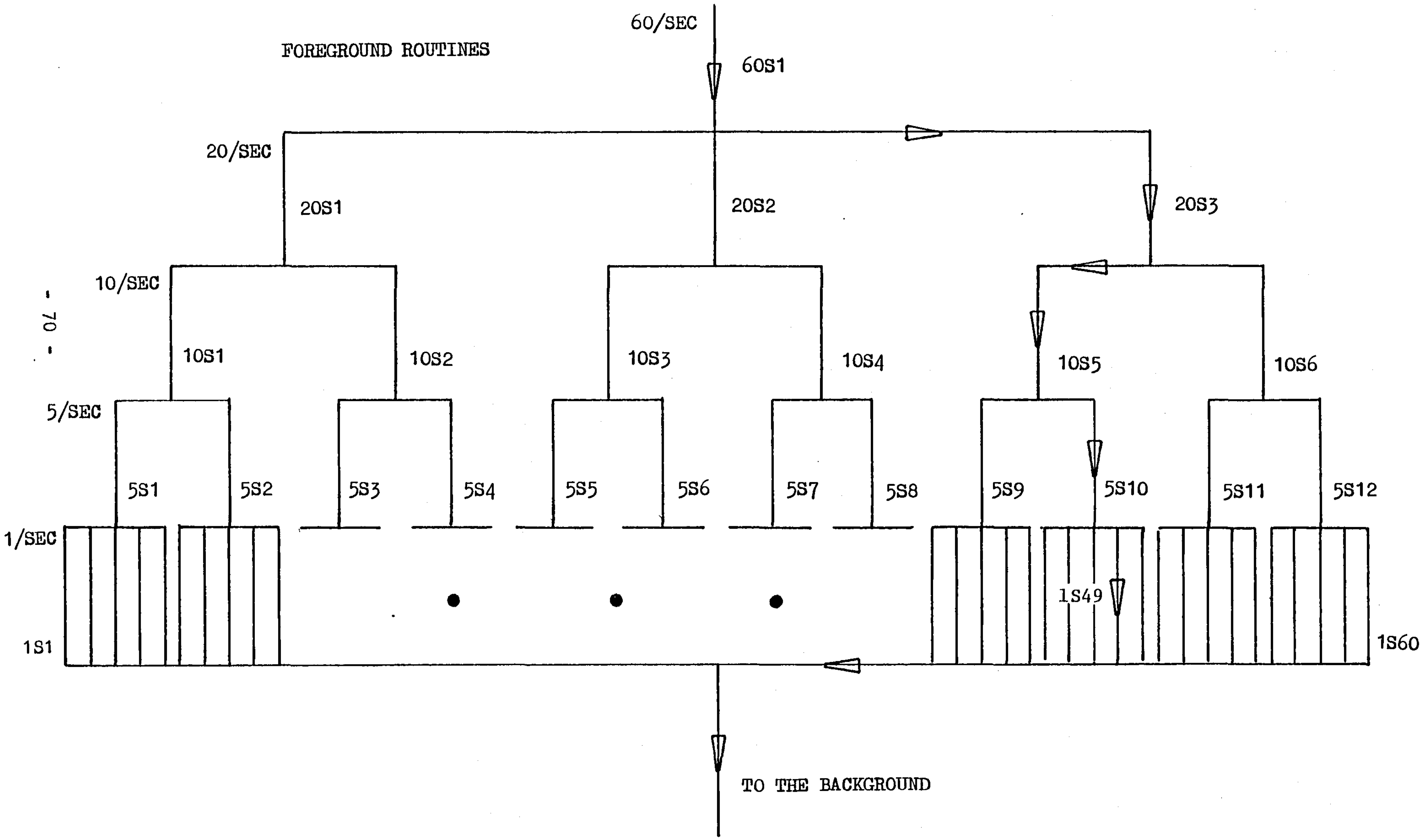



FIGURE 4-9 . TYPICAL STRUCTURE FOR MODEL CALLS

The example of Figure 4-9 is included merely to illustrate an efficient and flexible technique by which the various models can be called. The actual model execution sequence and timing implemented within a given simulator will obviously be a function of the peculiar needs of that simulator and can be controlled simply by selecting the appropriate RTC interrupt timing and transfer vector structure.

The advantages of the model calling mechanism outlined above include:

a) Ability to iterate a given model at the rate appropriate for the specific system or effect being simulated.

b) Flexibiity to add additional models simply by inserting their transfer vectors in the appropriate time slots.

c) Flexibility to delete a model or to temporarily suspend its execution simply by removing its transfer vector from the calling sequence.

As indicated in Figure 4-9, individual models can be called for execution in either the foreground or the background as appropriate. Foreground models include those which must be executed on a very carefully controlled cyclic basis if the fidelity of the simulation is to be adequately maintained. Background models generally run at a somewhat slower rate than do those in the foreground and execute on a time-available basis. That is, execution of background models can be delayed if necessary due to a temporary lack of sufficient processor time.

While the technique just described can be used to call models for execution on a cyclic basis, various functions within the software system will require execution on a totally asynchronous basis in response to a variety of interrupts. In this case, the normal execution sequence of the software system will be suspended long enough to provide the service demanded by the source of the interrupt.

Use of the ACRS for either research or training purposes requires that a high degree of fidelity be maintained within the overall simulation. As mentioned earlier, simulation of the various systems involves executing appropriate software models at carefully controlled rates so that the resulting effects will appear analog in nature. In actual operation, situations can arise in which the amount of processing required by the simulation software (the models, I/O and other functions) per unit time exceeds the amount of CPU time available. The simulation is then said to have "run out-of-time" and thus can no longer execute in true real-time.

In such a situation, two alternatives are available to the software designer. He can either:

a) Allow the simulation to continue running with attendant loss of fidelity, or

b) Halt the simulation on the basis of pre-determined out- of-time criteria.

Of these two approaches to simulation design, the second is preferable. This is especially true in the research/training environment where important results might well be masked or distorted by even a relatively small loss of simulation fidelity.

The actual out-of-time criteria used to terminate a given simulation is obviously a function of the specific situation in which the simulation is being applied. In a sophisticated mission-oriented crew training simulator, for example, the following out-of-time criteria is appropriate -- the simulation is immediately halted if the RTC interrupt for the next leg of the foreground processing is received before any models of the current leg have been executed. This defines a situation in which the execution of the simulation software is lagging to a degree which results in unacceptable real-time performance. Background routines can be allowed to lag behind progressively without halting the simulation, the assumption being that execution of these slower, less important routines will eventually catch up and resume at the desired rate.

#### 4.4.2.3 Peripheral Computer Software Structure

Structurally, the software system of each peripheral computer will parallel that of the host and will include an Executive which can call various models for execution in either the foreground or the background mode. Peripheral computers will be added to the ACRS as required to achieve the desired level of system flexibility and operational efficiency. As such, they will serve to relieve the host computer of much of the overall computational burden.

The primary function of the peripheral computers is to accomplish the I/O operations required to link the host computer with the simulator cockpit and other elements of the ACRS. Software within the various computers would thus be primarily I/O-oriented and would be designed to provide appropriate conversion and formatting of the various I/O parameters. Specific I/O functions performed by the peripheral computer software should include:

a) Acquisition of parameters in engineering units form from the host computer and their conversion to, and output in, the appropriate analog or discrete form to the various simulator systems.

b) Acquisition of raw simulator parameters, conversion of those parameters to corresponding engieering-units values and transfer of the parameters to the host computer upon request.

While the peripheral computers should serve primarily as intelligent I/O system controllers, the speed and processing power of the modern minicomputers and microcomputers that should be used is such that they can easily perform additional functions within the overall simulation system. In certain cases, software models designed to simulate systems, or portions of systems, could be included within the peripheral computers to improve the execution efficiency of the overall software ststem.

As a specific example, consider the case of an autopilot system. For purposes of math modeling and simulation, an autopilot can generally be divided into two distinct sections -- switching logic and control loop computations. While both sections may be included within the same software model, considerations of execution efficiency may dictate that the two be separated. In order to achieve the desired fidelity of simulation, the control loop computations must generally be executed at least ten times per second. The switching logic, on the other hand, may need to be computed only two times per second in order to provide acceptable performance. Execution of the switching logic at a rate of ten/sec in this example thus represents a waste of processor time (a valuable resource) with attendant loss of efficiency. The optimum solution in this case might well be to model the control loop within the host computer while performing the switching logic within one of the peripheral minicomputers, passing only a few necessary parameters between the two.

One consideration in configuring the overall software system within a multi-processor environment is obviously the language (or languages) to be used. This problem was addressed earlier with the conclusion being that efficient operation of a sophisticated simulation facility requires a mix of HOL and assembly language. While the software within the host computer and the peripheral minicomputers is envisioned as being written primarily in a standard HOL, most of the software within the peripheral microcomputers should be in assembly language form.

