

MIT
REPORT

NO. LED-570-10

DATE: 23 October 19

DETAILED PRESIMULATION REPORT

FOR SIMULATION IIIB:

HOVER AND LANDING; SEPARATION AND DOCKING

CODE 26512



To: J. Dahlen

GRUMMAN AIRCRAFT ENGINEERING CORPORATION
BETHPAGE, LONG ISLAND, NEW YORK

CABLE ADDRESS
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Subject: Contract NAS 9-1100 - Line Item 024 - Lunar
Excursion Module - Detailed Presimulation
Report for Simulation IIIB: Hover and Landing;
Separation and Docking

Reference: (a) Contract NAS 9-1100, Exhibit E, Para-
graph 5.1 as supplemented by MSC Letter
SPI-63-548, dated 3 January 1964

Enclosure: (1) Grumman Report LED-570-10 - Detailed
Presimulation Report for Simulation IIIB:
Hover and Landing; Separation and Docking
(Forty-eight (48) copies)

Gentlemen:

Enclosure (1) is forwarded herewith as Type II data in accordance
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Very truly yours,

GRUMMAN AIRCRAFT ENGINEERING CORPORATION

C. W. Rathke
Engineering Manager

RK/JR:ss

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REVISIONS			
DATE	REV. BY	REVISIONS & ADDED PAGES	REMARKS

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PART ISUMMARY

This simulation program will study the hover and landing and separation and docking phases of the LEM mission. The docking phase of the program will deal with LEM active docking with the CSM, starting with the two vehicles separated by a maximum distance of 500 feet. The separation portion of the program will study LEM-CSM separation up to the point of insertion of the LEM vehicle into the descent trajectory. The hover and landing phase of the program will study the terminal phase of the LEM descent to the lunar surface and will allow for the capability of initiating low level aborts.

This simulation will utilize an analog computer to solve the six degree of freedom equations which describe the vehicle dynamics and drive the visual displays. It will also utilize a pulse modulator to provide the desired RCS thrust levels, and a logic box to select the correct jet firing for a given command. The pilot will be presented with visual cues from the cockpit instruments and visual T.V. display generation system. Cockpit translational and rotational controllers will allow the pilot to exercise control over the simulated vehicle. A monitor console will enable the simulation engineer to control the operation of the simulation. This console contains remote controls for the analog computer and malfunction-insertion switches. The data acquisition equipment will record data as a function of time over the course of a run and end point data at the completion of a run.

The buildup to the ultimate IIIB Simulation capability occurs gradually over a period of time with limited Separation and Docking studies commencing first. This report covers the whole IIIB Simulation in a general fashion and the Separation and Docking portion more specifically. The report has been issued lacking certain detailed Hover and Landing information in order to be timely for the Separation and Docking studies which will commence shortly. Detailed Hover and Landing information will be forwarded as revisions to this report when studies of that type are due to commence.

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PART IIINTRODUCTION

This simulator is designed to explore Astronaut capability for actively participating in the control, guidance, and navigation of the manned LEM space vehicle during the hover and landing and separation and docking phases of the mission. The analog computer facilities are being used to solve the six degree of freedom equations of motion of the vehicle, as well as the equations describing the control system. The controllers and instrument displays located in a fixed base cockpit allow the control loops to be closed through pilot responses. The pilot views, through his windows, a continuously changing picture projected onto a screen in front of the cockpit, and on a T.V. monitor in his over-head window.

A monitor console is used to control the operation of the simulator. A digital data acquisition system using digital magnetic tape, a digital-volt-ratio meter with a printer and scanner combined with x-y plotters and strip chart recorders form the means for recording test data.

The IIIB Simulation will gradually be developed to the ultimate capability in certain well defined phases as follows:

<u>Capability</u>		<u>Time</u>
(1)	Limited Separation and Docking Capability.	Present
	(a) Cockpit docking displays only.	
	(b) Monitor Console bypassed.	
	(c) No x-y plotters.	
	(d) F-151 Gunnery trainer displays.	
(2)	Expanded Separation and Docking Capability.	November 1964
	(a) Monitor console in the loop.	
	(b) x-y plotters on the line.	
(3)	Ultimate Capability Including Hover and Landing	December 1964
	(a) Full M-1 cockpit displays and controls added.	
	(b) Nike-Ajax displays on-the-line.	
(4)	Cockpit Revisions.	April 1965
	(a) Full M-5 cockpit displays and controls added with electroluminescent lighting.	

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The following detailed information pertaining to Hover and Landing operations of the IIIB Simulation is missing from this report, and will be submitted as revisions to this report when appropriate.

- (1) Hover and Landing equations.
- (2) Nike-Ajax Display System drive equations.
- (3) Hover and Landing study plans and test matrices.
- (4) Hover and Landing analog block diagrams.

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PART III

EXTERNAL VISUAL DISPLAYS

A. General Discussion:

Two different external displays will be used for this simulation study. The first ("interim-interim") system to be used for separation and docking only temporarily is the "151 Gunnery Trainer" with a scanning optical head, T.V. cameras and a projector (see figure #11). The second ("interim") system, when available, will utilize a modified Nike-Ajax Radar Pedestal, an extendible boom, a scanning optical head, T.V. cameras and a projector for both the hover and landing and separation and docking phases.

There will be two lunar models used in the second system. Each of these models are flat with edges curved up and are $19\frac{1}{2}$ feet in diameter. The scales of each of these models will be the same (800:1) but the lighting and shadows will be different. This will enable landing in either earthshine or sunshine with or without shadow effects. The scale of these models will allow descent from altitudes of 2800 feet or lower with range from the selected initial point to touchdown of 7500 feet. Touchdown will appear to be seen at a distance of 25 feet from the pilots eye to the lunar terrain. The lunar map scale of 800:1 is consistent with the preceding dimensions. With this scale, touchdown with accurate visual cues at the instant of landing is achievable. Should it be desired to study the powered descent further up the landing trajectory, the map scale can be arbitrarily considered to be much larger since map object sizes are purely arbitrary to begin with. However, with greater map scaling, touchdown will no longer be possible, since the minimum approach distance of the scanning optical head to the map now represents greater-than-touchdown dimensions to the surface.

In addition to the above display systems, visual attitude information is also presented to the pilot by a servo driven three gimbal starfield generator which introduces a starfield into the T.V. displayed picture.

B. "151 Gunnery Trainer"

Figure #11 shows the 151 Gunnery Trainer with the scanning optical head located on the track bed. A 150:1 scale model of the CSM is mounted in a two degree of freedom gimbal housing. The two motions available in this housing are yaw and pitch of the CSM. A third degree of freedom is obtained by moving the gimbal housing axially toward the optical head which is mounted in front of the CSM model at the end of the track bed.

C. Scanning Optical Head

The optical head contains three rotational degrees of freedom: azimuth, elevation, and roll about the line-of-sight. The combination of these three rotational degrees of freedom and the three motions of the CSM in the 151 Gunnery Trainer, enable the simulation of translations and rotations of the LEM vehicle with respect to the CSM. In the same manner, the three rotational degrees of freedom of the optical head, coupled with the two motions (azimuth and elevation) of the Nike-Ajax pedestal and the boom extension, provide us with three translational and three rotational motions for the second display system that will be used for both landing and docking runs. This unit is also capable of servo focusing from infinity to a distance of $3/8$ of an inch range to the surface of a model. A servo light control device, which allows constant object illumination, is also included in the scanning head.

D. Nike-Ajax Radar Pedestal and Servo Systems

The Nike-Ajax Radar Pedestal and Servo Systems will be used as part of the visual display system to provide two degrees of freedom. The azimuth and elevation drives will have the ability to move smoothly at minimum rates of 0.17 milliradians per second. This is equivalent to a minimum smooth linear velocity of 1.36 ft/sec. for the hover and landing phase.

E. Starfield Generation

The Starfield Generation consists of a sphere containing an accurately positioned "point" light source. By means of lens cells, filters and variously sized small apertures, a minimum of 2,300 stars located within 20 minutes of arc of their true position, are projected. The star sphere is mounted on a three axis, gimballed system allowing complete, continuous rotation about these axes or about any axis in space. Each axis is servoed to a position corresponding to a desired input and each servo is capable of providing 60 degrees per second of rotational speed and up to 60 degrees per second squared acceleration. The stars are projected on a screen four feet from its center of rotation. On the other side of the screen (see figure #11), a T.V. camera picks up the starfield and feeds it through the special effects generator where it is combined with the T.V. signal from the camera looking at either the lunar terrain or the CSM and from there, it is feed to the Eidophor projector and presented on the screen in front of the pilot.

F. T.V. Mixing and Occulting System

The 1035 line T.V. presentation system consists of three cameras feeding information into a Special Effects Generator that mixes the T.V. signals and sends the mixed signals to the Eidophor projector to be presented on the screen in front of the pilot. The Special Effects Generator enables viewing of a composite video display consisting of two scenes.

The first and second cameras both view the lunar terrain or the CSM model through the optical head and the third camera views the starfield. The map terrain and its associated shadows, are painted specific colors related to the wavelength spectrum of the respective vidicon cameras. A dichroic filter located between the optical head and the first and second cameras, allows both of the model colors to pass through to the first camera and prevents one of the colors from passing through to the second camera (the keying camera). The second camera signals are mixed with the third camera signals (starfield camera) and prevents any stars from passing through the area where there is either lunar terrain or CSM on the presentation screen.

G. Eidophor Projector, Overhead Window Display and Monitor

The T.V. projection system consists of a 1035 line Eidophor projector that projects a composite picture of the lunar terrain and starfield or CSM and starfield, on a screen in front of the pilot. A 21 inch T.V. monitor is located over the window above the pilot in order to provide the pilot with a visual presentation to be used for the docking and separation phases of the LEM mission.

In order to present the presentation of the lunar terrain on the screen in front of the pilot at infinity, a virtual image lens will be placed in the front window during all landing studies.

PART IVCOCKPIT INSTRUMENTS AND MALFUNCTIONSA. General

The arrangement of the cockpit instruments and associated nomenclature are shown in figure #10. Each instrument in this drawing is listed by a panel number and a switch or meter number. Some of the instruments and switches are non-functional, although most of these are still capable of being moved to appropriate positions. There are some panels that have no significant effect on this simulation and therefore these switches and meters are represented in decal form.

B. Instrument Status

Legend

L = live - wired to computer

D = dummied

M = live - wired to monitor console

1. Panel #1

Main Engine Control Panel

<u>Instrument #</u>	<u>Status</u>	<u>Instrument #</u>	<u>Status</u>
s - 1	L	M - 1	L
s - 2	L		
s - 3	L		
s - 4	D		
s - 5	L		
s - 6	L		

2. Panel #2

Pyrotechnics Control Panel

<u>Instrument #</u>	<u>Status</u>	<u>Instrument #</u>	<u>Status</u>
B - 1	D	EE - 1	L
B - 2	D	EE - 2	L

<u>Instrument #</u>	<u>Status</u>	<u>Instrument #</u>	<u>Status</u>
SL - 1	D	SL - 7	D
- 2	D	8	D
- 3	M	9	D
- 4	D	10	D
- 5	D	11	M
- 6	D	12	D

3. Panel #3 Primary Navigation and Guidance Panel.
All instruments and switches are dummied.

4. Panel #4 Power Generation Panel.
All instruments and switches are dummied except
4 B - S - 1 to 5. - wired to monitor console.

5. Panel #5 Cryogenic Storage Panel

<u>Instrument #</u>	<u>Status</u>	<u>Instrument #</u>	<u>Status</u>
s - 1	M	M - 1	M
s - 2	M	M - 2	M
s - 3	D		
s - 4	D		
s - 5	M		
s - 6	D		
s - 7	D		

6. Panel #6 Caution and warning Panel.
All lights are live and are wired appropriately to
either the monitor console or to the computer.

7. Panel #7 Environmental Control Panel.
All instruments and switches are dummied.

8. Panel #8

Reaction Control Panel

<u>Instrument #</u>	<u>Status</u>	<u>Instrument #</u>	<u>Status</u>
s - 1	M	s - 11	L
s - 2	M	s - 12	L
s - 3	L	s - 13	L
s - 4	M	s - 14	L
s - 5	M	s - 15	L
s - 6	D	s - 16	L
s - 7	M	s - 17	L
s - 8	M	s - 18	L
s - 9	M	s - 19	M
s - 10	M	s - 20	D
M - 1 A,B	M	M - 3	L
M - 2 A,B	M	M - 4	L

9. Panel #9

Flight Control Panel

<u>Instrument #</u>	<u>Status</u>	<u>Instrument #</u>	<u>Status</u>
s - 1	M	s - 4	D
s - 2	D	s - 5	M
s - 3	M	s - 6	M
M - 1	L	M - 4	L
M - 2	L	M - 5	L
M - 3	L	M - 6	L

10. Panel #10 Main Propulsion Panel

<u>Instrument #</u>	<u>Status</u>	<u>Instrument #</u>	<u>Status</u>
s - 1	M	M - 1	M
s - 2	D	M - 2	M
s - 3	D	M - 3	M
s - 4	D	M - 4	M
s - 5	D		
s - 6	M		

11. Panel #11 Stabilization and Control Panel

<u>Instrument #</u>	<u>Status</u>	<u>Instrument #</u>	<u>Status</u>
s - 1	M	s - 4	L
s - 2	L	s - 5	L
s - 3	L	s - 6	L

12. Panel #12 Backup Guidance Panel

<u>Instrument #</u>	<u>Status</u>	<u>Instrument #</u>	<u>Status</u>
s - 1	M	s - 4	D
s - 2	D	s - 5	D
s - 3	D	s - 6	D
M - 1	D	M - 2	M

13. Panel #13 Communications Panel.
Decal complete panel.14. Panel #14 Communications Antennas Panel.
Decal complete panel.

15. Panel #15 Audio Control Panel.
Decal complete panel.

16. Panel #16
- Commander's Lighting Panel.
Decal complete panel.
 - Systems Engineer's Lighting Panel.

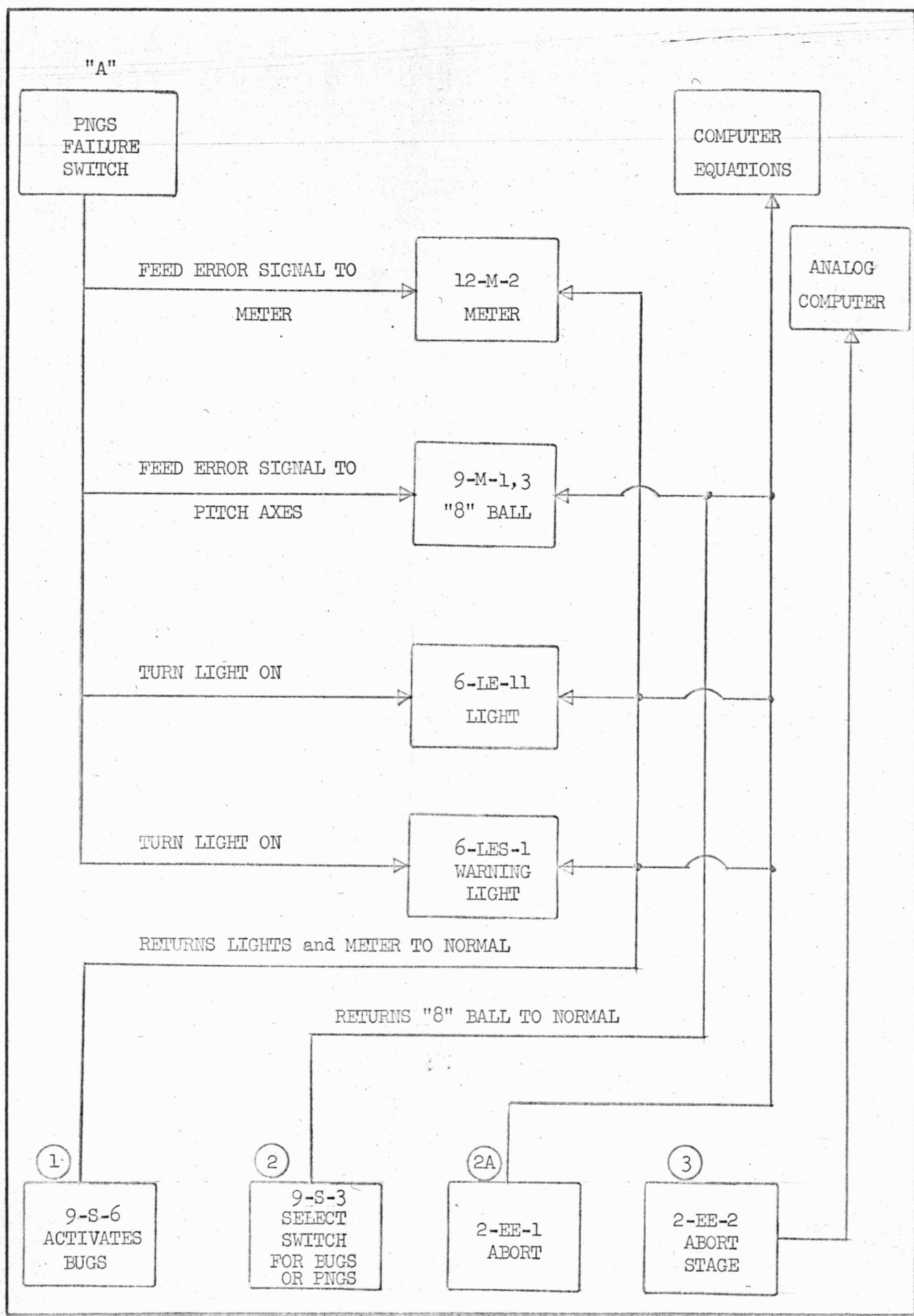
<u>Instrument #</u>	<u>Status</u>	<u>Instrument #</u>	<u>Status</u>
s - 1	M	s - 5	M
s - 2	D	s - 6	D
s - 3	M	s - 7	D
s - 4	D	s - 8	M

17. Panel #17 Radar Panel.
Decal complete panel.

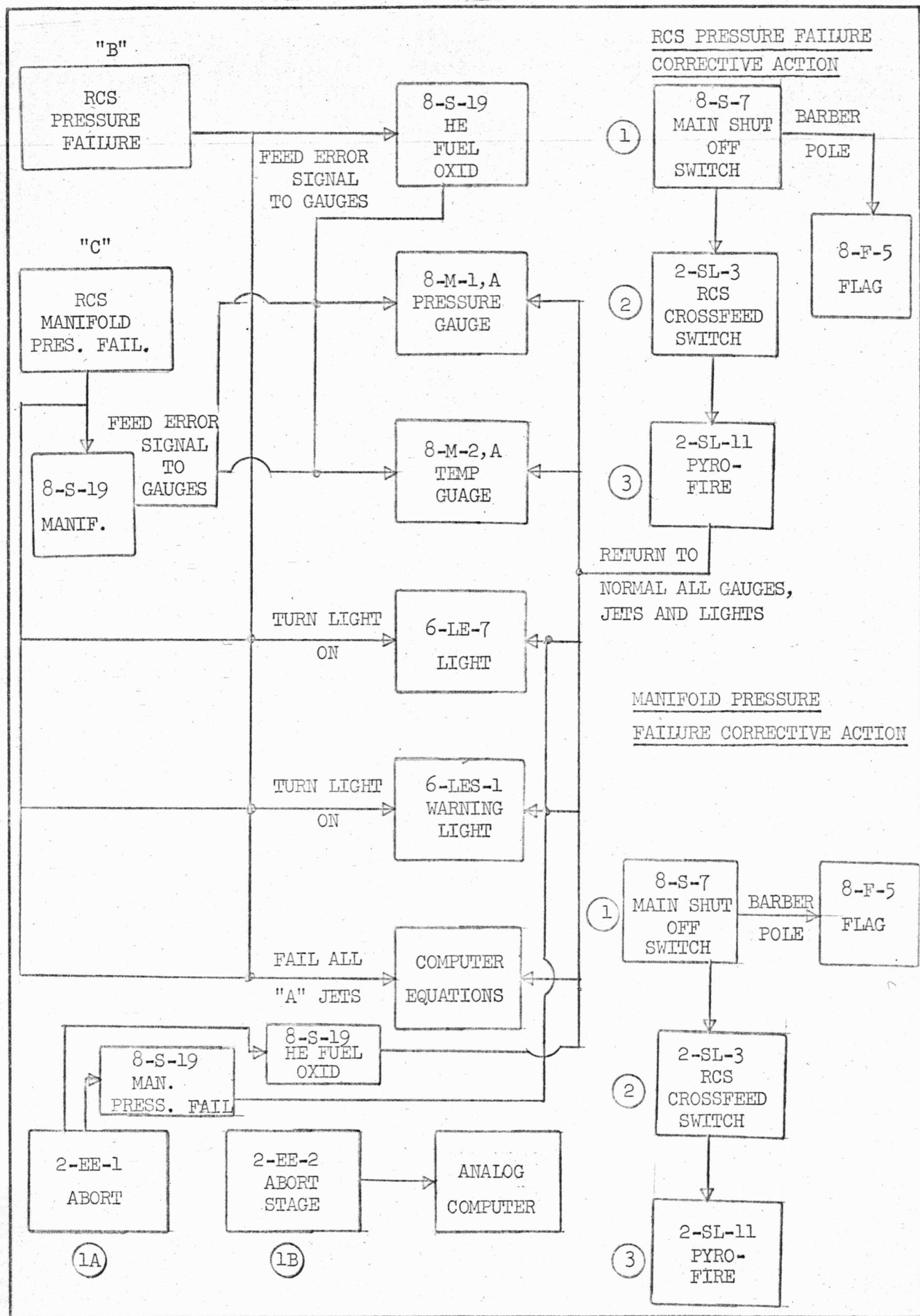
C. Malfunctions

The following section diagrams the malfunctions that will be inserted by the operator at the monitor console and the corrective action that should be taken by the pilot in order to correct for the malfunction.

