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MAN-VEHICLE SYSTEMS RESEARCH FACILITY: DESIGN AND OPERATING CHARACTERISTICS

Man-Vehicle Systems Research Division

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PREFACE

In 1979, in its FY 1981 Congressional budget submission, the National Aeronautics and Space Administration (NASA) requested and received funding for the construction of a National Aeronautical Human Factors Research Facility at Ames Research Center. Preliminary design was initiated in 1980, with construction beginning in early FY 1981.

The facility will be utilized for a broad range of human factors research in both conventional and advanced aviation systems. The objective of the research is to improve our understanding of the causes and effects of human errors in aviation operations, and to limit their occurrence. The facility will be used to:

1. Develop fundamental analytical expressions of the functional

performance characteristics of aircraft flight crews;

2. Formulate principles and design criteria for aviation environments of the future;
3. Evaluate the integration of new subsystems into contemporary flight and air traffic control scenarios;
4. Develop new training and simulation technologies that will be required by the continued technical evolution of flight systems and of the operational environment.

This document introduces the prospective user community (NASA, FAA, DOD and other government agencies, industry and university groups) to the facility's design and operating characteristics.

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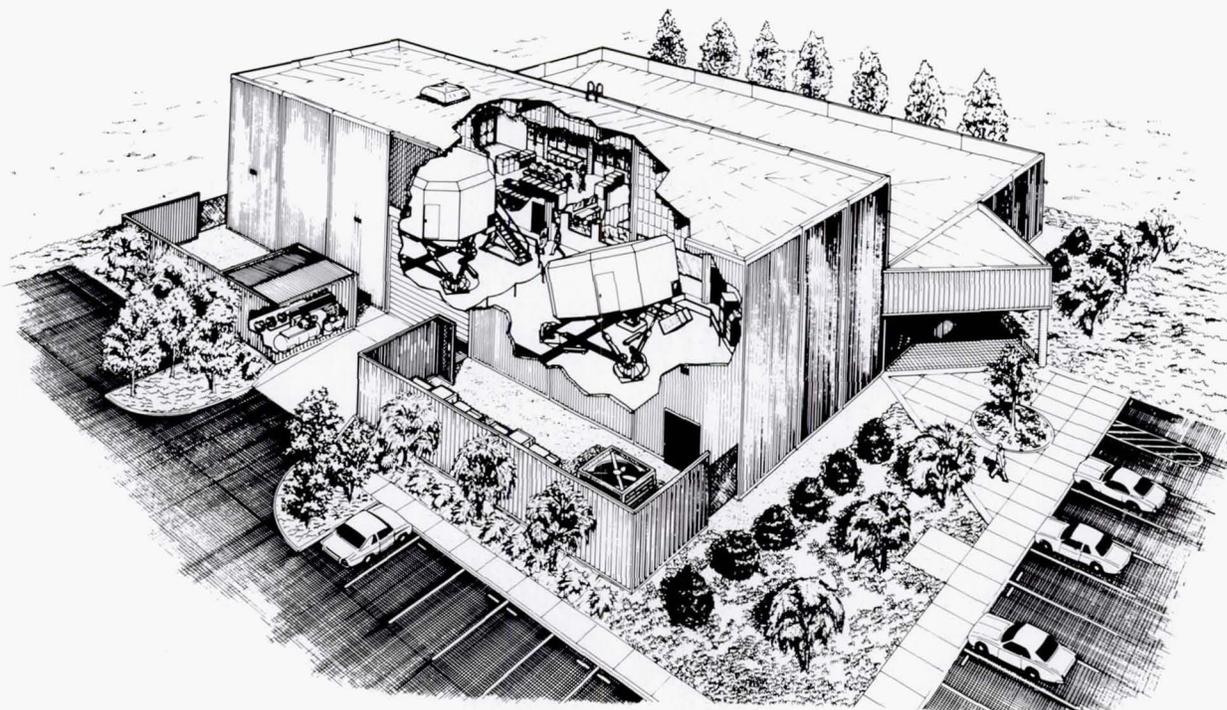
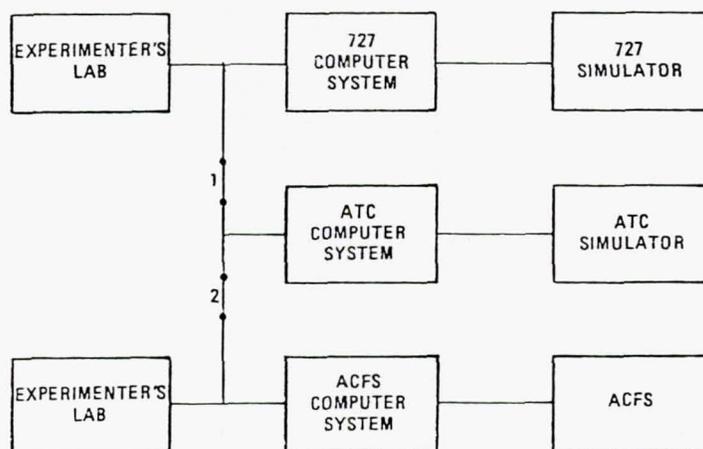


Fig. 1. - Cutaway sketch of Man-Vehicle Systems Research Facility



AVAILABLE MODES	SWITCH 1	SWITCH 2
FULLY INTEGRATED	CLOSED	CLOSED
727/ATC INTEGRATED, ACFS INDEPENDENT	CLOSED	OPEN
ACFS/ATC INTEGRATED, 727 INDEPENDENT	OPEN	CLOSED
FULLY INDEPENDENT	OPEN	OPEN

Fig. 2. - Schematic diagram of facility elements

MAN-VEHICLE SYSTEMS RESEARCH FACILITY: DESIGN AND OPERATING CHARACTERISTICS

1. INTRODUCTION

The Man-Vehicle Systems Research Facility (MVSRRF), a unique national research resource, will be used primarily for the study of human factors. The facility will include two flight simulators and a simulated Air Traffic Control System. Each flight simulator, a Boeing 727 and an Advanced Concepts Flight Simulator (ACFS) will be able to operate alone or interactively with the other simulators in an environment that also contains other aircraft.

