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DESIGN RATIONALE AND PERFORMANCE SPECIFICATIONS FOR A VISUAL FLIGHT RESEARCH FACILITY (VFRF)

Final Technical Report - November 1975

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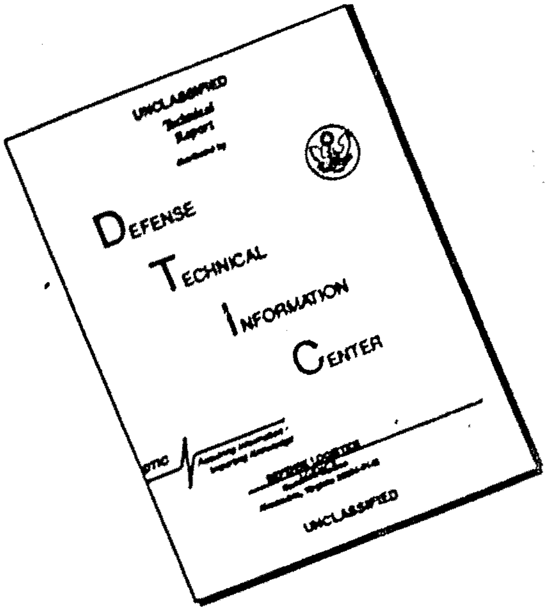

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This report documents a concept definition study for a Visual Flight Research Facility (VFRF) oriented toward research on nighttime Nap-of-the-Earth flight. A VFRF System Specification includes performance, design, development, and test requirements for an approach to achieving displayed windscreen image fidelity to actual night viewing conditions, and to allowing measurement of visually dependent flight crew tasks.

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FOREWORD

This concept definition study was performed by Martin Marietta Aerospace, Orlando Division, for the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI), Arlington, Virginia, under Contract DAHC 19-74-C-0065.

The encouragement, guidance, and direct assistance provided by Dr. Aaron Hyman, COTR, and Mr. Halim Ozkaptan, Alternate COTR, contributed materially to the successful completion of this task. Their contributions, plus the excellent cooperation of the ARI Contracts office and all levels of ARI management, are gratefully acknowledged.

DESIGN RATIONALE AND PERFORMANCE SPECIFICATIONS FOR A VISUAL FLIGHT RESEARCH FACILITY (VFRF)

BRIEF

This report documents the results of the concept definition study for a Visual Flight Research Facility (VFRF) conducted by Martin Marietta, Orlando Division for, and in conjunction with, the U. S. Army Research Institute for the Behavioral and Social Sciences (ARI), Arlington, Virginia.

The principal objective of this study can be summarized as follows: to define the integrated VFRF system concept best satisfying the requirements for a flexible facility oriented toward Nap-of-the-Earth (NOE) flight research (as opposed to operational flight training). The selected initial design shall permit accurate and repeatable measurement of helicopter flight crew visually-dependent task performance --both individual and coordinated types-- over a wide range of simulated night Nap-of-the-Earth conditions.

The primary purpose of this planned visually-oriented research is to bring about significant improvement in crew performance and safety by gaining a better understanding of existing problems and limitations, and by evaluating the effectiveness of various potential aids* and of modified crew operating procedures specific to the nighttime NOE operating environment.**

Key research objectives and related behavioral and functional requirements for the VFRF were identified initially by ARI, and subsequently refined in a joint effort with Martin Marietta as

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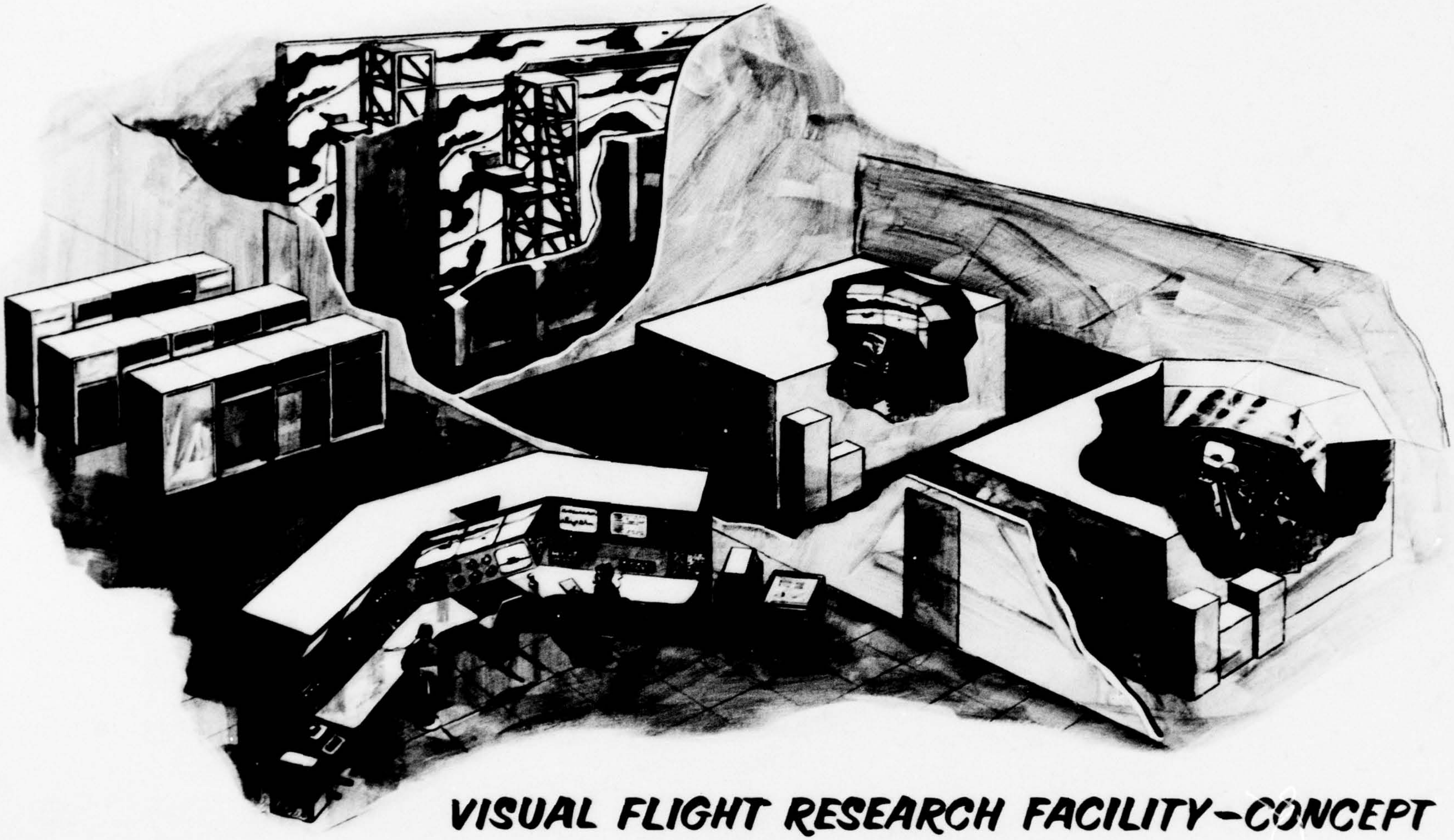
* In certain cases using special electro-optical (E-O) sensor techniques to simulate physical E-O hardware/systems

** Refer to ARI Technical Research Report, "Behavioral and Functional Requirements for a Visual Flight Research Facility", H. Ozkaptan April 1975.

this program progressed. These requirements formed the basis for the system and subsystem conceptual design and trade studies included in the Technical Supplement. These studies in turn provided the technical rationale for selection of the VFRF approach determined most cost effective in terms of: (1) achieving displayed wide field-of-view windscreen image fidelity approaching "perceptual equivalence" with real-world nighttime direct viewing conditions, and (2) providing the capability of performing an adequate range of high priority, nighttime NOE visually-related research tasks, with acceptably low development risk and in the earliest time frame consistent with established objectives and requirements.

Based on the results of the above study tasks, the VFRF System Specification was prepared. As a principal output of this study program, this specification includes the general performance, design, development, and test requirements for the selected approach. The selected system concept consists of the following principal functional areas: Primary and Secondary Operator Compartments, Test Station Complex, Image Generation, and Image Display.

Figure 1 depicts the basic VFRF system concept consisting of the above-listed areas, together with associated operating personnel and test subjects. Primary and Secondary Operator Compartments (flight crew station research modules) are located in the right forward area, each containing both windscreen and special electro-optical (E-O) image display elements (the nature of the research task determines which crewmember occupies which compartment). The Test Station complex including system control, monitoring, and measurement consoles, plus associated computational and support equipment are shown in the forward central and left regions. The System Control Operator (SCO) is at the left console and the Measurement Control Operator (MCO) at



VISUAL FLIGHT RESEARCH FACILITY—CONCEPT

Figure 1

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the right console. In these positions they each have unobstructed views of the central monitoring console elements, including selected critical visual displays. In those tests involving only one crewmember (pilot or copilot --located in the Primary Operator Compartment) the MCO can represent the other crewmember by moving to the central Monitoring station and perform simplified but necessary NOE flight functions --in coordination with the crewmember being evaluated. The final major functional area, located to the rear in this figure, contains the terrain model/probe/TV type image generation hardware. These coordinated subsystems furnish video signals to the simulated nighttime windscreen display and special E-O sensor display equipment, the latter providing simulations of key signal characteristics of vehicle-borne LLL-TV or FLIR systems.

Figure 2 further identifies major elements of the basic VFRF system. Differences between the Primary and Secondary Crew Stations are of special interest. The Primary Crew Station incorporates the added sophistication and capabilities of an "infinity" type windscreen display, pilots' basic flight controls and flight instruments, dynamic seat (G-seat), and physical measurement equipment (not shown). By means of the interfacing and computational functions available with the computer system, the pilot-operator, when positioned in this compartment, can effectively "fly" the windscreen image pick-up device (and slaved E-O sensor device -- to represent installed or pod-mounted sensor hardware) in unprogrammed paths over the respective terrain models.

In simulated dynamic flight, the windscreen display imagery derived from that pick-up device is accurately correlated with physical onset acceleration cues produced by the G-seat to provide the effective illusion of vehicle movement in any or all six degrees

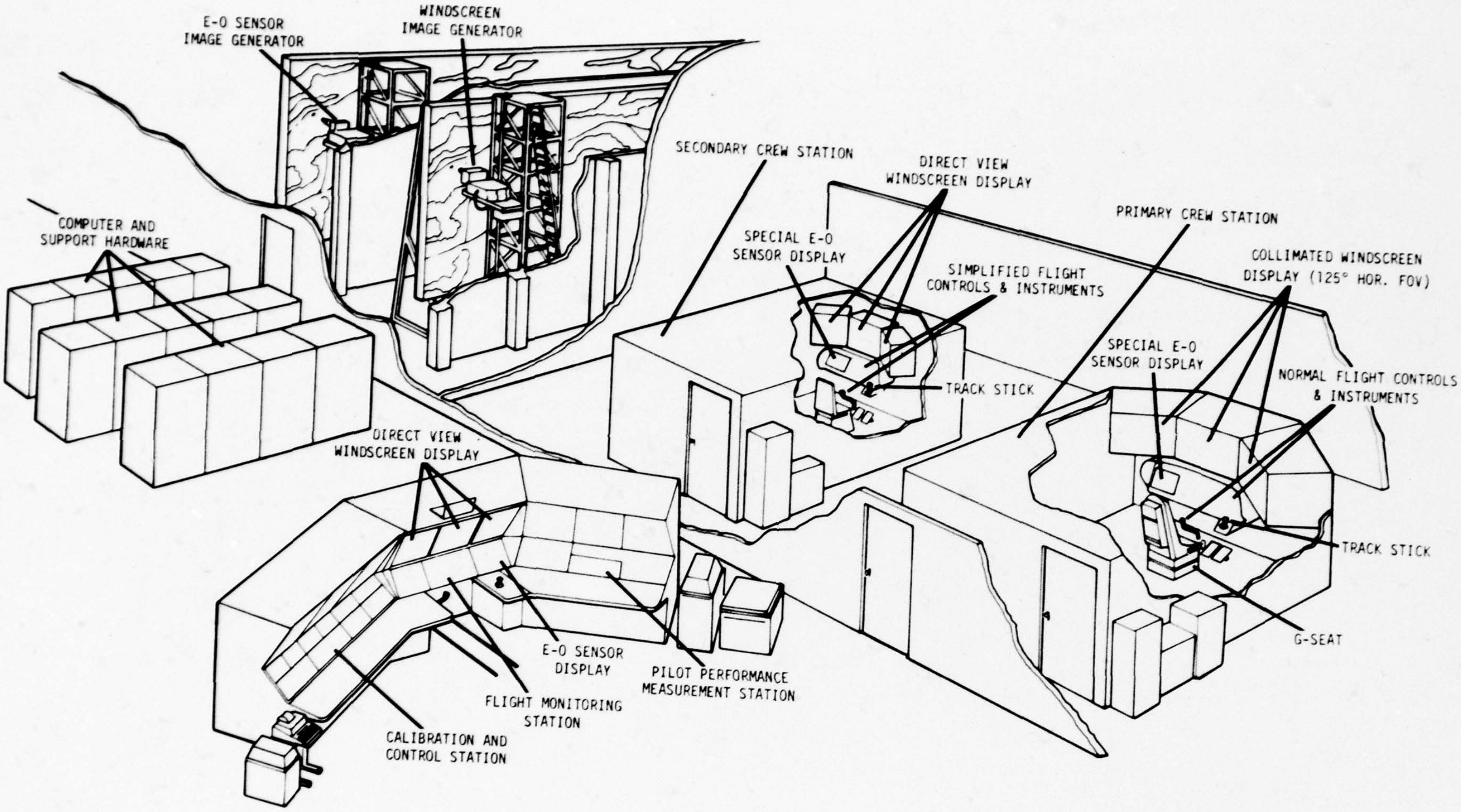

Figure 2 - Major Elements of Basic VFRF System

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of controlled flight motion. The level of flight fidelity achieved will be commensurate with visual flight research needs and objectives; that is, basically to provide sufficiently realistic operator flight task loading to validly assess the effectiveness of the potential visual aids in simulated NOE nighttime missions including selected work methods and procedures. This is expected to require a lower level of hardware complexity than is used in trainer-specific dynamic flight simulators, where all aspects of every flight mode must also be addressed and transfer of simulator flight training to the real-world flight environment is of prime importance.

In those research tasks where copilot/navigator/WSO functions are of primary interest (e.g., in acquiring navigational checkpoints, or other targets, with the aid of the special E-O sensor -- using a manual track stick or helmet sight for line-of-sight, LOS, alignment) that crewmember will operate from the Primary Compartment. This position provides the maximum level of test realism and also permits the MSO to make the desired range of behavioral measurements during each test sequence. In those tests where coordinated crew tasks are involved, the pilot crewmember will operate from the Secondary Compartment. Otherwise, in individual operator tests, the MSO can assume simplified piloting functions as previously noted.

Provision is made in the basic system design to incorporate, with a minimum of change to the basic facility, growth items including:

- Second crewmember compartment with an "infinity" type windscreen visual display subsystem equivalent to that used in the Primary Crew Station;

- A six degree-of-freedom motion base physically and functionally compatible with the crewmember compartment design.

Thus, as research needs subsequently expand, the total VFRF system can expand in corresponding fashion in order to satisfy the additional requirements.

DESIGN RATIONALE AND PERFORMANCE SPECIFICATIONS FOR A VISUAL FLIGHT RESEARCH FACILITY (VFRF)

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ILLUSTRATIONS

DESIGN RATIONALE AND PERFORMANCE SPECIFICATIONS FOR A VISUAL FLIGHT RESEARCH FACILITY (VFRF)

I. INTRODUCTION

The U. S. Army currently is placing increased emphasis on helicopter missions flown in the NOE (Nap-of-the-Earth) regime, especially under low light level conditions. NOE tactics have been shown to significantly enhance crew and aircraft survival probability in a hostile environment by minimizing exposure to enemy defenses. At the same time, NOE tactics, properly executed, can increase mission effectiveness by adding the important element of surprise through quick reaction strikes initiated from a concealed position.

Aircrew tasks in the NOE flight regime are quite demanding, and compared to conventional higher altitude rotary and fixed wing flight, distinctively unique --particularly in terms of the extreme and continual dependence placed on visual contact with various real world objects (natural and man-made) in essentially all phases of NOE operations.

In order to increase NOE flight crew effectiveness and safety in this environment, various Army agencies have recognized the need for additional research in the area of NOE visually-directed flight, both in the procedures employed and in the evaluation of various potential visual aids to the flight crew. The operational problems become increasingly acute with degraded vision experienced under atmospheric haze conditions and under lower scene illumination levels. The hazards, technical difficulties, and high cost of conducting extensive, controlled NOE in-flight research under realistic field conditions become extreme, particularly under these degraded viewing conditions.

Recognizing these problems, the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) Arlington, Virginia, has initiated an effort to define and to develop a unique simulation facility dedicated primarily to NOE visual flight research (as distinguished from NOE flight training), and identified as the Visual Flight Research Facility (VFRF). Here, greatest initial emphasis is to be placed on the high priority NOE-related needs which involve controlled studies of the complex interactions of the flight crew, their direct visual stimuli with simulated real-world imagery, the stimuli provided by various visual aids, and their NOE operational tasks. Accordingly, ARI set out to define the key research objectives and the behavioral and functional requirements which such a facility should satisfy. These are documented in the ARI Technical Research Report, "Behavioral and Functional Requirements for a Visual Flight Research Facility", H. Ozkaptan, April 1975.

The initial ARI effort preceeded the Martin Marietta study task summarized herein. These two efforts then were pursued essentially in parallel to arrive at: (1) the critical behavioral and functional characteristics which the VFRF should embody (near-term and longer-term), and (2) the selection and definition of the most cost-effective VFRF system concept which satisfies key ARI-defined research needs.

The following sections identify the major study objectives and the basic approach followed by Martin Marietta in the conduct of this VFRF system concept definition study. The major requirements derived from the ARI definition task are then summarized. In addition, the results of related Martin Marietta requirements analyses are defined, since these combined inputs formed the basis for the system and subsystem conceptual design and trade studies which have been conducted. These latter studies provided the technical basis for the selection of the preferred VFRF approach from among the candidate systems available. The final sections of this report identify the key candidate systems and associated subsystems, present the rationale and selection criteria employed in the system selection process, and then define the selected basic VFRF system concept in terms of key performance requirements, key interfaces, and general design characteristics. Finally, areas for potential system growth are identified, in keeping with the ARI "stay young" approach involving planned, systematic development and expansion in two or more program phases.

II. STUDY OBJECTIVES

The initial principal Martin Marietta study objective was to define the integrated VFRF system concept best satisfying the requirements for a flexible research facility, permitting accurate evaluation and improvement of helicopter flight crew visually-dependent performance in simulated day and night NOE missions. Broad program objectives were addressed. For initial development, however, the following guidelines were used: (1) The study would be tailored to be most responsive to the highest priority NOE research needs, and (2) The study would be strongly influenced by VFRF system capability limitations imposed by the current state-of-the-art in visual flight simulation technology.

Research on night NOE flight operations was identified as having highest initial priority. Based on analyses performed on daylight visual systems, it became clear that from the technology standpoint, displayed windscreen image fidelity approaching a level "perceptually equivalent" to the real world conditions can best be achieved for simulated nighttime conditions. This results from the fact that visual acuity and color perception characteristics are significantly degraded at the lower brightness levels; thus the demands on the visual display system are correspondingly relaxed, compared to those for a "perceptually equivalent" day (and night) windscreen visual display system.

III. STUDY APPROACH

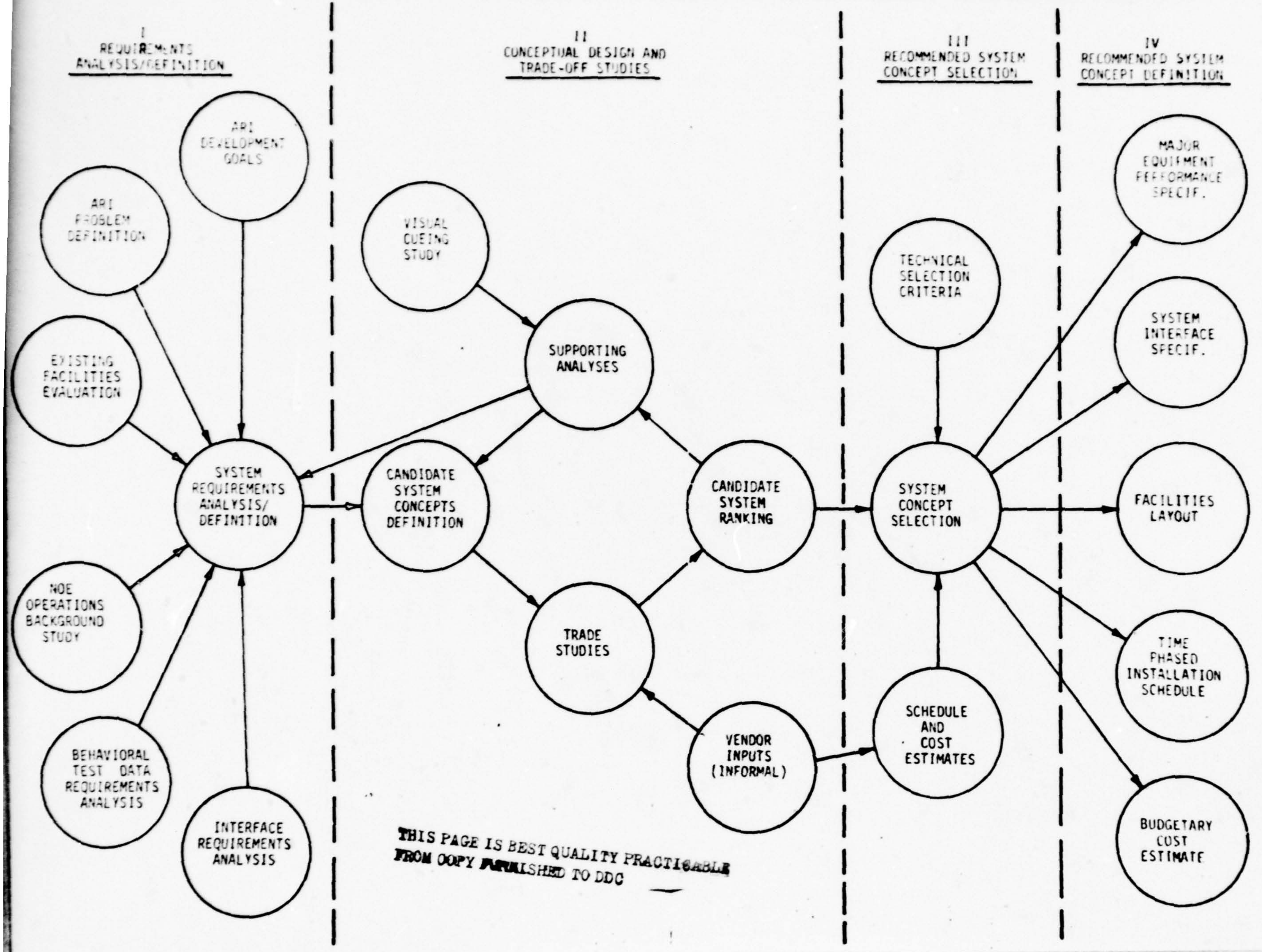
The VFRF/NOE study approach followed by Martin Marietta was divided into four major task areas, namely; Task I - Requirements Analysis/Definition, Task II - Conceptual Design and Trade-Off Studies, Task III - Recommended System Concept Selection, and Task IV - Recommended System Concept Definition. This study approach is depicted in chart form in Figure 3.

Referring to this figure, within each general task area will be seen various subtasks which collectively provided the necessary inputs to accomplish the objectives of the identified major tasks. In summary, Task I defined basically what is required of the VFRF from a functional and behavioral standpoint, Task II determined potentially the most feasible and desirable system candidates and implementations for the VFRF (based on system and subsystem analyses and trade studies), Task III evaluated the candidate systems against appropriate selection criteria, and provided the basis for recommending a basic VFRF system design concept, and finally, Task IV defined this recommended system concept in terms of a system design and performance specification directed toward subsequent VFRF system development.

IV. REQUIREMENTS ANALYSIS/DEFINITION

The following summary information represents the results of the previously identified combined ARI and Martin Marietta requirements-related study efforts. Collectively they represent the

Figure 3 VISUAL FLIGHT RESEARCH FACILITY STUDY TASK APPROACH



basic functional and behavioral requirements which the selected VFRF system concept is to satisfy to the maximum extent feasible within the limits of current state-of-the-art technology.

1. VFRF Research Scope and Goals

Initial emphasis will be directed toward the low light level flight regime. The main research problem areas to be addressed by the VFRF are:

- Visual Capabilities
- Visual Aids/Sensors
- Display Parameters
- Pilot Proficiency
- Crew Coordination
- Navigation
- Cockpit Layout

The principal research goals of the VFRF are to enable basic and applied studies leading to new information and advances in the state-of-the-art, with emphasis on exploratory studies and new concepts. Specific goals in this respect are as follows:

- To assess basic pilot visual capabilities,
- To investigate new visual aids and display concepts,
- To establish visual requirements and display design criteria,
- To evaluate alternative sensor systems*, techniques, and procedures,
- To conduct comparative hardware* and concept studies,

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* Using special E-O sensor techinques to simulate physical hardware/systems.

- To provide latitude for serving allied visual problem areas within the Army, such as surveillance, target acquisition, and remotely piloted vehicles (RPVs).

2. Key Features and Characteristics of the VFRF

Key VFRF features include the following:

- Wide angle visual display of the external world suitable for psychophysical studies,
- High caliber electronic and television subsystems to achieve the necessary quality and control of visual parameters,
- Helicopter controls and instrumentation at a level of simulation complexity adequate for behavioral studies,
- Comprehensive experimenter's control and monitoring station,
- Cockpit provisions and interface equipment for various visual aid devices,
- Multiple stimulus materials and sensors for the visible and simulated infrared range,
- Computer facilities for physical simulation, experimental control, data recording and pre-processing.

Special VFRF characteristics include:

- Control and repeatability of system parameters (including displayed image resolution, brightness and contrast levels, controlled flight compartment illumination etc.),

- Multiple levels of parameter control,
- Comprehensive interrelationship of parameters,
- Wide scope and latitude of potential studies,
- Flexibility of utilization,
- Comprehensive performance measurement (behavioral and physical) and data recording/reduction capability.

3. NOE Flight Functions and Characteristics, and Related Visual Effects

The VFRF design will incorporate sufficient flexibility to permit simulation of a broad range of NOE missions. In the course of various mission-related experiments, flight crew functions subject to measurement and evaluation shall include:

- Basic pilot NOE flight operations, including terrain and obstacle avoidance, hover, and special flight (including pop-up maneuvers);
- Copilot/navigator/WSO functions, including terrain surveillance and navigation, target search, acquisition (at near recognition thresholds)-- with and without special E-O sensor aids-- plus sensor-aid LOS alignment; and,
- Crew-coordinated and directed NOE flight and various related communications functions.

Flight characteristics associated with the above NOE missions can be typified as follows:

- Flight altitudes typically at and below tree-top level;
- Flight velocities ranging from zero (hover) to approximately 100 knots (maximum daylight conditions);
- Frequent azimuth heading changes and unlimited freedom in azimuth;
- Frequent angular accelerations of short duration in roll and pitch;
- Nominal maximum attitude change of $\pm 45^{\circ}$ in roll and $\pm 25^{\circ}$ in pitch;
- Translatory motion effects primarily sensed as vertical accelerations/decelerations of relatively low level;
- NOE flight path length typically of 25 km;
- NOE flight duration typically of 20 to 40 minutes.

Related visual effects associated with the above NOE missions are characterized by:

- Relatively short viewing ranges;
- Large visual field of view (instantaneous and total);
- Dependence upon a wide variety of scene cues for maneuverability;
- Intense visual concentration;
- High angular velocities of the viewed scene (especially on nearby peripheral objects);

- Frequent noncorrespondance between the visual line-of-sight and the flight vector;
- Significantly reduced visual cues with lower illumination levels;
- Criticality of depth and distance judgement;
- Limited time for reaction.

4. General VFRF Requirements Summary

To simulate the task environment with adequate fidelity to support the defined research and experimental objectives, the following general requirements for the VFRF system can be stated:

- The displayed windscreen scene will be responsive to, and coordinated with, pilot control movements in 6 degrees of freedom (DOF).

- The simulated flight compartment portion of the system will furnish acceleration cues to the pilot that are responsive to, and coordinated with, pilot control movements.

- Special E-O sensor display image source(s) will be provided with an additional 2 DOF beyond the helidopter's 6 DOF to simulate attachment to the exterior of the helicopter body. These additional degrees of freedom will be in azimuth and elevation for stabilized LOS tracking and surveillance functions.

- Pilot and copilot/navigator/WSO studies will be conductable independently or in coordination. Simplified flight control functions and simplified navigation criteria will be available to permit non-flight qualified operators to perform basic NOE flight functions in support of tests conducted on qualified operators.

- Typical crew coordinated NOE missions will extend for a 20 to 40 minute time period, with a desired total time of simulated flight of 90 minutes. A nominal one hour of this time preceding the NOE phase may consist of precision maneuvers at higher altitudes, under IFR conditions in simulated clouds or other adverse weather.

V. VFRF CONCEPTUAL DESIGN AND TRADE-OFF STUDIES

Overall system level and major subsystem level conceptual design and trade studies were conducted during this program phase in arriving at the recommended general system approach best suited to meet the defined research requirements/objectives, and the combination of principal subsystem approaches which collectively provide the most cost-effective, flexible implementation of the basic VFRF system concept.

The following summary subsections, (1) identify the basic visual flight simulation system concepts considered, (2) describe the principal factors involved in selecting the terrain model approach as the preferred method, and (3) identify the principal terrain model system options which were evaluated --these being formed by various combinations of subsystem configurations. These areas are covered in detail in the Technical Supplement, under the appropriate analysis and trade study sections.

1. Candidate System Identification

Each candidate system considered had to perform certain common basic functions in order to satisfy (with various levels of effectiveness) the above-defined requirements. For purposes of this study, these functions were grouped within several major functional subsystem blocks, namely; the experimental complex, control complex, image generation complex, and image presentation complex.

The system configuration trade study resulted in the identification of four candidate system concepts --identified on the basis of the image source/image generation method employed-- as follows:

- Film system(s) --Still and cine type projectors;
- Transparency system(s) -- Point light source and flying spot scanner types;

- Terrain model system -- Optical probe/TV camera pickup;
- Large scale computer generated imagery (CGI) system.

2. System Level Trades and Recommended System Approach

The system candidates were evaluated with respect to four major criteria:

- Experimental capability
- Implementation complexity
- Implementation risk
- Implementation cost

While generally satisfying the latter three evaluation criteria, both the film system and the transparency system candidates were found to have serious drawbacks from the standpoint of providing adequate experimental capability. Each of these candidates effectively satisfied only one out of the group of NOE mission-related flight crew functions identified for measurement and evaluation in the VFRF. This factor was considered sufficient reason to eliminate them from detailed consideration.

Of the remaining two candidate systems, the terrain model concept, while far from simple in terms of actual hardware implementation, was still considered less complex, lower risk, and of lower cost than the CGI approach (based on the use of a truly flexible CGI system with very large edge generation capability required to provide adequate image realism on the wide FOV windscreen display). Accordingly, the terrain model system concept was selected as the most cost effective VFRF approach.

3. VFRF Terrain Model System Options

Subsystem analyses and tradeoffs specific to the terrain model approach produced a potentially large number of candidate system configurations when the various combinations were identified. By using a preliminary screening process in which the various options were ranked on the basis of their research potential, plus gross cost, complexity, and development risk factors, the number of terrain model system options was narrowed to eight, which treated E-O sensors as an option. The decision to incorporate the E-O sensor capability in the basic VFRF system design reduced the number of options to four. Table 1 identifies these candidates in terms of windscreen image generation method and windscreen image display/ experimental station configuration employed. Also, major system elements common to all four candidates are identified.