Assembly language code should be used with the peripheral microcomputers for a variety of reasons, some of which are enumerated below:

a) While modern microcomputers do possess considerable processing capability, their speed characteristics are generally not compatible with execution of HOL code in a real-time environment.

b) These computers will generally be performing dedicated functions related primarily to I/O operations. The associated software should be written in assembly language to take full advantage of the particular computer's capabilities as implemented by its instruction set.

c) The software included within these computers should primarily consist of common, general purpose routines designed to perform all functions associated with I/O operations. These routines should be structured to easily accommodate expansion or contraction to adjust to various I/O situations without requiring major changes. Once written, they should remain essentially unchanged and should be usable in their original form in a variety of simulation applications.

4.4.2.4 Aircraft Systems Software

Software must be provided to simulate the various aircraft, systems and environmental characteristics necessary to accomplish the stated research goals. The software should be modularized to facilitate reconfiguration of a given ACRS and to allow the various routines to be easily transported from one simulation facility to another. The basic routines necessary to provide a high fidelity simulation of a modern aircraft include, but are not limited to, the following:

AIRPLANE FLIGHT ENVIRONMENT

Ground Handling
Ground to Air Transition
Airborne Characteristics
Airfield Conditions
Atmospheric Conditions

NAVIGATION ENVIRONMENT

Non-directional Beacon
VHF Omni-range
DME
Precision Approach Radar
ILS & MLS
Landing Markers
Airways Markers
OMEGA
GPS

COMMUNICATION SYSTEMS

HF
UHF
VHF
SELCAL
UHF SATCOM
Intercom
PA
Voice Recorder
Data Link
CDTI
Integrated Comm Management System

AIRFRAME SYSTEMS

Hydraulic
Electrical
APU
Propulsion
Fuel System
Electronic Flight Instrument System
Advanced Integrated Display System
Cabin Pressurization
Pneumatic System
Cabin Air Conditioning
Ice Protection, Defogging

Oxygen System
Fire Detection and Extinguishing
CADC/DADC
Flight Data Recorder
Caution and Warning System
Lighting
Weight and Balance
Crash Position Indicator

WEATHER RADAR

NAVIGATION

INS
MHRS
Attitude System
Laser IRS
ADF
Marker System
ATC Transponder
Stand-by Compass
Radio Altimeter
VOR/DME/ILS
MLS
OMEGA
GPS
GPWS
CAS

FLIGHT CONTROLS

Autopilot/Flight Director System
Flight Management System
Primary Attitude
Thrust Management System
Autothrottle
Landing Gear & Brake
Speed Brake
Flaps/Slats
Trim
Yaw Damper

#### 4.4.2.5 External Effects Software

In addition to providing a simulation of the aircraft and its systems, the ACRS must create a realistic environment of external effects. These external effects play a major role in providing the overall realism and fidelity needed to achieve the research goals. They include the:

a) Radio aids and ATC interface

b) Visual system

c) Motion system.

Each of these items requires appropriate software to accomplish, the exact form of which should be a function of the manner in which the ACRS is to be used. Certain types of research require that the simulator cockpit be mounted on a sophisticated 6-DOF motion system so that the appropriate motion cues can be provided to the crew. In other areas of research -- the interface of large transport aircraft with the projected ATC environment, for example -- motion may not be required at all. In any event, software to simulate the appropriate external conditions must be available.

Radio aids and ATC interface software will simulate the ground portion of the applicable guidance and control systems, including provisions for interaction between the flight crew and ground personnel as appropriate. In cases where interaction with the ATC environment is incidental to the research studies being conducted, the radio aids software can be included within the host computer. In cases where the ATC interface is the primary item of interest, extremely sophisticated software to simulate this interface should almost certainly be provided in a peripheral computer devoted primarily to this task. In any event, design of the radio aids software should be highly modular so as to be independent of the particular computer used.

A high quality visual system is unsurpassed in providing motion cues to the flight crew within a simulator designed for transport aircraft. Whether used for advanced research studies, systems development, or crew training, a full-task simulator should almost certainly include some type of visual system to provide a view of the external scene appropriate to the task at hand. With a wide variety of computer-based visual systems available, one can be purchased off-the-shelf for essentially any application. These systems are normally procured as stand a lone items, complete with the necessary computer, software, I/O and displays. The software impact of integration of such a system into a specific ACRS configuration involves two major areas:

a) Tailoring of the standard visual system software, if required, to satisfy peculiar simulation needs.

b) Provision of software within the host computer to transfer the necessary variables between the host and the visual computer.

Similarly, a wide variety of simulator motion systems are available off-the-shelf. Appropriate motion system hardware can usually be purchased to satisfy any particular simulation requirement. A software module must be provided within the host computer to generate the simulation parameters necessary to drive the specific motion system selected. While the details of this software must be a function of the particular motion system being used, a common routine structure can be designed. The only difference among ACRS's insofar as the motion system software is concerned would thus be the form of the software variables which must be provided to drive the individual hardware systems.

4.4.2.6 Control/Display Software

The full-task simulator, if properly instrumented, can be used as an effective tool for basic research, crew training or systems development purposes. If properly designed, the same physical facility may be used interchangeably to perform any of these functions as required. In any case, one of the keys to effective utilization is the manner in which the researchers, instructors and evaluators are allowed to exercise control over the facility and to extract information from it.

In general, the individuals controlling the ACRS will need the ability to input certain commands and data parameters into the facility in order to establish the desired test conditions. Examples of such inputs include simulated system malfunctions, navigation parameters, environmental conditions and ATC commands. Conversely, these individuals will require real-time access to the various types of information necessary to evaluate the progress of the mission or the test being conducted.

To achieve the highest degree of flexibility, the physical interface between the controllers and the ACRS should generally be provided by some type of CRT display/multifunction keyboard arrangement. Software should be provided to accept and react to the various input commands and to retrieve, format and display requested information. General-purpose software drivers should be used to service the CRT displays and multifunction keyboards. Where possible, general-purpose data retrieval/formatting routines should be provided. In certain cases, however, special-purpose software modules are required in order satisfy unique testing requirements.

Like all other software, the control/display package will execute under control of the master Executive. In cases involving periodic update of displayed information, the software will be executed on the basis of scheduled transfer vector calls. Those routines which require nonscheduled execution should be interrupt-driven.

#### 4.4.2.7 Software Life Cycle Cost Considerations

The true cost of the simulation software system must be computed in the context of its overall life cycle. This life cycle cost includes all effort expended in maintaining the software during its useful life as well as the effort required initially to design, develop and install it. Specific actions which can be taken to minimize software life cycle costs include:

a) Use of a standard HOL to the extent practical.

b) Implementation of a common system structure composed of compact software modules.

c) Development and sharing of common software packages by ACRS users.

d) Use of on-line diagnostic/development aids coupled with comprehensive configuration control techniques.

The simulation software system will include a mix of HOL and assembly language code. In order to reduce overall software life cycle costs, however, the standard HOL should be used to the maximum extent possible. Specific cost reductions which can be realized through use of the standard HOL include:

a) Development of the software with minimum expenditure of manhours as a result of the coding efficiency achievable with HOL.

b) Ease of software interpretation and modification.

c) Generation of the software code by HOL programmers as opposed to use of programmers who are experienced in various assembly languages.

d) The ability to share general simulation routines among various ACRS's with only minimum modification as a result of the inherent transportability of HOL software.

Design of the software system should be accomplished using proven top-down structured programming techniques. The overall system design should be generated by a small team of highly experienced simulation software experts that:

a) Establish the system requirements.

b) Plan the overall software structure.

c) Identify and describe specific software modules required, along wih their interface parameters.

d) Coordinate the development of the individual modules and their integration into the total software system.

Once the initial system design has been completed, a larger team of programmers can be used to code and develop the individual software modules.

An important factor which can be exploited to reduce life cycle costs is the concept of software modularity. While the overall simulation software system must be quite large and of necessity very sophisticated, it must be composed of compact modules. The structure of the software system must be such that individual modules can easily be added, modified or deleted as required to satisfy particular simulation situations.

Use of compact software modules provides numerous benefits. The first of these is the relative ease with which the software system can be modified, either to expand the simulator's basic research capability or to enhance its fidelity. If the overall system has been properly structured, desired modifications can be accomplished merely by adding or deleting appropriate modules or by modifying existing ones. In either case, the necessary changes can be accomplished quickly, easily and with minimum disruption of normal simulator operation.

A second, and very important, advantage is the inherent flexibility of a modular software system. Use of software modules in implementing a training simulator designed for a specific aircraft type affords significant cost savings over the life of the simulator. These savings can be realized even though the basic aircraft configuration can be expected to change only slightly over the years. Contrast that relatively static situation with the highly dynamic research environment in which the ACRS will be used to investigate a variety of advanced aircraft/systems configurations, in some cases being completely reconfigured from day-to-day. The use of software modularity is definitely a requirement for the ACRS in order to achieve the flexibility necessary to respond quickly and efficiently to changing research needs and goals.

Finally, use of a software system structure composed of compact modules would enhance the development of common software packages and their being shared among various simulation facilities. For example, a software module simulating an advanced flight control system could be developed by members of one ACRS and then implemeted and used at essentially no cost by other similar facilities. Various data bases -- aerodynamic packages, radio aids parameters and environmental packages for example -- can be easily generated in modular form for sharing among several simulation facilities.