The facility will make possible the creation of realistic single- and multi-aircraft, part- and full-mission scenarios. This inherent flexibility will permit the study and analysis of human-human and human-machine interactions, with the goal of decreasing the incidence of critical human errors in the operation of the National Aviation System.

Construction of the MVSRRF will be completed during calendar year 1983.

1.1: Facility Description

Figure 1 is a cutaway drawing of the facility showing the locations of two aircraft simulators, a Boeing 727 and an Advanced Concepts Flight Simulator (ACFS), the latter configured with state-of-the-art graphics displays in place of conventional cockpit instrumentation.

Both the advanced and conventional simulators will be capable of full mission simulation. Each will have a dedicated experimenter's control lab, capable of controlling and monitoring its simulator. Visual scene generation systems will provide out-the-window cues in both cockpits. An ATC system simulator will provide realistic control of and communication with the cockpits and will allow study of air-ground communications systems as they impact crew performance.

Figure 2 is a diagram of the facility components, showing their interconnections.

1.2: Management and Operations

Facility management responsibility is assigned to the Man-Vehicle Systems Research Division within the Life Sciences Directorate at Ames Research Center. Day-to-day management is the responsibility of the MVSRRF Facility Manager. Operation of the facility is provided by the Link Flight Simulator Division of the Singer Company, Binghamton, NY, which supplies maintenance, engineering, software and hardware support necessary for the conduct of specific experiments. Instruction (for both investigators and subject pilots) and operational support of investigators are also provided as needed.

Inquiries regarding usage of the facility should be forwarded to the MVSRRF Facility Manager, Mail Stop 257-1, Ames Research Center, Moffett Field, California 94035, telephone 415-965-6279

2. DESCRIPTION OF SIMULATORS

Human factors research requirements demand a facility that is capable of supporting simulations representative of both current and future aviation operations. The Boeing 727 simulator, representing the current fleet, is an exact replica of the cockpit of the the most widely-used domestic turbofan transport. Rigorous configuration control is maintained to ensure that aircrew behavior in simulated flights is representative of actual flight operations.

In contrast, the ACFS, configured with multiple electronic displays, advanced crew-aircraft interfaces and flight control devices, is designed to permit virtually unlimited flexi-



Fig. 3. - Photograph of Boeing 727-232 advanced transport aircraft

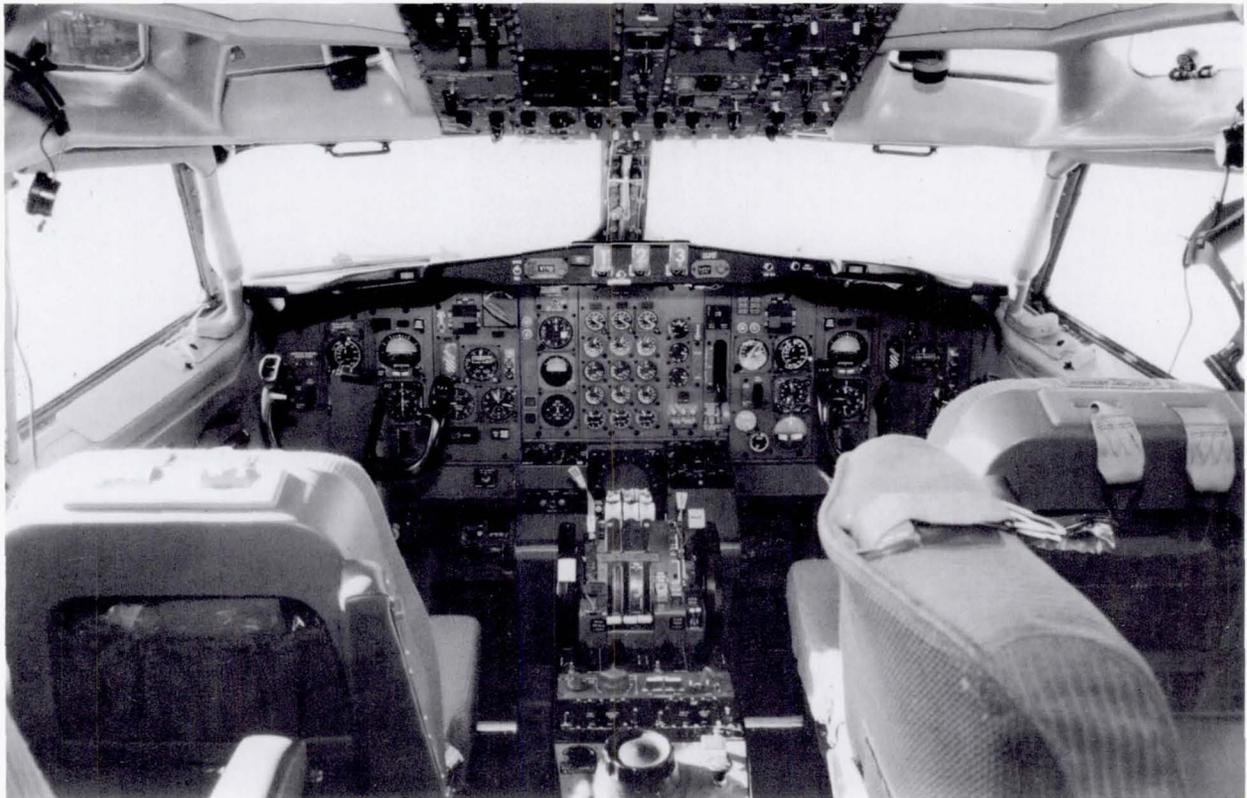


Fig. 4. - Photograph of crew compartment of Boeing 727-232 simulator

bility in information presentation and command and control by the aircrew. Such flexibility will permit the simulation of operations representative of those that may be possible with advanced aircraft and air traffic control concepts and equipment.