TABLE 1

VFRF SYSTEM OPTIONS

Option	Windscreen Image Generation		Windscreen Image Display/Configuration					
	Color Day/Night	Monochrome Night-Only	Experimental Station ∿ Infinity Display Type				Remote Crewmember Station ∿ TV Monitor Direct View Type	
			Dual Cockpit		Single Cockpit			
			Color Day/Night	Monochrome Night-Only	Color Day/Night	Monochrome Night-Only	Color Day/Night	Monochrome Night-Only
#1	x		x					
#2	x				x		x	
#3		x		x				
#4		x				x		x

NOTE: Above system options have the following common system elements:

- o Motion simulation subsystem
- o Simulated E-O sensor visual display system
- o Experimental Station subsystems (excluding windscreen display)
- o Test/Control Station Complex subsystems

VI. VFRF SYSTEM CONCEPT SELECTION AND DEFINITION

This section summarizes the criteria employed jointly by ARI and Martin Marietta in the selection of the recommended basic VFRF system option (from the four candidate approaches--see Table /) and then identifies the recommended concept. This is followed by a summary of basic system characteristics and key interfaces, with emphasis on visual aid devices for potential use in low light level NOE flight research.

1. Selection Criteria

The previous section discussed the system-related criteria used in arriving at the four terrain model-type system options considered for the basic VFRF design. Therefore, this section purposely is limited to a discussion of those selection criteria specific to these final four options. The principal criteria used were as follows:

a. Range of NOE Visual Research Tasks Permitted--The selected system concept must have sufficient capability to allow the conduct of pilot-oriented, of copilot/navigator/WSO-oriented, and of various levels of coordinated NOE crew visual flight research tasks.

b. Ability to Perform High Priority NOE Visual Flight Research--Evaluation of aircrew night vision capability in the simulated nighttime NOE environment, and methods of improving performance and increasing survivability, are currently among the most critical NOE problems which can be addressed in visual flight research.

c. Psychophysical Validity of Windscreen Display Imagery--A windscreen display capability is required which will permit the conduct of valid psychophysical experiments; that is, tests that can be expected to produce results which will approximate the visual performance levels achieved in the real world.

d. State-of-the-Art Status---This criterion is seen to potentially impact development risks, development costs, and development time. Since early availability at moderate cost is of considerable significance in this program, selection of state-of-the-art approaches is considered very important.

e. Task Loading Realism--The crewmember(s) under test must be subjected to appropriate NOE flight task loadings in order to validly evaluate the effectiveness of added visual aids, or a change in operational procedure, etc.

2. System Ratings and Recommended Basic VFRF System Concept

A qualitative evaluation method was used in arriving at the recommended system approach. Table 2 summarizes the ratings on the four options based on the above-defined selection criteria.

On the basis of these ratings, System Option #4(1) was selected as the most cost-effective approach to accomplish an acceptable range of high priority, nighttime NOE visual-related research tasks, with acceptably low risk and in the earliest time frame.

3. Basic VFRF System Characteristics and Functional Interfaces

Figure 4 is a functional diagram of the selected basic VFRF system concept. This diagram reflects the results of the

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(1) Single operator in the Experimental Station (Primary Operator Compartment) and second operator located at remote crewmember station (Secondary Operator Compartment)--Employs a monochrome, night-only image generation/windscreen display system.

TABLE 2

VFRF SYSTEM OPTION RATING

Criteria	System option (1)			
	#1	#2	#3	#4
• Range of NOE Visual Research Tasks Permitted	Good	Acceptable	Acceptable to Good	Acceptable
• Ability to Perform High Priority NOE Visual Flight Research	Acceptable	Acceptable	Acceptable	Acceptable
• Psychophysical Validity of Windscreen Display Imagery	Acceptable-Night Marginal-Day	Acceptable-Night Marginal-Day	Acceptable-Night N/A-Day (2)	Acceptable-Night N/A-Day (2)
• State-of-the-Art Status (Incl. Develop. Risk, Cost and Time Implications)	Marginal	Marginal	Marginal to Acceptable	Acceptable
• Task Loading Realism	Good	Acceptable	Good	Acceptable

(1) System Options -- (from Table 1)

#1 - Dual Cockpit -- Full color, day/night system
#2 - Single Cockpit, Second Operator Remote - Full color, day/night system
#3 - Dual Cockpit -- Monochrome, night-only system
#4 - Single Cockpit, second operator remote -- Monochrome, night-only system

(2) N/A - not applicable for rating

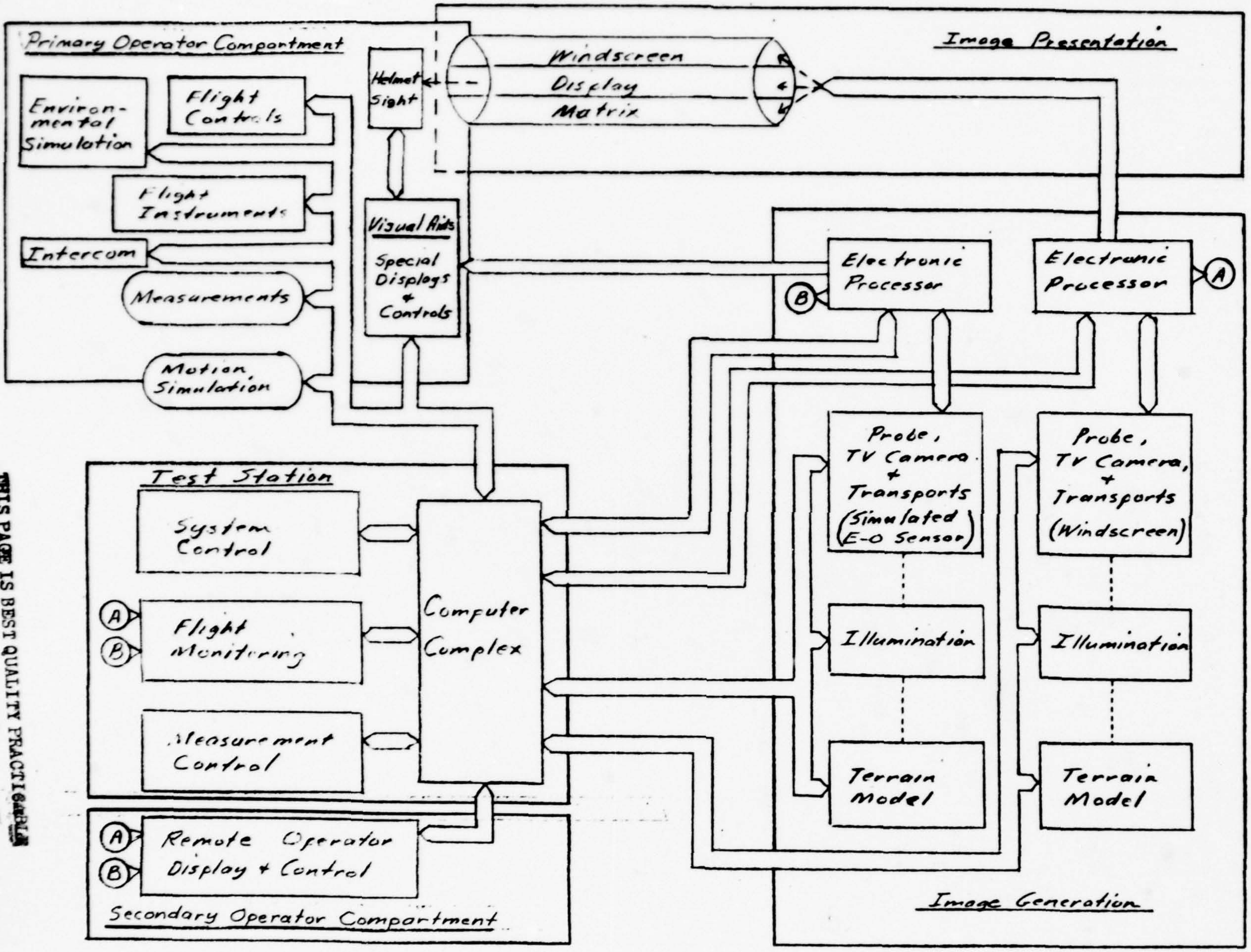


Fig.4 - VFRF SYSTEM DIAGRAM

subsystem trades and supporting analyses included in the Technical Supplement as well as the system option ratings given immediately above.

The selected system concept permits extensive research on nighttime NOE visually-dependent tasks:

- Primarily involving the pilot--including terrain and obstacle avoidance, and special flight (including hover).
- Primarily involving the copilot/navigator/WSO--including NOE navigation, target search and acquisition, and LOS alignment on selected targets (using visual aids).
- Coordinated crew tasks--including various directed-NOE flight functions.

The system design provides the capability to evaluate the the operators' basic visual performance in the above task areas, and permits research on the effectiveness of various low light level aids to these crew functions. A summary of key system, subsystem, and interface characteristics which enable this system approach to satisfy the basic VFRF functional and performance requirements outlined in Section IV is given below.

The principal system functional areas depicted in Figure 4 are: Primary Operator Compartment, Secondary Operator Compartment, Test Station Complex, Image Generation, and Image Presentation. The latter two functional areas can be recombined (from a physical hardware standpoint) to form two major system elements--windscreen visual display system and special (simulated) E-O sensor visual display system.

a. Visual Display Systems

These systems are designed and interfaced to function in the following manner:

Simultaneous and separate generation and presentation of two sets of simulated real-world imagery--wide FOV monochrome nighttime windscreen displayed imagery, and variable FOV displayed imagery (also monochrome) capable of simulating the output of special E-O sensor aids (principally LLL-TV and FLIR)--are accomplished by the use of two terrain model/optical probe type systems. These systems produce precise, coordinated, translatory movements (X,Y, and Z--longitude, latitude, and altitude) to achieve the effect of the sensor aid system being attached to the simulated helicopter airframe (e.g., pod-mounted). In the "caged" mode, the optical axis of the special sensor is effectively fixed relative to the airframe--and thus the windscreen probe--such that the effects of pitch, yaw, and roll angular motion, plus all X,Y, and Z motions, will result in coordinated image movements both on the windscreen display and on the special sensor display(s).

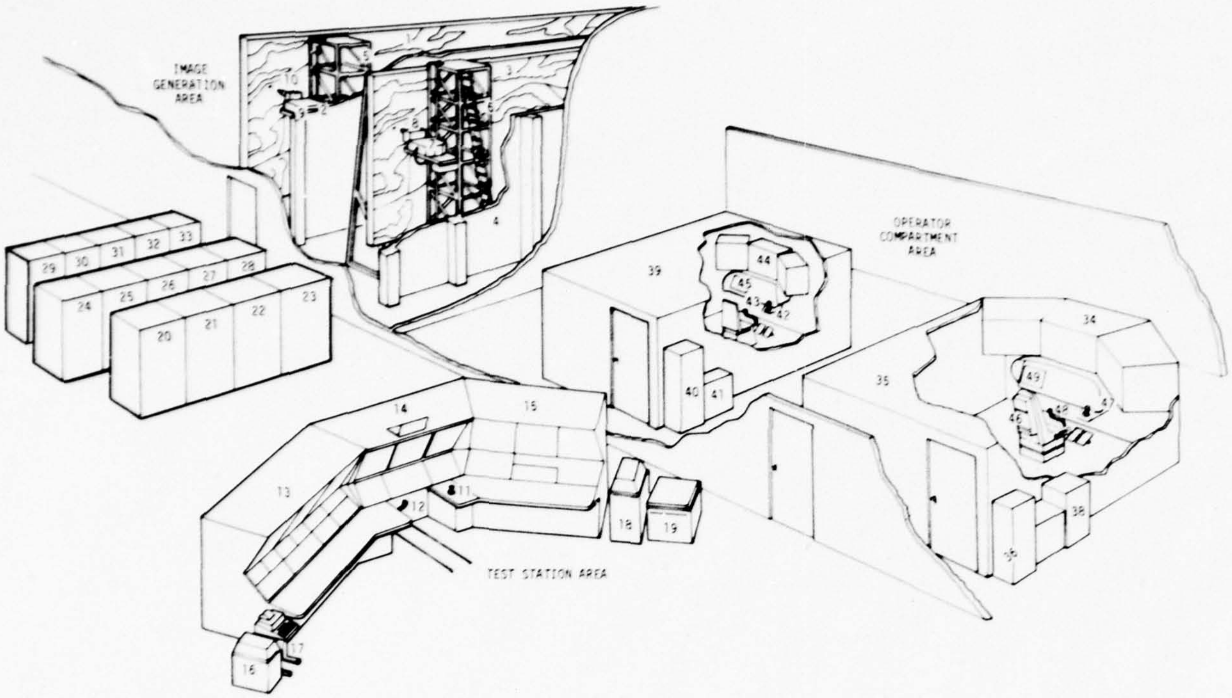
As seen in Figure 4, the windscreen visual display system includes the following principal subsystems: three-dimensional terrain model (model board), model illumination, wide FOV optical probe, monochrome TV camera pick-up, gantry/servo-controlled transport, electronic processor(including special effects generation--meteorological type), and collimated virtual image type windscreen display. With overall Test Station integration and control, this system is designed to cause the windscreen display to properly respond to the pilot subject's flight control commands in all six degrees of freedom (DOF). Effectively, the operator is provided with nonprogrammed, simulated helicopter flight capability in three-dimensional space. He accomplishes this simulated flight by remotely controlling, via the computer interface, the position and pointing of the windscreen probe relative to its associated terrain model--using normal, or in some cases, simplified helicopter flight controls.

When the simulated E-O sensor system control is switched to the "uncaged" mode, the test subject has the freedom to remotely control--by use of a manual track stick, of by use of a servoed helmet sight--the pointing of the simulated E-O sensor axis in pitch and yaw, independent (within specified design limits) of the simulated attitude of the helicopter airframe, as denoted by the scene orientation presented on the windscreen display. In this mode, the special sensor unit (probe) is "decoupled" from the airframe simulated roll motions, thus providing the effect--on the special display(s)--of roll-stabilized sensor operation. The sensor FOV size also is selected by the operator as a function of the particular task being performed(e.g., terrain avoidance, target search, target acquisition/recognition etc.).

From Figure 4 it is seen that the simulated E-O sensor aid visual display system is composed of the following subsystems: the second 3-D terrain model (dimensionally "identical" to the windscreen model board), model illumination, variable FOV optical probe, special monochrome TV camera pickup, gantry/servo-controlled transport, electronic processor (including special effects generation and specialized sensor signal processing), and special displays. As in the case of the windscreen visual display system, the Test Station provides integration and overall control of the special E-O sensor visual display system functions. Figure 5 identifies the hardware items associated with the basic VFRF system layout.

From the review of principal elements comprising the two visual display systems, it is evident that most of the corresponding elements perform similar basic functions within their particular system. However, their detailed requirements and resulting characteristics (both physical and performance) are substantially different--the principal exceptions being the terrain models, from the standpoint of dimensional and model configuration similarities, and the gantry/transport subsystems (except in those characteristics affected by the weight differences between the two probe/TV camera pickup subsystem configurations). Therefore, the summary system characteristics, subsequently provided, note the principal areas of commonality between the two visual display systems and also the critical functional and physical interface areas which affect the total integrated visual display system simulation fidelity.

At this point, the principal elements and functions of the additional major VFRF system functional areas--*Primary Operator Compartment, Secondary Operator Compartment,* and Test Station Complex--will be reviewed prior to a quantitative summarization of VFRF system characteristics.



ELEMENT NO.	IDENTIFICATION
1	TERRAIN MODEL - E-O SENSOR
2	MODEL ILLUMINATION - E-O SENSOR
3	TERRAIN MODEL - WINDSCREEN
4	MODEL ILLUMINATION - WINDSCREEN
5	GANTRY/TRANSPORTS - E-O SENSOR
6	GANTRY/TRANSPORTS - WINDSCREEN
7	TV CAMERAS - WINDSCREEN
8	OPTICAL PROBE - WINDSCREEN
9	TV CAMERA - E-O SENSOR
10	OPTICAL PROBE - E-O SENSOR
11	TRACK STICK
12	FLIGHT CONTROLS (SIMPLIFIED)
13	SYSTEM CONTROL STATION
14	FLIGHT MONITORING STATION
15	MEASUREMENT CONTROL STATION
16	CHART RECORDER
17	TELETYPEWRITER
18	CHART RECORDER
19	POSITION PLOTTER
20	COMPUTER CONTROL
21	PUNCHED TAPE READER
22	TAPE PUNCH
23	LINE PRINTER AND CONTROLLER
24	AUDIO ELECTRONICS
25	DIGITAL COMPUTER - CPU #1
26	DIGITAL COMPUTER - CPU #2
27	DISK OPERATING SYSTEM - CPU #1
28	DISK OPERATING SYSTEM - CPU #2
29	POWER CONTROL
30	INTERFACE D/A
31	INTERFACE A/D
32	AUXILIARY ELECTRONICS
33	AUDIO RECORDER
34	COLLIMATED WINDSCREEN VISUAL DISPLAY HOUSING
35	PRIMARY OPERATOR COMPARTMENT
36	INTERFACE CABINET
37	AIR CONDITIONER
38	G-SEAT CONTROLS/ACTUATORS
39	SECONDARY OPERATOR COMPARTMENT
40	INTERFACE CABINET
41	AIR CONDITIONER
42	TRACK STICK
43	FLIGHT CONTROLS (SIMPLIFIED)
44	DIRECT VIEW WINDSCREEN DISPLAY MATRIX
45	SPECIAL E-O SENSOR DISPLAY
46	G-SEAT AND VIBRATOR
47	TRACK STICK
48	FLIGHT CONTROLS
49	SPECIAL E-O SENSOR DISPLAY

Figure 5 - Basic VFRF System Layout and Hardware Identification

b. *Primary Operator Compartment*

Referring to Figure 4, this complex includes:

(1) Single crewmember simulated flight compartment (including flight controls and instruments).

(2) Wide FOV "infinity focus" type monochrome windscreen display -- provides 6 DOF scene dynamics via windscreen image generation system.

(3) Motion simulation (G Seat)-- To provide key acceleration "onset" cues coordinated with visual display -- (Plus seat vibration subsystem).

(4) Flight control and flight instrument responses adequate for NOE visual flight research (providing realistic pilot "task loading" minus trainer system sophistications not essential to flight research tests).

(5) Performance measurement instrumentation:

- o Human response type
- o Operational type

(6) Visual Aids, including the following: (Also see Table 3)

(a) Special displays (used to display simulated low light level E-O sensor imagery), using:

- o Direct view monitor(s)
- o Helmet-mounted display (1)
- o Head-Up Display (HUD)(1)

(b) Night viewing aid -- Night vision goggles

(c) Track stick -- For manual control of special E-O sensor pointing

(d) Helmet sight (cueing aid for target search, acquisition, and recognition using E-O sensor system)

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(1) Basic VFRF system design makes provision for integration of these units.

Table 3 VFRF VISUAL AIDS SUMMARY

	Internal to Primary Operator Compartment		External to Primary Operator Compartment	
	Pilot-Oriented Experiments	Copilot/Navigator/WSO Oriented Experiments	Remote Operator (In Secondary Operator Compartment)	Measurement Control Operator (at Flight Monitoring Station)
BASIC VFRF ELEMENTS	(1) Monitor Display (LLLTV and FLIR) (2) **Night Vision Goggles** (3) **Symbology Generator**	(1) Monitor Display (2) Helmet-mounted Sight (3) Track Stick (4) Auto-track mode*	(1) Monitor Display (2) Track Stick (3) Night Vision Goggles (4) Auto-track mode* (5) **Symbology Gen.**	(1) Monitor Display (2) Track Stick (3) Auto-track mode*
INTERFACE PROVISIONS	(1) HUD (2) Helmet-mounted Display	(1) Helmet-mounted Display (2) Advanced Navigational Aids (3) Different CRT sizes and locations	(1) Helmet-mounted Display	

*Computer-controlled functions

(e) Advanced navigational aids(1)

(f) Symbology Generator --Generates the following symbology (at a minimum) for presentation on special displays:
  - Aircraft axis relative to E-O sensor LOS
  - Artificial horizon
  - Radar altitude
  - Airspeed
  - Torque (power margin)
  - Heading

(7) Environmental simulation, including the following:

(a) Controlled lighting (compartment and instruments) for simulated night NOE missions;

(b) Noise simulation (rotor, transmission, engine, radio interference --via the intercom).

(8) Flight intercom -- Tied to Test Station Complex and to Secondary Operator Compartment.

c. <u>Secondary Operator Compartment</u>

- Manned by second member of flight crew (pilot or copilot) - Includes:
- Simplified flight control, plus necessary complement of flight instruments;
- Direct view type windscreen TV display array;
- Special E-O sensor Track Stick, Symbol Generator and display(s);
- Controlled lighting of compartment interior and instruments for simulated night viewing conditions;
- Night vision goggles;
- Helmet-mounted display(1)
- Flight intercom -- Tied to Test Station Complex and to Primary Operator Compartment;
- Noise simulation (rotor, transmission, engine, radio interference -- via the intercom);
- Controlled lighting (compartment and instruments).

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(1) Basic VFRF system design makes provision for integration of these units.

d. Test Station Complex

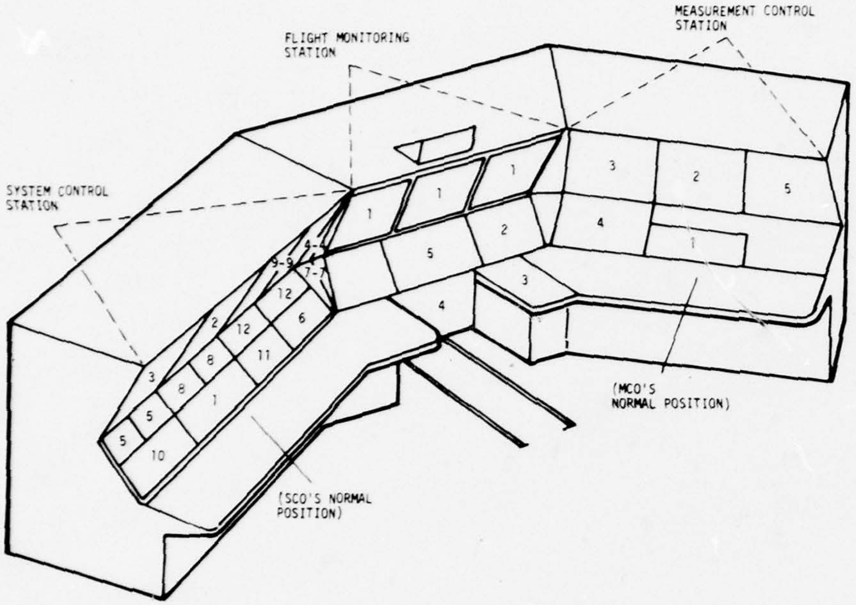
This complex includes the integrated system control, monitoring, and measurement consoles, plus the computer system and related support equipment. Figure 6 identifies the major functional control and display areas on this total console. A summary description of these Test Station elements follows:

(1) System Control Station

- o Manned by System Control Operator (SCO);
- o Contains the controls and displays required to operate and calibrate all visual stimulus mechanisms in the VFRF, via the computer -- including CRT-keyboard interface;
- o System calibration, monitoring and checkout controls and displays
- o Also contains all mechanical and electrical operational safety interlock controls;
- o SCO is responsible for safety of operation during all tests.

(2) Measurement Control Station (MCS)

- o Manned by Measurement Control Operator (MCO) -- also termed "Experimenter";
- o Contains the controls and display devices required to select the desired measurements, to operate the test measurement and recording equipment, and to



CONTROL/DISPLAY FUNCTION IDENTIFICATION

CONSOLE AREA	ITEM	FUNCTION
SYSTEM CONTROL STATION	1	KEYBOARD - COMPUTER INTERFACE
	2	CRT - COMPUTER INTERFACE
	3	MONITORING AND FAULT ISOLATING CRT
	4	LIGHTING CONTROL PANELS - WINDSCREEN AND E-O SENSOR
	5	PROBE CONTROL PANELS - WINDSCREEN AND E-O SENSOR
	6	MOTION SIMULATION CONTROL PANEL
	7	SYSTEM CALIBRATION CONTROL PANELS - WINDSCREEN AND E-O SENSOR
	8	TV CAMERA CONTROLS - WINDSCREEN AND E-O SENSOR
	9	SPECIAL EFFECTS SIMULATION CONTROL PANELS - WINDSCREEN AND E-O SENSOR
	10	TEST POINT PANEL
	11	CONTROLS AND SAFETY INTERLOCKS FOR DC POWER
	12	VIDEO TAPE RECORDER CONTROL PANEL
FLIGHT MONITORING STATION	1	WINDSCREEN DISPLAY - 3 TV MONITOR ARRAY
	2	E-O SENSOR DISPLAY
	3	E-O SENSOR TRACK STICK
	4	FLIGHT CONTROLS (SIMPLIFIED)
	5	FLIGHT INSTRUMENTS (BASIC)
MEASUREMENT CONTROL STATION	1	KEYBOARD - COMPUTER INTERFACE
	2	CRT - COMPUTER INTERFACE
	3	ANALOG CRT - HUMAN RESPONSE MEASUREMENTS
	4	COMMUNICATIONS SIMULATION CONTROL PANEL
	5	INDICATORS (CLOCKS, RECORDING ETC.)

Figure 6 - Test Station Control and Display Console Configuration

present selected data to the MCO for real-time monitoring and for post-exercise debriefing purposes. These functions are accomplished via the CRT-keyboard computer interface.

o MCO also may assume the secondary crewmember's function by performing simplified navigation or piloting functions from the Flight Monitoring Station Console area.

(3) Flight Monitoring Station

o When manned, the MCO shifts to this location -- time-sharing it with his Measurement Control functions.

o Contains:

- Direct-view type windscreen display array.
- Special E-O Sensor Track Stick and Display (see Visual Aids in Section b. (6)).
- Simplified flight control capability (including key flight instruments).

o Display outputs also are used by SCO in setting up initial test conditions and in periodic monitoring during test runs.

(4) Computer Complex

Consists of:

o General purpose commercially available computer of solid state, integrated circuit construction.

- Memory size -- At least 32,768 words
- Word length -- Minimum word length - 16 bits

o Interface for the total VFRF

- Peripheral equipment;
- All software required for VFRF to operate as a complete integrated system;
- The computer system will provide simultaneous computation for, and control of, all applicable Test Station functions and other equipment as required in the VFRF.

4. VFRF System Growth Areas

Two categories of growth items are identified below, the first being those items for which there is the higher liklihood of early incorporation in the VFRF and/or have a strong potential impact on the physical VFRF facility, and therefore must be considered in the basic system design to avoid major facility modifications if and when incorporated. The second category includes those items considered of a longer range nature.

Provision will be made in the basic design to interface with the items in the first category with a minimum of system modification. These items are:

- 6 DOF motion base;
- Second operator compartment with a collimated virtual image windscreen display subsystem equivalent to that in the Primary Operator Compartment (replaces the defined basic Secondary Operator Compartment);

Items included in the second category are as follows:

- Small scale computer generated imagery (SSCGI) for detailed terrain model lighting and/or for special targets;

- Daylight, high resolution, full color windscreen visual display system, including TV camera(s) and collimated virtual image display subsystems;

- Simulated wire avoidance sensing device (including integration with existing cockpit displays);

- Moonlight and sun simulators for terrain models and operator compartments;

- Capability to operate with altērnate cockpit configurations.

VII. VFRF System Summary Characteristics*

1. Windscreen Visual Display System

a. Terrain Model

- Scale 600 to 1
- Orientation - Horizontal or vertical - contractor option
- Size - Total area ≥ 1600 sq. ft.
  - Max. form factor - 3 to 1
  - Max. height (if vertical) - 24 ft.
  - With 3 to 1 form factor, size ≈ 24 x 66.5 ft.

    Scaled Size ≈ 4.4 kM x 13 kM
- Terrain/Targets
  - Rolling, moderately hilly type terrain, including rivers, streams, variety of roads, houses, bridges, railroad tracks, small farm, plus typical small rural towns (three). Towns to include area-type lighting (e.g., house windows and parking areas.)
  - Two types of terrain areas and tree distributions to be used--one typical of Ft. Rucker, Ala. area, and one typical of Central Europe (approx. equal areas).
  - Variety of military vehicles
  - Electrical power poles
- Coloring- Realistically colored.
- Typical NOE course length ≈ 20 kM
- Typical NOE flight time on model ≈ 15 minutes at average velocity of 40 knots

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* Refer to TECHNICAL SUPPLEMENT of this report for design rationale.

b. Terrain Model Illumination

- Type - Spectral output to provide reasonable match with TV camera sensor spectral response (to achieve illumination efficiency), while providing a displayed gray scale characteristic similar to that perceived by direct-viewing of the real world under LLL conditions.
- Illumination level on model - Determined by camera sensitivity and optical probe characteristics. (≈ 100 ft. candles estimated).
- Light pulse frequency - Phased to produce 360 pulses/second (nominal).

c. Optical Probe

- FOV -- 140° circular
- Effective focal length, EFL-- 6.5 ± 0.5mm
- Entrance pupil diam.-- 1 mm
- T number-- T/10.5 (nominal)
- Primary image format-- 17 mm diam. for 140° FOV
- Focus range-- 1.4 inches to infinity
- Focus control-- Remotely controllable with positional feedback capability
- Tilt focus correction - Schiempflug type
- Mapping -- $h = F\theta$ type
- Resolution across FOV at infinity focus

Semi-field Angle	Angular Resolution (nominal)
0°	3 arc min.
50°	4 arc min.
65°	7 arc min.

- Resolution at center of field vs altitude

Altitude	Angular Resolution (nominal)
∞ to 35 mm	3 arc min.
15 mm	5 arc min.
6 mm	7 arc min.

- MTF (object in plane of best focus, for visible spectral range of 400 to 700 nanometers).

  1 On-axis --70% of diffraction limit

  2 30° Off-axis-- 50% of diffraction limit.

- Optical Coupling -- Image generated by probe objective will be reimaged into the TV camera system via relay lenses. Use of field divider to share horizontal FOV among multiple TV cameras is allowable provided that field division is not accomplished in the straight-ahead position.
- Roll control excursion-- Unlimited.
- Pitch control excursion-- + 25°; - 40°
- Yaw control excursion-- Unlimited.
- Servo static accuracy-- 6 arc minutes (for each attitude servo).
- Probe protection-- To be provided by hardware techniques and software control.

d. TV Camera System

- Type sensor(s)-- High sensitivity type specified, such as a SIT. Must be a developed, proven type sensor of "broadcast quality", meeting premium (1st) level spurious signal specs.
- Operating mode-- Monochrome
- Configuration-- Separate camera head. Camera control unit remote from camera.

- Frame rate/interlace-- 60 field/sec., 30 frame/sec., 2:1 "locked" interlace
- Total scan lines/frame-- 945 (nominal)
- Total instantaneous FOV-- 125° horizontal and 35° vertical (nominal)
- Raster aspect ratio-- 1:3.67 for single sensor (nominal)
  1:1.29 for 3-sensor configuration (nominal)
- Vertical resolution (nominal)-- 600 TV lines - center
  500 TV lines - corner
- Horizontal resolution (nominal) --
  For single sensor-- 2140 TV lines/raster width
  For 3-sensor configuration-- 770 TV lines/raster width (per camera).
- Lag-- 10% residual signal after 50 milliseconds (NOTE: Lower lag desired to minimize loss of resolution under dynamic conditions).
- Sensitivity-- Video S/N $\geq$ 35 dB to be achieved with approx. 100 ft. cds. model illumination and specified optical probe.

e. Gantry/Servos/Transport

(1) Longitudinal and Lateral (scaled values)

- Velocity-- 200 knots (max); 0.34 ft/sec. (min.)
- Positional accuracy-- ± 5 ft. (unslaved mode)

(2) Altitude (scaled values)

- Max. excursion-- 2000 ft.
- Velocity-- 4000 ft/minute (max.); 0.06 ft/sec. (min.)
- Positional Accuracy-- ± 0.5 ft. (unslaved mode)

(3) Slaved operating mode (Two models)-- Scaled values

- Longitudinal and Lateral-- ± 5 ft. relative positional error (max.)
- Altitude - ± 2.5 ft. relative positional error (max.)

f. Special Effects

Following effects will be simulated, either by electronic, optical, mechanical, or a combination of these methods:

(1) Meteorological

- Visibility
- Haze and fog
- Overcast ceiling
- Horizon

(2) Sky background simulation

- Terrain model(s) only.

g. Visual Display Subsystem Characteristics

- Display type-- Collimated, virtual image type with mirror and beamsplitter
- Display image source(s)-- 26 inch (diagonal), high resolution (≈ 1500 TV line), monochrome TV monitor(s)
- Display configuration-- Overlapping horizontal matrix of three collimated units. NOTE: Central FOV (≈ 35°) shall be continuous, with overlapping seams at least 17.5° from the dead-ahead position.
- Total displayed FOV-- 125° horizontal and 35° vertical (nominal)
- System resolution* -- Approx. 8 arc min/TV line pair in central field.