#### 4.4.2.8 Development Software

One primary function of the computer complex is to exercise control over and drive all other elements of the ACRS. Its other primary function is to provide all resources, both hardware and software, necessary to allow efficient software development. As noted earlier, the level of utilization of the computer complex in some facilities may be such as to allow the host computer to provide both simulation and software development capability on a time-shared, non-interfering basis. In others, the level of activity will preclude this type of operation and will require that a separate computer be dedicated to the software development function.

In either case, the computer designated for software development use must provide certain basic capability insofar as its software operating system is concerned. As a minimum, it should include the following features:

a) A disc-based, hierarchical file system which provides adequate protection and privacy of individual files.

b) Ability to perform time-shared interactive and batch processing.

c) Capability to support multiple interactive terminals.

d) Availability of compilers for various HOLs.

e) Availability of an assembler for the host and peripheral computers.

f) Sophisticated text editing and word processing capability for use in creating, documenting and maintaining configuration control of the simulation software packges.

g) A structure which allows additional routines to be added easily when required to facilitate software development activities.

4.4.2.9 Software System Design Tasks

The following tasks must be accomplished in order to design the ACRS software system:

a) Establish design requirements for the total ACRS software system, including both the operational simulation software and the software development system.

b) Identify the aircraft type (or types), systems and external effects to be simulated and determine the optimum iteration rate for each.

c) Identify the software packages required to allow research and maintenance personnel to control operation of the ACRS.

d) Perform a top-down structured design of the total software system, identifying all required modules and specifying their interface characteristics. Include all interfaces with purchased software packages such as the visual system software.

e) Specify the distribution of the software modules among the host and peripheral computers.

f) Select the HOL to be used.

g) Design, code and checkout the required software modules.

h) Integrate the individual modules into an overall ACRS software system.

i) Provide documentation to the level required to maintain configuration control of the software system.

### 4.4.3 I/O SYSTEM

The I/O system provides the interface between the simulation software contained within the host and peripheral computers and the hardware components associated with the simulator cockpit. As such, it is a major factor in determining the overall operational capabilities of the simulation facility. Selection of the appropriate I/O system architecture is thus one of the more critical design considerations involved in configuring the ACRS. Once the basic architecture has been specified, a secondary consideration is the question of whether it is more cost effective to purchase an off-the-shelf system or to configure one from available components.

#### 4.4.3.1 System Architecture

The two competing I/O system architectures applicable to real-time flight simulation can be characterized by the terms centralized I/O versus distributed I/O. A centralized architecture involves direct control of the I/O system by software contained within the host computer. This concept is illustrated in simple block diagram form in Figure 4-10. The contrasting distributed I/O architecture is illustrated in Figure 4-11. In this case, overall control still resides within the host computer software, but the individual I/O operations are accomplished under the direct control of a number of peripheral computers (microcomputers) located throughout the ACRS. Software is included within the peripheral computer to:

a) Control the individual I/O components.

b) Provide any data formatting and conversion required.

c) Communicate with the host computer for transfer of I/O parameters when necessary.

Of the two architectures, the distributed approach offers significant advantages, several of which are enumerated below:

a) The host computer is relieved of the software burden of directly controlling the I/O operations and formatting the variables.

b) The I/O system is composed of a number of powerful modules employing a common design. As such, it is inherently expandable simply by the addition of standardized modules to satisfy changing simulation requirements.