Both aircraft simulators can operate in conjunction with the facility's Air Traffic Control Simulator. The ATC simulator can be configured to represent either today's aviation system or various possible systems of the future. Connection of either the aircraft or the ATC simulator with the advanced air traffic control simulator at the FAA Technical Center in Atlantic City, NJ, may be possible in the future.

The research to be performed in the MVSREF demands highly representative external visual scene presentations in both aircraft cockpits. This facility is one of the first to employ Link's new-generation Image II visual system for this purpose.

2.1: Boeing 727-232 Simulator

A key component of the facility is a Boeing 727-232 flight simulator with a six degree-of-freedom motion system. Figure 3 shows the airplane. The simulator provides all modes of operation, including preflight, push-back, engine start, taxi, take-off, climb, cruise, descent, approach for landing, flare, touchdown, and park. The simulator crew compartment is a full-scale replica of a current airline cockpit; all instruments, controls, and switches operate as they do in the aircraft (Fig. 4). All functional systems of the aircraft are simulated in accordance with aircraft data. All normal and many abnormal procedures can be simulated.

Changes in aircraft attitude, thrust, drag, altitude, temperature, gross weight, center of gravity and configuration are accurately modeled. Ground effects are modeled, including tire and brake effects with various

runway conditions: dry, wet, icy, patchy wet, and patchy ice. Sounds simulated include those of power plants, aerodynamic noise, landing gear actuation, and runway effects. Auxiliary device sounds such as horn, bells and chimes are produced with actual aircraft hardware.

Simulator motion is provided by a six-degree-of-freedom synergistic system of an entirely new design employing advanced concepts to achieve the dynamic requirements of Federal Aviation Administration Advisory Circular AC 121-14C.

A hydraulic control-loading system simulates the characteristics of the aircraft's primary flight controls -- wheels, columns and rudder pedals. Changes in the amount of movement and force on the controls are a function of aircraft acceleration, velocity, configuration, center of gravity and the type of control system peculiar to the aircraft. It is expected that this simulator will be eligible for Phase 2 FAA certification in accordance with FAR part 121, Appendix H.

2.2: Advanced Concepts Flight Simulator

The ACFS flight crew station is a unique design that more closely resembles a generic operator's console than today's cockpits. Such a design is feasible because of the expected development of fly-by-wire or fly-by-light flight and thrust control systems without mechanical redundancy. Such advanced systems will eliminate the requirement for large, cumbersome control columns and mechanical throttle levers, permitting designers to make other use of the critical space presently occupied by these controls. Features such as a desk-top design, small side-stick controllers, location of other controls and displays for convenient access and optimal visualization become possible. The ACFS is being developed jointly by NASA and the Lockheed-Georgia Company.

