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INTERMETRICS

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LINK GAT-1/PWI OVERALL SIMULATION EXPERIMENT DESIGN

by

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Electronics Research Center
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Note: System diagram for GAT-1 modifications is an integral part of this report and specifically of the specification detailed in Section V.

List of Illustrations

I. INTRODUCTION

A. Aircraft Hazard Avoidance Systems

Increasing congestion in the nation's airspace has led to a variety of public and private efforts to find technical means to enhance the safety of air travel. Added motivation is given to such efforts by predictions of massive growth in air carrier and general aviation traffic levels by the 1980's with consequent increasing probability of tragic air-to-air collisions (1). New study efforts are under way to deal with the overall air transportation system growth in an orderly manner (2,3). In the meantime, it has been recognized that the design and implementation of aircraft hazard avoidance systems could enhance air safety well before the longer range air traffic control system improvements can be effective.

Such hazard avoidance systems fall into two general categories. Collision Avoidance Systems (CAS) have the capability of providing onboard the protected aircraft a warning to the pilot of the threat of a collision and specific guidance commands to him which are compatible with commands simultaneously being displayed to the pilot of other aircraft. The air carriers of the United States are sponsoring the design, development, and evaluation of CAS through their agency, the Air Transport Association.

It had been hoped that CAS could be unilateral in design, not depending on there being a cooperative system on the opposite (threat) aircraft. Practical CAS,however, requires cooperative systems on all aircraft that are to participate. Furthermore, the economic burden of purchasing and maintaining CAS equipment will place it beyond the reach of most general aviation users of the airspace.

Pilot Warning Indicator (PWI) systems are the other category of hazard avoidance concepts. Here the emphasis is on reducing the goals and costs of the system to permit widespread use, to make it basically passive, and to provide a significant enhancement of air safety at least under Visible Flight Rule (VFR) conditions. PWI uses a beacon, required on all aircraft, and a sensing, signal processing, and warning-and-display device on the protected aircraft.

B. Pilot Warning Indicator Programs at NASA Electronics Research Center

Research and development of PWI Systems has been under way for several years. NASA/ERC has conducted both in-house research (4) and a system development program with qualified contractors (5). It was recognized that the program would soon be reaching a point where developmental PWI systmes would be on hand and ready for evaluation. A flight test program was planned. It was also recognized that simulation could play a powerful role, as an adjunct to flight testing, to move PWI development to an early and successful conclusion.

C. Link GAT-1/PWI Overall Simulation Experiment

Accordingly, under Contract NAS 12-2192, Intermetrics, Inc. undertook to design the proposed experiment. This task involved establishing a mechanization concept based on using a Link General Aviation Trainer (GAT-1) now in NASA/ERC's inventory. Secondly, a specification for the experiment, complete enough to be the basis for implementation is to be generated and set forth in a Final Technical Report. This document is intended to fulfill these requirements, and indeed to be the basis for early implementation of the GAT-1/PWI Experiment.

II. PWI OVERALL SIMULATION OBJECTIVES

The general objectives of this experiment are to provide a real-time, ground-based simulation to evaluate the man-machine problems with PWI and other types of collision avoidance or hazard avoidance systems. Initially, the simulation is to be based upon the Atlanta air traffic data (6), use the Link General Aviation Trainer (GAT-1), and to focus on P.W.I. systems now under development at E.R.C. PWI system features or functions such as range of detection, angular field-of-view, displays and presentations, and other significant functional aspects are to be evaluated on a parametric basis.

More specific objectives of the simulation have emerged in the course of the contract through discussions with technical personnel at ERC (7) and increasing familiarity with the great potential of the proposed simulation. These specific objectives are listed in the following paragraphs.

A. Intruder for the Atlanta Environment

The Atlanta ARTS* data represents a twelve hour sample

*Airport Radar Terminal System

of one environment in the continental U. S. air transportation system. In this sample there are no near-collisions, but there are encounters which trigger various hazard criteria algorithms.

The GAT-1 Simulation Experiment offers the opportunity for augmenting the Atlanta environment by the introduction of an additional general aviation threat aircraft. This aircraft can be injected into the time history at specified initial conditions and then operated randomly by the simulator pilot as an uncontrolled intruder. Or, its trajectory can be controlled by a test director issuing pseudo-ATC instructions to the GAT-1 pilot.

B. Parametric Design Tool

Previous work (6 ibid.) had identified several criteria by which a hazard situation may be defined. These criteria are the range altitude guard criterion, acceleration criterion, the tau criterion and the modified tau criterion. Initial analytical studies of the integrity of proposed PWI systems can be and have been done without the simulator (6 ibid). However, the GAT-1 can add the factor of transient aircraft attitude to the basic question of the surveillance detector geometry. Initial system values for detector surveillance geometry, detection range, and warning threshhold can be set by quasi-static encounter analysis. The effectiveness of these system values in the presence of normal aircraft rotational dynamics can then be evaluated by repeating the same encounter situations in real-time simulation.

C. Cockpit Display Design Tool

The GAT-1 Simulation Experiment offers an effective first step in designing and evaluating the PWI cockpit display. The cockpit is provided with visual, aural, and aircraft motion response effects which duplicate, to a high degree, sensation associated with operating a single-engine private aircraft. The proposed horizon display (See IV. A. below) will add to this effect.

The PWI candidate systems to do their job, should provide in the cockpit:

1. Warning
    a. Visual and/or
    b. Aural

2. Approximate relative bearing and elevation (thus giving the pilot some idea as to the geometry of the hazard situation he is in).

The above display characteristics can be evaluated without outside scene generation, either of the horizon of of the threat aircraft beacon.

3. Visual Acquisition Aid

4. Tracking Aid

The ability of the proposed display to guide the pilot's eyes to the threat aircraft (acquisition) and to follow the aircraft under difficult visibility conditions (tracking) is a key function intended for the PWI equipment. Simulator evaluation of this function will require outside scene generation. The effectiveness of the evaluation will depend on the fidelity of the outside scene generation. This is an involved question and is given detailed discussion in Sections IV, V, and VI below. Taking into account the qualifications listed above, the use of the GAT-1 Simulation Experiment as a cockpit display design tool remains a powerful and efficient means of accomplishing a basic PWI development task.

D. Operational Response Evaluation

The PWI concept represents a basic coupling device between the pilot and his machine in the air traffic environment. The reaction of the pilot to the information presented to him in terms of its quantitative effect on his safety and on the safety of the other users of the airspace is of vital concern in development of PWI systems. The GAT-1 Simulation Experiment can play a vital role in evaluating pilot reaction and its overall impact on safety. The following aspects are involved:

1. <u>Encounter Geometries</u>

The pilot will react to a PWI warning even without a successful visual acquisition. Accordingly, even prior to or in the absence of outside scene generation, the following encounter geometries should be presented to a cross-section of simulator pilots:

a. Coplanar headon

b. Coplanar from side

c. Coplanar overtaking

d. Ascent from below

e. Descent from above

2. Single Versus Dual Threat Aircraft System Design Implications

The capability of candidate PWI systems for dealing with two simultaneous threat aircraft is a matter of some concern. The pilot in such a two-aircraft threat situation will have PWI information that may well be seriously deficient, if not extra-hazardous. It is not the role of the simulation experiment to rate the probabilities of multiple-threat situations. However, it should be a valuable part of the experiment to rate PWI systems and pilot reactions in situations where multiple threats exist.

3. Visual Acquisition Dynamics

In Section II. C. above, the role of the simulation was stated in design cockpit displays. The requirement for outside scene generation was mentioned. In a broader context, the GAT-1 simulation can go beyond the design support of cockpit displays and carry out studies of the effectiveness of PWI candidates in improving visual acquisition dynamics. For this work, however, a high-fidelity approach to outside scene generation will be required.

Frequently in aviation operations, flight personnel watch another aircraft for a period of time, look away for other purposes, and then look back and have difficulty reacquiring the target. This happens particularly where the background is such that a) there is no visual locator cue (broad, open, amorphous sky), or b) there are too many cues (mottled landscape below). Accordingly, a study of the dynamics of visual acquisition and tracking should include the following variables:

a. Varied Encounter Geometries

b. Varied Target Illumination

c. Varied Background Illumination

Given the technical means to provide a good degree of fidelity in these areas, much worthwhile work can be done by the proposed experiment.

E. Flight Test Support

Flight testing is expensive, time consuming, and sometimes hazardous. Yet a PWI flight test program is needed to prove that the proposed PWI systems are effective in significantly increasing aviation safety. With the best digital and real time simulation conceivable, PWI systems cannot be conclusively justified and optimized, because conditions external and internal to the aircraft cannot be adequately simulated.

The GAT-1 PWI Simulation Experiment can make a significant contribution to a concurrent flight test program in terms of overall efficiency, cost and safety. This applies both to planning and to operations.

1. <u>Planning</u>

The entire range of encounter geometries and system parameter settings should be explored by simulator. This mapping will determine key situations to emphasize in flight test and also suggest safety guidelines which may be invoked without comprising the flight evaluation. For example, the altitude difference in a headon encounter can be varied in an attempt to find a maximum altitude differential which can be used in flight without invalidating the test data.

2. <u>Operations</u>

Each individual flight test should be run on the simulator for the system and encounter conditions to be utilized. Post-flight comparison of results will be useful in verifying proper test conditions, proper system operation, and the next step in the flight test program.

III. REVIEW OF COCKPIT-TYPE SIMULATORS

The contractual effort requested by NASA/ERC included a review of other cockpit-type simulators such as are already planned for use at ERC or are available for such purposes. This request had the objective of deriving technical information on possible growth configurations for the simulator.

A. XC-142 Cockpit

NASA/ERC has a cockpit section cut-away from a damaged XC-142 VSTOL aircraft. This equipment was reviewed early in the course of this contract. The cockpit was in a state of partial disassembly. The equipment was a long way from being operational for simulation purposes, although it was understood that there is an active program underway to prepare this equipment as a simulator. It appeared that the stated time scale of the PWI simulation and flight test program phases completely precluded the incorporation of the XC-142 cockpit into the design.

B. Helicopter Cockpit Mockup

Also during the course of this contract, a helicopter cockpit mockup located adjacent to NASA/ERC's SDS-9300 Beckman Computer facility was reviewed. This cockpit was already linked to the hybrid computer. A similar plan for the GAT-1 was considered and rejected because the GAT-1 is expected to be located too far away for the easy transmission of analog signals, and because the GAT-1 already contains much of the analog computing equipment required for the PWI experiment.

Furthermore, the experiment design set forth in this report is non-dedicated as far as the GAT-1 is concerned, i.e., a variety of computers may have access to the GAT-1 via standard common carrier data transmission lines.

Finally, the helicopter cockpit mockup and simulation was not considered because it had absolutely no provision for the level of encounter simulation required for the PWI program and described in this report.

C. The Link General Aviation Trainer (GAT-1)

The GAT-1 is an electro-mechanical analog training simulator designed for wide commercial use in aviation training programs and educational institutions. It can develop skills in both visual and instrument flight rule operations of single-engine light aircraft. The student or simulator pilot is provided with all conventional basic flight and engine instruments and controls. Simulated gyro instruments, VHF NAV/COM, ADF, are options. In its standard form, the trainer has an instructor's control panel on the side of the fuselage. There is an X-Y plotter for following cross-country flights and simulated ILS approaches to a sea-level and mountain-region airport respectively. Airspeed, sideslip, and altitude deviation can be monitored externally. The trainer motion drive is limited physically to +16° and -8° degrees of pitch, with +48° and -24° degrees displayed as analog solutions. Roll angles are physically limited to ±12.5 degrees with simulated solutions of ±75 degrees. Scaling of actual angles in this way provides helpful motion cues to the pilot without going to incorrect, excessive g forces. The trainer has complete rotational freedom in yaw, with a 1:1 relationship between yaw motion and the analog solution.

The other features which help simulate reality include effective simulation of engine noise, tire squeak, and rough air. Also, the classical, linear longitudinal and lateral equations of motion are implemented in the GAT-1 analog computer. The VOR, ADF, and ILS radio navaid environment in the existing simulator is limited to and compatible with the imaginary area shown on the X-Y recorder charts.

Following initial review of the GAT-1 trainer design features, two conclusions were reached.

1. The GAT-1 trainer is an economical, and appropriate device around which to base the simulation phase of NASA/ERC's PWI program. Indeed, given the flexibility of the trainer and the flexibility proposed in the simulation design given below, the experiment should prove an effective, efficient simulation tool for many different ERC programs over many years to come.

2. The GAT-1 motion attenuation (3:1 in pitch and 6:1 in roll) presents some real simulation design challenges with respect to the outside scene generation requirements of the PWI experiment. This is because the GAT-1 mechanization is neither truly fixed-base nor truly correct in its execution of angles computed by the analog simulator. This is a statement of fact not a criticism of the design. Because of the in-between nature of GAT-1 motion, much thought was given to the best way to provide the required PWI Simulation Experiment capabilities. These considerations will be expanded in the next sections.

IV. MECHANIZATION CONCEPT FOR THE SIMULATION EXPERIMENT

This section of the report concerns itself with concepts and tradeoffs for mechanization of the Experiment. For each aspect of the problem, there is a discussion of the various possibilities considered and a statement as to the decision made. The next section then goes into the details of the complete specification.

A. System

Reference may be made at this point to the System Elements depicted in Figure IV-1. It was determined at an early point in the task that:

1) The Experiment is to use the GAT-1 trainer.
2) The GAT-1 trainer is an electro-mechanical analog device.
3) All position, velocity, and attitude signals are produced by the analog computation, though not necessarily in the most convenient form.
4) Analog computation takes place on the moving base.
5) Limited number of spare slip rings is a severe limiation on the design.
6) The PWI System emphasizes a VFR situation and the GAT-1 trainer must be provided with a visual horizon stimulus for the trainer pilot making up for the attenuated pitch and roll motions.
7) Simulation of at least one threat aircraft beacon is a requirement for the Experiment.

The new System Elements identified in Figure IV-1 are centered around the Teleprocessing Interface. This unit, to be discussed in detail below receives incoming digitized GAT-1 variables, performs any transformations that can be done more efficiently and economically at the simulation site, reformats them, and places them on the transmission line to a centrally-located computer. Conversely, calculation results from the remote computer are received and re-formated for use in the Simulation. The crucial role of the GAT-1 sliprings is highlighted in Figure IV-1, in terms of the key data categories which must use the sliprings assuming 360° of yaw base motion is preserved. The choice between GAT-1 and Fixed Base Scene Generation is also shown. The need to transmit PWI information into the cockpit is identified and an assumption is made that these are digital signals. The need for a local input/output facility is also shown.

Turning now to a discussion of choices in mechanization concepts, it is helpful to use the decision tree shown in Figure IV-2. Details of the GAT-1 trainer will be brought, where pertinent, to the discussion.

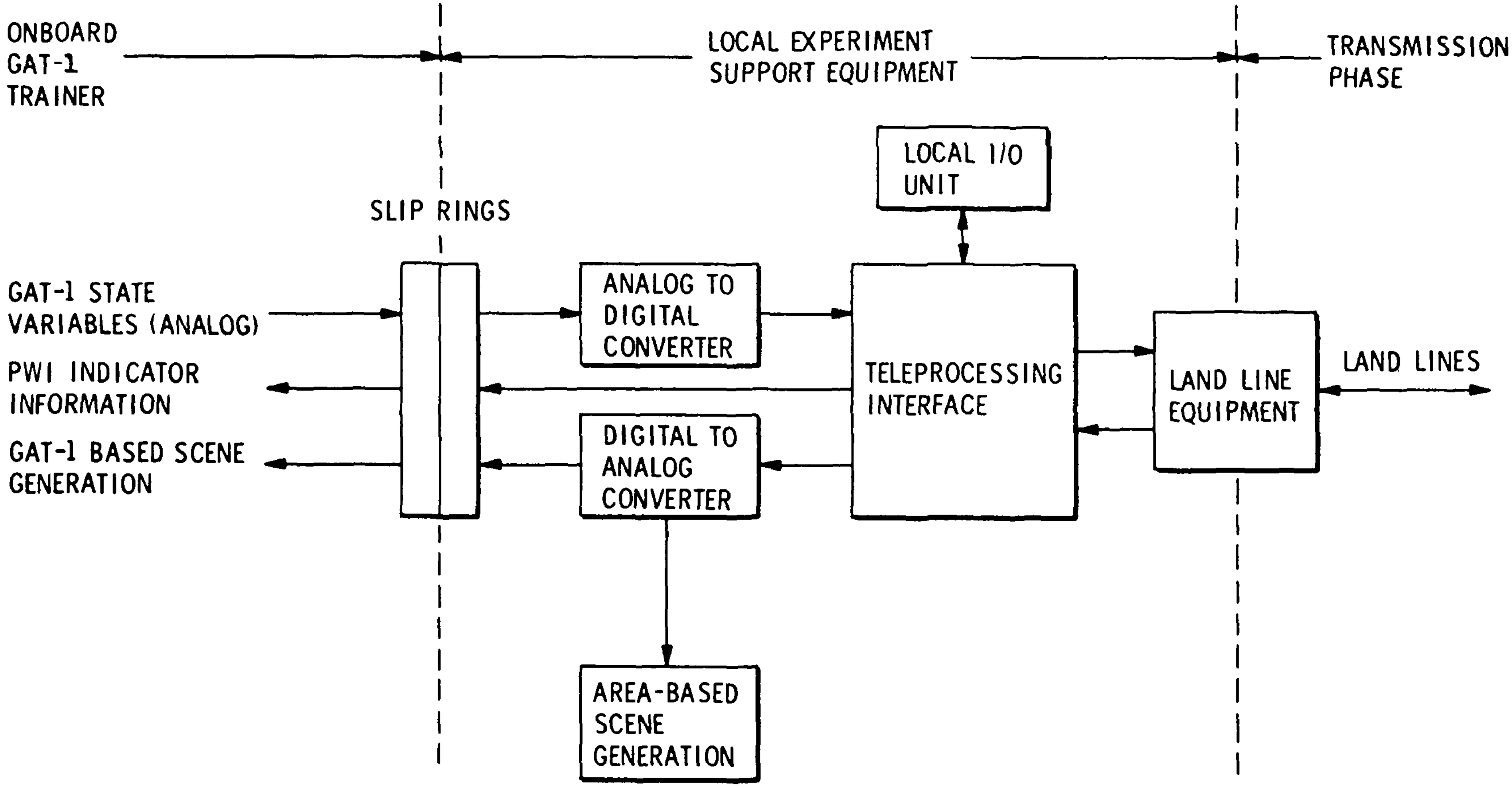


Figure IV-1

GAT-1/PWI Overall Simulation Experiment Elements

The decision relative to trainer motion is not a simple one, given the fact that the motion does not conform to the analog computation angular outputs, but only to a fixed fraction of them in pitch and roll. In favor of maintaining complete GAT-1 motion is the desire expressed by NASA/ERC to maintain the effect of cues associated with trainer motions as part of the overall simulation effectiveness (8). Inhibiting the yaw motion has the immediate advantage of freeing up the Experiment hardware from the slipring restraints on number of quality of signals. However, the GAT-1 flight instrument signals are peculiarly vulnerable to motion cut-off. The 400 Hz signal generators for the attitude reference displays on the instrument panel are mechanically driven at the correct ratios from the base motion. This would not be a problem if these signals were driven from the Euler angle outputs of the analog computation. (Some thought was given to duplicating the motion drive elements in a rack-mounted external unit to generate the instrument panel signals given above, but this approach was not as attractive as those discussed below.)

The impact of these choices on scene generation is outlined in Figure IV-2, and can be expanded upon here. If all motions were inhibited (Fixed Base Simulation), horizon and target projection drives would use body coordinate signals whether they were mounted on the simulator cabin, the floor, or the ceiling.

Given a decision not to alter the GAT-1 motion, the further choice exists of mounting scene projection equipment on the floor/ceiling or on the GAT-1. If these drives are mounted on the floor/ceiling, their command angles must recognize that the floor-ceiling reference frame is biased away from the earth-fixed reference frame by the differences between GAT-1 analog computation angles and the actual GAT-1 motions. A matrix for conversion from earth-fixed reference to floor/ceiling reference is provided in Appendix C.

If these projection drives are mounted on the GAT-1, they must be driven in GAT-1 body coordinates. For the target vector, which will be generated in earth-fixed coordinates, a transformation matrix must be applied which recognizes the true rotations ψ, θ, and ϕ of the simulated aircraft with respect to the earth. This matrix is provided in Appendix B. For the horizon, however, it is significant to note that the body coordinates of a horizon projector free of azimuthal cues (topographical features, clouds, etc.) are available as direct 400 Hz signals ϕ and θ onboard the GAT-1 trainer.

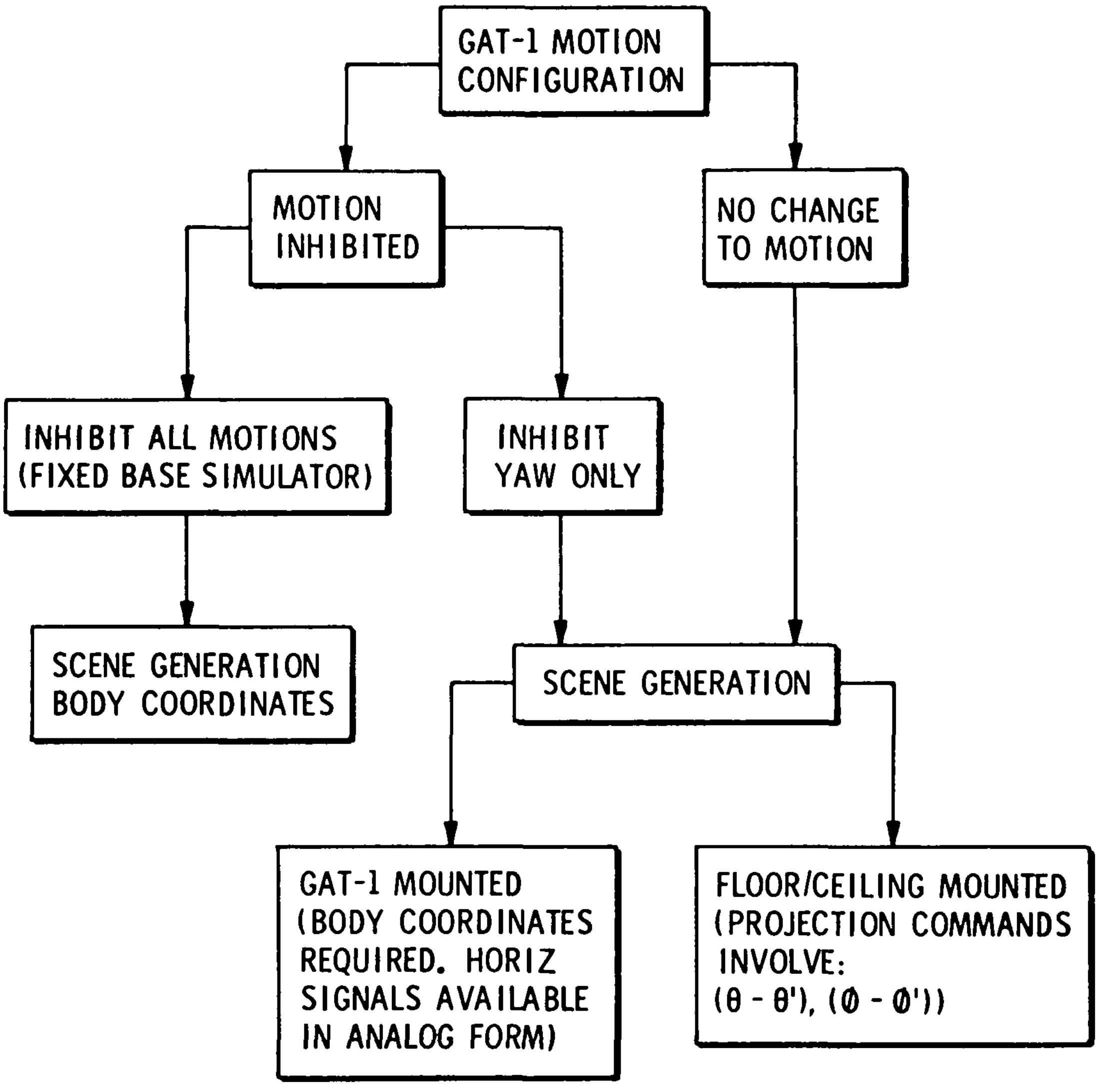


Figure IV-2

Choices in Experiment Mechanization Concepts

The specification set forth in Section V below is based on no change in simulator base motion from the normal GAT-1 configuration. This decision is based on the following points:

1) The NASA/ERC direction received above (7).

2) A system specification (see below) which utilizes the existing slipring assignment.

3) A belief that the overall value and flexibility of the GAT-1 trainer for all of NASA/ERC's program is greatly enhanced by retaining it in its original configuration.

B. Gat-1 Modifications (Including Horizon Display)

As implied in the above discussion, it is the intent of this mechanization concept to interfere as little as possible with the normal GAT-1 configuration, and to enhance its value as much as possible by an effective, efficient coupling of the GAT-1 to remote computational facilities. In more specific terms. this means the careful use of normal precautions in tapping into analog signal sources, whether from amplifiers, synchros, or potentiometers. Restraint must be exercised in terms of added power and mass loading on the GAT-1.

It is particularly helpful that some of the required state vector signal outputs from the GAT-1 analog computer are brought out of the trainer base through regular slip ring assignments. These signals are north and east position and altitude. Other signals, although not available external to the base, are brought conveniently to one of two interconnect printed circuit boards, designated "mother boards". These signals include the sine the cosine of the heading angle ψ, the sine of the motion pitch angle θ', and the sine of the motion pitch angle ϕ'. Altitude rate is available also at the mother board.

The two ground speed signals are not directly available in the GAT-1 analog computer, except when the simulated wind input is set to zero. This situation exists because north and east position are generated by differencing north and east airspeed and wind components at the input to integrating amplifiers with north and east position, not velocity as the output. This situation could be met by differentiation of position values in the digital portion of the Experiment. This solution is rejected as incompatible with the goal of generating high quality state vector signals. The recommended solution consists of breaking into the input to the integrating amplifiers and differencing airspeed and wind components with unity gain and no sign inversion. This output is then injected into the integrating amplifier with no change in function or performance.

In general, any new signals to be tapped off for purposes of this experiment are to be isolated by operational amplifiers to guarantee that implementation of the Experiment is on a non-interference basis with normal GAT-1 operation. Thus the specification given below details an operational amplifier unit located above the onboard computer cards. This unit will process all of the additional signals to be transmitted to the teleprocessor. Table IV-1 summarizes all signals, their scaling, and their limits.

Following through on the basis of non-interference, reference may be made to Figure IV-3 which details how the use of a single external cable configuration can couple the GAT-1 into the teleprocessing equipment or return it to its basic role in a few minutes change-over time.

As mentioned at the beginning of this section, the addition of a horizon cue to the GAT-1 equipment seems an essential part of this Experiment because of its basic VFR orientation. (Discussion of a screen will be left to Section F below.) It is felt that the primary Experiment objectives listed in Section II. do not require (and cannot wait for) a simulation with complete photometric fidelity. Such fidelity is certainly required for Visual Acquisition Dynamics simulation as described in IID3. However, it is believed that the other Experiment Objectives listed in Section II. can be adequately served by a horizon simulation which presents the simulator pilot with a sky-ground interface line defined by a simple shadow without azimuthal cues.

A further decision needs to be made about horizon generation. ERC thinking about PWI Systems has concentrated on altitude ranges below 10,000 feet and this is a regime where variations of the negative elevation angle to the horizon are of interest. Recognizing and simulating this horizon elevation is of secondary importance until high fidelity in scene generation is required.

One horizon projection mechanism is illustrated in Figure IV-4. It is mounted from the ceiling and has three angular degrees of freedom θ_1, θ_2, and θ_3. In addition, a sleeve with a horizontal slit surrounds the light source.