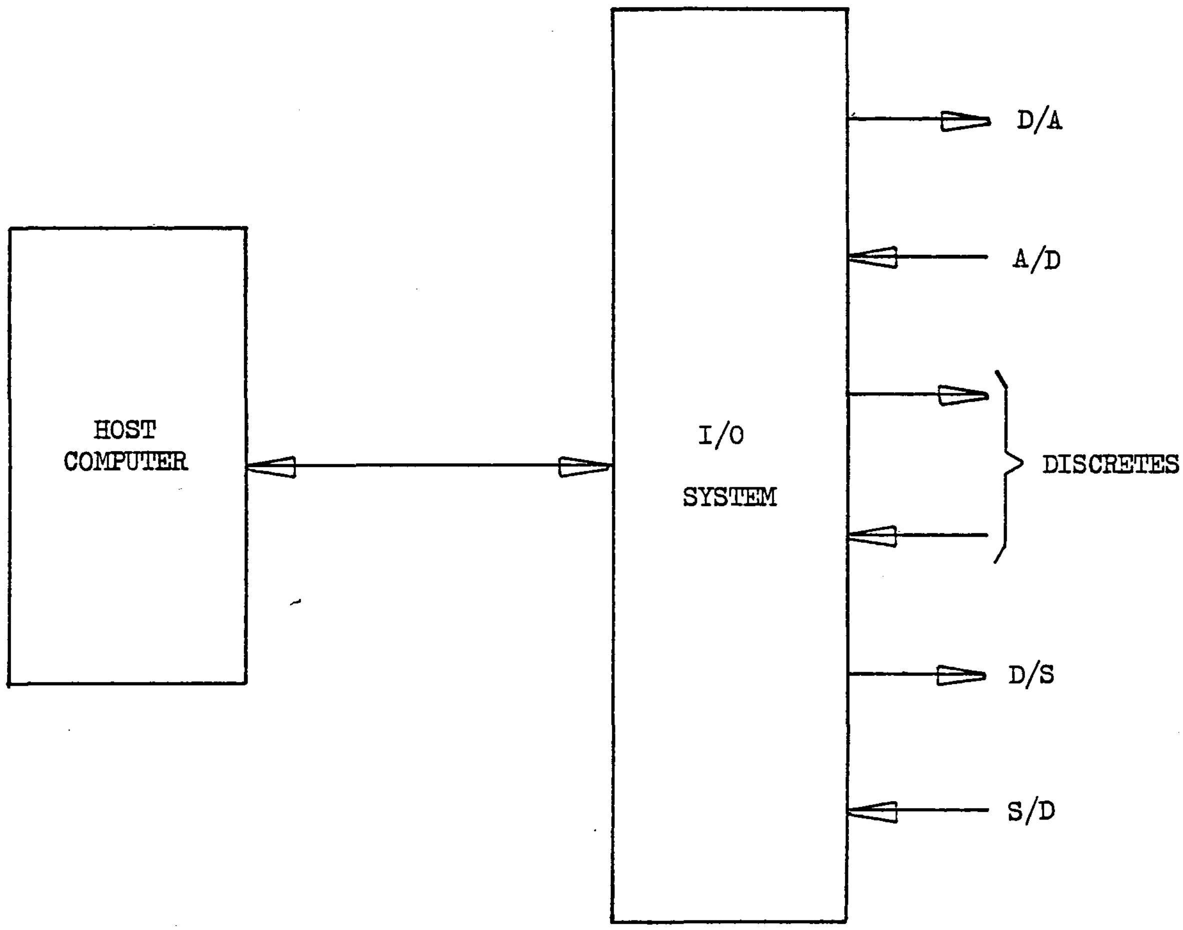



FIGURE 4-10. CENTRALIZED I/O ARCHITECTURE

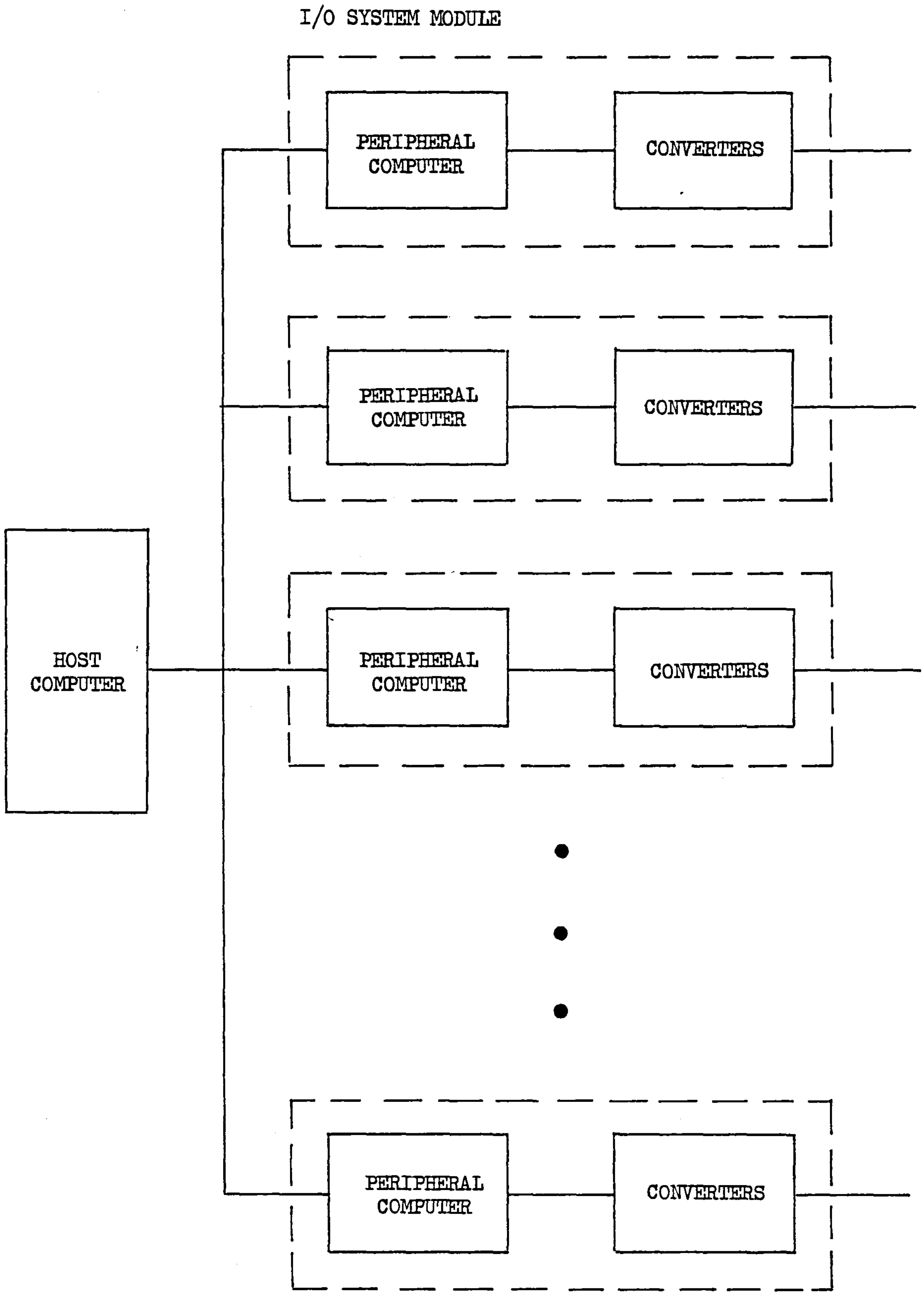



FIGURE 4-11. DISTRIBUTED I/O ARCHITECTURE

c) The ease with which the system can be expanded implies a high degree of flexibility. The availability of standardized modules make it possible to easily reconfigure the ACRS by adding, deleting or relocating the modules within the simulation facility as required.

d) Each of the distributed modules is a very powerful element by virtue of the intelligence provided by its controlling microcompter.

e) The I/O process can be placed where needed -- near the source or destination of the signals as appropriate.

f) Packaging of I/O capability within compact modules offers the potential for significantly reducing the initial cost of fabricating the ACRS. For example, complex flight station panels, complete with I/O, can be fabricated separately, and simply plugged into the cockpit rather than having to wire the panels to the I/O system after installation (a much more difficult, time consuming and costly procedure). Further, the availability of complex panels, complete with I/O, in simple plug-in form implies that the cockpit can be easily reconfigured to satisfy changing research requirements.

g) While designed primarily to control the I/O operations, the microcomputers included within the various modules possess the potential to perform additional computational tasks. As such, they can be programmed to perform a variety of tasks designed either to further relieve the host computer of some of its computational burden or to provide additional features not previously available within the simulation facility.

As a result of its inherent power and flexibility, the distributed I/O architecture should be implemented within a modern flight simulation facility such as the ACRS.

The distributed I/O architecture may be implemented in a number of ways using a variety of components and techniques. As noted earlier, an I/O system may either be purchased as a complete operational package or configured from available components. The primary design concern is achievement of the full flexibility offered by the distributed approach, not necessarily the details of the system used to accomplish it.

As an example of the type of flexible I/O system which can be easily configured from available components, consider a system composed of individual I/O modules built around the TM990/101 microcomputer. In addition to being a powerful microcomputer fully supported by a variety of development hardware and software, the TM990/101 offers a number of further advantages in the variety of chassis configurations, power supplies and general purpose interface cards available. The available interface cards include analog converter cards, a discrete interface card providing 64 inputs, 64 outputs or a combination of the two and a 4-channel digital/synchro converter card. Figure 4-12 illustrates the way in which this type of standard I/O module can be employed to greatly simplify the interface with a conventional flight engineer's panel. Again, this example is included merely to illustrate the concept. Similar modules can be structured around other available microcomputers and converter components.

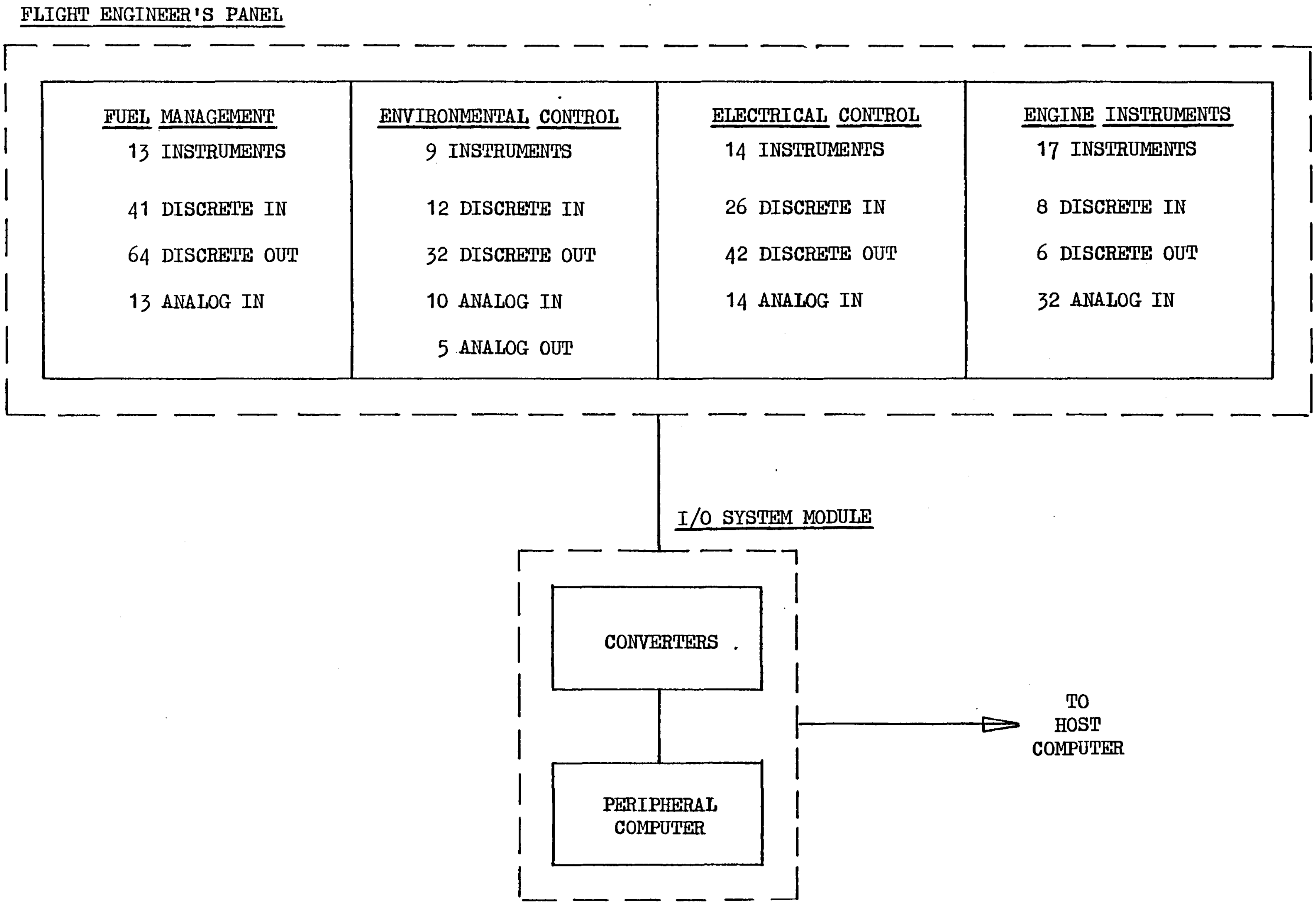



FIGURE 4-12. APPLICATION OF STANDARD I/O SYSTEM MODULES

4.4.3.2 System Implementation

Current technology aircraft will in the near term continue to use a large number of individual electromechanical instruments, discrete controls and switches within the cockpit. The trend of future aircraft designs, however, is obviously oriented toward use of a smaller number of integrated electronic displays and multifunction keyboards to provide the necessary interface with the crew. As a result, flight simulation facilities oriented toward the two generations of designs present somewhat different I/O requirements. The existence of these differences further highlights the advantages of the distributed I/O architecture. A general-purpose facility such as the ACRS will, during its lifetime, be configured to simulate a variety of types of aircraft employing the entire spectrum of available technology. flexibility of the distributed I/O system will be a vital factor in determining the ease with which the ACRS can be reconfigured to satisfy the multitude of research requirements which will be imposed upon it.