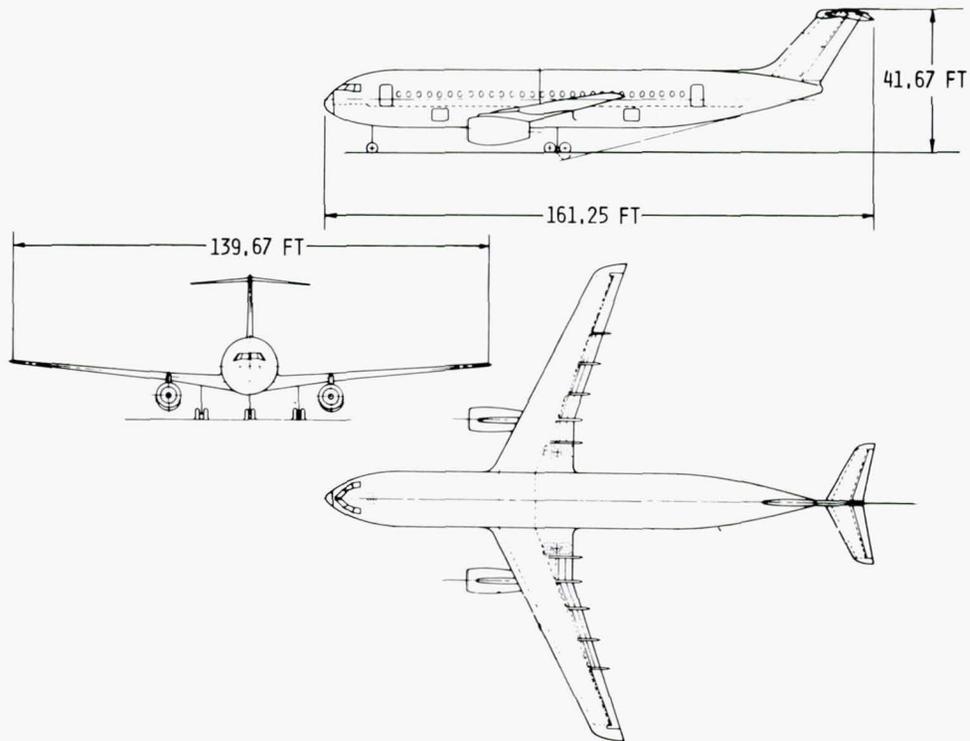


Fig. 5. - Design sketch of Lockheed 1995 transport aircraft

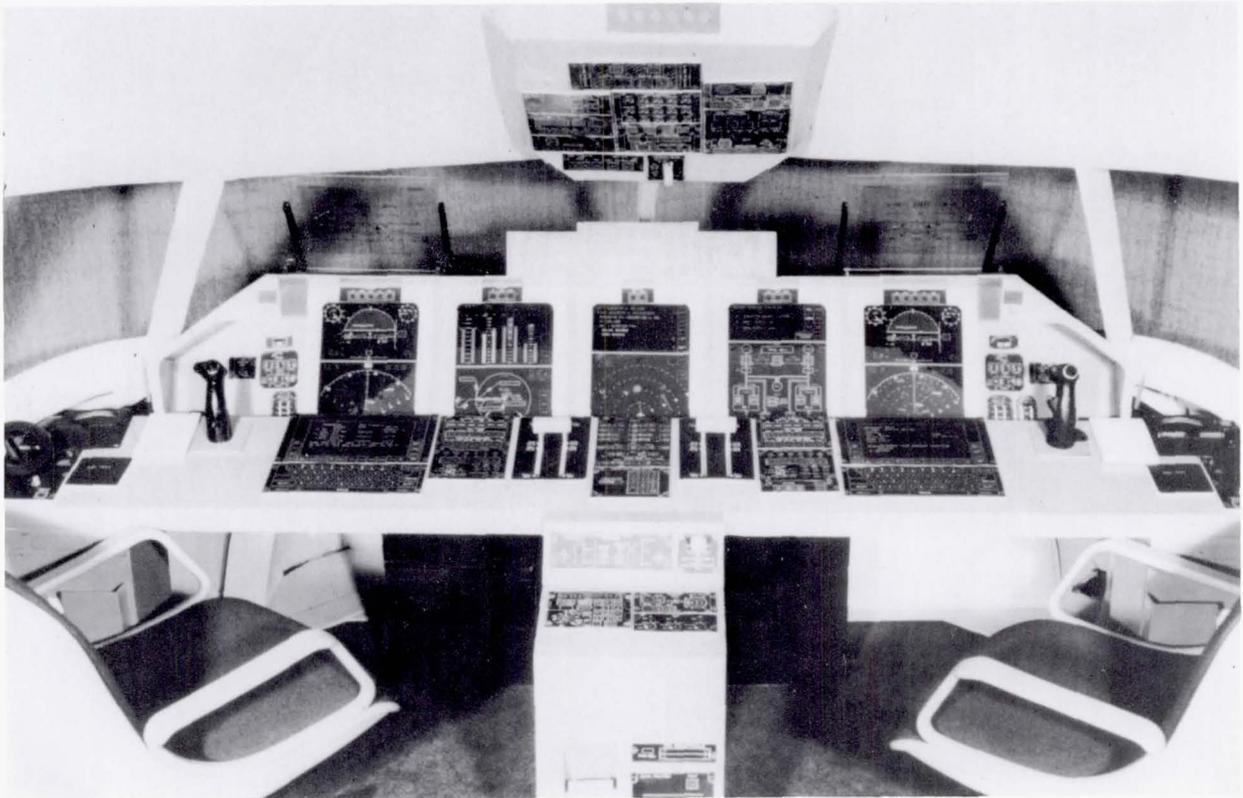


Fig. 6. - Advanced flight crew station of Lockheed 1995 aircraft simulator

Within the next few years, advances in display technology will make possible the use of large, high-resolution, color, flat-panel displays. The ACFS functionally emulates such displays by five vertically oriented 13-inch diagonal, color, cathode ray tubes mounted side by side on the main instrument panel, and two monochromatic, flat-panel displays on the desk top. The three center displays and the two flat-panel displays have touch-sensitive panels over their faces to provide pilot control of aircraft and navigation systems.

The ACFS design architecture provides the flexibility to alter aircraft design and operating characteristics as well as pilot station information and control characteristics through high level software changes in the host computers. Though the aircraft is hypothetical, the design is complete enough to permit full-mission simulation in a normal transport operating environment, as in the Boeing 727 simulator. The aircrew can interface with the outside world, air traffic control, and all functional aircraft systems, while performing typical (or atypical) flights.

2.2.1: ACFS Aircraft Description

The advanced concept generic aircraft was formulated and sized on the basis of projected user needs in 1995 and a hypothetical technology cutoff date of 1990. This concept led to the design of a hypothetical aircraft shown in figure 5, with the following characteristics:

- o Maximum gross weight - 223,740 thrust each engine
- o Payload - 60,000 pounds; capacity - 200 passengers
- o Twin engine - 29,566 pounds thrust each engine

- o Speed - 0.78 Mach; range - 2500 miles
- o Flight crew - two persons
- o All-electric airplane (no hydraulics)
- o Fly-by-wire (or -light); active flight controls
- o Negative static margin; load alleviation
- o T-tail, low wing, supercritical airfoil
- o Composites for primary and secondary structures
- o High-density fuel

2.2.2: Baseline Flight Station Geometry

The baseline flight station is designed for operation by a two-pilot crew. It is configured so that all controls pertinent to operation of the aircraft are accessible for operation by both pilots (Fig. 6).

All controls and displays are placed in a convenient location for the pilots on the main instrument panel, desk top, glare shield, center console, overhead console, and side pedestals. Figure 7 (next page) shows the baseline layout of the various components.

The main instrument panel contains five multifunction electronic displays (three with touch panel overlays) upon which the majority of information for the pilot is presented. The desk top contains the nosewheel steering controls, side-arm controllers, control/display units, integrated comm/nav system, throttles, parking brake, rudder pedal adjust, coffee cup holders, and ash trays.