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*These are total visual display system requirements.

GENERAL NOTE: The windscreen display will be physically and functionally compatible with the operational conditions imposed by the future possible addition of a 6-DOF motion base.

- Output highlight brightness-- ≥ 1 ft lambert (max.); 10^{-5} ft lamberts (min.); continuously variable.
- Collimation-- The final image will be collimated to a minimum distance of 40 feet.
- Contrast ratio-- 30 to 1 (min.)
- System gamma*-- Unity ± 0.1
- Image distortion (without probe and TV camera)-- <5% relative to picture height
- Image distortion (with probe and TV camera)*-- <8% relative to picture height
- Viewing volume-- ≥ 1 foot diam. sphere centered at the observer eye centerline position
- Variation in output brightness*-- Max. variation of ± 5% in contiguous areas and ±20% overall (achieved with TV camera(s)/probe viewing a terrain model surface of uniform brightness).

2. Simulated E-O Sensor Visual Display System

a. Terrain Model

Model dimensions and target configurations (natural and manmade) are similar to the windscreen system terrain model. Some alteration of model coloration is likely to enhance the "signature" of certain natural features in a manner representative of the simulated LLL sensor(s). Also, special "active" target sources may be used to simulate additional sensor target enhancement characteristics (e.g., "hot" targets viewed by a FLIR system).

b. Terrain Model Illumination

- Type - Source characteristics will depend on unique sensor simulation techniques proposed by the contractor, including possible use of optical filtering to enhance and to suppress certain model features.

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* These are total visual display system requirements.

- Illumination level on model-- Determined by camera sensor subsystem sensitivity (in spectral regions of interest) and optical probe characteristics. Estimate 500 foot candles (max.).
- Light pulse frequency-- Phased to produce approximately 360 pulses/sec.

c. <u>Optical Probe</u>

- FOV-- 60° and 8° circular (selectable, with 1/4 sec. changeover time).
- Effective focal length, EFL-- 16 ± 2 mm*
- Entrance pupil diameter-- 2.5 mm
- T number-- T/10.5 (nominal)*
- Primary image format-- 17 mm dia. for 60° FOV*
- Focus range-- 1.4 inches to infinity
- Focus control-- Remotely controllable with positional feedback capability
- Mapping-- $h = F\theta$ type*
- Resolution at center of field-- 1 arc min (nominal max.)
- MTF (object in plane of best focus for the spectral region of 0.4 to 1.0 microns)
  - <u>1</u>-- On-axis - 95% of diffraction limit
  - <u>2</u>-- 30° off-axis - 50% of diffraction limit
- Roll control excursion-- unlimited
- Pitch control excursion-- +40°; -60°
- Yaw control excursion-- Unlimited
- Servo static accuracy-- 6 arc min. (for each attitude servo).
- Probe protection-- To be provided by hardware techniques and software control.

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* Interrelated parameters subject to trade-off

d. TV Camera System

- Type sensor(s)-- High sensitivity type specified with good near-IR response and high resolution (> 1000 TV lines). Possibly 1 1/2 or 2" vidicon plus S-20 type intensifier(s). NOTE: Specific sensor is a contractor option.
- Operating mode-- Monochrome
- Configuration-- Separate camera head. Camera control unit remote from camera.
- Frame rate/interlace-- 60 fields/sec., 30 frame/sec., 2:1 "locked" interlace.
- Total scan lines/frame-- Selectable-- Typical range from 175 to 1225.
- FOV-- Selectable-- 60° and 8° diagonal (determined by optical probe).
- Raster aspect ratio-- Adjustable: Typical range 1:1 to 1:2
- Vertical resolution-- Determined by lines/frame selected
- Horizontal resolution-- Maximum ≥ 1000 TV lines. Lower resolution achieved as desired by limiting video bandwidth with selectable low-pass filters.
- Lag-- 10% residual signal after 50 milliseconds (desired).
- Sensitivity-- Sufficient when operating with specified probe to produce 35 dB video S/N with model illumination ≤ 500 ft candles.

e. Gantry/Servos/Transport

Same as for Windscreen Display System, except that the E-O sensor probe will have the capability of being biased to ride a nominal 5 to 10 feet (scaled) above the windscreen probe at and below tree-top level when feasible to minimize probe protection problem.

f. Special Effects

Meteorological and sky background simulation effects, similar to those used with the windscreen display system, will be used. In addition, special processing techniques will be employed to modify the characteristics of the basic video signal from the TV sensor. These are expected to include:

- Gamma changing
- Noise insertion (calibrated levels)
- Scan beam defocusing
- Signal clipping (black level and/or white level)
- Video bandwidth modification
- Signal polarity inversion

g. Visual Display Subsystems

As noted previously, the direct view type monochrome TV monitor (with its size dependent on the particular flight compartment configuration) is the basic display device planned for use with the special E-O sensor system. Typical basic characteristics will include:

- Resolution-- 1,500 TVL (nominal max.)
- Brightness-- Normally operated at relatively low levels (≥2 foot lamberts (max.), continuously adjustable for optimum operator viewing in conjunction with lower windscreen display brightness levels.

Additional special devices potentially will be used as the basic VFRF system expands. These include, as noted in Table 3, the helmet-mounted display and the HUD devices.

TECHNICAL SUPPLEMENT

Three analyses and/or trade studies are included herein as supplementary material. They are:

- o System Configuration Trade Study
- o Visual Display System Analyses and Tradeoffs
- o Motion Simulation Analysis

In combination, the results of these sub-tasks provided the background and the technical rationale for selection of the most desirable VFRF system approach to meet major ARI research requirements and test objectives.

TECHNICAL SUPPLEMENT

SYSTEM CONFIGURATION TRADE STUDY

CONTENTS

CONTENTS (Cont'd.)

SYSTEM CONFIGURATION TRADE STUDY

1.0 SCOPE

The magnitude of the Visual Flight Research Facility (VFRF) study task's conceptual system definition phase requires an approach definitized by several analyses and trade studies. This document, the first of the group, analyzes the spectrum of candidate systems and selects the one most suited to meet the VFRF requirements.

2.0 REQUIREMENTS

2.1 Preliminary VFRF Concept and Characteristics

The following initial requirements were established by ARI (Reference 1). Subsequent and expanded requirements are listed in Reference 2.

"VFRF" Concept

The basic components of the envisioned laboratory will include:

- Wide angle visual display of the external world suitable for psychophysical studies.
- High caliber electronic and television subsystems to achieve the necessary quality and control of visual parameters.
- Helicopter controls and instrumentation at a level of simulation complexity adequate for behavioral studies.
- Comprehensive experimenter's control and monitoring station.
- Cockpit provisions and interface equipment for special devices such as helmet-mounted display.
- Multiple stimulus materials and sensors for the visible and simulated infrared range.
- Computer facilities for physical simulation, experimental control, data recording and pre-processing.

Special "VFRF" Characteristics

- Control and repeatability of system parameters (e.g., illumination levels, gray scale, etc.).
- Multiple levels of parameter control.
- Comprehensive inter-relationship of parameters.
- Scope and latitude of potential studies.
- Flexibility of utilization.
- Comprehensive performance measures and data recording technology.

A listing of preliminary characteristics envisioned for the VFRF were also submitted with the initial requirements and subsequently were expanded in Reference 2. These are presented below, not as actual requirements, but as a listing of strongly desired system features which helped determine the recommended system-level concept for the VFRF.

Visual "Requirements" (Preliminary)

- Field of View
  - Horizontal 120° - 140°
  - Vertical (down) 20°
  - (up) 10°
- Resolution - 6 arc minutes (vertical and horizontal)
- Contrast - minimum of 10 shades of gray at the display
- Scene Brightness - infinitely variable from 0 to 100 foot lamberts (uniform and non-shadow)
- Chrominance - full color with "white light"
- Focus - 50 feet to infinity
- Simultaneous perspective viewing: pilot and co-pilot
- Head Motion ± 10 inches horizontal
  ± 5 inches vertical

- Depth Illusion (display and stimulus characteristics)
- Angular velocities and scene perspective without distortion
- Simulated eye height - 8 feet
- Atmospheric visibility: 0 to 10 miles
- Sun simulation: variable from 20° to 60° in elevation, and 360° in azimuth.

2.2 Experimental Requirements

2.2.1 Crew Tasks - Analysis of the crew tasks in NOE flight, from TC1-15 "Nap-of-the-Earth Flight Training", combined with the chapter on "Range of Research Studies", from Reference 1, gave the following basic crew task definitions:

a. Pilot Activities

(1) NOE Flight - Terrain avoidance flight with minimum skid and rotor clearance of ground, trees, or other man-made and natural obstacles. This will include vertical and azimuthal maneuvers as close to these obstacles as possible to provide maximum visual concealment.

(2) Hover and Special Flight - Flight with zero velocity vectors, again utilizing maximum cover during periods simulating troop delivery, evasion, or preparation for attack.

b. Co-pilot/Navigator -WSO Activities

(1) Terrain Observation - Flight path monitor and navigation feature or target detection. This includes enroute navigation with both detection and recognition of outstanding features, and at least detection of less well defined features or targets.

(2) Feature Recognition - Feature recognition includes utilization of the special display for feature or target recognition.

c. Coordinated Crew Activities

(1) Directed NOE Path Flight - A combination of pilot NOE flight on a 1 to 2 second response cycle with navigation terrain observation and special display feature recognition on a 20-30 second response cycle.

(2) Point Recognition - A combination of pilot hover or special flight techniques with navigation windscreen or special display target recognition and attack initiation.

2.2.2 General Requirements - To simulate the task environment with adequate fidelity to prevent erroneous data from clouding research and experimental results, the following general requirements for the system can be stated:

a. The windscreen scene shall be responsive to pilot control movements in 6 DOF.

b. The crew position portion of the system shall furnish motion cues to the pilot that are responsive to control movements.

c. Special display image sources shall use an additional 2 DOF beyond the helicopter's 6 DOF to simulate attachment to the exterior of the helicopter body. These additional degrees of freedom shall be in azimuth and elevation for both surveillance and stabilized LOS track.

d. Pilot and navigator studies shall be conductable independently or in coordination. A simplified flight control set and a simplified navigation criteria shall be available for the single tests to alleviate distractions encountered in crew coordinated flight conditions.

e. Typical crew coordinated NOE missions shall extend for a 15-30 minute time period, with a desired total time of simulated flight of 90 minutes. As an option, one hour of flight preceding NOE may consist of precision maneuvers at a higher altitude than NOE, or under IFR conditions in simulated clouds or other adverse weather.

2.3 VFRF System Requirements (Preliminary)(1)

The VFRF system requirements shall be defined along the subsystem lines of the experimental complex, control complex, image generation complex, and image presentation complex. These areas, along with major internal blocks, are shown in Figure B-1. The requirements are derived from the information sources identified in Section 2.1, crew task studies mentioned in Section 2.2, review of various related references, vendor discussions, and meetings with ARI and with NTEC and USATDA (Orlando, Florida) personnel.

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(1) The preliminary requirements listed in this system-level trade study were modified as the overall VFRF NOE study progressed. However, the initial requirements discussed here provided a common basis on which the several candidate system approaches could be compared and recommendations/selection made on the best general system concept for the VFRF.

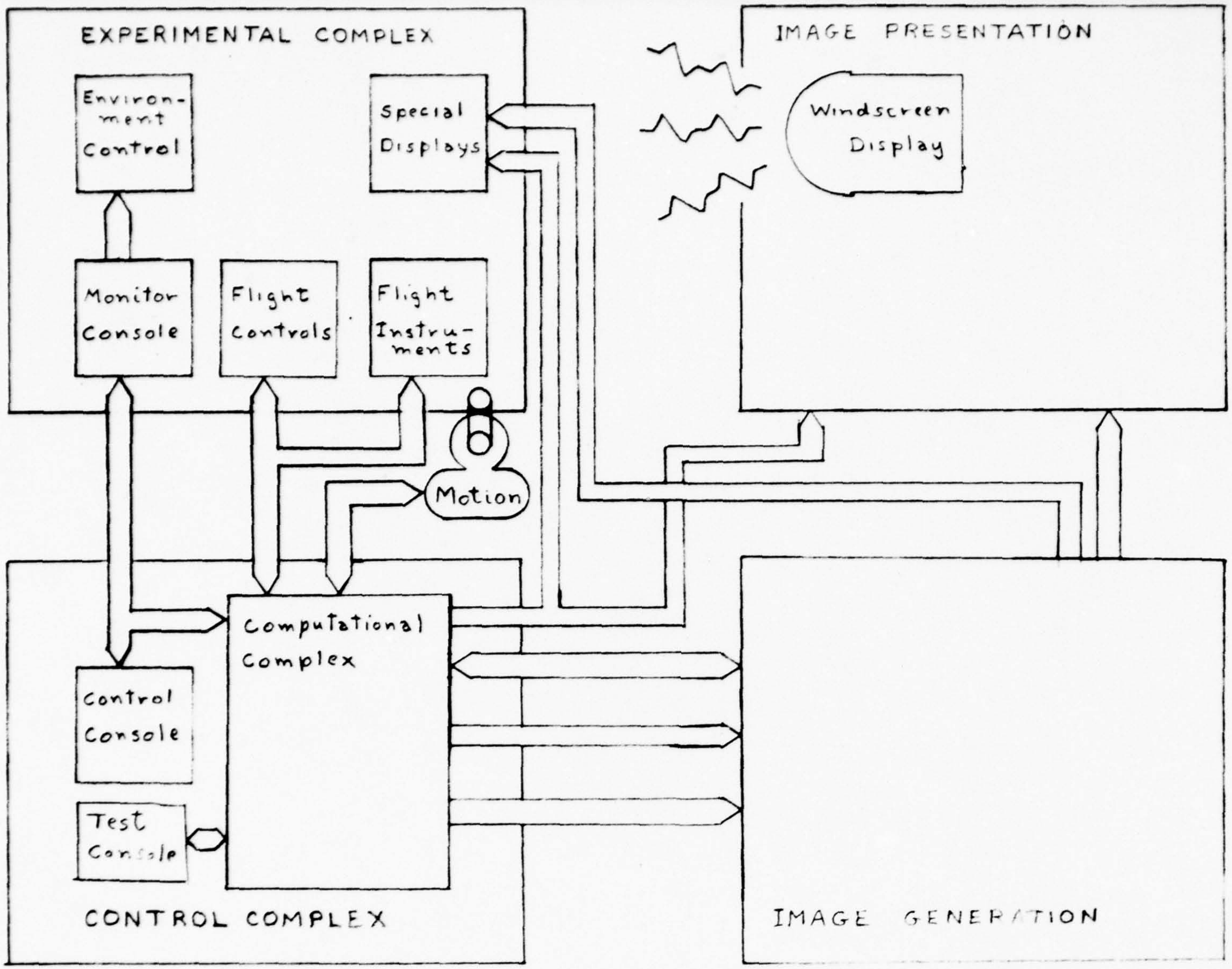

Fig. B-1 VISUAL FLIGHT RESEARCH FACILITY FUNCTIONAL CONCEPT

2.3.1 Experimental Complex

2.3.1.1 Compartment Description - The flight compartment interior shall represent the basic design of a UH-1C or similar type side-by-side seating helicopter. All instruments, indicators, gauges, controls, and placards that will be furnished shall be located in the same position as in the helicopter. All components shall have proper operating limits marked or printed on in the appropriate places. The interior trim and furnishings need not duplicate those of a standard UH-1C. An observer jump seat shall be installed directly behind each crew member seat. The unassembled compartment shall be capable of passage through a 6' by 7'6" by 2" doorway. The assembled compartment shall be capable of complete and unrestricted operation while confined within a volume defined by 500 square feet floor area with a ceiling height of 20 feet.

2.3.1.2 Flight Controls - The simulated flight controls shall include, but not be limited to, the cyclic stick, collector, rudder pedals, and their associated trim. Control forces shall be simulated in the flight compartment within the limit of travel of the controls and similar to the control loading system existing in the actual helicopter. A mode control shall be available to allow total helicopter flight control from the cyclic stick and collector, with one performing a throttle function and the other a directional function.

- Cyclic Stick — Pitch, Roll, Yaw
- Collective Pitch — Pitch, Altitude, Velocity
- Throttle — Altitude, Velocity
- Rudder Pedal — Yaw

Parameter	Range	Quantization
• Pitch	± 25 deg.	2 mr
• Roll	± 45 deg.	2 mr
• Yaw	360 deg. cont.	2 mr
• Altitude	0-2000 ft.	10 feet
• Velocity	0-100 knots	3 knots

2.3.1.3 Flight Instruments - The cockpit instrument panels, pedestals, consoles, and communication panels shall be simulated in accordance with approved flight manuals for the UH-1C helicopter. All but the following instruments may be photo mockups or dummies:

Instrument	Range	Quantization
• Airspeed	0-200 knots	3 knots
• Attitude Direction Indicator	±60 deg. θ, ±90 deg. ϕ	1 deg.
• Altimeter	0-2000 feet	10 feet
• Rate of Climb	0-300 ft/sec	10 ft/sec
• Compass	360 deg.	3 deg.
• Course Indicator	360 deg.	3 deg.
• Turn and Slip	±6 deg/sec, ±0.15	0.25 deg/sec, ±0.05
• Torquemeter	0-50 psi	1 psi
• Gas Gen. RPM	0-101.5%	1%
• Dual Tachometer	0-7000 RPM	100 RPM
• Turbine Inlet Temperature	0-1000°C	100°C

2.3.1.4 Special Displays - The special display system shall include an image processor designed to simulate the characteristics of a variety of sensors based on specification data provided by the manufacturers. The processor is used in conjunction with a standard sensor whose signal characteristics it varies to match the desired simulated sensor. Heads-up display (HUD) interface capability shall be provided, as well as space availability to allow installation of a nominal 19-inch TV monitor. Further potential display capability that shall be considered is a helmet-mounted display and/or sensor LOS cueing requiring a means of head (helmet) translational and rotational measurement for both the pilot and copilot of the simulated vehicle.

2.3.1.5 Motion Simulation - The motion system shall be mechanized to maximize the onset cues to the experimental subject so that actual cockpit motions stay within physical limitations and correctly track the frequency of the motions but not necessarily the amplitudes. The motion base system shall allow movement in four degrees of freedom:

• Vertical Displacement	
0-24 in. min.	±0.5 g accel. above and below
0-30 in. max.	the normal 1 g min.
• Roll Displacement	
± 15 deg. min.	± 70 deg/sec^2 min. accel.
• Pitch Displacement	
± 15 deg. min.	± 25 deg/sec^2 min. accel.
• Yaw Displacement	
± 15 deg. min.	± 100 deg/sec^2 min. accel.

A "Dynaseat" or alternative motion system may be utilized if it can be shown that it will cause experimental subject response equivalent to that available from the above motion base system.

2.3.1.6 Monitor Console - The monitor console shall contain the controls and displays to operate environmental and visual stimuli as well as monitor selected measured parameters. It shall, at a minimum, contain the following functions:

Function	Range	Quantization
· Keyboard	0-63	6 bits
· Function Bank	0-15	4 bits
· D/A Display	±10 VDC, 16 bits	12 channel, 16 bits
· CRT	±50 V	0.020" spot

2.3.1.7 Environment Control - Normal cockpit ventilation outlets shall be installed and operable to distribute air from the crew station cold and warm air sources. It shall maintain a standard temperature - humidity environment throughout ambient room temperatures ranging from +60°F to +100°F without subjecting crew members to a maximum aimed cooling air velocity in excess of 300 FPM.

- Temperature variability 35°F to 110°F
- Aural Simulation
  - Airflow
  - Turbine Engine
  - Drive Assembly
- Aural Limits
  - 0 to 130 dB

2.3.2 Control Complex

2.3.2.1 Control Console - The control console shall contain the controls and displays to operate environmental and visual stimuli, as well as monitor selected parameters or combinations of selected parameters for the test sequence. It shall, at a minimum, contain the following functions:

Function	Range	Quantization
• Keyboard	0-63	6 bits
• Control Functions	0-31	5 bits
• D/A Display	5 - ±10 VDC	12 bits
	20 channels	16 bits
• CRT	± 50 V	0.020 spot
• 19-inch TV Windscreen Display		≥ 525 line
• 19-inch TV Special Display		≥ 525 line

Calibration and test initialization to desired values of accuracy shall be controlled through this console.

2.3.2.2 Computational Complex - The digital computer complex shall consist of one or more general purpose digital computers (or a multi-processor configuration) for the entire VFRF system. All processors (CPU's) shall be identical and completely interchangable or they shall all be selected from a manufacturer's family for upward compatibility.

2.3.2.3 Software - Software design shall reflect studied modularity and task orientation. The executive and supervisory programs shall be the only portions of the computational package impacted by system modification and growth.

2.3.2.4 Test Data Evaluation and Recording Console - A test data evaluation and display console shall: a) be available to provide selective real-time monitoring of flight parameters, b) contain a facility for collection of all experimental data, c) contain the interface and capability for reduction of experimental data, and d) allow display and printout of data on a post-experimental basis. This console shall have the capability of allowing real time manual interface with the system during a test, and it may be placed in automatic mode for other tests.

2.3.3 Image Generation

2.3.3.1 Image Source - The image source shall consist of a representative 10 kM by 10 kM area around Ft. Rucker, Alabama. It shall include selected airfields, typical wooded areas, cleared areas, and some residential building areas. At least two vehicular moving targets shall be available in the image source (desired feature).

If a terraim model is selected as the image source, its scale shall be dependent on the image pickup technique. Control accuracy studies indicate that the model shall be bounded by scale limits of 300:1 to 1000:1 to meet constraints related to:

a) Pickup sensor characteristics
b) Realism of viewed scene detail
c) Mission length
d) Control accuracy and repeatability.

2.3.3.2 Image Pickup

a. Windscreen Display Pickup - This image pickup device shall be compatible with the following desired visual display system criteria:

• Field of view	Horizontal 120° - 140° Vertical +10°, -30°
• Resolution	6 arc minutes, vertical and horizontal
• Grey scale redition	Min. 10 shades of grey at display
• Chrominance	Full color
• Focus	50 feet to ∞ (simulated)
• Simultaneous Perspective	- Pilot and Copilot
• Simulated Eye height	8 feet
• Sun Simulation	Variable Elevation 20° to 60° Variable Azimuth 360°

b. Special Display Pickup - This image pickup device shall incorporate 2 DOF capability (azimuth and elevation) beyond the 6 DOF of the windscreen display. It shall provide a variable FOV - nominally 5 to 20 degrees (or greater) - and furnish monochrome signals to the special display device(s).

2.3.4 Image Display

2.3.4.1 Windscreen Display - This display shall satisfy the desired criteria under section 2.3.3.2, and in addition, shall incorporate the following characteristics:

- Depth illusion
- Angular velocities and scene perspective without significant distortion
- Atmospheric Visibility - very hazy to unlimited
- Display brightness - 0 to 10 foot lamberts (100 foot lamberts desired)

Applicable display compensation also shall be included to minimize geometric distortion effects peculiar to the selected display technique.

2.3.4.2 Special Display - The imagery displayed on this device shall simulate the characteristics of selected sensor aids which may be incorporated on actual helicopters. The normal display device employed shall be a direct-view type of TV monitor; however, provision also shall be made for the use of helmet-mounted display devices for this purpose.

3.0 DESIGN CANDIDATES AND CHARACTERISTICS

Research and literature surveys coupled with vendor interviews and analysis limited the choice of subsystem candidates to the following group:

Experimental Complex

a. UH-1C Equivalent Flight Compartment

b. Standard Flight Instruments and Controls

c. Design-to-Requirements Monitor Console

d. Design-to-Requirements Environmental Control

e. 4 DOF motion base or Dynaseat type motion simulation

f. Design-to-Requirements Interface for:

  1) Night Enhancement Device

  2) Goggle or Visor Helmet-Mounted Display

  3) Heads-Up Display (HUD)

  4) Cockpit TV Monitor

Control Complex

a. Design-to-Requirements Control and Test Consoles

b. Design-to-Requirements Computer Complex

c. Design-to-Requirements Software

Image Generation

a. Source-Terrain Model or Film or Transparency or CGI

b. Pickup-Optical Probe or Projector or Point Light or Flying Spot Scanner

Image Presentation

a. Processing - TV-LLL-IR simulation and Electro-Optical or Optical or LSCGI

b. Display - remote screen, cab attached projection screen, or cab attached virtual image display.

Using the image source as the key to system categorization, the application of straightforward combinatorial logic techniques gave over 240 possible terrain model system configurations, 16 possible film system configurations, 64 possible transparency system configurations, and 48 possible computer generated system configurations, each acceptable for at least one portion of a research or experimental goal. This cross-matrix of goals and candidates cannot be considered without the use of sophisticated processing techniques, unless a set of simplifying criteria is used for initial system selection. The criteria used in this study is the general task list from Section 2.2.1.

The following system configurations are defined to meet at least one set of pilot or copilot/navigator-WSO flight task or activity criteria and meet at least one set of general requirements (both Section 2.2), plus as many of the preliminary subsystem requirements as possible (see Section 2.3).

3.1 System Configurations

3.1.1 Terrain Model System - The terrain model system configuration is illustrated in Figure B-2. The system consists of the following:

a. Experimental Complex (UH-1C equivalent)
   1) Flight Controls
   2) Flight Instruments

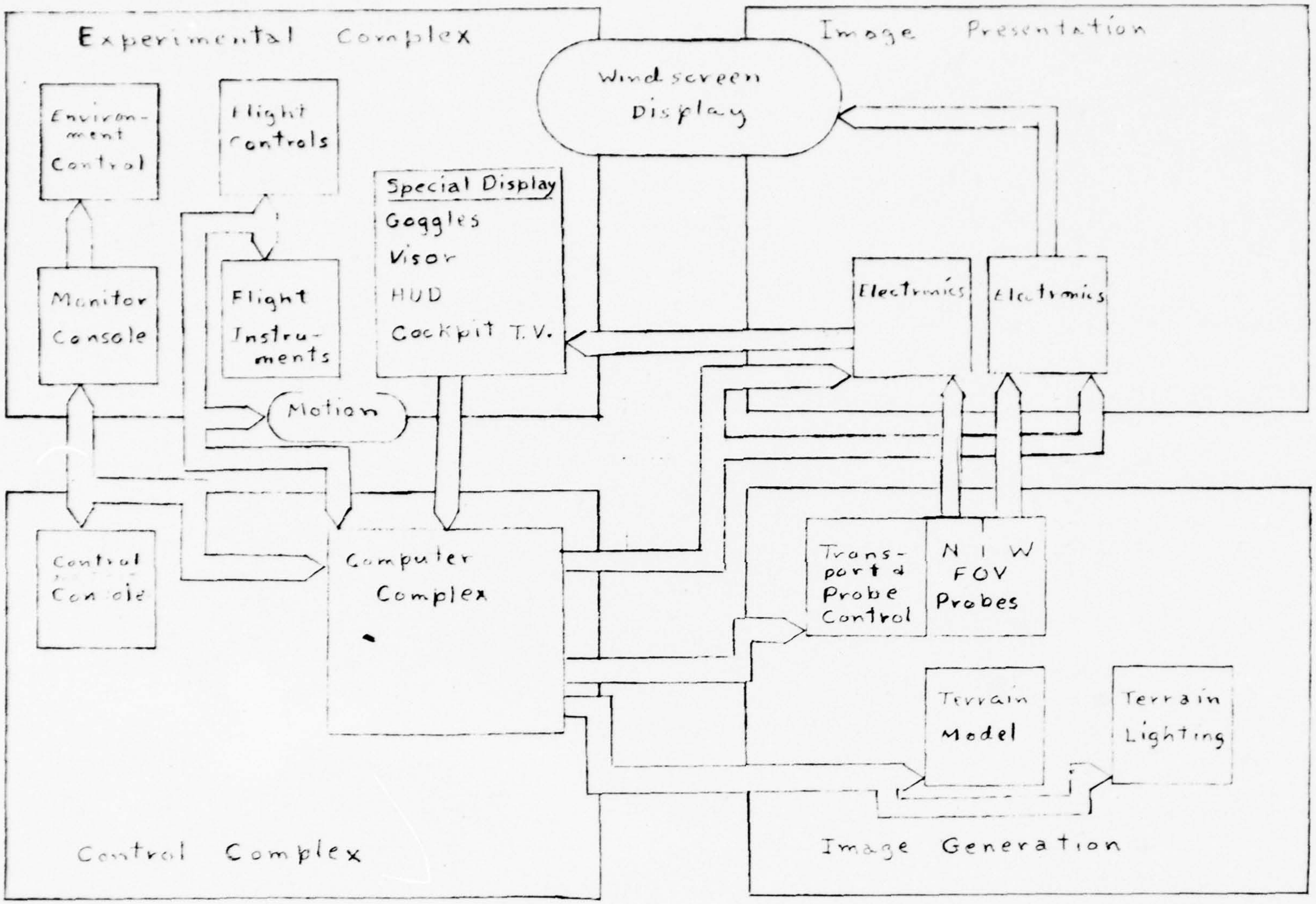

Fig. B-2 TERRAIN MODEL SYSTEM CONFIGURATION

3) Monitor Console

4) Environment Control

5) Motion Simulation - 4 DOF or Dynaseat

6) Special Display Attachable Options

- Goggles or Visor
- HUD
- Cockpit TV

b. Control Complex

1) Control Console and Test Data Console

2) Computer Complex and Software.

c. Image Generation

1) Source - Terrain Model

2) Pickup - Dual Input Optical Probe.

d. Image Presentation

1) Processing - TV

2) Display - remote screen, attached screen, or virtual image display.

The flight controls in the experimental complex are coupled through the control complex computer to drive the flight instruments and motion subsystem in the experimental complex, and the scene pickup transport and WFOV probe in the image generation complex. The special display controls in the experimental complex are coupled through the control complex computer to drive the NFOV probe in the image generation complex. The WFOV probe and NFOV probe images are coupled to TV cameras and transmitted through their electronic processing circuitry to the windscreen display and special display subsystems, respectively. The computer in the control complex may inject small scale computer generated imagery (SSCGI) into either of the electronic processing channels. The experimental complex and control complex consoles are interfaced to drive the experimental complex environmental control and through the computer, to exercise control over the NFOV probe display and terrain model lighting characteristics.