Table IV-1

GAT-1/PWI Signal List

Item	Slipring	Engineering Units	Volts
Sin	J35/43-6	N/A	±10 VDC
Cos	J35/43-7	N/A	±10 VDC
Sin ϕ'	J35/43-8	N/A	±15 VDC
Sin θ'	J35/43-9	N/A	±15 VDC
Vert Speed	J35/43-10	2500 ft/min	-10 V
V_{gx}	J44/45-5	160 MPH	+10 V
V_{gy}	J44/45-4	160 MPH	+10 V
Alt	J44/45-8	20,000 feet	-15 V
X	J35/43-17		
Y	J35/43-16		
PWI Clock	Spare 1/2-12	N/A	
PWI Reset	Spare 1/2-11	N/A	
PWI Shift	J44/45-10	N/A	
PWI GND	J44/45-9	N/A	

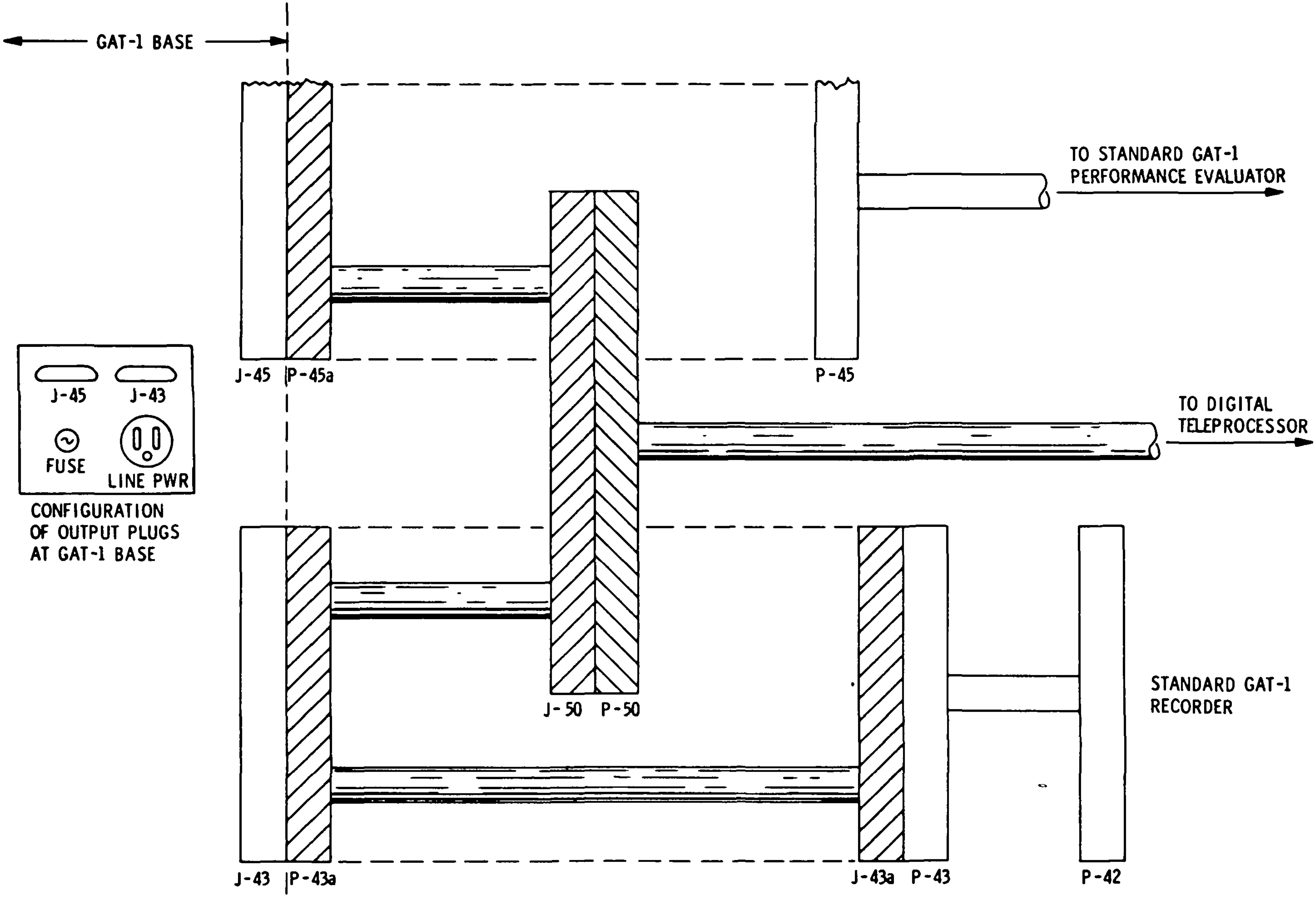


Figure IV-3

Experiment External Cable Configuration

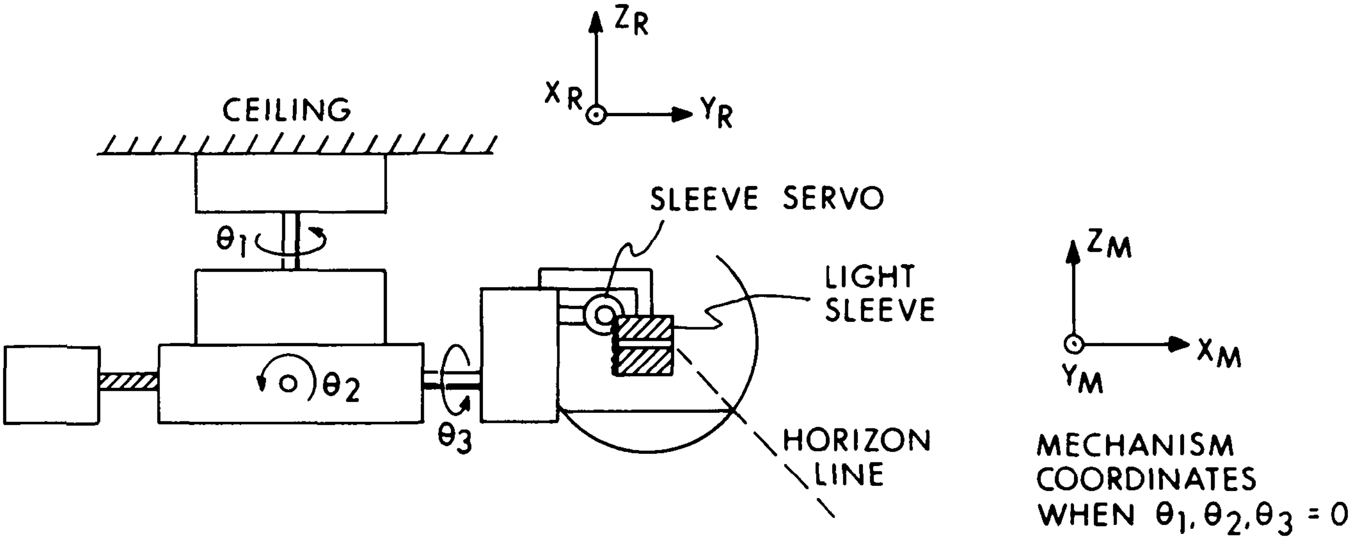


Figure IV-4

Ceiling Mounted Horizon Generator

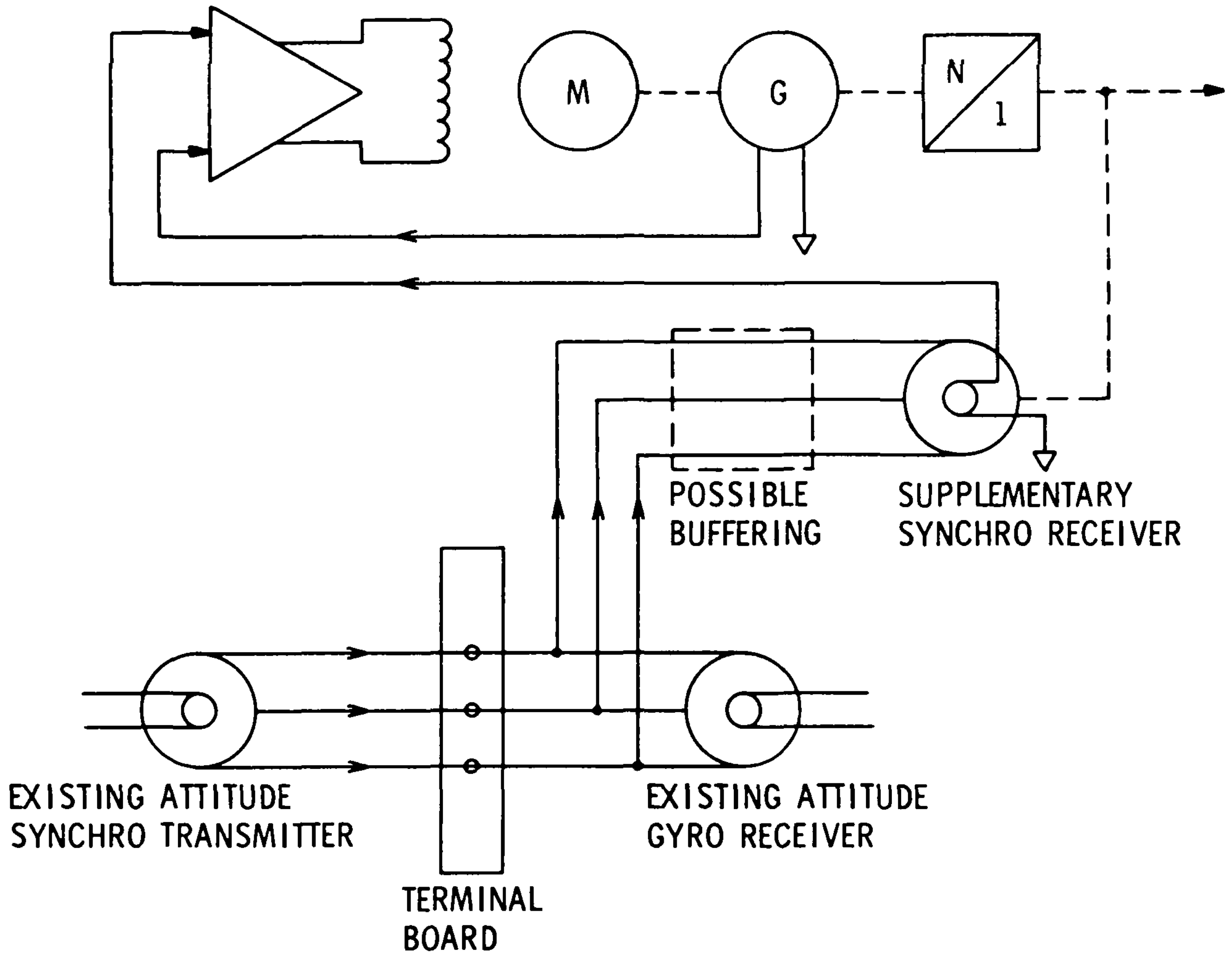


Figure IV-5

Pick-off Circuit for Driving Horizon Projector

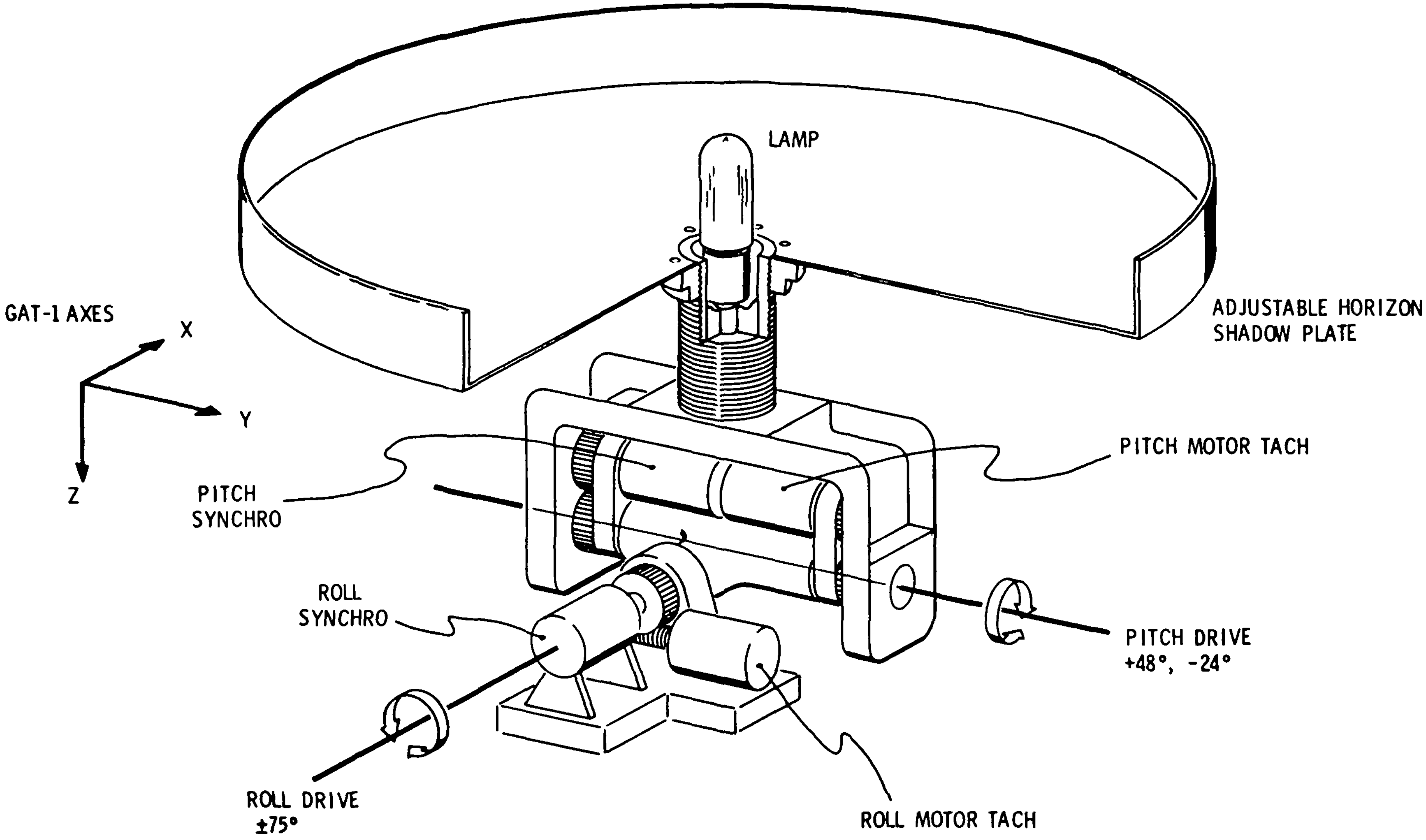


Figure IV-6

Body-Mounted Horizon Projector

(Symbolic)

This sleeve moves to simulate change in altitude of the GAT-1. The light source and sleeve are surrounded by a glove which is opaque below the horizon line.

The θ_1 axis has unlimited freedom and in fact duplicates heading motion. The other two angular motions have motion limits of about 60°.

Slip rings passed through the θ_1 axis could supply, by a dropped cable, signals to and from GAT-1. Note that this is a four degree of freedom device.

It was stated above in Figure IV-2, that a horizon projector located on the GAT-1 itself would be oriented according to the analog computer generated signals for true elevation (θ) and true bank (ϕ). These signals are available in the synchro system which is used for driving the attitude instruments. With proper isolation, if necessary, the same synchro transmitters could be tapped for positioning the horizon unit. Such a system is shown in Figure IV-5.

It is also true that a horizon shadow projector is easier to mount from below with the light source on top. The combination of a straight-forward two-degree-of-freedom position system, and a pie plate horizon shadow generator with manual adjustment for height seems to meet the needs for initial stages of the GAT-1/PWI Experiment. No slip rings are involved. Accordingly, this approach, shown symbolically in Figure IV-6, is recommended as the basis for the specification in Section V.

C. PWI Equipment

This section refers to the specific requirement for generating onboard display information for the GAT-1 pilot which will simulate PWI displays to be evaluated.

Earlier work (ibid. 4, p. 71) has demonstrated an interest in heads up displays on or near the aircraft windshield or the use of stereo aural cues to assist the pilot in locating the threat aircraft. During the course of the contract, consideration was given to PWI Systems under development by aerospace vendors with emphasis on the display means. However, for the purposes of the present design specification, it was decided that a display instrument under development by ERC using an array of lights (See Figure IV-7) would be a representative end item in designing this part of the experiment. It was further decided that a thirty-two (32) bit word would be sufficient to implement the representative

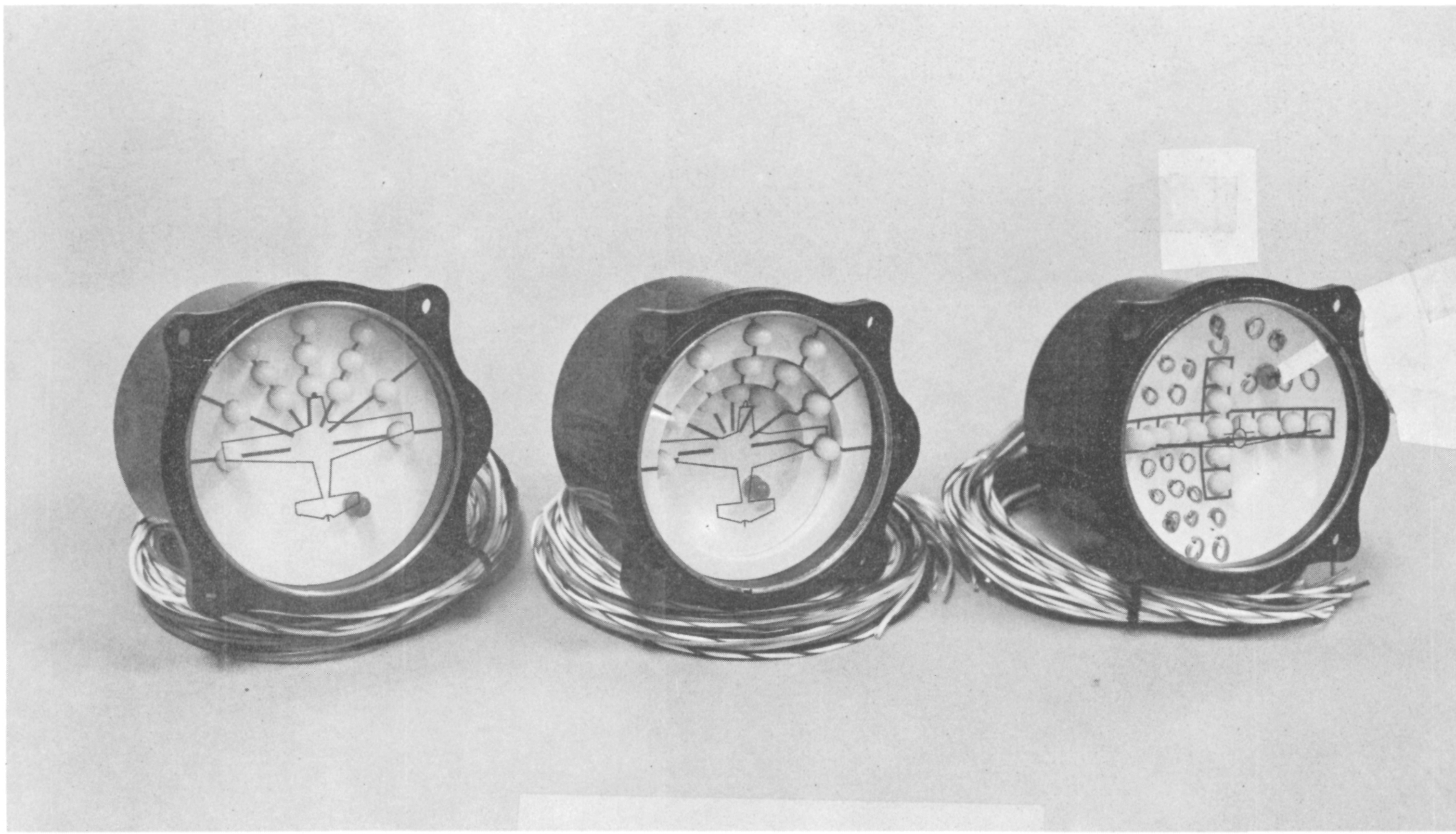


Figure IV-7
Various Pilot Warning Instruments

display or a variety of others that might be candidates for evaluation. Accordingly, the PWI equipment included in this concept consists of a 32-bit shift register inside the GAT-1 trainer driven by outputs from the digital teleprocessor. In order to conserve slip rings, the specification described below requires serial transmission of data.

D. Digital Teleprocessor

Early in the study, it became apparent that special coordinate conversion problems existed because of the need to project a threat aircraft beacon image in a reference coordinate system compensated for by the attenuated trainer motion. Accordingly, studies were initiated which would process this coordinate by analog means. It was further thought that the simulation site local teleprocessing would be limited to little more than prepackaged A/D conversion and parallel-to-serial formatting. On the basis of this limited teleprocessing concept, a system (See Figure IV-8) involving analog conversion was developed and included in the first progress report (8).

As the work progressed, Intermetrics sought and received specifications from fourteen (14) vendors of main frame and peripheral teleprocessing equipment. It became apparent that a system concept based on an integrated local digital teleprocessing facility would in the end save NASA/ERC procurement time and money while providing superior performance and expansion potential for the future. Accordingly, specifications given below for A/D, D/A, Input-Output, and transmission line interface equipment combined with coordinate conversion matrix operations are based on this concept, and are built around a specific vendor choice.

E. Software Needs

1. Local Digital Teleprocessor

Teleprocessing software at the GAT-1/PWI Experiment is to include reading the A/D interface, transmitting the data from the teleprocessor to the central processor, receiving the data, setting the 32-bit register for PWI equipment, a matrix conversion of target image data to biased reference coordinates, and conversion of digital target image data to target image analog drive signals. A general flow diagram for this process is shown in Figure IV-9.

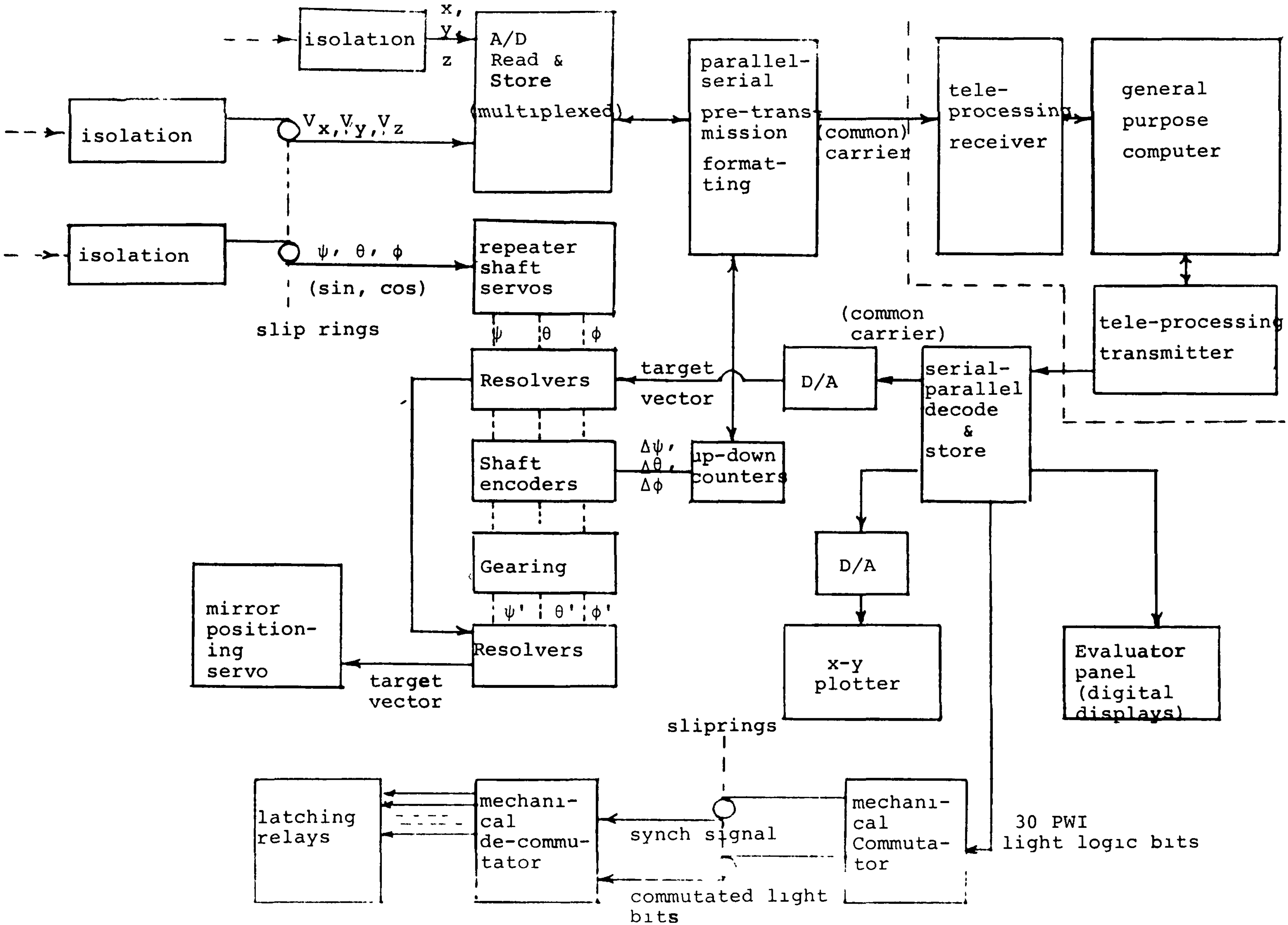


Figure IV-8 **Analog Coordinate Conversion System**

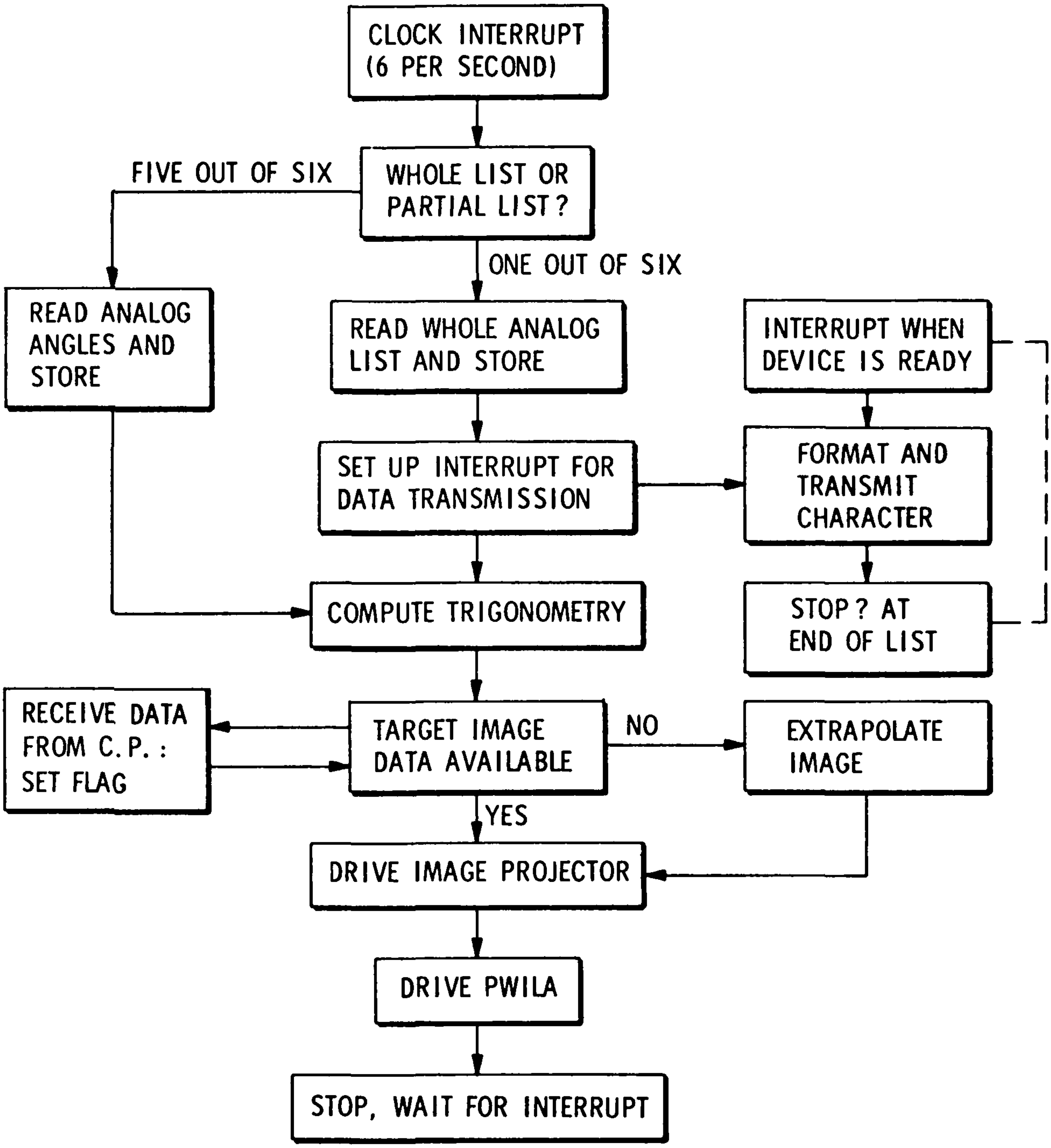


Figure IV-9
Flow Diagram for GAT-1/PWI Teleprocessor

It will be evident from this figure that a basic cycle frequency of six updates per second has been chosen. This is a compromise between 1) high quality motion picture cartoon work which is done at twelve frames per second and 2) the fact that the target image recommended for this GAT-1/PWI Experiment implementation is limited to the threat aircraft beacon which has a few milliseconds duration and a basic repetition rate of once per second.