The controls for the automatic flight control system, auto-throttle engage, altitude alerting systems, barometric pressure and radar altimeter set knobs, and the master caution and warning lights are located on the glareshield. The overhead console

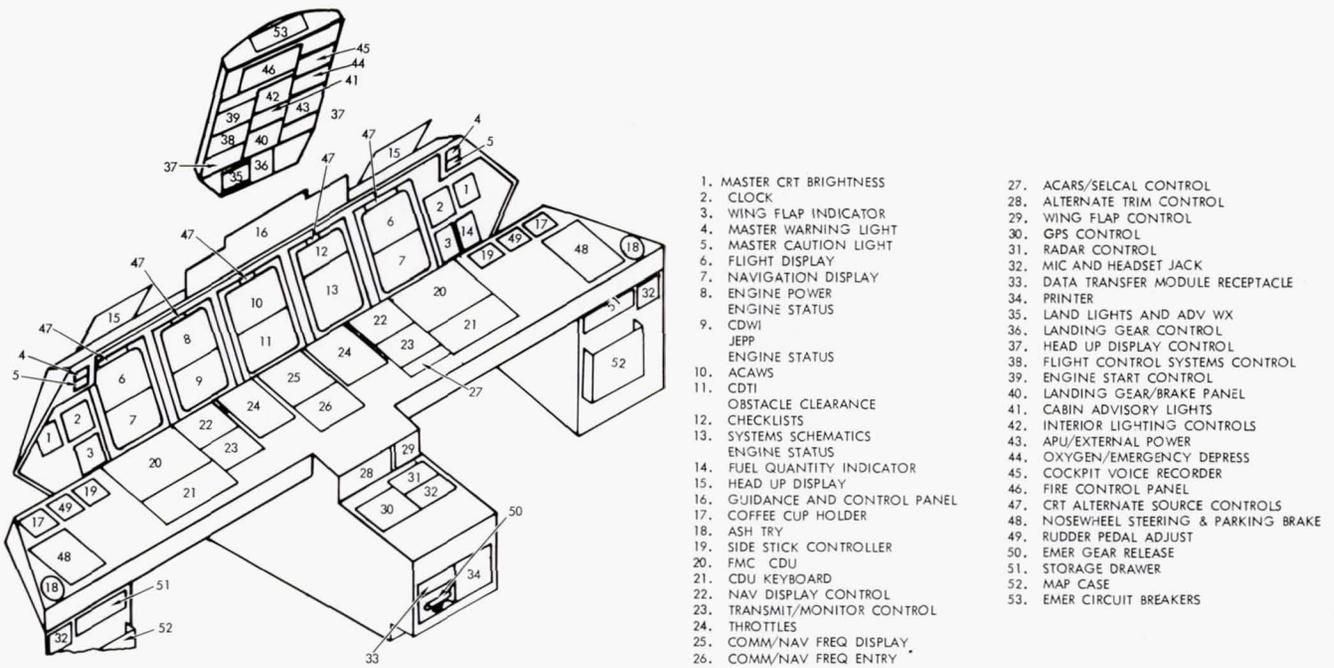


Fig. 7. - Advanced concepts flight simulator: Baseline crew station

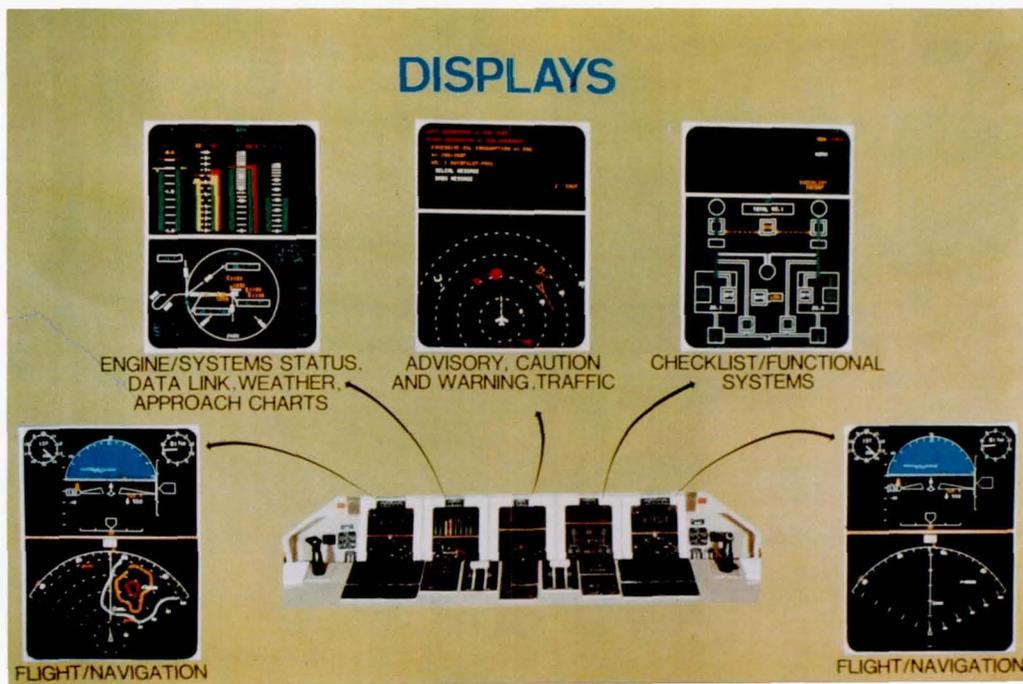


Fig. 8. - Advanced concepts flight simulator: Baseline displays

contains controls for the fire control system, engine start, flight control system, head-up displays, interior and exterior lights, landing gear, brake system, oxygen system, cockpit voice recorder, auxiliary power unit, adverse weather system, and emergency circuit breakers. The center console contains controls for the alternate trim system, wing flaps, global positioning system, radar, printer, data transfer module, and emergency landing gear release. The side pedestals contain oxygen and smoke mask storage units, microphone and headset jacks, drawers for storing papers, and chart and map storage areas.