3.1.2 Film System - The film system is illustrated in Figure B-3. The system consists of the following:

a. Experimental Complex (UH-1C equivalent)

   1) Flight Controls
   2) Flight Instruments
   3) Monitor Console
   4) Environmental Control
   5) Motion Simulation
   6) Special display attachable items
      - Helmet Mounted
      - HUD
      - Cockpit TV

b. Control Complex

   1) Control Console and Test Data Console
   2) Computer Complex and Software

c. Image Generation

   1) Film

d. Image Presentation

   1) Narrow FOV windscreen pickup and special display electronic processing

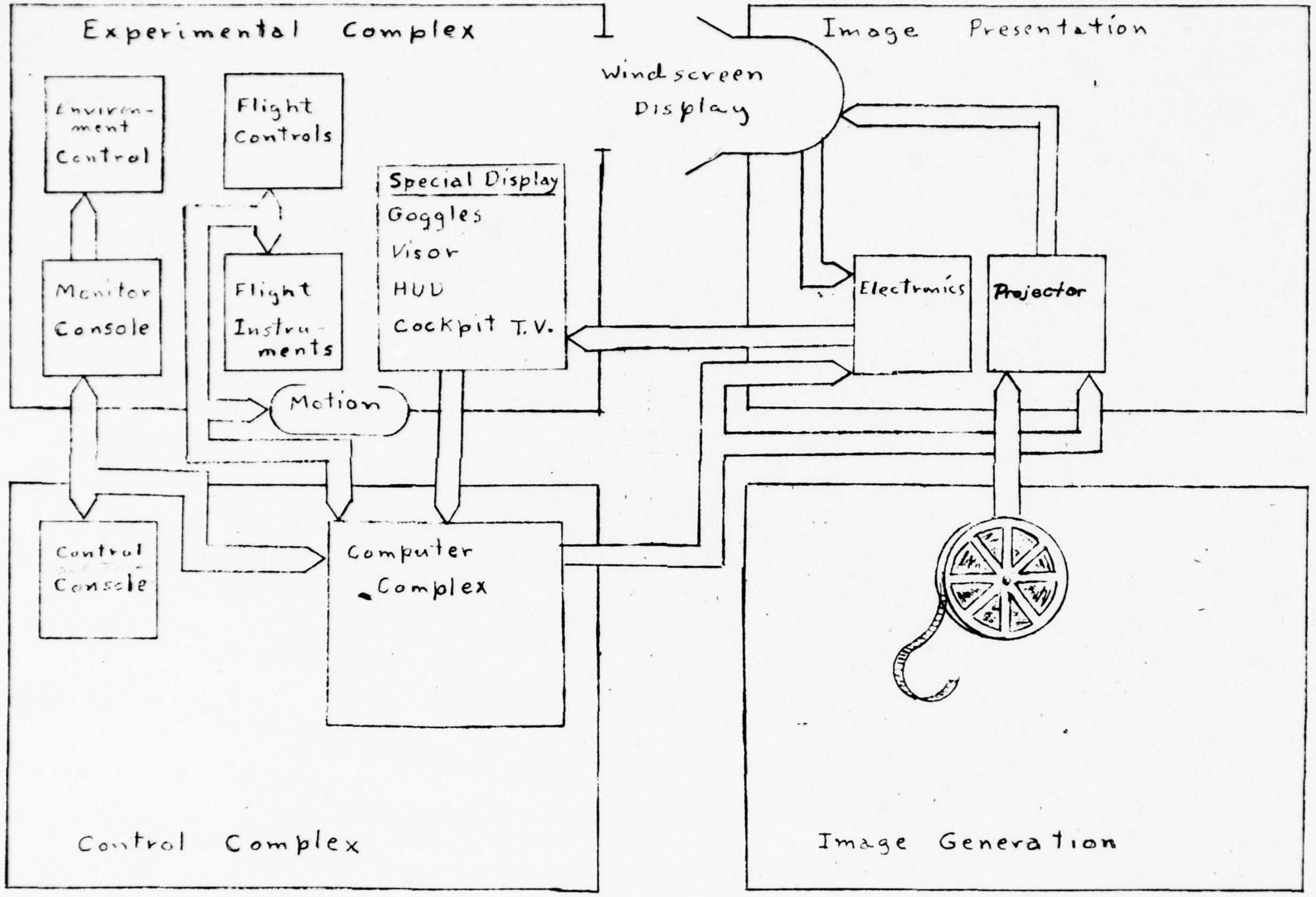

Fig. B-3 FILM (CINE) SYSTEM CONFIGURATION

2) Wide screen front or back projection.

The flight controls in the experimental complex are coupled through the control complex computer to drive the flight instruments and motion subsystem in the experimental complex. The special display controls in the experimental complex are coupled through the control complex computer to drive the widescreen segment scanner in the image presentation unit. This scanner transmits the widescreen segment through its electronics processing to drive the special display. The widescreen display in the image presentation complex is driven by the film projector from cine image storage. The computer in the control complex may inject SSCGI into the special display electronic processing channel. The experimental complex and control complex consoles are interfaced to drive the experimental complex environment control.

3.1.3 Transparency System - The transparency system is illustrated in Figure B-4. The system consists of the following:

a. Experimental Complex (UH-1C equivalent)
   1) Flight Controls
   2) Flight Instruments
   3) Monitor Console
   4) Environment Control
   5) Motion Simulation
   6) Special Display Attachable Options
      - Helmet Mounted
      - HUD
      - Cockpit TV

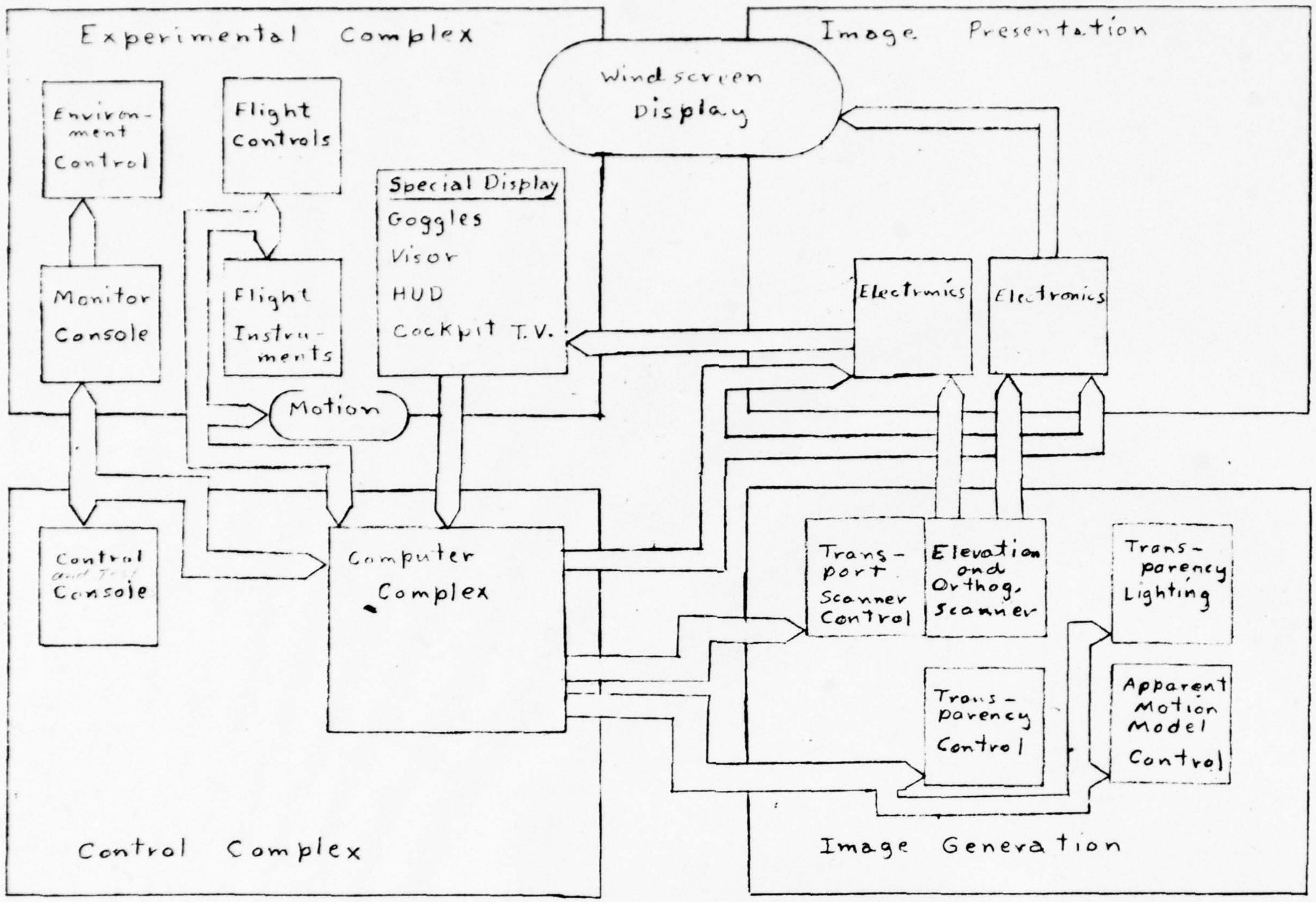

Fig B-4 TRANSPARENCY SYSTEM CONFIGURATION

b. Control Complex

   1) Control Console and Test Data Console
   2) Computer Complex and Software

c. Image Generation

   1) Transparency
   2) Transparency Lighting
   3) Apparent Motion Model
   4) Transport and Scanner Control
   5) Point source optical or Flying Spot Scanner*

d. Image Presentation

   1) WFOV Electronic Processing
   2) NFOV Electronic Processing
   3) Display - Remote screen, attached screen, or virtual image display

The flight controls in the experimental complex are coupled through the control complex computer to drive the flight instruments and motion subsystem in the experimental complex, and the scene pickup transport, transparency, and wide FOV scanner in the image generation complex. The special display controls in the experimental control complex are coupled through the control complex computer to drive the narrow FOV scanner in the image generation complex. The wide and narrow FOV scanner signals are transmitted through their respective electronic processing units to the windscreen and special displays. The computer in the

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* The flying spot scanner is the assumed image generation pickup method in the subsequent summary description.

control complex may inject SSCGI into either of the electronic processing channels. The experimental complex and control complex consoles are interfaced to drive the experimental complex environmental control and to exercise control of the NFOV scanner display, motion model control, and transparency control.

3.1.4 Large Scale CGI System - The Large Scale CGI system is illustrated in Figure B-5. The system consists of the following:

a. Experimental Complex (UH-1C equivalent)

  1) Flight Controls

  2) Flight Instruments

  3) Monitor Console

  4) Environmental Control

  5) Motion Simulation

  6) Special Display Attachable Items

    - Helmet Mounted

    - HUD

    - Cockpit TV

b. Control Complex

  1) Control Console and Test Data Console

  2) Computer Complex and Software

  3) CGI add-on and Software

c. Image Generation provided in b. above.

d. Image Presentation

  1) Processing - Minicomputer and CRT

  2) Display - remote screen, attached screen, or virtual image display

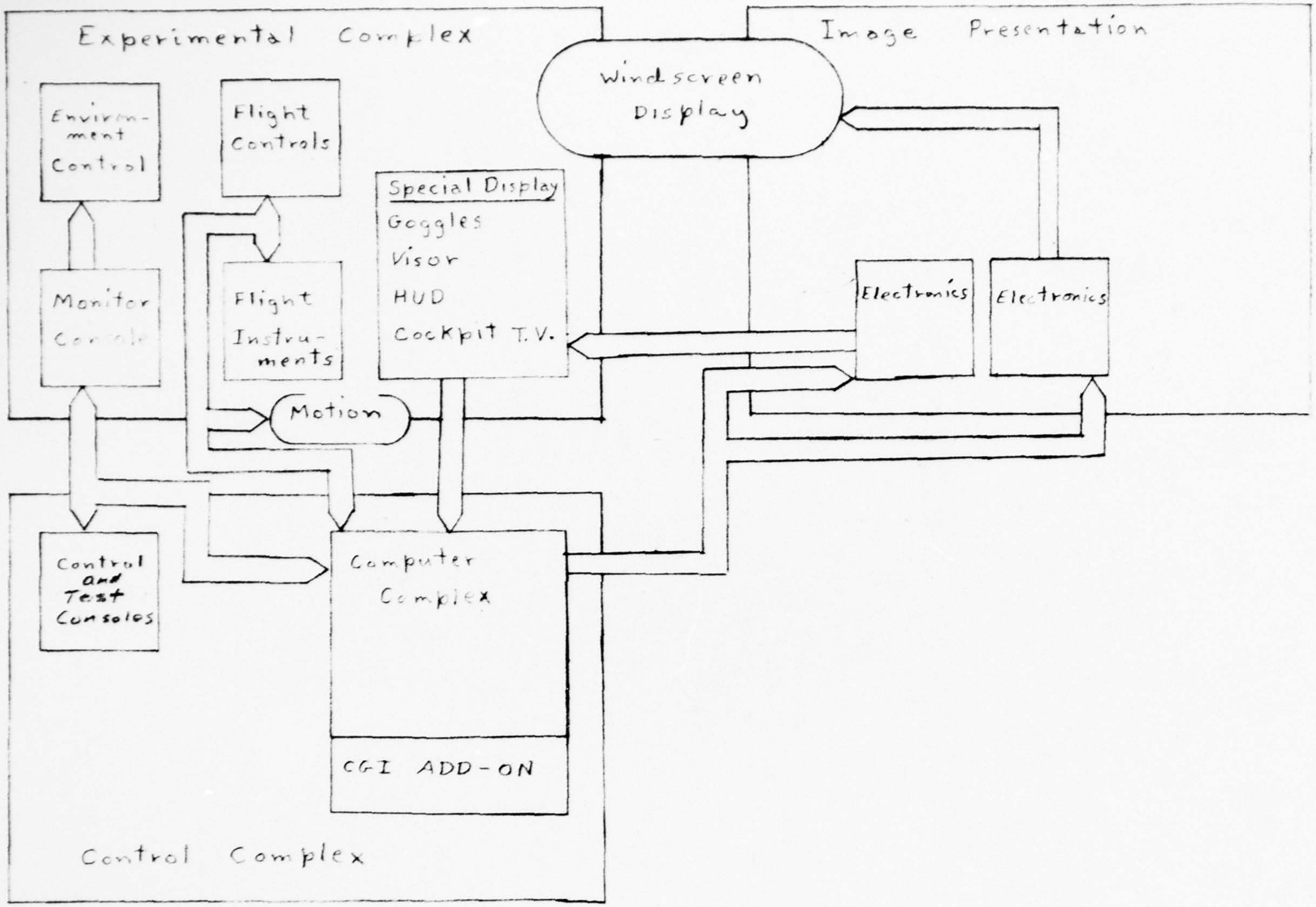

Fig. B-5 LARGE SCALE CGI SYSTEM CONFIGURATION

The flight controls in the experimental complex are coupled through the control complex computer to drive the flight instruments and motion subsystem in the experimental complex, and the eye position for CGI displacement computations in the computer's CGI add-on. The special display controls in the experimental complex are coupled through the control complex computer to provide display LOS for CGI displacement computations in the computer's CGI add-on. The CGI windscreen display and special display signals are transmitted through their electronic processing to the windscreen display and special display, respectively. The experimental complex and control complex consoles are interfaced to drive the experimental complex environmental control and through the control complex computer, special display variations.

3.2 Design Candidate Characteristics

The systems defined in Section 3.1 will be covered herein from a more detailed subsystem standpoint. This will allow a deeper level of comparison and analysis of the system configurations. The detailed characteristics of areas such as the computational complex, software, and other "engineering design" decision-dependent portions of the system will not be considered in this document, which is more system configuration trade oriented.

3.2.1 Experimental Complex

3.2.1.1 Flight Compartment, Controls and Instruments - The UH-1C has been baselined as the flight compartment equivalent for all four system configurations. This helicopter cab is inexpensive, readily available on the surplus market, and familiar to most helicopter rated pilots. The latter point will make transition to the simulator relatively easy for an experimental subject. The fact that many of the UH-1C series of helicopters are in active service will make validation of the experiments relatively easy.

The instruments and controls for the compartment can be readily obtained on the surplus market. The only variation from actual flight characteristics of this subsystem will be the "single stick" control. This mode of operation will be used by a non-pilot qualified subject for simulation of flight dynamics without excessive degradation of experimental objectives.

3.2.1.2 Special Display - Implementation of alternative special displays for use as portions of cueing subsystems to aid NOE flight - especially in night operations - forms a major part of the VFRF's experimental goals. The three major special display alternatives are helmet mounted, HUD, and cockpit TV, or a combination of two of the three for pilot and navigator simultaneous use. Additionally, the helmet mounted display may be subdivided into goggle or visor type full vision displays or single eye CRT displays. The images generated for these displays may be from a computer, a TV camera, or from simulated IR or LLLTV sources. Finally, the FOV may be the full windscreen, or it may be a zoomable 5°-20° segment of the windscreen.

The subsystem will be configured to allow direct view and enhanced direct view - through the goggle or visor type display and the HUD - of the windscreen imagery for the pilot or navigator. This will allow studies in the areas of night vision augmentation through simulated LLLTV or IR and automated cueing through use of a view-directing pipper. The single eye CRT display may also operate in this mode, or it might be driven by the smaller zoomable FOV image generator in the form of a separate actual or simulated gimbaled sensor directed by head movement. The cockpit TV display, for navigator use only, will be driven by the zoomable FOV separate source directed by either head movement or a separate control stick. CGI may be used to generate the scene, to overlay the scene in either of the special display concepts, or it may be used as the view-directing pipper.

3.2.1.3 Motion Simulation - A 4 DOF motion base will provide the required proprioceptive cues in pitch, roll, yaw and vertical translation (see Appendix C). The positional, velocity, and acceleration limits spelled out in the requirements in this document may be modified in order that a "production" or "surplus procurable" base may be integrated into the system.

3.2.1.4 Monitor Console and Environmental Complex - This is considered one of the areas discussed in Section 3.2 which will principally impact engineering design trades rather than system configuration trades. Therefore, no additional detailed information is warranted in this study.

3.2.1.5 Control Complex - No additional information is included here for the same reason given in Section 3.2.1.4.

3.2.1.6 Image Storage/Generation - The areas of image storage and generation are two of the more significant trade areas for the VFRF. The basic methods of image generation for simulation purposes is documented in NACTRADEVCGN 70-C-0312-1, Appendix B, by Collier, Peters, and Simpson. They include the area of image generation under image storage systems, pp 153 to 177. Portions of that document which are particularly germane to characteristic descriptions are presented here. Additional data gained from vendor interviews also will be covered. The four basic image storage system types available for use in visual simulation include (1) models, (2) films, (3) transparencies, and (4) computer memories (the image display generators are included in the image presentation section).

3.2.1.6.1 Model Source - Models or scaled replicas of the real world have been used extensively because a high degree of realism can be generated in representing three-dimensional areas of natural terrain and manmade features and objects.

The scale of the model is determined by the degree of detail required and the characteristics of the pick-up device. Several 600:1 scale terrain model systems have been built which exhibit total transport system controllability and repeatability to 0.125 inch for a 40 x 40 foot size. At the 600:1 scale, this provides a simulated area 7.5 by 7.5 kM. As the scale is changed toward 300:1, the physical size of the model must correspondingly increase for equivalent area display. Also, this leads to increased size and weight in the transport mechanism. As the scale is changed toward 1000:1, increased difficulties arise as a result of requiring increased precision in transport control, especially where a fixed, simulated low altitude approach is required. For example, a 10-foot "eye level" requirement scales to 0.2 inch at 600:1, and it becomes 0.12 inch at 1000:1.

A 600:1 scale model system appears to be a reasonable compromise to meet the multiple constraints of total model board size, adequate detail, and pickup controllability. Its design also will be significantly influenced by the characteristics of the pickup device, in terms of required detail, color fidelity, and lighting requirements.

3.2.1.6.2 Film Source - Film is the most compact and efficient means of storing data, with a typical storage density increase of 20:1 over three dimensional models. This source category includes still and cine film.

Film provides the maximum fidelity within a restricted spatial envelope. This limits its usefulness for some applications since simulated maneuvers cannot be realistically accomplished outside of this spatial envelope. Also, it provides only a 2-dimensional representation of a 3-dimensional scene.

The latest military films have very high resolution capability, and future improvement in commercial film is feasible, although present commercial types are adequate for most applications.

The film system will consist of photo flight files from the required area. These will be in color and include the desired characteristics (where possible) defined in Section 2.3.3.1.

3.2.1.6.3 Transparency Source - The transparency can store information relative to a large geographic area. Small areas of the transparency are selected for viewing with information retrieval obtained generally through the use of flying spot scanner or point light source devices. Since orthographic single transparencies carry no terrain elevation information, and oblique single transparencies correctly present the scene only when the simulated line of sight coincides with the position and line of sight of the "taking" camera, only dual transparency units are considered for this system.

In this approach, an orthographic image (luminance transparency) and vertical topographic image (elevation transparency), - positive, congruous, and coplaner - are mounted in a common motion plane. The visual image is derived from a simultaneous scan of a vertical photographic image of the ground plane and a transmission-encoded elevation plate.

Dual transparencies with and without point light source systems are considered as candidate subsystems.

3.2.1.6.4 Computer Memory Source - Computer memories may be used in generation of imagery (CGI) or they may be used for detail information storage to enhance test and mission repeatability.

Regardless of the growth and potential in mainframe memory capability, the key to computer utilization in CGI or repeatable testing lies in rapid accessibility of tape or drum bulk anxiliary storage coupled with "virtual" memory concepts. This will substantially decrease mainframe memory requirements through use of memory look-ahead, DMA aux-to-cue data transfer, and multiprocessing to complete the navigational or CGI computations.

The system concept envisioned for computer data storage consists of a dedicated CGI computer function or dedicated portion of multiprocessor function with extensive tape-disk library and library access peripherals.

3.2.1.7 Image Processing/Presentation - Image processing and display are additional significant areas for VFVF subsystem trades. This includes the method of retrieval of information from storage and processing for optimum display relative to the image pickup method.

Pickup from film-based storage requires a suitable illumination source and projection optics; for point light sources direct methods of projection may be used. Flying spot scanner pickups from transparencies typically use photomultipliers for photon-to-electron signal conversion, while terrain models employ optical probe/TV camera type signal conversion. Computer memory reading requires sophisticated electrical accessing and sensing hardware. All of these systems have been used in visual simulation applications, and each has its own unique advantages and disadvantages.

3.2.1.7.1 Display and Viewing Optics - The output of a visual system is the display. The simplest form of viewing system in use is a direct viewing type, where the subject looks directly at the screen. Infinity image display systems use optical elements to produce a virtual image of the observed scene at (or near) infinity.

The resolution of display systems using a CRT input, a "light valve" projector input, or a film projector input have maximum resolution limits established by these devices (and their input sources). Viewing screen and/or viewing optics characteristics act to further limit display system performance.

Direct viewing systems have a well developed state of the art with few additional improvements anticipated. The infinity system types include: reflective single mirror and beamsplitter, dual mirror and beamsplitter, polarizer (Pancake Window), matrix configurations - to produce panoramic displays - as well as refractive type infinity systems.

3.2.1.7.2 Optical Projection - Anamorphic and zoom lens elements can be used to achieve some perspective alternations. These techniques may be used in cine pickup and combined with panoramic film projectors (wrap around) to give apparent lateral and vertical displacement from a cine presentation.

A point source projection system may be used in conjunction with a movable transparency to give relative image movement on a front or rear projection screen. Since the point light source should be as small and as bright as possible, factors such as heat radiation and source geometry must be considered in concept definition.

The direct display system (front or rear projection on a screen at a finite distance) is an applicable candidate. Both plane or curved screens may be used with both having potential limitations in the areas of brightness (dependent on screen type and projector design) and parallax (dependent on distance from viewer and on viewer movement).

Both the film and transparency systems are implementable with the panoramic film projector technique and a curved or flat screen using front or back projection.

3.2.1.7.3 Optical Probe and Camera - The collection of visual windscreen data from a model is accomplished by the optical probe and TV camera combination. Translational movements of this assembly are produced by an X, Y, Z transport subsystem. Roll, pitch and yaw LOS changes can be accomplished within the probe assembly. Depth of focus limitations at close approaches can be overcome by use of Scheimpflug tilt-focus correction. An additional optical probe pickup element will allow generation of special display data.

Model illumination must be sufficient to produce low-noise camera signal output(s) for the visual display. The minimum desired field of view is 120° horizontal by 35° vertical. This is achievable with state-of-the-art optical probes.

3.2.1.7.4 Flying Spot Scanners - Flying spot E-O scanners are used for information retrieval from transparencies. A relatively small scan section coupled with X-Y translation of the transparency produces the effect of motion relative to the photographic scene.

Apparent altitude changes can be generated by changing the scale of the transparency and/or by varying the X-Y scan deflection amplitudes in the FSS. Small values of roll also can be generated by raster control of the FSS.

The FSS system is capable of producing low noise, good quality video from high quality transparencies. However, maximum-to-minimum simulated altitudes variations are limited by the combination of scanner spot size and transparency scale factor. A range of scan rates and raster form factors are available to satisfy various display requirements.

3.2.1.7.5 Computer Display Processor - The computer data base is converted to imagery through a display processor. The display processor contains selection functions and computing capabilities that keep all visible objects in proper view and perspective relative to the pilot's eye by distance-point computations.

The display processor output is video which is capable of "painting" pictures via the CRT raster scan mode. This requires D/A conversion or special raster-display interfaces.

3.3 Candidate System Summaries

3.3.1 Terrain Model System Summary - This system as conceptually configured in Section 3.1.1 will allow evaluation of all six task-oriented experiments identified in Section 2.2.1. Principal trade-off areas foreseen are in the experimental complex with respect to motion simulation, in the image generation complex with respect to the optical probe(s) and TV camera(s), and in the image presentation complex with respect to remote screen versus attached infinity display(s) and their associated, unique features.

The baseline image generator source will be a 7.5 x 7.5 kM terrain representation rather than 10 x 10 kM. This will allow use of a 40 x 40 foot, 600:1 scale model. Systems of this type have been built that exhibit the required controllability and repeatability criteria for precision probe positioning. Insertion of SSCGI will allow "change" in the available terrain by superposition of different checkpoints into the same background, effectively increasing the flexibility of the model.

3.3.2 Film System Summary

This system will allow evaluation of the Navigator-WSO terrain observation tasks, and, with some resolution degradation, the feature recognition tasks. Some apparent response to pilot control will be possible through motion simulation and display image shift, but the fact that the display is primarily oriented to the perspective and line of sight of the "taking" camera will cause considerable distortion if significant flight path deviations are allowed. A cueing mechanism giving suggested flight path can alleviate the gross requirements for scene shift but such an aid will definitely detract from desired experimental conditions.

A satisfactory means of generating the special display imagery with desired resolution quality is not apparent. Use of a windscreen image segment scanner, such as a TV with a zoom lens to generate special display imagery, generally will result in poorer resolution than that seen by direct viewing of the windscreen image. However, this approach may have limited usefulness for simulation of IR or LLL display systems.

3.3.3 Transparency System Summary

This system will allow evaluation of the same navigator-WSO terrain observation and feature recognition tasks that are identified in Section 3.3.2. Apparent pilot control response will be somewhat more realistic due to the additional transport and scene movement capability available. However, the fixed perspective produced by the "taking" camera still places definite limitations on the flight path deviations allowed before unacceptable distortions are experienced.

As in the film system case just discussed, a suitable method of providing a flexible improved resolution special display capability is not apparent.

3.3.4 CGI System Summary

This system will allow evaluation of all six task-oriented experiments identified in Section 2.2.1. Trades are possible with respect to motion simulation implementation and remote screen versus attached infinity display techniques.

The image generation data base is considered a high risk area. Present systems will not provide sufficient data for NOE simulation. Future identified systems are being styled to other simulation tasks. Development of an NOE data base and image generation processor could exceed the time (and cost) allowable for acquisition of the VFRF experimental capability.

4.0 SYSTEM CONCEPT EVALUATION AND SELECTION

System candidates previously described were evaluated with respect to the following four major criteria:

- Experimental capability
- Implementation complexity
- Implementation risk
- Implementation cost

4.1 Experimental Capability

The cine film and transparency system candidates both effectively satisfy only one of the six major task oriented experiments defined in Section 2.2.1; namely, copilot/navigator terrain observation and large feature recognition for flight path monitoring/navigation (plus the WSO-related task of target detection). In contrast to this, the terrain model and CGI system candidates generally satisfy all six experimental objectives.

Although the cine film and transparency system concepts compare much more favorably on the latter three evaluation criteria, their inability to satisfy the major portion of the identified experimental objectives is considered sufficient reason to eliminate them from further consideration. Therefore, only the two remaining system concepts will be discussed relative to the additional evaluation criteria.

4.2 Implementation Complexity

Of the two remaining candidate systems, the terrain model approach, while far from simple in terms of actual hardware implementation, still is considered less complex than the CGI system. The significant increases in computational and memory requirements for multi-line image generation consistent with NOE simulation needs are particularly undesirable CGI features.

4.3 Implementation Risk

Essentially all general aspects of the terrain model system have been implemented by contractors and government labs in part or whole at this stage of visual flight simulator system development. That is, the system concept is within the current state of the art. Since CGI systems having 5000 line (edge) generation capability* are still in the developmental stage, the terrain model approach is considered to have a lower risk factor.

4.4 System Cost

Overall development costs - and, in particular, the software costs - for a truly flexible CGI system with a 5000 edge generation capability, make the terrain model system the more attractive candidate.

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* The required line generation capability for effective NOE simulation was not established in this study. However, it is apparent that terrain features at short ranges and low altitudes present in NOE flights are complex in the real-world case. The level of simplification that can be accepted without jeopardizing the validity of the NOE research tasks has not been established at this time.

5.0 SYSTEM CONCEPT SELECTION

The terrain model system is the recommended system concept for the VFRF. It will meet all research test objectives, its basic implementation is within the current state of the art, and it is competitive in the cost and risk areas compared with other system concepts. The final VFRF system implementation may vary considerably from the evaluation baselines used in this document without affecting the selection of the terrain model system concept as the most cost effective approach.

REFERENCES

1. Ozkaptan, H. - "Visual Flight Research Facility (Preliminary Recommendations)" - U. S. Army Research Institute, 27 February 1974.

2. Ozkaptan, H. - "Behavioral and Functional Requirements for a Visual Flight Research Facility" - U.S. Army Research Institute, April 1975. Printed as ARI Research Problem Review 78-28, September 1978.

TECHNICAL SUPPLEMENT

VISUAL DISPLAY SYSTEM ANALYSES AND TRADEOFFS

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VISUAL DISPLAY SYSTEM ANALYSES AND TRADEOFFS

1.0 SCOPE

This Technical Supplement presents principal Windscreen and E-O Sensor Visual Display System analyses and tradeoffs performed in support of the total VFRF concept definition study.

2.0 INTRODUCTION

The foregoing Technical Supplement, "System Configuration Trade Study",discusses the preliminary overall VFRF requirements, identifies candidate system concepts, and provides the rationale by which the general terrain model system approach was selected as the most cost effective concept for the VFRF. These preliminary requirements also served as the starting point for the visual display subsystem analyses and trade studies specific to the terrain model system approach to NOE visual flight simulation.

Key visual display system functions and characteristics summarized below are derived from the above source:

- o Provide a windscreen display which is, to the maximum extent feasible, "perceptually equivalent" to the real world dynamic imagery directly viewed by helecopter crewmembers in the NOE flight regime;

- o Provide E-O sensor aids (or simulations thereof) to achieve enhancement of direct visual perception and target acquisition especially under (simulated) low illumination and/or poor visibility conditions.

Initial study emphasis was placed on defining subsystem characteristics and synthesizing system concepts in an effort to satisfy the above needs both for daytime and nighttime NOE operations. From the standpoint of the windscreen display system design, effectively this would require achieving system resolution performance which is primarily eye limited rather than display system limited over the entire day/night brightness range. Satisfying the above technical objective was further compounded by the defined need to provide a wide FOV (120 degrees desired) windscreen display to the helicopter crewmember(s) and also to achieve broad operational flexibility in terms of simulated NOE flight maneuvering freedom. This latter need was a major factor in selecting the terrain model/optical probe/TV camera configuration as the basic windscreen visual display system approach, since it can provide nonprogrammed freedom of simulated flight in all six degrees of freedom. Additionally, a side-by-side cockpit arrangement was defined as the baseline configuration for the VFRF. Also of major importance was the need to incorporate adequate flexibility in the basic design to provide for future growth in selected areas.

Concurrent with these initially specified performance features, certain constraints also were imposed by the study contract statement of work, based on practical matters of development time, development risks -and associated costs- which could be accepted in the acquisition of the basic operating research facility. A major constraint in this respect was that at least one basic VFRF system concept selected and defined for procurement would consist of subsystems all of which are within the state-of-the-art. Given the additional constraint of short development time (<two years desired), the practical consequence of this was to place major emphasis in the visual display system studies on current state-of-the-art developments in these related technology areas. Thus, primary consider-

ation was given to techniques/designs which have been reduced to practice --if not in operating simulators, at least in demonstratable laboratory hardware form. This study approach maximized the probability of successfully synthesizing and defining the VFRF visual display system concepts best meeting highest priority visual flight research needs identified by ARI, with the potential for subsequent growth in other specialized areas of visual flight research.

3.0 REQUIREMENTS DEFINITION SUMMARY

The Requirements Analysis/Definition task discussed in the main body of this report provided an expanded set of flight crew functions, flight characteristics and related visual effects, and general VFRF system requirements. They are specific to NOE simulation but still general in terms of visual display system configuration and implementation. For this reason, they supplement the above-identified objectives (and constraints), and are summarized below since they directly influenced the course of the visual display system analyses and trade studies.