It is a probability that completion of the return data transmission to GAT-1 will occur a significant fraction of a second after the reading of the GAT-1 state vector on the A/D channels. This can be compensated for if desired by an extrapolation of the GAT-1 state through the total time delay involved. This is not considered necessary and is not recommended. The most rapid rate of change of relative motion occurs due to angular motion of the GAT-1 itself. This motion is processed locally at the Experiment site. It is not subject to delays involved in transmission to and from the central processor.

Thus, six times a second, the target vector direction received in reference coordinates from the central processor is biased to compensate for the GAT-1 pitch and roll attenuations before being converted to target projector drive signals.

2. Interprocessor Actions

Tables IV-2 and IV-3 depict proposed data lists to and from the Central Processor. These are based on eight bits per character, with two of the eight bits reserved for internal control. Thus, a twelve bit word, giving resolution of one part in 4096, requires the transmission of two characters. However, for the PWI display equipment only bit changes will be transmitted, with two PWI bit changes per transmission. Thus, with 5 bits assigned to an address and one to state, two changes require two characters.

3. Central Processor

Master synchronization is performed by the six per second interrupt at the GAT-1 site. To begin an Atlanta-based simulation, the PREPR2 Binary Output Tape which contains the Atlanta traffic data is searched to obtain a desired starting point. This data consists of a sequence, at three second inter-

Table IV-2

Teleprocessor to Central Computer

Variable	Words	Characters
x	1	2
y	1	2
z	1	2
$\dot{x}$	1	2
$\dot{y}$	1	2
$\dot{z}$	1	2
$\sin \psi$	1	2
$\cos \psi$	1	2
$\sin \theta'$	1	2
$\sin \phi'$	1	2
extra	3	6
		26 Characters

Table IV-3

Central Computer to Teleprocessor

θ_1	1	2
ψ_1	1	2
θ_2	1	2
ψ_2	1	2
- - -	- - -	- - -
θ_6	1	2
ψ_6	1	2
Range	1	2
TAU	1	2
PWILA	-	2
		30 Characters

vals of many aircraft state vectors. The data for the starting time is read into core.

The time read from the PREPR2 record is assigned to the state vector received from GAT-1. The PREPR2 records produce data at three second intervals. For the two data transmissions intervening between indexing to new PREPR2 data, time is incremented by one second and assigned to the GAT-1 state vector. In order to distribute computation load and to assign only a minimum load to high priority main frame operation, the following division of computation is made. Reference to Figure IV-10 at this point will prove useful.

a. Data Processing at High Priority

The completion of a data transmission from GAT-1 begins the high priority portion of the central computer task. Prior to this time, a variation of the CASTE program has selected one or no aircraft from the PREPR2 data to be the threat aircraft. The high priority task is to create a relative position vector for time T and five state vectors at one-sixth second intervals in the future. These state vectors are transformed into protected aircraft-threat aircraft direction angles and range. Also, the relative state vector for t=T is transformed into GAT-1 body coordinates and is used to decide which light(s) on the PWI cockpit display to drive. The algorithm involved here will vary with the geometry of the PWI display configuration. This data; six direction angles, six ranges, and a list of bits called PWILA (PWI Light Array), is transmitted to the GAT-1/PWI teleprocessor. The central processor then leaves the high priority mode.

b. Write Evaluation Tape

At lower priority, the state vector of the threat aircraft and of GAT-1, the Euler angles of GAT-1, time T, and the track number of the threat aircraft are written on tape for later evaluation. It is presumed that this can be done before the next data receipt from GAT-1 although buffering can be provided at increased complexity.

c. Read PREPR2 Record into Core

Following completion of the next high priority

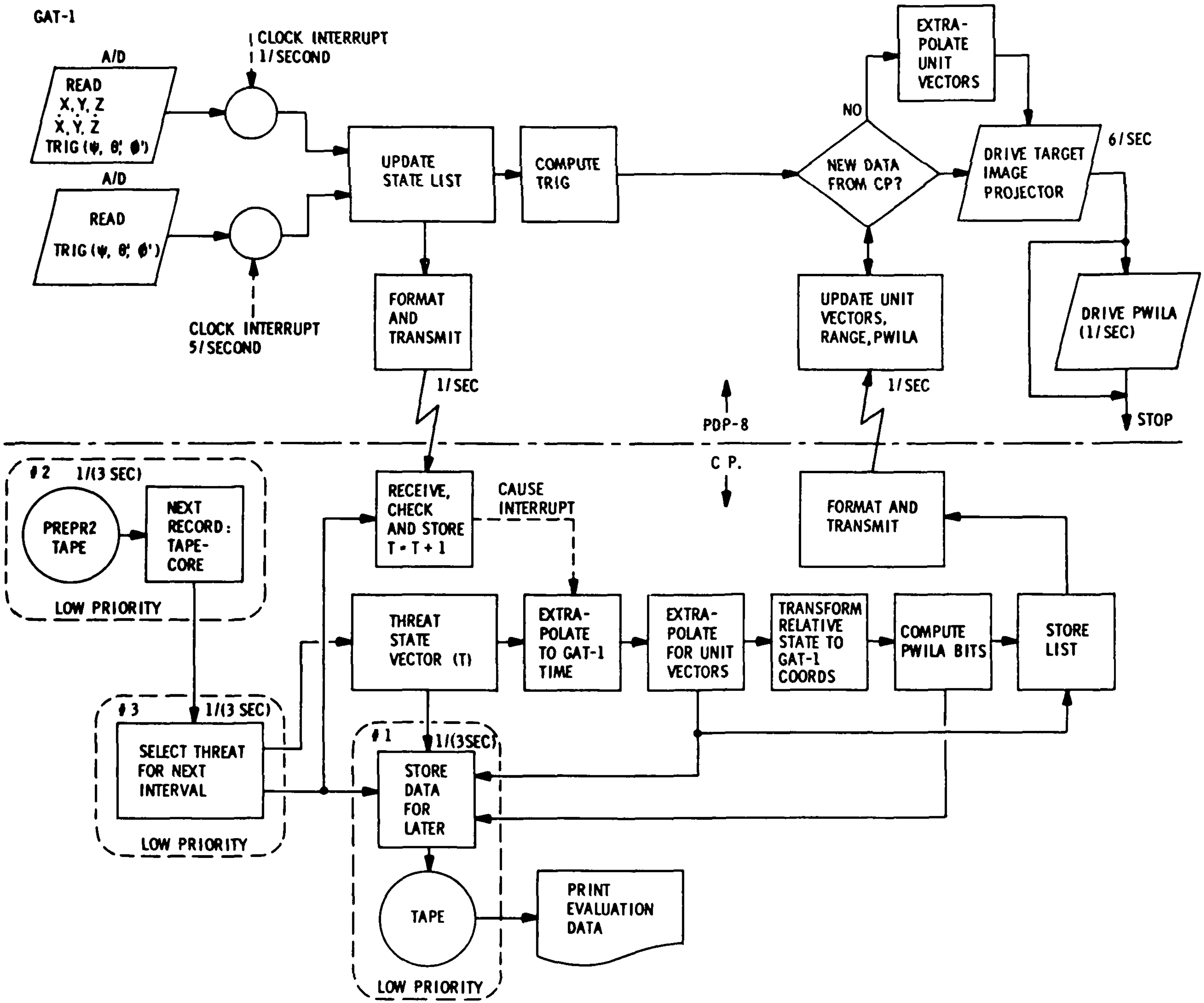


Figure IV-10

GAT-1/PWI Experiment Information Flow

task, the PREPR2 data record to be used next is read from tape to core. It is presumed that this can be done before the next GAT-1 transmission.

d. Re-evaluate Threat Situation

Following completion of the next high priority task (which was time-tagged 2 seconds beyond the time of its PREPR2 record), GAT-1 data is extrapolated to T+3, and compared with the PREPR2 data read into core in the previous second (Paragraph c. above,) This process consists of selecting which if any aircraft are to be singled out for use during the following three second sequence. This selection will use one of several algorithms under study by NASA/ERC (ibid. 6). The threat aircraft selected is then placed in position for relative comparison with GAT-1 on receipt of the next GAT-1 state vector transmission.

e. Buffering and Extrapolation

If it is the case that the computations and tape operation described above do not fit into the allowed time frame, the following procedure is suggested. First, the calculations will be more evenly distributed in each of the three seconds that make up a cycle. Second, provision will be made if necessary to begin a cycle with the state vector of the threat aircraft used during the previous cycle, since the search to decide that this aircraft is still the threat aircraft is not complete. The penalty here is that the transition from one threat state to another threat state may be delayed.

F. Screens

The need for a projection surface in the GAT-1/PWI Experiment arises from the decision to project both a simulated horizon and threat aircraft flashing beacon. These decisions derive from the basic VHF nature of PWI systems.

Screen concepts of two basic types were considered: body-mounted and floor/ceiling mounted. There are commercially available body-mounted projection screens for simulator-cabs of commercial airliner configuration. Typically, visibility is limited in its angular scope to ensure that the resulting physical size of the screen is not excessive and that it does not overload pitch and roll simulator servo drives. A projector is mounted on the simulator cab roof, and virtual image devices in cab windows give the illusion of distance.

For the GAT-1/PWI experiment, the use of body-mounted screens would have meant a substantial wrap-around configuration because of the ample visibility of the GAT-1 windows. Servo drive performance could be seriously impaired. Parallax effects (see below) at such close range would be hard to compensate. Finally projectors for the horizon and one or more threat aircraft would all have to be mounted on the cab roof to further aggravate design problems. Accordingly, body-mounted screens were rejected.

Turning then to screens mounted between the floor and ceiling, interest becomes focussed for the first time on the facility to be made available for the GAT-1/PWI Experiment, as shown in the geometry of Figure IV-11 (a. and b.) As shown in the Figure IV-11 b., the inclination of the rolled horizon line with respect to the floor is 62.5°. Figure IV-11 a. shows that the inclination of the pitched horizon line is 32° with respect to the floor. Assuming that the simulator pilot by moving his head, can see these extreme portions of the horizon simulation, then an approximate requirement for distance of the ceiling above the floor below the GAT-1 trainer is given by R sin 62.5°. The height of the room would then be 2R sin 62.5°. Spherical planetarium projection surfaces are commercially available in the sizes given below and the theoretical room heights are shown.

R	H
24'	42.5'
30'	53'
40'	71'

A further implication of these severe ceiling height requirements is that the key simulation elements should be located at h/2, or on a plat-

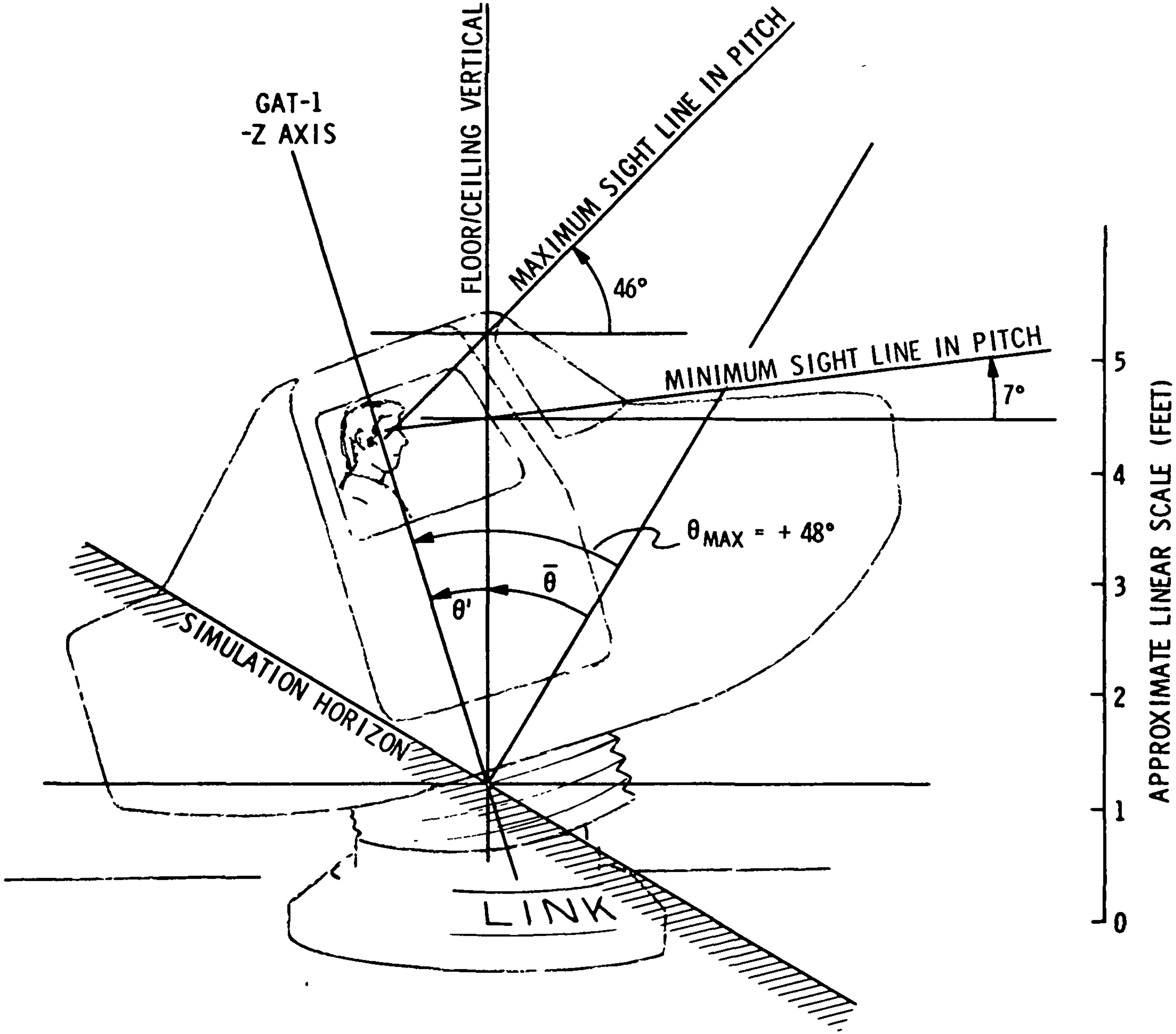


Figure IV-11a.

GAT-1/Projector/Screen Geometry - Pitch

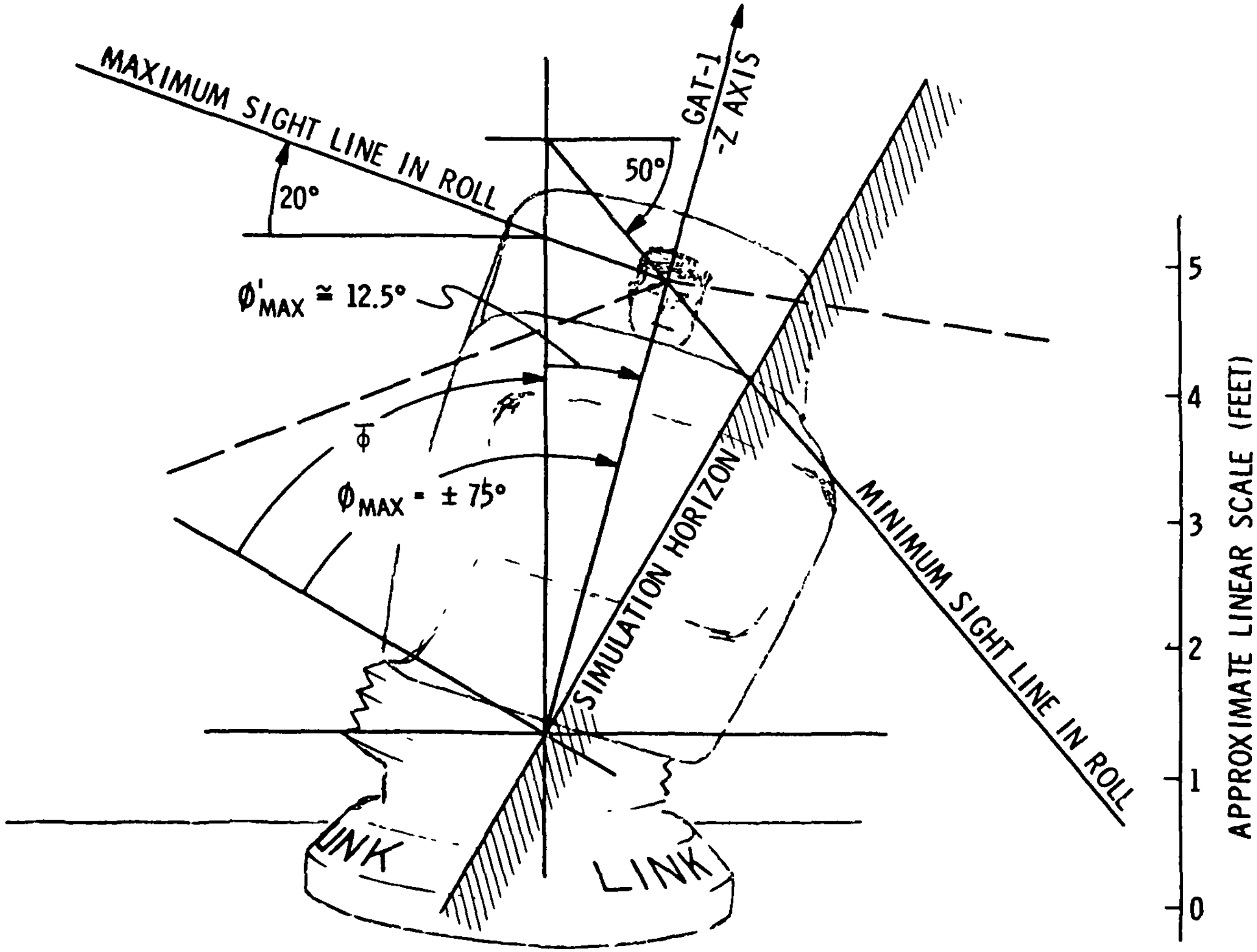


Figure IV-11b.

GAT-1/Projector/Screen Geometry - Roll

form some height from the floor. A reason then obviously exists for lowering the projection screen radius to create an economical overall physical size to the simulation facility. This brings up the subject of parallax problems in scene generation.

Parallax problems would not exist if the GAT-1 pivot point, the pilot's eyes, the horizon projector, and the threat aircraft target projectors could all be located at the same physical point. This cannot, in fact, be accomplished. The GAT-1 pilot's eyes are some 3 1/2 feet above the pivot point. The horizon projector must be placed above the cab, and the threat aircraft target projector above that. Referring to Figure IV-12 the general geometry of parallax is given by

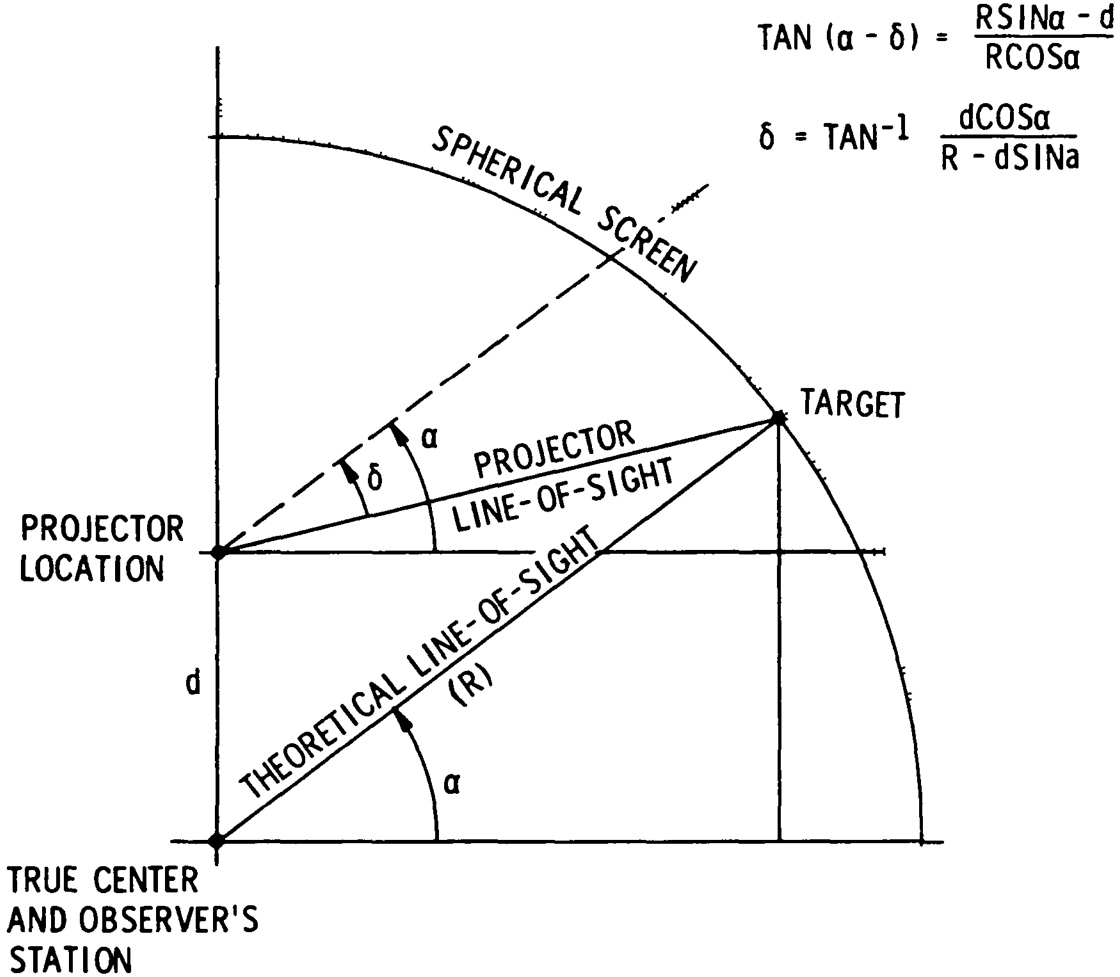
$$\tan(\alpha - \delta) = \frac{R \sin\alpha - d}{R \cos \alpha},$$

where α is the line-of-sight direction desired, d is the projector offset from the true center and δ is the bias angle that must be used to correct the projector. Further manipulation yields an expression:

$$\delta = \tan^{-1} \frac{d \cos\alpha}{R - d \sin\alpha}$$

This expression is plotted in Figure IV-13 for $\alpha = 0°$, and a family of geometries. The penalty for small facility size in terms of required parallax correction is highlighted for different offsets of the projector from the center of the screen radius.

The screen design thus involves a compromise between ceiling height at the GAT-1 facility location, the cost of implementing parallax bias corrections, and the required projection accuracy. Ceiling height for the GAT-1/PWI Experiment facility is not known, pending a NASA/ERC decision on the final location for the Experiment. Although the display dial shown in Figure IV-7 indicates that quantization of direction information displayed to the pilot will be



$$\tan(\alpha - \delta) = \frac{R\sin\alpha - d}{R\cos\alpha}$$

$$\delta = \tan^{-1} \frac{d\cos\alpha}{R - d\sin\alpha}$$

Figure IV-12

Parallax Geometry

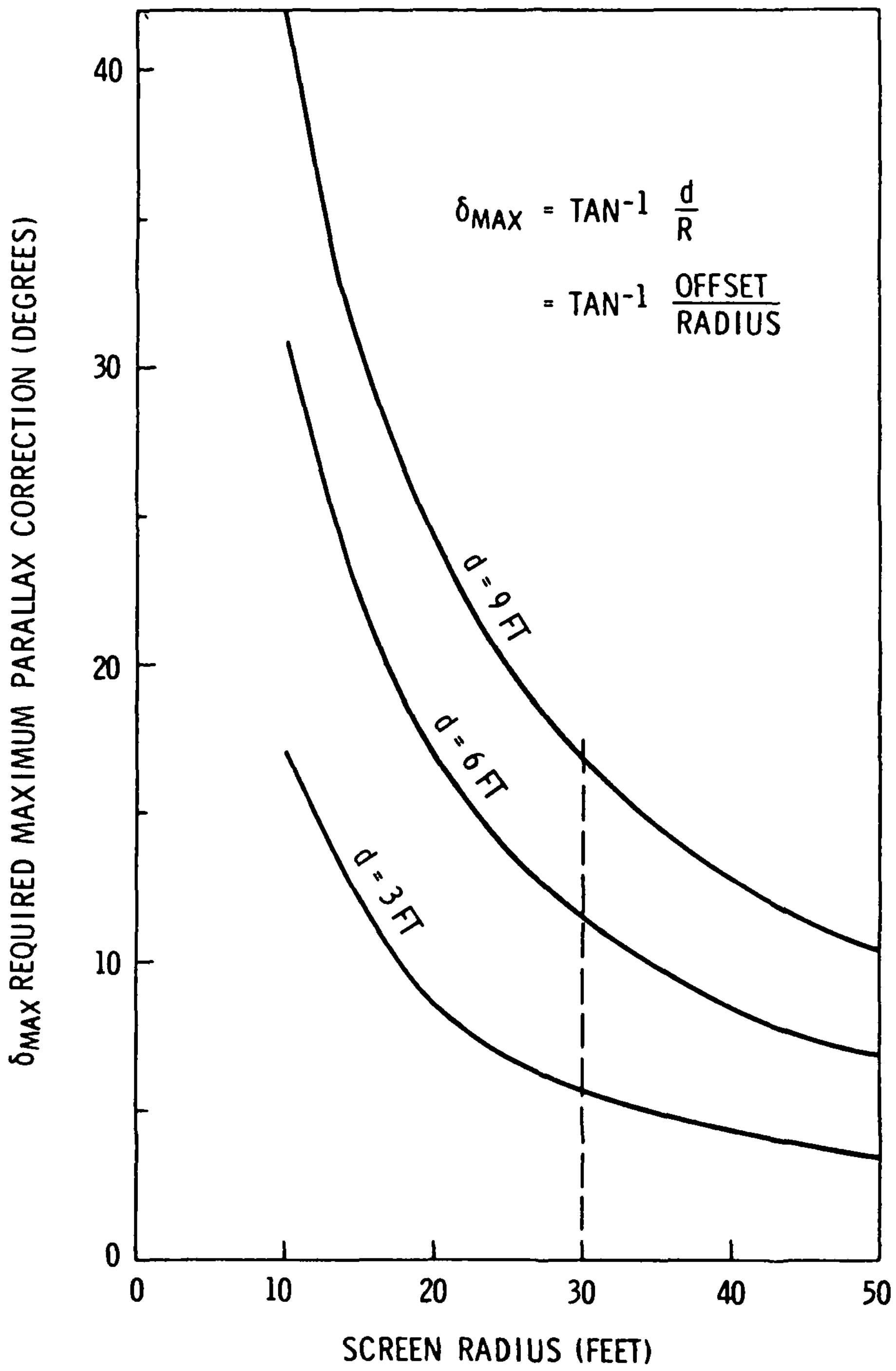


Figure IV-13
Maximum Parallax Angles

gross indeed, the projector for the target beacon should be as accurate as economically feasible. It is felt that the parallax correction can be easily implemented as an algorithm in the local teleprocessor. Accordingly, the penalty for parallax correction will be accepted in return for a smaller facility size requirements.

Serious questions still remain about the compromise between available ceiling height and the elevation angles for which the projection is valid. Most encounter situations can be near-coplanar which decreases the need for high elevation and low elevation projections. However, the horizon projector theoretically requires a high projection elevation angle (62.5°) with a consequent theoretical ceiling height of 2R ($\phi - \phi'$) or 2 x 30 x sin 62.5° = 53 feet. The economics of such a special ceiling height will have to be carefully weighed against the additional fidelity resulting from screening that portion of the horizon which is at a high angle.

Another aspect of projection screens relates to the economics of construction. In the course of this study, it was determined that commercial spherical screen elements can be obtained from planetarium system vendors. It was further realized that the program involving GAT-1/PWI scene generation might be transitory in nature, and an alternate screen design concept was generated involving lower costs, lower quality of projection, and flexibility of use. (Figure IV-14)

This concept involves roll-up planar screens, whose geometry (with fillers) approximate the desired spherical surface. The panel structures would be fabricated of wood and composition board. If alternate use were to be made of the GAT-1 facility, these screens could be unhooked and rolled away into storage.