Most of the controls are of the lighted push-button variety, which are easy to use, offer a clean, uncluttered appearance, and eliminate protrusions. While the switch labels are readable under any lighting conditions, the circuits are designed so that the switch lights are only illuminated under abnormal circumstances. This provides for a dark cockpit when systems and switches are normal.

All formats required for a baseline full-mission simulation have been developed and assigned to each CRT, as shown in figure 8. Inherent flexibility of this system, however, permits reasonably easy changes in formats and locations. In the baseline configuration the flight and navigation displays present all of the information typically found in the standard "T" on the pilots' instrument panels.

A voice command and response system in the baseline design has a single mode of speech recognition and three types of speech synthesis.

A flight management computer is available to the flight crew which in the baseline design contains the executive and applications software necessary to support the aircraft flight profiles and performs the following functions:

1. Operating System
2. Flight Planning
3. Navigation & Steering
4. Performance Management
5. Displays Formatting
6. Navigation & Communications
Tuning Support
7. System Test & Monitoring
8. Voice Command & Response

An integrated communications and navigation system is also provided in the baseline design.

ACFS software is designed in a modular fashion to permit future alteration or expansion of the baseline design. For example, various future airborne and ground-based air traffic control systems are currently under study. Incorporation of a specific system into the baseline ACFS design would typically involve only recoding of the specific functional module and perhaps redesign of the appropriate display graphics. Full documentation of the ACFS, including the underlying mathematical models and documentation of the software, is a part of the ACFS system.

2.3: External Visual Display

The Image II visual system is a compact flight simulator attachment which presents computer-generated color scenes representing the outside world. These scenes normally depict specific airports and their surroundings, as viewed at dusk or night from the cockpit. Enroute visual scenes are also simulated.

Night scenes include light points, horizon glow, and runway markings and textures in the area illuminated by the simulated aircraft's landing lights. In dusk conditions, ground surface and building textures are shown in addition to the light points (Fig. 9). At all times, occulting of lights, surfaces, and horizon glow by intervening surfaces is simulated.

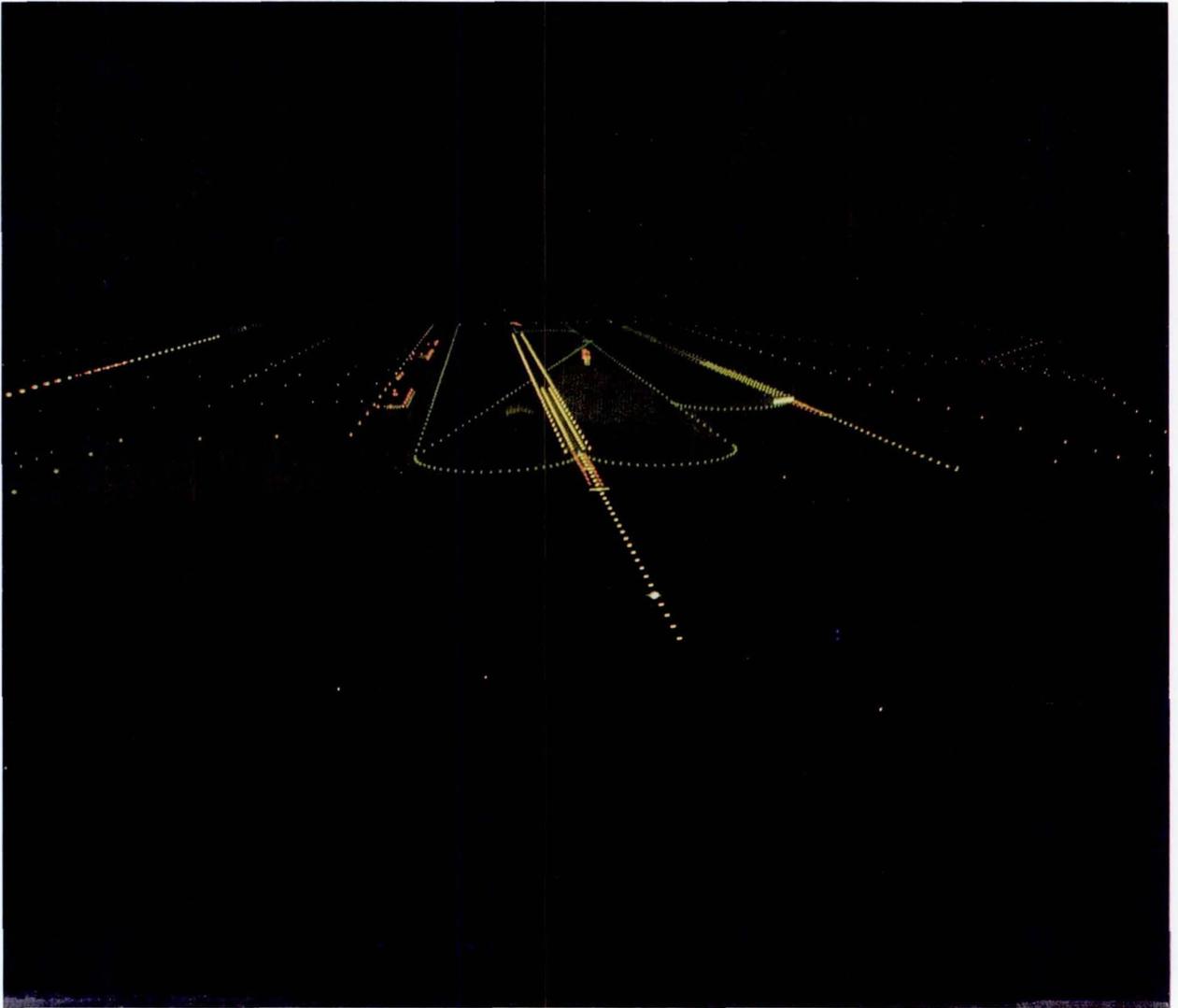


Fig. 9. - Image II dusk scene; aircraft on final approach

Thirty-two occulting surfaces and levels are provided. The system can create strings of random lights in addition to curved strings.