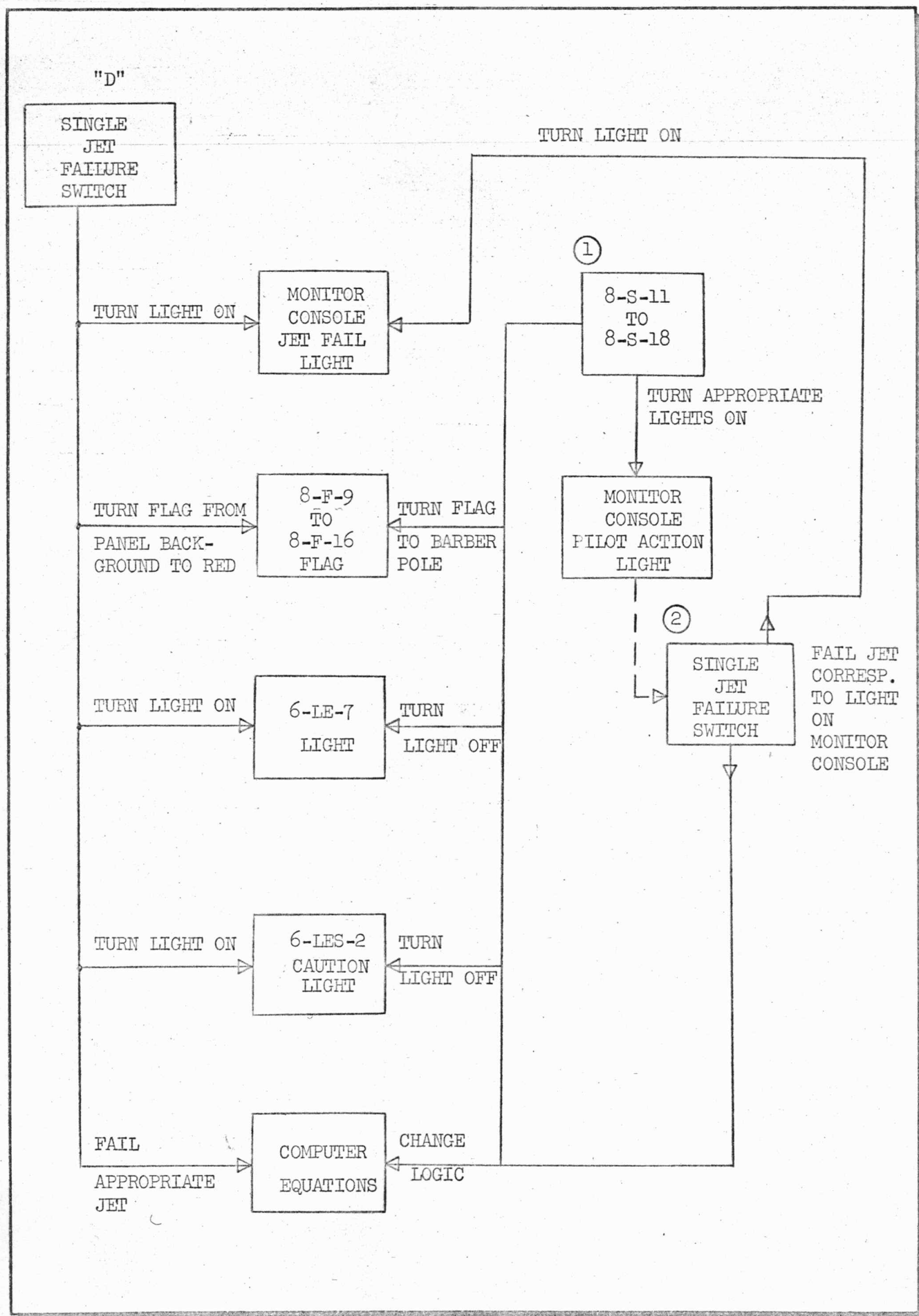
- "A-M"
- Lettered boxes ☐ are malfunction buttons located on monitor console.
 - Numbers under ^{over, beside,} boxes ☐ indicate the order the button in the cockpit must be pushed by the pilot to correct for the malfunction condition. As each button is pushed, the effect it has on the instruments is noted.
 - Numbers and letters in the boxes correspond to the buttons and switches in the cockpit panel (see figure #10).



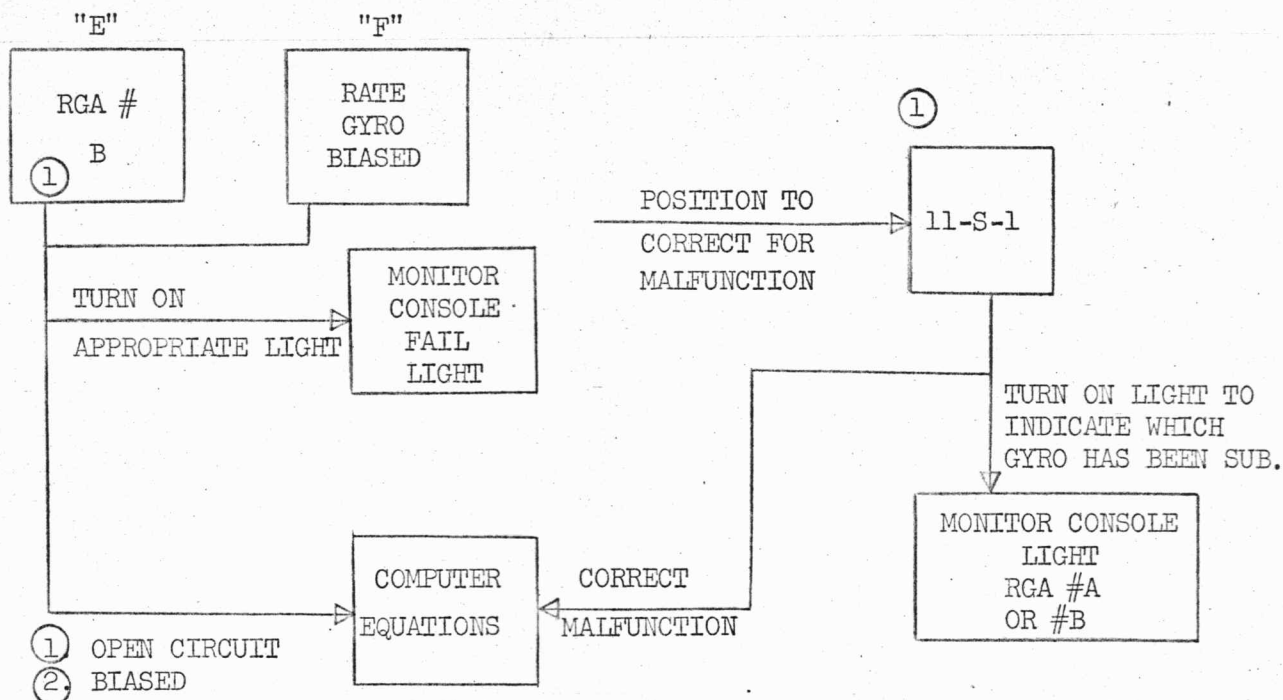
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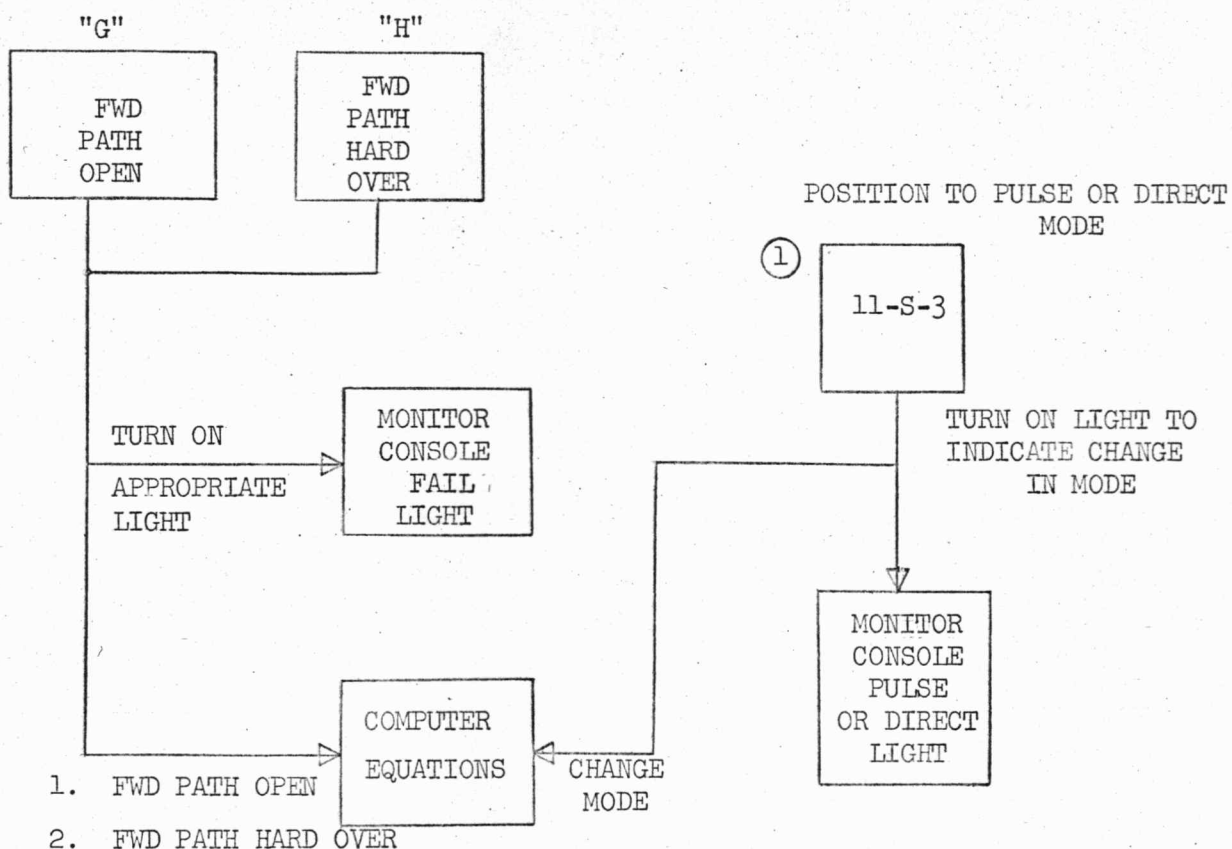
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RATE GYRO FAILURE - PITCH AXIS ONLY

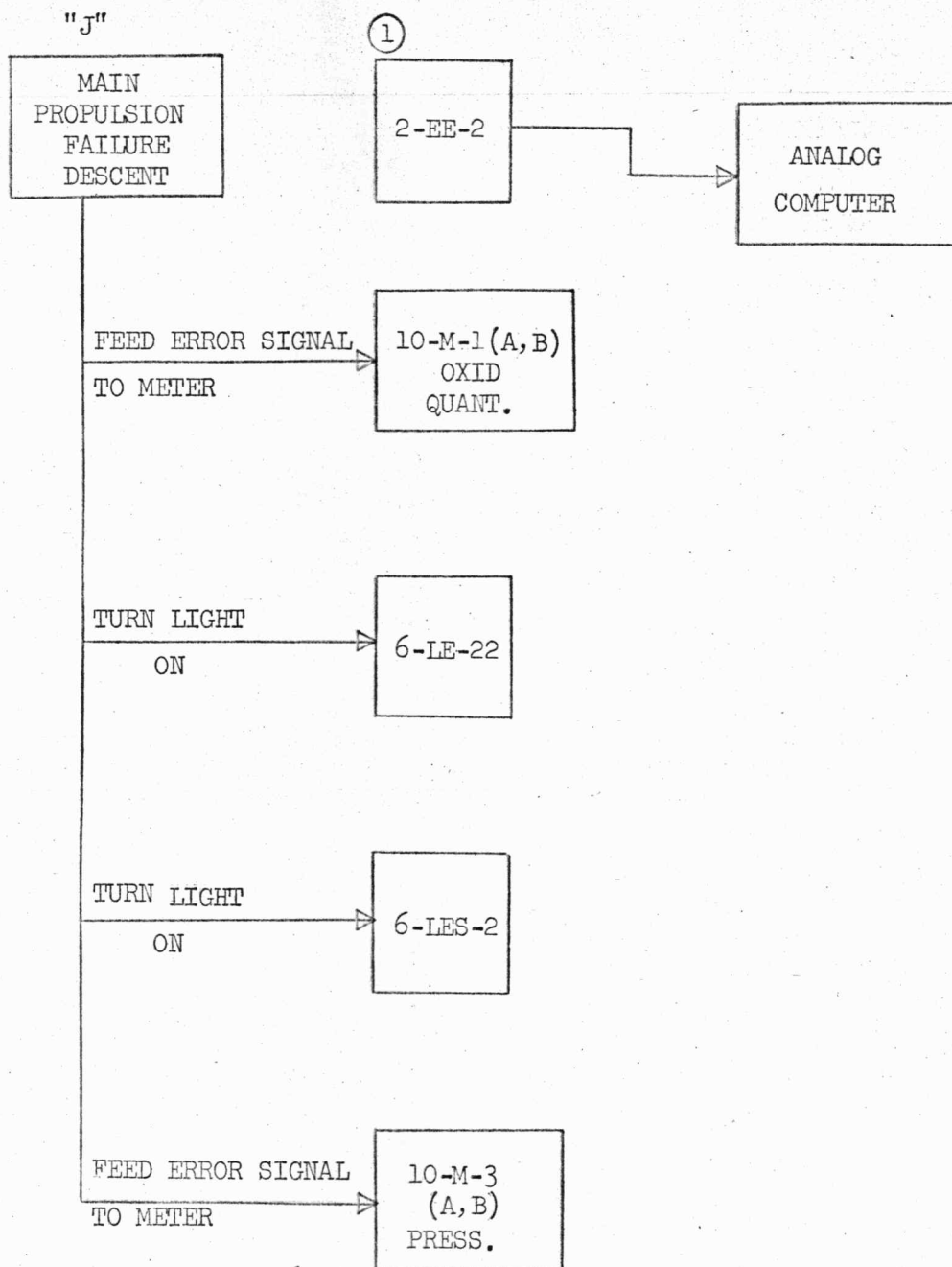


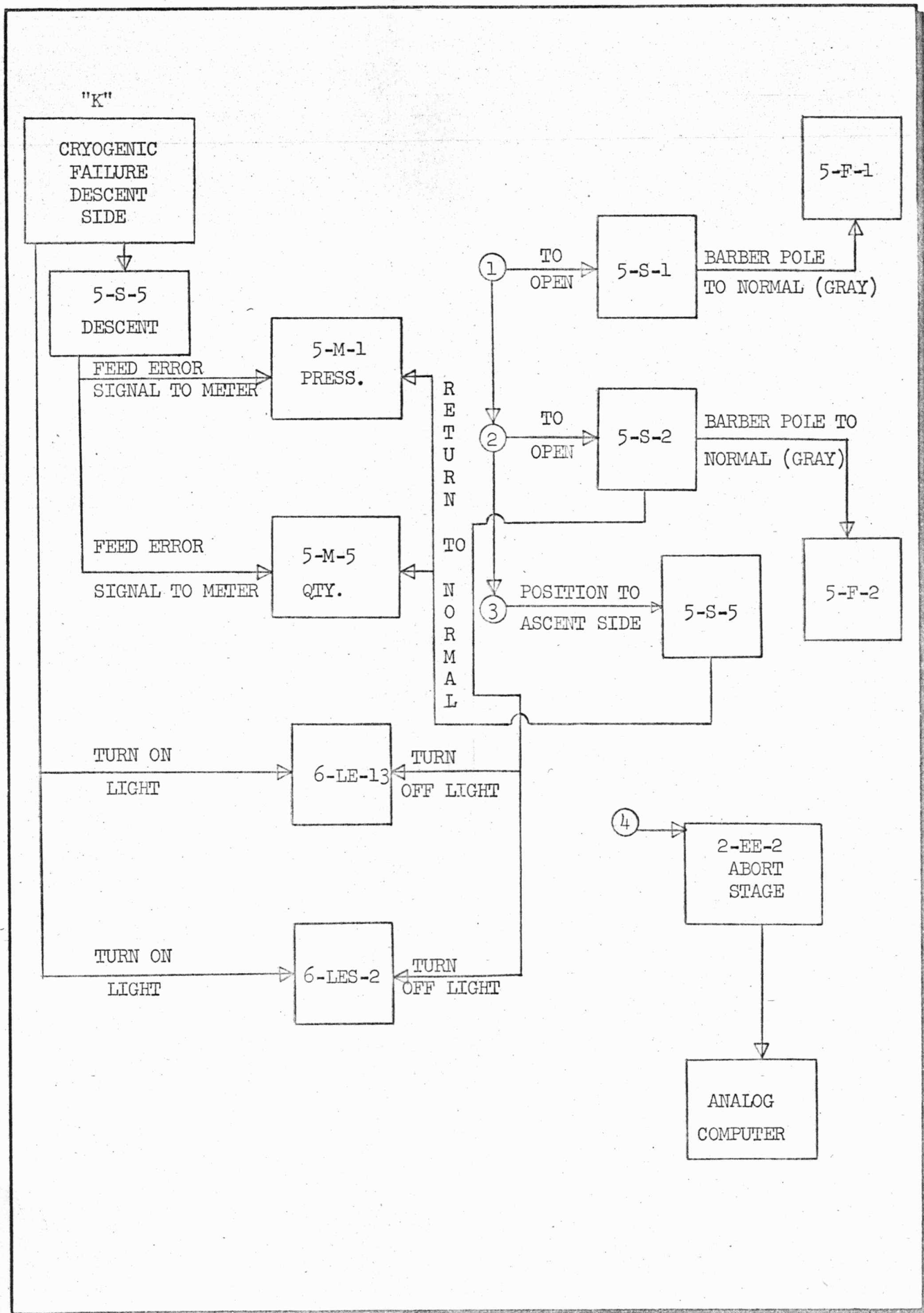
1. OPEN CIRCUIT - Ground Pitch Attitude Rate Input into Rate Gyro Logic Circuit.
2. RATE GYRO BIASED - Substitute a Fixed Voltage Level for the Rate Input into the Rate Gyro Logic Circuit.

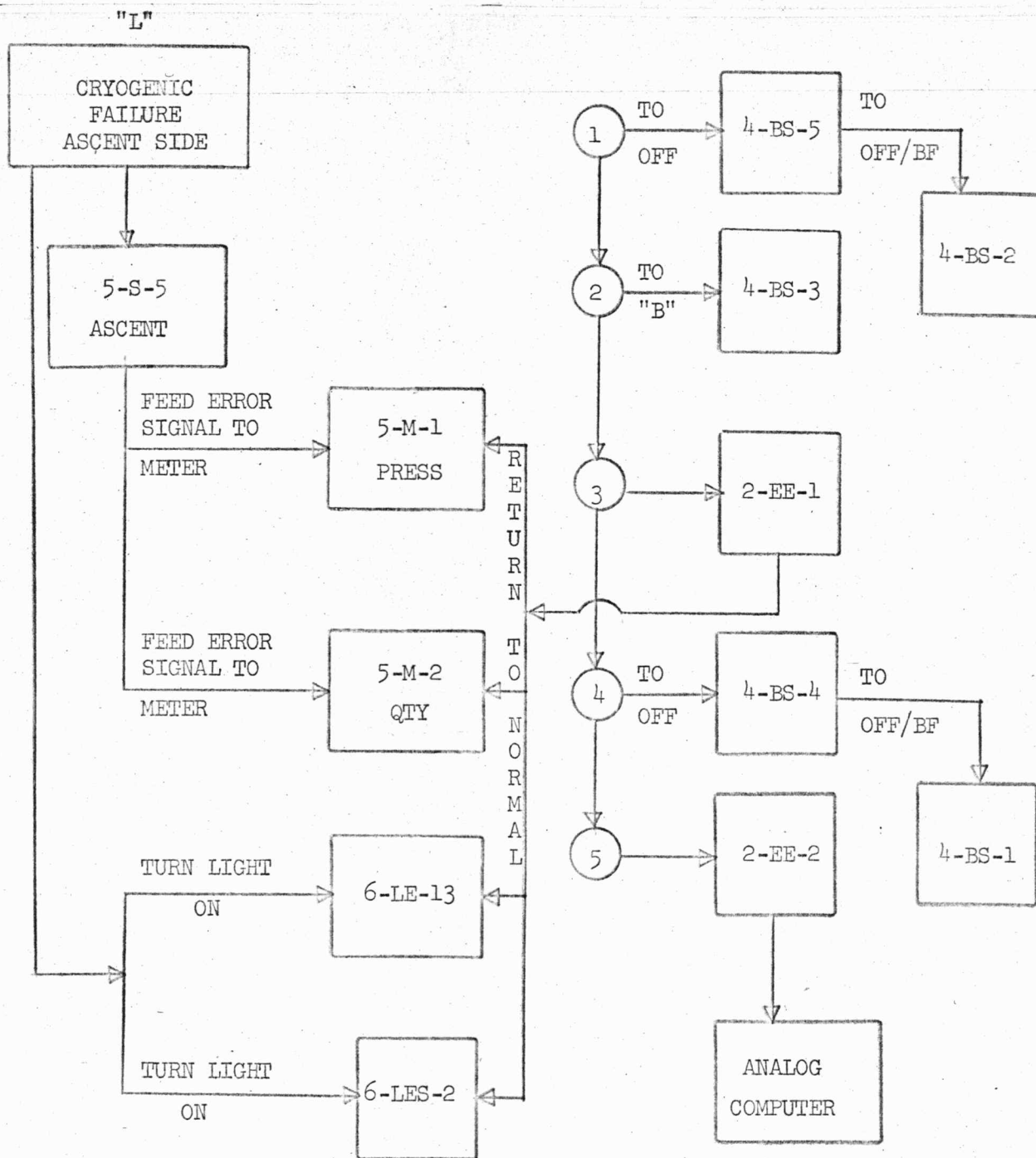
RATE GYRO FAILURE - PITCH AXIS ONLY

1. FWD PATH OPEN - GROUND RATE AND ATTITUDE ERROR SIGNAL
- OCCURS BEFORE PULSE INPUT TO
S & C JET LOGIC.

2. FWD PATH HARD OVER - SUB. A FIXED SATURATION LEVEL VOLTAGE
FOR THE PITCH ATTITUDE ERROR SIGNAL.

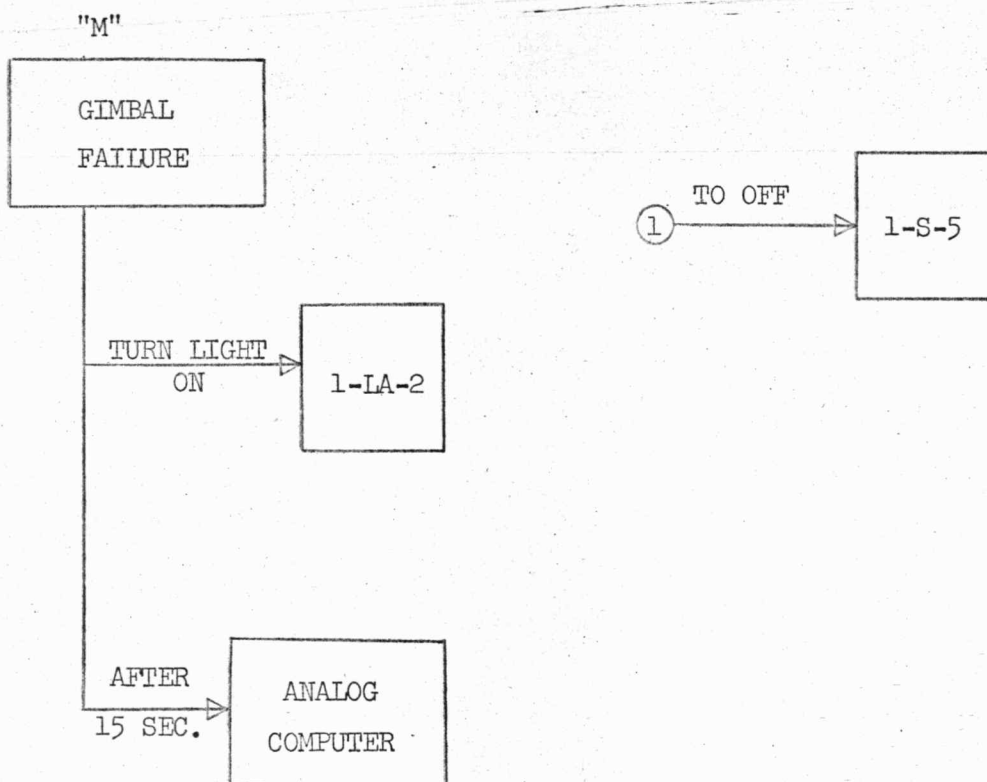




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NOTE: For all abort conditions:

1. When the Abort button 2-EE-1 is activated:
 - a) The vehicle is erected to a predetermined attitude.
 - b) The descent engine is fired at full throttle.
2. When the Abort Stage button 2-EE-2 is activated:
 - a) The vehicle is erected to a predetermined attitude.
 - b) The problem goes into hold, or the descent engine is staged and the ascent engine is used for the abort phase.