Flight crew (test subject) functions to be simulated include:

- Basic pilot NOE flight operations, including terrain and and obstacle avoidance, hover, and special flight, including pop-up maneuvers;
- Copilot/navigator/WSO functions, including terrain surveillance and navigation, target search, acquisition (at near recognition thresholds) --with and without special E-O sensor aids-- plus sensor-aid LOS alignment; and,
- Crew-coordinated and directed NOE flight and various related communications functions.

Flight characteristics particularly applicable to simulation include:

- NOE flight altitudes typically at and below tree-top level; however, extending up to 2,000 feet for other mission phases;
- Flight velocities ranging from zero (hover) to approximately 200 knots (maximum daylight conditions, with advanced helicopter designs);
- Frequent aximuth heading changes and unlimited freedom in azimuth;
- Frequent angular accelerations of short duration in roll and pitch;
- Nominal maximum attitude change of ±45° in roll and ±25° in pitch;
- NOE flight path length typically of 25 km;
- NOE flight duration typically of 20 to 40 minutes;

Related visual effects associated with the above NOE missions are characterized by:

- Relatively short viewing ranges;
- Large (nominal 120° wide) visual field of view of "wind-screen" display simultaneously required by both operators for most coordinated missions;
- Dependence upon a wide variety of scene cues for maneuverability;
- Intense visual concentration;
- High angular velocities of the viewed scene (especially on nearby peripheral objects);
- Frequent noncorrespondance between the visual line-of-sight and the flight vector;
- Significantly reduced visual frame of reference with lower

illumination levels;
- Criticalness of depth and distance judgement;
- Limited reaction time.

Additional VFRF general requirements impacting the visual display system designs include the following:

- The displayed windscreen scene will be responsive to, and coordinated with, the pilot's control movements in 6 DOF;
- The simulated flight compartment portion of the system will furnish acceleration cues to the pilot that are responsive to, and coordinated with, pilot control movements. Further, the visual display system image dynamics must be properly coordinated with these effects;
- The special E-O sensor display image source (generating the simulated LLL-TV or FLIR imagery) will be provided with an additional 2 DOF beyond the helicopter's 6 DOF to simulate attachment to the exterior of the helicopter body. These additional degrees of freedom will be in azimuth and elevation both for surveillance and for stabilized LOS tracking functions;
- Pilot and copilot/navigator/WSO studies will be conductable independently or in coordination;
- Typical crew coordinated NOE missions will extend for a 20 to 40 minute time period, with a desired total time of simulated flight of 90 minutes. A nominal one hour of this time preceding the NOE phase may consist of precision maneuvers at higher altitudes, under IFR conditions in simulated clouds or other adverse weather.

4.0 MAJOR TRADEOFF AREAS

Several of the previously identified requirements/design objectives were of particular importance in the evaluation of the terrain model type visual display system candidate configurations and in the final NOE simulation system concept selection process. They are summarized below because of their special significance:

(1) Wide FOV windscreen display for two crewmembers, providing image fidelity "perceptually equivalent" to real world dynamic imagery directly viewed through a helicopter windscreen;

(2) Simulated E-O sensor functions (LLL-TV or FLIR) accurately coordinated with the windscreen display system, but independently steerable and capable of enhanced target acquisition performance compared to unaided direct vision;

(3) Simulated visual flight at and below tree-top level, characteristic of NOE conditions.

4.1 Day/Night vs Night-Only Windscreen Display System Considerations

With the primary objective of satisfying requirement (1) above for both day and night simulation, a survey was made of state-of-the-art wide angle visual display systems to compare their operating characteristics and quoted performance with the principal requirements/characteristics derived for the VFRF visual display system, with daylight simulation being the controlling case. Items of particular importance, and their desired characteristics, are:

. Total FOV	120° horizontal $\geq 35^\circ$ vertical
. Resolution	2 arc min/TV line pair (to approach direct visual resolution)

. Brightness	≥ 50 foot lamberts (FL)
. Color	Full color capability for daylight operation

Driskell[1] provides a good summary of current and near-term capabilities in wide angle visual display system technology applicable to training devices, based on a survey of seven wide angle systems of the unprogrammed type (thus excluding motion picture film techniques). From a review of the characteristic data presented in this reference, it is evident that none of the systems even approach the requirements given above in the combined areas of resolution and display brightness. The combination of high brightness, wide FOV, and high resolution represents a particularly difficult requirement. For example, of the above seven systems, the one providing the highest luminance -8 foot lamberts- (consisting of a matrix of 6 color monitors with associated mirror/beam splitter virtual image optics) achieves a resolution of 11 arc minutes per optical line pair across a total FOV of 108° horizontal and 48° vertical. Cooksey and Tong[2] also give a relatively detailed description of this, or an equivalent system, identified as the Singer F4E-18 type. The highest resolution device described in Reference 1 provides 4 to 15 arc minutes per optical line pair. This is a point light source system with a gimbal-mounted planar transparency, and it achieves an output

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[1] Driskell, C. "Capabilities of Wide Angle Visual Technology" Technical Report NAVTRAEQUIPCEN IH-237, Dec. 1974

[2] Cooksey, J. and Tong, H. "A Compound Wide Angle Color Visual Display System and a High Resolution High Sensitivity Closed Circuit Color Television Camera Developed for Wide Angle Color Visual Systems" AIAA Paper No. 73-925, AIAA Visual and Motion Simulation Conference, Sept.10-12, 1973

luminance of 1 to 5 foot lamberts with a total FOV of 200° horizontal and 60° vertical.

Hurd[3] defines the hardware requirements for a 1 arc minute, high brightness, full color, wide angle visual system for possible use as a general aviation flight simulator in the FAA's Airborne Proximity Warning Indicator program. The system as proposed requires a mosaic of 27 display elements to produce a 45° x 180° image focussed at infinity. Each display element consists of an Eidophor simultaneous color TV projector (modified to operate at a line rate of 36 KHz --compared to the standard 15.7 KHz-- and a video bandwidth of 50 MHz --compared to the normal 15 MHz) and associated "infinity" type optical systems. The displays are fed by high resolution color cameras operating at approximately 1200 lines per frame, 30 frames per second, 60 fields per second, with 2:1 interlace. The cameras have a resolution capability of at least 800 TV lines vertically and 1200 lines horizontally. Hurd indicates that the design is feasible from an <u>engineering</u> sense, but it is large and expensive. In rough terms, the cockpit visual display system would occupy a volume of approximately 44 feet wide by 22 feet deep by 15 feet high, and the display components alone would weigh in the order of 50,000 pounds. The estimated cost for the display and image generation system, not including non-visual aspects such as the cockpit, motion system, computer complex etc. is in excess of $16 million. Although the

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[3] Hurd, W. "Airborne-Proximity-Warning Indicator Visual Display for Preliminary Design Simulation" Mitre Technical Report MTR-6588, February 6, 1974

requirements of this system are somewhat in excess of that indicated for the VFRF daylight visual simulator, they do give a reasonable indication of the magnitude of the problem if limited to current state-of-the-art (or slightly beyond SOA) hardware techniques and performance.

Based on the comprehensive surveys referenced above, reviews of available technical literature from major suppliers of visual simulation equipment, and direct discussions with representatives of a number of these suppliers, it was concluded that attainment of the stated levels of performance for daylight, full color capability presently is beyond the state-of-the-art in terms of a practical hardware design and a reasonable development cost. Daylight, full color capability is identified as a growth item in the VFRF System Specification however, since this capability would significantly expand the range of research tasks available.

Accordingly, the basic VFRF windscreen visual display system is defined as a night-only simulator. This substantially decreases the system demands for "perceptually equivalent" displayed performance at these lower brightness levels, and thereby reduced the difficulty of selecting and defining a feasible total system concept within the constraints imposed by the statement of work.

Ozkaptan[4] discusses the implications of night-only simulation from the standpoint of NOE visual flight research effectiveness and concludes that there is substantial justification for this level of experimental capability. This is due in large measure to the high priorities presently placed on night-NOE flight research

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[4] Ozkaptan, H. "Behavioral and Functional Requirements for a Visual Flight Research Facility" Army Research Institute for the Behavioral and Social Sciences, Arlington, Va., July 1975

directed toward improving both flight crew safety and mission effectiveness.

4.2 Night-Only Windscreen Display System Tradeoffs

4.2.1 Image Generation --Monochrome vs Color

With the decision made that an acceptable daylight visual simulator presently cannot be obtained, it was then necessary to perform a tradeoff between nighttime monochrome system and nighttime color system approaches. Other factors being equal, the clear choice would be in favor of color, since as discussed by Ozkaptan (in Reference 4), at the higher range of night scene liminance levels (e.g., 10^{-2} FL) pilots have reported color perception (of nonluminous objects) including green and brown hues. Therefore, the lack of color will detract from the realism of the visual display at the higher brightness levels, and especially near dusk (in the 10^{-1} FL region). However, other factors considered in this study were determined of sufficient practical importance to swing the choice to the monochrome display approach for the basic system. Principal among these are: system complexity, operating stability, reliability, maintainability for a given level of resolution performance, size, weight, and cost. State-of-the-art simultaneous color camera systems used with high resolution type shadow-mask color monitors (26 inch diagonal type) can achieve resolutions approaching those available from high quality monochrome systems (in the 800 to 1200 TVL range). However, in the case of the color system, this level of performance, especially for the wide-FOV display configuration, is achieved at substantially higher initial cost than the monochrome system, due to its significantly greater complexity (including precision dichroic optics, typically four (vs one) TV sensors per camera system, electronic signal processing, and advanced color display). Equally or of even greater importance, the difficulty of maintaining the required level of performance in a dynamic simulator environment is appreciably greater in the case of the color system.

Use of the sequential color TV system approach offers certain advantages over the simultaneous type(s) especially in the areas of complexity, stability, maintainability, plus size and weight of the camera head[5]. A single, high quality, high sensitivity type sensor (generally a SIT or Image Isocon type) is sequentially presented red, blue, and green image fields by the action of a rotating filter wheel assembly in front of the sensor. A similar, synchronized R,B,G filter wheel is used at the receiver terminal to display the sequential R,B,G image fields to the viewer. To achieve an acceptably low display flicker condition, it is necessary to operate typically at a color field rate of three times that used in the simultaneous system (or 3x60=180 fields per second, providing 30 full-color frames per second with 2:1 interlace). Under dynamic scene conditions, the higher field rate offers the advantage of reduced image smear caused by sensor integration effects, resulting in improved dynamic resolution performance. However, at higher image rates (e.g., a peripheral near-in scene streaming condition), color fringing occurs; that is, there is sufficient image movement between color fields to produce discernible separation of image edges into narrow, single-colored lines. At the typical angular rates expected in the NOE flight simulation

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[5] The MARK XV CBS color TV camera system is a representative commercial design --technical information obtained from direct discussions with A. Kaiser, CBS, plus technical data sheets.

this would not be expected to be a serious problem; that is, the advantage of reduced smearing due to the faster field "shuttering" would outweigh the undesired color fringing effect. The more basic problems with the field sequential system are; (1) the high video bandwidths required at the camera and at the display (typically three times greater than the luminance channel in a simultaneous color system having an equal number of scan lines per frame) which restrict the maximum achievable video S/N (approximately 32 dB obtained with the CBS MARK XV system , with a static resolution of approximately 400 lines vertical and 485 lines horizontal), and (2) the limited selection of field sequential display sources available for use with the system. At present, only the rotating drum monitor --useful only for direct viewing due to the small CRT size used-- and field sequential type projection CRT units (employing filter wheel assembly) are recommended display sources. Gretag presently is not offering a field sequential version of their Eidophor light valve projector, having removed the Model EP8-SQ from their commercial product line. However, a replacement unit is reported by their U.S. distributor, CONRAC, to be under development and is expected to be available in the 1976 time frame. Advanced design work on higher resolution field sequential camera and display hardware also is being performed by Grumman, L.I.[6] They currently have an 800 line system, and anticipate upgrading this to 900 to 1000 lines in the near future. Concurrently they are developing compatible high resolution field sequential projection CRT devices. As of this report date, however, no data

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[6] Based on telecon discussions with Al Cosentino, Grumman, L.I.

is available on the expected operating life (MTBF) of this advanced projection source. This could be a critical performance factor in a system employing a high resolution field sequential system, based on reported field experience[7] on existing lower resolution, high brightness projection CRT systems. Operating life on these CRTs has been a problem area (with a maximum of 300 to 400 hours but with some as short as 8 hours). However, if limited to a low brightness, nighttime visual display application, this potential problem area may well disappear.

From the standpoint of growth to a full-color, daylight visual system providing displayed image fidelity "perceptually equivalent" to real-world daylight conditions, neither the state-of-the-art monochrome nor the state-of-the-art color systems (simultaneous or field sequential) appear to offer a clear advantage in terms of simplest modification of existing components; i.e., use of the "building block" approach.

4.2.2 Windscreen Visual Display Subsystem Tradeoffs and Impact on VFRF System Configuration

The requirement for "perceptual equivalent" wide FOV windscreen imagery directly affects the selection of display types best suited to the VFRF application. The choice between fixed projection screens (or displays) remote from the operator flight compartment and attached screens or display devices was made early in the study, in favor of the attached type devices. A principal reason for this was the desire to minimize the interface problems which would result if a motion base (growth option) were

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[7] Based on telecon discussions with Frank Vinz and Maurice Knighton, NASA, Huntsville.

added at a later date. With a fixed display, complex coordinate transformations would be required in the computer system in order to minimize image distortions and undesired interactions between the physical displacements of the operator's LOS (angular and translational) and image motion on the fixed display. Also, the physical size of the remote screen becomes quite large for a wide FOV windscreen display when located at a sufficient distance to minimize parallax errors and produce the perceptual sensation of "distant viewing".

Two general classes of attached display devices were considered in this study --the direct projection screen type and the collimated ("infinity") display type. Although the attached screen approach has been used successfully in visual training equipment simulator designs, a continuing controversy exists as to the effectiveness of this approach in simulating a distant viewing condition with a desired close physical separation of screen and observer. Estimates on required separations range from 10 feet to as much as 100 feet. Even a 10 to 20 foot distance could result in physical problems of screen clearances and of light shielding for nighttime simulation, especially if used with a motion base. From the physical standpoint, the infinity display configurations generally lend themselves more readily to effective light shielding. They also offer increased realism and improved utility due to the following characteristics[8]:

- o Generation of correct parallactic angles between objects located at various distances from the observer eye position (in this case, actually the optical probe entrance pupil position). Thus, correct scene perspective is provided to

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[8] Derived primarily from the reference -- LaRussa, J. "A New Infinity Image System" Presented at the Second NTDC/Industry Conference, 28-30 November 1967

the viewer (pilot or copilot).

- o Elimination of parallax errors due to the viewer's head movement;
- o Compatability with conventional head-up display (HUD) devices (as planned for future integration in the VFRF flight compartment) which project symbology to infinity. Thus, the viewer's head motion does not produce relative motion between the HUD symbology and the background imagery on the windscreen display. Similar compatability exists with the helmet-mounted sight, used by the test subject in the VFRF Primary Operator Compartment to remotely control the pointing of the simulated E-O sensor.
- o Generation of proper motion parallax between the cockpit structure and display windscreen imagery, with viewer head movement --providing added realism to the visual display.

With emphasis on real-world "perceptual equivalence", and based on the above factors, it was concluded that the attached infinity type device is the better choice for the range of research studies planned for the VFRF.

4.2.2.1 Infinity Display Type Selection

As subsequently discussed in the windscreen display system resolution calculations section, the state-of-the-art in video projector resolution performance (CRT and light valve types) requires a mosaic of infinity displays to provide the wide FOV coverage with resolutions needed for effective nighttime simulation. In their recent report, Irish and Orszulak[9] include a good summary of monochrome video display device performance capabilities, and the reader is referred to this document for detailed information in this area. This same reference provides an equally good treatment of infinity type optical display techniques potentially applicable to the VFRF type windscreen visual display requirements. In addition to the above source, other particularly useful references in this area include: J. La Russa (Reference 8) and Heintzman, Basinger, and Doty.[10]

Candidate infinity display configurations considered for the VFRF system include refractive and reflective designs. Both pupil forming and non pupil forming types are potentially available; however, the need for a relatively large exit pupil (approximately one foot diameter centered about the viewer's nominal eye position being desired) for reasonable crew freedom of movement in helicopter flight simulation results in a strong preference for the non pupil forming type system for this application. Candidate refractive display techniques include the single lens, the multi-element lens, and the Fresnel lens. These types often are made of plastic primarily for weight reduction purposes. Candidate reflective display techniques include; single spherical mirror and beamsplitter configurations, the off-axis Duoview system (Redifon design), and the in-line Pancake Window (Farrand design).

As previously noted, a matrix (mosaic) configuration is required to achieve the needed display resolution/wide FOV coverage

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[9] Irish, K. and Orszulak, J. "Visual Simulation Video Processing Techniques" Air Force Human Resources Lab. Report AFHRL-TR-74-76 Dec. 1974.

[10] Heintzman, R., Basinger, J., and Doty, A. "Optical Mosaics for Large Field Visual Simulation Display Systems" AIAA Paper No. 73-926 AIAA Visual and Motion Simulation Conf., Sept 1973

characteristic. A review of all available references, plus discussions with various industry sources, failed to identify a mosaic type refractive design --with the necessary wide FOV (total horizontal FOV of 125° desired)-- which has been reduced to practice. Although some vendor interest was evidenced,[11] no experimental results or design data were available to indicate the degree of design complexity and resulting levels of collimation errors and chromatic aberrations which would exist in a wide-angle matrix type refractive system.

In contrast to this, reflective infinity displays have been constructed in matrix configurations and presently are in use in advanced visual flight simulators. Heintzman, Basinger, and Doty (Reference 10) discuss the application of segmented polarized optics (Pancake Windows) both for the SAAC and the ASUPT visual display systems, plus a segmented reflective optics system (color monitor/single mirror/beamsplitter type) for the F4 Area of Interest Visual Display System. This reference indicates that acceptable levels of performance had been obtained with each configuration for their intended applications, and additional refinements were in process for the F4 system. Thus, favorable practical experience has been gained with the above type reflective systems. In addition, there has been a related successful development (for NASA Huntsville) by Farrand[12] using a "classical" infinity display system employing a mirror/beamsplitter configuration with a diffusing screen input (fed by two side-by-side field sequential projection CRT sources, producing overlapped images with minimum seam junction

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[11] Telecon discussion with Diffraction Optics, Palo Alto, Calif.

[12] Direct discussions with J. La Russa, Farrand and telecon discussions with M. Knighton and F. Vinz, NASA, Huntsville.

visibility). This system, basically designed for side-by-side operator viewing, provides a total horizontal FOV of 95° and a vertical FOV of approximately 35°. As presently configured, the horizontal FOV (and associated optics) is offset to accommodate a second, similar system for the second operator. This design provides a common central FOV of 54° and separate left and right views of approximately 41° for the corresponding operator positions.

Based on the demonstrated performance of the reflective type systems, the decision was made to specify this general approach for the VFRF windscreen display. It has the potential of meeting system requirements at lower risk than any known refractive display technique.

Of the reflective types, the Pancake display matrix is definitely most attractive from an overall packaging standpoint, and for a nighttime display, its low transmission (about 1%) still would permit use of standard brightness TV monitor inputs. The principal known problem with the device is one of ghost images (internal reflections) which are present in the units constructed to date. Under bright background conditions, in training situations, this effect apparently has not created serious problems. However, for nighttime NOE visual research, a not uncommon situation would be one in which bright light sources will be viewed against a dark background. Under these conditions the ghosting would be expected to have definite detrimental effects. Farrand (J. La Russa) concurs that the present Pancake window design could produce this type of effect; however, he indicates that the ghosting could be significantly reduced by redesigning the device to tilt the birefringent plate internal to the unit. However, lacking experimental data on the degree of improvement which could result from this modification, we concluded that the selection of a redesigned Pancake display constituted a higher risk than did the mirror/beamsplitter approach.

The feasibility of using the Redifon Duoview display in a matrix configuration to provide the needed wide FOV could not be established. Based on a telephone discussion with their U.S. representatives (in the Fall of 1974) it appeared that this had not been accomplished to date. Accordingly, we were unable to rate this approach as an acceptable low risk for use in the VFRF basic design.

Of the reflective display approaches potentially available, the spherical mirror/beamsplitter, with monochrome TV display input --arranged in a horizontal matrix of three units to effectively form a symmetrical arc in front of the viewer-- was selected as the lowest risk approach meeting the "infinity" display viewing requirements for a single operator.

4.2.2.2 Basis for Separation of Crewmember Compartments

The selected display configuration, being a compromise choice, naturally is not without some drawbacks, and its overall size is one of the principal ones. Lacking detailed design information, only a rather coarse estimate was possible during this study program of the overall width of this three-unit display matrix. The width dimension is significant because it determines the minimum spacing between operators seated side-by-side, each (necessarily) viewing his individual matrix display. The width of one complete subsystem is estimated to be 10 feet (including suitable enclosures for the beamsplitter elements). Therefore, to locate two crewmembers side-by-side with similar matrix display subsystems, the crewmembers would be spaced 10 feet apart, and the minimum width of the simulated flight compartment containing thses subsystems would be in excess of 20 feet. A compartment of this size, for use in a flexible research facility, was judged to be definitely undesirable. Particularly if the motion base capability were added later, significant operational problems would be expected. This is due partly to the crewmembers being well offset from the center(s) of rotation of the base, and partly to the large physical size of the research compartment. In short, considerable system complexity could result, and considerable research flexibility would be lost with such an arrangement.

After a review of alternatives, ARI and Martin Marietta mutually agreed that separation of the operator compartments was the preferred solution to the above problems. There was initial concern that physically separating the crewmembers (including no visual contact) might significantly interfere with their team performance in simulated NOE missions. Experienced NOE flight crews were queried in this regard, and the definite consensus of opinions, based on acual operational experience, was that the loss of visual contact between crewmembers is not a critical item. However, two factors identified as very important in coordinated NOE flight are: (1) good verbal communication (via intercom) between crewmembers, and (2) wide-angle views of windscreen imagery simultaneously available to both crewmembers.

The recommended (and specified) basic VFRF system configuration includes separate research modules for the flight crew test subjects, identified as the Primary Operator Compartment and the Secondary Operator Compartment. The Primary operator station, planned as the area providing the higher level of psychophysical validity (and instrumented for extensive biophysical and system performance measurements), incorporates the selected collimated, virtual image, reflective type matrix windscreen display. The Secondary operator station in the basic VFRF system design is equipped with a horizontal array of three direct-view type TV monitors* which present the same terrain model-generated windscreen imagery to the second test subject, with approximately the same FOVs available with the above infinity display. As discussed in the main report text, either test subject --pilot or copilot-- can occupy the Primary Operator Compartment, depending upon the nature and objectives of the research task being conducted. For a particular test series, the crewmember requiring maximum "perceptual equivalence" to the real-world dynamic scene in his windscreen display will be located in the Primary compartment. The VFRF System Specification identifies as a growth area the modification of the Secondary compartment to incorporate an infinity windscreen display subsystem similar to that used in the Primary compartment. This change will provide greater research flexibility plus some increase in the range of tests available to the Experimenter.

4.3 Optical Probes -- System Design Implications

Two primary system functions are performed by optical pickup devices at the terrain model (input) end of the generalized VFRF visual display system. They are:

- o Pickup of wide FOV terrain model image information and transfer in the desired format to the TV camera subsystem which drives the windscreen displays. The entrance aperture of the probe effectively corresponds to the pilot's eye point, and to properly simulate nonprogrammed NOE flight

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* and correspondingly simpler cockpit flight controls and instrumentation.

in 6 DOF, it must: (1) be responsive to computer-generated LOS angular commands in 3 DOF, and (2) operate in conjunction with the 3 DOF servo-controlled gantry/transport subsystem.

- Pickup of higher resolution, variable, "narrow" FOV terrain model image information and transfer in the desired format to the TV camera subsystem which drives the special E-O Sensor (visual aid) displays. The entrance aperture of the probe effectively corresponds to the location of the scanning head of the simulated E-O sensor (LLL-TV or FLIR) carried on the helicopter. In its "caged" position, its LOS will be fixed relative to the windscreen display, requiring the 6 DOF capability of the windscreen probe. In the "uncaged" mode, the probe will respond to pitch and yaw commands independent of the windscreen probe LOS, to provide target search, acquisition/recognition, and tracking functions.

The following subsections provide the rationale for certain key decisions made in connection with the optical probe design and performance requirements, and also include information on the impact of these decisions on other VFRF system elements.

4.3.1 Integrated Probe vs Separate Probes

In keeping with the defined study approach of employing the latest (but within) state-of-the-art techniques, where feasible, to satisfy system requirements, initial emphasis was placed on adapting a current, proven probe design to accomplish the above-listed functions. From the wide FOV ($\approx 120^{\circ}$) windscreen probe standpoint, the only existing identified designs which approach the minimum requirements for NOE visual simulation are the Scheimpflug Tilt Focus correcting probes developed by Farrand Optical Company.[13,14,&15] Direct discussions were held with Farrand, principally with J. La Russa, to review the capabilities and application of the basic wide FOV probe for NOE windscreen image generation, and to discuss the general feasibility of incorporating the second E-O Sensor probe function into this existing design.

Given the need for higher optical resolution from this second probe --in order to provide enhanced E-O sensor performance relative to direct-viewed windscreen display performance-- it was agreed that a second, optically separate unit with a larger aperture would be required. The principal modification considered was the "piggy-back" probe approach, in which the E-O sensor probe assembly would be attached to the windscreen probe to achieve X, Y, and Z translational motions (provided by the gantry/transport subsystem) identical to those of the windscreen probe. Angular drives would be independent, but capable of being slaved, as indicated by the second defined system function.

A review was made of the principal functional and physical areas in the existing wide FOV probe design which could be impacted by this type of modification. It was concluded that a major

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[13] Nagler, A. "140° Close Approach Optical Probe for Visual Simulation" Presented at the 5th. NTDC/Industry Conference, 1972

[14] Optical Scanning Probes (Scheimpflug Type), Farrand Optical Company Technical Brochure M.132-A

[15] Nagler, A. and Mazurkewitz, A. "Wide Angle, Infinite Depth of Field Optical Pickup for Visual Simulation" Technical Report AFHRL-TR-71-41 November 1971

redesign effort would be required to achieve an "effective" integrated probe design. Even so, the level of effectiveness would be in question since the heading mirror or prism elements of the two probes would be vertically displaced (to prevent mutual interference between the FOVs). This vertically displaced element design would place undesired restrictions on the minimum simulated NOE altitudes attainable and/or further complicate an already serious problem of probe crash protection.

Based in part on the above factors, and partly on specific E-O sensor visual display system considerations (subsequently reviewed), the decision was made to specify separate optical probes, and associated image generation subsystem elements, to accomplish the above-defined primary functions. This decision was not made lightly since we were aware that the design and development of separate but accurately coordinated visual systems (including not only the probes but the terrain models, gantry/transports, and TV camera subsystems) is a challenging engineering problem. However, of the options available, this approach offers the greatest operating flexibility, and the overall development task is considered within the state-of-the-art, based on satisfying the derived design and performance requirements summarized in Section 5.

4.3.2 Windscreen Probe -- System Related Characteristics

As previously discussed, the Farrand wide angle tilt-focus probe designs were considered primary candidates for windscreen image pickup due to the general applicability of their performance characteristics and to their state of development. In addition to probe-specific characteristics which were evaluated for applicability to the VFRF system specification, there also was the question of how the probe performance interacted with other subsystem elements. Two examples of this are discussed below. The first concerns the criticalness of Scheimpflug correction in the expected NOE flight regime; basically, what degree of computer-generated control is required to provide acceptable corrections. The second example concerns the terrain model and the determination of the effect of scale factor on probe performance when operating at desired NOE altitudes (physical heights) off the model surface.

4.3.2.1 Probe Scheimpflug Correction Considerations

It should be pointed out at this time, that to say the probe design has been developed, does not mean that it covers all situations. "Tuning" of the basic design may be necessary to match the NOE situation for maximum performance.

The probe as developed covers a 140° circular field-of-view, and is equipped with a two-stage 1:1 tilting relay system employing the Scheimpflug principle in order to attain an infinite depth-of-field. On-axis resolution of the probe is essentially diffraction limited and requires a television system of extremely high resolution to be opto-mechanically mated for peak performance as a system.

a. Requirements Discussion

(1) General- From the point of view of geometric optics, the ideal optical probe would be a copy of the human eye scaled to match the scale of the terrain model at which it is looking. Magnifications, distortions, and the elements of focus would all be correct reproductions of the real world.

Geometry, however, is only one consideration of probe utilization; illumination, physical and physiological optical considerations, and also the ability to design and manufacture the probe impose some very severe and practical restraints. System engineering, therefore, becomes very important. Elements of tradeoff are many and very subtle, requiring a broad and yet in-depth understanding of the problems to be solved.

(2) Visual- The design of an optical instrument must include considerations for the use of the instrument. When the human eye is to be used as the sensor or radiation receptor, the instrument must be designed for proper seeing.

Seeing is a learned ability and training can improve the individual's seeing to the limits set by the eye, nervous system, and processor ability of the brain. Seeing is a perceptual process that is affected by and incorporates other sensations, emotions, and association mechanisms simultaneously active with vision, education, and past experience. Seeing varies with the condition of the individual and the entities must be statistical probabilities of seeing rather than absolute values. Matching the two, visual requirements and the instrument, is at best a very difficult jub full of many areas of grey unknowns. Much of the information regarding vision is based on static testing and does not provide for the dynamic situation present in the NOE simulator.

(3) Scheimpflug Correction- A mathematical analysis was performed which confirmed that Scheimpflug correction has much to offer in enhancing probe performance in general visual simulation usage. However, this does not necessarily hold true at very low altitudes such as found in NOE flight. If one could define resolution requirements and choose a short probe e.f.l. with a low enough model scale factor, Scheimpflug correction might be desirable for NOE simulation. Since it was not possible to define these factors in a perceptual manner (of much importance

in a visual simulator) it was decided to perform an experimental investigation of a real probe's performance. A photographic study of the Farrand feasibility model probe developed for AFHRL (Reference 15) was performed by Martin Marietta as part of this overall VFRF study effort, and a study report submitted.[16] The study did not arrive at a single-valued conclusion to fit all cases, but rather presented data from which a choice of probe operation could be arrived at for a particular application. Using the NOE application, a matrix of study photographs of resolution targets was established. Six subjects were asked to order the photos on the basis of best-to poorest overall subjective quality. The results of this ordering were quite uniform. They suggest that the probe would perform satisfactorily with a two-position tilt relay --zero tilt down to approximately 50 feet (at a 600:1 scale), then one tilt correction for the remainder of the altitude range down to minimum altitude. Additional photo examination matrices (available from those supplied with the above report) are necessary to confirm and validate this conclusion. In particular, matrices using the 600:1 terrain model targets should be set up for this purpose.

4.3.2.2 Effects of Model Scale Factor on Probe Performance

Table 1 relates the model scale factor to wide FOV probe performance for various scaled pilot eye heights and corresponding physical probe heights off the model. This table shows that for pilots' minimum eye height in the region of 16 feet (scaled), 600:1 is the largest acceptable model scale ratio to provide

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[16] "Photographic Performance Study of a Wide Angle (140°) Optical Probe for Visual Simulation" - Martin Marietta Aerospace, Rough Draft Report, July 1975

	RELATIVE DEPTH-OF-FIELD	CLOSEST PER WP/AFB PROBE	← PROBE HEIGHT →					BEST MTF PER WP/AFB PROBE
Model Scale Factor		5 mm	6 mm	7 mm	8 mm	9 mm	10 mm	25 mm
		ALTITUDE – PILOT'S EYE HEIGHT						
1000 : 1	0.36	16.6	20	23.2	26.6	29.8	33.2	83
600 : 1	1.0	10	12	14	16	18	20	50
500 : 1	1.44	8.3	10	11.6	13.3	14.9	16.6	41.5
400 : 1	2.25	6.7	8	9.4	10.7	12	13.4	33.5
300 : 1	4.00	5	6	7	8	9	10	25
Probe Performance								
RESOLUTION - MIN		10	8.5	4.5	4.0	3.8	4.0	3.2
LP/MM		50	59	112	125	132	125	156
MTF for ∞ FOCUS 92 LP/MM - 6.5 MIN		N/A	N/A	16%	20%	22.5%	25%	44%
RELAY TILT ∡		13.5°	12.8°	12.1°	11.4°	11°	10.7°	5°

Table 1 – Probe Performance as a Function of Model Scale Factor, Scaled Pilot's Eye Height and Physical Probe Height

acceptable probe resolution performance. Section 5.1.1 shows that this scale factor is consistent with other test requirements for the windscreen visual simulator system.