The basic differences in the two approaches to cockpit design must be recognized along with the fact that the interim period will certainly see a mix of the two types of technology within the cockpit. Design of the I/O system for the ACRS must, therefore, provide for interfacing both conventional analog and advanced data bus-compatible equipment. For conventional analog-type interfaces, the basic design decisions involve specification of the types of signals to be handled (and thus the types of converters required) as well as the number of channels of each which must be provided. In general, the I/O system must provide analog/digital, digital/analog, synchro/digital, digital/synchro, discrete input and discrete output capability. The number of channels required is obviously a function of the specific cockpit configuration of the type (or types) of aircraft to be simulated. Due consideration must be given, especially in the case of a research simulator, to provisions for expansion of the number of channels to satisfy future needs.

Design of the necessary data bus-compatible I/O capabiity involves three considerations:

a) The basic philosophy as to the way in which data buses are to be employed in the overall simulation facility.

b) The types of bus structures to be accommodated.

c) The number of each type of bus to be provided.

Concerning philosophy of use, the basic data bus concept offers a number of advantages in the implementation of airborne systems -- improved integration and control of the various systems, simplified interfaces and reduced wiring complexity to name a few. These same advantages apply equally well to the implementation of a general-purpose flight simulation facility and should be fully exploited in the design and construction of the ACRS.

Two distinct possibilities exist for the effective use of data bus techniques within the ACRS. The first of these is the more obvious one in which the availability of the appropriate data bus will allow actual

AVE hardware to be easily included as part of the overall simulation. This concept was illustrated earlier in Figure 4-2 which includes provisions for the optional installation of bus-compatible AVE components within the ACRS. This is an extremely powerful feature which, when coupled with a modularized software architecture, will provide a high degree of simulation flexibility. Simulation of a given system can be accomplished either by a software model or by the actual hardware as appropriate to the research task. If desired, competing hardware designs can be easily installed and compared, with the bus-compatibility feature eliminating many potential interface difficulties.

The second possibility for application of data buses within the ACRS involves their use in providing interfaces among the host computer, the peripheral computers, the simulator cockpit and the various consoles. This approach can offer significant savings in the construction, operation and maintenance of a flight simulation facility by greatly reducing its wiring complexity. For example, the distributed I/O concept is totally compatible with the use of data buses to interconnect the host computer with the various I/O modules. This is, in fact, a very simple way in which the necessary electrical interfaces can be accomplished.

The application of data buses within the ACRS is somewhat unique in that it provides several significant advantages while imposing no offsetting disadvantages. Basically, the availability of appropriate data buses in conjunction with the necessary analog-type I/O signals ensures that the facility will possess the necessary flexibility to accommodate changing flight simulation requirements, many of which cannot be predicted at this time.

The specific type (or types) of data buses to be implemented must be addressed on a simulator-to-simulator basis, taking into account the potential uses for which each facility is designed. A facility dedicated to investigation of commercial operations will certainly include the ARINC 429 data bus while one oriented toward military aircraft will include at least the MIL-STD-1553 data bus. In actual practice, each simulator may well include both types since in the near term AVE systems which can be effectively utilized within the various facilities may be designed to be compatible with either ARINC 429 or MIL-STD-1553, but not both. In any event, an initial decision to install one type of data bus within a given simulator will not preclude installation of the other type at some later date if the need arises.

In addition to the buses mentioned above, the EIA RS-232C bus will be used extensively within the ACRS, primarily to provide communication between the computers and various peripheral devices such as CRT terminals. The IEEE 488 data bus may be applicable in certain instances, particularly in interfacing various portions of the data acquisition and recording system with remaining elements of the ACRS. In addition, the IEEE 488 standard includes features which can be employed to easily implement intercomputer data links.

Once it is decided which buses are applicable to a given simulator, the question as to the number of each type to be installed must be addressed. Again, this is a function of the overall design criteria of the facility itself.

In summary, effective utilization of data bus techniques depends somewhat upon the specific uses envisioned for each ACRS. Generally, however, availability of data buses appropriate to the facility's intended use will greatly enhance its overall flexibiity as well as its potential for expansion.

4.4.3.3 I/O System Design Tasks

The following tasks must be accomplished in order to design the I/O system:

a) Establish overall design requirements for the I/O system.

b) Design the I/O system architecture.

c) Identify the types of conversion necessary and the the number of channels required within the ACRS.

d) Identify specific data buses to be used within the ACRS and provide for their installation and implementation.

e) Generate the documentation required to establish configuration control of the I/O system and to facilitate its maintenance.

## 4.5 SIMULATION ENVIRONMENTAL SYSTEMS REQUIREMENTS

The simulation environmental systems as described in this section create the environment in which the flight station is immersed. The systems that are discussed in this section are the visual, motion and aural systems.

### 4.5.1 VISUAL SYSTEM

The most important element of the ARCS, external to the aircraft simulation itself, is the visual scene presentation. There are several reasons for this. The development of new operational techniques in the terminal area demands a very realistic visual presentation for valid evaluation. Ground operation in a full mission simulation, particularly high speed turn off, is a very important element in decreasing aircraft spacing and must not be adversly affected by an inadequate visual presentation. Extensive control of light levels, fog and haze, ceiling, and RVR are required for terminal area investigations. The most important phase of the scene generation is the terminal area presentation. A multiple airport complex capability is necessary to evaluate procedures and performance under different conditions. Terrain scene generation during the enroute phase, although highly desirable, is less important since it can be masked by enroute weather.

The functional requirements for a visual system to provide these capabilities are presented in the following sections.

4.5.1.1 General Requirements

The heavy emphasis on the visual requirement dictates the highest degree of realism practically possible. Color scenes are required to give the crew approximately the same capability to discriminate features as they would have in the real world situation.

Flexibility of scenes, particularly different airports, will be required for the full mission scenario. This capability is most cost effectively achieved with computer generated scene systems. The requirements that will increase the cost of a computer generated scene system are daylight, and high degree of realism. Overall this type of scene generation remains the most cost effective, with the ratio continuing to improve.

The system selected for an ACRS should have full day/night capability and variable dawn/twilight lighting levels with additional horizon intensity adjustment.

4.5.1.2 Field-of-View

The extensive use of this type of facility for research of circling or curved approaches places the most stringent requirements on the overall display system field-of-view. In a facility for developing aerial refueling techniques, stringent requirements also exist. The field-of-view does not completely describe the need during cross cockpit viewing requirements. Window display units tend to break up as a scene traverses from one window to the next. The ideal solution is to project a continuous scene around the flight station, eliminating the break up and giving a viewing volume that is adequate for cross cockpit viewing.

Based on these assumptions, the field-of-view requirements for the flight station are:

180 Degrees Horizontal

45 Degrees Vertical (Minimum)

55 Degrees Vertical (For aerial refueling)

4.5.1.3 Terrain Features and Airfield Marking

All prominent features in the terminal area such as passenger terminals, hangers, roads, towers, etc., and nearby towns or housing areas must be a part of the visual scene. In addition, all runway features such as lighting, painted patterns, overrun areas and tire marks need to be modeled in detail. All of these features must be modeled in three dimensions with the proper perspective shading, color and occultation.

4.5.1.4 Weather

The visual system must be capable of simulating a wide variety of weather conditions. Visibility must be selectively restricted due to both cloud or overcast conditions and fog or haze. The overcast height should be adjustable from zero to 40,000 feet, and cloud tops should be adjustable from 20,000 to 40,000 feet. Visibility through haze or fog must be controllable from zero to 5 miles, and runway visibility range must be independently adjustable down to zero. Scud cloud conditions with fade in and out at random intervals should also be simulated.

4.5.1.5 Traffic

The emphasis on experiments in the terminal area, and with decreased traffic intervals means that much of the simulation will take place in the proximity of other aircraft. This traffic must be visible to the simulator crew during VMC conditions. The visual system must have the capability of presenting a minimum of two aircraft targets under computer control to provide the required traffic.

4.5.1.6 Visual System Control Requirements

All features of the visual system should be controlled from a remote panel that can be installed on the test conductor's panel. The intensity of the approach, strobe, VASI, and runway lights should be individually controllable, and should have individual on/off capability. The horizon intensity and runway surface brightness must be controllable. All intensity controls should have 5 levels of brightness with equal increments.

4.5.2 MOTION SYSTEM

Although the trend in recent years has been to use full 6 DOF motion system for transport category aircraft, questions concerning their contribution to the simulation, versus the relatively high cost have arisen. The general feeling among those submitting their facility requirements and discussing planned research indicates that a motion system was a low priority item. The only concern mentioned was the loss of realism during ground operation, specifically, push back, brake release and vibration during taxi. These "motion" cues could be accomplished with far less than a 6 or even a 3 DOF system.

The other area requiring a trade-off decision concerns the use of a 180 degree wrap-a-round projection system for the visual display. If this type of display is used it would be very difficult to operate with a motion system.

### 4.5.3 AURAL SYSTEM

The sound system for the simulation must provide the aural cues that are heard by the crew member, and are probably used in the performance of his duties. These sounds must be automatic and function as a result of the state of the simulator. They must vary in tone and intensity and be induced into the flight station to simulate their representive location.

Some representive sounds that should be simulated are:

- Ground Operation
  - Power Carts
  - Engine Start, Idle, Reverse
  - Taxi and Runway Noise
  - Flight Station Equipment & Cooling
  - Air Conditioning

Flight
- Engines
- Strut Extension (if audible)
- Aerodynamic Noise
- Gear & Flap Retraction
- Spoiler & Flap Buffet
- Gear & Flap Extension
- Touchdown Impact

Abnormal
- Stall Buffeting
- Compressor Stall

This is a partial list but may include some items that do not apply to the simulated aircraft.