PART VDATA ACQUISITION SYSTEMA. General

The data acquisition system to be used for this simulation consists of a digital volt-ratio meter with a printer and scanner, a 70 channel digital tape data acquisition system, strip chart recorders and x-y plotters.

B. Digital Volt-Ratio Meter System (see figure #13)

The digital volt-ratio meter system has the following characteristics:

1. Digital Volt-Ratio meter with:
 - a) Infinite impedance.
 - b) 4 digits + sign with moveable decimal.
 - c) Meter speed of ten (10) readings per second average.
 - d) Capability of accepting external reference.
2. Paper tape printer with:
 - a) Channel identification including five (5) information channels.
3. Capability to scan 100 points.
4. Sample and hold any selected channel during a run (one channel at a time).
5. Control panel with:
 - a) Specified computer controls.
 - b) Selector switch for 100 channels.
 - c) DVM mode.

C. Seventy (70) Channel Digital Data Acquisition System (see figure #16)

The digital data acquisition system has the following characteristics:

1. Digital information: 13 bits + sign.
2. Tape is in IBM format with 556 bpi density.
3. Elapsed time generation with a minimum resolution of 1 part in 10^6 for recording and display.

4. System front end is equipped with dual connectors for carrying input signals to analog "Quick Look" instrumentation.
5. System has capability of selecting any one channel and displaying information on front panel in octal.
6. System is capable of single or continuous scanning.
7. Sampling rates are variable in 5 discrete increments with 100 sps/channel being maximum and 20 sps/channel being minimum.

D. Strip Chart Recorders

The strip chart recorder that will be used in the "control room" for a "quick look" at various preselected channels, is of the Brush "Mark 200" series with a paper take up reel attached. Additional strip chart records are available in the analog computer room that will be used to record pre-determined variable parameters during a run.

E. X-Y Plotters

Two x-y plotters are available for use by this program. One is a 30 x 30 2 arm, 2 pen plotter that can receive and plot up to 4 variables. The second plotter is a 11 x 17 2 arm, 2 pen plotter that can receive and plot up to 3 variables (the base is common).

PART VIDOCKING MATH MODELA. Vehicle Dynamics Equations

The assumptions implicit in the equations of motion, shown in figures #1 and 2, are as follows:

1. The CSM is assumed to be in a circular lunar orbit.
2. The relative displacement between the LEM and CSM is assumed to be small compared with the CSM orbital altitude.
3. Reaction jet fuel consumption during the docking mission is assumed to cause a negligible change in LEM mass, inertias, and C.G. position.
4. The exhaust gases are assumed to have no angular velocity with respect to the LEM.
5. Jet damping forces are assumed to be negligible.
6. The reaction jets are assumed to have no thrust misalignment.

The translational equations of motion, derived in reference 1, describe the relative velocity and position of the LEM with respect to the CSM. With the translational equations in this form, the need is eliminated to first compute each vehicle's inertial velocity and position in order to find the relative position and velocity of the LEM with respect to the CSM. The reference coordinate system for these equations is LEM local vertical centered at the CSM. The geometry of the translational equations of motion are shown in figure #3.

The azimuth and elevation angles are calculated using geometrical properties, as shown in figure #4. This provides better analog computation accuracy than the technique of integrating azimuth and elevation rate equations. These rates are not required for output and so do not appear in the equations. The docking hatch position equations are provided to indicate when the docking hatch has made contact with the CSM.

The order of rotation of the Euler angles with respect to the LEM local vertical is the standard LEM pitch-roll-yaw order of rotation (figure #5). The order for the inertial Euler angles, however, has been changed to conform to starfield projector gimbal requirements to yaw-pitch-roll.

The direction cosine matrix, relating the LEM local vertical axes to the body axes, has a 45 degree bias such that, for $h = z = 0$ and a negative value for S , the pitch angle would be 45 degrees for the LEM Z_B -body axis pointing at the CSM (see figure #6). The equations were derived with this bias to avoid singularities in the external visual display equations when being used for docking.

To obtain accurate outputs of propellant consumption, the effect of variable specific impulse is included. The specific impulse is calculated as a function of the electrical pulse width of each of the eight RCS pulse modulators. These values of specific impulse are used in the calculations of translational and total propellant consumption along each body axis.

The LEM body axis moment equations have been written in a way to reduce the number of input variables. This is accomplished by first computing the moments about a fixed reference point and then transferring the moments to the center of gravity. The reference point selected lies in the YZ plane of the reaction jets and on the nominal thrust axis for the descent and ascent engines, as shown in figure #7.

It should be noted that post-docking dynamics have not been included in this math model. If the need for such equations arises, they will be included in the simulator at a later time.

Definitions of the symbols in the equations of motion, as well as a range of variables, appear in Appendix A. Values of masses and inertias have been given to correspond to the LEM weight at separation, after completion of abort with fully loaded ascent tanks, and after nominal rendezvous.

B. External Visual Display Drive Equations

The external visual display drive equations, shown in figure #8, are derived to drive the visual display system utilizing the F-151 Gunnery Trainer range bed and provide outputs to drive the CSM model attitude and motion along the range bed and the optical head attitude.

The optical head is assumed to be at the position in the LEM corresponding to the pilot eyeball. Equations relating the position of the pilots eyeball to the CSM (h_c, s_c, z_c) are computed and used to determine the proper rotation of the model and optical head to correspond to apparent LEM translation. The resulting optical head attitude due to translation effects (θ_T, ϕ_T) is combined with the optical head attitude due to rotation (θ_R, ϕ_R, ψ_R).

Because the projection system is designed such that the image is projected along the optical axis which is perpendicular to the LEM window, the transformation between this optical axis and the LEM body axis must be included in the equations. Thus the angular position of the window (either overhead or front left) is needed as an input (A_0 and E_0). The angles used to drive the optical head (ϕ_c, θ_c, ψ_c) are therefore derived from the direction cosines relating the local vertical axes to the optical axis.

The optical head drive is not a gimballed system. Therefore the values of θ_c' and ϕ_c are corrected using spherical trigonometric relations resulting in the corrected angles θ_c and A_{zc} . The angles θ_c , ψ_c , and A_{zc} are used to drive the optical head.

C. Flight Control System

Introduction

Figure #9 contains a block diagram of the simulated LEM flight control system. It reflects the most recent design criteria as outlined in the various flight control hardware specifications, and summarized in references (2) and (3).

The modes of operation are summarized in the discussion and a list of constants is included in Appendix B to enable scaling on the computer.

The jet select logic is not presented here in detail because it is outlined in the attitude and translation control assembly specification (LSP-300-14), and simulated accurately as specified in that document.

Modes of Operation

The following is a list of control system modes which are currently being used.

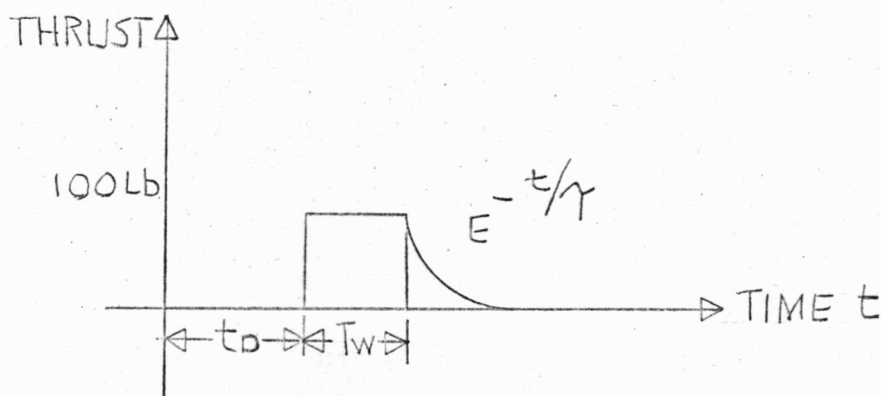
1. Rotation
 - a. auto
 - b. manual
 - (1) rate command with simultaneous 3 axis attitude hold
 - (2) rate command only
 - (3) pulse (open loop with logic)
 - (4) direct 2 jet response in linear range and 4 jets at hard over position
 - (5) pilot select 2/4 jet control in (1), (2) and (3) above.
2. Translation
 - a. auto
 - b. manual
 - (1) pulse (with logic)
 - (2) direct - 4 jet on-off with emergency solenoids
(Note: only 2 jets available in y and z translation)
 - (3) pilot select 2/4 jet control in (1) above.

The following are proposed alternate modes for evaluation. These modes are included in the simulation and are shown on the diagram. Analog computer switches select either the "current" or the "proposed" mode for operation at any particular time.

3. Rotation - same as above except:
 - (1) single axis attitude hold operation
 - (4) direct - emergency solenoid operation with 4 jets at the hardover position
4. Translation - same as above except:
 - (2) direct - 2 jet (y and z) or 4 jet (x) on-off with logic

Thrust Function

The thrust function of reference (4) is shown below:



The values of t_D and γ are dictated by the value of T_{WMin} . (minimum pulse width) in the pulse ratio modulator. These constants are chosen so that the total impulse for a modulator pulse equal to T_{WMin} is the same as the minimum impulse firing expected from the RCS engines.

Rotation Controller

The attitude mode switch has two manual positions both of which allow manual translation control as well as rotation control. In the attitude hold mode, the time integral of the body rate is used to hold the pilot's desired attitude when his rate command (stick output) is zero. Maximum rate command from the pilot's controller is 10 deg. sec.* The emergency mode (4 jets on continuously) operation is available regardless of the position of the attitude mode switch.

* Provisions for increasing this value to 20 deg./sec. have been made.

Controller Non-Linearities

The signals S_1 through S_6 are described as follows:

- S_1 maximum body rate command from stick
- S_2 pulse train signal to modulator in translation and rotation
- S_3 threshold for jet emergency solenoid operation
- S_4 4 jet response emergency full on command
- S_5 2 jet response emergency full on command
- S_6 2 jet response full on logic command

Translation Controller

The translation controller puts out open loop commands which can be:

1. minimum impulse pulse train of specified frequency
2. full on thrusting-emergency solenoid operation
3. full on thrusting with logic

Here again, the emergency mode is available to the pilot regardless of the attitude mode switch position.

Rate Command Limits

In manual mode, the rate command limit is provided in the rotation controller (S_1). Since the stick output is summed directly with the body rate, only one limit has to be mechanized regardless of rate gain (staging switch) or modulator deadband (deadband select switch).

In automatic mode, the rate command signals are summed with the scaled rate gains and therefore, two rate command limits have to be provided and switched as a function of the staging switch.

When the deadzone and rate gain are 5 degrees and .35 seconds⁻¹ (ascent coast), the limits should be bypassed (or at least, switched to the descent stage limit as an alternative), because a 5 degree attitude error will correspond to a 14.3 deg./sec. rate command. This value of rate command cannot be passed through the ascent rate limiter.

PART VIIMONITOR CONSOLE

The monitor console, as shown in figure #12, is the control center of the simulation. From this point, control is exercised over the computers and display rig. All the malfunctions are initiated here. The simulation engineer can monitor any parameter on the DVM he desires by merely pressing the button corresponding to the channel on which the variable is monitored.

The monitor console contains, in the upper left hand section, (figure #13) the digital volt-ratio meter, a printer and a scanner. The lower left hand section contains the remote controls for the analog computer and the channel selection switches for the DVM. The upper right hand section (figure #14) contains a series of instruments that monitor various vehicle parameters during a run. The lower right hand section (figure #15) contains all the malfunction switches for both the flight controls and system malfunctions.

PART VIIISTUDY PLANSPart A Separation and Docking1. Introduction

The study plans discussed below cover the first phase of the pre-simulation report for the IIIB simulation study program. This first portion of the report deals with anticipated study areas for the separation and docking phases of the LEM mission. A second portion of the report will deal with the remaining mission capabilities of the simulator - i.e., hover-to-landing and low altitude abort.

Selection of pertinent study areas for IIIB Simulation and ordering of their priority will be based on the following criteria:

- a. Determination of unresolved design decisions.
- b. Verification of the current LEM man/machine system to accomplish the mission successfully.
- c. Investigation of effects of required equipment on performance.
- d. Alternative procedures and operational modes.

For example, under the categories of design verification would be those studies concerned with pilot manual control capability at touchdown and at docking. These would serve to verify design of the landing gear, the vehicle structural limitations for docking impact velocities, or window configuration based upon visibility requirements and vehicle propellant requirements under normal operation. Other design study objectives would deal with optimum subsystem mechanization, such as comparative evaluations of flight control system parameters, control modes, display techniques, cockpit optical devices, etc.

Under the study areas concerned with flight crew procedures and operational modes will be the evaluation of alternative flight profiles and crew techniques of control, for carrying out each mission phase. In addition, it will be necessary to verify previously determined flight techniques and uses of cockpit instrumentation as well as the effects of crew procedures in detection, isolation and correction of malfunctions on manual vehicle control.

The objectives described and the specific variables listed below serve as a framework for more detailed study matrices, not an exposition of all possible study efforts for the IIIB simulation. It is intended that flexibility be retained in the planning, in order to deal with new

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variables or study areas that become apparent as the simulation program progresses and as modifications are made with respect to LEM mission requirements.

2. Subjects

Training of a group of simulator pilots has been recommended (see reference 5) as a means of assuring an available pilot pool from which individuals can be drawn during the course of the simulation test runs. In order to achieve the most representative study data, it has been suggested that the pilot pool consist primarily of astronauts and test pilots. Pilots are to be familiarized with LEM subsystem operations, and trained to deal with a number of subsystem malfunctions. Training will be to criterion levels of flight performance with respect to pilot consistency of performance.

3. Study Areas

The discussion below is divided into study areas for the separation and docking phases along with a listing of variables to be considered, the estimated number of levels for each variable (where possible) and, based upon these, a rough approximation of operational simulator time required to obtain the data. Specific flight techniques, types of devices or values of a given variable and number of levels (e.g., number of inertias to be varied and the specific values) will be specified when the detailed study runs are drawn up.

The problem areas have been divided into separate study phases, but it is apparent that many of the study variables overlap from area to area and would logically be considered, at times, in conjunction with one another.

A specific study design and test trial schedule are presented for the first month (i.e., 80 hours) of simulator operating time. Periodically, (prior to the completion of the first run schedule of approximately two months) a new run schedule will be issued covering the next study phase and specific problem area(s).

a. Effects of Natural Lighting Conditions

Manual control performance in active LEM docking could be influenced by the natural lighting conditions at the time of the maneuver. Varying amounts of earthshine and sunshine (or absence of this light); the angles of the light source(s) and the angle of LEM approach to the CSM could influence visual judgements of distance, orientation and approach rates. The basic lunar and solar geometry influence the amount and pattern of light falling on the docking target as well as the contrast conditions created by the background (starfield, earth or lunar surface).

(1) Study Variables

(a) Initial Positions (of LEM and CSM at start of Docking)

5 Positions (from about 300 feet distance)

- . +h; -z (LEM above and to the left of CSM)
- . -h; -z (LEM below and to the left)
- . -h; +z (LEM below and to the right)
- . +h; +z (above and to the right)
- . Lined up along s (h and z = 0)

(b) Lighting

- . Darkness (starfield background)
- . Earthshine
- . Sunshine
- . Transition from one lighting condition to another.

(c) Variations in Light Source Angle (and associated lunar-solar-earth geometry.)

- . Dock in earthshine, with CSM against lunar landscape.
- . Sunshine with CSM against lunar surface.

(2) Estimated Simulator Flight Time = 35 flight hours to be carried out in two (2) study phases.b. Flight Control Capability

Basic to all mission phases is the study of crew ability to manually control vehicle attitude and translation under varying flight control modes and degradation conditions. Selection of appropriate control system parameters under such conditions requires evaluation under the LEM active docking condition. This phase also serves to verify previous study efforts on the definition of flight control system parameters.

(1) Study Variables(a) Degraded Modes

- . Direct (all 3 axes; pitch axis only)
- . Direct Pulse
- . Rate Command.

(b) Distance from Docking Target (at which degraded mode is introduced).

- . 3 distance variations

(c) Vehicle Configuration

- . Inertias (minimum of 3 variations)
- . CG offsets and moment unbalances (minimum of 2 variations)

(d) Control System Parameter Evaluation

- . Deadband (minimum of 3 variations)
- . System gains (minimum of 2 variations)

(e) Unstable CSM

- . Varying degrees (and types) of CSM instability.

(2) Estimated Simulation Flight Time = 140 flight hours to be carried out over three (3) study phases.c. Dual Operator Task Sharing

Display and control requirements and general console configurations are designed, to some extent, to meet assumptions concerning dual crewmember operations. This area of study is intended to verify such design assumptions. Further, it will determine the extent to which overall vehicle control might be effected by division of the in-flight crew tasks - including direct vehicle and subsystem control tasks and by sharing the acquisition of necessary information from cockpit displays or visual cues external to the LEM cockpit.

Optimum instrumentation layout and flight techniques related to crew task division will be derived in this phase and contrasted with cockpit design and flight techniques required for single crewmember operation.

(1) Study Variables

(a) Division of RCS Control

- . At various maneuvers of the docking Phase (e.g., at initiation; at pitch over)
- . Rotation - Translation control division (e.g., task division of controller use with pitch control by one crew member, roll and yaw by the other).
- . Task Division under various control degradation conditions

- (b) Division of crew visual tasks for information exterior to cockpit and for cockpit displays. This would also include techniques for task division in use of cockpit optical devices, charts and graphs.
- (c) Task takeover by one crewmember from another at various phases of the docking maneuver.
- (2) Estimated Simulator Flight Time = 45 flight hours to be carried out in two (2) study phases.

d. CSM Running Lights and Markings

For LEM active docking, it will be necessary to make accurate visual judgments of CSM orientation and distance as well as LEM closing rates. Appropriate markings or use of running lights can help provide such attitude and closure information. Docking in darkness would require specially positioned running lights or flood lighting of the CSM markings to provide such information.

(1) Study Variables

Under variations in natural lighting discussed previously (Section 3, a) variations would also be introduced in:

- (a) CSM external lighting configuration (minimum of 2 configurations with variation in number of lights and light location).
- (b) CSM Marking Scheme
(Minimum of 3 variations; including variations in probe markings and types of targets).
- (c) Flood Lighting Arrangement and Type of Lighting
 - . Variations in arrangement and location of lights (minimum of 3 variations).
 - . Variations in intensity and type of floodlighting.
- (2) Estimated Simulator Flight Time = 30 flight hours to be carried out in three (3) study phases.

e. Cockpit Visual Aids and Optical Devices

Various visual aids and optical devices, suitable for evaluation, are to be studied under nominal and degraded docking conditions with regard to their effect upon docking precision.

(1) Study Variables(a) Type of Optical Devices

- . Mounted reticle sights (e.g., wire lubber line; collimated reticle)
- . Window markings
- . Hand-held devices
- . Direct window view (no optical aids)

(b) Cockpit location and design variations of optical devices.

(c) Techniques of crew member use of optical devices during front face and overhead docking.

(2) Estimated Simulator Flight Time = 30 flight hours to be carried out in two (2) study phases.

f. Overhead Docking Capability

The availability of an overhead docking window, along with front-face windows during the docking phase, present a number of considerations for window configuration, crew control techniques and available visual information.

A window over the Commander's station, for example, requires an assumption of unusual head positioning for viewing, limits visual observation of the CSM to only the one crew member (during the terminal phase) and results in fairly abrupt transition from visual cues and control actuation correlated with a "z" axis view to the same control orientation and actuation correlated with visual cues varying along the vehicle "x" axis.

(1) Study Variables

(a) Window Size and Configuration

- . Nominal window of 4 5/8" x 11 7/8"; $\pm 10^\circ$ in the y axis; $+41\ 3/4^\circ$, -5° in z.
- . Minimum of one (1) additional configuration (e.g. size reduction).

(b) Positioning of optical devices with relation to overhead window.

(c) Range from CSM at which LEM 90° rotation (i.e., pitch down) is initiated for terminal docking (3 ranges to be employed.)

(2) Estimated Simulator Running Time = 45 flight hours to be carried out in one (1) study phase.

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g. Docking with Voice Communication Link

Under LEM active docking, voice communication between LEM and CSM could prove useful in augmenting external visual or cockpit displayed information. This would be of particular concern with the overhead docking technique and where only degraded or insufficient external visual information is available (through a meteorite or UV clouded window) requiring an all instrument approach.

The type and amount of information required and the techniques of passing the information between CSM and LEM crewmembers remain to be studied under dynamic flight conditions.

(1) Study Variables(a) Communication Techniques

- . Docking range points at which presentation of voice link information is given (minimum of 3 ranges).
- . Amount of information presented by voice (i.e., number of specific parameters read off by CSM crewmember).
- . "On-demand" information vs. continuous ("GCA type") presentation of docking parameters.

(b) Approach Profile Difficulty Level

- . Variations in degree of off-nominal IC's.

(2) Estimated Simulator Flight Time = 20 flight hours to be carried out in one (1) study phase.

h. Malfunction Detection and Correction

A major influence on pilot performance which should shape vehicle design and flight procedures, is crewmember capability to respond to vehicle malfunctions or degraded conditions. Of particular interest is the effect of such occurrences upon manual vehicle control (and subsequently, on vehicle trajectory characteristics) during critical portions of any given mission phase.

(1) Study Variables(a) Time of Malfunction Insertion

- . Minimum of two (2) "worst-case" insertion points for terminal docking phase (e.g., at initiation, 90° pitchover, just before docking contact).

(b) Malfunction Type (and Complexity Level)

- . Minimum of two (2) malfunctions during separation or docking maneuver each at different "complexity levels"

(based upon difficulty of diagnosis and number of responses required to correct the malfunction).

- (2) Estimated Simulator Flight Time = 35 hours to be carried out over three (3) study phases.

Estimated Total Simulator Flight Time for all Separation and Docking Phases of Study = 380 flight hours.

i. Pressurized vs. Unpressurized Suit Conditions

It is intended that all of the above docking studies would be conducted under pressurized and unpressurized suit conditions. Variations in this condition can influence other study variables owing to effects of suit restriction on crewmember mobility and on visual capability with the helmet donned and the visor down.

SEPARATION AND DOCKING (IIIB)

STUDY MATRIX #1

Introduction

Listed below are 5 specific studies in order of priority, for the first 80 hours of simulator flight time. Details of the variables planned and the total number of study trials required for these initial 80 hours of the separation and docking phase are presented.