4.3.3 E-O Sensor Probe -- System Related Characteristics

No single design was identified which incorporates essentially all of the principal functions and characteristics needed in the pickup device for the simulated E-O Sensor Visual Display System. An important initial consideration, therefore, was to obtain sufficient confidence that the unique probe requirements determined by overall system considerations could be satisfied by state-of-the-art design techniques.

Summary design and performance requirements given in Section 5.2 are considered within the current state-of-the-art in probe design. Optical resolution is a particularly important factor, since a key function of the E-O sensor/display subsystem is to provide enhanced low light level viewing for the test subject. The effect of this requirement on the probe characteristics (entrance pupil size in particular) is discussed in Section 5.2.

4.4 E-O Sensor Simulation Approach

Section 3. defines the functional requirement to incorporate simulated LLL-TV and FLIR type sensor image displays as aids to the windscreen direct viewing mode. It is evident at this point that the terrain model approach has received primary emphasis both for the windscreen and the simulated E-O sensor visual display techniques. This point is brought out to emphasize that this was the only simulated E-O sensor technique given serious consideration during this study. Other techniques very possibly could be considered as potential candidates, notably computer generated imagery (CGI). The previous Technical Supplement, "System Configuration Trade Study", concluded that the complexity, risk, and cost factors favor the terrain model system over the CGI system. This was based on a single terrain model, dual optical probe concept. However, despite the added complications of a second image generation subsystem, the conclusions are still considered valid. The demands on the CGI system remain quite severe from the standpoint of edge generation (large number of edges required to adequately simulate complex terrain features and targets) and required coordination with the windscreen imagery derived from the non-programmed type terrain model system.

Restricting the simulated E-O sensor display study to terrain model techniques, the most promising combined analytical and experimental work which came to light was that recently performed at Night Vision Laboratories, Fort Belvoir, Virginia, and reported by V. Bly.[17] In the referenced report, Bly discusses four potential techniques for simulation of the far infrared (and in some cases, jointly simulating the low light level visible spectrum --applicable to LLL-TV) using terrain models as image sources. They are:

(1) Direct simulation using a terrain model with correct far infrared signatures as viewed directly with a FLIR system.

(2) Encoding of the emissive signatures in the visible reflectivity of the terrain and target features, viewing with a

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[17] Bly, V. "Multi-Spectral Terrain Simulation Feasibility Study- A Preliminary Report" ECOM Report scheduled for publication in May or June 1975

visible probe and emulating the performance of a given FLIR (or LLL-TV) by processing the video signal.

(3) A special case of the second approach where an already existing "visible" model is used with only the targets treated to accurately represent the far infrared and approximation of a FLIR's (or LLL-TV's) performance is made by rather simple means.

(4) Encoding in the visible spectrum, as in the second approach; however, the video signal is used to modulate a dynamic, two dimensional, far infrared display which would be viewed by the actual FLIR through a collimator.

Of the above techmiques, approach (2) was determined most applicable for the VFRF simulation needs, based primarily on the tradeoff of achievable simulation fidelity vs acceptable development time and risks. The description of this selected technique was adapted to a requirements type format and incorporated in the VFRF System Specification as the selected Simulated E-O Sensor Visual Display System Approach. The technique is summarized below:

4.4.1 Description of Selected Technique

This simulation is achieved by encoding not only the visible signatures but also the characteristic far-IR emissive signatures of the terrain and target features in "visible" model reflectance values*, viewing the model with a "visible" spectrum probe/TV sensor, and modifying the video signal so as to synthesize the output of a FLIR or a LLL-TV system.

As noted by Bly, the effectiveness of this approach to FLIR simulation is keyed to the unique role and particular characteristics of thermal backgrounds (the terrain and terrain features). Backgrounds act as low contrast clutter, or stationary noise, making the task of acquiring a given target or navigational reference point more difficult. At the same time, backgrounds also produce a spatial frame of reference, providing those pattern recognition cues critical to target acquisition. It is important that the simulator system design meet the following performance criteria in order to provide simulated FLIR background imagery which satisfies the above-defined characteristics to the maximum extent feasible:

- Maintenance of the apparent thermal range (overall contrast) of representative real-world backgrounds;
- Maintenance of the spatial frequency distribution, or power spectrum, of representative backgrounds, and,

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* The spectrum of interest may extend beyond the visible to approximately 1 micron.

o Availability of sufficient characteristic shape and contrast in the particular terrain features for them to be recognizable (as roads, trees, houses, etc.)

In order to obtain the higher target/background contrast levels often encountered in the far infrared, a selected number of active target sources can be used on the model.

Since both simulated LLL-TV and FLIR scenes are to be (sequentially) generated on the common E-O sensor terrain model, suitable means must be employed not only to encode both types of representative terrain and target characteristics but also to separate these image pickup subsystem inputs (to the degree required) to emphasize, and de-emphasize, characteristic features which distinguish these different sensor system types. The general method proposed by V. Bly to accomplish this separation is one of encoding the simulated far-IR (3 to 5 microns or 8 to 14 microns) thermal signatures in one portion of the E-O sensor operating spectrum and the LLL-TV "visible" reflectance signatures in another. By selecting the appropriate spectral filters to be used with the image pickup subsystem, first one and then the other simulated E-O sensor signals can be produced in basic form (to be further processed before being displayed to the crewmembers). This is the signal separation technique selected for the VFRF E-O Sensor system design approach and is specified accordingly .

The variable parameter TV system used for image generation is adjusted to obtain the scan format which approximates that of the low light level sensor system being simulated. The camera output video then undergoes special electronic processing to enhance desired, and de-emphasize undesired, signal characteristics. This processed signal then is presented on special display(s) also designed for compatibility with the selected image generation scan format, and in some cases, themselves emulating special characteristics of the simulated real world sensor system. As noted by Bly, the key questions regarding the modification of the video signal to emulate a FLIR's (and LLL-TV's) performance are:

a The accuracy of the method for determining the sensor system's performance parameters and

b the degree of emulation possible with reasonable expenditure.

He identifies the most important parameters in terms of their effect on the output display as follows:

- MTF (Modulation Transfer Function)
- SNR (Signal-to-noise ratio--temporal, both additive and multiplicative)
- Signal transfer function (display brightness vs input radiance)
- Scan structure or format (number of lines, frame rate, interlace, overscan, if any).

The simulated E-O sensor system will be designed to permit the adjustment of the most critical of these parameters in a simple, calibrated, repeatable fashion. It is important that these parameters be adjustable over a sufficiently wide range to achieve realistic representations for valid operator responses to both FLIR and LLL-TV imagery.

The system shall be designed to accomplish quick and simple switchover from the LLL-TV to FLIR mode, and vice versa to facilitate research operations.

4.4.2 Advantages of Two-Terrain Model Configuration

From the foregoing description , it now can be seen that the two-terrain model concept adopted for the VFRF offers several significant advantages in terms of implementing the above simulation technique. Principal among these is the freedom provided for altering the coloration and reflectivities of the E-O model surface and targets as necessary, plus the addition of selected active target sources, without affecting in any way the basic windscreen terrain model characteristics. This physical separation of windscreen and E-O sensor image sources gives the research team considerable flexibility for adapting the E-O sensor system to varied simulation requirements as they arise in the future. Other advantages resulting from the two-terrain model approach include freedom in selection of E-O model illumination characteristics and added operating flexibility available for the optical probe/TV camera subsystems. Although not defined as an operating mode in the basic VFRF system concept, the E-O sensor system can be operated while the windscreen sensor system is inoperative to simulate and evaluate an independent vehicle-borne (e.g., RPV) sensor system's performance.

5.0 Selected Analyses and Rationale Related to Visual Display System Conceptual Designs

This section includes (or references) the more important analyses and related rationale used in defining the required characteristics of major subsystems comprising the two VFRF visual display systems. These characteristics are presented in summary form in Section VII in the main body of this Final Technical Report, and in detail in the System Specification --The Appendix to this report. The reader is referred to these sources for any additional desired information relating to specific subsystem characteristics.

5.1 Windscreen Visual Display System --Analyses and Rationale

5.1.1 Terrain Model

a. Size and Scale Factor- Based to a large degree on operational flight test conditions employed at Ft. Rucker, Alabama, the desired typical NOE course length was established at 20 KM (approximately 66,000 feet). To minimize physical model size, a large scale factor ratio (e.g., 1000:1) would be desired. However, based on the need to simulate low altitude NOE flight (≈16 foot pilot's eye height) with good fidelity, the windscreen probe performance at the corresponding physical separation from the model dictates use of a smaller scale factor. Based of the tradeoff of probe performance at this minimum altitude condition and terrain model physical size --as a function of scale factor-- a 600:1 scale was determined to be a reasonable compromise (see Section 4.3.2).

For an average flight speed of 40 knots, and an average NOE mission time of 15 minutes, the simulated flight path length is approximately 18.5 KM. For the defined model maximum height of 24 feet and form factor of 3 to 1, the model scaled size of 4.4 KM by 13 KM will accommodate this, and a wide range of other mission profiles, by having the flight path double back or cross over once or possibly more times if needed. Due to the varied nature of the defined model and a minimum of prominent features (by design) this flight procedure is considered quite feasible without running a significant risk of introducing undesired learning effects into the tests due to test subject familiarity with specific flight paths and/or terrain features.

b. Coloring- Realistic, real-world coloration is specified on the basis that: (1) model makers' experience is primarily related to techniques to achieve proper color rendition; therefore, even though a monochrome windscreen visual display is specified for the basic system, for a given model cost, more realistic displayed tonal rendition would be expected from a colored model than one restricted to shades of grey, due primarily to this experience factor, and (2) the full-color model is compatible with any growth version of the VFRF incorporating color display capability.

5.1.2 Terrain Model Illumination

a. Type- A specific type of illumination source is not defined, since an optimized system design will require full knowledge of the spectral characteristics of the model surface and of the windscreen image pickup elements (subject to contractor selection) to provide the proper overall system match. Thus, this will be a contractor option. Mays and Irish[18] provide a good survey of model illumination sources potentially suitable for this type of application.

b. Illimination Level- See Section 5.1.4 for representative image generation system sensitivity calculations.

5.1.3 Optical Probe

The defined requirements summarized in Section VII of this Technical Report and in the System Specification are for the most

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[18] Mays, J. and Irish, K. "The Development and Evaluation of an Optimized Video Output from a Wide Angle Optical Probe" Report AFHRL-TR-73-22, December 1973

part derived from published performance and characteristic data obtained from previously referenced Farrand-generated documents (References 13, 14, and 15) plus system-related considerations discussed in Section 4.3.2. Potential simplifications are indicated in the areas of control of probe focus and Scheimpflug tilt correction for the NOE flight regime.

5.1.4 TV Camera System

a. Design Options- Two optional camera configurations are defined; the single-camera type and the three-camera type. Either approach is expected to satisfy defined system performance requirements, however there are substantial differences between the two types with respect to:

- o Sensor type
- o Optical probe/TV camera coupling
- o Video processing
- o Windscreen display interfacing (and impact on windscreen display design)

The single-camera design requires use of a very high resolution, high sensitivity sensor to maximize the displayed wide FOV windscreen fidelity and minimize the required model illumination. A representative monochrome TV design approach is described by Mays and Irish (Reference 18), in which an ITT magnifying type image intensifier (25mm input, 50 mm output) is fiber optic coupled to a 2 inch Westinghouse very high resolution vidicon --providing 2000 TVL resolution per raster width at 10% modulation).

In the three-camera approach, the resolution requirement per sensor is reduced by virtue of dividing the optical probe's horizontal field into three sections, with each section viewed by a separate camera. Thus, on a first-order basis, the resolution requirement of each sensor (to be equivalent to the single-camera approach) is reduced by a factor of three. In practice, where adjacent image overlaps are used, somewhat less than an three times reduction is permitted. The advantage to the three-camera approach in this respect is that standard, high quality 16mm SIT type sensors should be satisfactory choices. However, there is the obvious offsetting physical disadvantage of three (vs one) cameras to mechanically and electrically interface with other system elements.

In terms of probe/TV camera coupling, techniques applicable to both camera arrangements have been successfully used. The single-camera approach, with the magnifying intensifier coupling, proved successful according to data given in Reference 18. The three-camera approach, employing a field divider-relay lens technique, has been implemented by Farrand and successfully used in the NASA, Huntsville visual simulator referred to in Section 4.2.2.1 (and Reference 12).

From the video processing standpoint, the single-camera design requires relatively high video system bandwidths (> 30 MHz) which impacts the camera electronics, special effects circuits, and display circuit designs. However, no advanced techniques beyond the state-of-the-art are believed required. The video bandwidth demands on the three-camera design are substantially less, but this is offset (to a considerable degree) by the need for three individual sets of camera video circuits.

The windscreen display matrix electronic design is the final area where significant differences are known to result from the use of the different camera configurations. With the single-camera approach, the camera horizontal scan (corresponding to the probe's total horizontal FOV) must be time-shared among the three display units. Thus, the horizontal scanning velocity of each display must be correspondingly increased, and precise time-sequencing circuitry is required to properly divide the horizontally-displayed image fields. The F-4 Area of Interest Visual Display System (Reference 10) uses a similar (but more complex) time-sharing arrangement and it is reported to perform satisfactorily. In the case of the three-camera approach, the horizontal FOV is separated spatially by feeding the outputs of the individual camera units each to its respective TV monitor in the display matrix. No state-of-the-art development problems are foreseen with this approach either.

b. Camera Resolution- As discussed above, the camera configuration (single or three-unit types must produce very high resolution across the total FOV width to achieve an acceptable displayed image fidelity. Displayed system angular resolution is controlled by the combined resolution performance of the optical probe, TV camera, and visual display subsystems. The calculation of system resolution is included in the visual display subsystem section (5.1.5).

c. Camera Sensitivity- The following calculation is based on use of the three-camera approach, using the field divider technique to separate the wide FOV probe output image into the three required sections:

(1) Conditions (Assumed)

o Sensors - Three SIT 16mm Type 4804 (or RCA C21125A)

- o Optical probe - Farrand 140° design with T/no = 10.5
- o Optical coupling from probe (17 mm format) to the three SIT sensors:
  - Relay lens transmission, $T_R = 0.8$
  - Optical field divider --Reflect/Trans., $D_T = 0.96$
  - Reduction factor, K, in sensor illumination due to effective sensor-to-probe magnification,M, of

    $\frac{17x3}{16} \approx 3.2$ is:

    $K = M^2 = (3.2)^2 = 10$
- o ← Terrain model highlight refl., $R_M = 0.4$ (assumed)
- o Desired highlight S/N = 35 dB min. (= S/N ratio of 56/1)

  Note: This is achievable with an estimated video preamp noise current, $I_n = 10$ nAmp. and 560 nAmp. highlight signal current. From RCA data sheet on C21125A SIT (Fig. 3), required faceplate illumination, E_s (at $2854^{\circ}K$) to produce 560 nAmp is approx. $2X\ 10^{-3}$ foot candles.

(2) Calculation

Model Illum., $$E_M = \frac{E_s \cdot 4T^2 \cdot (1 + m) \cdot K}{T_R \cdot D_T \cdot R_M} \qquad \text{(Where } m \approx 0\text{)}$$

$E_M \approx 30$ foot candles of $2854^{\circ}K$ ilimination

The System Specification desired maximum value of 100 foot candles was selected to allow for different optical coupling methods, flexibility in illumination source selection, and, within limits, use of different sensor types and associated video circuitry.

5.1.5 Visual Display System

Pertinent characteristics of the selected visual display subsystem have been discussed at some length earlier in this report supplement. The primary remaining area of interest concerns the system-related performance factor of displayed resolution.

As previously noted, system resolution is determined by the combined characteristics of the optical probe, TV camera, and display subsystems. At least in the critical central field region, the limiting element in the system in this regard is the TV camera subsystem, as will be evident from the following calculation:

a. Conditions (Assumed)

- o TV camera nominal total horiz. resol. = 2140 TVL (Central field)
- o TV camera effective vert. resol. = 600 TVL (Central Field)
- o Total horizontal FOV = 125°
- o Total vertical FOV = 35°
- o Optical probe angular resol. = 3 arc min/optical lp (Central field --down to 35mm probe height)
- o Three-element display matrix - Composed of three monochrome TV monitors with resol. = 1500 TVL/pict. height (Central field resol. per monitor)

b. Calculation

(1) Basic TV Camera Resolution

o Camera horiz. angular resol. $= \frac{125 \times 60}{2140}$ = 3.5 arc min/TVL
= 7 arc min/TVlp

o Camera vert. angular resol. $= \frac{35 \times 60}{600}$ = 3.5 arc min/TVL
= 7 arc min/TVlp

(2) Basic TV Monitor Resolution (Single Unit)

o For vertical FOV of 35^{o},

$$\text{Angular resol.} = \frac{35 \times 60}{1500} = 1.4 \text{ arc min/TVL}$$

$$= 2.8 \text{ arc min/TVlp}$$

(3) Displayed System Resolution (Central Field)

o Resultant system resol. ≈ 8 arc min/TVlp

Note: The controlling factor is the basic TV camera resolution of 7 arc min, which in combination with the significantly higher resolutions of the probe and TV display elements, produces the above resultant system resolution value.

5.2 E-O Sensor Visual Display System -- Analyses and Rationale

5.2.1 Terrain Model

The same rationale and calculations pertaining to the dimensional data for the windscreen model apply here also, since by the very nature of the selected two-terrain model concept, these characteristics are the same for both model boards.

Section 4.4 discusses the pertinent factors contributing to the uniqueness of this particular model board design, in terms of the special "signatures" of selected terrain features and targets to be viewed by the E-O sensor pickup elements. Unlike the windscreen model, no constraints are imposed here on achieving real-world model coloring; rather, it is highly probable that wide departures from real-world colors and visible reflectance characteristics will be required for effective E-O sensor simulation.

5.2.2 Terrain Model Illumination

a.Type- Again, as in the windscreen visual simulation area, no attempt is made to restrict the contractor to a particular illumination source. Reference 18 again is offered as a valuable compilation of data on potential sources; however, the final selection, being directly related to the specific system implementation proposed, will be a contractor option.

b. Illumination Level- Section 5.2.4 discusses representative image generation subsystem sensitivity characteristics and the effect on model illumination.

5.2.3 Optical Probe

a. General- The primary purpose of this probe is to pick up special terrain model imagery for processing and display to the test subjects as simulated FLIR and LLL-TV signals. Since the system purpose is to simulate a wide range of sensor performance parameters, the probe must be compatible with the expected range of characteristics.

b. Requirements

(1) Focus- No practical E-O sensor operational systems exhibit an infinite depth-of-field. Accordingly, there is no requirement for probe Scheimpflug tilt correction. However, since some systems do have focus provisions, there is a requirement that the probe have adjustable focus capability.

(2) Resolution- State-of-the-art FLIR sensor systems typically achieve about 1.5 arc minute resolution using narrow FOV optics. Thus, it is necessary that the probe have an entrance pupil of no less than 2.5mm diameter to provide diffraction limited resolution (in the visible spectrum) in

the range of 1 arc minute, and thus achieve the 1.5 arc minute simulated system resolution.

(3) Field-of-View - Based on available nighttime flight test data[19] using LLL-TV and FLIR systems, a 60° FOV is the minimum needed for use as an effective navigational and piloting aid; however, sensors for such purposes as target acquisition employ much smaller FOVs (8° or less). The range of FOVs from 60° to 8° is obtainable using state-of-the-art probe design techniques. The FOV changes can either be made through lens switching or zooming of the optics.

Figure 1 shows FOV vs Resolution vs Entrance Pupil Diameter for a variety of TV system resolutions and, as such, parametrically joins together the various factors involved.

5.2.4 TV Camera/Electronic Processing/Display Subsystems

The broad design latitudes necessarily given the contractor in these simulated E-O sensor subsystem areas limit the specific requirements which can (or should) reasonably be imposed. Section 4.4 identifies major performance criteria which must be satisfied in order to obtain an effective simulation of FLIR and of LLL-TV type imagery. A key characteristic of the integrated TV camera/electronic signal processing/display subsystems is the ability to perform over a wide range of operating parameters, and to obtain these parameter variations in a simple, calibrated, repeatable manner.

The type of TV sensor used for this purpose basically must

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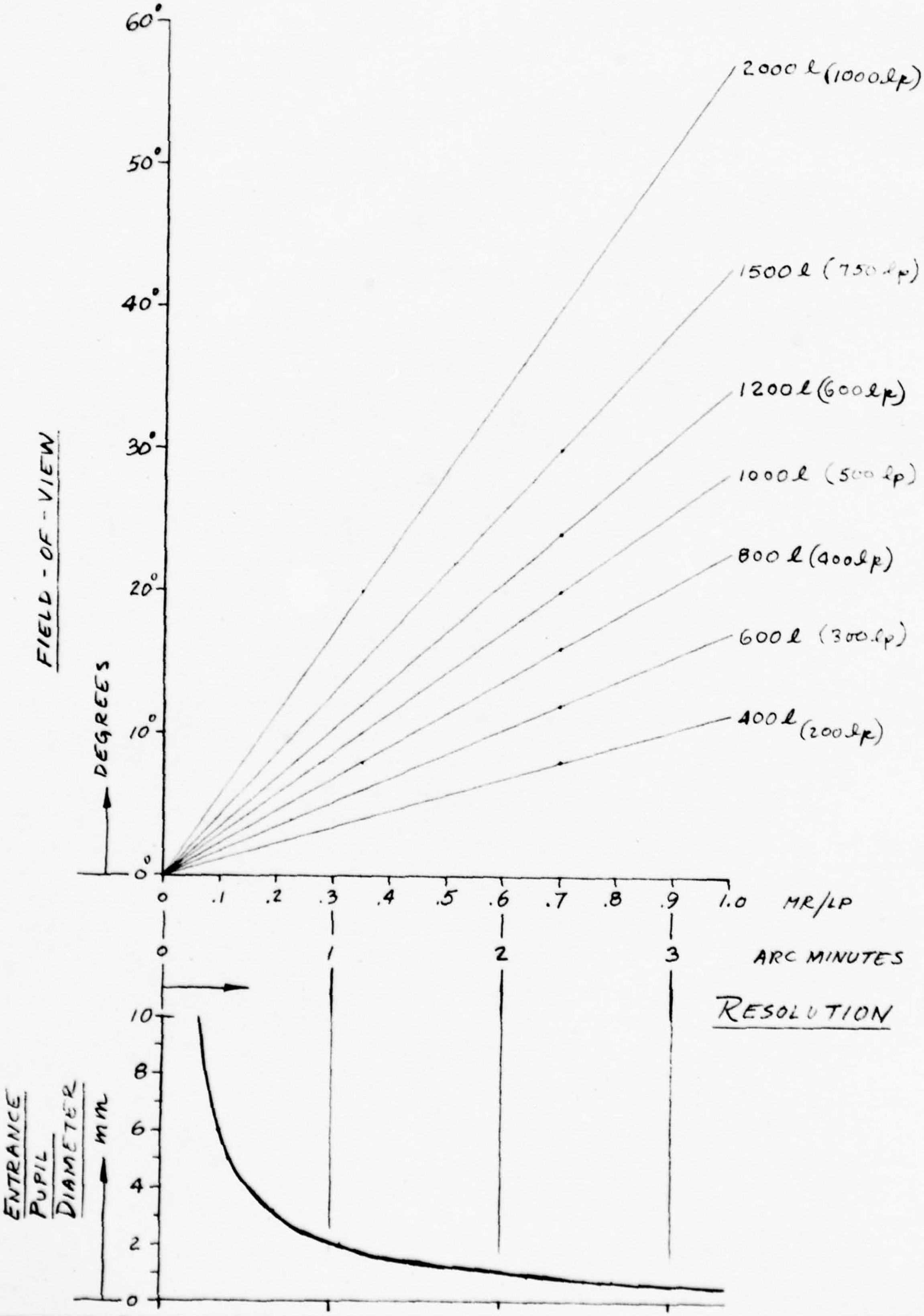
[19] Stich, K. and Palmer, J. "Investigation of Night Vision Equipment as a Helicopter Flight Aid: Low Level Night Operations with LLL-TV and FLIR Systems" Research and Development Technical Report, ECOM-7030, November 1973

Figure 1 - DISPLAY RESOLUTION vs. F.O.V. & PUPIL DIA.



possess high sensitivity and high resolution capability, plus the ability to properly operate over a wide range of scan formats and scan rates. High camera sensitivity is required to keep the terrain model illumination level within reasonable bounds. A 500 foot candle maximum illumination limit is specified, and should be adequate for intensified type sensors operating in conjunction with the defined E-O sensor probe (plus spectral filters as required for signal enhancement and/or signal separation purposes).

A high resolution ($\geq$ 1000 TVL) camera and nominal 1500 TVL display are required to simulate the high resolution type of low light level sensor devices (both TV and FLIR types). From Figure 1, it can be seen that a 1000 line TV sensor (500 TV/line pair) operating with a FOV of 8° will provide a basic angular resolution better than 0.3 mr/line pair. When combined with the probe resolution characteristic, the signal fed to the special E-O sensor display is representative of advanced FLIR sensor performance as well as high resolution LLL-TV sensor performance. By incorporat- variable scan rate/scan format capability, this performance can be degraded as required for simulation of lower resolution low light level sensor devices.

TECHNICAL SUPPLEMENT

MOTION SIMULATION ANALYSIS

CONTENTS

MOTION SIMULATION ANALYSIS

1.0 INTRODUCTION

The requirement for motion simulation in the Visual Flight Research Facility (VFRF) for experimentation relative to nap-of-the-earth (NOE) helicopter flight is an area that requires as much justification as possible. A literature search and personal interviews have both turned up conflicting information on the relative effectiveness of a motion base, G-seat alone, and of motion base plus G-seat, compared with fixed base simulators. This document attempts to summarize the available data and present sufficient information for valid recommendations and conclusions regarding the need for (and degree of) motion simulation for the VFRF.

1.1 Approach - Computation of acceleration peaks encountered in NOE helicopter flight, vendor-user surveys, and literature surveys were used to bring all available relevant factors bearing on the problem to light. These factors were used in evaluating the alternative methods of accomplishing the requirements. A conclusion as to the best method of meeting the requirements was reached as a final result.

1.2 Requirements - The VFRF is required to allow experimentation on the pilot and copilot crew members to evaluate flight procedures and equipment (including some simulated types) that will enhance night NOE flight (with growth potential to simulated daytime flight). Adequate fidelity of response of the cockpit (flight control) and maximum fidelity of the visual scene is desired, within cost and schedule limitations, to assure that valid experimental results are available from VFRF utilization. The question of whether the requirement for cockpit fidelity of response translates into a requirement for motion simulation is first addressed. Then the question of the degree of motion simulation - if required - is engaged.

In the selected base VFRF system design concept, the crew members will be separated and actually operating in distinct crew compartments. However, only one crew station will be equipped as a flight compartment, while the second station, although serving as a cockpit from the standpoint of basic flight instruments and displays, will incorporate only a simplified flight control function. Therefore, consideration of the need for simulated cockpit motion is restricted here to the first mentioned compartment, which, depending on the particular research task, can alternately house the pilot or the copilot.

1.3 Method of Accomplishing Requirements - Motion simulation could either be deleted as a requirement, implemented with a partial set of motion stimuli, or implemented with a full motion base plus G-seat. VFRF cost increases, as do maintainability requirements, and reliability decreases as the complexity of the motion simulation is varied from none up to the combined system.

2.0 SUMMARY OPERATING CHARACTERISTICS OF CANDIDATE APPROACHES

2.1 Fixed Base - The fixed base approach utilizes only visual cues to create the illusion of motion. A windscreen display for a fixed base simulator must operate in 6 DOF to provide motion cues for the pilot and/or copilot experimental subjects. In the case of a terrain model and optical probe system, this can be achieved through the combined operation of the probe transport and pick-up optics' 6 DOF capability. If a remote screen of practical size is used in this system, detracting, fixed, screen edge cues can result in cases of more extreme roll and pitch maneuvers. Also, an analysis was conducted to determine the resulting scene geometrical distortions based on a representative range of NOE flight dynamics. It was concluded that the image distortions and other false cues inherent in the remote screen, fixed base system generally fall within the subjective tolerance limits of the average observer. Therefore, other limitations of the fixed base system would have to assume importance in order to rule out this simple approach for VFRF use. The limitation which does appear significant is the inability of the fixed base system to provide any proprioceptive cues (neither ear channel nor muscular feel) to the test subject. The significance of these missing cues is discussed in more detail in subsequent sections of this report.

2.2 Dynamic Seat (G-Seat) - The G-seat device which is designed to replace the conventional pilot's seat in the simulator flight compartment has been developed to provide the capability for sustained acceleration simulation as experienced in high performance fixed wing aircraft. In actual tests, however, there is considerable evidence that in addition to the sustained acceleration effects, the G-seat provides significant onset acceleration cues which are considered to be of primary importance in critical rotary-wing aircraft flight control functions.

The G-seat couples to the body system's haptic sensor elements to induce pressures similar to those resulting from body/seat coupling experienced during translational and rotational accelerations in flight. These are produced in the G-seat by independently altering the elevation, attitude, and shape of the seat and backrest surfaces, and, in addition, controlling the pressure of thigh panels located on either side of the seat pan. Also, the degree of extension and contraction of the lap belt assembly is controlled.

The G-seat software package produces the excursion commands for each element of the seat assembly. The G-seat software package, in turn, draws upon flight software for simulated aircraft acceleration inputs. The above commands must be properly coordinated with the optical probe/transport subsystem drive inputs to maximize the desired 6 DOF motion simulation effects. Test results obtained by several research groups using G-seats, with and without motion bases, are subsequently discussed (also, see Reference 1).

2.3 Motion Base - The full motion base system is capable of providing 6 DOF proprioceptive cues to operate in conjunction with the 6 DOF visual cues. The motion base moves through a portion of the commanded maneuver to generate the proprioceptive cues (inner ear and muscular) that will effectively lead the visual velocity cues (Reference 2). The visual velocity cues will continue to supply the sensation of motion while the base settles back (very slowly) into its original position.

The interaction of a remote (fixed) display screen and motion base to provide the full range of compensated velocity cues can be very complex. This becomes a very important consideration if the baseline VFRT system does not include a motion base, but identifies it as a growth item. In this case, extreme care must be taken in specifying the type of visual display which will be compatible with the added motion base capability.

3.0 ANALYSIS

3.1 Factors Bearing on the Problem - Three methods of data collection were used, including; (1) defintion of the proprioceptive cues available, and correlation with proprioceptive cue thresholds, (2) survey of the literature including approaches and trades, and (3) vendor-user survey for their approaches and trades.

3.1.1 Analytic Data Definition

3.1.1.1 Proprioceptive Cue Availability - The roll, pitch, and yaw proprioceptive cues are generated through aircraft maneuver. Utilizing movie film sequences taken by Martin Marietta engineering personnel at Ft. Rucker on a recent visit, the attached set of roll maneuvers was analyzed and the results plotted. These maneuvers, Figures C-1 through C-12, were not selected because of some special attribute of high angular acceleration. Instead, they are typical of NOE flight path terrain avoidance.