## 4.6 TEST CONDUCTOR CONSOLE

The Test Conductor Console should include CRT displays and multifunction keys in an uncluttered, yet complete control panel for all simulation functions normally performed by the test conductor. The CRT displays can be monochromatic or multi-color and can have calligraphic capability. The use of keys adjacent to the CRT allows maximum flexibility rather than having a fixed number of dedicated keys. Each key can be used for a function designated on the CRT for each different display or page called up on the CRT. A certain number of the keys would be dedicated for special purpose functions such as page forward or reverse or for specific topic areas such as malfunctions or approach parameters.

Other types of keyboard systems can be used where the keys have multiple legends built in, and display only the legend appropriate to the current function of the key. This does have some limitations in terms of number of legends per key; however, displaying the function on the CRT as part of the display eliminates this difficulty and gives maximum flexibility. The test conductor can perform pre-flight, inflight or post-flight functions. For example, test scenarios would be programmed pre-flight, monitoring and fault insertion during inflight, and data analysis and replay at post-flight phases.

The test conductor console should include:

a) Communications (Flight Station, ATC Console, and Computer Complex)

1) Frequency Readout for all communications/ Navigation Equipment
2) Indicators - Position of transmitter selector and systems being monitored
3) Indicators - Position transmitting

b) Test Control Panel

1) Test start/stop/reset
2) Freezing of specific or all parameters
3) Repositioning of aircraft
4) Time scale changes
5) Replay of certain time frame
6) Emergency shutdown of any or all systems

c) Visual System Controls Panel

d) Flight Station Video Panel

1) Monitors

2) Camera zoom and pan controls

e) Flight Station Display Repeaters

1) Monitors

2) Select controls for specific display units.

f) Scenario Control Panel

1) Initialization parameters

- o Specific mission or scenario profiles with all communication, navigation, and environmental factors preplanned.
- o Setup of all weather radar functions such as weather type and location.

2) Inflight conditions

- o Malfunctions and emergency conditions - initiation of subtle catastrophic malfunctions.
- o Time changes - expansion or contraction of specific flight segments.
- o Observation of track plots, approach graphs or other selected real time parameters.

- o System status and flight situation including systems activated, parameter monitoring, and event, sequencing information, comm/nav time system status, any flight instrument, engine performance instrument or caution and warning status.

3) Post flight analysis

   - o Playback of any portion or all of flight exercise to allow post-flight debriefing and analysis.

The usual location for the test conductor console is in the simulator cab, allowing the test conductor complete control and monitoring capability over the entire simulation. It may be desirable, however, for the test conductor station to be located outside the confines of the cab itself. Should this be the case, additional information from the cab could be obtained through the use of multiple TV video cameras situated in appropriate locations in the cab.

In some cases, it may be desirable to have two test conductor consoles, one in the cab and the other located remotely outside the cab. All functions provided by the console can be permitted to operate in a parallel manner such that the computer complex could accept inputs from either console separately but would have to make a software judgement concerning simultaneously inserted or conflicting inputs.

## 4.7 COMPUTER CONTROL CONSOLE

The variety of computers necessary to efficiently accomplish all computational tasks requires an integrated control station to allow facility personnel to exercise control over and monitor the performance of all aspects of simulator operation. Specific functions provided by the computer control console include:

a) Unified control of the computer complex including all computers, their peripherals and the I/O system.

b) Initiation of automatic sequencing of ACRS components.

c) Control of manual activation of system elements.

d) Display of the operational status of the computers, peripherals, sensors and other components of the ACRS.

e) Interactive communication with the Test Conductor and Air Traffic Control consoles to provide the coordination required during research activities.

f) Real-time interrogation of the various computers to allow their memory contents to be examined and/or modified as required to facilitate either simulator operation or software development activities.

To ensure both utility and flexibility, the computer control console should be built around one or more CRT display/multifunction keyboard elements. The number of such elements required should be a function of the specific configuation implemented, and the overall research goals of the facility. Discrete controls and displays must be integrated into the console when appropriate for a given function. In certain simulators, the console should be directly interfaced with the host computer which will contain the software necessary to implement the desired control/display functions. In others, the console should contain its own computer which would be interfaced with the host. In either case, the interface of the computer control console with the other functional elements of the ACRS would be accomplished indirectly through the host computer.

Use of CRT displays and multifunction keyboards to provide the desired interactive control capability ensures that the initial computer control console design will be sufficiently flexible to expand with the ACRS to accommodate changing research requirements and tasks. Generally, the need for new control/display functions requires only that the existing software be modified to incorporate the new features. Modular design of both the hardware and software elements will allow the console to be easily modified in response to either a minor simulator reconfiguration or a major simulator expansion.

## 4.8 DATA ACQUISITION AND RECORDING

The ACRS will be used for a wide variety of research and development activities related to the operation, performance and implementaton of advanced aircraft-related systems, concepts and techniques. As such, it must include the hardware components and software packages that are required to acquire, record, and analyze data generated during the various test sequences. Specific functions involved in this aspect of simulator operation include:

a) Ability to interactively specify the data parameters pertinent to a given research task.

b) Acquisition and formatting of the selected parameters.

c) Display of selected parameters in real-time or recording of them as appropriate.

d) Reduction of recorded data to aid in post-test analysis and evaluation.

In general, the ACRS must be capable of generating data in digital, analog, audio and video form. The data acquisition and recording system must therefore be capable of accommodating any of these formats. While the specific data acquisition and recording requirements would vary with the type of facility developed, each should include the following types of equipment:

a) Audio recorders with playback capability

b) Video recorders with playback capability

c) X-Y plotters

d) Strip chart recorders

e) Magnetic tape recorders

f) CRT terminals with hardcopy capabiity.

The data system must interface with all functional elements of the ACRS to acquire the necessary parameters. Use of data bus techniques to implement the simulation facility as discussed earlier will make it easier to gain access to the required data. The IEEE 488 data bus would be particularly appropriate here, as a wide variety of instrumentation components are available today with IEEE 488-compatible interfaces.

An interesting potential use of the data acquisition and recording capabilities of the ACRS is the accurate recreation of previous events. If the system is properly designed, the role of the data acquisition and recording system can be reversed to allow recorded information, in a variety of forms, to serve as the input stimuli to the simulator. In this mode, the simulator would respond with a very high degree of fidelity and repeatibility to the recorded data so as to create, within the carefully controlled and instrumented simulator environment, sequences of events which may have occurred previously.

Several interesting applications of this replay capability can be postulated. They include:

a) The ability to repeat with a high degree of accuracy specific test sequences, eliminating variables due to the human test subjects. Replay of these sequences can be used either to demonstrate the results or to allow detailed analysis and evaluation. In some cases, the research task may be aided by the ability to replay the test in "slow motion" while retaining accurate synchronization of all effects.

b) The ability to transfer experimental results from one facility to another for use in a variety of research studies.

c) Recreation of conditions encountered during actual flight. This feature could be used either to evaluate flight test results or to investigate incidents which occurred during flight.

d) Replay of flight sequences for crew training purposes.

# 5.0 CONCLUSIONS AND RECOMMENDATIONS

## 5.1 COMMONALITY OF RESEARCH NEEDS

During the investigation of research needs with various industry, NASA and Air Force organizations, it became apparent that there is some degree of overlap in planned areas of research. This is vividly evident in Figure 3-1, shown previously. The division of research into broad areas in this figure does not present the entire picture, however, because although more than one organization is planning research in a given area, the specific goals and ultimate application of that research may differ considerably.

It would be a misnomer to call this a duplication of effort. The specific goals range from the development of concepts and procedures to the development and testing of hardware. Some of the research areas, such as development of the aircraft interface with the 1990's ATC environment will have significant long term impact on both the aviation industry and related industries. These areas should be investigated from every practical angle to assure that decisions are based on a total data base that includes operationally sound techniques and criteria that have been subjected to extensive study and investigation.

As a part of the study documented by this report, methods of exploiting the similarity in facility requirements were explored. The following sections describe specific areas in which this commonality of functional requirements could provide a far more effective program to resolve the issues confronting future development of the air traffic system.

The survey of the research needs of the various organizations involved in advanced flight station studies did not indicate any major areas of omitted research. Continued coordination among the organizations is recommended to point out areas of additionally required research that might grow out of planned research or changes in the present constraints that have been assumed at this time.

## 5.2 SPECIFIC RECOMMENDATIONS FOR EXPLOITING COMMONALITY

One of the major benefits that can be realized from this task is the exploitation of areas of commonality in the development of the various research facilities being planned. These benefits can accrue in areas such as reduced total cost, faster facility development, and the capability to transfer experiments between facilities.

During the coordination required to develop an understanding of research needs and requirements, almost without exception, intense interest was expressed in sharing in the common development of basic simulator requirements.

Analysis of the individual facility developers' requirements, points to a number of specific tasks that should be implemented immediately for use by almost all agencies involved in this study.