It is assumed that an average of six trials per simulator flight hour can be achieved and that six pilot-subjects will fly at least two trials under each study condition. All flights for this initial study phase are to be carried out with a single crew member in the Commander's position. Studies selected are based upon requirements arrived at by the LEM Crew Systems, Dynamics and Flight Control Groups. Values for the study variables are specified, in most instances, although several remain to be derived prior to the beginning of simulator test flights (e.g., cg offset values; off nominal IC's.).

Study #1 Overhead Docking Approach Technique

An initial study is necessary to define a nominal overhead docking technique for use throughout the remaining studies.

This first study will utilize a nominal vehicle configuration, with an empty ascent stage, attitude hold mode for the RCS, a simple sighting reticle in the cockpit and nominal exterior lighting conditions (i.e., CSM in sunlight).

Three conditions are planned for evaluation:

(1) Rotation Near CSM

Approach front-face from 175 feet to 30 feet - arriving at 30 feet with "h" and "z" variations visually nulled and \dot{s} reduced to approximately 1 fps. or less (based on visual judgement). Begin 90° pitchover at about a distance of 30 feet from the CSM and at a rate of $10^\circ/\text{sec.}$ so that pitchover is completed prior to arriving at about 20 feet of range. Translate along "+x" axis to docking contact using the overhead window.

(2) Rotation at Distance from CSM

Approach front-face from 175 feet to 75 feet nulling h and z variations. \dot{s} should be reduced to approximately 2 ft./sec. (based on displayed information) begin $10^\circ/\text{sec.}$ rotation at 75 feet. Complete 90° rotation to overhead docking by about 55 feet range from CSM. Translate along "+x" to contact reducing \dot{s} as required.

(3) Overhead Docking Under Off - Nominal IC's

Approach front face from 175 feet without nulling of h and z variations. Rotate to overhead position at 75 feet as in condition # (2) above.

Null all h and z variation (visually) after rotation is achieved. Complete overhead docking maneuver.

Test Trials Required

Two (2) trials for each of six (6) subjects under each of the three (3) conditions. Total number of test trials = 36.

Study #2 Docking Targets and Optical Devices

The Nominal overhead docking technique as derived in Study #1 is to be used, with all other vehicle conditions nominal.

(a) Target Conditions

- (1) No target markings and no reticle.
- (2) Reticle only; no target marking.
- (3) Target marking scheme #1 (present nominal scheme)* with reticle.
- (4) Target marking scheme #2 (alternate scheme) with reticle.*

(b) Initial Docking Conditions

- (1) Nominal IC position (h and z = 0, velocities nominal)
- (2) Off-nominal IC position (+h, -z, excessive velocities)
- (3) Off-nominal IC position (-h, +z, excessive velocities)

Test Trials Required

Two (2) trials flown by each of six (6) subjects under each of twelve (12) conditions.

Total number of test trials estimated = 144.

Study #3 Abort at Separation

This study provides for variations in inertia by varying the point at which the abort is initiated following separation. The target marking and reticle combination would be the optimum one determined in Study #2 along with nominal vehicle configuration and overhead docking technique. All other conditions would be nominal.

*Marking schemes #1 and #2 entail the use of 2 inch wide painted strips in one case and a "bulls-eye" target in the other as illustrated in Enclosure (2) to LIR-480-30, dated 13 August 1964.

(1) Immediate Abort After Separation

At 15 feet distance from CSM, following separation; LEM turns around and completes docking (i.e., dock with full ascent and descent stages).

(2) Abort Just Prior to Powered Insertion

Abort at 500 feet, turn around and return for overhead dock with full ascent and descent stages (this also provides data for the nominal separation profile up to the point of abort).

(3) Abort and Stage Descent Engine

Separate to 500 feet as in #2 above and abort, staging descent engine. Return for overhead dock with full ascent stage.

Test Trials Required

Two trials would be flown by each of six (6) pilots under each of the three (3) conditions.

Total number of test trials estimated = 36.

Study #4 CG Offset Evaluation

Nominal overhead docking maneuver would be used from an initial range of 175 feet. Vehicle initial position should be off nominal (+s, + z). All other conditions should be nominal.

- (1) No CG offset.
- (2) CG offset - (residuals in ascent tanks)
- (3) CG offset - (1/2 RCS propellant unbalance)
- (4) CG offset - (full RCS propellant unbalance)
- (5) Double control weight CG values.

Test Trials Required

Two (2) trials flown by each of six (6) pilots under each of the five (5) conditions.

Total number of test trials estimated = 60.

Study #5

Use worst case(s) CG offset as derived from Study #4. All other vehicle conditions and procedures nominal.

(a) Flight Control Modes

- (1) Direct (pitch axis only, 2 jet rotational authority)
- (2) Direct (all axes, 2 jet authority)
- (3) Rate command (all axes)
- (4) Pulse (pitch axis only)

(b) Initial Conditions

- (1) Minor off nominal (+h, +z and low \dot{s})
- (2) Major off nominal (+h, +z and high \dot{s})

(c) RCS System Failure

- (1) No failure.
- (2) RCS System A failure.

Test Trials Required

Two trials flown by each of six (6) pilots under each of 16 study conditions, results in a total of 192 trials.

The total number of trials required for the first 80 hours of simulator flight time would be a maximum of 468 trials.

PART IX

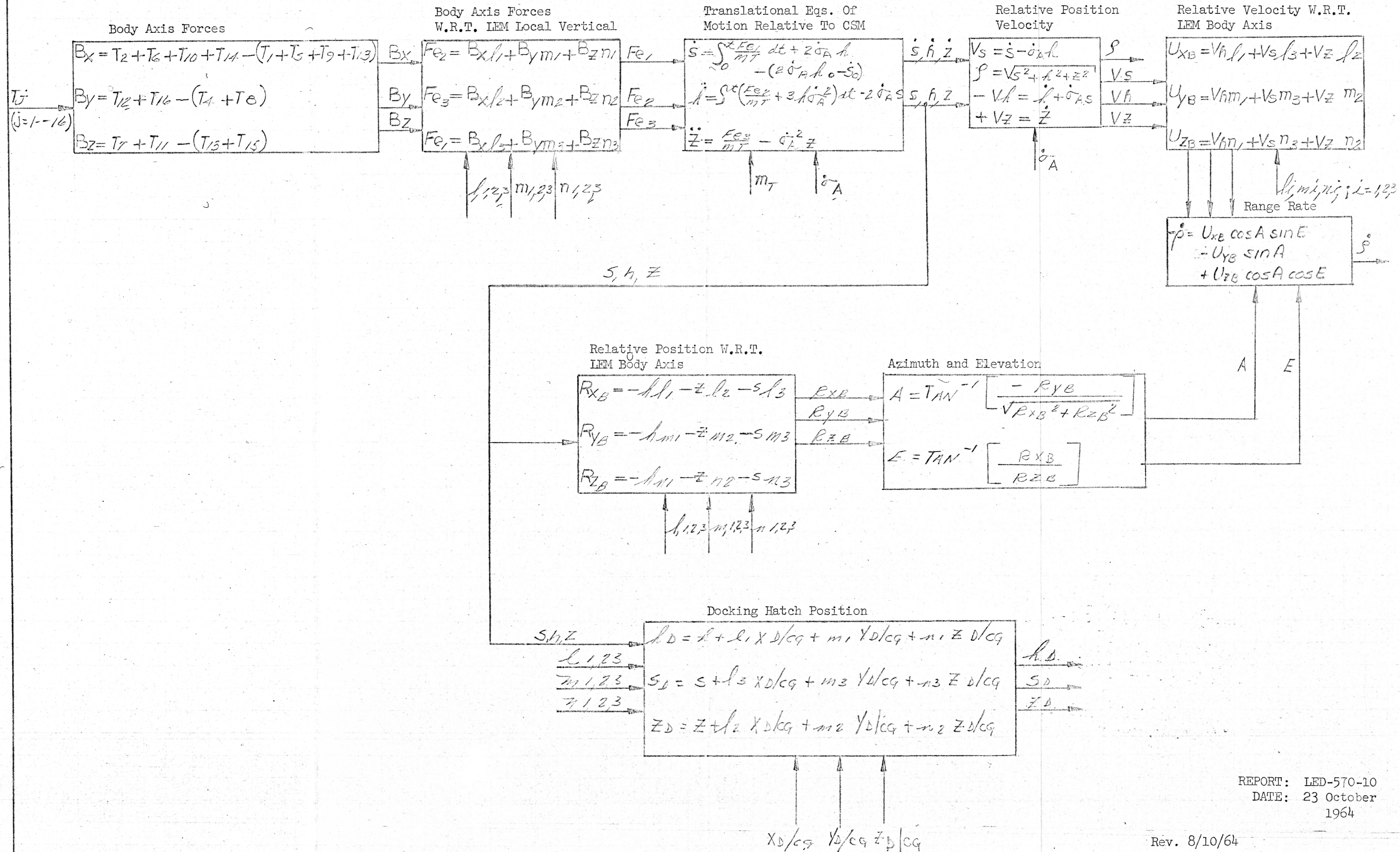
R E F E R E N C E S

- A Burri, H.U., "Linearized Equations of Motion of a Mass Particle in a Central Force Field," RCA Systems Memo.
- B IMO-500-152 - 4 March 1964 - LEM Flight Control System for the Phase IIB Simulation - H. Satz.
- C LAV-290-61 - 7 May 1964 - Revisions to Phase IIB Simulation - H. Otten.
- D IMO-500-94 - LEM Attitude Control for IA2 Docking Simulation - R. Portroy, H. Satz.
- E IMO-480-120 - Pilot Training Program for Phase IIB and IIIB Simulation Studies - N. Freeberg, M. Pollack.

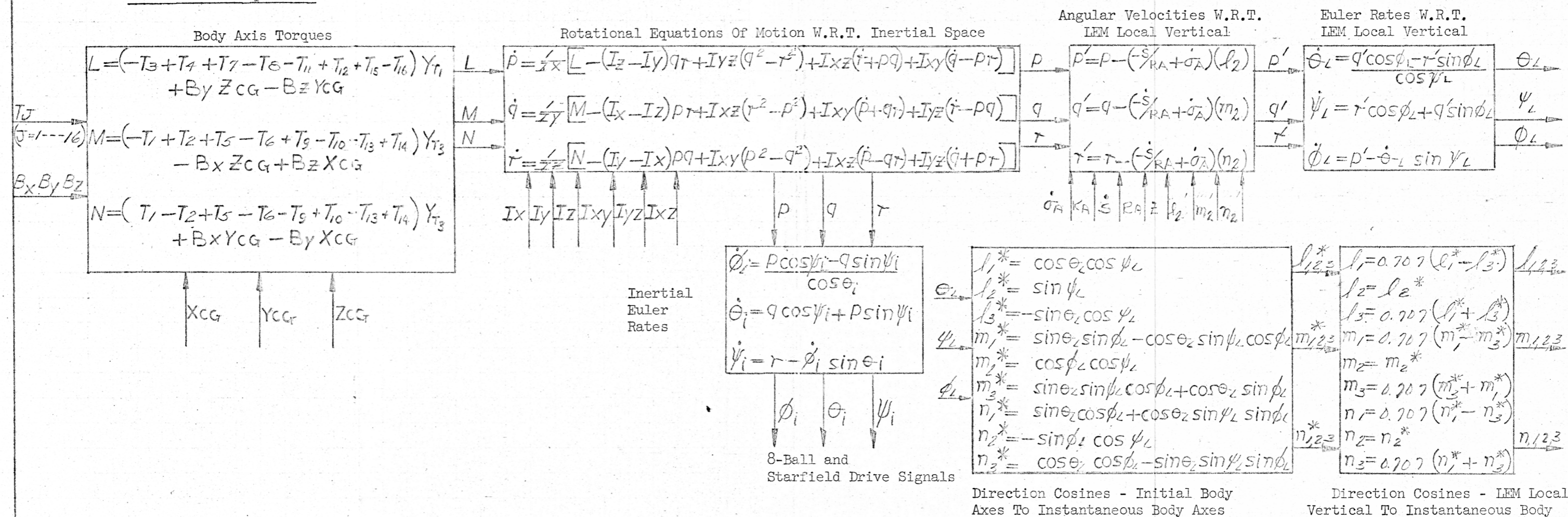
PART X

ILLUSTRATIONS

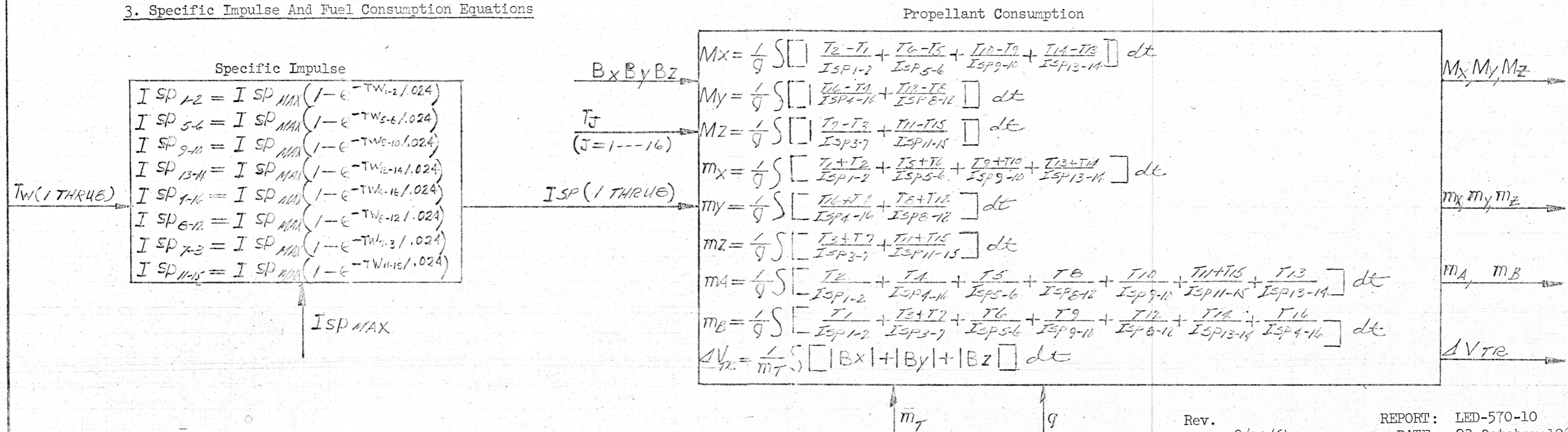
1. Translational Equations

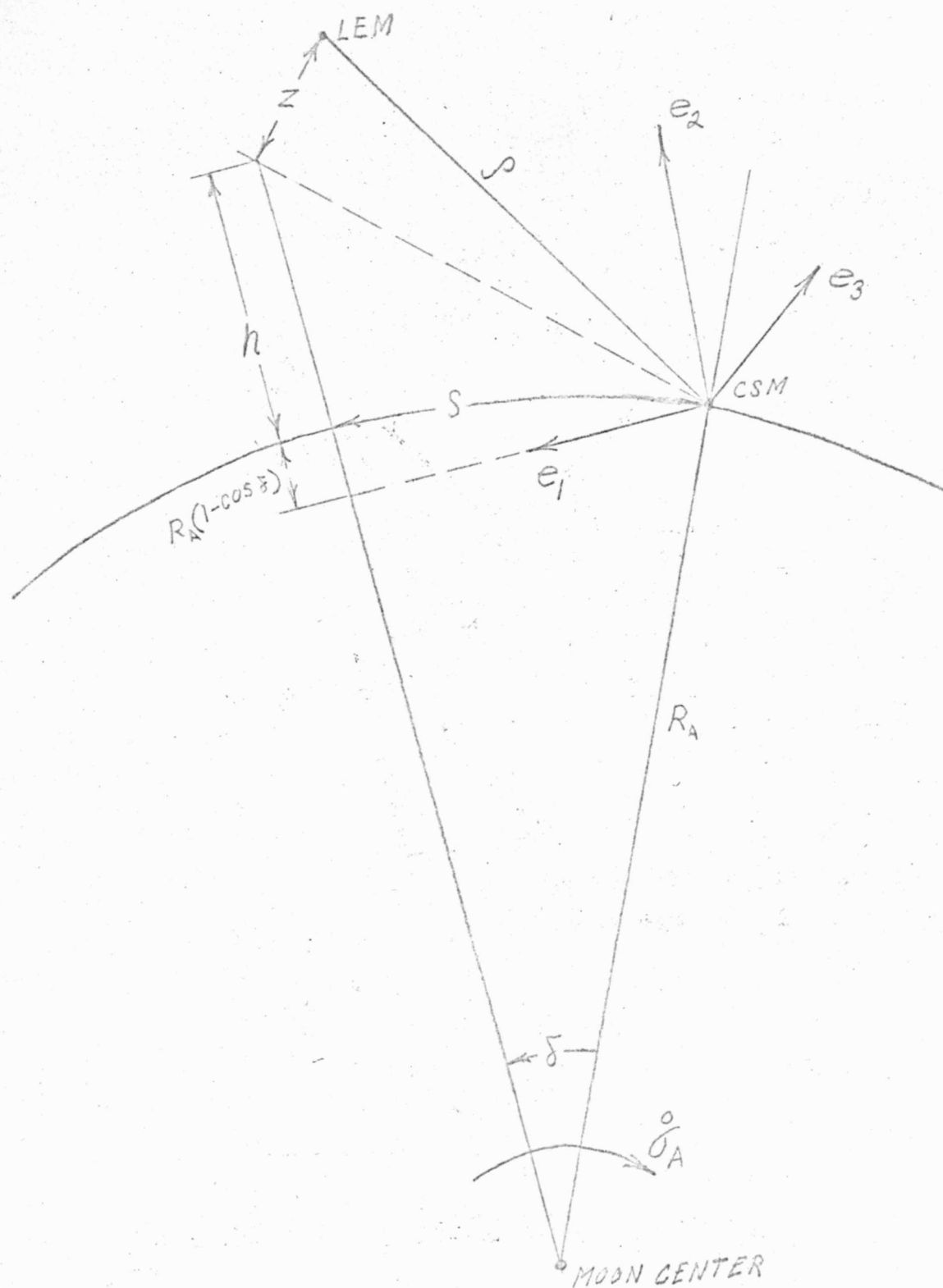


2. Rotational Equations



3. Specific Impulse And Fuel Consumption Equations





3. GEOMETRY OF CSM-LEM RELATIVE TRANSLATIONAL EQUATIONS OF MOTION

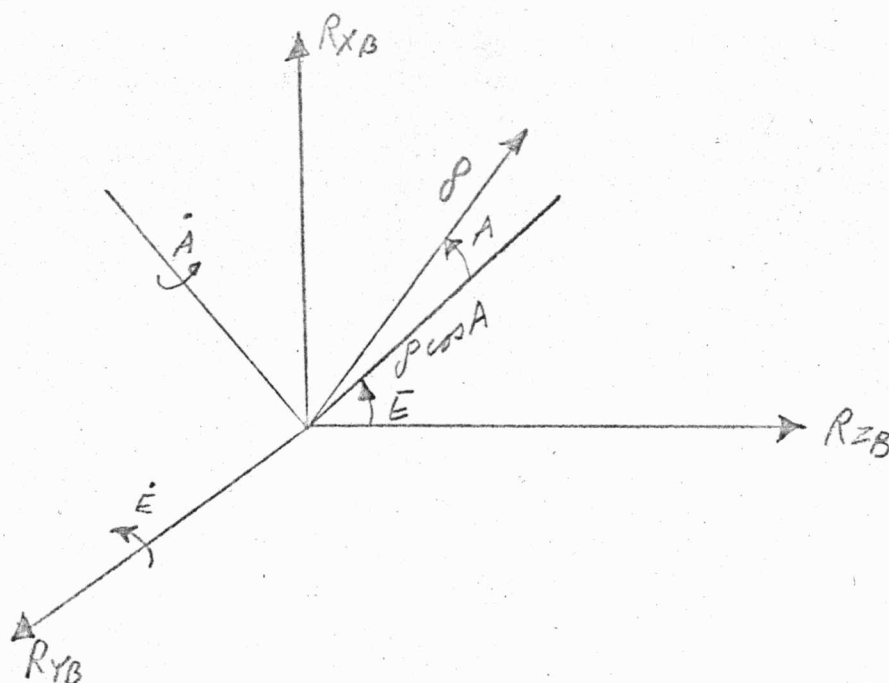
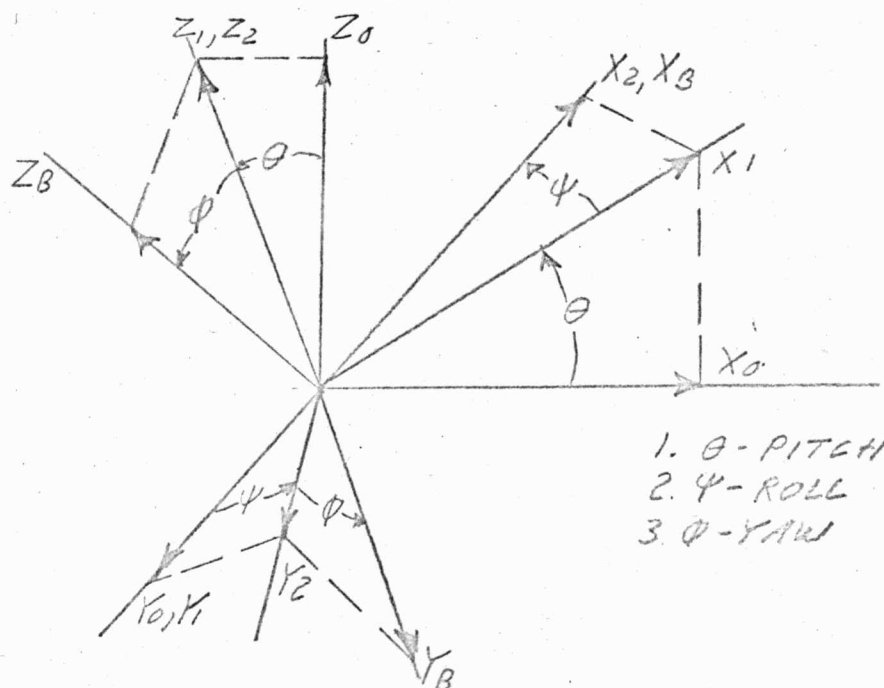