Airport scenes initially available will include:

Amsterdam - Schipol
 Atlanta - Hartsfield
 Boston - Logan
 Chicago - O'Hare
 Denver - Stapleton
 London - Heathrow
 Los Angeles International
 Manchester, England
 Minneapolis, Minnesota
 New York - Kennedy
 Pittsburgh, Pennsylvania
 Prestwick, Scotland
 San Francisco International
 Seattle-Tacoma, Washington
 Stockton, California

2.4: Air Traffic Control Simulator

The Air Traffic Control (ATC) environment is a significant contributor to the workload, and therefore to the performance, of crews in flight. As a result, the usefulness of a full-mission simulator is greatly affected by the realism with which the ATC environment is modeled. The MVSRF ATC environment has been developed by the Massachusetts Institute of Technology.

From the crews' standpoint, this environment consists of dynamically changing verbal or data link messages, some addressed to or generated by them, others addressed to or generated by other aircraft flying in the immediate vicinity.

The dynamic nature of ATC is achieved through the use of "operators" manning the equivalent of an ATC controller station, and controlling both the test aircrew and a number of other aircrew whose actions may interfere with the test crew's actions. Controllability and repeatability of an experiment is achieved by an ATC Script Mechanism which al-

lows the experimenter to exercise varying degrees of control over the performance of the "operators" as well as the timing of simulation events.

In order to provide a maximum of flexibility in the scope of experiments as well as in their preparation, the ATC simulator is capable of operating in three modes:

1. Standalone, without required participation by the rest of the facility;
2. Single-cab mode, with either the advanced or conventional cab actively participating in the study, and
3. Dual-cab mode, with both cabs actively participating.

To increase simulation flexibility, the ATC simulator provides three independent controller stations. These stations can be reconfigured from one simulated geographical area to another in less than 60 seconds, allowing the simulated control positions to "leapfrog" in order to follow the progress of a mission. Single-controller operation is also possible for simpler missions, albeit with some loss of realism.

The training required of the controller operators has been reduced by three means: first, the format of the displays has been modified from that of the current NAS and ARTS systems to be oriented toward the needs of an engineer or an experimenter rather than toward an experienced professional controller; second, some automated aids have been added to assist the operator in the controlling task; and third, a script mechanism is available to assist all the operators, ATC and pseudo-pilots with the "canned" or static part of the simulation scenario. Three pseudo-pilot stations are provided, each able to control up to 12 pseudo-aircraft simultaneously, for a maximum total traffic of 36 aircraft.