The twelve run segments give the histogram of Figure C-13, with accelerations in deg/sec^2 taken at the data points. Three attempts to curve fit to the data evaluated over 25°/sec^2 intervals were made, giving:

$$p(x)_1 = 43\ e^{-(43\ x/2000)}$$

$$p(x)_2 = 40\ e^{-(40\ x/2000)}$$

$$p(x)_3 = 43\ e^{-(x^2/2\sigma^2)} \qquad \sigma^2 = 1533.22$$

The validity of these curves was established by:

a. Exponential

$$p(t) = \nu\ e^{-\nu t}$$

$$\int_o^{.1} p(t)\ dt = \int_o^{.1} 43\ e^{-43t} = -(e^{-4.3} - e^o) = -.014 + 1 \simeq 1$$

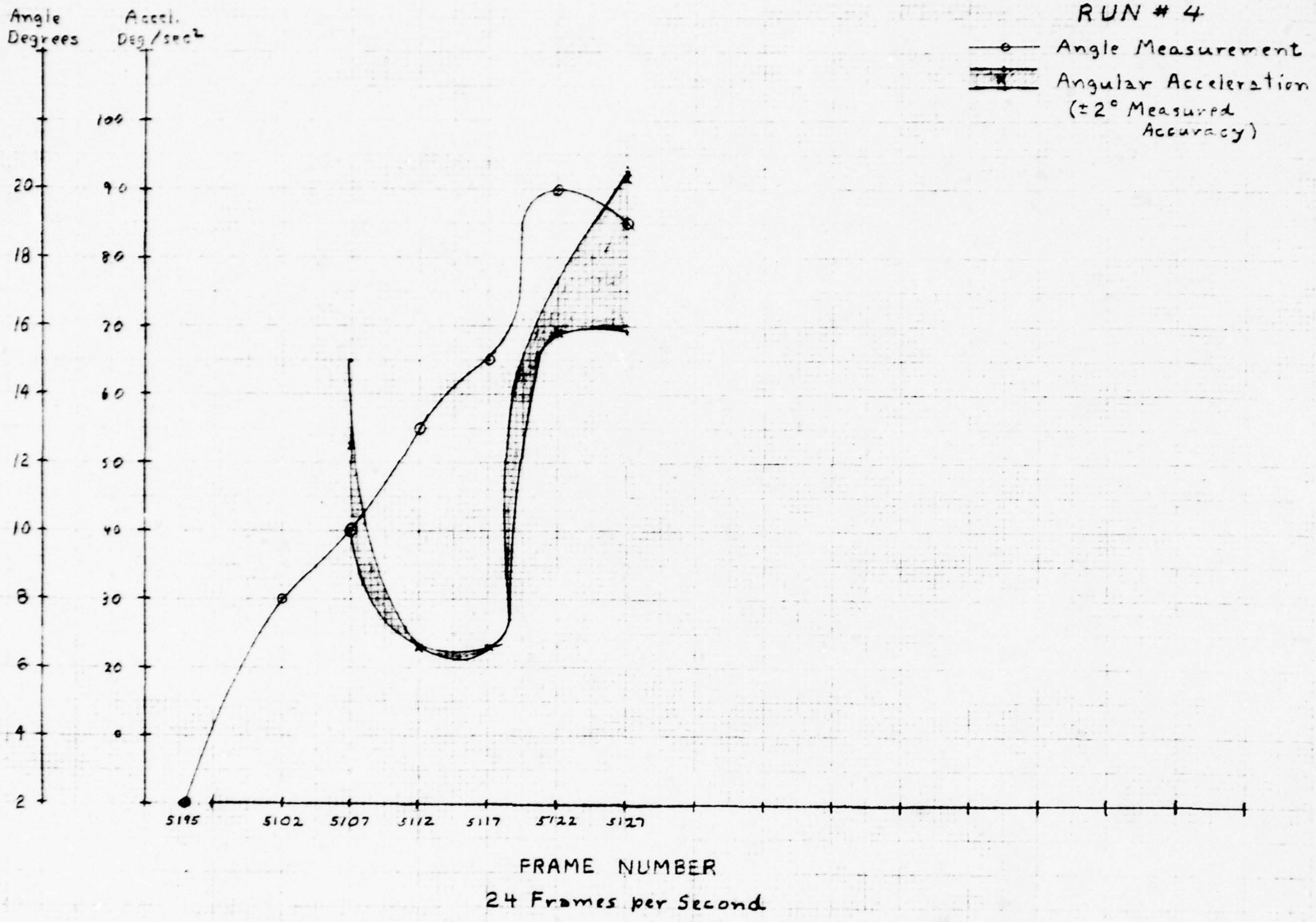


Fig C-1 Roll Angle and Acceleration Run #4

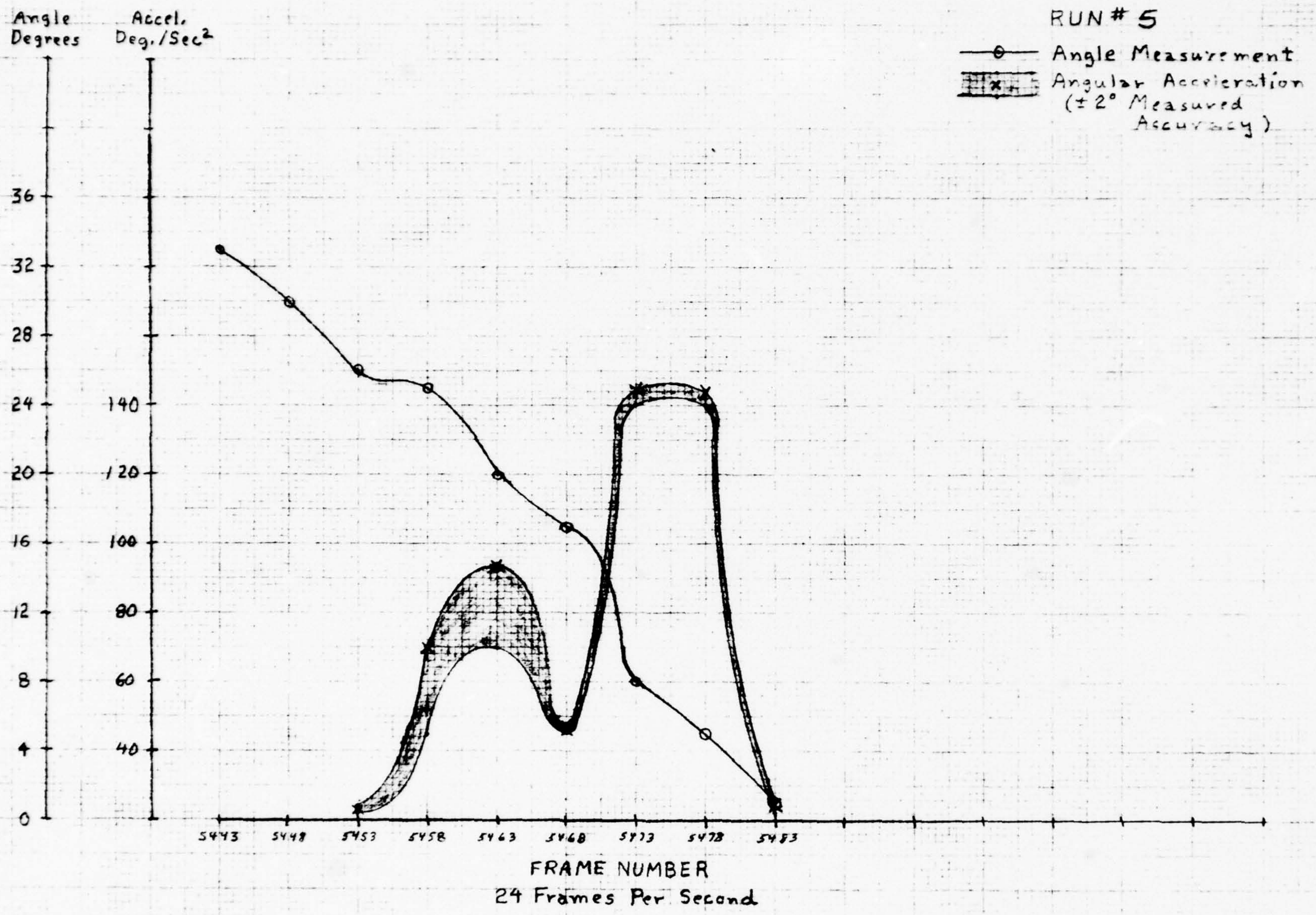


Fig C-2 Roll Angle and Acceleration - Run # 5

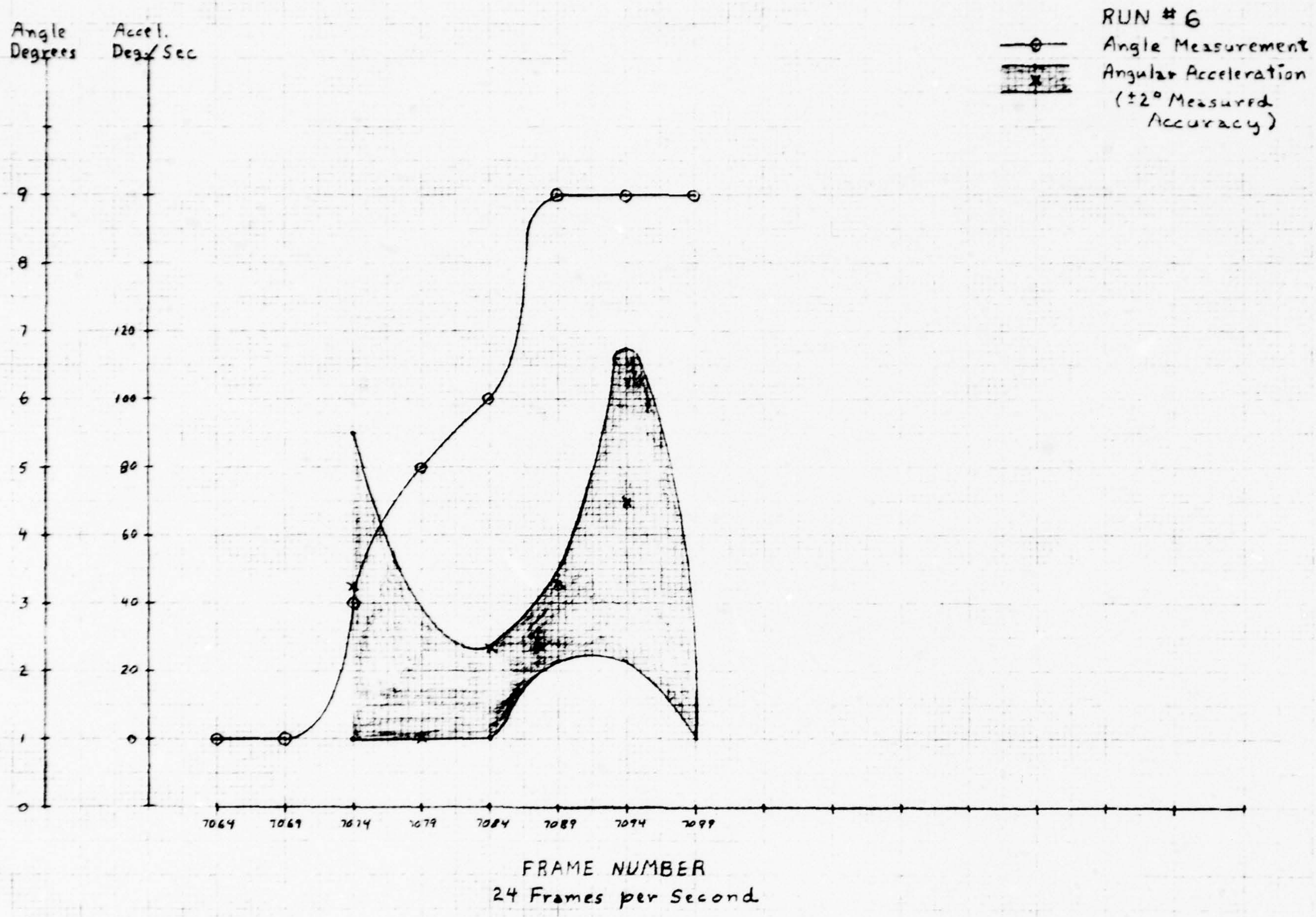


Fig C-3 Roll Angle and Acceleration - Run # 6

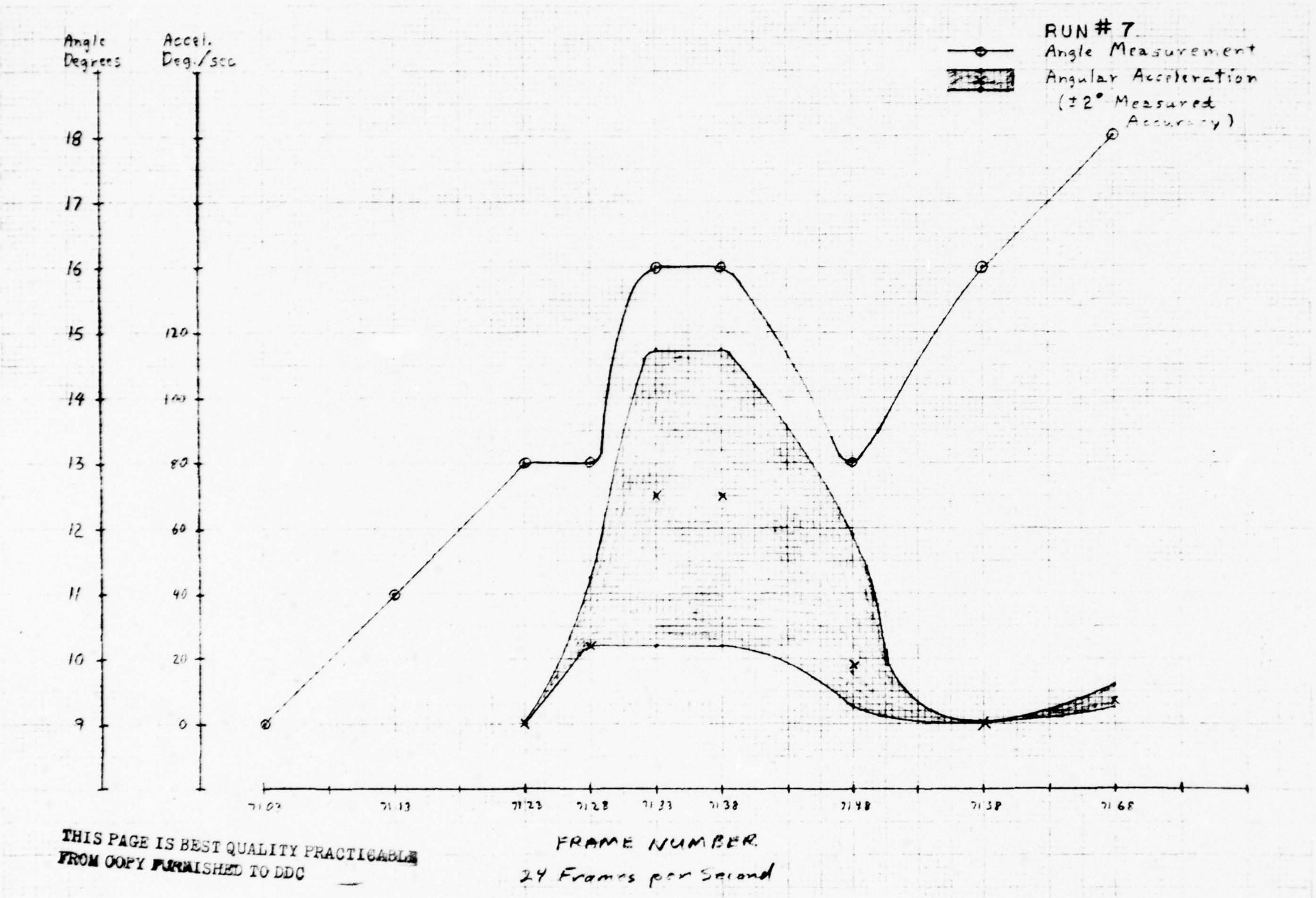


Fig C 4 Roll Angle and Acceleration - Run #7

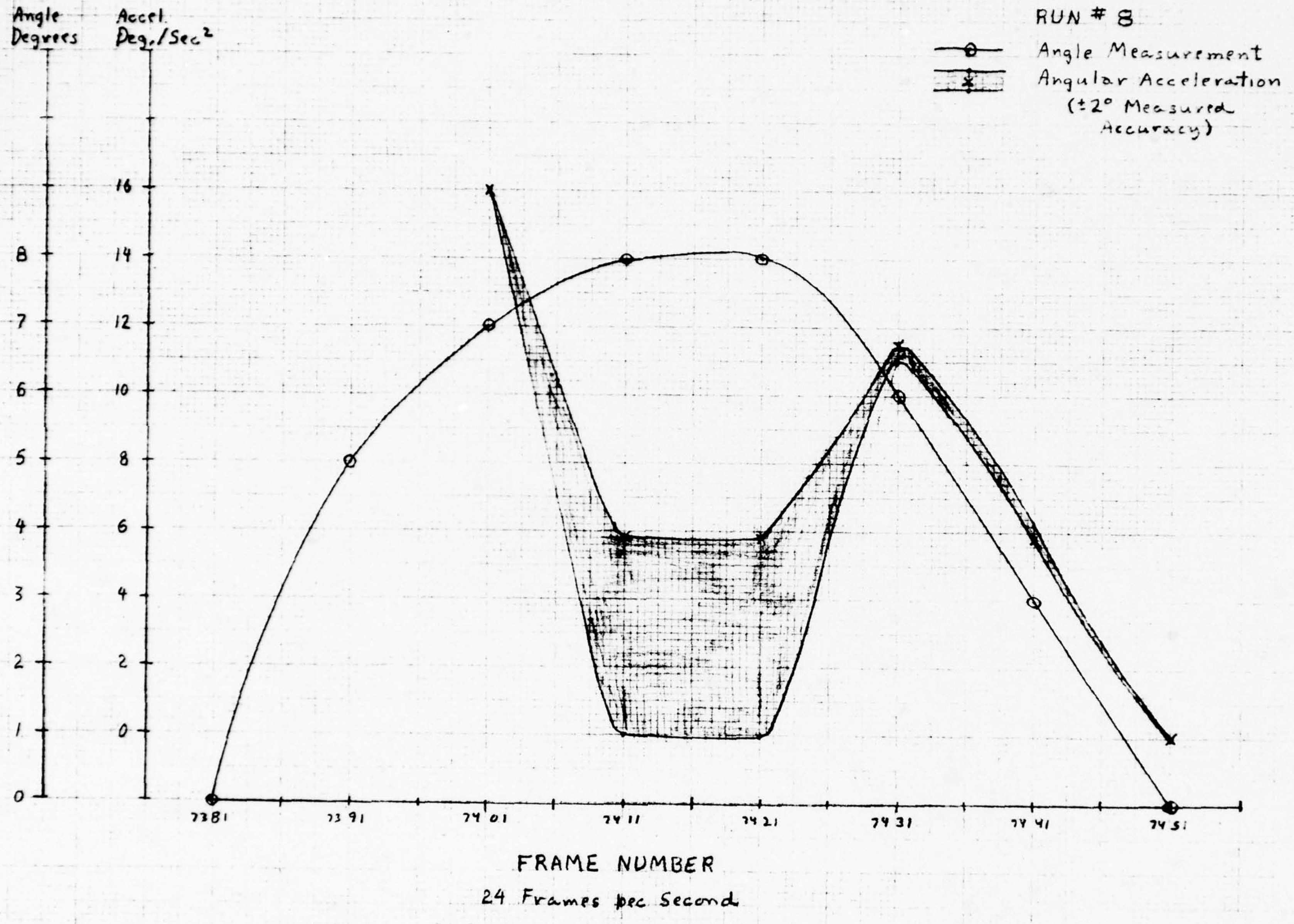


Fig. C-5 Roll Angle and Acceleration - Run # 8

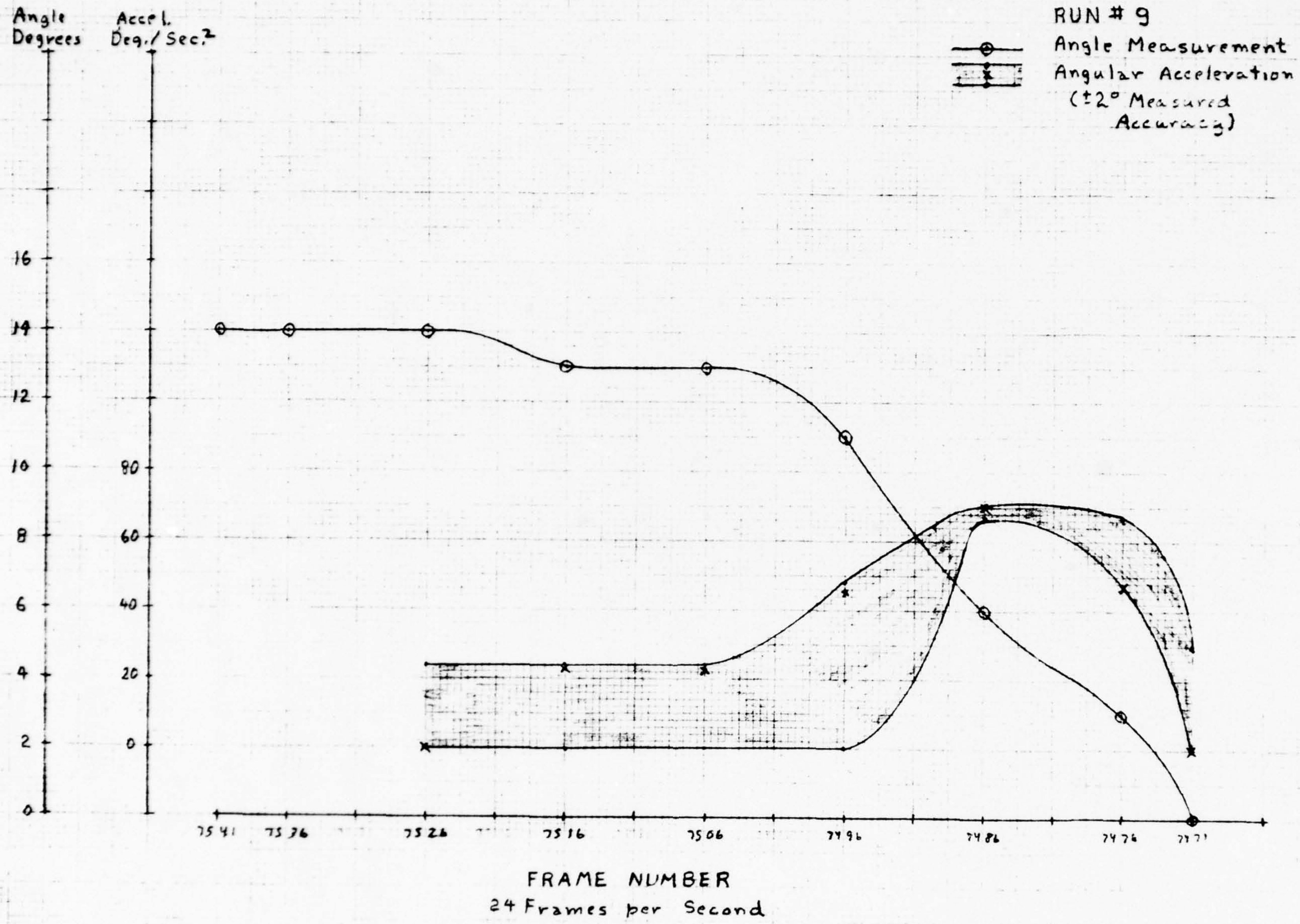


Fig C-6 Roll Angle and Acceleration - Run #9

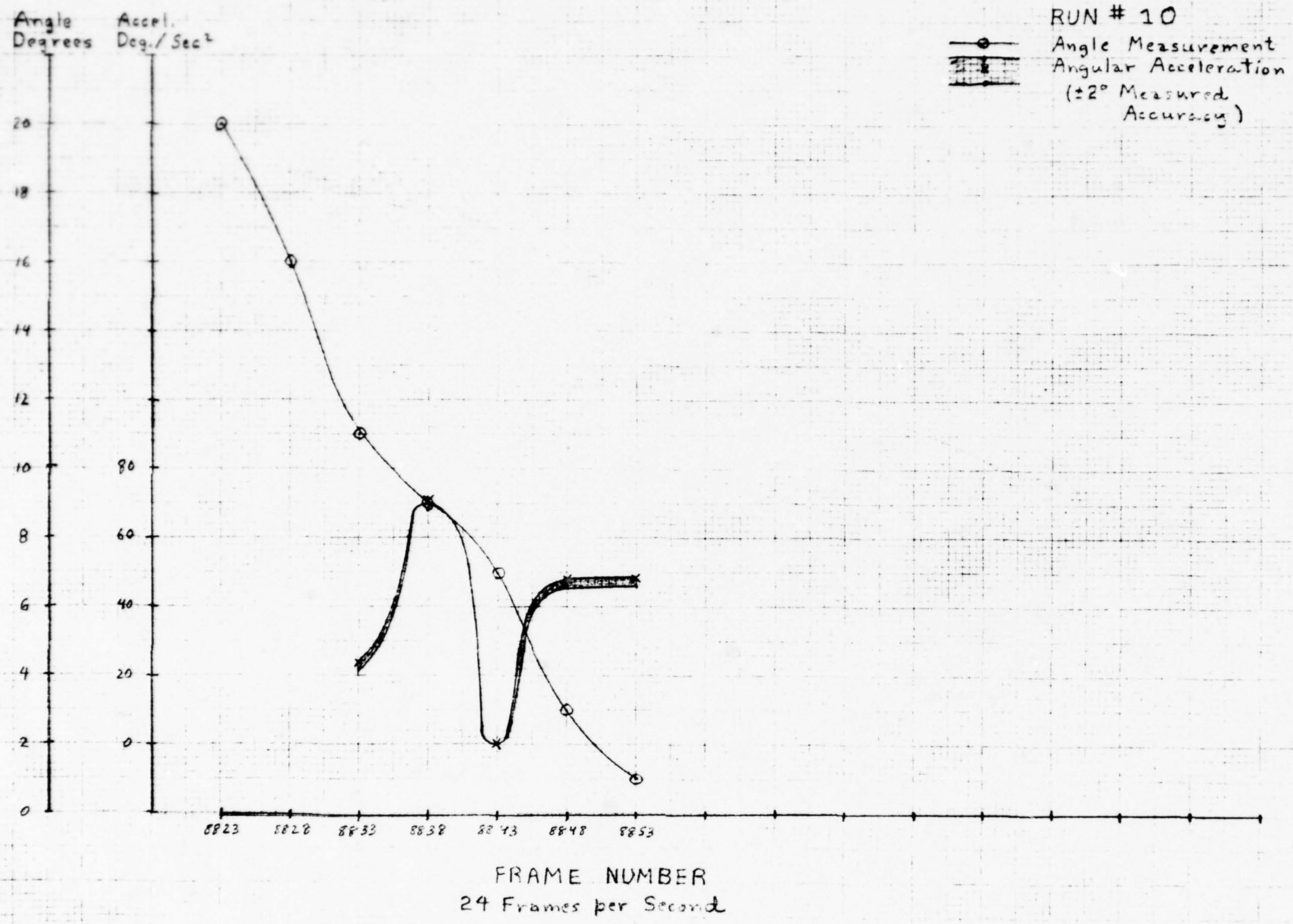


Fig C-7 Roll Angle and Acceleration - Run #10

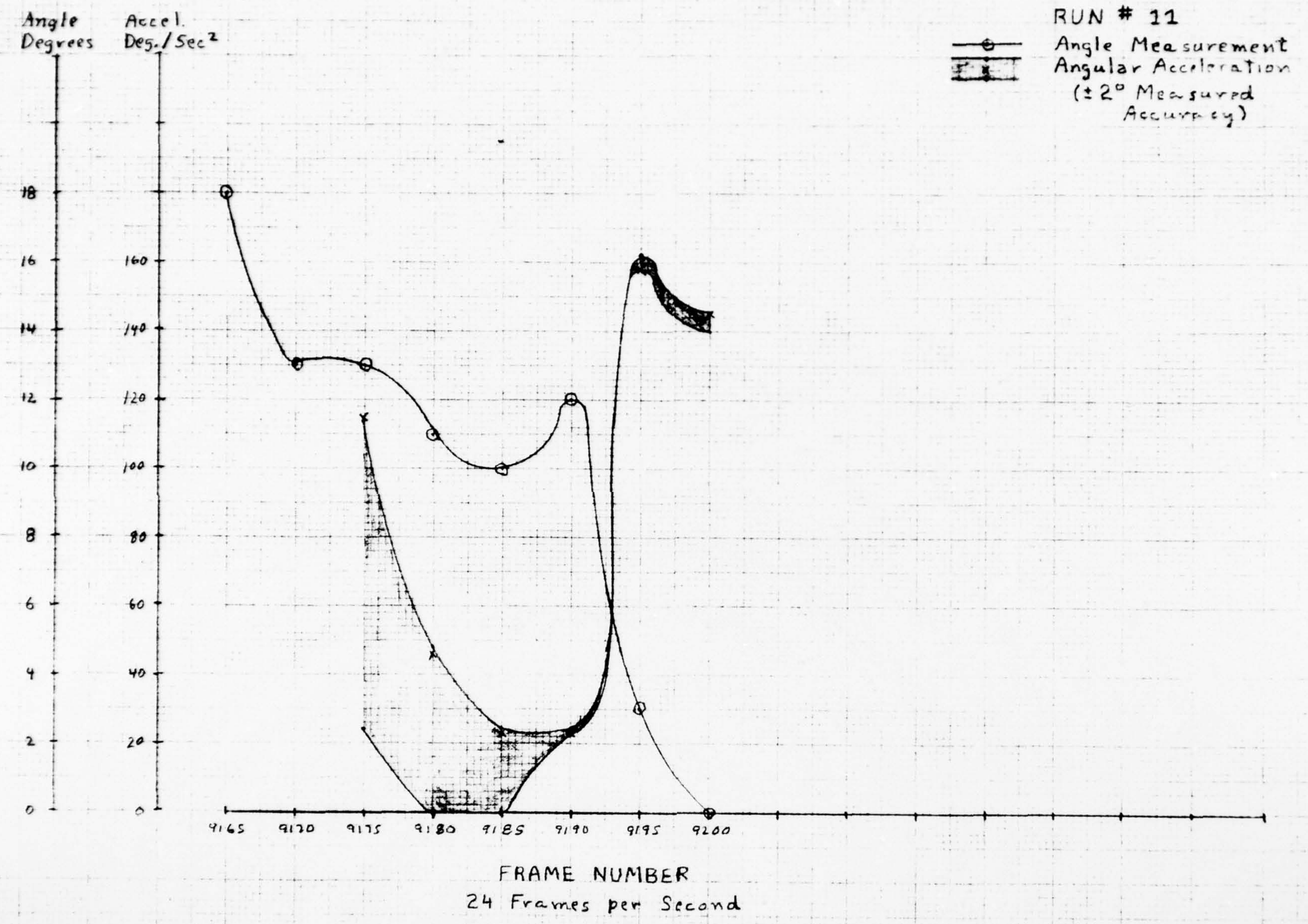


Fig C-8 Roll Angle and Acceleration - Run #11

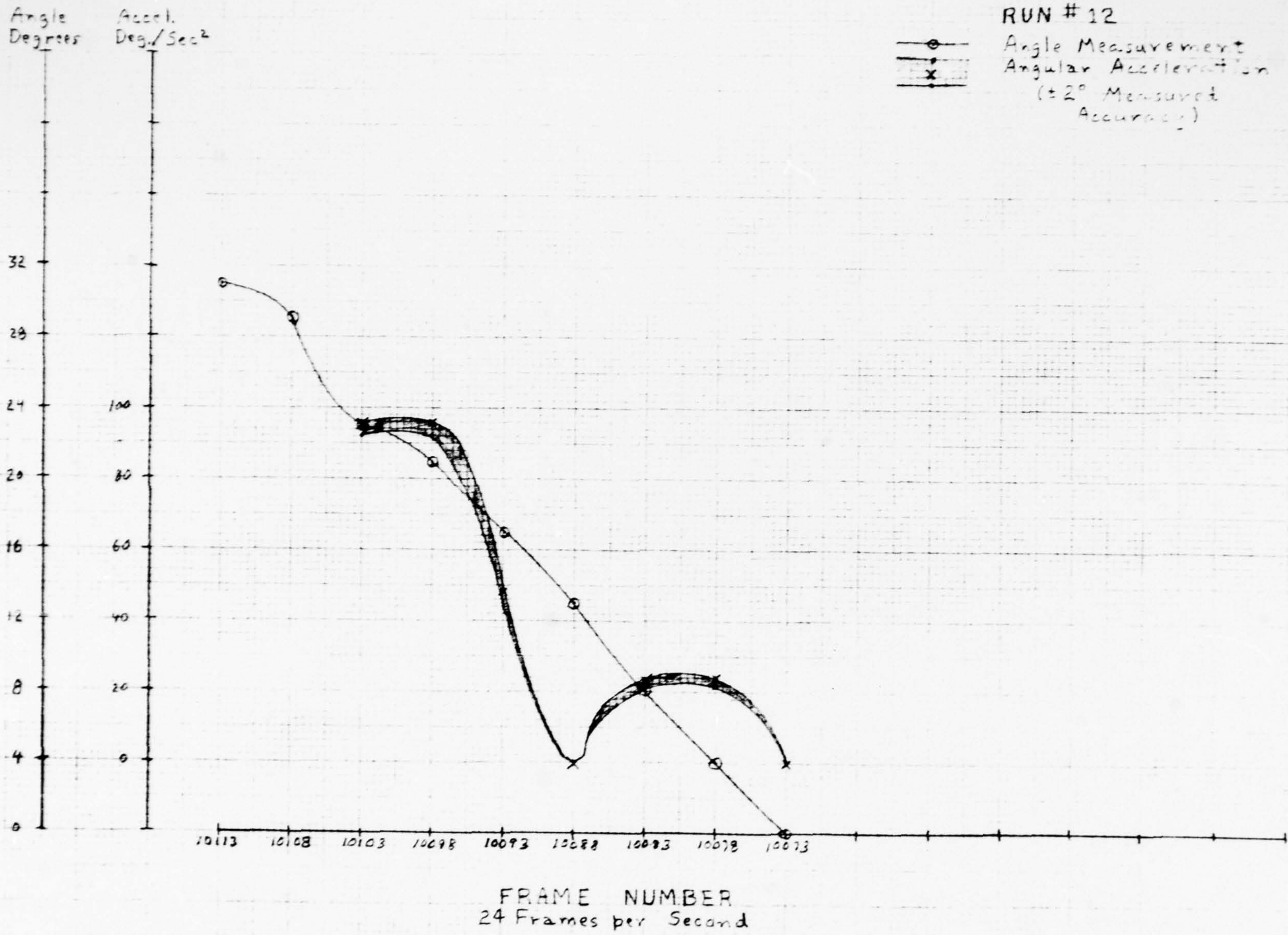


Fig C-9 Roll Angle and Acceleration - Run # 12

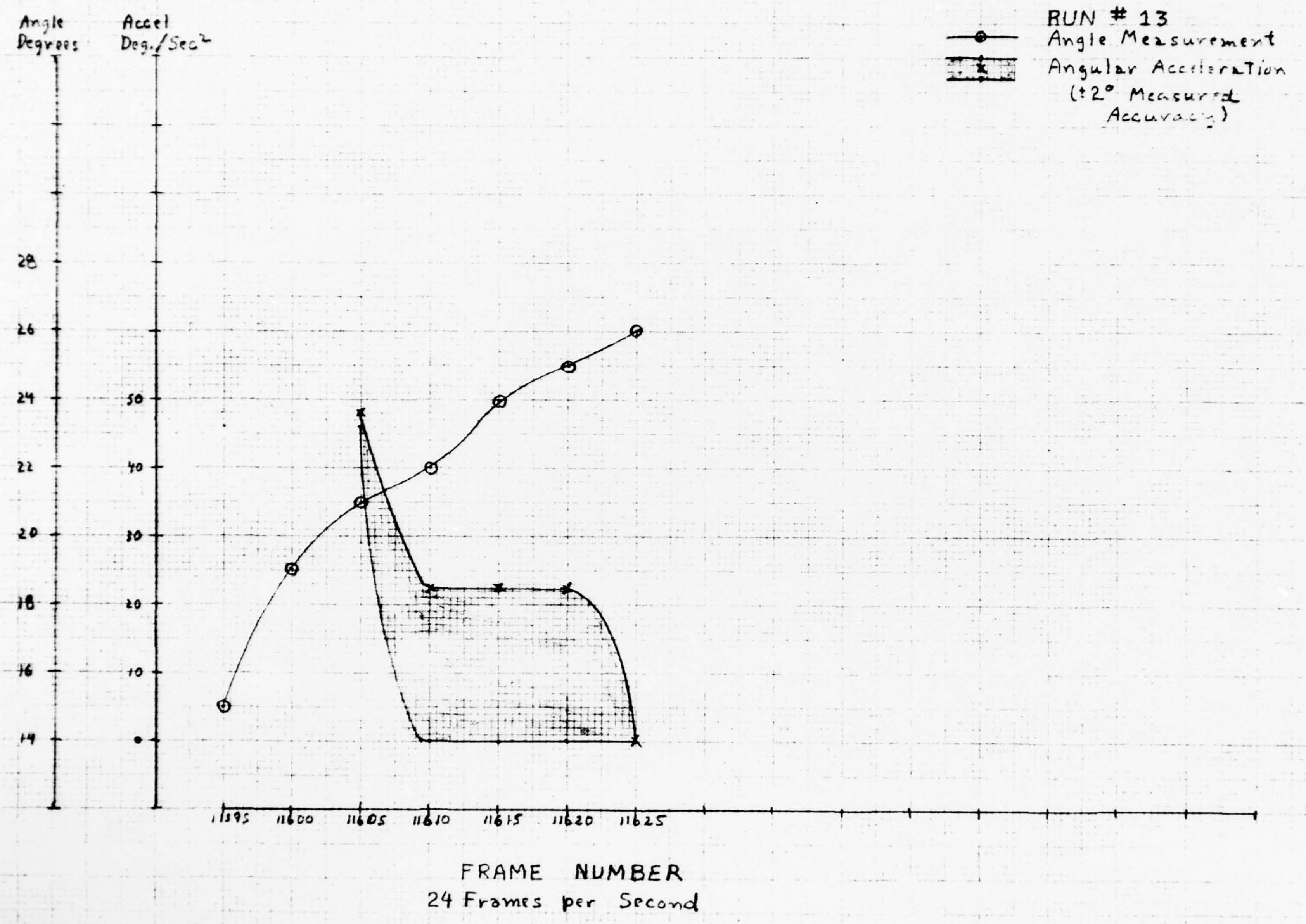


Fig C-10 Roll Angle and Acceleration - Run #13

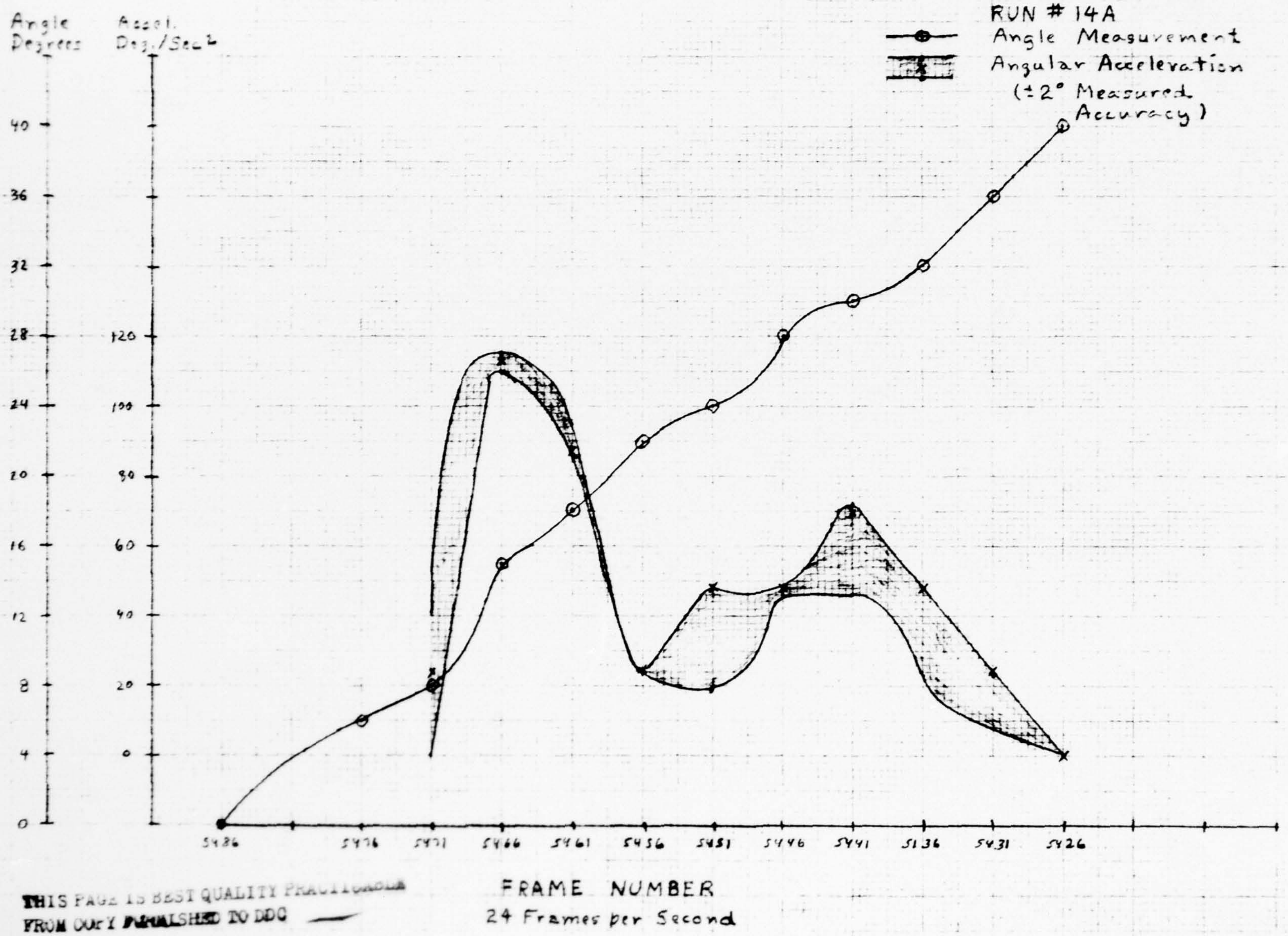


Fig C-11 Roll Angle and Acceleration - Run # 14A

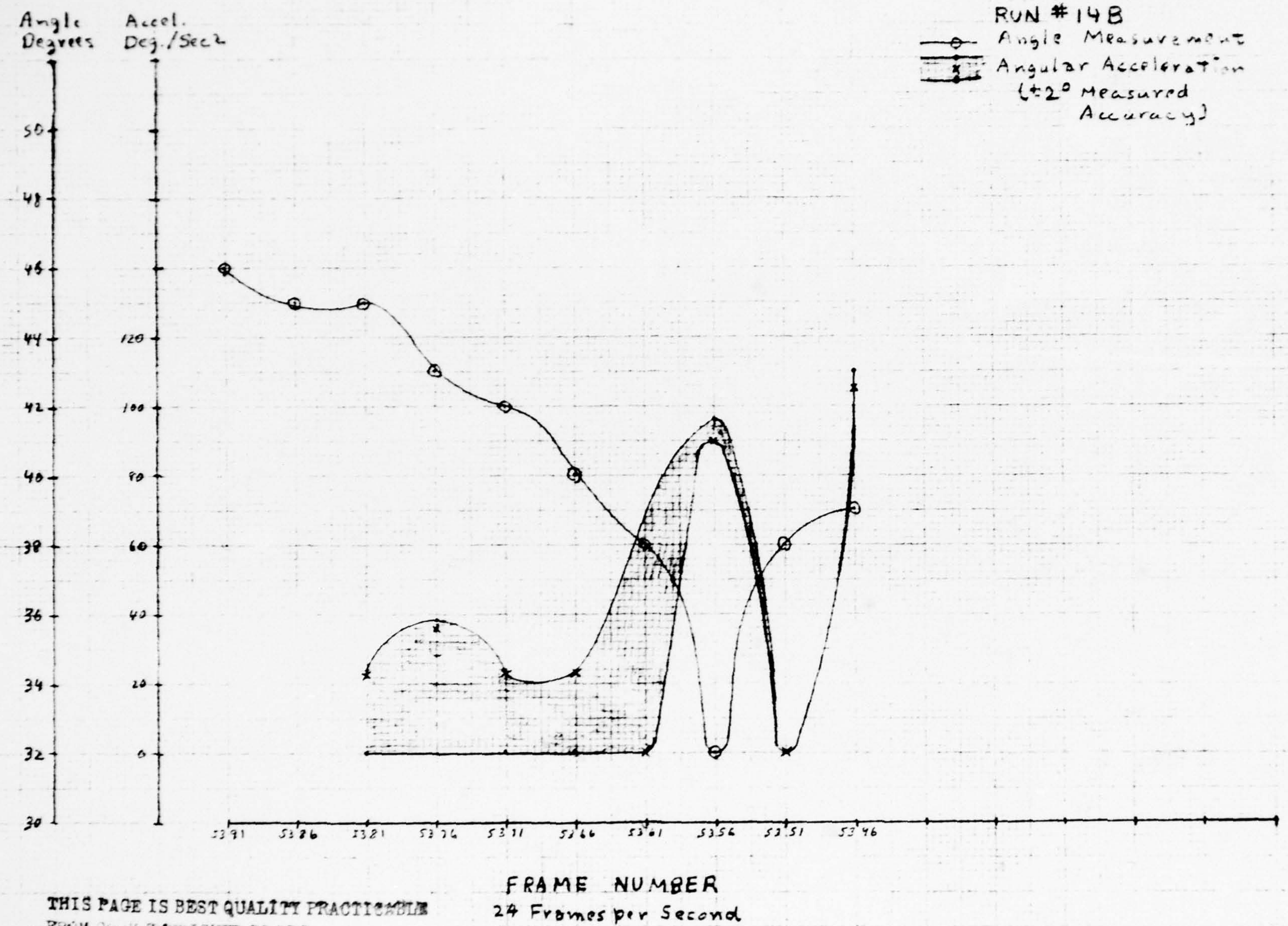


Fig C-12 Roll Angle and Acceleration - Run #14B

Fig. C-13 ACCELERATION ANALYSIS - CURVE FIT

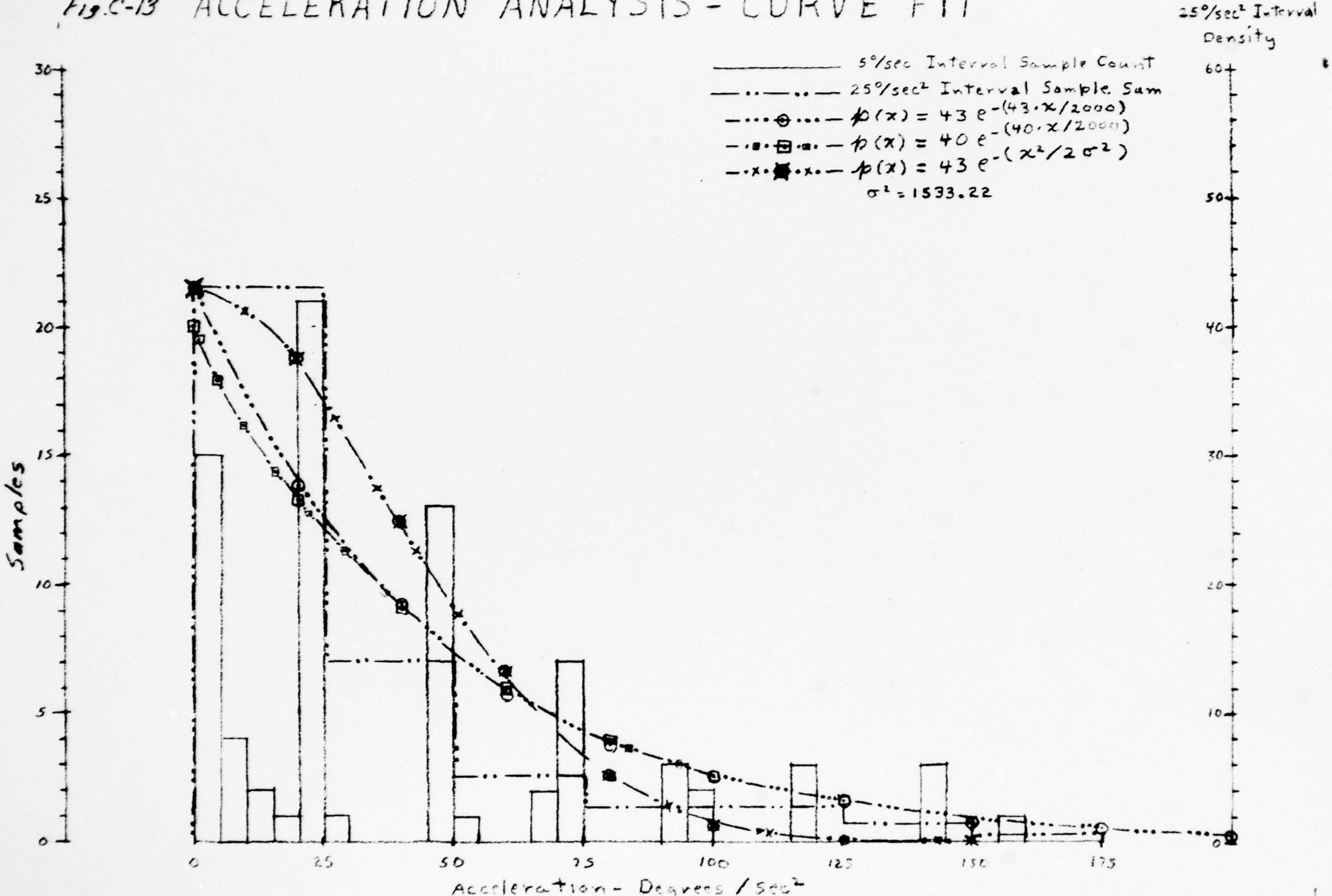


Figure C-13

$$t = \frac{x}{2000} \qquad dt = \frac{dx}{2000}$$

$$\int_{o}^{200} \frac{43}{2000} e^{-43\,x/2000}\, dx = -(e^{-4.3} - e^{o}) = -.014 + 1 \approx 1$$

$$\int_{o}^{200} \frac{40}{2000} e^{-40x/2000}\, dx = -(e^{-4.0} - e^{o}) = -.018 + 1 \approx 1.$$

b. Half-Normal

$$\int_{o}^{\infty} 2\,\phi\,(x)\, dx = \frac{2}{\sigma(2\pi)^{1/2}} \int_{o}^{\infty} e^{-\frac{x^2}{2\sigma^2}}\, dx$$

$$= \frac{2}{\sigma(2\pi)^{1/2}} \cdot \frac{1}{2}\left(\frac{(\pi)^{1/2}}{\frac{1}{\sqrt{2}\,\sigma}}\right) = \frac{2}{\sigma\sqrt{2}\;\pi^{1/2}} \cdot \frac{\sigma\,\sqrt{2}\,\pi^{1/2}}{2} = 1$$

where

$$\frac{2}{\sigma(2\pi)^{1/2}} = 43 \text{ for scaling.}$$

$$\int_{o}^{\infty} 2\,\phi(x)\, dx - \int_{200}^{\infty} 2\,\phi(x)\, dx$$

$$1 - (\approx 0) = 1$$

Last integral by graphic techniques.

An evaluation of the estimates, based on actual samples versus the curve, gives the following, Table C-1:

TABLE C-1

Actual versus Curve Comparison

Occurrence	Actual (79)	$p(x)_1$	$p(x)_2$	$p(x)_3$
150 - 175 deg/s^2	0.01266	0.01653	0.01959	.00010
125 - 150 "	0.03797	0.02839	0.03230	.00218
100 - 125 "	0.03797	0.04843	0.05325	.00848
75 - 100 "	0.06329	0.08288	0.08779	.04667
50 - 75 "	0.12658	0.14194	0.14475	.15186
25 - 50 "	0.17721	0.24291	0.23865	0.3064
0 - 25 "	0.54430	0.41579	0.39346	0.4843
TOTAL	0.99998	0.97687	.96979	.9999

Table C-2 gives a difference comparison for the curve match, and indicates that curve p(x) is the best average fit of the three curves.

TABLE C-2

Curve Match Comparison

Range	Actual	$p(x)_{1/act}$	$p(x)_{2/act}$	$p(x)_{3/act}$
150 - 175 deg/s^2	1.0	1.3056	1.5474	.0078
125 - 150 "	1.0	.7477	.8506	.0574
100 - 125 "	1.0	1.2755	1.4024	.2233
75 - 100 "	1.0	1.3095	1.3871	.7374
50 - 75 "	1.0	1.1213	1.1435	1.1997
25 - 50 "	1.0	1.3707	1.3467	1.7290
0 - 25 "	1.0	.7639	.7639	.8897
Ave.	1.0	.9638	1.2059	.6920
		Δ = .0362	Δ = .2059	Δ = .3080

This data shows that during a NOE flight maneuver, the pilot has a probability of .0884 of experiencing an angular acceleration of over 100°/sec^2, a probability of .2781 of experiencing over 50°/sec^2, and 0.4553 of experiencing over 25°/sec^2. The article "Thresholds for the Perception of Angular Acceleration in Man", from Aerospace Medicine, May '67, shows a 0.10 to 1.5 deg/sec^2 threshold for angular acceleration in man.

3.1.2 Vendor-User Survey (Telecon)

3.1.2.1 Singer-Link, Dr. Ed Stark

Dr. Ed Stark of Singer-Link has been involved in air-to-air gunnery flight simulation which uses a motion base, G-seat, and G-suit. In a series of tests, Dr. Stark stated that the G-seat used in conjunction with the motion base has improved tracking in the air-to-air gunnery system and has enhanced the simulated acrobatic flight response. Dr. Stark also mentioned that the reason why the G-seat has helped in these situations is not well understood at present. Dr. Stark is readying a series of tests with the G-seat and motion base versus the G-seat alone. The results of this experiment will be of particular interest in subsequent VFRF study phases.

3.1.2.2 ASD/ENCTS, WPAFB, Mr. Richard Heintzman

Mr. Richard Heintzman of Wright Patterson AFB was contacted with respect to his use of the F-4 G-seat and motion base. He stated that the G-seat was preferable to the G-suit for unloading cues and in the 0 g environment. He stated that his simulator hasn't flown much and that more answers are needed.

3.1.2.3 ASD/ENCTS, WPAFB, Mr. Jack Wilson

Mr. Jack Wilson has worked with Mr. Heintzman on their simulator and has flown their G-seat system with and without the motion base. He stated that the G-seat alone gave insufficient cues in ± and 0 g's vertical, gave only a very small roll cue, and only a very small longitudinal cue. The onset cues provided by the motion base are essential to the air-to-air gunnery mission. One pilot flying the G-seat without motion base ended in a lateral PIO, or case of severe disorientation. Mr. Wilson stated that he will be working with Dr. Stark on the upcoming test series. He further stated that the personnel involved would be F-4 qualified Nellis and Luke pilots.

3.1.2.4 NTEC, Orlando, Florida, Mr. Joseph Puig

Mr. Joseph Puig stated that the requirement for motion simulation cannot be generalized; it is extremely task-specific. The training application is extremely clear cut, the objective is established and the evaluation is made to specify whether motion is needed or not needed to meet the objective. The research application, in Mr. Puig's estimation, requires the highest degrees of fidelity because objectives are variable. He stated that most subjects do not notice the motion cues, but most certainly utilize them as evidenced by their ability to complete a variety of tasks simultaneously.

Mr. Puig's experience with G-seats has been most satisfactory from the standpoint of high performance aircraft simulation. He said that in his opinion the "seat of the pants" cues were at least as good as the vestibular cues. He did state that vestibular cues were required for avoiding disorientation, as in instrument trainers. He has witnessed good flight performance in simulators with the motion base off and G-seat on.

The argument that "all the other simulators have motion" is invalid, according to Mr. Puig. He did indicate though that the helicopter hover and slow flight regime are definitely areas where motion cues are important, and possibly even critical in the research flight fidelity respect.

3.1.2.5 Goodyear Aerospace

A conversation with the local (Orlando) Goodyear Aerospace representative revealed that the "Dynaseat" has not been a production item for that company in four years.

3.1.3 Literature Survey (References)

3.1.3.1 Articles Surveyed

A set of 9 relevant and timely articles and papers were surveyed to give further insight into the requirement for a motion base in the VFRF. These include:

1. "Motion Simulation Enhancement: The Development of a Research G-Seat System" - G. J. Korn, Sixth Naval Training Equipment Center and Industry Conference, November 13-15, 1973, NAVTRAEQUIPCEN IH-226.

2 "Use of Flight Simulators for Pilot Control Problems" - Rathert, Greer, Douvillier, NASA Memorandum, AD 210526.

3 "Simulation of Visual and Motion Cues in Air Combat Maneuvering", Dr. E. A. Stark and Mr. J. M. Wilson, Jr., Sixth Naval Training Equipment Center and Industry Conference, November 13-15, 1973 NAVTRAEQUIPCEN IH-226.

4 "Motion, Visual and Aural Cues in Piloted Flight Simulation", K. J. Staples, January, 1970, AD 871716.

5 "Simulator Motion in Aviation System Design Research", Robert C. Williges and Stanley N. Roscoe.

6 "Threshold for the Perception of Angular Acceleration in Man", Brant Clark PhD, Aerospace Medicine, May 1967, Vol. 38, Number 5, May 1967.

7 "The Use of Piloted Flight Simulators in General Research", George A. Rathert, Jr., Brent Y. Greer, and Melvin Sodoff, AD 404196.

8 "The Role of Motion Information and Its Contribution to Simulation Validity", W. E. Feddersen, Report D228-429-001, April 1962, AD 281855.

9 "Motion in Flight Training: A Human Factors View", Joseph A. Puig, NAVTRADEVCEN IH-177.

3.1.3.2 Summary of Article Survey Data