FIGURE 4 GEOMETRY OF RADAR
AZIMUTH AND ELEVATION



1. θ - PITCH
2. ψ - ROLL
3. ϕ - YAW

FIGURE 5 ORDER OF EULER ANGLE ROTATION

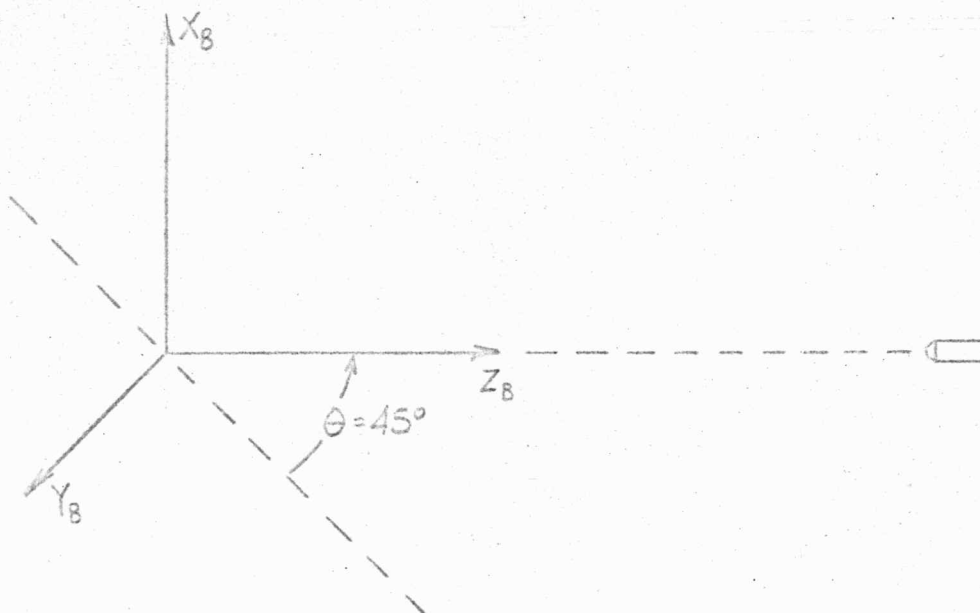


FIGURE 6. BIAS IN DEFINITION OF
LOCAL VERTICAL PITCH ANGLE

CONDITIONS

$$X_{T_1} = Y_{T_a} = Y_{T_m} = Z_{T_a} = Z_{T_m}$$

$$Y_{T_1} = Y_{T_2} = Z_{T_3} = Z_{T_4}$$

$$Y_{T_3} = Y_{T_4} = Z_{T_1} = Z_{T_2}$$

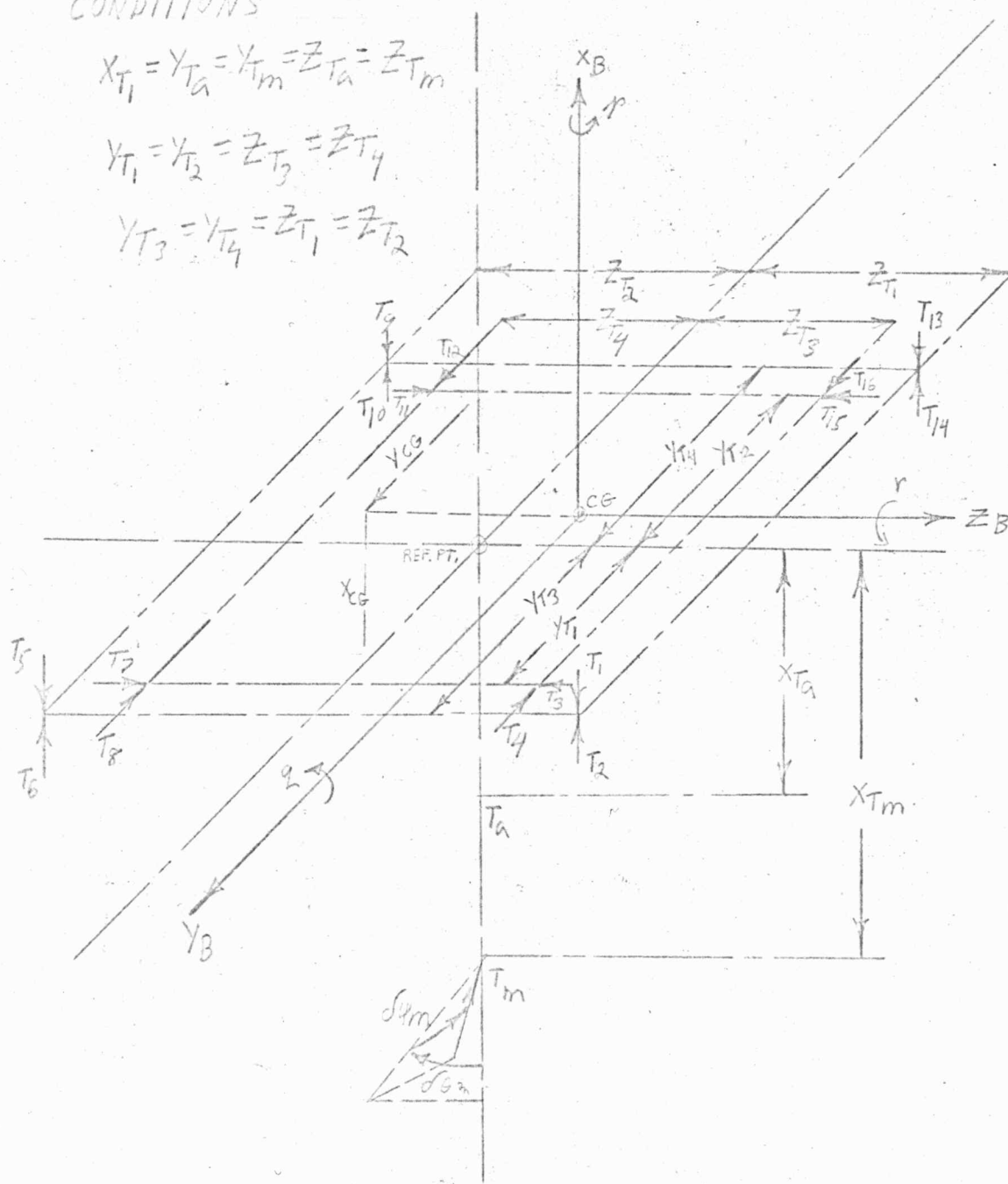


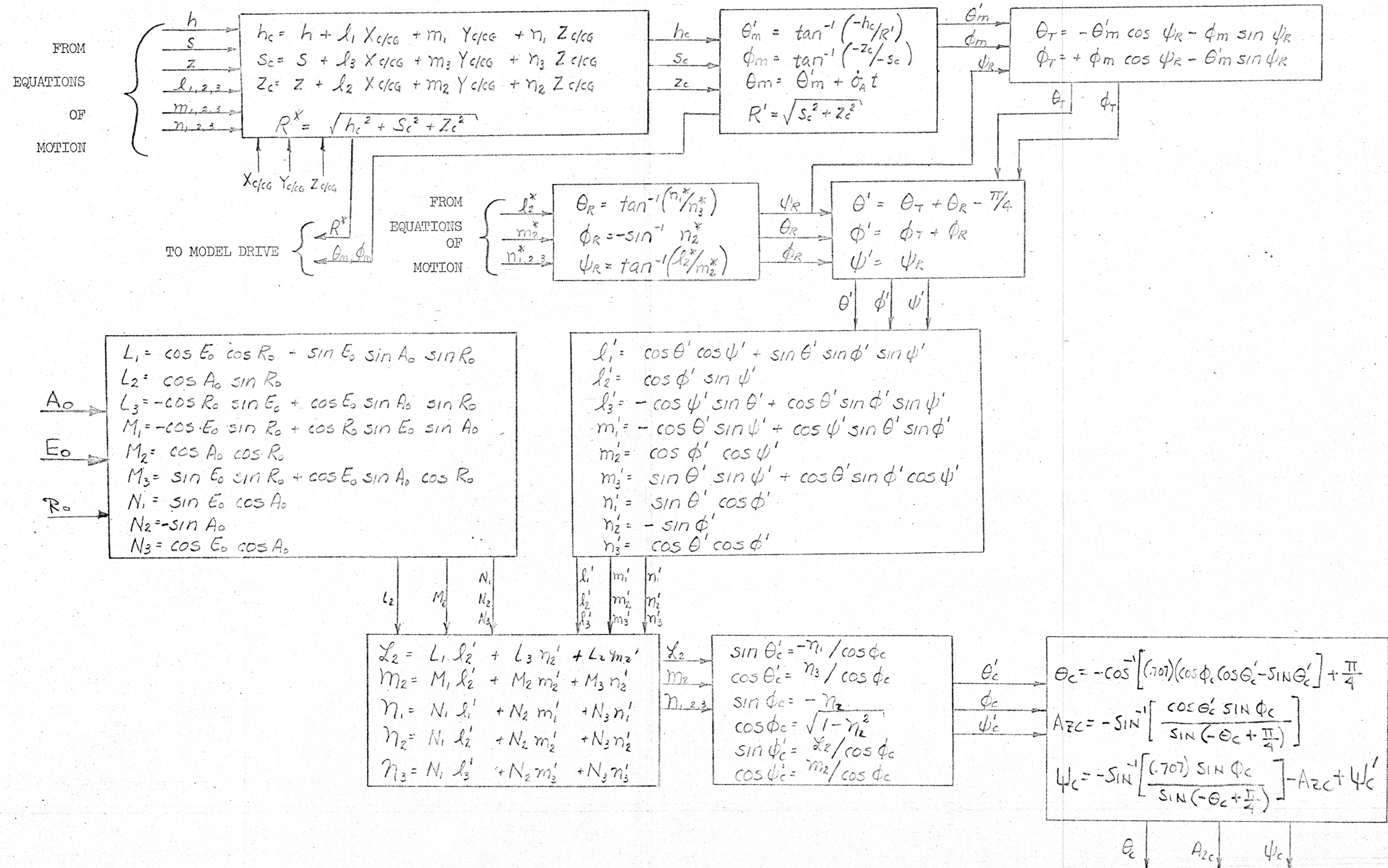
FIGURE 7. REACTION JET GEOMETRY

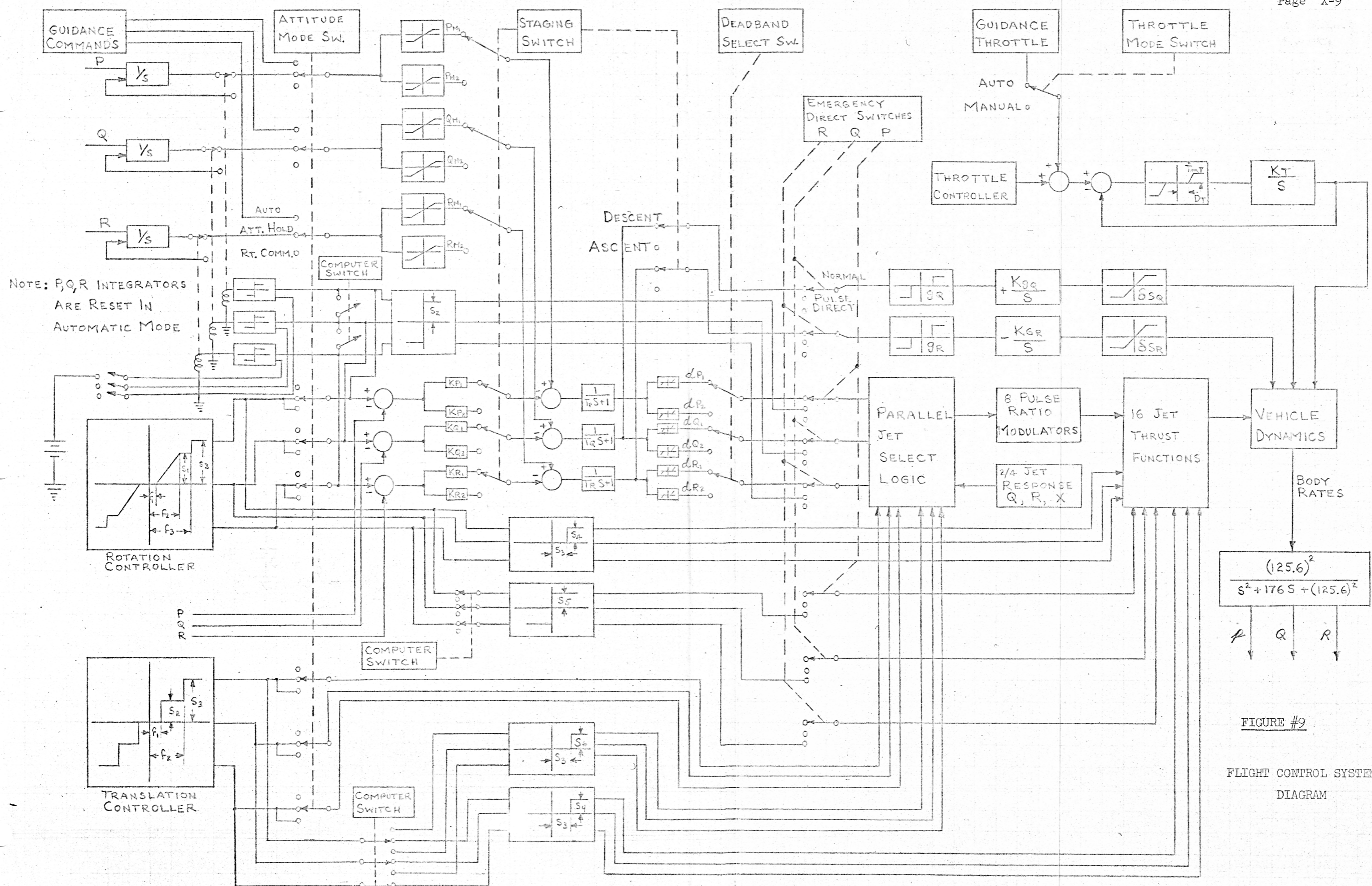
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Figure 8.

INTERIM INTERIM DISPLAYS





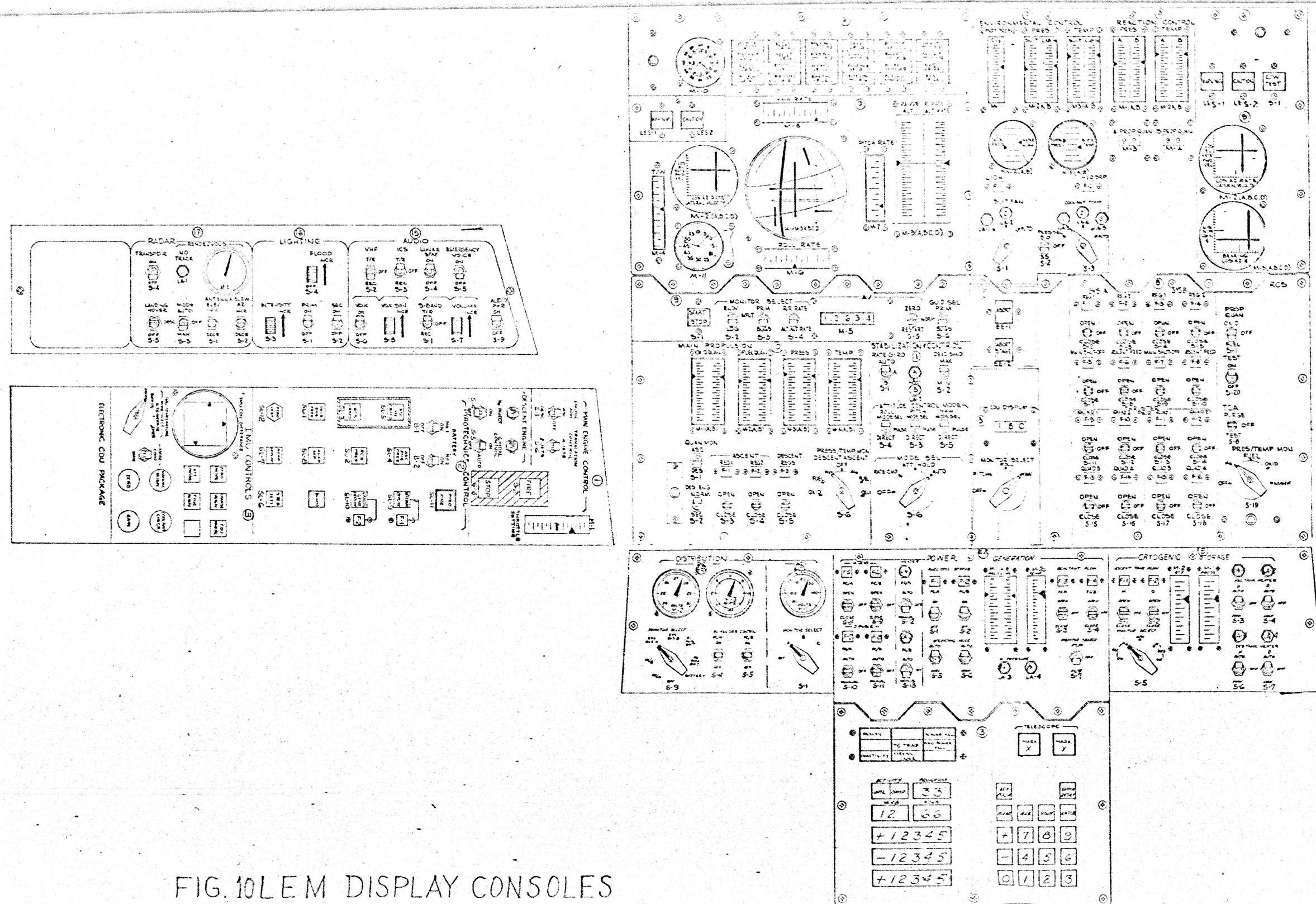
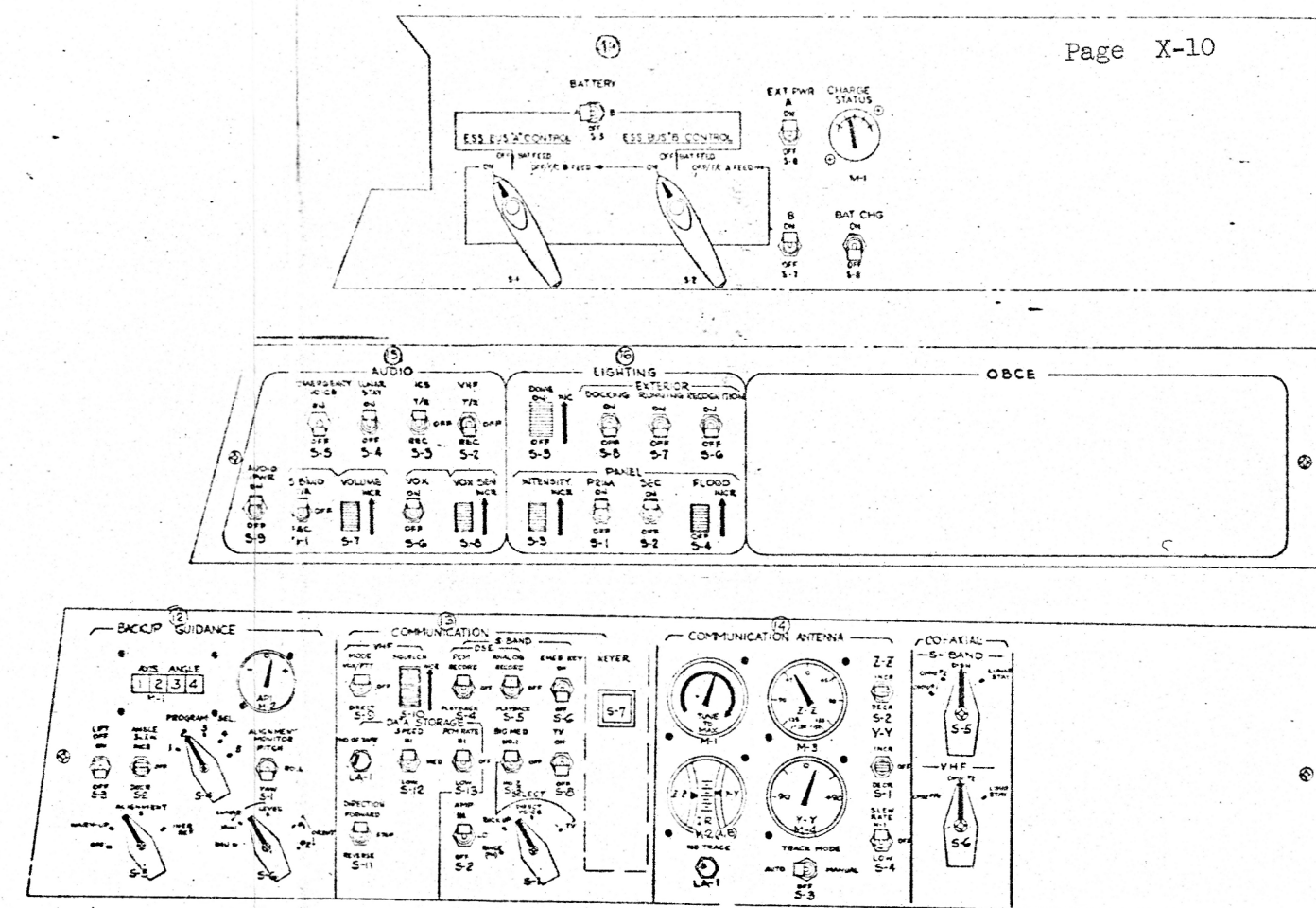