G. Threat Aircraft Projection

The PWI system has as a major objective improving the pilot's ability to visually acquire and track a threat aircraft. As mentioned in Section IIC. this problem involves many factors and a quantitative simulation should ultimately include the following characteristic of the threat aircraft:

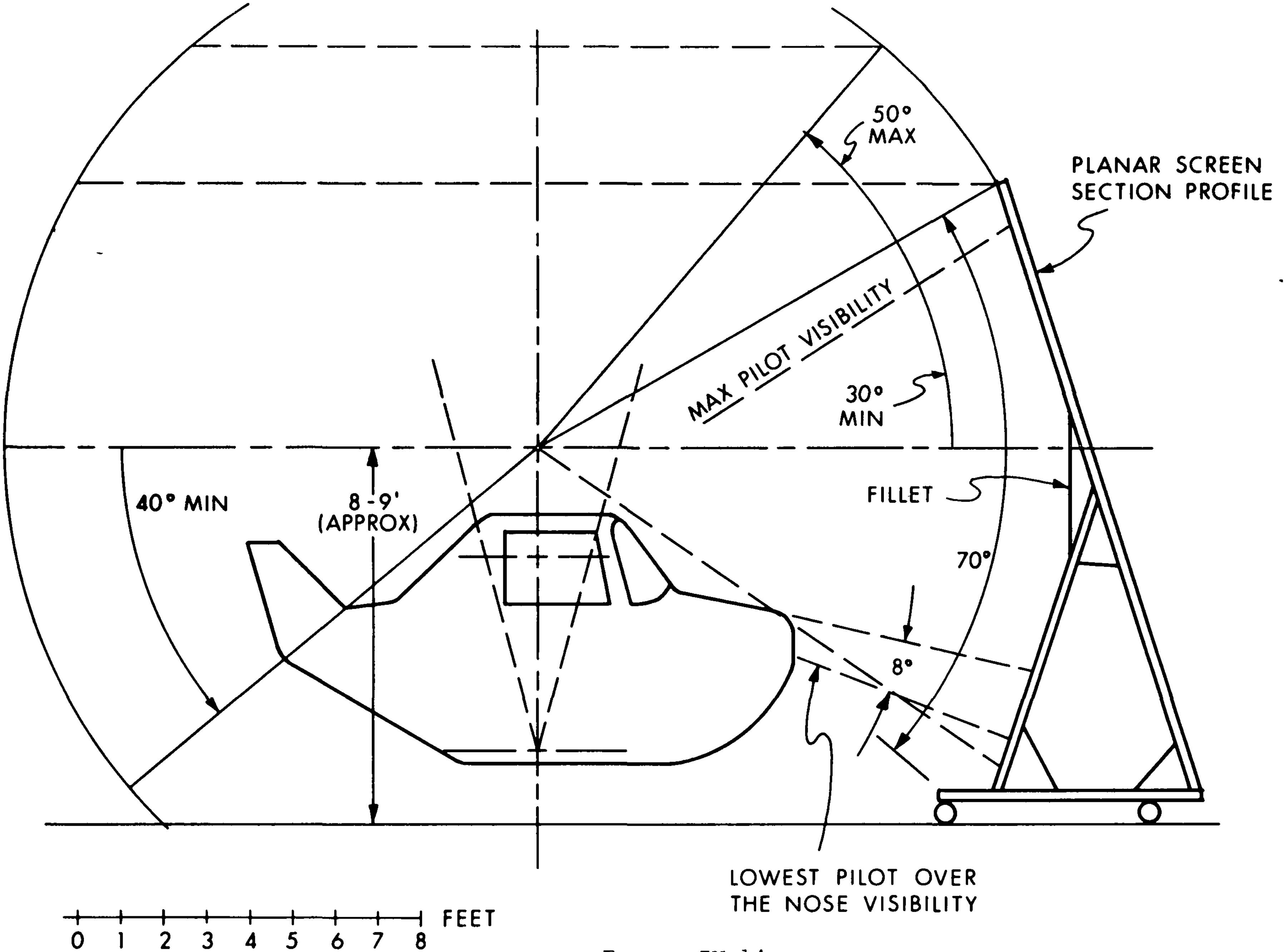


Figure IV-14.a.

Alternate Roll-up Screen Design - Configuration Sketch

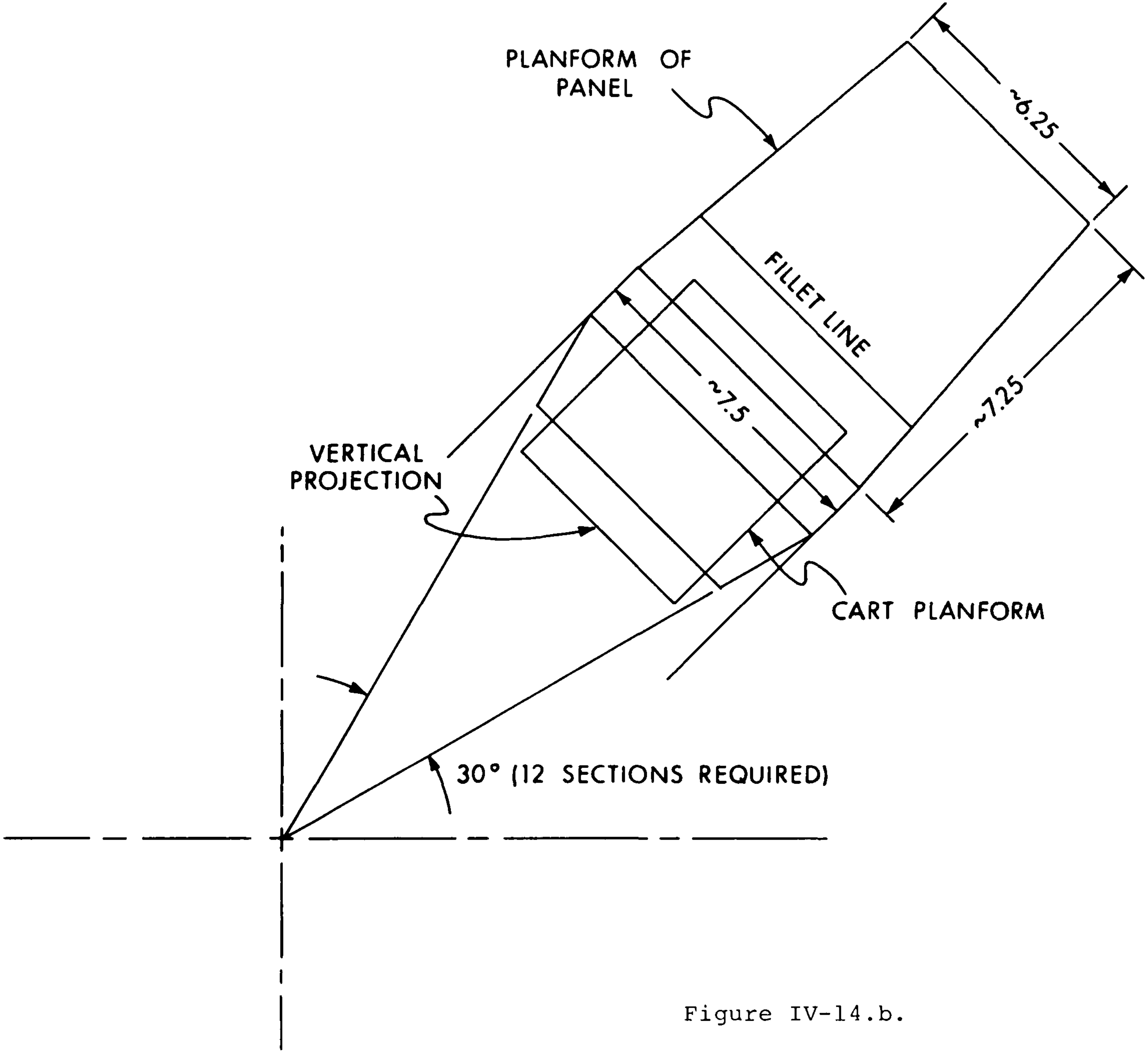


Figure IV-14.b.

Alternate Roll-up Screen Design - Planar Screen Projection (Approximate)

Apparent Size (Dynamic)

Orientation (Dynamic)

"Front" Surface

- Illumination
- Color

Background

- Illumination
- Texture
- Color

Beacon Blinking and Blanking (The latter would be present with improper installation on an aircraft.)

Reviewing all of the objectives from Section II, it is apparent that the first two and a part of the third objectives can be advanced without the threat projector. It is further believed that a significant evaluation of a certain subset of visual flight conditions can be evaluated by using a flashing light projector to simulate the threat aircraft. Accordingly, this limitation is accepted for the initial implementation of the GAT-1/PWI Experiment with the high fidelity implementation deferred for a later phase. From here on, the projector will be referred to as the beacon projector.

Consideration was given during the course of the contract to a choice of location for the beacon projector between body-mounting on the GAT-1 and a floor-ceiling mount. Reference to Figure IV-15 will show a plot of line-of-sight angular velocities versus to time go for passing encounters at several offset distances. Rates in excess of 10 degrees per second may be required of the beacon projector. There are a number of reasons for keeping the projector off the GAT-1. First, with the projector body-mounted, its maximum slew rate must be the sum of line-of-sight rates and body rates in yaw. Second, the horizon projector has already been allocated the prime position atop the GAT-1 cab, and third, a dual beacon projecting capability may be desired and the configuration of such projectors presents problems enough in non-interference without having to be mounted on the GAT-1.

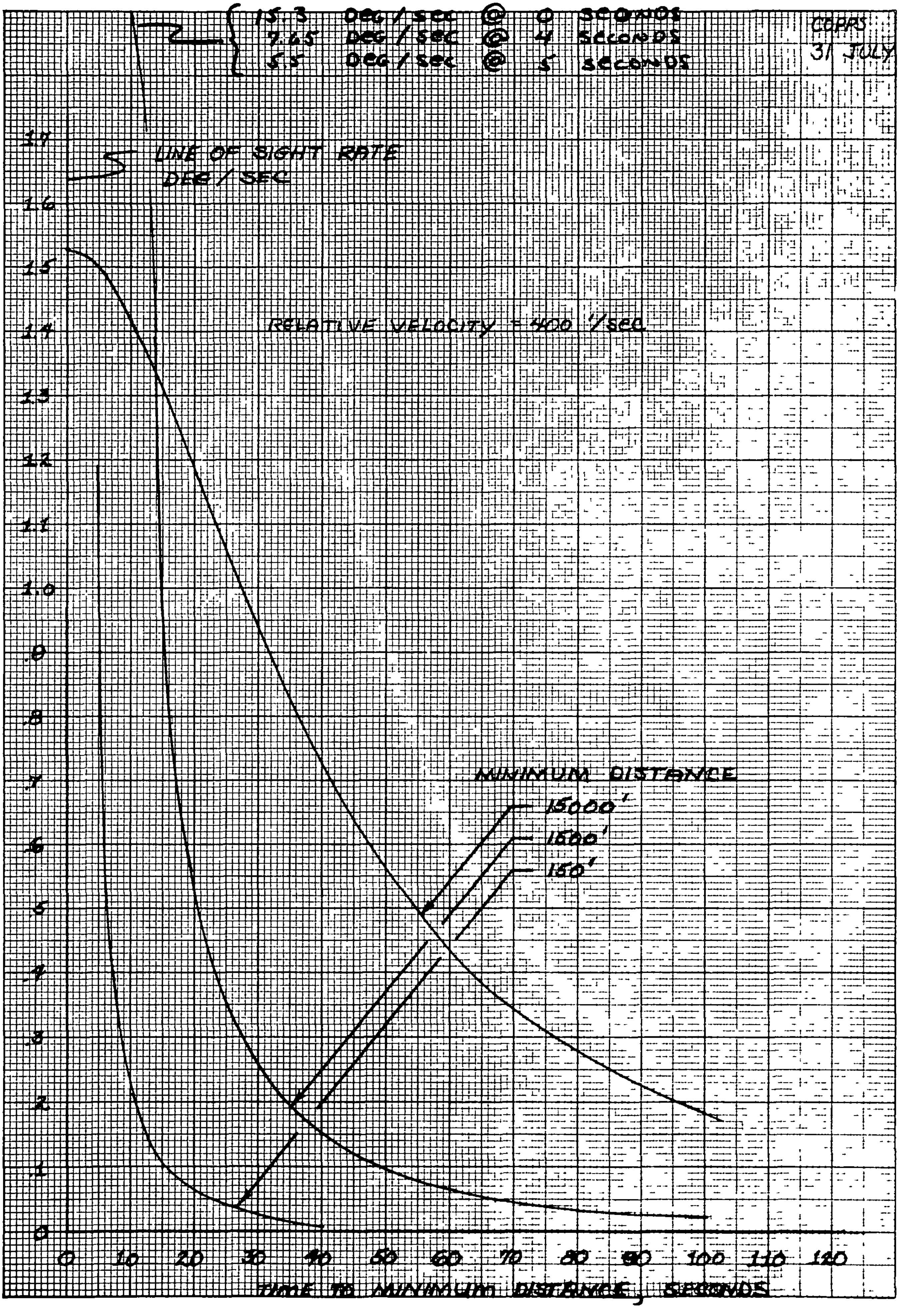


Figure IV-15 Encounter Line-of-Sight Rates

Accordingly, the GAT-1/PWI design concept assumes a target beacon projector suspended from the ceiling and located as low as possible over the GAT-1 to minimize parallax error.

This completes Section IV with its discussion of the alternative mechanization concepts for implementing the GAT-1/PWI Experiment. Section V. constitutes a specification based upon the concepts described above.

V. SPECIFICATION FOR THE GAT-1/PWI SIMULATION EXPERIMENT

Note: This section is intended to stand alone as a specification, on the basis of which, implementation of the GAT-1/PWI experiment can proceed.

A. Overall System Description

The equipment specified herein is to provide an interactive simulation involving the following items:

1. Link General Aviation Trainer (GAT-1) as modified. A demountable horizon projector on the GAT-1 is one of the required modifications. All modifications are to be reversible with a few man-hours of technician labor to restore the trainer to its normal configuration.

2. PWI Display Driver Equipment located on the trainer and suitable interface connections for 32 discrete signals for warning and display command.

3. Digital Teleprocessor located at the simulation facility to perform interface functions between the GAT-1 analog computer and the transmission coupler to a remote computation facility, Preparation of data for transmission in either direction may involve local coordinate transformations or other teleprocessing functions.

4. Digital Teleprocessor Software

   Machine language programs for cycle control, analog-to-digital conversion, digital-to-analog conversion, data transmission and acceptance, coordinate conversion, self-test, and the driving of local peripheral equipment. Guidelines for adapting the CASTEM program in the central processor to this new interface are required. The software shall be designed to permit the GAT-1 facility to transmit its state vector to other computers and other programs to ensure the general utility of this facility to other NASA/ERC Avionic programs.

5. Projection Screen

   This screen shall be 360° in circumference with a vertical profile which approximates a sphere centered at the simulator pilot's nominal eyeball location.

6. Threat Aircraft Beacon Projector

   A projection device rigidly suspended from the ceiling and capable of projecting a simulated threat aircraft warning beacon on the screen. This projector shall be driven in azimuth and elevation by servo command signals which represent the unit vector from the protected aircraft to the threat aircraft in"earth-reference"coordinates. The brightness of the beacon shall be controllable. Command angles and brightness settings shall come from the teleprocessor.

7. Miscellaneous Facility Equipment including cabling, experiment director's station, and supplemental ventilation and air conditioning if necessary.

B. GAT-1 Modifications

(For this section, reference may be made to the System Diagram for GAT-1 Modifications appended to this report.)

1. There shall be provided an operational amplifier unit consisting of eight (8) operational amplifiers mounted on a circuit board. The purpose of these channels is to isolate the GAT-1 analog circuits from the loading effects of the PWI Experiment. Also, the V_{gx} and V_{gy} signals are obtainable only by extra summing. The circuit board shall be fabricated from rigid plastic at least 1/16" thick. Approximate dimensions will be 8" x 10" providing room for eight potted amplifier units (Philbrick/Nexus QFT-2 or equivalent) and the circuit elements necessary for each amplifier. Seven (7) amplifier channels are identified in the System Diagram, with the eighth channel included for a spare. The operational amplifiers circuits are each to be designed for unit gain. Sign inversion of the signal is permissible in all but two channels, V_{gx} and V_{gy}.

   The operational amplifier unit is to be rigidly mounted in the aft compartment of the GAT-1 above the printed circuit boards plugged into the Flight Mother Board, Part #633756. Care must be taken in this location to ensure that temperature levels experienced in operation do not exceed specification levels on any of the components selected. If marginal thermal levels exist, a supplementary blower or aluminum heat sinks are indicated.

The operational amplifier unit shall be equipped with a connector or connectors, such that the entire board can be quickly removed for maintenance and repair.

2. Modification to X-Y Board

As mentioned in Section IV. B., ground speed signals are not directly available in an unmodified GAT-1. On the X-Y Printed Circuit Board (Part #633712) North airspeed and windspeed are differenced to find North ground-speed at the inputs to an integrating amplifier (AR-1) so that position, not velocity is the output. The printed circuit board shall be modified so that the amplifier sides of the adding resistors (R5 and R6, for East and R13 and R14, for North) go not to the respective switches (SWI for East and SW2 for North) but to unused contacts on the board's jack. These signals are picked up on unused pins of J-6 (Mother Board #633758), go to the operational amplifier unit and back, to two more unused pins on J-6. The X-Y Board is then to be further modified so that the return signal does indeed go to Pin 2 of Switches 1 and 2.

Modifications to the X-Y Board may be permanent in nature, since no interference with or degradation of non-PWI operation of the GAT-1 should occur. The machanical aspect of the modification shall be such that it shall be immune from damage caused by routine handling of the X-Y Board during normal maintenance. As an alternative, a special board may be procured from the original equipment vendor.

3. Slipring Assignment and Checkout

The required slip ring assignments are shown in the System Diagram which meets the basic initial needs of the GAT-1/PWI Experiment. It is intended to implement the Experiment on a non-interference basis with the normal GAT-1 functions.

The above slip ring assignments are based on available system information. Early in the modification of the GAT-1 trainer it will be necessary to test each of the proposed assigned slip rings through 360° of GAT-1 motion. D.C. signals shall be monitored by oscilloscope and strip recordings to identify any faulty or defective slip ring channels. It cannot be too strongly emphasized that reliable, trouble-free operation of the proposed Experiment over a prolonged period is dependent on the good health of these slip rings.

4. Horizon Projector

There shall be provided a horizon projector device similer in concept to Figure IV-5 and IV-6. This unit shall be mounted atop the GAT-1 cab roof as an integral detachable unit. Its maximum weight shall be fifteen pounds, including two axis drive systems, light, amplifiers, and mounting.

The upper portion of this device shall consist of an ordinary 110 volt 60 cycle lamp socket set in the center of the horizon shadow "pie-plate". The inside of the "pie-plate" shall be painted flat black. The lamp shall be adjustable in intensity by a rheostat available on the unit base. The angle made between the plane normal to the centerline of the lamp-filament and the rim of the "pie-plate" shall be manually adjustable ±15°. (See Figure V-1). This will allow settings for different altitude ranges.

The upper degree of freedom of the horizon projector shall be the pitch axis and shall have 48° degrees of freedom towards the front of the GAT-1 and 24° towards the rear. The lower degree of freedom shall be the roll degree of freedom with ±75° of motion involved. Great care shall be taken with the geometry of these servo-drives such that stops are reached before the moving members strike the top of the GAT-1. Standard synchro followers and motor-tachs shall be used in the design. Flexprints may be used but slip rings are not permitted. A fixed shade may be necessary to keep horizon projector light from impinging on the GAT-1 nose.

The horizon projector drive system shall have the static ability to assume a position within ±2.5°, 3σ, of the position of the synchro transmitter, at any setting in the latter's range. Furthermore, the projector drive shall remain with ±5°, 3σ, of the synchro

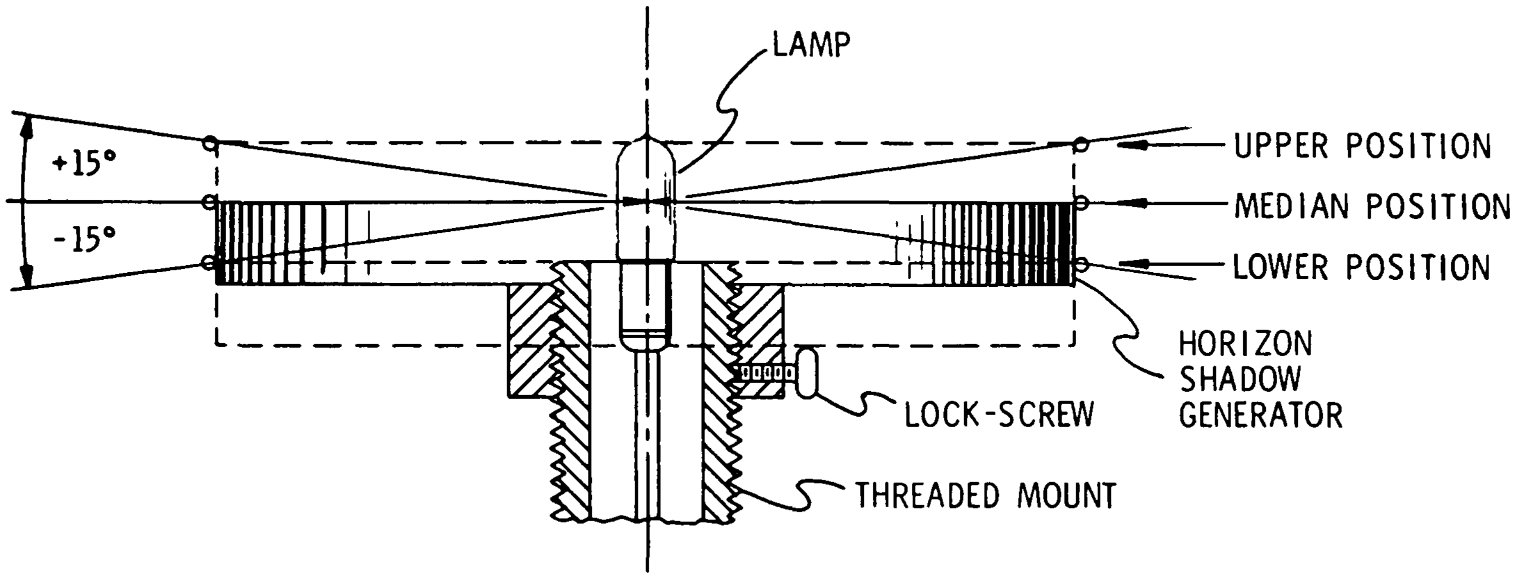


Figure V-1

Altitude Adjustment

transmitter at the maximum rates of which the GAT-1 is capable. Finally, the projector drive servos shall be critically-damped to over-damped. Evaluation methods for these specs are described below.

The designer of the horizon projector shall secure duplicates of the GAT-1 synchrotransmitters (Link Part Nos. 670407 and 6700120) and the instrument panel attitude and directional gyros. These units shall be combined with the horizon projector and operated on the bench in a series of tests. These tests shall determine effects caused by the projector synchros in terms of degradation of gyro accuracy and response. Buffer circuitry shall be added to eliminate this effect if necessary. Finally, the breadboard setup shall be used to verify horizon projector dynamic and static response.

5. Onboard Harness and Wiring

The GAT-1 trainer is designed for growth and modification. Most signals are brought to the so-called Mother Boards in the tail computer compartment. There the ready availability of the signals on open pins is of great help. The following internal harness shall be provided:

a) Mother Board to Operational Amplifier Unit. 12 Conductors Minimum.

b) Operational Amplifier Unit to the Slipring Assembly. 7 Conductors Minimum. (If the spare slip rings are already brought to the Mother Boards, this harness merges into the first one.)

c) Slip ring Assembly to the PWI Equipment. 4 Conductors. (Note: These signals are digital pulses and shall be shielded and provided with good ground returns.)

(No requirements is stated for the harness from the PWI Equipment to the GAT-1 instrument panel since this is a function of the location and nature of the PWI Display equipment under test.)

d) Pitch and Roll Synchros, etc. to the Horizon Projector.

3 Wire Signal for Pitch Synchro Follower

3 Wire Signal for Roll Synchro Follower

2 Wire 400 Hz Excitation Supply

2 Wire 60 H_z Light Supply

6. External Cabling

There shall be two cable assemblies directly connected with the GAT-1 Modification. Reference may be made again to the System Diagram. The first shall be a small local harness involving the indicated connections between P43a, J43a, P45a, and J50. The second cable is indicated by the P50 end and the description "To PDP-8". Both cables shall be wrapped or otherwise covered with a tough rubber or plastic coating, since there may be no provision to get them out of the way of foot-traffic. Connectors shall be of the highest quality where electrical conductivity and mechanical strength are concerned. Dust covers are to be provided for use when the cables are detached.

7. Interface Summary

The required interface signals in the basic GAT-1/PWI Experiment in Table V-1.

C. PWI Display Equipment

Provision shall be made to drive a PWI display on the GAT-1 instrument panel. Current concepts for PWI instrumentation involve an array of lights indicating direction to a detected threat aircraft. Figure IV-7 illustrates typical PWI instruments.

Since more than one aircraft may be detected, it shall be possible to light more than a single light. The first version of the simulation software will however, be limited to one aircraft.

In order to conserve slip rings, however, the PWI light array (PWILA) bits shall be serially shifted into a shift register, located in the GAT-1. The shift register shall be 32 bits in length and built-up by serially connecting four DEC M 208 8 bit buffer/shift registers. Each light is to be driven by the one state of a separate bit. It is expected that several of the 32 bits provided will be available for use for purposes other than driving the PWI instrument.

The output signal shall maintain +2.4 volts or greater while supplying 0.4 milliamps current. When off, it shall sink 16 milliamps current while maintaining +.4 volts or less. Power amplification shall be provided if necessary to drive each light.

Table V-1

GAT-1/PWI Signal List

Item	Slipring	Engineering Units	Volts
Sin ψ	J35/43-6	N/A	±10 VDC
Cos ψ	J35/43-7	N/A	±10 VDC
Sin ϕ'	J35/43-8	N/A	±15 VDC
Sin θ'	J35/43-9	N/A	±15 VDC
Vert Speed	J35/43-10	2,500 ft/min	-10 V
V_{gx}	J44/45-5	160 MPH	10 V
V_{gy}	J44/45-4	160 MPH	10 V
Alt	J44/45-8	20,000 ft.	-15 V
X	J35/43-17		
Y	J35/43-16		
PWI Clock	Spare 1/2-12	N/A	
PWI Reset	Spare 1/2-11	N/A	
PWI Shift	J44/45-10	N/A	
PWI GND	J44/45-9	N/A	

The M208 shift registers have the configuration characteristics shown in Figure V-2 . Explanatory material describing the operation of the PWILA registers follows below.

The clear line, the load lines, the load enable line, and one clock line need not be brought through the slip rings. The shift enable, and serial input lines must be brought through the slip rings. It is likely that the other clock line need not pass through the slip rings. Lines not brought through must be connected to ground or to +3 volts. It is probable that the ground signal must be passed through the slip rings unless the PDP-8 output channels can use the GAT-1 signal ground which is already available on both sides. Thus, the most probable list of signals passing through the slip rings is:

A. Shift Enable

B. Serial Input - 0

C. Ground

with a possible addition of

D. Clock

To drive the shift register, an otherwise unused device number is assigned to this function, and a device selector is wired to respond to the binary number assigned when it appears on the BMB lines as a result of an IOT instruction. These are three separate events that can be caused by various single IOT instructions, corresponding to the IOP pulses; 1, 2 and 4. One of these would be used to cause both a shift and a serial input to the first stage, another to cause a shift without serial input. The clock signal if required, would be connected to each of these outputs.

Figure V-3 illustrates a typical device selector. The BMB lines select a single device on the basis of bits 4 through 9 of an IOT instruction, the IOP pulses on the basis of bits 10 through 12.

A five volt (one watt) power source is required to service the shift register. This can be obtained from 115v AC by a power supply similar to the DEC H716, if a GAT-1 power source is not available.

All of the above, including lamp driver modules, shall be mounted on a single standard connector block and placed inside the GAT-1 card bin, preferable so as to receive some circulation cooling from the fan.