Mr. Korn's article on the research G-seat system points out that the G-seat primarily provides stimuli for sustained acceleration, exciting man's haptic (muscular or seat of the pants) system. The G-seat is developed independently and separately from motion base operation, with full capability of insertion into a motion system environment. The G-seat is extremely important to the system because the nature and importance of stimulus coupling between the haptic, vestibular, and visual sensory systems is not known. The seat will furnish the translational accelerations, and will provide roll acceleration and velocity cues through thigh pads and/or outboard bank of underlying seat air cells forming the thigh panel.

The memorandum by Rathert, Greer, and Douvillier points out that there are some regions where motion stimulus is mandatory in order that the pilot operate the simulator realistically, particularly for pitch and roll control systems with a sensitive rapid response to control movements . . . in maneuvering flight.

Dr. Stark and Mr. Jack Wilson in their NAVTRAEQUIPCEN paper point out that in general, cockpit motion cues derived from a motion base were considered the most important effects of the cockpit motion simulation system (which included a G-suit and G-seat) in supporting flight control over a 16 maneuver test sequence designed for A-A combat. Their analysis of the results indicated a need for pitch, roll, yaw, heave, longitudinal, and lateral angular and translational accelerations, as well as buffet, vibration, and sustained acceleration. Visual cues were not sufficient for pitch, high speed roll, yaw (except low altitude), and heave in coordination with pitch. Visual and instrument cues are too late to be relevant.

Mr. K. J. Staples in his article states that without motion, visual, and aural cues, the full inclusion of man in the simulation loop is not possible. He rates motion cues as provoking the quickest operator reaction, auditory cues next, and visual cues the slowest. Motion cues are required where an unstable or modestly stable situation has to be controlled.

Messrs. Williges and Roscoe state that the uncertainty introduced into research findings by imperfect fidelity of cue environment . . . is particularly acute with respect to performance primarily dependent upon the general class of cues associated with the kinesthetic and vestibular senses.

Feddersen says that pilots are more proficient in flying a helicopter simulator with motion than without. He cites Borlace who concluded that pilots in simulators with motion fly more precisely with shorter response lags and with higher frequency response components than they do in simulators without motion. Their conclusion is that motion cues could unburden the pilot so that he can devote more visual attention to other tasks.

Dr. Clark's Aerospace Medicine article, cited in Section 3.1.1.1, concludes that the stimulus thresholds vary between 0.035°/sec^2 and 8.2°/sec^2 with a median around 1°/sec^2. Generally, he states, the threshold of angular accelerations perception is subjective and varies with a variety of circumstances.

Messrs. Rathert, Greer, and Sodoff state that for dynamic stability, the longitudinal and lateral areas are harder to control in fixed simulators, the visual simulator is harder in roll only for large amounts of control coupling. They conclude that the fixed cockpit is adequate where control stick dynamics are such that the mission is easy to fly. Motion cues aid the pilot by supplying a necessary lead or anticipation cue, as in coping with a lightly damped or unstable vehicle or a sluggish control system.

Fedderson has rather explicit comments with respect to helicopter motion simulation, and contrasts laboratory results with actual flight results for given subjects. He states, as a test philosophy, that the simulator as a research tool should exhibit dynamic characteristics such that performance data obtained in the laboratory should approximate that of in-flight research. The test sequence was designed to investigate relative effects of motion information upon performance of a simulated hovering task in both a fixed base and dynamic simulator situation and to relate these data to that obtained under controlled conditions of helicopter flight with parameters of:

	Position	Velocity	Acceleration
Pitch	±10°	16°/sec	40°/sec^2
Roll	±10°	17°/sec	60°/sec^2
Yaw	±10°	10°/sec	15°/sec^2
Heave (Vert.)	±3.5 ft.	6.6 ft/sec	6.5 ft/sec^2
Surge (long.)	Compensating for		
Sway (lateral)	pitch and yaw		

His summary and conclusions were that inclusion of simulator motion provides a more realistic and valid basis for system evaluation. More specifically, (1) motion contributed to significant proficiency differences in both rate and level of proficiency attainment; (2) when motion was removed from the simulation, performance deteriorated; (3) the use of motion provided "advanced" or "quickened" information to the pilot and allowed higher frequency, lower amplitude control inputs; and (4) motion in the simulation produced results that more closely approximated in-flight performance.

Mr. Puig's interview covered data in his report. Under his motion system recommendations, he states that because it is difficult to distinguish between vestibular and somesthetic sensations, comparison studies should be made of performance using a fixed base simulator with and without a G-seat, and motion base simulator with and without a G-seat.

3.2 Evaluation of Alternatives

The alternatives of deletion of motion simulation as a requirement, partial implementation, or total implementation for the VFRF, as typified respectively by a fixed base cockpit, a motion base or G-seat motion simulation, or a combined motion base and G-seat motion simulation, will be evaluated by:

a. Definition of general VFRF simulation requirements

b. Definition of degree of motion experienced in NOE, and

c. Definition of the required degree of simulation.

3.2.1 Definition of General VFRF Simulation Requirements

The general requirements related to motion simulation can be established through:

a. Statement of VFRF test objectives

b. Statement of methods to meet objectives

c. Implementation to utilize methods to meet test objectives.

The VFRF test objectives include evaluation of piloted flight near terrain and obstacles. This evaluation will include use of new aids and procedures to assist the pilot in NOE flight. The methods used to evaluate pilot performance with or without the new aids and procedures will include task-oriented measurements analogous to a tracking task in A-A missions. Interviews, plus the literature, indicate that helicopter flight in the low speed or rapid maneuver (obstacle avoidance) regime can be simulated with highest fidelity (assuring responses most like actual flight) with the inclusion of motion cues. The NOE flight dynamic evaluation shows that sufficient accelerations are present to provide cues. This fact, coupled with the interviews and literature survey, substantiates the requirement for motion simulation and eliminates a fixed base VFRF concept.

3.2.2 Definition of Degree of Motion Experienced in NOE Flight

The degree of motion effects experienced can be established through:

a. Further study of flight dynamics through film, field experimentation with instrumented helicopters, or other evaluation approaches.

b. Experimentation with scaled simulation in available research vehicles.

The first step above has been initiated with the film study. This data set is very preliminary, and can only be used as a basis to infer that motion simulation is required, but not the degree of simulation. The preliminary steps in the second set should be available from Dr. Stark's continued work.

3.2.3 Definition of the Required Degree of Motion Simulation

Definition of the degree of motion simulation that is required for the VFRF centers around the question of whether a motion base or a G-seat is sufficient to provide critical motion cues, or if both a motion base and G-seat are required. This definition is dependent on the results of the additional studies and experiments discussed in the previous section.

4.0 CONCLUSIONS AND RECOMMENDATIONS

It is concluded that motion simulation is a requirement for the basic VFRF system concept. The degree of motion simulation required to satisfy a potentially wide range of research purposes cannot be defined at this time. However, the experimental results obtained to date using G-seats of latest design are sufficiently promising to justify recommending that the G-seat be specified as the minimum motion simulation device for the basic VFRF. In addition, the VFRF specification shall provide that a motion base can be added at a later time without major modification to the basic VFRF system. In this way, initial motion simulation capability is provided at the lowest cost, but the system design flexibility will permit future addition of a motion base should further studies and experimentation justify this action.