FIG. 10 LEM DISPLAY CONSOLES



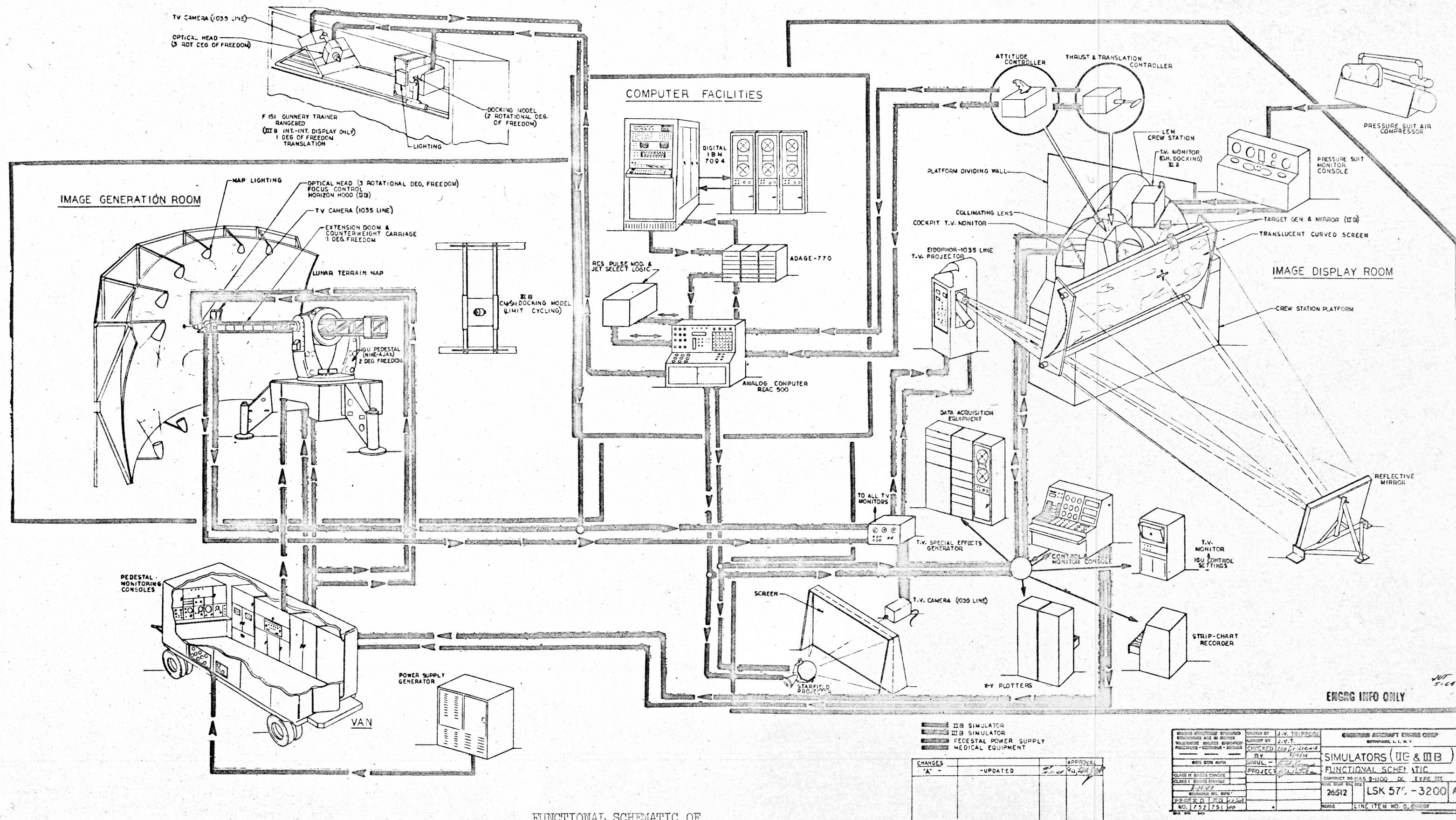


FIGURE #11

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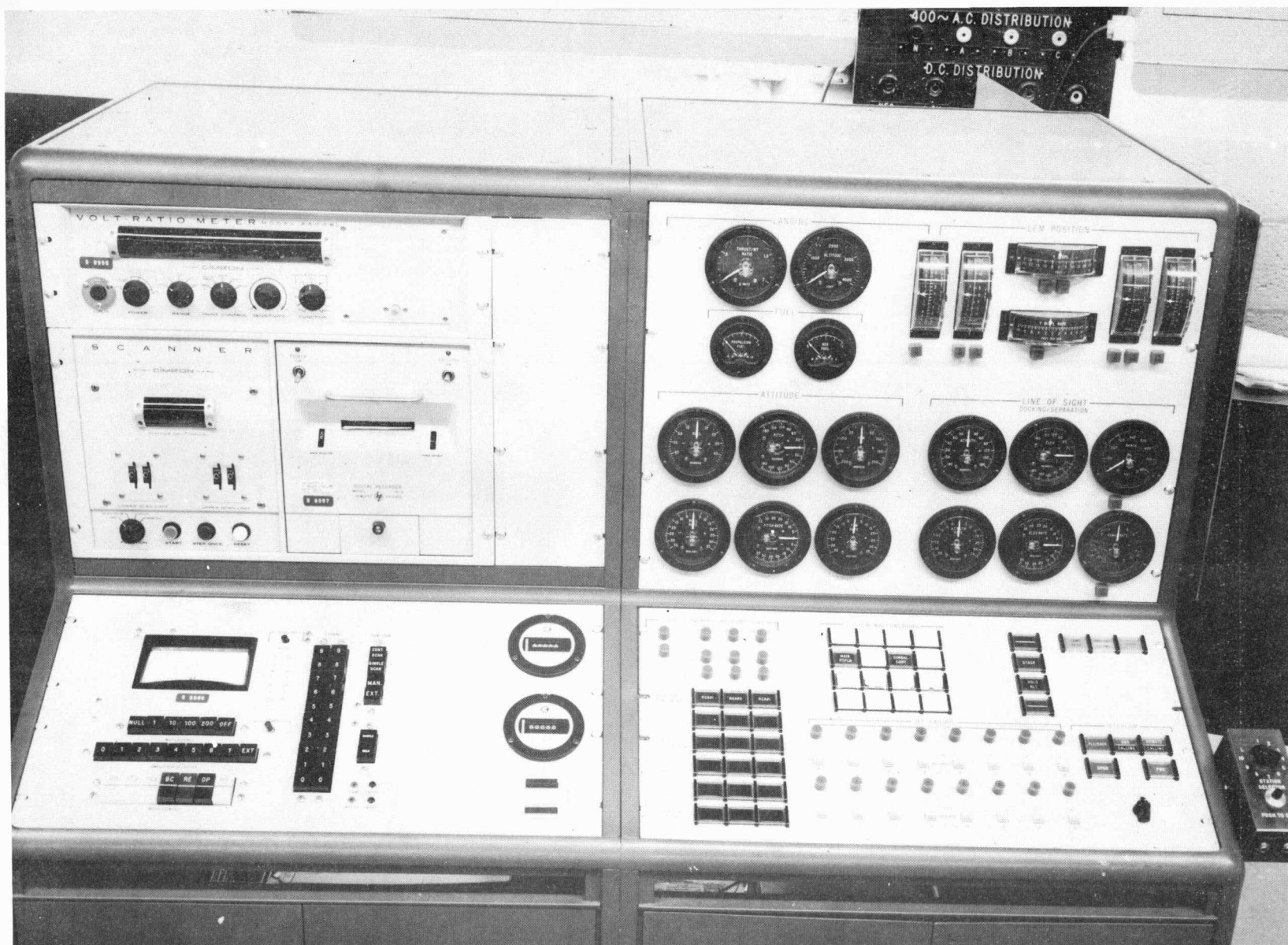


Figure #12 Monitor Console

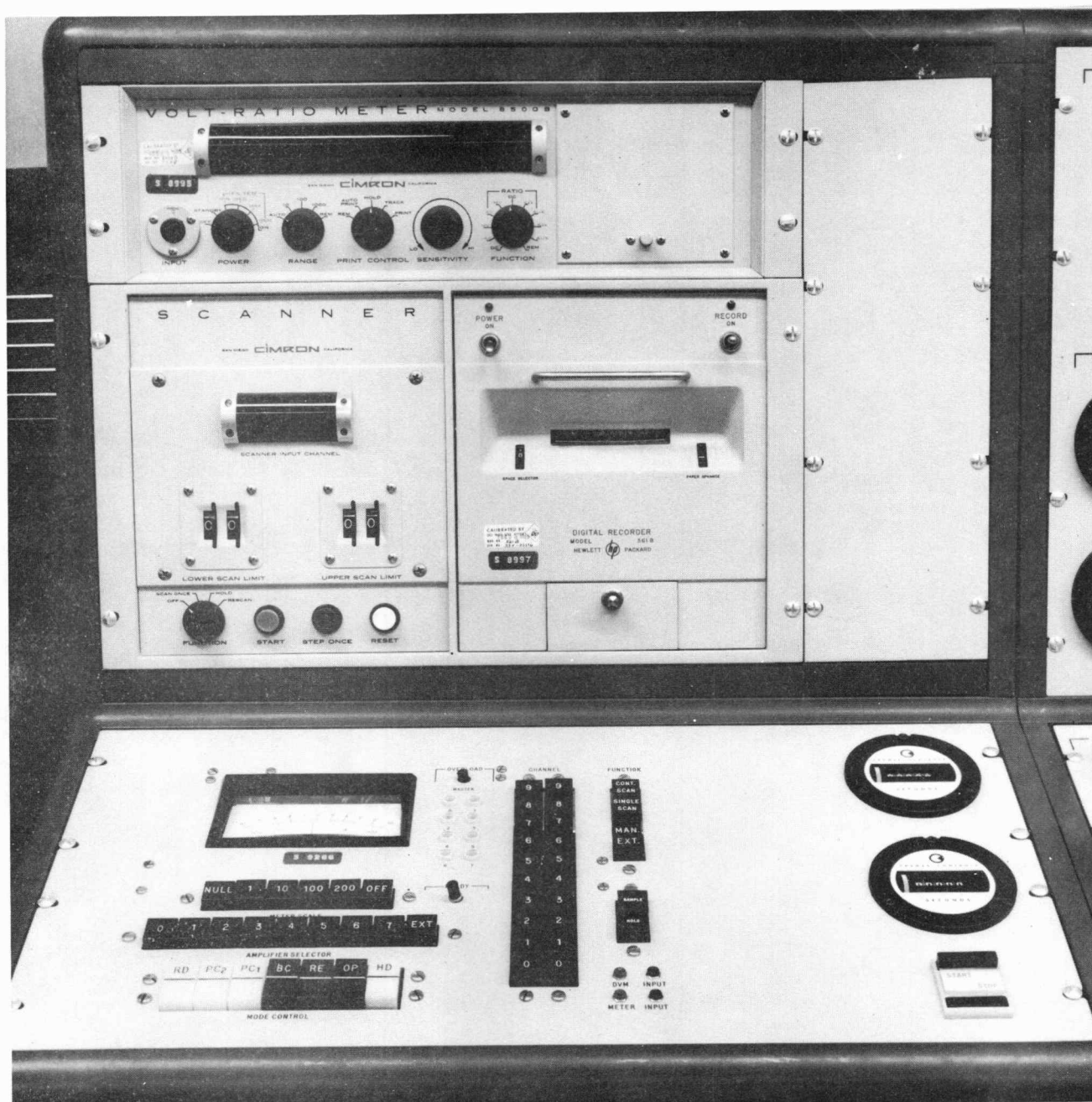


Figure #13 Monitor Console - Left Hand Section

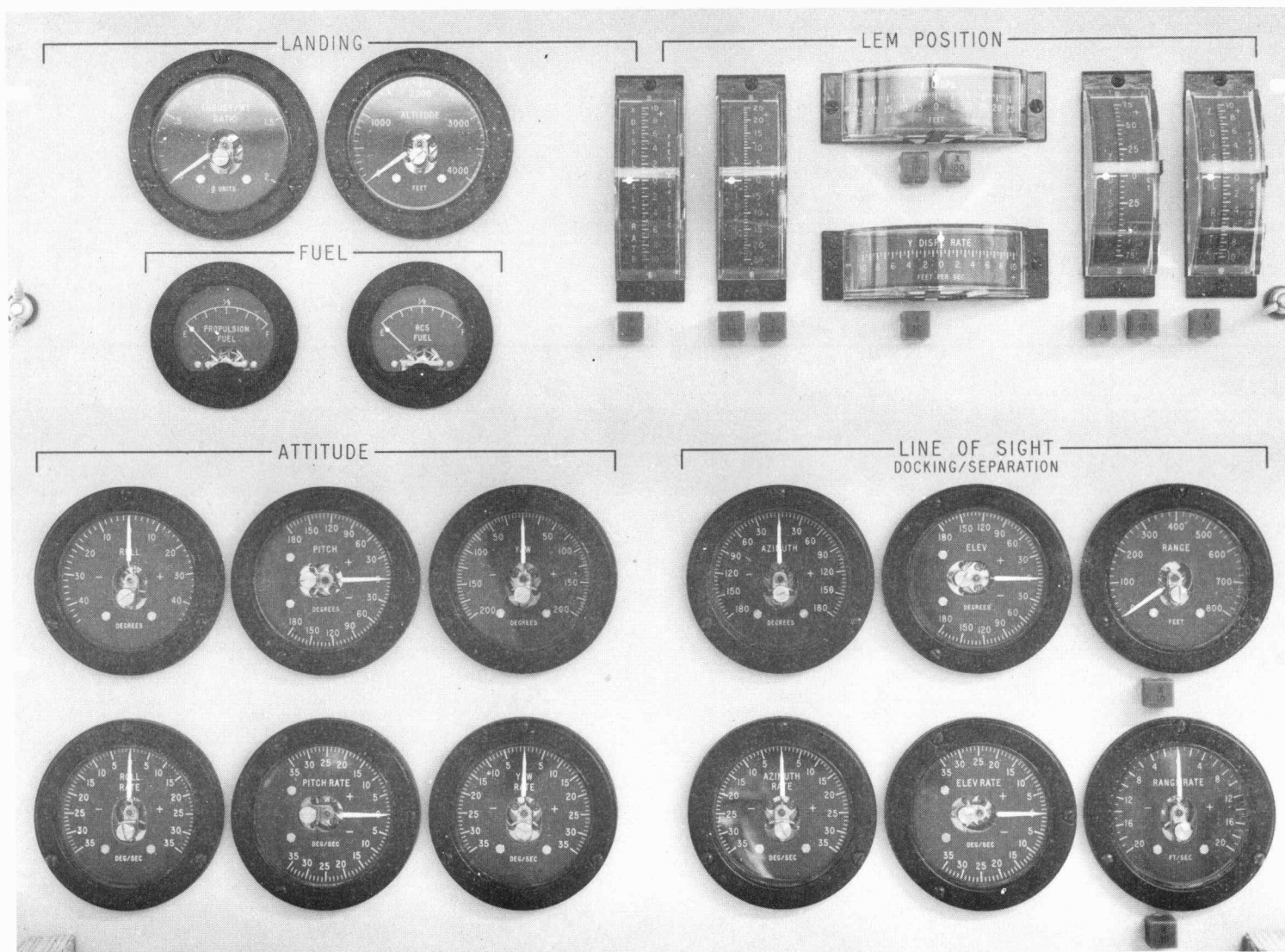


Figure #14 Monitor Console -Upper Right Hand Section

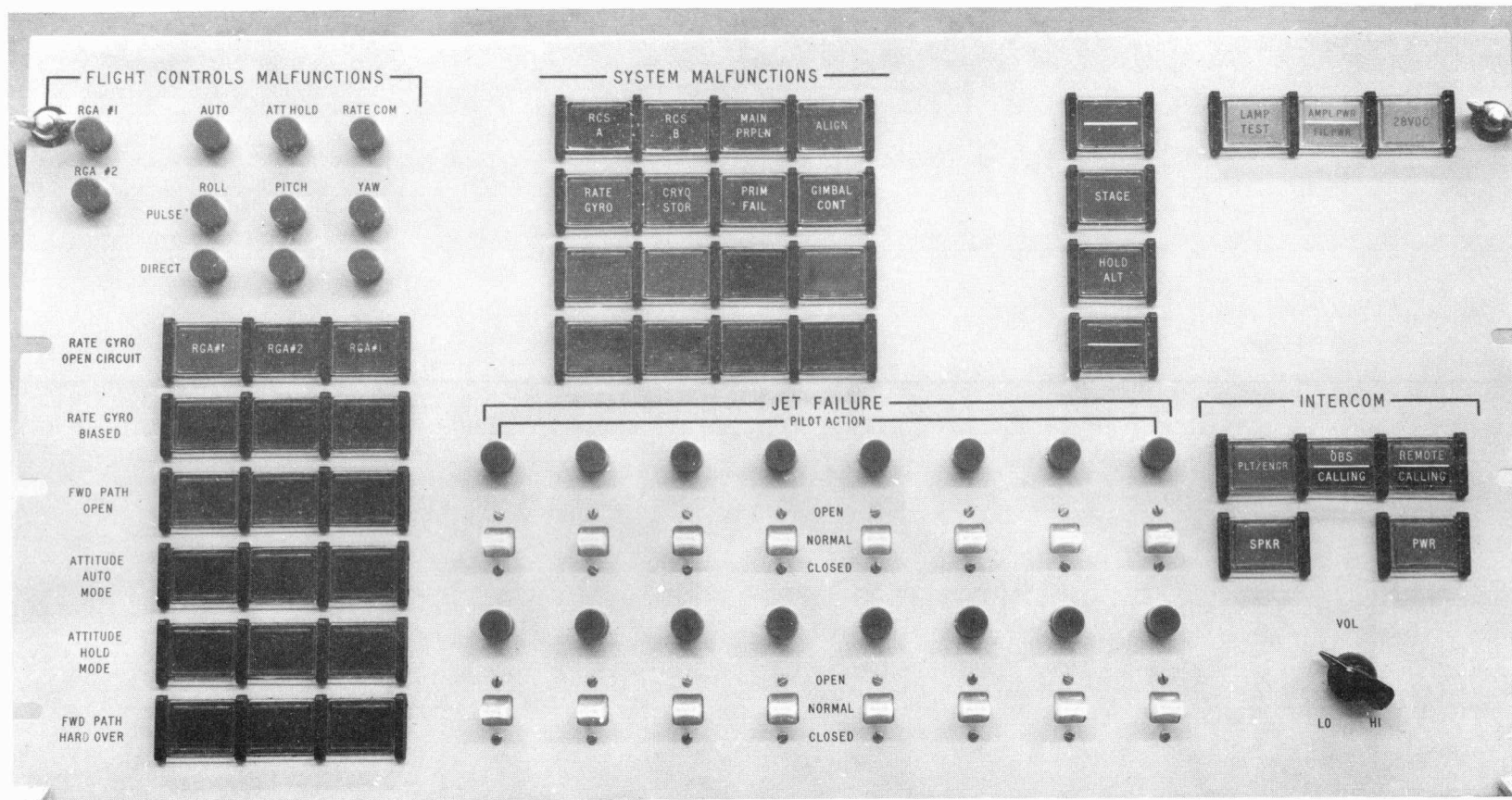


Figure #15 Monitor Console - Lower Right Hand Section



Figure #16 Digital Data Acquisition System

APPENDIX A

DEFINITION OF SYMBOLS FOR EQUATIONS OF MOTION

SYMBOL	Table I - Definition of Symbols DEFINITION	RANGE	UNIT
A	Azimuth Angle - Measured between LOS vector and its projection on X_B-Z_B plane	$\pm \pi/3$	RAD
B_x	Applied force along LEM X_B - Body axis	± 400	LBS.
B_y	Applied force along LEM Y_B - Body axis	± 200	LBS.
B_z	Applied force along LEM Z_B - Body axis	± 200	LBS.
E	Elevation Angle - measured bet. Z_B axis and proj. of LOS vector on X_B-Z_B plane	$\pm \pi/3$	RAD
F_{e1}	LEM local horizontal force-positive opposite to direction of motion of CSM	± 500	LBS.
F_{e2}	LEM local vertical force-positive away from lunar center	± 500	LBS.
F_{e3}	LEM local horizontal force-completes Rt. Handed System with F_{e1} and F_{e2}	± 500	LBS.
h	LEM-CSM relative radial displacement	± 500	FT.
h_o	Initial relative radial displacement	± 500	FT.
\dot{h}	Relative radial velocity	± 20	FT./SEC.
\dot{h}_o	Initial relative radial velocity	± 20	FT./SEC.
I_x	Moment of inertia about X_B - axis	1000 to 23000	SLUG-FT. ²
I_y	Moment of inertia about Y_B - axis	1000 to 23000	SLUG-FT. ²
I_z	Moment of inertia about Z_B - axis	1000 to 23000	SLUG-FT. ²
I_{xy}	Product of inertia in X-Y plane	200 to 300	SLUG-FT. ²
I_{yz}	Product of inertia in Y-Z plane	200 to 300	SLUG-FT. ²
I_{xz}	Product of inertia in X-Z plane	200 to 300	SLUG-FT. ²

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GRUMMAN AIRCRAFT ENGINEERING CORPORATION

SYMBOL	DEFINITION	RANGE	UNIT
L	Applied moment about X_B - axis	± 3000	FT.-LBS.
M	Applied moment about Y_B - axis	± 3000	FT.-LBS.
N	Applied moment about Z_B axis	± 3000	FT.-LBS.
p	Angular rate about X_B - axis	± 0.5	RAD/SEC.
\dot{p}	Angular acceleration about the X_B - axis	± 1.0	RAD/SEC. ²
q	Angular rate about Y_B - axis	± 0.5	RAD/SEC. ²
\dot{q}	Angular Acceleration about Y_B axis	± 1.0	RAD/SEC. ²
r	Angular rate about Z_B - axis	± 1.0	RAD/SEC.
\dot{r}	Angular acceleration about Z_B - axis	± 2.0	RAD/SEC. ²
R_{X_B}	CSM-LEM relative position in body axis X_B - direction	± 500	FT.
R_{Y_B}	CSM-LEM relative position in Y_B - body axis direction	± 500	FT.
R_{Z_B}	CSM-LEM relative position in Z_B - body axis direction	± 500	FT.
S	Relative displacement in CSM orbital direction - positive LEM behind CSM	± 500	FT.
S_0	Initial relative displacement in CSM orbital direction	± 500	FT.
\dot{S}	Relative velocity in CSM orbital direction	± 20	FT./SEC.
T_j $j = 1-16$	Reaction Jet Thrust Magnitudes	± 100	LBS.
U_{X_B}	CSM-LEM Relative Velocity in X_B - body axis direction	± 20	FT.
U_{Y_B}	CSM-LEM Relative Velocity in Y_B - body axis direction	± 20	FT.

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GRUMMAN AIRCRAFT ENGINEERING CORPORATION

SYMBOL	DEFINITION	RANGE	UNIT
U_{Z_B}	CSM-LEM Relative Velocity in Z_B - body axis direction	± 20	FT.
V_S	CSM-LEM Relative Velocity in LEM Local horizontal direction	± 20	FT./SEC.
V_h	CSM-LEM Relative Velocity in LEM Local vertical direction	± 20	FT./SEC.
V_Z	CSM-LEM Relative Velocity Perpendicular to the CSM orbital plane	± 20	FT./SEC.
X_{CG}	LEM CG Location in the X_B direction WRT the fixed Reference Point	± 0.25	FT.
Y_{CG}	LEM CG Location in the Y_B direction WRT the fixed Reference Point	+0.25 to -0.6	FT.
Z_{CG}	LEM CG Location in the Z_B direction WRT the fixed Reference Point	+1.7 to -0.25	FT.
Y_{T_1}	Distance between X_B axis and RCS Jets 3, 4, 7, 8, 11, 12, 15, 16	5.0	FT.
Y_{T_3}	Distance between Y_B and Z_B axes and RCS Jets 1, 2, 5, 6, 9, 10, 13, 14	5.5	FT.
Z	Relative normal displacement to CSM orbital plane	± 500	FT.
Z_o	Initial Relative Normal Displacement to CSM orbital plane	± 500	FT.
\dot{Z}	Relative Velocity normal to CSM orbital plane	± 20	FT./SEC.
\dot{Z}_o	Initial Relative Velocity Normal to CSM orbital plane	± 20	FT./SEC.
\ddot{Z}	Relative acceleration normal to CSM orbital plane	± 2	FT./SEC. ²
$l_{1,2,3}^*$	Direction Cosine relating LEM X_B body axis to LEM instantaneous body axes	± 1	
$m_{1,2,3}^*$	Direction Cosine relating LEM Y_B body axis to LEM instantaneous body axes	± 1	
$n_{1,2,3}^*$	Direction Cosine relating LEM Z_B body axis to LEM instantaneous body axes	± 1	
$\dot{\phi}_A$	CSM Longitude rate east to west	$\times 8.54716794 \times 10^{-4}$	RAD/SEC.