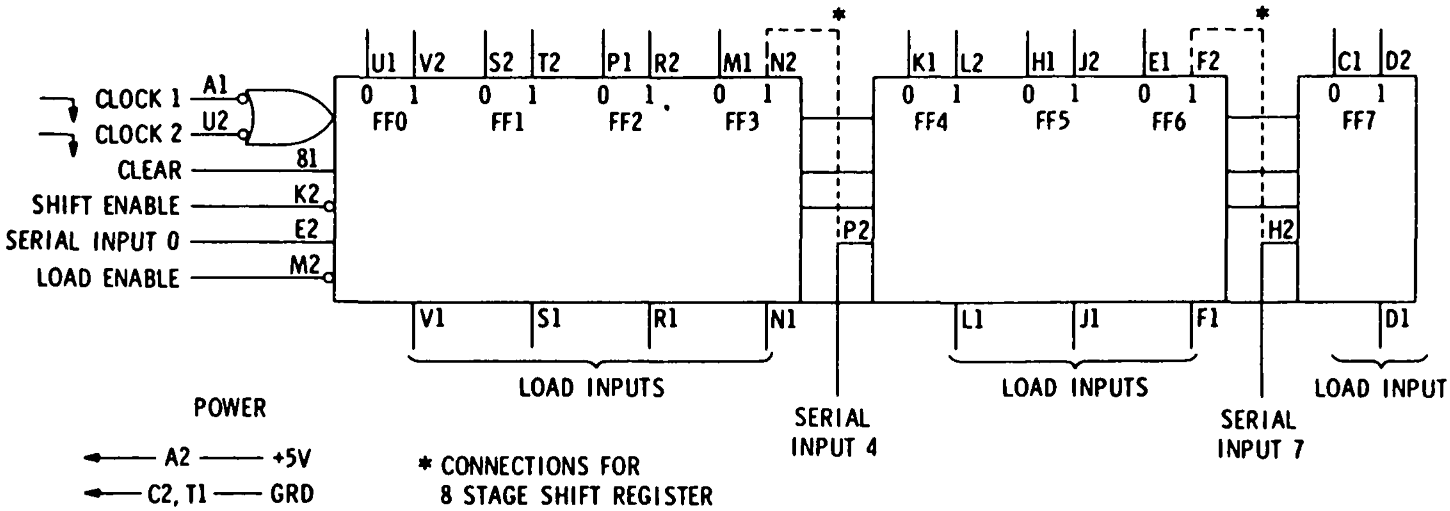


Figure V-2

M208 Shift Registers

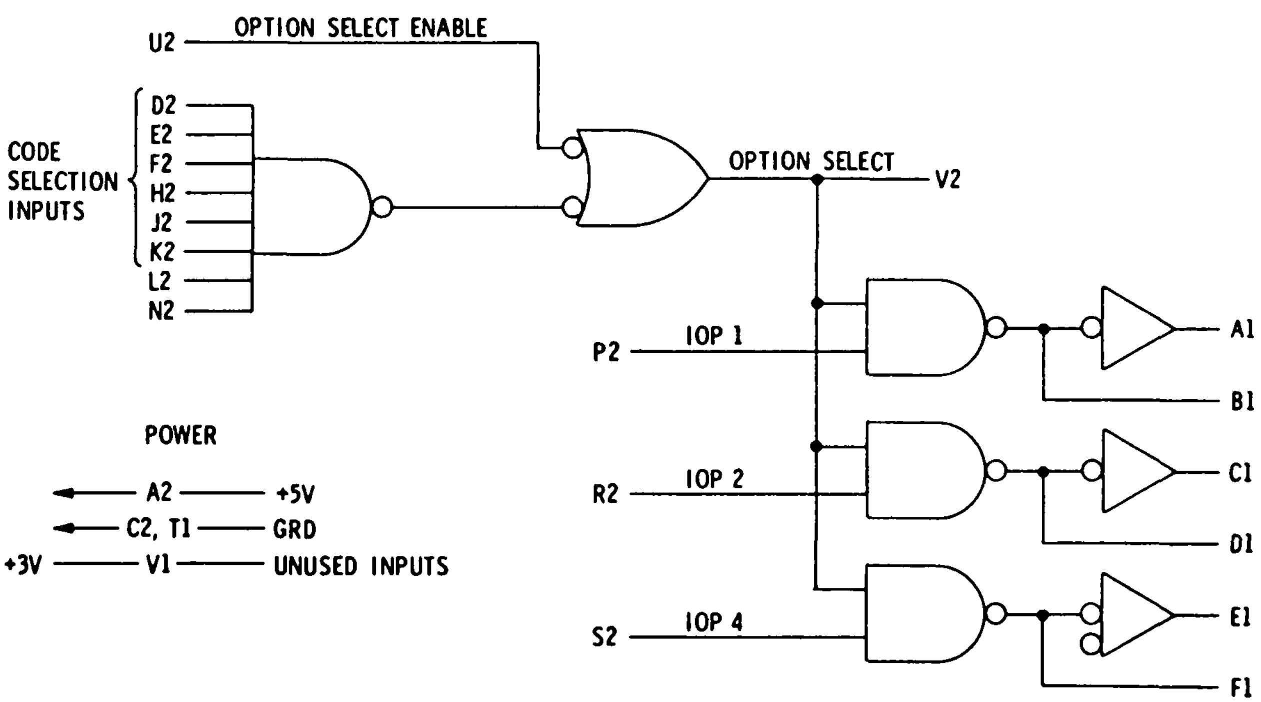


Figure V-3

Typical Device Selector

D. Digital Teleprocessor

1. Introductory

This part of the specification involves the central element of the experiment, the teleprocessor. As indicated in Section IV, it was found that the requirements of the Experiment could best be met by integrated equipment which tied analog-to-digital, digital-to-analog, main frame, and peripherals into one subsystem of the Experiment. Accordingly, the teleprocessing provisions of this specification are built around the DEC PDP-8/L or its close equivalent.

The PDP-8/L has had extensive use in industry. The supporting documentation is comprehensive. DEC maintains sales and service facilities in Cambridge, Mass. and its main facility is in Maynard, Massachusetts.

These features: access to the vendor, integrated peripherals, supporting documentation and supporting software must be heavily weighted in one-of-a-kind applications, where programming, engineering and development cannot be written off over multiple delivered items. Digital Equipment Corporation best meets the requires standards in these areas.

The Digital Equipment Corporation Programmed Data Processor-8/L (PDP-8/L) is a small-scale general-purpose machine. TTL monolithic integrated circuit modules are used throughout thereby providing efficient packaging, high reliability and noise immunity. The PDP-8/L is a one address, fixed word length, parallel system using 12 bit, two's complement arithmetic. Cycle time of the 4096-word random-address magnetic-core memory is 1.6 microseconds. Standard features of the system include indirect addressing and facilities for instruction skipping and program interruption as functions of input-output device conditions.

Addition is performed in 3.2 microseconds (with one number of the sum in the accumulator) and subtraction is performed in 6.4 microseconds (with the subtrahend in the accumulator). Multiplication is performed in approximately 336 microseconds by a subroutine that operates on two signed 12-bit numbers to produce a 24-bit product, leaving the 12 most significant bits in the accumulator. Division of two signed 12-bit numbers is performed in approximately 474 microseconds by a subroutine that produces a 12-bit quotient in the accumulator and a 12-bit remainder in core memory.

Flexible, high-capacity, input-output capabilities of this teleprocessor allow it to operate a variety of peripheral equipment. In addition to standard Teletype and perforated tape equipment, the system is capable of operating in conjunction with a number of optional devices such as high-speed perforated tape readers and punches, card equipment, a line printer, analog-to-digital converter, cathode-ray-tube displays, magnetic-tape equipment, and a 32,000 word random access disc file.

The PDP-8/L is completely self-contained, requiring no special power sources or environmental conditions. A single source of 115-volt, 50-60 cycle, single-phase power is required to operate the machine. Internal power supplies produce all of the operating voltages required. Modules utilizing TTL monolithic integrated circuits and built-in provisions for marginal checking insure reliable operation in ambient temperatures between 50 and 130 degrees Fahrenheit.

Figure V-4 is a layout showing the interrelationship of equipment in the design.

Prior to placing an order for the teleprocessor, it is suggested that another review be made of the estimated software demand on the PDP-8/L and of other activities possibly planned by NASA/ERC for the simulation capability made available by the GAT-1 Experiment. With this in mind, a final choice can be made between the PDP-8/L and the PDP-8/I. The latter machine has faster multiply-times and its memory capacity is more easily expanded.

E. Software Specification

1. Teleprocessor Computer Sizing

The trigonometric processes involved in manipulation of kinematic data represents the greatest main-frame time burden. The PDP-8/L does multiplication and division by subroutine. The result is that the capacity is determined by the multiplication requirements. These requirements are documented in the following sections.

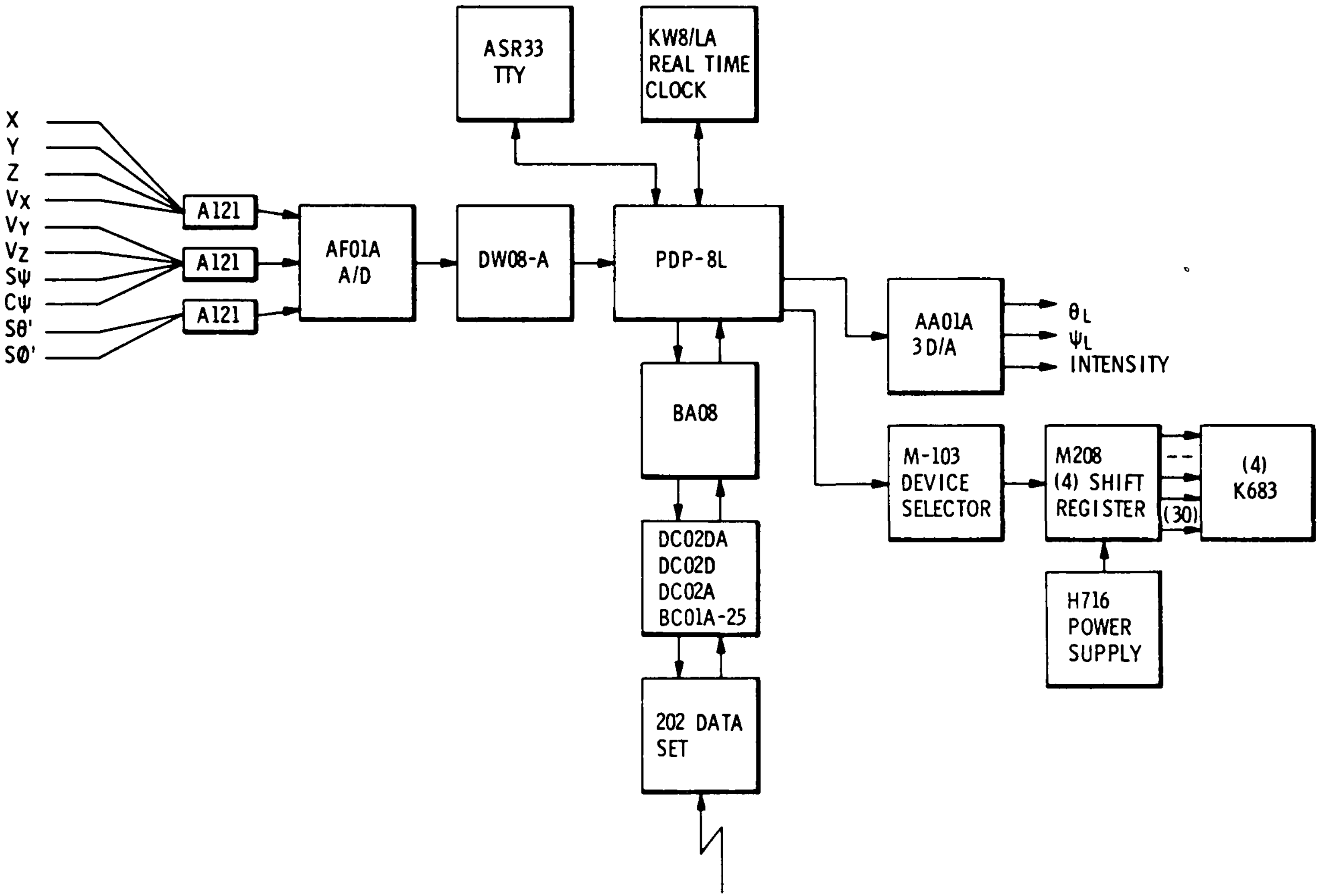


Figure V-4. Equipment Mechanization Layout

PDP-8/L Operating Speed

Instruction	Speed
Add	4.8 μs
Store	4.8 μs
Multiply	350μs (max.)

For purposes of estimation, multiplication, division, and square root operations were counted, but conservative time increments were presumed per operation, e.g. 600 μs for multiplication.

a. Target Angle Computations

FLOW	DIVIDE	MULTIPLY
$\theta' = \sin^{-1}(\sin\theta)$		4
$\sin\theta = \sin(3\theta')$		4
$\cos\theta = \cos(3\theta')$		4
$\phi' = \sin^{-1}(\sin\phi')$		4
$\sin\phi = \sin(6\phi')$		4
$\cos\phi = \cos(6\phi')$		4
$\underline{1}P = M_P^A \times M_A^R \, \underline{1}R$		46*
$\theta_L = \sin^{-1}(1_z)$		4
$\cos\theta_L = \cos(\theta_L)$		4

* See Matrix Vector Computations

$\lvert 1_y \rvert < \lvert 1_x \rvert$		2

No ↓   Yes ↓

$\sin\psi_L = 1_y/\cos\theta_L$ $\cos\psi_L = 1_x/\cos\theta_L$

$\psi_L = \sin^{-1}(\sin\psi_L)$ $\psi_L = \cos^{-1}(\cos\psi_L)$

$84 \times 6 \times 600 \times 10^{-6} = 30\%$ 84

b. Matrix Vector Computations

FLOW (Ref. to Airframe)

$1_x^A = c\theta \cdot s\psi \cdot 1_x + c\theta \cdot c\psi \cdot 1_y + s\theta \cdot 1_z$	5
$s\phi s\theta = s\phi \cdot s\theta$	1
$1_y^A = (s\psi \cdot s\phi s\theta + c\phi \cdot c\psi) \cdot 1_x$	3
$+ (s\phi s\theta \cdot c\psi - c\phi \cdot s\psi) \cdot 1_y$	3
$- s\phi \cdot c\theta \cdot 1_z$	2
$c\phi s\theta = c\phi \cdot s\theta$	1
$1_z^A = (c\phi s\theta \cdot s\psi - s\phi \cdot c\psi) \cdot 1_x$	3
$+ (c\phi s\theta \cdot c\psi + s\phi \cdot s\psi) \cdot 1_y$	3
$- c\phi \cdot c\theta \cdot 1_z$	2
	23

(Conversion from Airframe to Floor Coordinates - See Appendix C. - involves same computation load.)

Note: $c\phi = \cos\phi$, etc.

PDP-8 Time Loading Estimate (Main Frame)

Operation	Time (μs)	Rep. Rate	% of Time
A/D & STORE Whole List	600	1/sec	.6
A/D STORE Partial List	260	5	1.3
Transmit List	1,360	1	1.4
Compute Target Angles	30,000	6	30
Duty Cycle			33.3%

(Other unaccounted operations can be expected to raise the duty cycle towards 60%)

2. Sample Teleprocessor Coding

Several subroutines have been rough coded to insure understanding of program implications. They have been timed to obtain main frame loading. They are documented in the following sections.

a. SUBROUTINE: TO READ THE A/D INTERFACE (Figure V-5)

There are 10 signals, at channels 0 through 9. The last four signals are sines and cosines of angles. Either the whole list or the angles only can be read and stored.

The reading is sequential, and is stopped on the basis of a number auto-indexed in register 11.

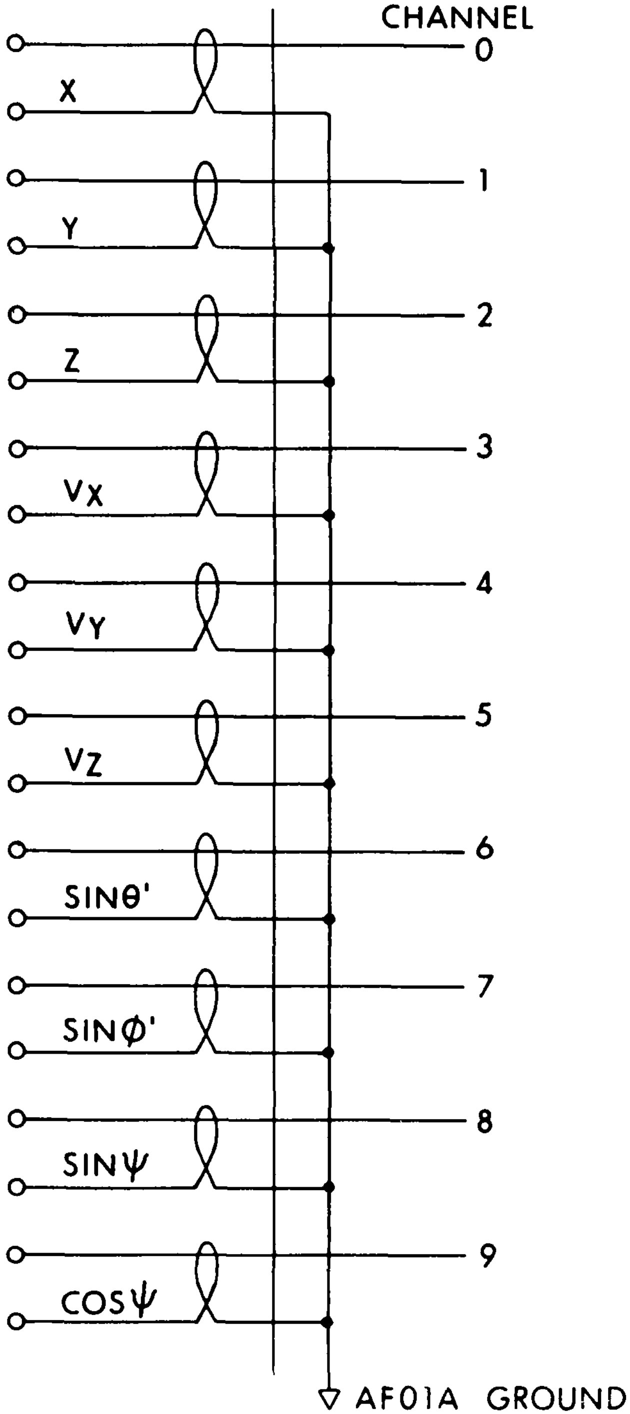
The digital number is stored in a memory list on the basis of an address auto-indexed in register 10. The accumulator must be set to 0000 on subroutine transfer to read the whole list. To read angles, the accumulator should contain the number 0300.

Calling sequence to read list:

(μs)		
1.6	CLA	
3.2	TAD K-10	register 11 counts up to zero to end sequence
3.2	DCA 11	
3.2	TAD ( )	address of first word in list, minus one
3.2	DCA 10	
3.2	JMS ATOD	go to subroutine with C(AC) = 0
17.6 μs		

b. SUBROUTINE TO TRANSMIT DATA FROM PDP-8 TO CENTRAL PROCESSOR (See Figures V-6 and V-7)

The following subroutine was designed to use the entire 8 bit content of each transmission character. To do this, two 12 bit words are packed into three characters.



INTERFACE:

DC VOLTS	NUMBER
0	4000_8
- 5	0000_8
-10	3777_8

INPUT IMPEDENCE $10 \times 10^6\ \Omega$

Figure V-5. Analog/Digital Interface

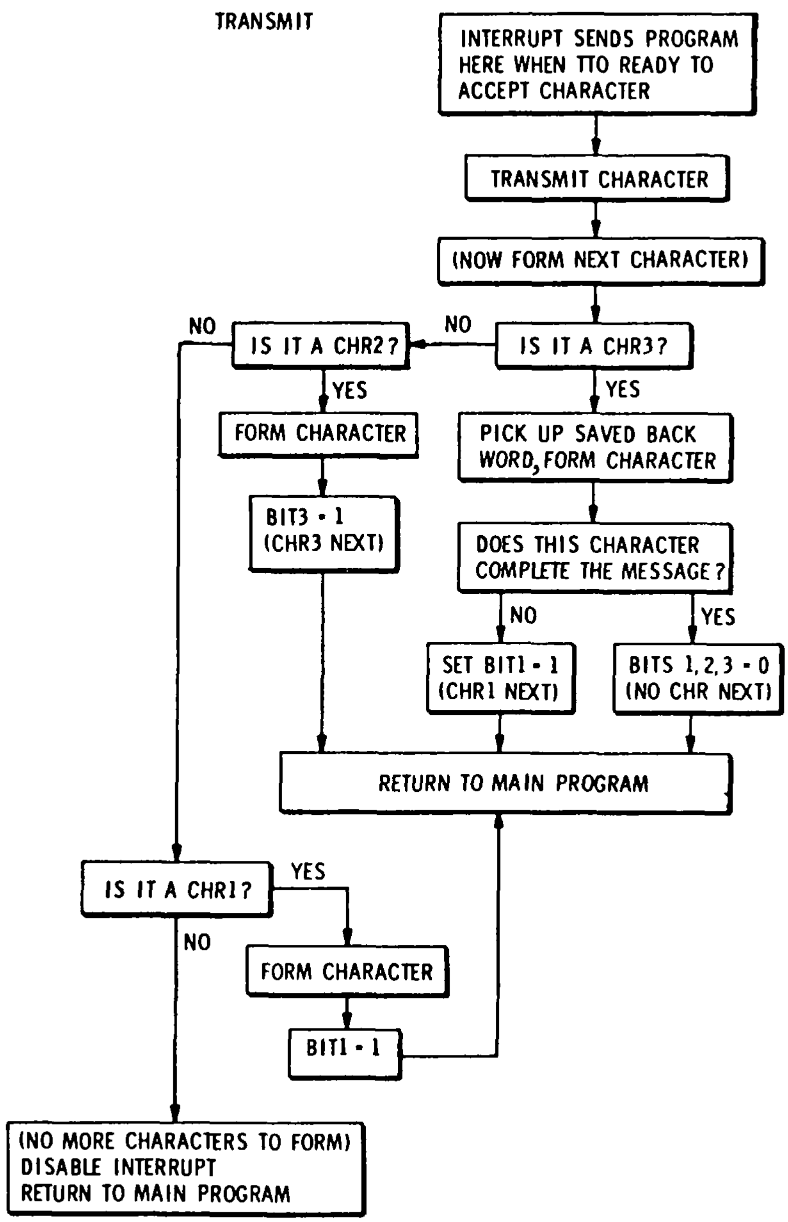


Figure V-6. Flowchart, Data Transmission

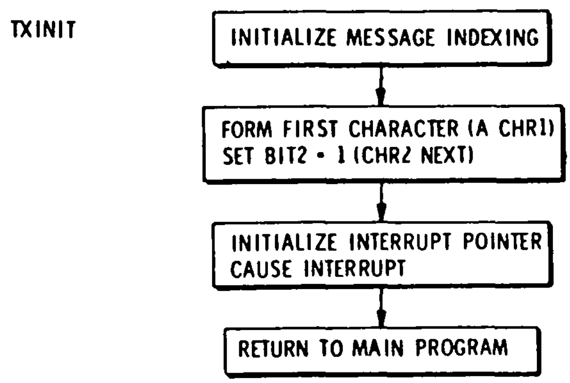


Figure V-7. Flowchart, Data Transmission Initiation

```
TXINIT    TAD       A(ML)      place((address of ML)-1) in register 10
          TAD       NEGONE     for auto-indexing through the message
          DCA    0  10         list

          TAD   IO  10         pick up words/message,(in ML)
          CMA
          DCA       WDSLFT     initialize words left = -words/message

          JMS       CHR1       subroutine CHR1 gets first word, forms
                               CHR1 in NXTWRD

          DCA       NXTCHR
          ----------------     (set up interrupt to return to TRANSMIT)
          ----------------
          ----------------     (cause interrupt)

TRANSMIT  CLA                  comes here on interrupt caused
          TAD       NXTCHR     by TTO ready for next transmission
          TLS                  TRANSMIT character AC11-4 → TTO8-1

          AND       BIT3       now prepare next character
          SPA                  are we forming a CHR3?
          JMP       NOTCHR3    no

          CLA                  yes, this is to be a CHR3?
          TAD       TEMP       backword was stored in temp during CHR2

          RTL                 } rotate three left
          RAL                 }
          AND       TTOBITS    set bits 12, 3-1, = zero
          DCA       TEMP       store while checking to see if end of message

          DAD       WDSLFT
          TAD       TWO        counting the two words transmitted by current
                               three characters

          SZA                  will this CHR3 complete the message?
          JMP       MORE       no

          TAO       TEMP       note: bits 1, 2, & 3 are zero
TTORETRN  DCA       NXTCHR     ready and waiting for next interrupt
          JMP   IO  0          return from interrupt

MORE      TAO       TEMP
          TAD       BIT1       CHR1 is to be assembled next time
          J
          JMP       TTORETRN
```

```
NOTCHR3  CLA
         TAD         NXTCHR
         NAD         BIT2         are we to form a CHR2?
         SPA
         JMP         NOTCHR2      no

         CLA                      form CHR2
         TAD         TEMP         front word was stored in
         RTL                      temp while forming CHR1
         RTL                      rotate left seven places
         RTL
         RAL
         AND         TOPBITS      set bits 12, 7-1, = 0
         DCA         TEMP 1       save while forming lower half

         TAD    IO   10           pick up back word
         DCA         TEMP         save for forming CHR3
         TAD         TEMP
         RTR
         RTR                      rotate right five places
         RAR
         AND         LOWBITS      set bits 12-8, 3-1, = 0
         TAD         TEMP1        form complete character
         TAD         BIT3         CHR3 to be assembled next time
         JMP         TTORETRN

NOTCHR2  CLA
         TAD         NXTCHR
         AND         BIT1         are we to form a CHR1?
         SPA
         JMP         MSGOVER      bits 1, 2, 3 all zero, msg has been sent
         JMS         CHR1         form CHR1, using subroutine
         JMP         TTORETURN

CHR1                 0
         CLA
         TAD    IO   10           pickup front word
         DCA         TEMP
         TAD         TEMP
         RAR                      rotate right one place
         AND         TTOBOTS
         TAD         BIT2         CHR2 to be assembled next time
         JMP    I    CHR1         return from subroutine, C(AC) = NXTCHR
```

It now appears that less than the full eight bits will be used in order to permit parity checks on transmitted data and to save several bit arrays for special purposes, such as "end of message", etc.

1. The message list is stored in sequence starting at location ML+1. The number of words in the message is stored in ML. It must be an even number.

2. Two words are packed into three characters:

```
| FRONT WORD || BACK WORD |
12          1 12        1


| CHR1 |  | CHR2 |  | CHR3 |
 8    1    8    1    8    1
```

   with the sequence repeated until the complete message has been transmitted.

3. The routine is designed to transmit a character upon notification via interrupt that the TTO register is available. Following loading of the TTO register, the next character is formed and then the routine exists to a main program to await the next interrupt.

3. Central Processor Operation (See Table V-2)

The central processor shall receive data once per second from the PDP-8. This data shall represent position, velocity and Euler angles. Using this data and information about the position, speed, altitude and heading of aircraft maintained on the PREPR2 magnetic tape (See Table V-4), relative information is evaluated to select threat aircraft from this list. Relative position is extrapolated using relative velocity through six time steps.

If there is a threat aircraft, a sequence of six unit vectors are calculated suitable for driving a visual projector at the GAT-1. These 6 vectors are extrapolations at one-sixth second intervals. In addition, the on/off status of the PWI cockpit display lights are also computed and transmitted.

TABLE V-2.

PREPR2 BINARY OUTPUT TAPE DATA

FORTRAN Symbol	Description
Time and Number of Tracks	
LT	Time (sec)
NUP	Number of tracks at time LT
Track Data	
NTSAVE	Track Number
XSAVE	x position (nmi)
YSAVE	y position (nmi)
ZSAVE	Altitude z (ft)
VX	$\dot{x}$ velocity (kts)
VY	$\dot{y}$ velocity (kts)
VZ	$\dot{z}$ velocity (kts)
ROLL	Bank angle ϕ (rad)

PREPR2 TAPES

Description	FORTRAN Logical Unit No.
FAA ARTS smoothed-tape, BCD	11
PREPR2 output tape, binary	9
System output	6

TABLE V-3

Definition of Symbols

F	parity fails. incremented if GAT-1 data fails parity check
THREAT	= 0 no threat at this time = 1 threat exists
PWILA	PWI light array, sequence of bits, to indicate which lights are on, which are off
R	range of threat from GAT-1
RMAX	a very large number
$\overline{DELR}$	relative position vector GAT-1 to threat, at time corresponding to PREPR2 record
$\overline{VELR}$	relative velocity vector, as in $\overline{DELR}$
N	counter, to obtain 6 extrapolated unit pointing vectors
M_A^R	defined on flow diagram
$\overline{RM}$	$\overline{DELR}$ in aircraft coordinates
$\overline{ONERM}$	Unit of $\overline{RM}$
T_G	time associated with each GAT-1 transmission, originally synchronizes with PREPR2 time (T) and incremented on each pass
T	time read from PREPR2 tape
K	switch, set to 1 on pass before use of new PREPR2 data, set to 0 on pass that uses new PREPR2 data
$\overline{R}_I$	GAT-1 position vector at PREPR2 time, for later evaluation
$\overline{V}_I$	GAT-1 velocity vector, as in $\overline{R}_I$

Following transmission of data to GAT-1, the central processor has other tasks to perform. These tasks must be performed before the next receipt of GAT-1 data. There are three separate tasks and only one is done each second. Thus, the basic repetition period is three seconds, coincident with the period of the data stored on the PREPR2 tape. These tasks are done in the following sequence, starting after the first transmission using a new PREPR2 time/data record.

1. Store evaluation data on tape

2. Read next PREPR2 record into memory

3. Re-evaluate threat situation

Figures V-8, V-9, and V-10 flow chart central processor operation.

4. Test Data Reduction and Analysis of System Performance

Other areas of software specification include initialization and control, test data reduction, system performance evaluation criteria, and performance analysis against such criteria.