### 5.2.1 FLIGHT STATION SHELL

One of the requirements established for this study was to investigate use of the flight station shell recently developed by Boeing. Lockheed's investigation determined that use of this flight station shell and base is a feasible and cost effective approach that would enhance the commonality of facilities.

### 5.2.2 COMPUTER COMPLEX

An important purpose of this study has been the identification of common elements within the computer complexes. A corollary purpose has been the suggestion of ways in which this commonality can be exploited to eliminate duplication of development effort and thereby reduce the life cycle costs of each facility. Emphasis has thus been placed upon identification of ways to achieve the desired level of functional commonality, recognizing that the common design criteria can, in some cases, be satisfied by a variety of hardware system configurations.

A network composed of a host and several peripheral computers is recommended for the ACRS. In addition to providing the real-time computational capability required, the network architecture would make it possible to achieve the desired level of flexibility and expandability within the simulation facility. Ideally, the computers utilized within the basic computer complex of each facility would be identical. The computer resources already in-place must be recognized, however, and this existing capability must be integrated into the framework of the common computer complex. As a minimum, the basic computer complex can be utilized to provide the common simulation, control, and data gathering functions of the ACRS.

Development of a common software system structure would provide a high level of functional commonality. Use of a common HOL to implement the majority of the software would drastically reduce the software system life cycle costs and would make possible the exchange of software packages among the various facilities. In addition, the inherent transportability of HOL software would simplify the integration of the basic ACRS computer network with existing computer facilities.

Implementation of a modular I/O system would provide the interface flexibility required to allow the ACRS to be easily and quickly reconfigured in response to changing research requirements. Multiplex data bus techniques can be very effectively used to simplify the necessary interfaces among the various functional elements of the facility.

### 5.2.3 DETAIL TASKS

The following are those specific common tasks that should be implemented in beginning the design process.

a) Design of the ACRS baseline flight station configuration, which includes detail design of all features required to facilitate reconfiguration of the flight station to satisfy changing research requirements. It would involve design of consoles, panels, primary and secondary controllers, display device installation, etc. In addition, definition of all auxiliary items within the flight station such as cupholders, ashtrays and trim items would be included.

b) Definition of the design details of all common elements such as cooling, lighting, communications facilities, intrafacility wiring, the electrical power system and all safety-related features and systems.

c) Flight station integration by a single organization to assure interchangeability and utilize experience gained during first buildup.

d) Design of the ATC and Test Conductor consoles and definition of their interfaces with other elements of the ACRS.

e) Development of specific software system requirements and design of the overall software structure.

f) Identification of the aircraft systems to be simulated and specification of the appropriate iteration rate and computer (host or peripheral) to be used to simulate each one.

g) Definition of an advanced aerodynamics data base.

h) Definition of advanced aircraft systems such as primary/ secondary flight controls, both manual and automatic, including active control systems.

i) Development of a simulation model to implement the advanced aerodynamics data base and aircraft systems.

j) Identification of potential malfunctions and their consequences.

k) Selection of specific malfunctions and their implementation for effective use within the ACRS to facilitate research, development and training activities.

l) Definition of the ways in which data bus techniques can be used within the ACRS to facilitate operation and minimize life cycle costs.

m) Identification of specific data buses to be used, and design of their implementation within the ACRS.

n) Design of the computer complex configuration, including all interfaces among the host computer, peripheral computers and I/O system.

o) Design of the hardware and software elements of the common I/O module.

p) Definition of the data acquisition and recording requirements of the ACRS. Specification of the hardware and software modules to be used and their interfaces with other ACRS elements.

q) Definition of the requirements for self testing of elements within the ACRS.

## 6.0 REFERENCES

1) Holt, A.P., Walthour, L., Noneaker, D.O.:
A Survey of New Technology for Cockpit Application to 1990's Transport Aircraft Simulators, NASA CR 159330, December 1980.

# APPENDIX A

## SIMULATOR REQUIREMENTS AND GROUND RULES

This appendix consists of a summary of the future research needs and requirements as submitted by both NASA-LaRC and NASA-ARC, and a compilation of typical research needs of industry. Inasmuch as implementation of the USAF TACS 2000 program is not nearly so near term, a definitive set of requirements and research needs does not exist at this time.

## LANGLEY RESEARCH CENTER
## ADVANCED MISSION SIMULATION

Purpose of Facility:

Develop efficient operating concepts, procedures and functional requirements for airborne avionic systems to operate effectively in a 1990's airspace environment.

a) Quantify benefits and sensitivites of advanced concepts, systems, and procedures.

b) Establish flight management emphasis and functional criteria for design and operation of an advanced flight station and associated systems, procedure and information interfaces.

c) Verify credibility and promote early acceptance of new technology into the commercial fleet.

Research Time Frame:

a) Support NASA/Industry research milestones for FY-82 through FY-88.

b) Update facility in FY-84/85 to full-workload capability.

Configuration Envelope:

a) Cab geometry/dimensional configuration should consider the recent Boeing design.

b) The flight station should be a basic two-man crew configuration capable of expanding to three-man configuration within limits of the TCV B-737 cabin envelope.

c) The flight station should not be constrained by present and near-term limitations (e.g. panel depth, geometry, electronics packaging, etc.)

Functional Envelope And Interfaces:

a) Capability and workload envelope to realistically simulate all-mission gate-to-gate operations, including abnormal or failure intensive workload options (as a module for later incorporation).

b) Redundancy should be provided only for operational expediency.

c) Hardware should reflect FY 1981 state-of-the-art.

d) Maximize use of CRTs and Dot-Matrix displays (LED, LCD, EL and/or Plasma) and multifunction key boards for:

-Primary Flight

-Engine

-Flight and System Management

-Navigation/Communication and Advisory

-Caution and Warning.

e) Use fly-by-wire (electronic) digital control systems and electrical throttles.

f) Programmable multi-function cockpit displays and interface reconfigurable without significant change to host computer.

g) Interface and interact flexibly with cruise and terminal area traffic models and with simulated ATC controller stations.

h) Enable expedient transfer of simulator developments (algorithms, software and flight procedures) to aircraft experimental systems for flight verification.

i) Feature higher-order software language that is compatible with resident support software.

j) Ensure computer configuration allows use of display and control software in either simulation or airplane.

Functional Modularity:

a) Possess high degree of modularity to enable maximum flexibility of systems.

b) Provide for alternative display methods and programmable display generators to reflect opportunities afforded by technology developments projected through 1981.

- DISPLAYS AND CONTROLS

  CRT vs Flat Panel Option

  CRT Shadow-Mask vs Color (CRT's & Dot-Matrix)

  Single (large) vs Multiple (small) Displays

  Writing Speed, Brightness, Contrast Ratio, etc.

  Ambient Lighting in Cockpits

- PROGRAMMABLE DISPLAY GENERATOR

  Electrical Inputs and Outputs

  Stroke, Raster and/or Hybrid

  Symbology, Formats, Line Resolution,
    Color Capabiity, etc.

  Interface with Host Computers

- PRIMARY FLIGHT CONTROLLERS

  Center Stick

  Side Arm Controller

  Brolly Handles

Sensors, Data Processing, and Test Operations:

a) Provide

- Oculometer for each crew station
- Data bus capability and flexibility for reseach modularity and data extraction
- Experimenter station for time/cost/ manpower-effective operations
- Real-time quick-look data review capability
- Integrated workload measurement battery

**AMES RESEARCH CENTER**
**MAN-VEHICLE SYSTEMS RESEARCH FACILITY**
**RESEARCH SUPPORT REQUIREMENTS**

## I. General

In general, it is not intended that the Advaned Technology Cockpit be used for exploratory research. Ames has a complement of part task simulators and basic laboratory apparatus that can be used for basic or exploratory research in aeronautical human factors. Rather the cab will the used, as will be the remainder of the Man-Vehicle Systems Research Facility, for those studies that require either high operational and systems fidelity with part of full crews or full mission operation with full c9ews. Both requirements imply that the cockpit be as much like a real aircraft as is practicable and that most if not all of the major flight and aircraft systems function in a realistic manner.

In addition to this fundamental requirement, it is further required that performance of the part or full crew be measured in as broad a sense as possible. Categories of measurement shall include:

1. Measures of system performance - rms flight path errors, control movements, airspeed, sink rate, power settings, etc.

2. Measures of crew communication and coordination - video and audio recordings of crew interactions, observer ratings of crew activities and performance, and recordings of air/ground communication and information transfer.

3. Analog measures of crew state and crew performance - physiological measures such as heart rate, peripheral cardiovascular condition, breathing rate, eye point-of-regard, voice.

4. Discrete measures of crew state and performance - reaction time, time estimate, crew rating and categorization, discrete decisions, performance on side tasks, crew-machine interactions.

Other general guidelines for performance measurement shall include: minimum intrusion onto normal crew activities, flexible specification and storage of specific performance measures for a given experiment, efficient data base management, on-line and off-line data display, common time/event synchronization of separate performance measurement "channels."