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SYMBOL	DEFINITION	RANGE	UNIT
P	Line of Sight CSM-LEM position vector	0-500	FT.
\dot{P}	Line of Sight CSM-LEM velocity vector	-5 to +20	FT./SEC.
h_c	Relative CSM - pilot eye position in h direction	± 500	FT.
s_c	Relative CSM - pilot eye position in s direction	± 500	FT.
z_c	Relative CSM - pilot eye position in z direction	± 500	FT.
h_D	Relative CSM - docking hatch position in s direction	± 500	FT.
s_D	Relative CSM - docking hatch position in s direction	± 500	FT.
z_D	Relative CSM - docking hatch position in z direction	± 500	FT.
I_{SP1-2}	Specific impulse - function of output of modulator for jets 1 - 2	0-270	SEC.
I_{SP5-6}	Specific impulse - function of output of modulator for jets 5-6	0-270	SEC.
I_{SP9-10}	Specific impulse - function of output of modulator for jets 9 - 10	0-270	SEC.
$I_{SP13-14}$	Specific impulse - function of output of modulator for jets 13 - 14	0-270	SEC.
I_{SP4-16}	Specific impulse - function of output of modulator for jets 4 - 16	0-270	SEC.
I_{SP8-12}	Specific impulse - function of output of modulator for jets 8 - 12	0-270	SEC.
I_{SP7-3}	Specific impulse - function of output of modulator for jets 7 - 3	0-270	SEC.
$I_{SP11-15}$	Specific impulse - function of output of modulator for jets 11 - 15	0-270	SEC.
$I_{SP11-15}$	Maximum value as RCS specific impulse	270	SEC.
M_x	RCS propellant used for translation with x - jets	0-4	SLUGS

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SYMBOL	DEFINITION	RANGE	UNIT
M_Y	RCS propellant used for translation with y - jets	0-4	SLUGS
M_Z	RCS propellant used for translation with z - jets	0-4	SLUGS
M_T	Total LEM mass	100 to 1000	SLUGS
p^l	Angular rate about X_B axis W.R.T. LEM local vertical	± 0.5	RAD/SEC.
q^l	Angular rate about Y_B axis W.R.T. LEM local vertical	± 0.5	RAD/SEC.
r^l	Angular rate about Z_B axis W.R.T. LEM local vertical	± 1.0	RAD/SEC.
θ_i	Inertial pitch angle	$\pm \pi$	RAD
ψ_i	Inertial roll angle	$\pm \pi/3$	RAD
ϕ_i	Inertial yaw angle	$\pm \pi$	RAD
$\dot{\theta}_i$	Inertial pitch rate	± 1	RAD/SEC.
$\dot{\psi}_i$	Inertial roll rate	± 2	RAD/SEC.
$\dot{\phi}_i$	Inertial yaw rate	± 1	RAD/SEC.
θ_L	Local vertical pitch angle	$\pm \pi$	RAD
ψ_L	Local vertical roll angle	$\pm \pi/3$	RAD
ϕ_L	Local vertical yaw angle	$\pm \pi$	RAD
$\dot{\theta}_L$	Local vertical pitch rate	± 1	RAD/SEC.
$\dot{\psi}_L$	Local vertical roll rate	± 2	RAD/SEC.
$\dot{\phi}_L$	Local vertical yaw rate	± 1	RAD/SEC.

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SYMBOL	DEFINITION	RANGE	UNIT
m_x	Total RCS propellant used with x - jets	0-4	SIUGS
m_y	Total RCS propellant used with y - jets	0-4	SIUGS
m_z	Total RCS propellant used with z - jets	0-4	SIUGS
m_A	Total propellant used by RCS system A	0-4	SIUGS
m_B	Total propellant used by RCS system B	0-4	SIUGS
ΔV	ΔV used for translation with RCS jets	0-30	FT/SEC.
R_A	CSM orbital altitude	6.188484.2 $\times 10^6$	FT.
g	Earth gravitational constant	32.174048	FT/SEC. ²
θ_m	Pitch model drive		RAD
ϕ_m	Yaw model drive		RAD
R^*	Range model drive	0-500	FT.
θ_c	Optical head elevation drive		RAD
ψ_c	Optical head derotation drive		RAD
A_{zc}	Optical head azimuth drive		RAD

APPENDIX BDEFINITION OF SYMBOLS AND VALUES
FOR FLIGHT CONTROL SYSTEM

g	$= .1 \text{ deg}$	gimbal command deadzone
K_g	$= .2 \text{ deg/sec}$	gimbal actuator speed
δ_s	$= \pm 5.5 \text{ deg}$	maximum gimbal angle
ω_n	$= 100 \text{ rad/sec}$	rate gyro natural frequency
ξ	$= .7$	rate gyro damping
d_{P_1}	$= .1 \text{ deg}$	thrust period attitude control deadzone
d_{Q_1}	$= .1 \text{ deg}$	
d_{R_1}	$= .1 \text{ deg}$	
d_{P_2}	$= 5 \text{ deg}$	coast period attitude control deadzone
d_{Q_2}	$= 5 \text{ deg}$	
d_{R_2}	$= 5 \text{ deg}$	
T_P	$= .01 \text{ sec}$	error signal filter time constant
T_Q	$= .01 \text{ sec}$	
T_R	$= .01 \text{ sec}$	

$$\left. \begin{aligned} K_{P_1} &= 1.5 \text{ sec}^{-1} \\ K_{Q_1} &= 1.5 \text{ sec}^{-1} \\ K_{R_1} &= 1.5 \text{ sec}^{-1} \end{aligned} \right\} \text{descent stage rate gain}$$

$$\left. \begin{aligned} K_{P_2} &= .35 \text{ sec}^{-1} \\ K_{Q_2} &= .35 \text{ sec}^{-1} \\ K_{R_2} &= .35 \text{ sec}^{-1} \end{aligned} \right\} \text{ascent stage rate gain}$$

$$\left. \begin{aligned} P_{\max} &= 5 \text{ deg/sec} \\ Q_{\max} &= 10 \text{ deg/sec} \\ R_{\max} &= 5 \text{ deg/sec} \end{aligned} \right\} \text{rate command limit in automatic mode}$$

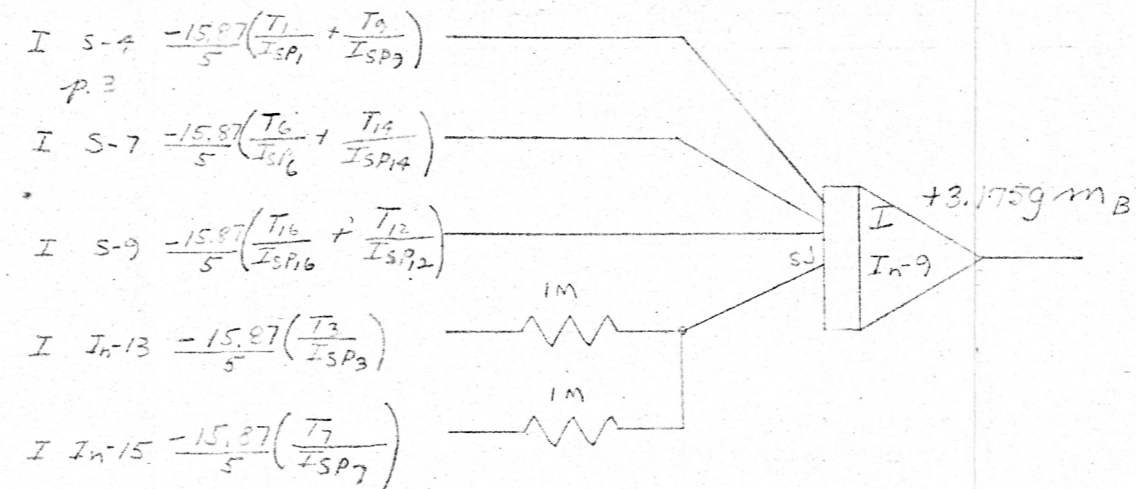
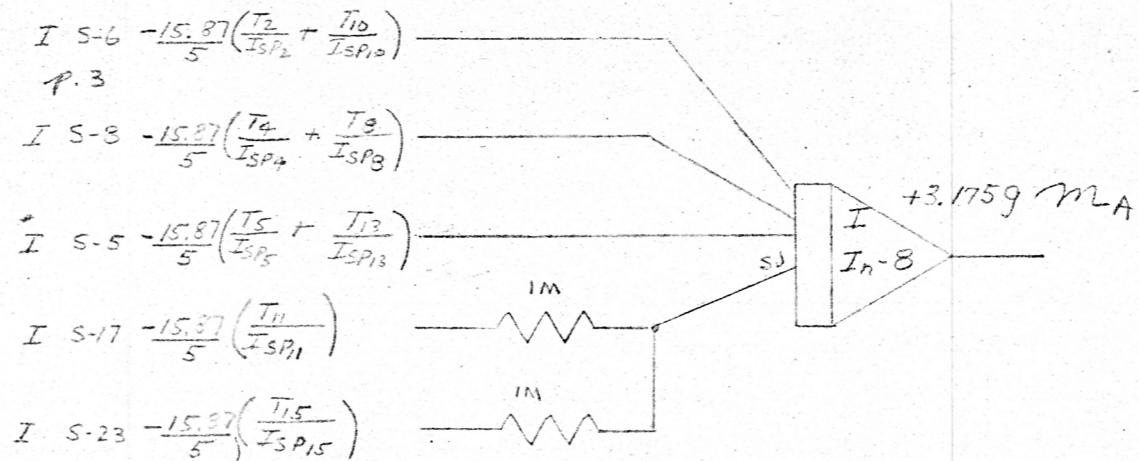
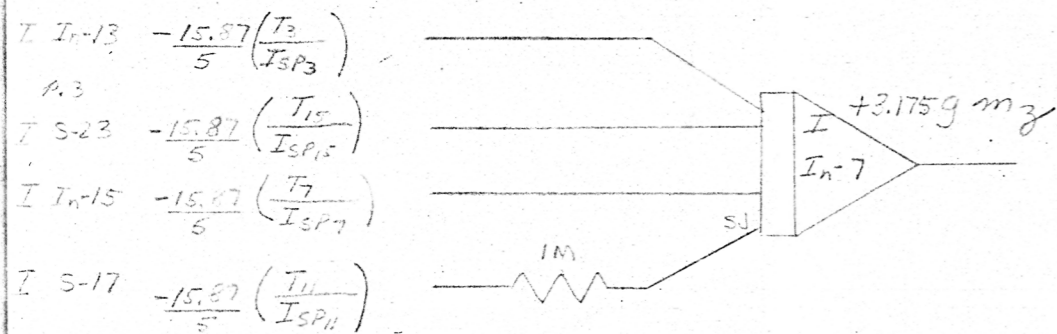
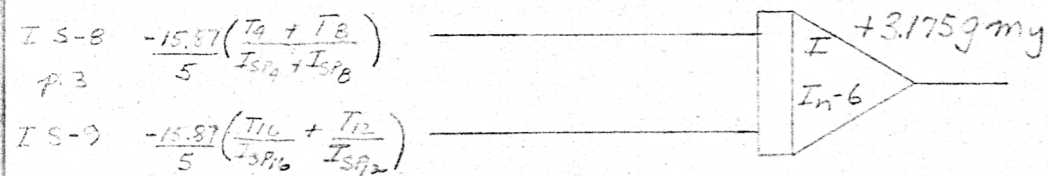
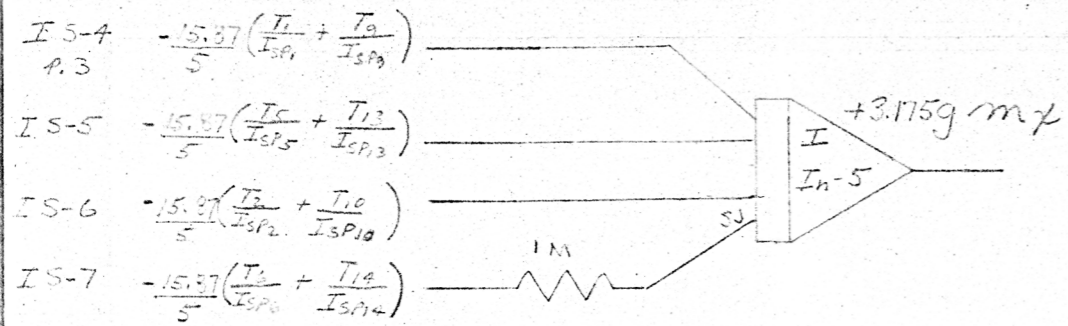
$$\begin{aligned} F_1 &= 5\% \text{ of full stick motion to either side} \\ F_2 &= 75\% \text{ of full stick motion to either side} \\ F_3 &= 90\% \text{ of full stick motion to either side} \end{aligned}$$

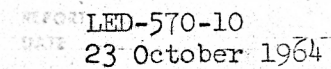
$$\left. \begin{aligned} S_1 \\ S_2 \\ S_3 \\ S_4 \\ S_5 \\ S_6 \end{aligned} \right\} \text{voltage levels necessary for the required logic and jet commands}$$

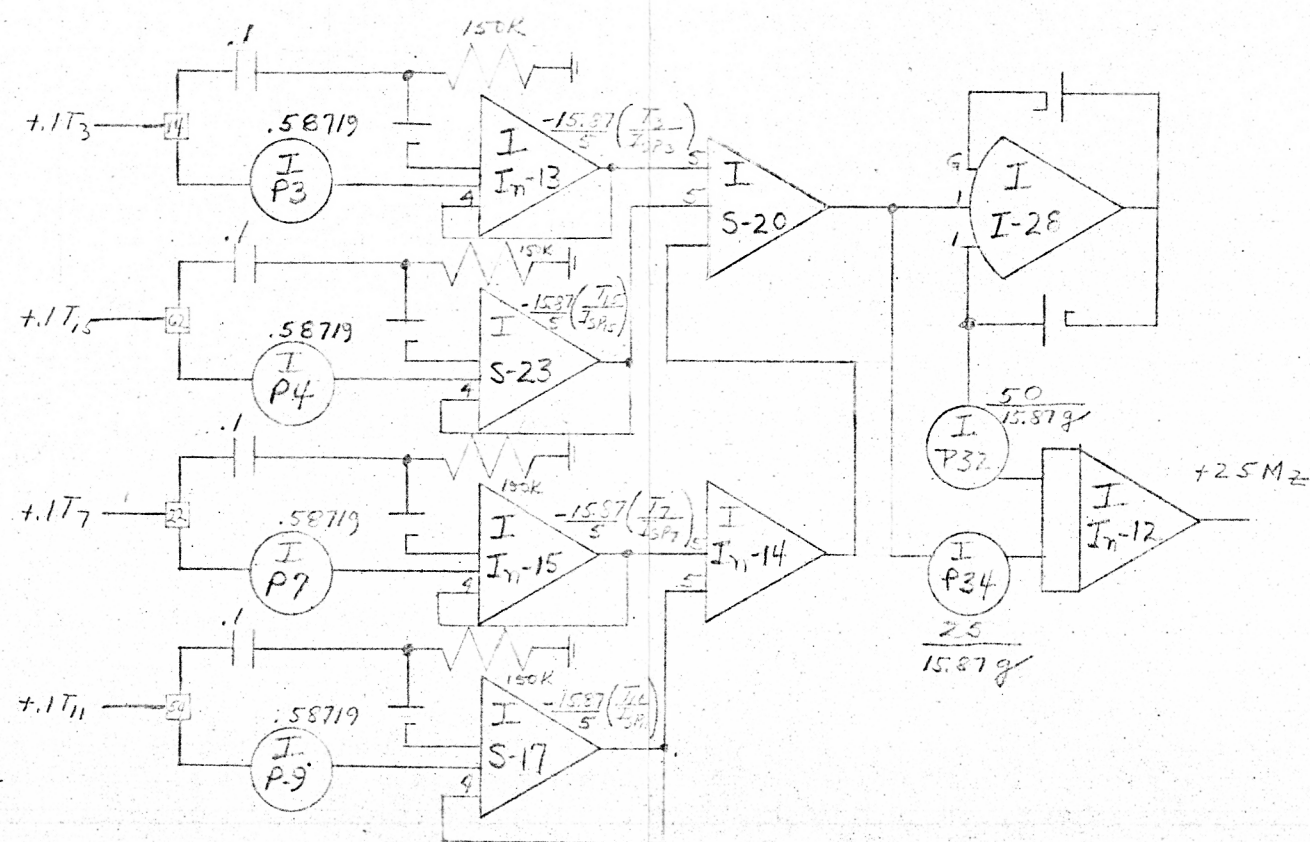
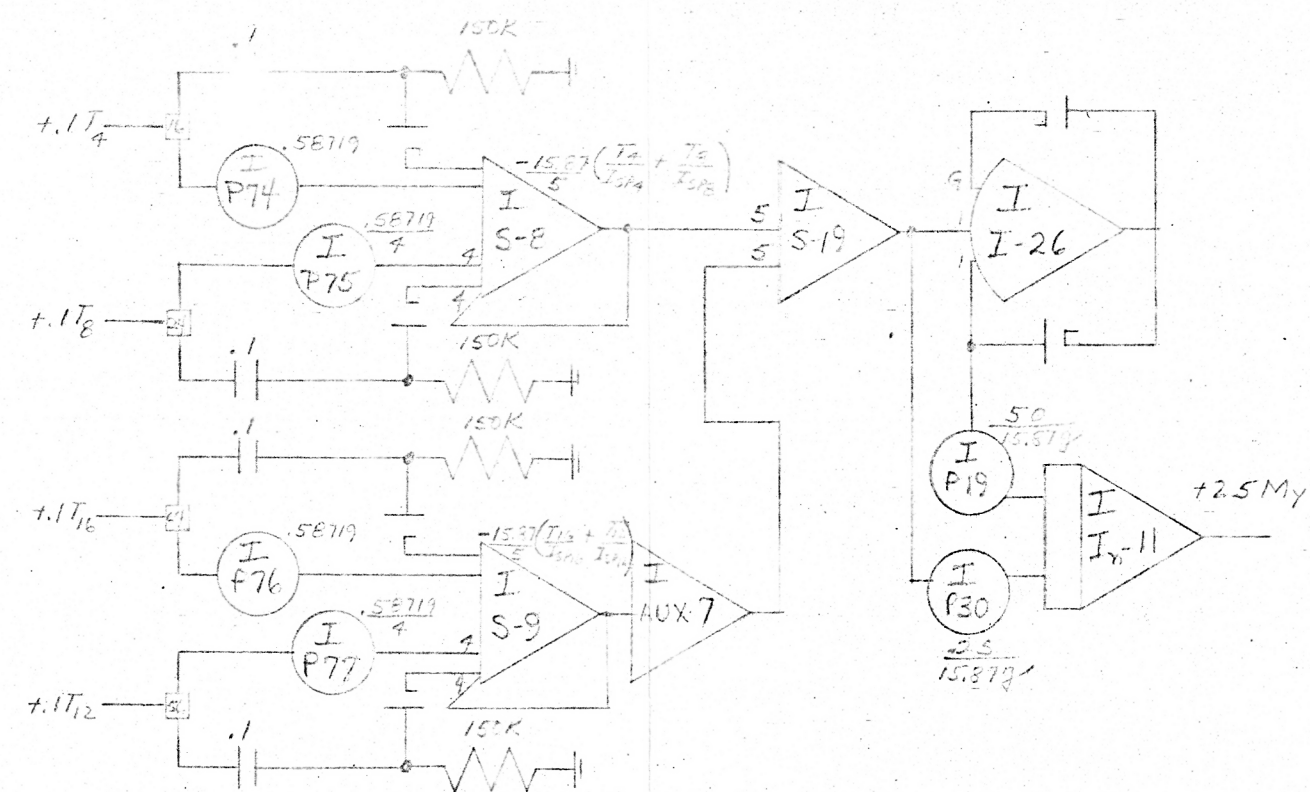
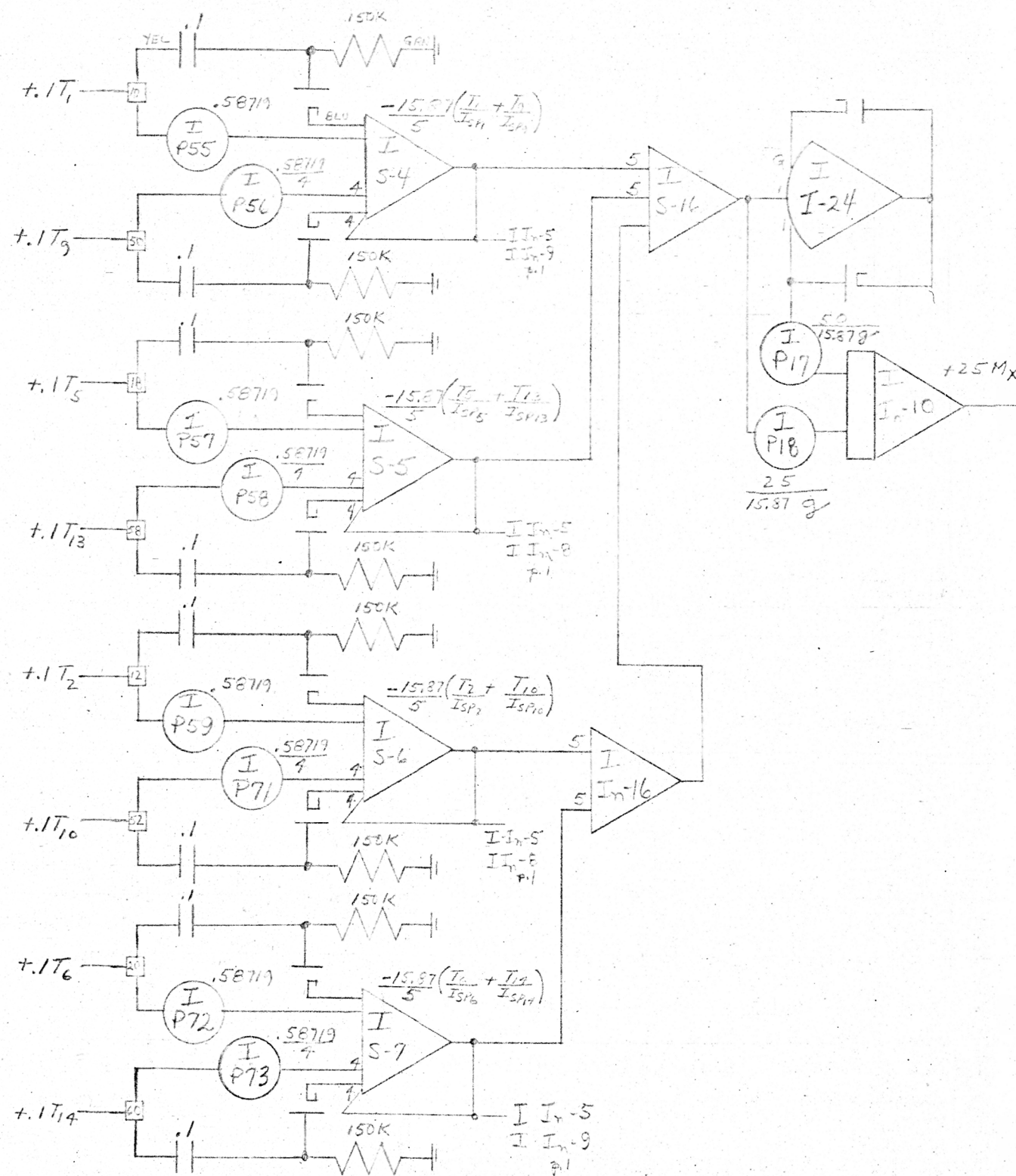
$$T_{TS} = .3 \text{ sec} \quad \text{throttle servo time constant}$$