The input/output unit at the teleprocessor shall consist minimally of an ASR-33 teletype. The Experiment controller shall have at his command the necessary software to initialize, control, stop, and evaluate individual Experiment runs. Control shall include the selection of available air traffic environments within which the GAT-1 is to operate. The controller shall be able to select threat aircraft from a catalog of same which shall approach the GAT-1 in standardized encounters. Experiment data available at the teletype during a run shall include print-out of GAT-1 position, velocity, and attitude upon request. When the PWI warning is sounded, both GAT-1 and threat aircraft state vectors shall be typed out. At the conclusion of a warning condition, the GAT-1 and threat aircraft state vectors shall be provided and an audit of the PWI performance during the encounter. A hazard condition may not necessarily coincide with a PWI warning condition. State vectors shall be provided at the beginning and end of a hazard condition along with a similar audit of PWI performance. State vectors shall be provided upon notification that the GAT-1 pilot has visually acquired the simulated flashing beacon. Performance audits have to be carried out against

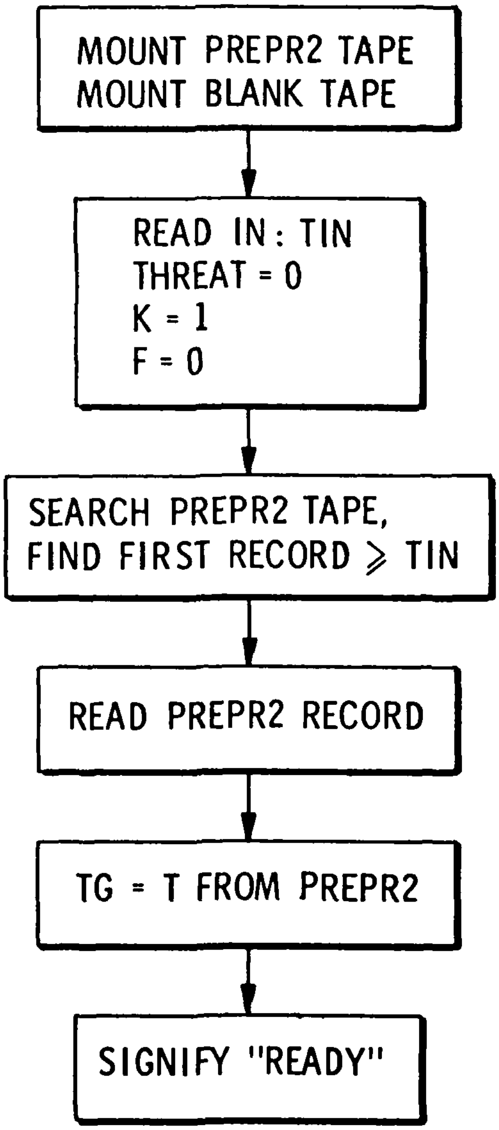


Figure V-8. Central Processor Initialization

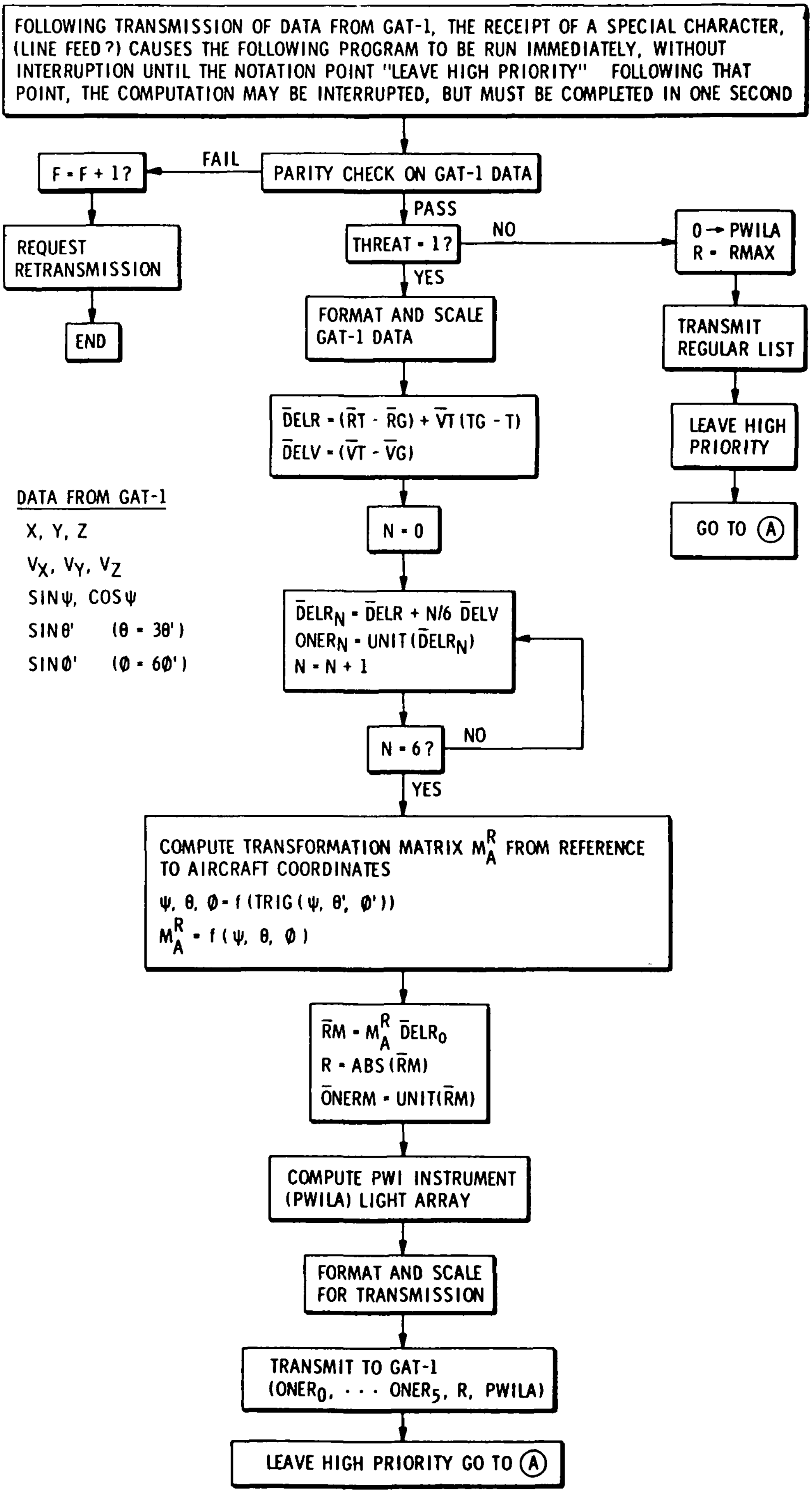


Figure V-9. C.P. High Priority Flow

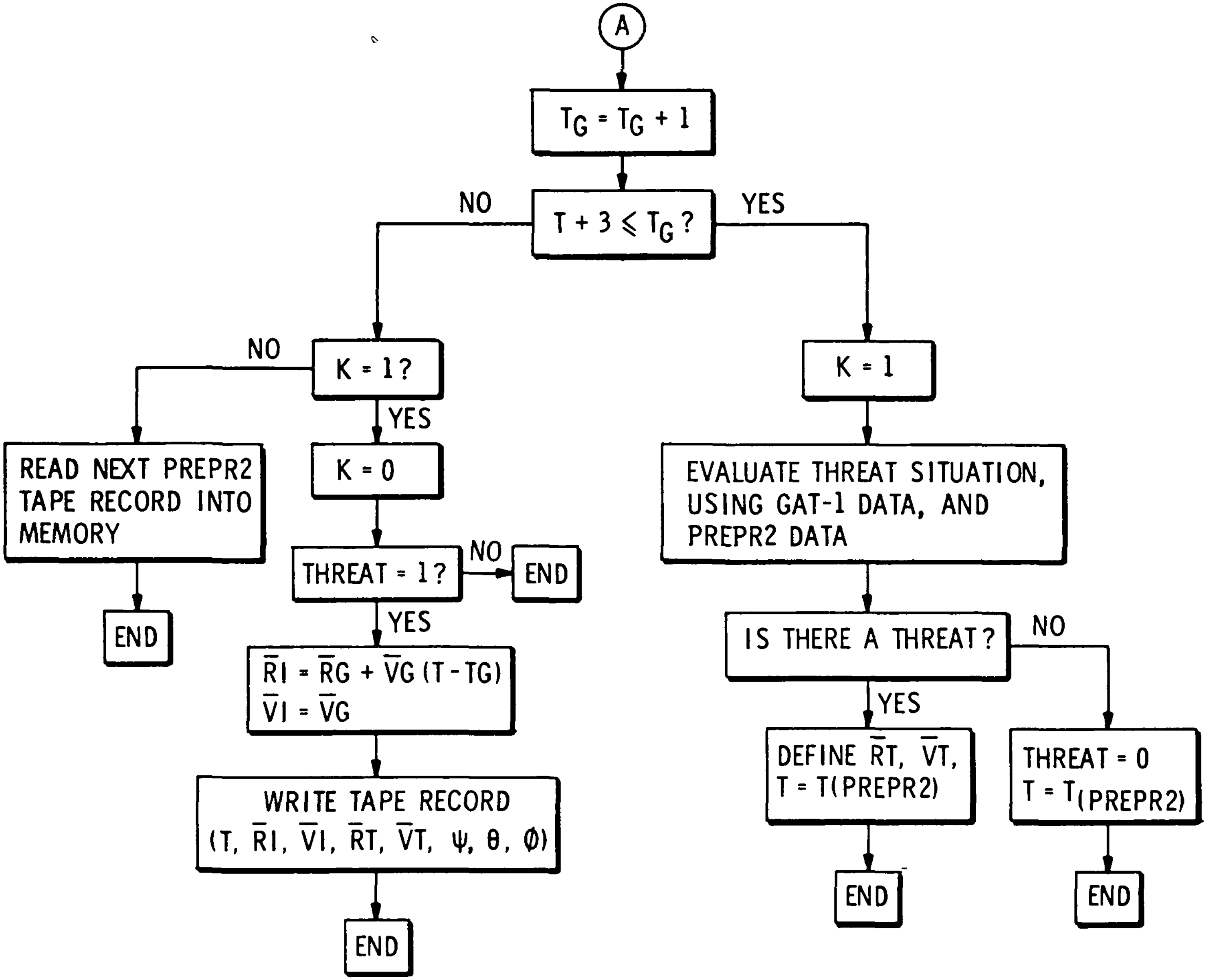


Figure V-10. C.P. Low Priority Flow

performance criteria. The AHEP1 and AHEP2 Programs (described in reference 6) have not been superceded by any new performance criteria generated in the course of this study. Direction was received (7) not to place emphasis on developing performance evaluation criteria during this contract.

F. Screen Specification

The screen shall be 360° in circumference with a vertical profile which approximates a sphere centered at the simulator pilot's nominal or equilibrium eyeball location. The radius shall not be less than 15 feet. (With assumed pilot vision elevation angles of ±50°, a facility height of 23 feet is implied. Lesser facility height is acceptable with possible slight loss in fidelity due to excessive sphere truncation at floor and ceiling planes of intersection. Larger radii up to 30 feet are preferable, except that the following limit shall be observed:

$$R < \frac{h}{2 \text{ Sin } 50°}$$

The inside projection surface of the screen shall be coated with a reflective surface of good quality. Means shall be provided for forced ventilation of the simulation facility inside the screens, such that a temperature not to exceed 70°F can be maintained inside the screen and around the GAT-1 during continuous operation of up to 3 hours.

Access to the simulation area, through a door or hatch, must be both convenient and practical both for operations and maintenance. In particular, provision must be made for the remote necessity of lifting the GAT-1 from its base with a hoist. In this case, a tripod stand must be assembled within the screen area without difficulty.

Consideration shall be given to the location and operation of the Experiment Director's station, situated outside but adjacent to the screen installation. For the convenience of the Experiment Director, installation shall be provided of a port or flap in the screen for observation of the Experiment operations.

The choice is left open between a commercial planetarium-type spherical screen and the roll-up panels described in Section IV-F:

1. Roll-up Panels

The use of these panels is suggested if (a) the available ceiling height is normal office room height, (b) the Experiment is initiated in a temporary location, and (c) the available funds are severely limited.

2. Spherical Surface

The commercially fabricated truly spherical screen is recommended if (a) substantial ceiling height is available, and (b) the Experiment is housed in a permanent area.

G. Threat Aircraft Beacon Projector

1. Subsystem

The threat Aircraft Beacon Projector shall consist of a unit rigidly suspended from the facility ceiling and capable of projecting a simulated warning beacon in any vector direction covered by a screen. This projector shall be driven in azimuth and elevation by servo command signals which represent the unit vector from the protected aircraft to the threat aircraft in earth-reference coordinates, but adjusted for GAT-1 motion attenuation. The brightness of the beacon shall be controllable. Command angles and brightness settings shall come from the teleprocessor via digital-to-analog interfaces. The timing and duration of pulses should be manually adjustable.

2. Optical Unit

The light source to be used shall approximate as closely as possible the visible spectral characteristics of the xenon lamp used in beacons, namely 4000 - 7000 Å. The transmitted light from the projector to the screen shall consist of pulses. These pulses may be achieved by either of two means.

a. The light source itself may be a flash lamp triggered by a pulse circuit.

b. The light source may be continuous and the light interrupted by a shutter. In this case, the lamp housing shall not emit any leaked light and ventilation of this housing shall be sufficient to permit continuous operation for three hours with one hour off-times without seriously reducing normal lamp life.

In both cases, the light pulsing pattern shall be adjustable so that the repetition rate can be controlled from one to two pulses/second, ±10%, and the pulse duration within ±25% of 1 millisecond. The combination of light source and projection optics shall create a spot of light on the screen, essentially circular in form and starlike in its apparent size.

3. Positioning Servos

The projection optical unit shall be driven by a two-degree-of-freedom servo system which shall be oriented by azimuth and elevation angles (moving from ceiling coordinates out to the projection vector). The static accuracy of these servos shall be such that the steady state position error shall not exceed ±2.5°, 3σ, of the analog voltage input provided multiplied by the chosen volts-to-angle design value. The drives for both motions shall be capable of slew rates up to 60 degrees per second and accelerations of 20 degrees per second^2. The frequency of "rough air" inputs to the GAT-1 motion drives is not known. The target servos shall have a bandpass that exceeds the "rough air" excitation frequency.

4. Brightness Control

The projected intensity of the beacon image shall be fully variable from the equivalent of magnitude -1.0 down to the equivalent of magnitude +6.0. This capability may be implemented by a potentiometer control if the lamp is susceptible to this type of control. Alternatively, a variable-density neutral filter may be employed if the lamp is non-variable in setting. In both cases, the setting shall be controllable from a computer-generated command voltage. In neither case is it necessary to have a linear relationship between intensity and control setting. This relationship shall be calibrated and carried in the software as a control command algorithm.

5. Multiple Threat Aircraft

Ultimately, the Experiment should possess the capability for driving two beacon projectors simultaneously. Accordingly, from the first, the support structure coming down from the ceiling shall be stressed and designed for the mounting of two projectors side by side. (There are distinct interference problems associated with dual projectors. They can be mounted side by side and a handoff algorithm implemented when the vector swings from one hemisphere into the other. When both vectors are in the same hemisphere, operations can continue until one vector passes through the other projector at which time the second image is lost. One solution is to double the blink rate as long as the two target vectors nearly coincide. This capability is not to be implemented initially, but provision shall be made for its eventual use.)

VI. GAT-1/PWI SIMULATION EXPERIMENT IN PERSPECTIVE

A. Relationship to Flight Test

It is believed that the Specification contained in Section V. represents a technically sound and functionally appropriate basis upon which to proceed with the Experiment. The specified equipment would meet all the objectives of Section II. except for in-depth studies of visual acquisition and tracking dynamics. Special importance should be given to the relationship between the GAT-1/PWI Experiment and a PWI Flight Test Program.

As mentioned earlier in the Report, only flight tests can prove under operational conditions that the proposed PWI devices are effective in significantly increasing aviation safety. The main output of these tests should be an array of data demonstrating 1) number of false alarms, number of missed hazards, and number of true and successful alarms for a variety of encounter situations and 2) in how many of the above cases was the pilot substantially aided by PWI in visually acquiring the threat aircraft.

Flight evaluation of PWI systems has some unusual problems over and above the usual requirements for test aircraft, flight crews, and ground support. PWI systems are for use in encounter situations which are inherently hazardous. Accordingly, the safety aspects of PWI flight testing should be uppermost in the minds of flight test program planners. Consequently, the entire range of encounter geometrics and system parameter settings should be explored by simulator. This mapping will determine key situations to emphasize in flight test and also suggest safety guidelines which may be invoked without compromising the flight evaluation. For example, the altitude difference in a headon encounter can be varied in an attempt to find a maximum altitude differential which can be used in flight without invalidating the actual encounter in flight.

B. Advanced Simulation

Under this section, there will be discussed several supplementary capabilities for the Simulation Experiment which are not included in the present specification. These capabilities are either mentioned in the work statement or have presented themselves in the course of the present work.

1. RF Navaid Environment

The standard GAT-1 trainer is equipped with a pseudo-environment in which to operate. This environment includes a graphical representation of a sea-level airfield, an upland airfield, (each with ILS systems), and six Omni stations. The navigation and landing aid simulation data are physically embodied in the parameters of two circuit boards (Link Part Nos. 633727 and 633635).

The question arises as to whether or not the Atlanta radio navaid environment should be added to the simulation when the GAT-1 is being used as an intruder. It would appear of some value to have the GAT-1 intruder simulate the behavior of enroute private aircraft by flying to and from these Omni stations as if in uncontrolled VFR flight. Implementation of this specific RF navaid environment can best be accomplished by working with the original manufacturer of the equipment to secure a special circuit board for this area.

Looking however, to a more general flexibility in the future, the theoretical possibility exists of implementing any radio environment desired in the United States. To accomplish this would involve providing the GAT-1 instrument panel with a simulated channel selector accommodating the several hundred VHF frequencies used in aviation. This channel selection discrete would have to be transmitted downlink to the digital teleprocessor. The teleprocessor or the central computation system would have all of the desired station identities and positions in storage. A vector difference between station position and aircraft position would be computed and sent uplink to interface with the present function now found on the GAT-1 card. This capability would increase the scope and role of the GAT-1 simulation. Difficulty is anticipated in generating radio I.D. code signals for the simulator pilot's headset, however,

2. Other Aircraft Dynamics and Characteristics

The question is raised by the Contract as to the possibility of simulating other classes and sizes of aircraft with the GAT-1 equipment. In its standard form, the GAT-1 is a highly effective and efficient representation of a light private aircraft. It is very useful on any programs or experiments in which such an aircraft is a key element. Every effort has been made in this specification to leave the basic GAT-1 characteristics unchanged. Conversion of the GAT-1 to other aircraft models represents a major effort. The GAT-1 analog computer contains the basic non-linear aircraft equations of motion with several ingenious short-cuts and extras. Conversion of these dynamics to a different aircraft would involve a general reworking of all those circuits which represent the airplane. General flexibility between aircraft types is definitely not a possibility.

3. Other Hazard Avoidance Systems

On the other hand, there is no intrinsic limitation in the present Specification against any other class of hazard avoidance systems. The present mechanization sets a 32-bit word as an onboard representation of a hazard avoidance system output to a display. Algorithms representing that system are located in the on-site digital teleprocessing and remote computational equipment. The GAT-1 is limited in its ability to simulate a wide variety of systems only by its inability to support a display subsystem. Such inability would include:

a) Insufficient room in the cockpit, and particularly on the instrument panel.

b) The Display generates too much heat.

c) Power requirements exceed slip-ring capability.

4. High Fidelity Visual Acquisition and Tracking Studies

The Specification set forth what is believed to be the minimum required scene generation capabilities for the GAT-1/PWI Experiment, namely a horizon plane dynamically maintained in a proper orientation in GAT-1 body coordinates and a flashing light projector to represent the threat aircraft warning beacon. As indicated earlier in this report, an overall objective of evaluating pilot visual acquisition dynamics in the encounter situation would require a high fidelity simulation of the following characteristics of the scene:

- Apparent Size (Dynamic)
- Orientation (Dynamic)
- "Front" Surface
  - Illumination
  - Color
- Background
  - Illumination
  - Texture
  - Color
- Beacon Flashing and Blanking (Sometimes present with improper installation on aircraft.)

It would appear that high fidelity simulation of these characteristics would involve major changes in outside scene generation. The aircraft simulator should be at least semi-fixed base (attenuated pitch and bank motion are retained for pilot cues in some commercial versions) or else fixed-base. Scene generation should be based on a closed circuit television system in order to give a degree of flexibility and scope in constructing the scene image.

In constructing such a video scene generating capability, only a symbolic approach to the problem was possible in the present contractual effort. Reference may be made to Figure VI-1. The threat aircraft is represented by a miniature model suspended by two spring-tautened wires at the wing tips. It is equipped with a flashing light powered through the two wires. The two wires are driven by a servomotor so as to give the aircraft bank angle capability. The end pulleys for these wires are in two turntables mounted within the large frame and driven by selsyn motors to change the azimuthal aspect of the threat aircraft to the target aircraft. The outside frame is driven in tilt by servos to represent the positive and negative elevation of the line-of-sight. The target aircraft is viewed by a commercially available, high resolution television camera mounted on a track. Motion along this track is in response to varying line-of-sight distances. This mechanization does not accommodate changes in threat aircraft pitch attitude. The outrigger lamps on the camera side of the frame provide for front surface illumination where required.

The background projection system shown in Figure IV is depicted again in Figure VI-3, and is principally conceived as supplying flexible images of sky, horizon, and earth. This projection system has a single degree of freedom in elevation which provides the proper elevation angle between the horizon and the line-of-sight to the threat aircraft.

The aviation trainer in this complete visual acquisition study is now dependent on a forward hemisphere outside scene.

VII. RECOMMENDATIONS AND CONCLUSIONS

The Pilot Warning Indicator (PWI) development program is a part of NASA/ERC's Aircraft Hazard Avoidance Program. The PWI development has reached the point where concepts need to be evaluated both by simulation and flight test. This study has reviewed the PWI Overall Simulation Experiment objectives and the means available for their accomplishment.

It has been determined (Section II) that a Simulation Experiment can make a timely, effective contribution to the PWI program by advancing the following phases of study and evaluation:

1. Intruder Action in the Atlanta Air Traffic Control Environment.

2. Parametric System Design Activities.

3. Cockpit Display Design.

4. Operational Response Evaluation.

5. Flight Test Support.

A review was conducted (Section III) of the status of three cockpit-type simulators at NASA/ERC. These three were

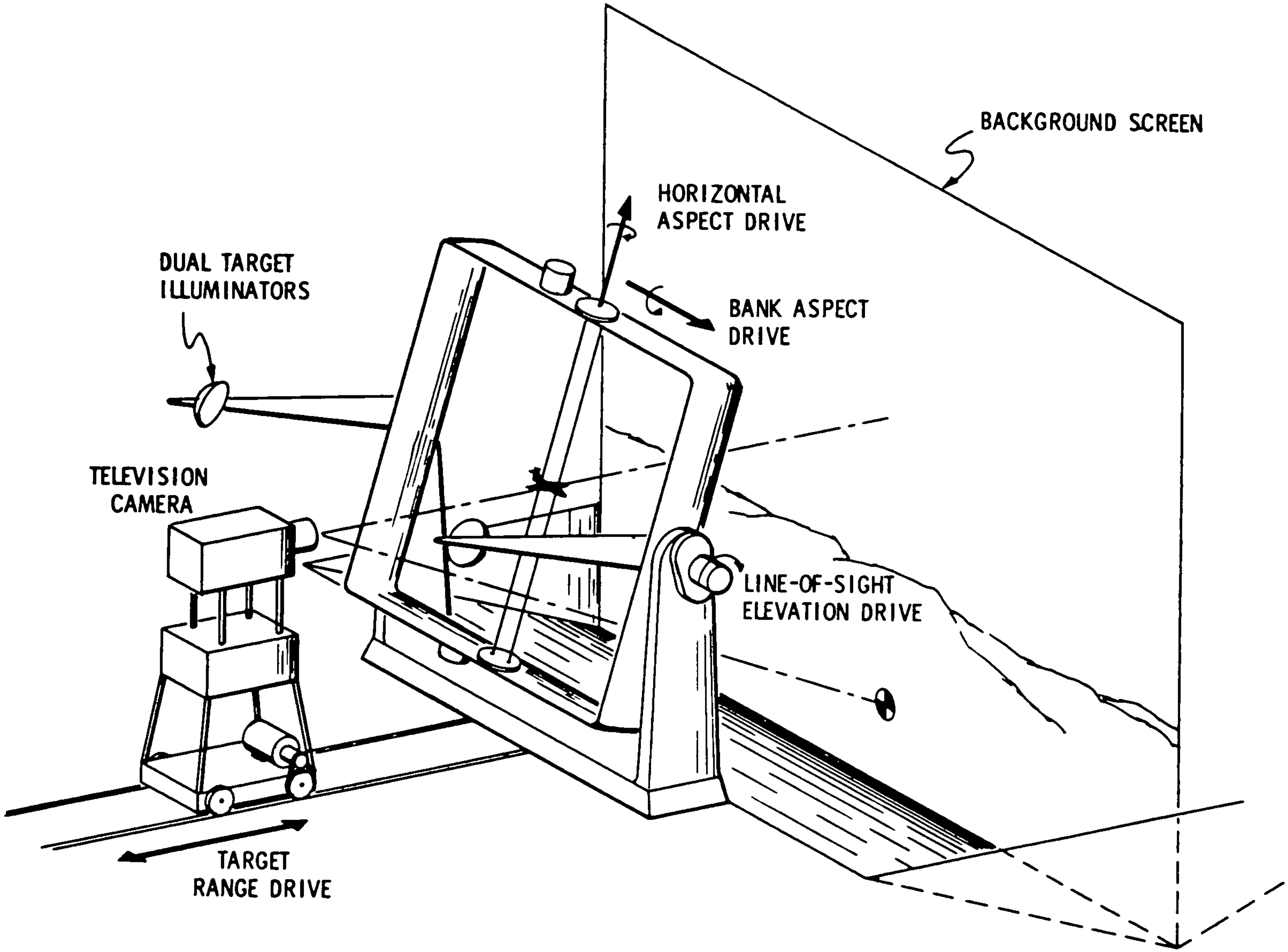


Figure VI-1.
Advanced PWI Simulation Geometry (SYMBOLIC)

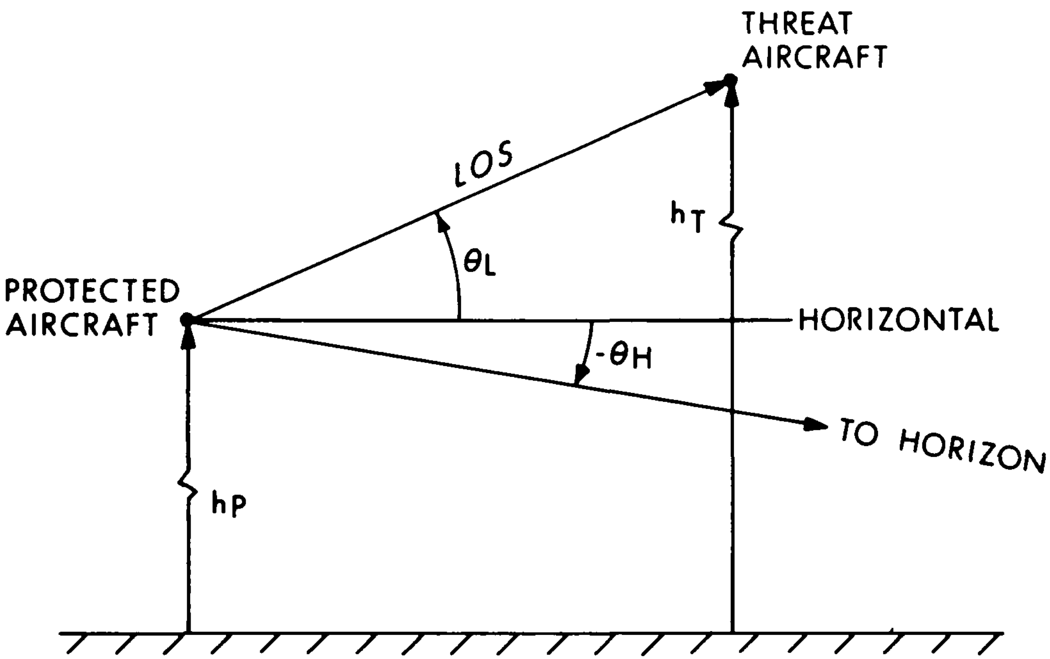


Figure VI-2.
Vertical Encounter Geometry

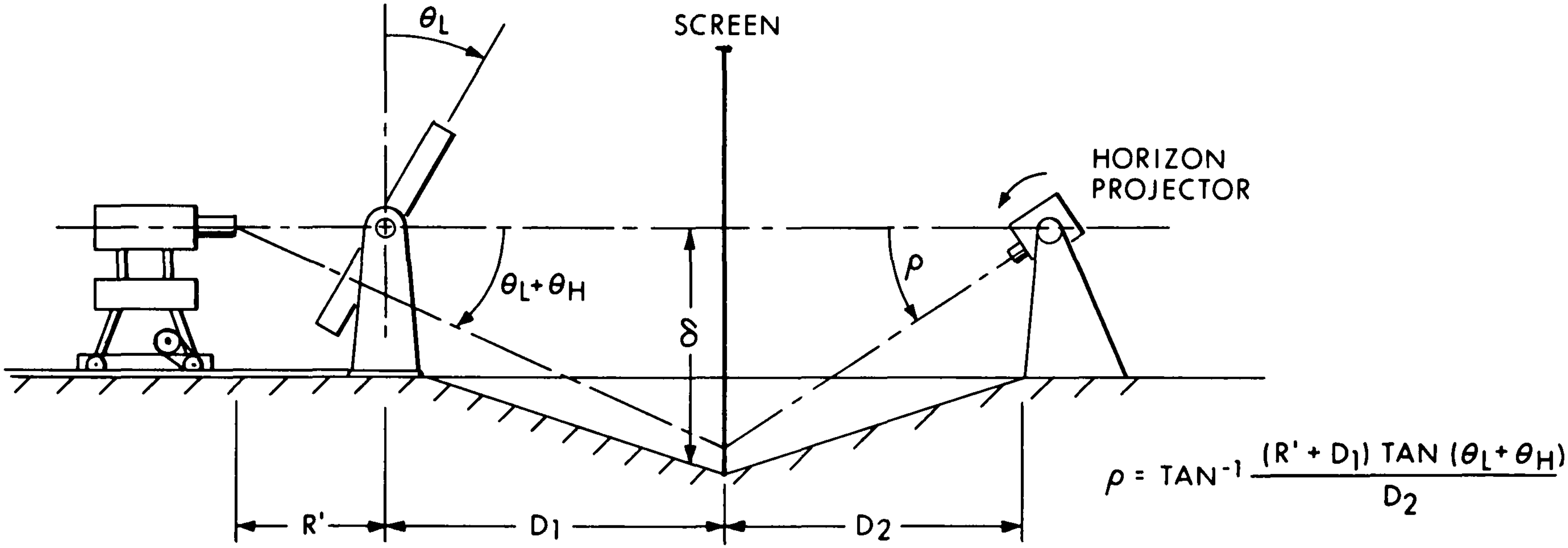


Figure VI-3.