## II. Specific Research Areas Supported

### 1. Human Error and Aviation Safety

Specific research areas will arise from analyses of the existing Aviation Safety Reporting System data bases. Possible experimental scenarios include the study of crew behavior as a function of specific accident scenarios or classes of accidents involving communication/information problems between air and ground personnel.

Performance measures would likely include cockpit observer analyses of crew performance, analog recordings of voice communications, and state information for all involved aircraft.

2. Automation

A major question is the degree to which automation of the cockpit is helpful/desirable from the perspective of crew behavior, workload, and performance. Two major issues are apparent at this stage:

a. Skill Erosion - to what extent does/will dependence on automated equipment in the cockpit for functions currently manually performed result in the erosion of specific flying skills and how may deficits, if any, best be ameliorated.

b. Failure Detection - what information logic/performance is optimal so that automated system failures may be detected and diagnosed with minimum latency and maximum effectiveness.

Specific performance measures would likely include subsets of system performance (control errors, etc.) as well as measures of reaction time to specific system failures and discrete crew responses to equipment failures and malfunctions. Direct observation of crew performance may also be used.

3. Crew Information Requirements

The major questions here revolve about the issues of the relative degree of responsibility between air crews and ground based control, be it automated or human. A related issue concerns the display requirements which derive from the various responsibility distribution scenarios.

System performance measures here may necessarily involve more complex system considerations since more elements of the overall aviation system may be involved in any specific experimental scenario. For example, for the terminal area case in which multiple aircraft (piloted or "pseudo piloted") occupy a given volume of airspace, complete aircraft state data should be recorded at periodic intervals throughout a given simulation.

Crew performance measures may also vary widely as a function of the the specific experimental design. Eye-point-of-regard, reaction time to system anomalies, blunders, and visual representation of traffic threats would likely be used, as would perhaps observer ratings of crew performance and interaction. Crew workload measures of physiological, voice, side task performance, etc., might also be used here.

4. Human Factors of Advanced Crew Stations

Specific research issues here center around the introduction of advanced systems into current technology flight decks and the design and crew utilization of advanced flight decks.

Since, to a great extent, crew workload and safety considerations will probably influence the evolution in the design of the use of systems like head up displays, advanced head down displays, caution and warning systems, speech input and output units, programmable display units, and multifunction displays and controls. Measures of workload, crew problem solving, and decision making will index performance in this category of study. For specific aspects of display work, eye point-of-regard measures may also be used.

For CAWS work, measures of crew response to caution and warning signals will be emphasized. For this work it will be necessary to selectively fail simulated aircraft subsystems so that aircraft performance and state is consistent with the caution and warning "messages". It must be possible, in addition, to adequately monitor the coordination and management of the flight crew. For this, an on-board observer will be used. This individual should have available an automated and non-obtrusive means for systematically recording crew behavior.

In general, studies in this category will place the greatest demands on the configuration flexibility of the simulator cockpits, including both the location of display and control subsystems as well as the location and number of crew members.

5. Air Crew Behavior

Under the category of aircrew behavior will be included studies and training, workload and performance measurement, decision making, fatigue and crew complement. Taken as a whole, research studies in this category may involve the widest range of performance measures including those in all four of the categories listed in Part I above.

## NASA-AMES RESEARCH CENTER
## MAN-VEHICLE SYSTEMS RESEARCH FACILITY
## PERFORMANCE CRITERIA AND DEVELOPMENT GROUNDRULES

(1) Two cabs capable of full mission simulations: filing of flight plans, taxi, takeoff, climb, cruise, approach, landing and final roll-out;

(2) Independent or simultaneous operation of both cabs in the same airspace;

(3) Full three person crews, both simulator cabs, reconfigurable to two person crew, cab base and shell to be modified (stretched) version of the Ames "Interchangeable Cab";

(4) Functional representation of terminal area, tower and center air traffic control, current configuration;

(5) Three (minimum) pseudopilot stations, each capable of simulated operation of six independent aircraft;

(6) Current technology simulator cab to be equipped as a facsimile of a current commercial transport aircraft with all flight displays, controls and other major aircraft systems operable and functioning for three crew members;

(7) Advanced technology cab to be equipped with computer generated display systems for flexible presentation of all primary flight and

aircraft systems data to three flight crew members; displays to be reconfigurable relative to location, information content and symbology;

(8) Flexible and realistic intercommunication system to provide communication links between air and ground crews and between air crews, including provision of background communication, and to provide communication between the experimental flight and ground crews and simulation operators and experimenters;

(9) Computer generated visual scene display generator, capable of storing and displaying (in real time) a data base consisting of at minimum, two terminal areas and visual conditions. Capabilities to include simulation of night, dusk, and limited day conditions and conditions of reduced visibility and ceiling; 2 channel scene to be switchable between simulator cabs;

(10) Each cab to be equipped with a two window visual display system, one window each for pilot and first officer. Each display window to provide a 45 degree x 35 degree field of view (minimum) and a virtual image at optical infinity;

(11) Visual scene generator to be capable of representing other visual traffic, during all three modes of operation. It shall be possible to control the the trajectory of this traffic either under program control or under experimenter control from either experimenter's console;

(12) Each simulator cockpit to be equipped with a cabin sound generation system capable of creating a realistic cockpit interior noise environment. The sounds shall include those of each turbofan engine, including jet and turbomachinery noise during each phase of operation including startup, and of air conditioning noise, landing actuator gear, auxiliary power unit and other hydraulic system noise, and of runway rumble noise. Engine noise shall vary, in a realistic manner, as a function of engine RPM and thrust level, at minimum;

(13) It shall be possible for the experimenter to introduce failures of the major aircraft systems independently in each of the two simulator cabs. Specific mode and timing of the failures shall be at the discretion of the experimenter;

(14) It shall be possible to digitally record all data descriptive of the simulated flight envelope and aircraft system function for an entire aircraft mission as well as selected subsets of crew behavioral data (e.g. pilot and first officer control movements, etc.) under control of the experimenter. Means shall also be provided to retrieve and display selected channels of data, either for previously stored data or in real time;

(15) A system shall be provided to simulate a wide variety of aural warning signals, in each of the simulator cabs, under control by the experimenter. Signal specification shall be flexible with provision for both speech and non-speech sounds. Signal presentation shall be made in a realistic manner in each of the simulator cabs;

(16) Electrical, mechanical and structural provision shall be made, during construction of the building housing the simulation equipment, for the eventual installation of a hydraulically actuated six-degree of freedom motion base. Sufficient interface capacity to drive the motion base shall also be provided.

(17) A computer-controlled test system shall be provided to perform evaluations of status and operability for all major electronic systems in each of the simulator cabs, for the visual scene generation and display systems, for the simulation computers, and for the experimenters′ and simulation control consoles, to maximize operational efficiency and realibility;

(18) A digital simulation computer or computers shall be provided to solve equations of motion for each of the simulator cabs, to model avionics, computer-generated instrumentation, to implement data collection, perform input/output operations, control each of the facility subsystems such as noise and warning sound generators, etc. and that, in general, shall control an entire simulation. The same or a separate digital computer shall also be provided to perform area simulation for the Air Traffic Control function. A program development capability shall also be provided as shall a sufficient hardware and software communication network to tie together all computation system components;

(19) System software shall be provided to support high level and assembly level language processing as well as program editing, debug, etc. A nominal set of program modules shall also be developed including

flexible aerodynamic models for each simulator cab as driver modules for each of the facility systems under control by the facility simulation computer(s);

(20) Primary flight controls to be of an advanced type, e.g. side arm, Brolly handles, or center stick.

## TYPICAL INDUSTRY RESEARCH REQUIREMENTS

1) Evaluate different types of displays, display formats, arrangements, etc.

2) Evaluate limits of automation that can be implemented and still maintain the pilot as an effective system manager.

3) Perform workload and performance evaluation with various levels of integration.

5) Demonstrate the effectiveness of a master caution or positive alert panel.

6) Explore crew complement issues.

7) Explore application of voice recognition and voice speak-back concepts.

8) Investigate techniques for integrating new ATC systems into the cockpit.

9) Determine feasibility of software controlled switches for data entry (touch sensitive panels and LCD displays, etc.).

10) Explore new aircraft subsystem control and display techniques.

11) Development of closed-loop flying qualities.

12) Investigation of innovative approaches to enhance pilot control of flight (side arm controllers, etc.)

13) Define and develop systems for control of flight on advanced and derivative aircraft configurations.

14) Determine flying qualities requirements on active controls.

15) Assess control system criticality.

16) Assess pilot performance and safety related parameters.

17) Evaluate flight worthy hardware and software and conduct failure effect studies.

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16. Abstract

This report documents a study of flight deck/crew system research facility requirements for investigating issues involved with developing systems, and procedures for interfacing transport aircraft with air traffic control systems planned for 1985-2000.

Crew system research needs of NASA, the U.S. Air Force, and industry were investigated and reported. A matrix of these is included, as are recommended functional requirements and design criteria for simulation facilities in which to conduct this research. Methods of exploiting the commonality and similarity in facilities are identified, and plans for exploiting this in order to reduce implementation costs and allow efficient transfer of experiments from one facility to another are presented.



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