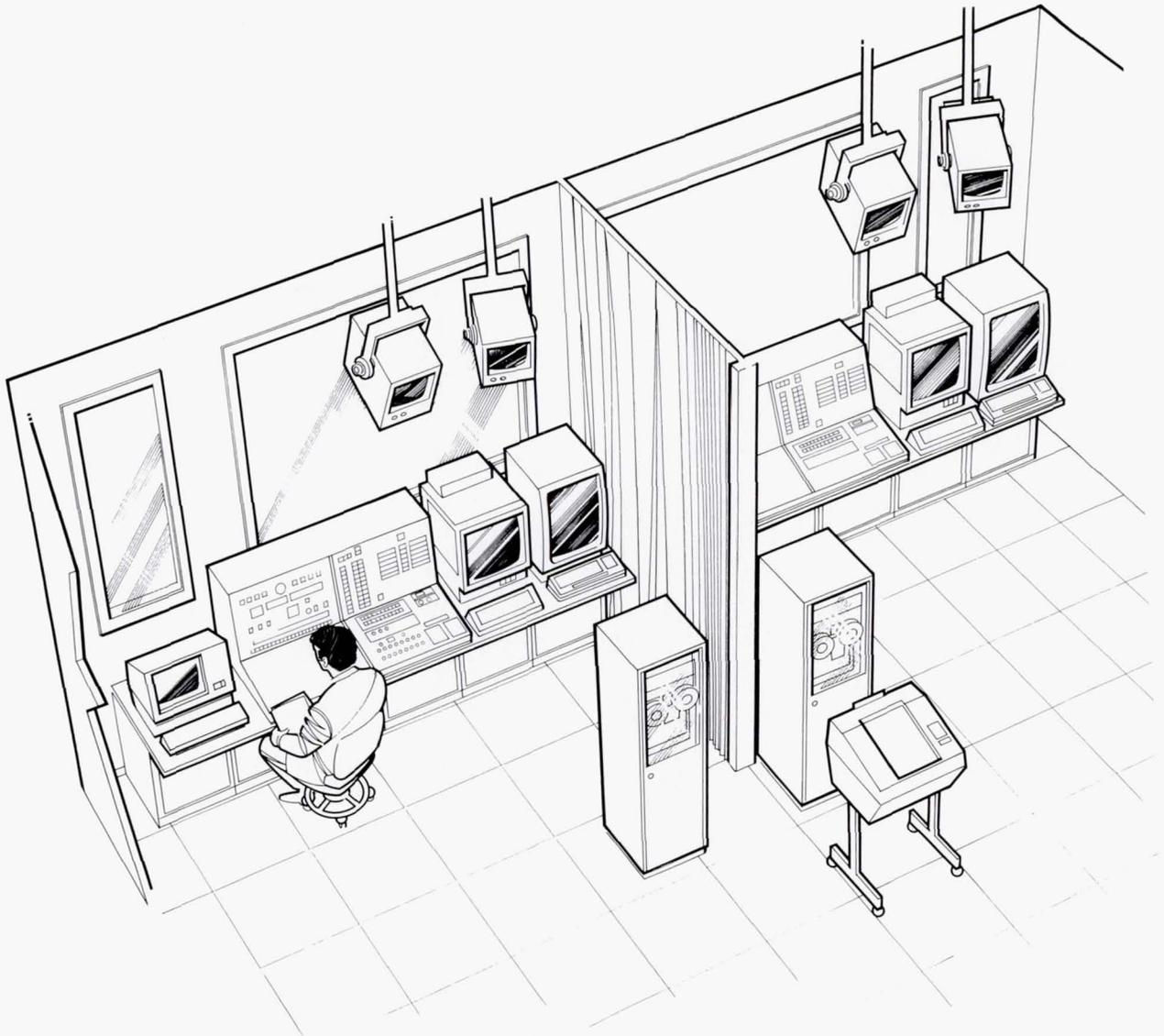


Fig. 10. - Experimenter station

3. EXPERIMENTER INTERFACE

It is assumed that most investigators will wish to observe, record and where possible, quantify many aspects of flight crew behavior during studies in the MVSRF. The aim of the facility is to permit fine-grained evaluation of individual and crew performance under a wide variety of circumstances. The system will be able to assist the observer to document his own observations. It is capable of being tailored to meet the needs of individual investigators, but a core of basic data will always be obtained in order to build a MVSRD database on flight crew behavior in full mission simulation.

The experimenter interface is flexible enough to permit its modification in the light of increases in our knowledge of performance assessment in line-oriented simulation. Subroutines can be altered as necessary to achieve desired processed results. It is anticipated that much or most of the basic data collected will be useful for a considerable period of time and that experimenters will want to have repeated access to it.

3.1: Experimenter Station

Two experimenter stations are provided, one for each of the flight simulators. They are colocated and may be reconfigured to support future experiments involving simultaneous operation of both flight simulators. Each experimenter station contains two computer graphic display systems, keyboards and terminals for interacting with the simulation computers, status lights and emergency controls, communication systems, and other equipment useful or necessary for controlling the flight simulators and conducting simulation experiments. Figure 10 shows one of the stations.

Each experimenter's laboratory also contains an audio station so that experimenters may communicate

with the simulator flight crews during an experiment or with observers located "on-board". Under certain circumstances, the experimenters can act as air traffic controllers or as pilots of other aircraft, to reduce the number of personnel required to conduct certain simulations. In addition to the main experimenter consoles, two experimenter (or observer) stations are located aboard each of the flight simulators. Equipped with a graphic system, keyboard, and other controls and communicators, these stations may be used to perform most of the functions that are possible in the remote stations. It is also possible to communicate with the Air Traffic Control simulator from each of the experimenter stations.

The computerized script mechanism allows the experimenter to control the performance of any of the operators in the ATC simulator (controllers and pseudo-pilots) while at the same time allowing the operators to react in realistic ways to unforeseen changes in the simulation event baseline.

3.2: Data Collection and Analysis

Data collection within the MVSRF is very flexible. Each of the flight simulator data variables within a "global data pool" may be sampled according to the needs of the experiment or simulation. While there exists an upper limit to the total amount of data which may be sampled and stored, this limit is large. The typical practice is to sample and store a selected number of variables, each of which is time coded to facilitate later analysis. Following completion of a simulation, this data file is available for postexperimental analysis.

The ATC simulator maintains a separate data collection capability. ATC simulation data also are time-stamped and may be merged with the data from the piloted simulators following completion of a given simula-

tion or experiment. As noted above, selected variables may be monitored in real time during the course of a simulation. Repeater display systems are also located in each experimenter station so that the progress of a flight can be closely monitored by the experimenter. It is also possible to record time-coded communications between simulator crew members and ATC personnel (or experimenters) for correlation with the objective flight data.

Other measurements of crew behavior and performance can be effected as experimental needs dictate. Closed circuit TV monitoring and recording are possible, if required. Direct observation and monitoring of flight crew behavior and performance are also possible from within each

simulator cab through use of the experiment/observer station. Data thus recorded can be integrated with the remaining simulation data. A "replay" capability for each simulator allows limited recreation of portions of simulated flights or ATC scenarios when desired. The simulations can also be "frozen" at selected points within the simulation if required by the experimenter.

Postexperimental and postsimulation data analysis may be performed within the MVS RF. A variety of standard statistical and other analysis packages are available. Special analyses, of course, may also be developed on an individual basis. (A very limited amount of real-time data analysis may be possible during some simulation experiments).

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16. Abstract <p>The Man-Vehicle Systems Research Facility (MVS RF) will uniquely provide the capability of simulating multiple aircraft (two with full crews), en route and terminal Air Traffic Control (ATC) and aircrew interactions, and advanced cockpit (1995) display technology representative of future generations of aircraft, all within the full-mission context. The characteristics of this facility derive from research, addressing critical human factors issues that pertain to: (1) information requirements for the utilization and integration of advanced electronic display systems, (2) the interaction and distribution of responsibilities between aircrews and ground controllers, and (3) the automation of aircrew functions. This research has emphasized the need for high fidelity in simulations and for the capability to conduct full-mission simulations of relevant aircraft operations. This report briefly describes the MVS RF design and operating characteristics.</p>			
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