Background Projection Geometry

the XC-142 cockpit, a helicopter cockpit mockup, and the Link General Aviation Trainer (GAT-1). Of these three possible simulators, the first two were ruled out as not being available or appropriate for the Experiment. The study effort then concentrated on the feasibility of modifying the GAT-1 and making it part of a simulation which included centrally-located digital computation.

It was determined that the GAT-1 is a practical element around which to build an initial Experiment. All objectives can be met except for quantitative studies of the role of PWI in threat aircraft visual acquisition and tracking under VFR conditions. The GAT-1/PWI experiment can go a significant distance towards this objective by representing the threat aircraft by a projected flashing light. Only where a high-fidelity simulation of sky and ground background and threat aircraft dynamic orientation are required does the proposed implementation not meet requirements. Conceptual material is provided to indicate the nature of this advanced scene generation problem.

The GAT-1 is a moving base simulator whose pitch motion is attenuated to one-third of the analog solution and whose roll motion is attenuated to one-sixth of the analog solution. Consequently, extra care must be taken with data processing and scene generation to obtain correct answers.

The mechanization concept for the GAT-1/PWI Simulation Experiment (Section IV) retains GAT-1 motion in its normal mode. An horizon scene generator is mounted on top of the GAT-1 cab for providing the simulator pilot with correct horizon cues. GAT-1 state vector analog signals, suitably buffered, are brought out through the existing slip-rings and sent to an on-site digital teleprocessor. This teleprocessor is the interface unit between the on-site simulation equipment and the transmission line to a central digital computer.

The teleprocessor additionally does local coordinate conversion where GAT-1 motion angles must be used to bias the threat aircraft beacon projector. It plays an essential role in formatting and timing the Experiment data to be sent over transmission lines.

The threat aircraft beacon projector is mounted from the facility ceiling and is driven in azimuth and elevation by simulation derived signals. Provision is made for varying the intensity of the beacon image as a function of range.

The projection screen associated with the Experiment is a segment of a sphere truncated at the top and bottom by physical height restrictions to be found at the facility. An economical roll-up screen design is suggested as a possible solution.

Throughout the course of this contract emphasis has been placed on great flexibility and adaptability in the Experiment design. The proposed mechanization concept does not impair normal operation of the GAT-1. Furthermore, if necessary, removal of all PWI Experiment elements can be accomplished in a few hours of labor. The digital link between the GAT-1 and a remote computation center has been kept general, so that the GAT-1 can be used for a variety of programs and interfaced with a multiplicity of computers.

A specification (Section V) is provided for the GAT-1/PWI Simulation Experiment. This serves as a basis for the implementation phase. The teleprocessor specification is specifically built around the Digital Equipment Corporation (DEC) PDP-8/L. The specification for the horizon projector and the threat aircraft beacon projector, on the other hand, sets forth the required performance and configuration, but leaves the implementation open to the most economical and timely route.

A final comment should be made with regard to implementation schedules. Reference may be made to Figure VII-1. GAT-1/PWI Program Summary Schedule, and Figure VII-2. GAT-1/PWI Experiment Implementation Schedule. It is believed that the flight test phase of NASA/ERC's PWI systems is not too far away. The key role of the Simulation Experiment has been emphasized in this study. The procurement and fabrication steps for all but the scene generation equipment are very straightforward. Important support can be given by the Experiment to the program prior to having scene generation capability. Accordingly, the program plan recommended in the two referenced figures divides implementation effort between the basic system and the scene projection equipment. It is believed that the resultant phasing of the GAT-1 operations (shown in Figure VII-2) are sound and effective.

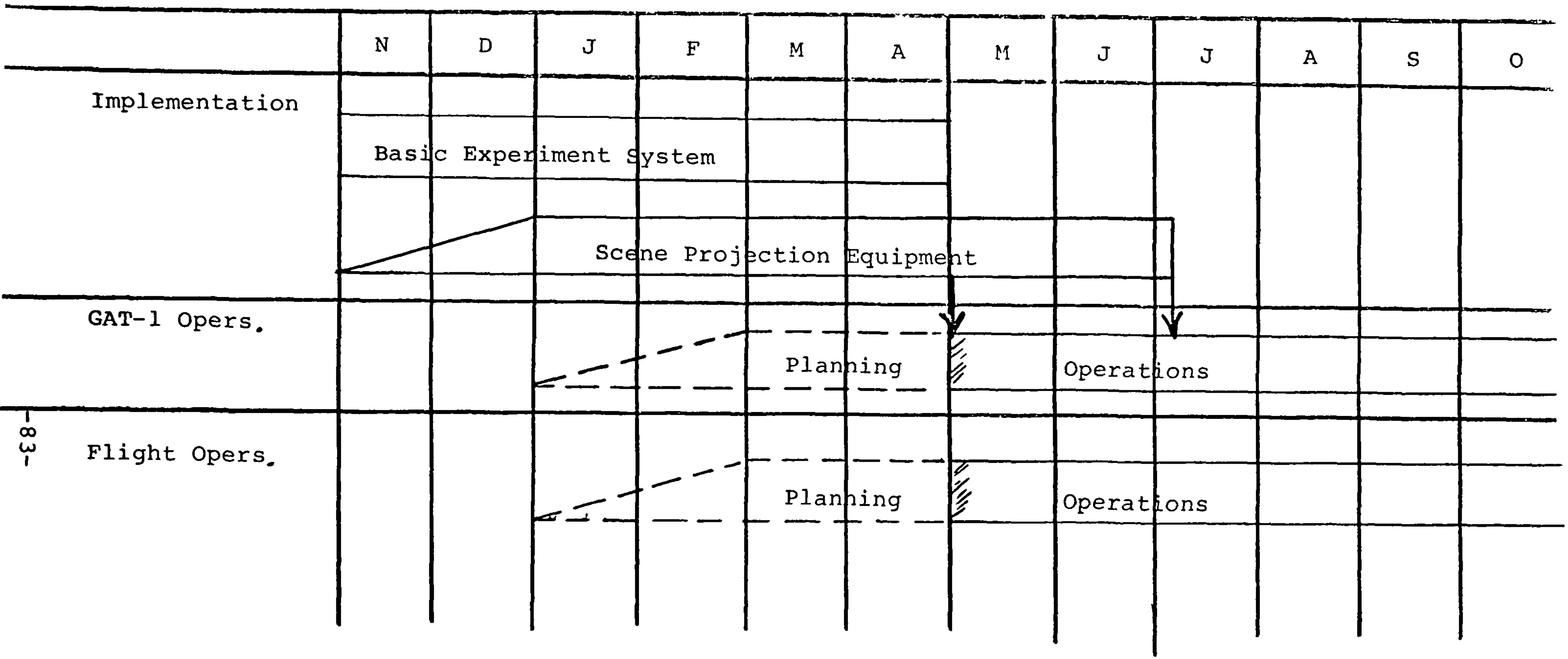


Figure VII-1
GAT-1/PWI Program Summary Schedule

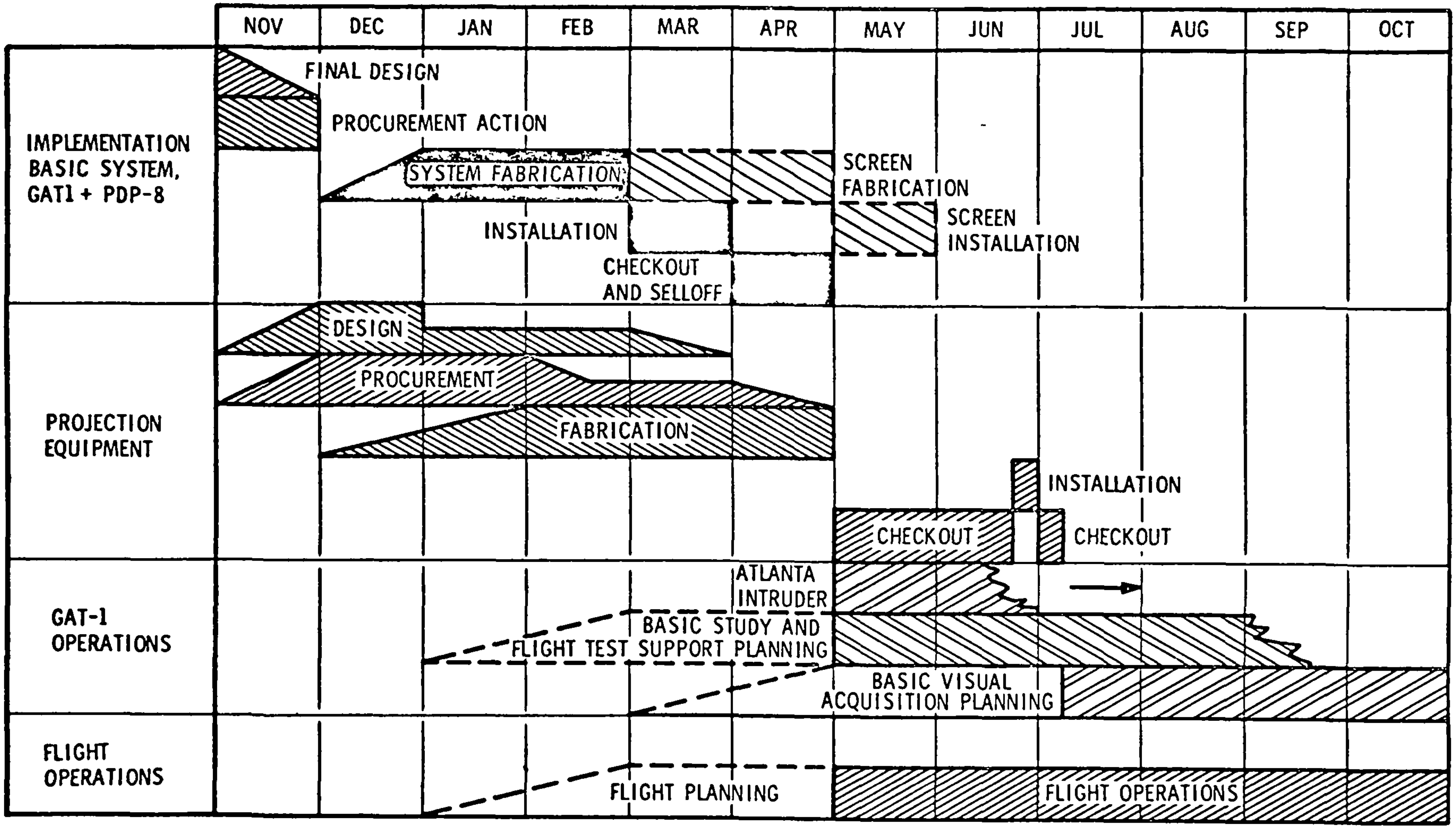


Figure VII-2.

GAT-1/PWI Experiment Implementation Schedule

Appendix A.

New Technology

National Aeronautics and Space
Administration
Electronics Research Center
575 Technology Square
Cambridge, Mass. 02139

Attention: Mr. Frederic A. Hills, Director
Technology Utilization

Reference: Contract NAS 12-2192

Dear Mr. Hills:

It is the purpose of this letter to accomplish a new technology transmittal under the referenced contract. NASA Form 666 is used to provide material on three device concepts generated in the course of this contract. These device concepts are:

1. Simulation Facility Screens
2. Horizon Projector (Ceiling Mounted)
3. Horizon Projector (Moving Base Simulator Mounted)

This contract is nearing completion with the submittal of a Draft Final Report as of this date. No further reportable items exist with regard to this contract than the three items listed above.

Intermetrics recognizes its obligations under the New Technology Clauses of this and other NASA Contracts which it has undertaken. Early in this contract, New Technology Review was informally carried out by Edward M. Copps and James H. Flanders, Senior Scientists assigned to this contract. Starting on Monday, November 17th, Intermetrics began monthly New Technology Reviews on a Company-wide basis. Once a month, at the Monday Staff Meeting falling closest to the middle of the month, all NASA Contracts will be reviewed for any reportable items under the New Technology clauses. Both Project Leaders and Staff will participate.

Intermetrics believes that this letter completes its reporting requirements under the New Technology section (May 1966) of Contract NAS 12-2192.

James H. Flanders
GAT-1 Project Leader

JHF:vw

cc: E. M. Copps
J. E.Miller
W. Cashman, PHS
R. Valente, AACK

Enclosures: New Technology Reports (3)

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NEW TECHNOLOGY TRANSMITTAL

(See Instructions on Reverse)

NT CONTROL NUMBER *(CC 4-11)*

1. TITLE

Simulation Facility Screens

2. INNOVATOR(S) *(Name and Social Security No.)*

Edward M. Copps [redacted]

3. EMPLOYER *(Organization and division)*

Intermetrics, Inc.

4. ADDRESS *(Place of performance)*

380 Green Street
Cambridge, Mass. 02139

5. DOCUMENTATION *(Full and complete disclosure must be enclosed, the contents of which are discussed in NHB 2170.3, Documentation Guidelines for New Technology Reporting. Place an "X" to the left of those items of documentation which are available but NOT enclosed with this transmittal)*

	ENGINEERING SPECIFICATIONS		OPERATING MANUALS		COMPUTER TAPES/CARDS
	ASSEMBLY/MFG DRAWINGS		TEST DATA		
	PARTS OR INGREDIENTS LIST		ASSEMBLY/MFG PROCEDURES		

6. PREVIOUS PUBLICATION OR PUBLIC DISCLOSURE

PUBLICATION

TYPE: ☐ JOURNAL ☐ REPORT ☐ CONFERENCE OR SEMINAR

BY: ☐ NASA ☐ OTHER GOVT ☐ CONTRACTOR ☐

VOLUME NO	PAGE	DATE	STATUTORY BAR ESTABLISHED *(Date)*
NA	36-38	Oct. 10, 1969	October 10, 1969

TITLE: Monthly Technical Report No. 2-3, Contract NAS 12-2192

PATENT

STATUS: ☐ APPLICATION FILED ☐ ISSUED — NO — DATE

7. STATE OF DEVELOPMENT

☒ CONCEPT ONLY ☐ DESIGN ☐ PROTOTYPE ☐ MODIFICATION ☐ PRODUCTION MODEL ☐ USED IN CURRENT WORK

8. ORIGIN *(CC 12)*

9. NASA PRIME CONTRACT NO. *(CC 13-23)*: N A S 1 2 - 2 1 9 2

10. SUBCONTRACT TIER *(CC 24)*

11. CONTRACTOR REPORTABLE ITEM NO. *(CC 25-33)*

12. CONTRACTOR/GRANTEE NEW TECHNOLOGY *Not* SUBMITTED PURSUANT TO NT/PRI CLAUSE PROVISION *(CC 34)* ☐

13. SUBCONTRACTOR CIC *(CC 35-41)*

14. NT RECEIPT DATE *(CC 42-47)* MO DAY YR

15. PROJ NO. *(CC 48-51)*

16. EVALUATION ORGANIZATION *(CC 52-54)*

17. NT FORWARDED FOR EVALUATION *(Date)* *(CC 55-60)* MO DAY YR

18. COMMENTS

19. PREPARED BY	NAME AND TITLE	SIGNATURE	DATE
	James H. Flanders Senior Scientist	James H. Flanders	26 Nov. 1969
20. APPROVED (Center TUO)	NAME	SIGNATURE	DATE

NASA FORM 500 SEP 68 PREVIOUS EDITIONS ARE OBSOLETE

Simulation Facility Screens

The purpose of this device is to provide an economical screen for a real-time flight simulation where the moving base simulator has 360° of yaw freedom. The screen segments are planar, but when equipped with fillets approximate a complete spherical screen, truncated at the top and bottom. The screen segments are on rollers and can be wheeled into place and bolted together for use. When not in use they can be placed in storage. The design is intended to permit nested storage.

(Also see Section IV-F, Final Technical Report.)

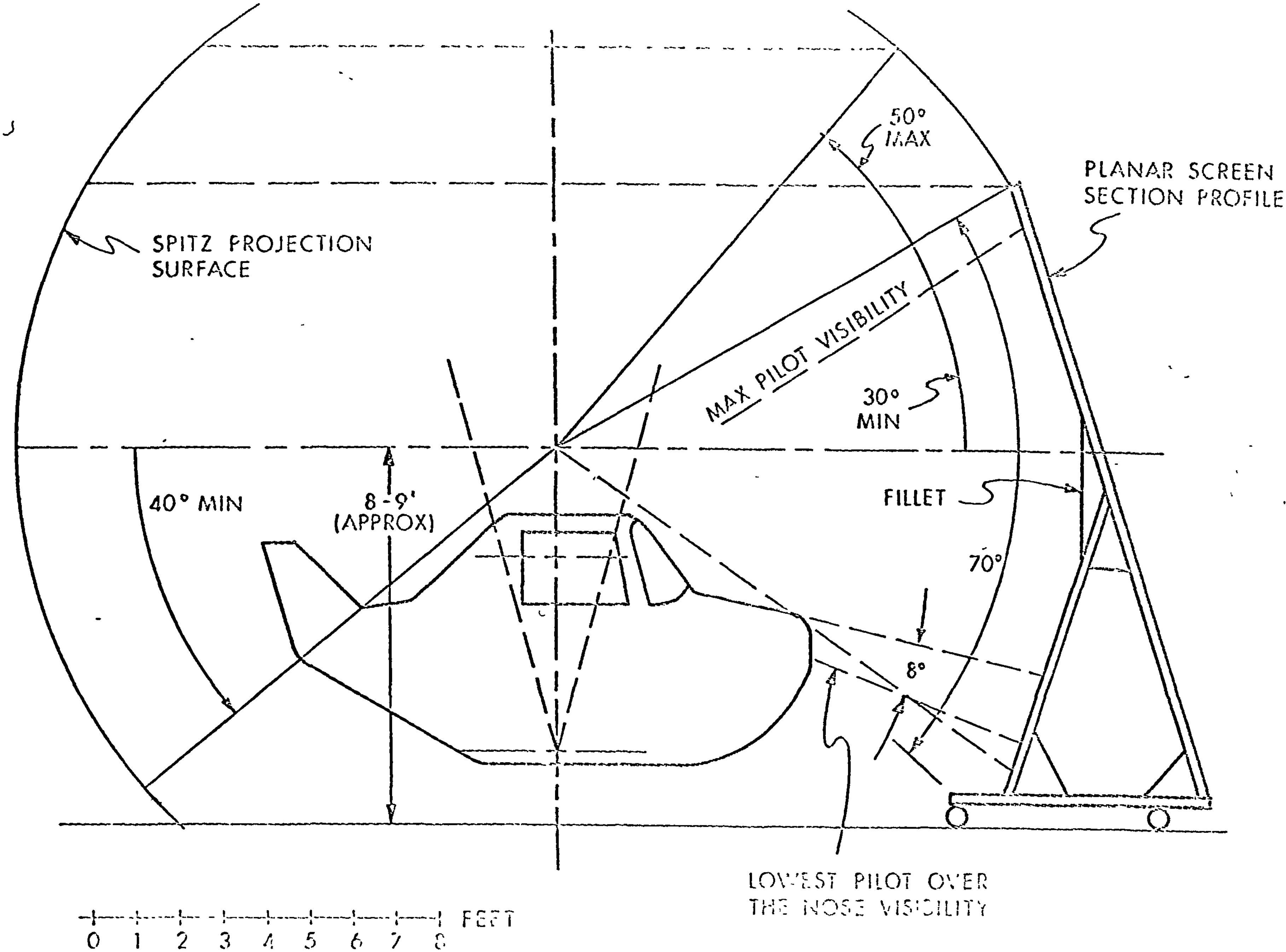


Figure 1.
Alternate Roll-up for [illegible] Configuration Sketch

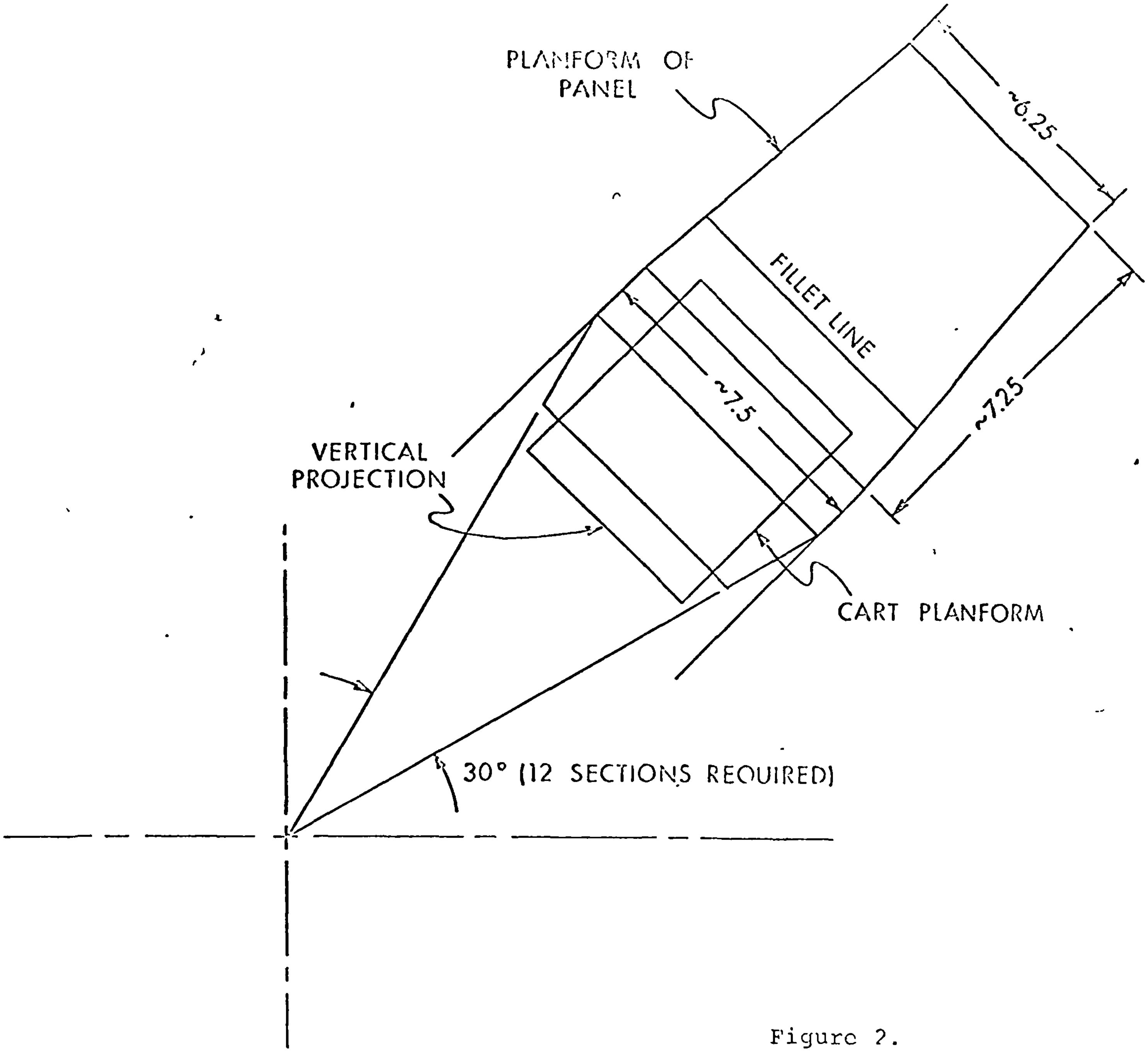


Figure 2.

Roll-up Screen Design - Plan [illegible] Projection ([illegible])

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NEW TECHNOLOGY TRANSMITTAL

(See Instructions on Reverse)

NT CONTROL NUMBER *(CC 4-11)*: [4 | 5 | 6] – [7 | 8 | 9 | 10 | 11]

1 TITLE

HORIZON PROJECTOR (Ceiling Mounted)

2 INNOVATOR(S) *(Name and Social Security No.)*

Edward M. Copps [redacted]

3 EMPLOYER *(Organization and division)*	4. ADDRESS *(Place of performance)*
Intermetrics, Inc.	380 Green Street Cambridge, Mass. 02139

5 DOCUMENTATION *(Full and complete disclosure must be enclosed, the contents of which are discussed in NHB 2170 3, Documentation Guidelines for New Technology Reporting. Place an "X" to the left of those items of documentation which are available but NOT enclosed with this transmittal)*

	ENGINEERING SPECIFICATIONS		OPERATING MANUALS		COMPUTER TAPES/CARDS
	ASSEMBLY/MFG DRAWINGS		TEST DATA		
	PARTS OR INGREDIENTS LIST		ASSEMBLY/MFG PROCEDURES		

6. PREVIOUS PUBLICATION OR PUBLIC DISCLOSURE

PUBLICATION

TYPE: ☐ JOURNAL ☒ REPORT ☐ CONFERENCE OR SEMINAR

BY: ☐ NASA ☐ OTHER GOVT ☒ CONTRACTOR ☐

VOLUME NO.	PAGE	DATE	STATUTORY BAR ESTABLISHED *(Date)*
NA	32-34	Oct. 10,'69	Oct. 10, 1969

TITLE: Monthly Technical Report No 2-3, Contract NAS 12-2192

PATENT

STATUS	NO.	DATE
☐ APPLICATION FILED ☐ ISSUED		

7. STATE OF DEVELOPMENT

☒ CONCEPT ONLY ☐ DESIGN ☐ PROTOTYPE ☐ MODIFICATION ☐ PRODUCTION MODEL ☐ USED IN CURRENT WORK

8 ORIGIN *(CC 12)*: P (12)

9. NASA PRIME CONTRACT NO. *(CC 13-23)*: N A S 1 2 – _ _ 2 1 9 2 (13 14 15 16 17 18 19 20 21 22 23)

10 SUBCONTRACT TIER *(CC 24)*: ☐ (24)

11 CONTRACTOR REPORTABLE ITEM NO *(CC 25-33)*: ☐☐☐☐☐☐☐☐☐ (25 26 27 28 29 30 31 32 33)

12 CONTRACTOR/GRANTEE NEW TECHNOLOGY *Not* SUBMITTED PURSUANT TO NT/PRI CLAUSE PROVISION *(CC 34)* ☐

13 SUBCONTRACTOR CIC *(CC 35-41)*: ☐☐☐☐☐☐☐ (35 36 37 38 39 40 41)

14. NT RECEIPT DATE *(CC 42-47)*: MO / DAY / YR (42 43 44 45 46 47)

15 PROJ NO *(CC 48-51)*: ☐☐☐☐ (48 49 50 51)

16. EVALUATION ORGANIZATION *(CC 52-54)*: ☐☐☐ (52 53 54)

17. NT FORWARDED FOR EVALUATION *(Date)* *(CC 55-60)*: MO / DAY / YR (55 56 57 58 59 60)

18 COMMENTS

	NAME AND TITLE	SIGNATURE	DATE
19 PREPARED BY	James H. Flanders Senior Scientist	James H Flanders	26 Nov. 1969
20 APPROVED (Center TUO)	NAME	SIGNATURE	DATE

NASA FORM 655 SEP 68 PREVIOUS EDITIONS ARE OBSOLETE

Horizon Projector (Ceiling Mounted)

This device is intended to provide an horizon image on a spherical screen during a real-time flight simulation. The device requires three angular position servos which respond to command values (θ_1, θ_2, and θ_3) generated by a simulation computer. The apparent altitude presented to the simulator pilot is varied by a position servo which moves a light sleeve up and down with respect to a horizon line generator. Finally, the device can provide supplementary slipring capacity in configurations where there is a moving base simulator with 360° of freedom in yaw.

(Also see Section IVB, Final Technical Report)

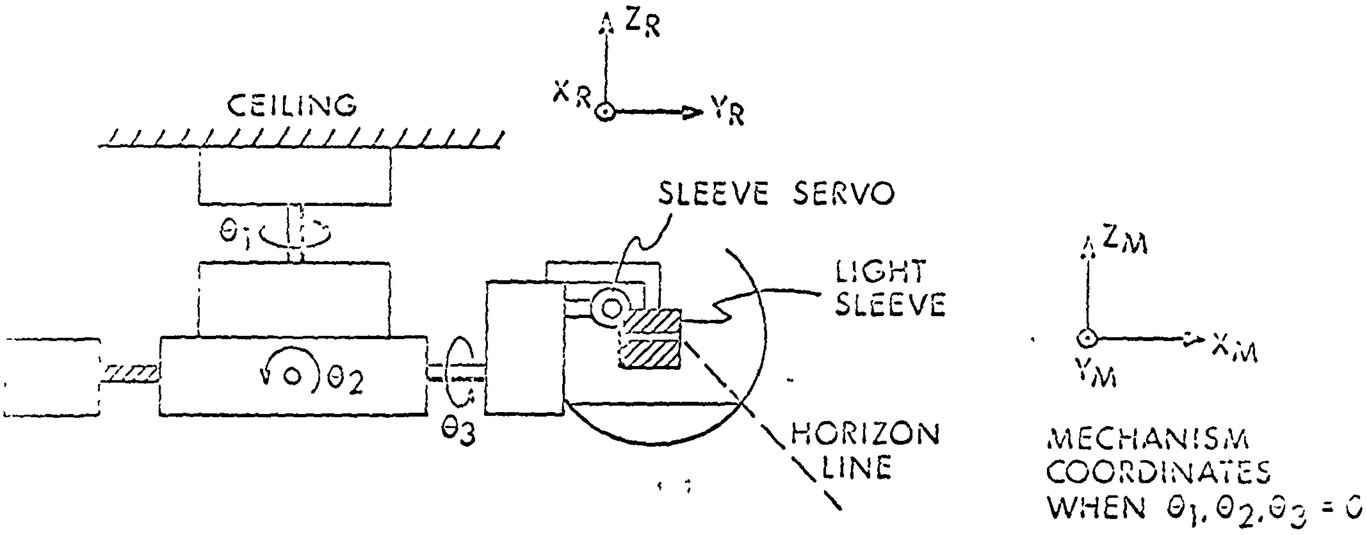


Figure 1.

Ceiling Mounted Horizon Generator

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NEW TECHNOLOGY TRANSMITTAL

(See Instructions on Reverse)

NT CONTROL NUMBER (CC 4-11)

4	5	6	–	7	8	9	10	11
			–					

1. TITLE

Horizon Projector (Moving Base Simulator Mounted)

2. INNOVATOR(S) (Name and Social Security No.)

James H. Flanders [redacted]

3. EMPLOYER (Organization and division)

Intermetrics, Inc.

4. ADDRESS (Place of performance)

380 Green Street
Cambridge, Mass. 02139

5. DOCUMENTATION (Full and complete disclosure must be enclosed, the contents of which are discussed in NHB 2170 3, Documentation Guidelines for New Technology Reporting. Place an "X" to the left of those items of documentation which are available but NOT enclosed with this transmittal)

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	ASSEMBLY/MFG DRAWINGS		TEST DATA		
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6. PREVIOUS PUBLICATION OR PUBLIC DISCLOSURE

PUBLICATION

TYPE: ☐ JOURNAL ☐ REPORT ☐ CONFERENCE OR SEMINAR

BY: ☐ NASA ☐ OTHER GOVT ☐ CONTRACTOR ☐

VOLUME NO	PAGE	DATE	STATUTORY BAR ESTABLISHED (Date)

TITLE

PATENT

STATUS	NO.	DATE
☐ APPLICATION FILED ☐ ISSUED		

7. STATE OF DEVELOPMENT

☒ CONCEPT ONLY ☐ DESIGN ☐ PROTOTYPE ☐ MODIFICATION ☐ PRODUCTION MODEL ☐ USED IN CURRENT WORK

8. ORIGIN (CC 12): P (12)

9. NASA PRIME CONTRACT NO. (CC 13-23)

13	14	15	16	17	–	18	19	20	21	22	23
N	A	S	1	2	–			2	1	9	2

10. SUBCONTRACT TIER (CC 24): (24)

11. CONTRACTOR REPORTABLE ITEM NO. (CC 25-33)

25	26	27	28	29	30	31	32	33

12. CONTRACTOR/GRANTEE NEW TECHNOLOGY Not SUBMITTED PURSUANT TO NT/PRI CLAUSE PROVISION (CC 34) ☐

13. SUBCONTRACTOR CIC (CC 35-41)

35	36	37	38	39	40	41

14. NT RECEIPT DATE (CC 42-47)

MO		DAY		YR	
42	43	44	45	46	47

15. PROJ NO. (CC 48-51)

48	49	50	51

16. EVALUATION ORGANIZATION (CC 52-54)

52	53	54

17. NT FORWARDED FOR EVALUATION (Date) (CC 55-60)

MO		DAY		YR	
55	56	57	58	59	60

18. COMMENTS

	NAME AND TITLE	SIGNATURE	DATE
19 PREPARED BY	James H. Flanders Senior Scientist	James H. Flanders	26 Nov. 1969
20 APPROVED (Center TUO)	NAME	SIGNATURE	DATE

NASA FORM 666 SEP 68 PREVIOUS EDITIONS ARE OBSOLETE.

Horizon Projector (Moving Base Simulator Mounted)

This device is intended to provide a horizon image on a spherical screen during a real-time flight simulation. It is to be used with a moving base simulator whose motion drive has the following ordered rotations:

Yaw	±360°
Pitch	+16°, -8°
Roll	±12.5°

Also, required are synchro transmitters as part of the normal simulator equipment which generate roll, pitch, and yaw signals as outputs from the simulator computation.

The device is mounted on top of the moving base simulator with sufficient clearance so that its indicated motion can be accommodated. The apparent flight altitude can be adjusted manually by rotating the horizon shadow plate about its threaded shaft.

Also, see Section IV-B, Final Technical Report.

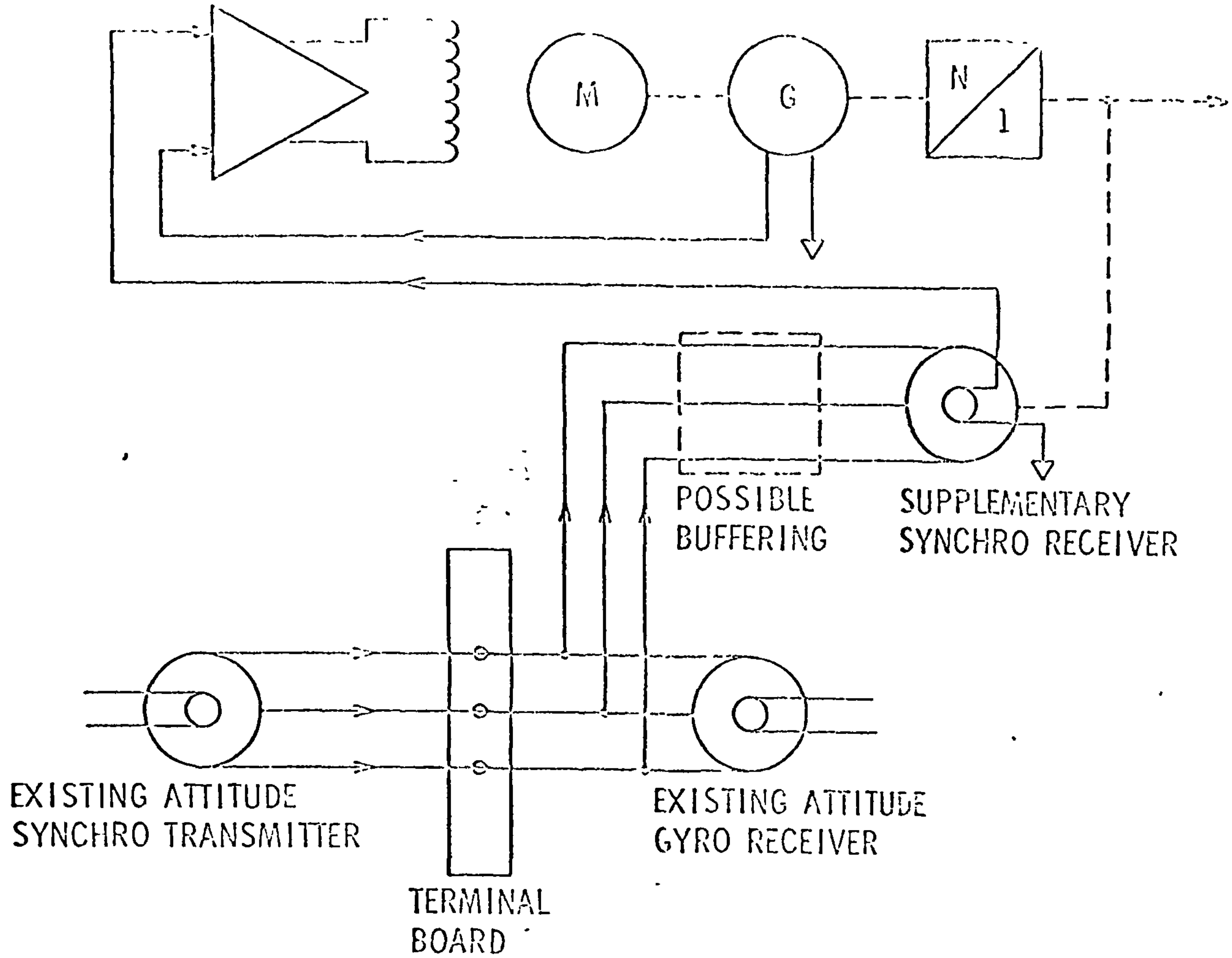


Figure 1.
Pick-off Circuit for Driving Horizon Projector

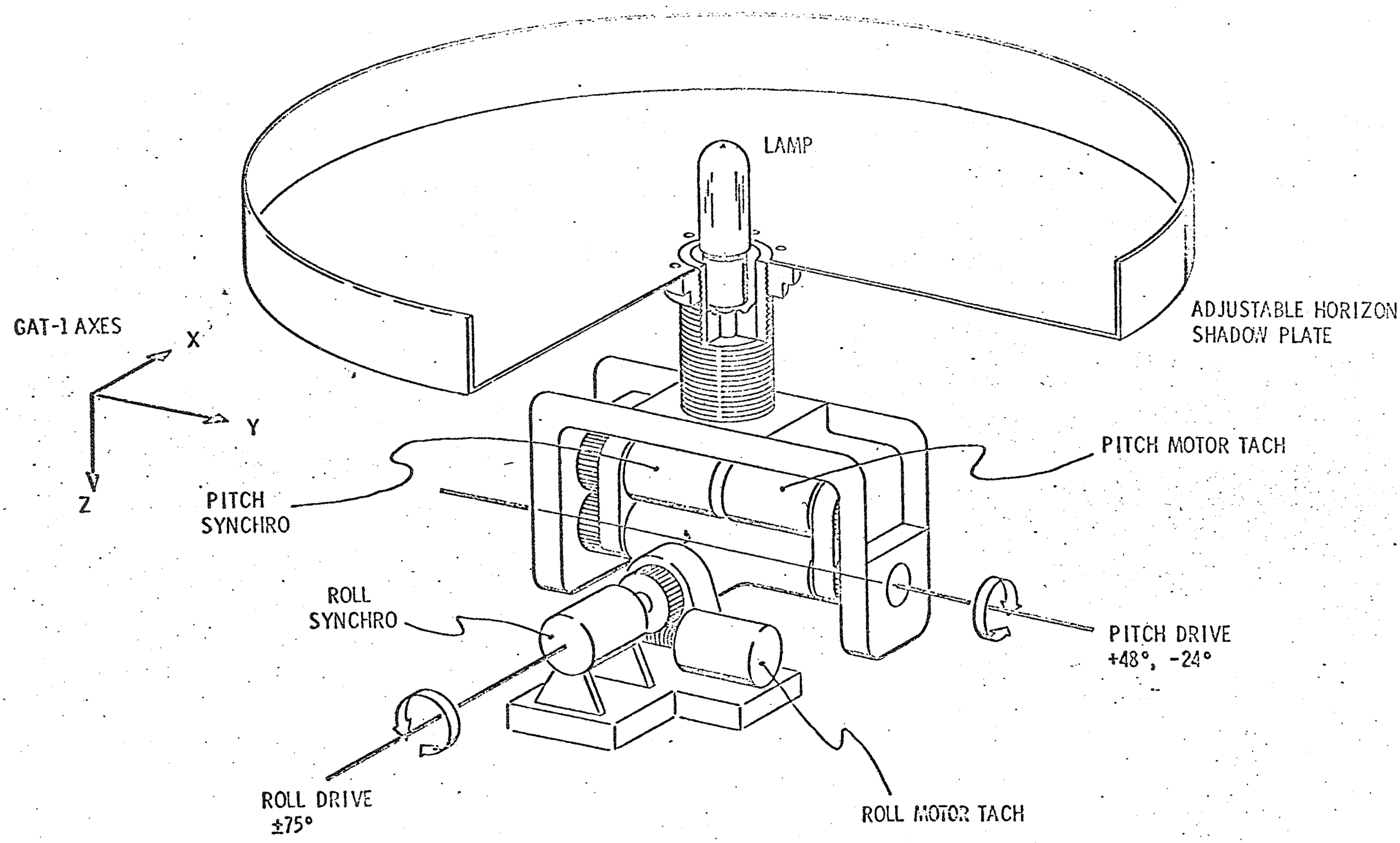


Figure 2.

Body-Mounted Horizon Projector

(Symbolic)

Appendix B

Conversion from Earth-Fixed Reference Frame to Aircraft-Fixed Reference Frame

1. Earth Reference Coordinate system

   X_E - east

   Y_E - north

   Z_E - up

   consistent with previous ERC PWI simulations (6)

2. Aircraft Body Coordinates, defined by three Euler angles ψ, θ, ϕ. Defining aircraft axes as:

   X_A - aircraft longitudinal axis

   Z_A - perpendicular to X_A in aircraft plane of symmetry

   Y_A - to form a right hand triad

   then $\psi = \theta = \phi = 0$, is defined as

   X_A along Y (north)

   Y_A along X (east)

   Z_A along -Z (down)

   and the following ordered rotations define ψ, θ, and ϕ.

   a. Rotate the aircraft about Z_A through ψ.

   b. Rotate the aircraft about Y_A through θ.

   c. Rotate the aircraft about X_A through ϕ.

   These angles are called heading, elevation and bank.

3. Matrix Transformations

   The transformation of any vector $\underline{S}$ in reference coordinates to aircraft coordinates is accomplished by

$$\underline{S}^A = M_A^R \underline{S}^R$$

where

$$M_A^R = \begin{bmatrix} c\theta s\psi & c\theta c\psi & s\theta \\ s\psi s\phi s\theta + c\phi c\psi & s\phi s\theta c\psi - c\phi c\psi & -s\phi c\theta \\ c\phi s\theta s\psi - s\phi c\psi & c\phi s\theta c\psi + s\phi s\psi & -c\phi c\theta \end{bmatrix}$$

Where $c\theta = \cos(\theta)$, $s\theta = \sin(\theta)$, etc.

This matrix is orthogonal and its transpose is the vector M_R^A, the inverse transformation.

Relationship between body rates and Euler angle rates.

The following differential equations relate $\dot{\psi}$, $\dot{\theta}$ and $\dot{\phi}$ to components of angular velocity p, q, r, expressed in body coordinates:

$$p = \dot{\phi} - s\theta\,\dot{\psi}$$

$$q = c\phi\dot{\theta} + s\phi\, c\theta\,\dot{\psi}$$

$$r = -s\phi\,\dot{\theta} + c\phi\, c\theta\,\dot{\psi}$$

and the inverse equations are

$$\dot{\phi} = p + \tan\theta\,(\sin\phi\, q + \cos\phi\, r)$$

$$\dot{\theta} = \cos\phi\, q - \sin\phi\, r$$

$$\dot{\psi} = \frac{1}{\cos\theta}\,(\sin\phi\, q + \cos\phi\, r)$$

Appendix C.

Conversion from Earth-Fixed Reference Frame to Flocr/Ceiling Reference Frame.

Because GAT-1 motions are scaled to one-third of pitch analog solutions and to one-sixth of roll analog solutions, the floor-ceiling of the simulation facility does not represent the earth-fixed frame of reference. A transformation matrix must be used to create the proper projection vector in floor coordinates. The need for this correction can be more easily understood by reference to Figure C-1 which shows the two-dimensional situation in a pitch-only (a) and a roll-only (b) maneuver. Since the GAT-1 moves only a fixed ratio of the actual attitude change, the floor must "move" up from the horizon to make up the difference. To the observer, standing on the floor, the horizon seems to dip "below" the floor.

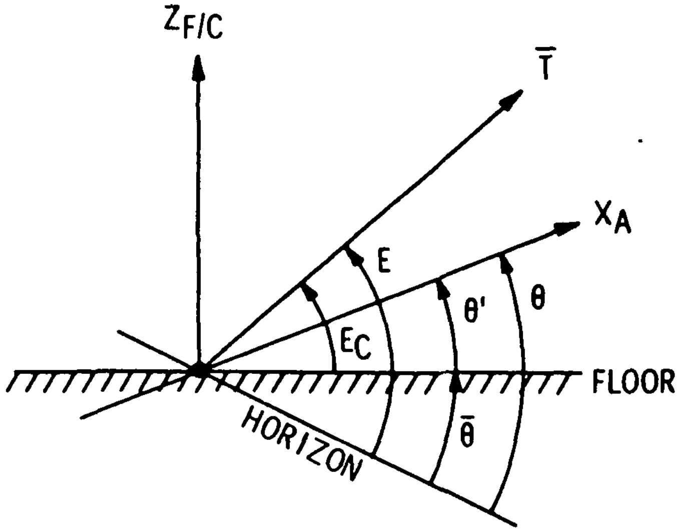
A straightforward way to explain the transformation from earth-fixed to floor/ceiling coordinates is to express it as the vector product of the transformation from earth-fixed to GAT-1 times GAT-1 to floor-ceiling reference frames. The former transformation is already derived in Appendix B. The latter transformation is the same matrix transposed with θ' substituted for θ and ϕ' substituted for ϕ.

The final answer is given by:

$$1_{T_{F/C}} = \left[M^{A}_{F/X} \times M^{R}_{A} \right] 1_{T_R}, \text{ where}$$

M^R_A is derived in Appendix B, and $M^A_{F/C}$ is given below:

$$\begin{bmatrix} c\theta' s\psi & s\psi s\phi' s\theta' + c\phi' c\psi & c\phi' s\theta' s\psi - c\phi' c\psi \\ c\theta' c\psi & s\phi' s\theta' c\psi - c\phi' s\psi & c\phi' s\theta' c\psi + s\phi' s\psi \\ s\theta' & -s\phi' c\theta' & -c\phi' c\theta' \end{bmatrix}$$

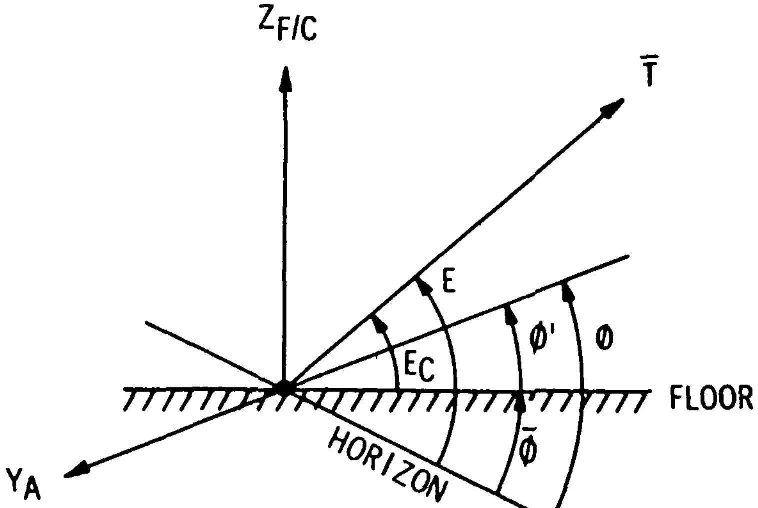


HORIZON TO FLOOR ANGLE = $\bar{\theta}$ $\quad$ $\bar{\theta} = \theta - \theta' = 2/3\theta$

PROJECTOR ELEVATION = E_C $\quad$ $E_C = E - \bar{\theta}$

TARGET ELEVATION = E

a) GAT-1 MOVES IN PITCH ONLY (θ)



$\bar{\phi} = \phi - \phi'$ $\qquad$ $E_C = E - \bar{\phi}$

b) GAT-1 MOVES IN ROLL ONLY (ϕ)

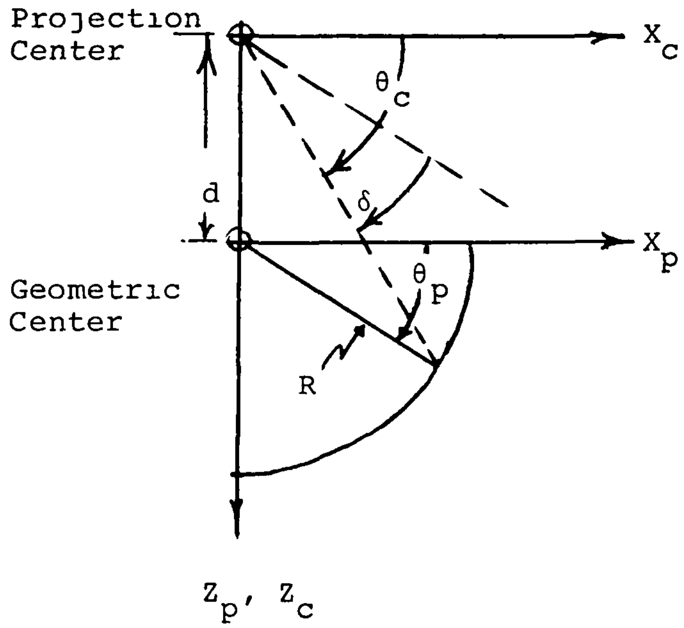
Figure C-1

Simplified Relationship between GAT-1, Floor/Ceiling, and Horizon Motions

Appendix D.

Correction of Projection Coordinates for Nominal Parallax

Nominal parallax is assumed to be that in the vertical plane only:



$$\theta_c = \theta_p + \delta$$

$$= \theta_p + \tan^{-1}\left[\frac{d \cos \theta_p}{R - d \sin\theta_p}\right], \text{ from Section IV-F.}$$

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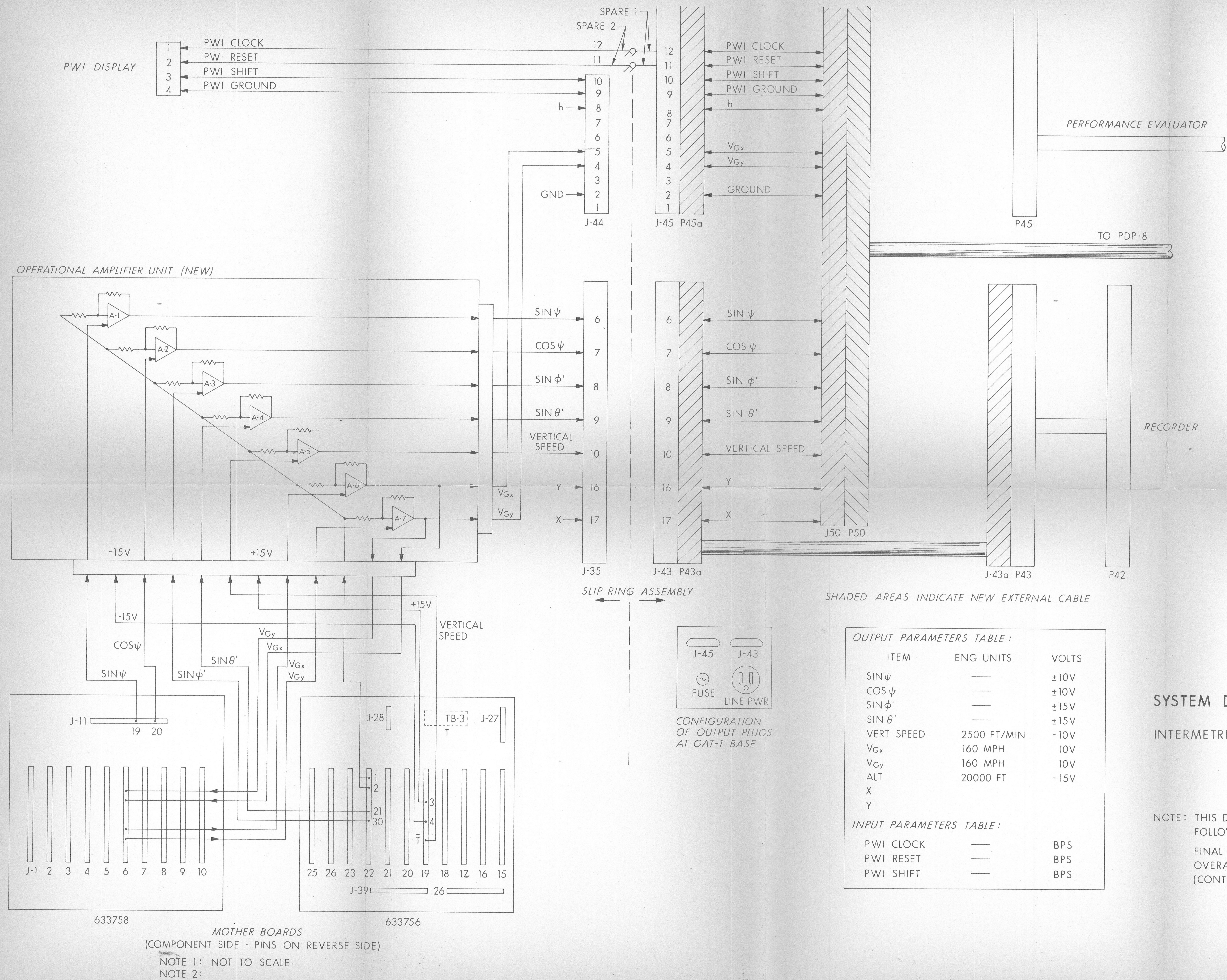
5. NASA RFP SA8-0001, 1969

6. Ruetenik and Thompson, Phase I Report Computer Simulation Model of Terminal Air Traffic and PWI Systems; Section II, NAS 12-698, Kaman Avidyne TR-57, Burlington, Mass., March 28, 1969.

7. Internal NASA/ERC Memorandum; PHS/B. Wong to PH/W. Rhine; July 23, 1969 Meeting between Aircraft Hazard Avoidance Programs and Intermetrics, Inc.

8. Monthly Technical Report #1, Link GAT-1/PWI Overall Simulation Experiment Design, Contract NAS 12-2192, E. M. Copps, August 11, 1969.



OUTPUT PARAMETERS TABLE:

ITEM	ENG UNITS	VOLTS
SIN ψ	—	±10V
COS ψ	—	±10V
SIN φ'	—	±15V
SIN θ'	—	±15V
VERT SPEED	2500 FT/MIN	-10V
V_{Gx}	160 MPH	10V
V_{Gy}	160 MPH	10V
ALT	20000 FT	-15V
X		
Y		

INPUT PARAMETERS TABLE:

PWI CLOCK	—	BPS
PWI RESET	—	BPS
PWI SHIFT	—	BPS

SYSTEM DIAGRAM FOR GAT-1 MODIFICATION

INTERMETRICS, INC., CAMBRIDGE, MASS. 02139

NOTE: THIS DIAGRAM FORMS AN INTEGRAL PART OF THE FOLLOWING DOCUMENT:

FINAL TECHNICAL REPORT ON THE LINK GAT-1/PWI OVERALL SIMULATION EXPERIMENT DESIGN, (CONTRACT NAS-12-2192) NOV. 27, 1969