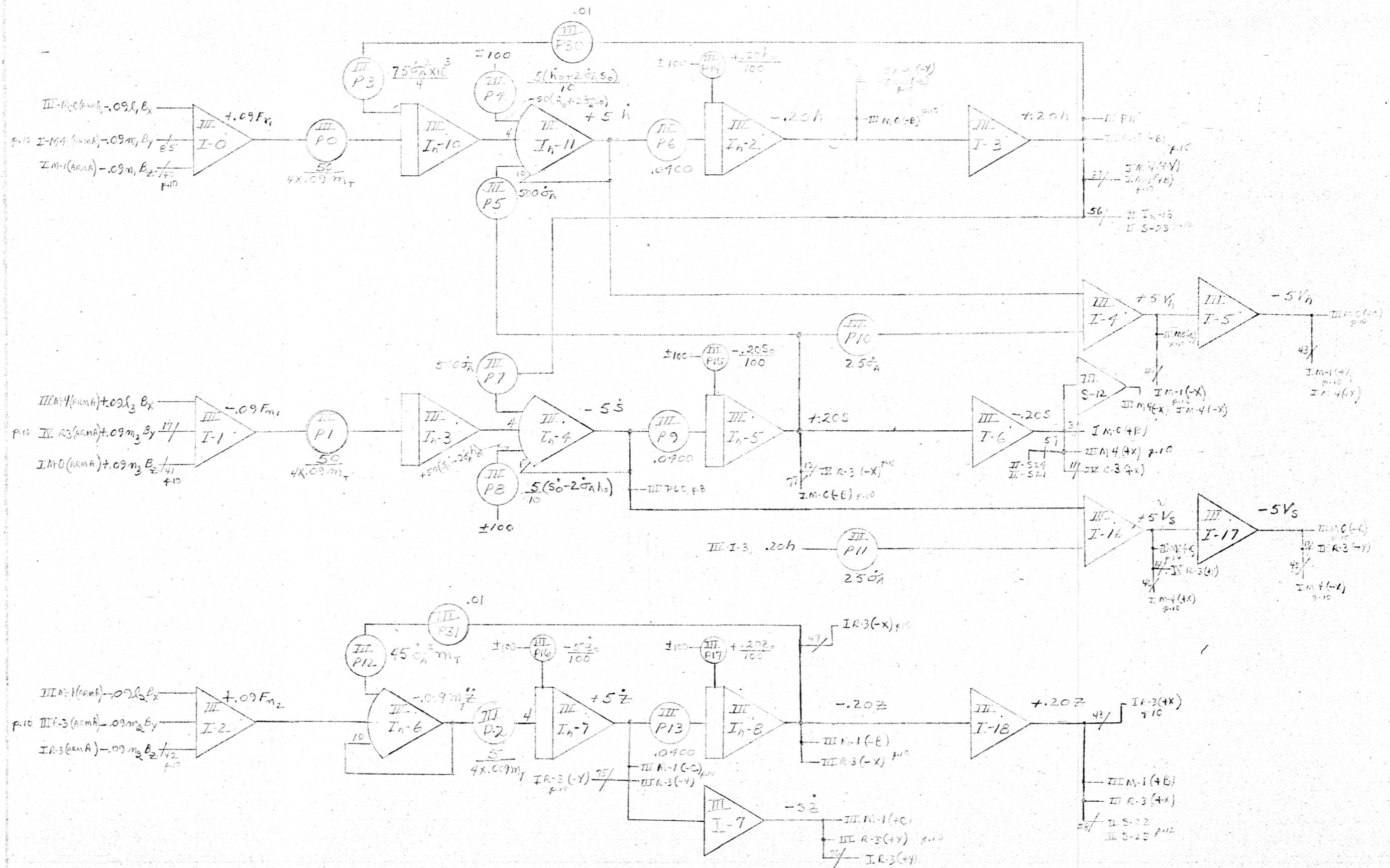
APPENDIX C

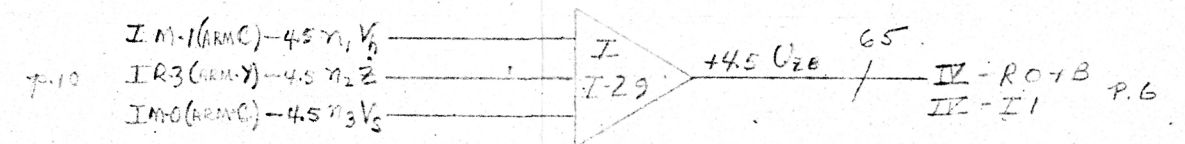
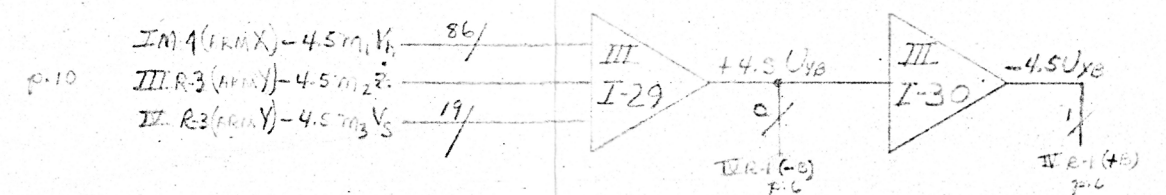
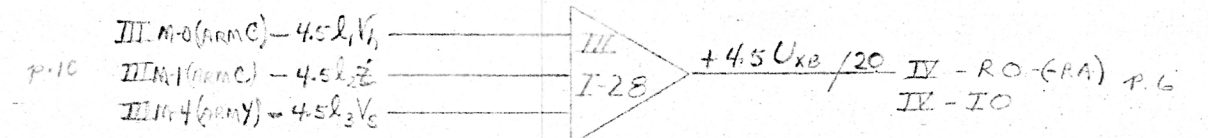
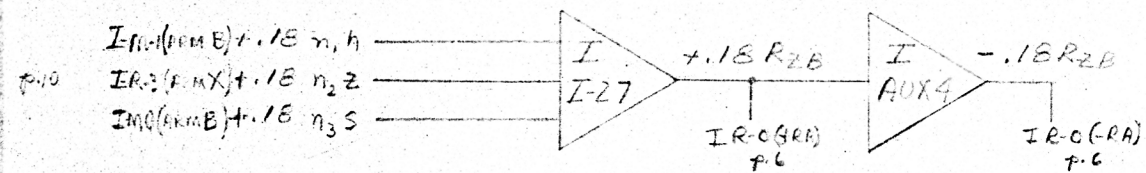
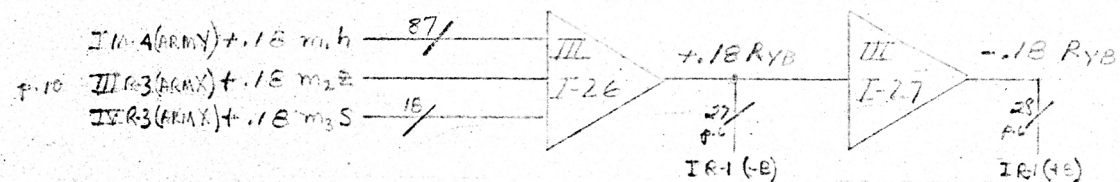
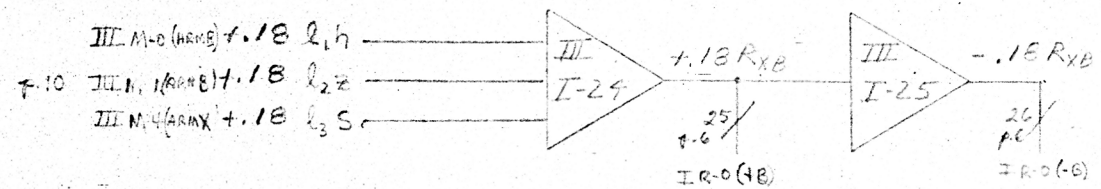
ANALOG COMPUTER BLOCK DIAGRAM
FOR DOCKING; F-151 RANGE BED DISPLAYS



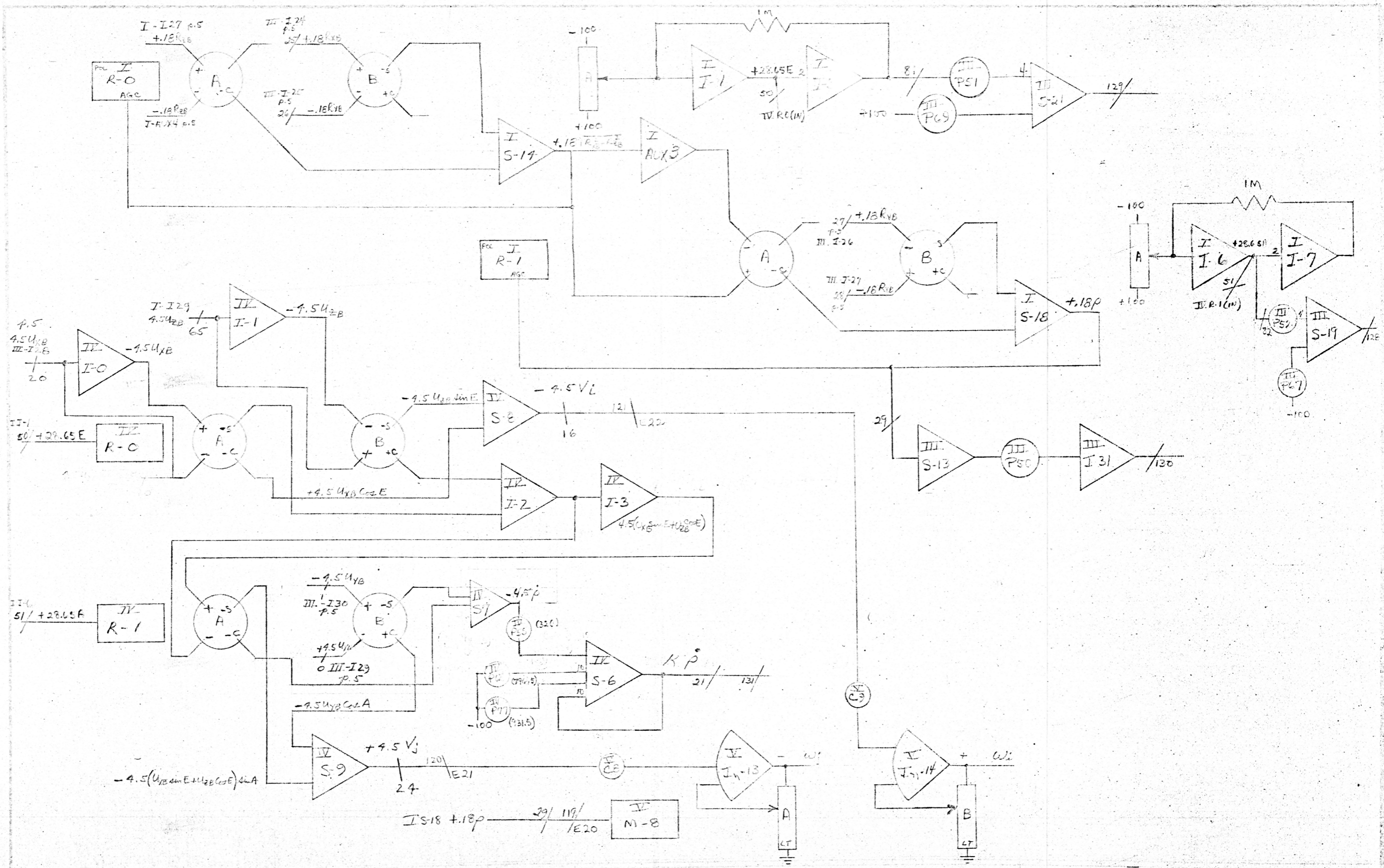


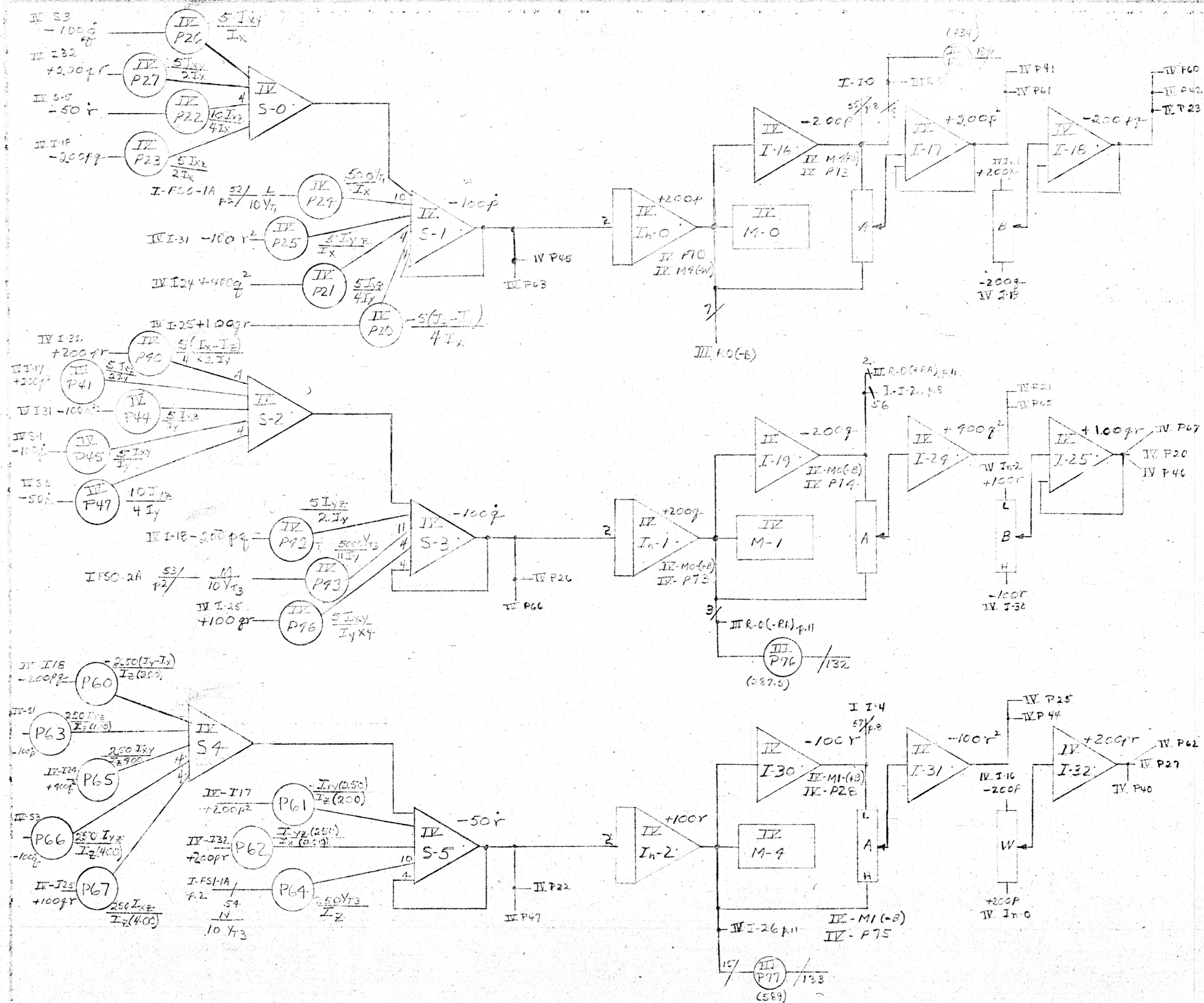


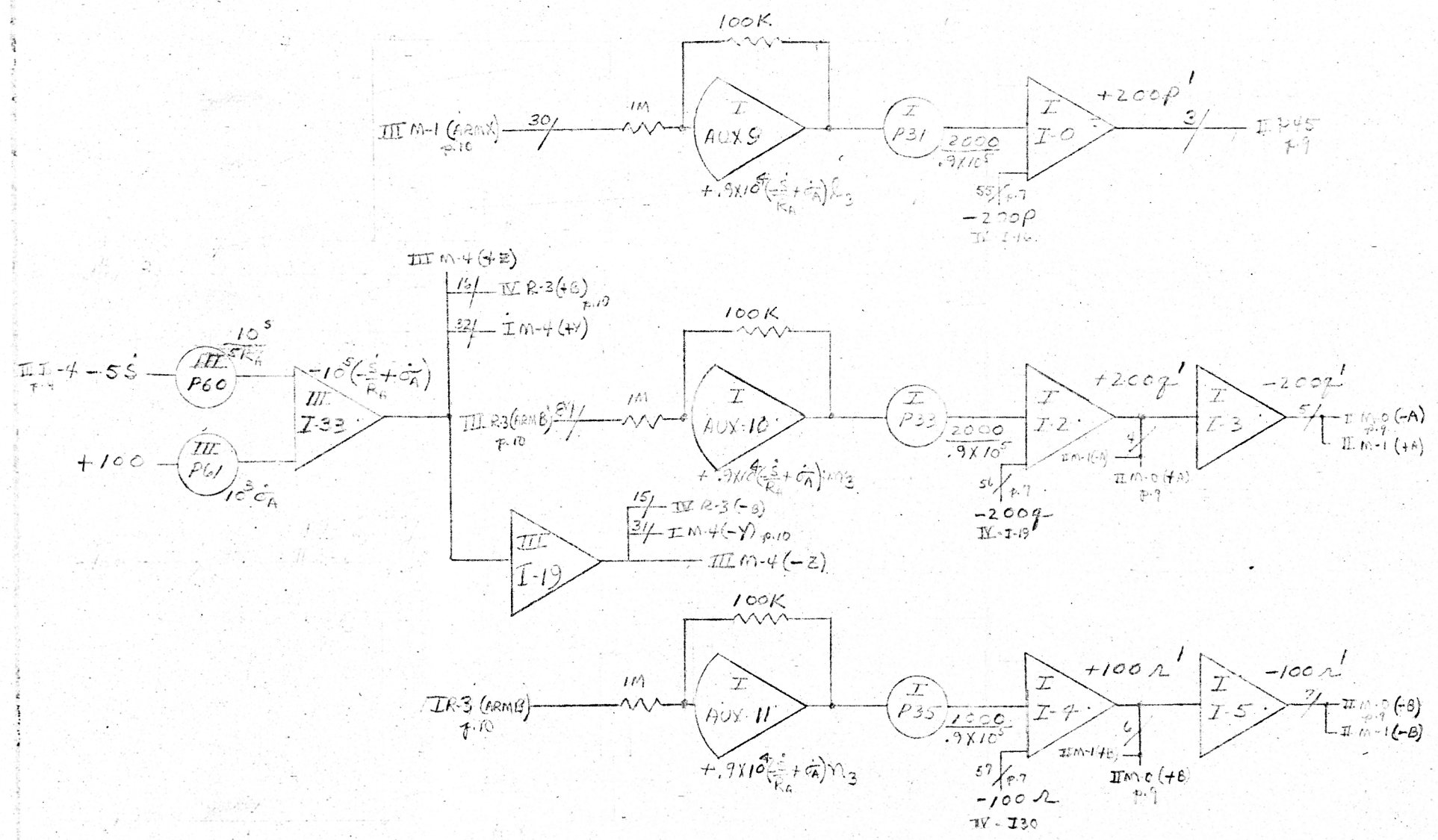


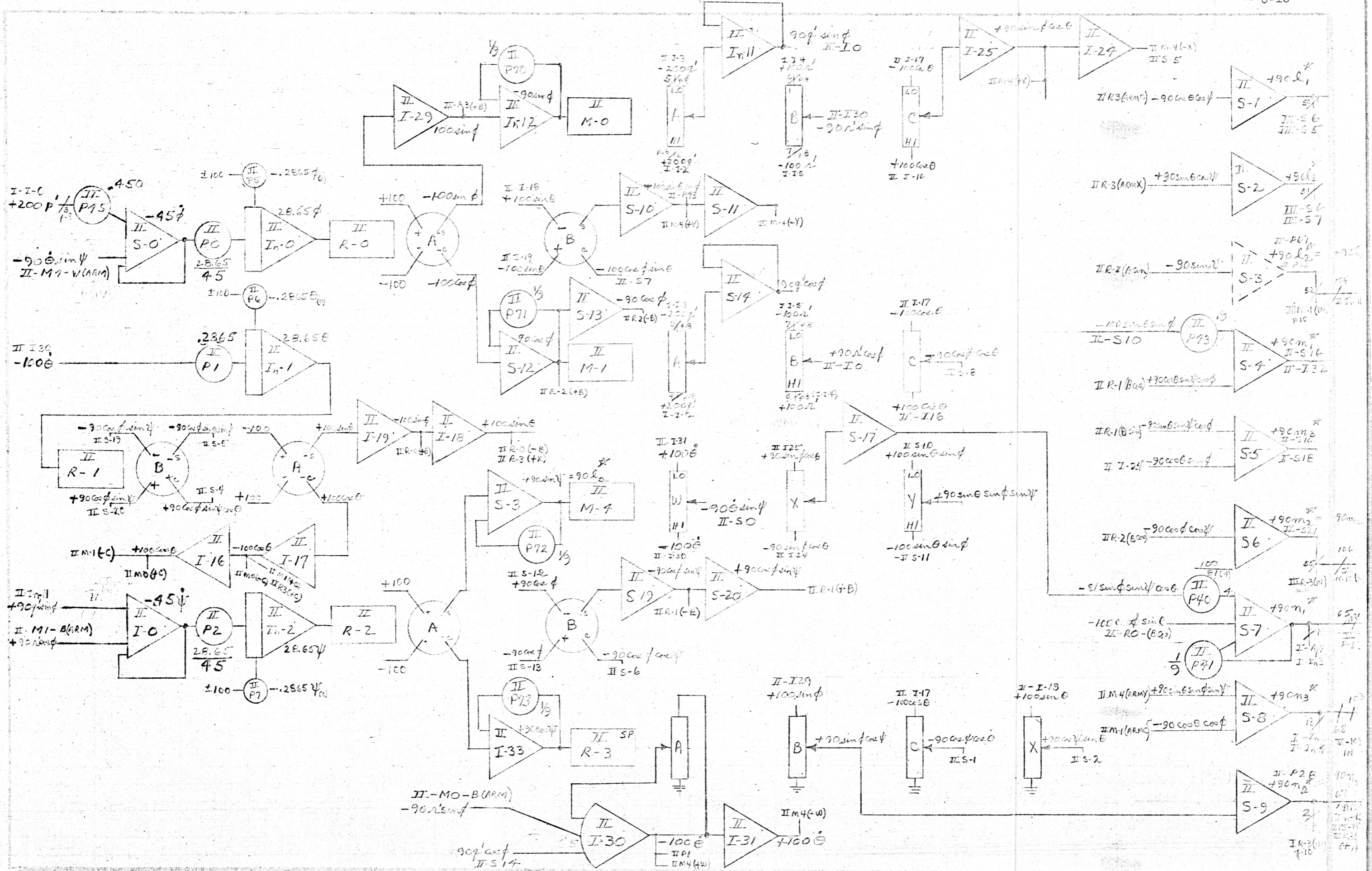


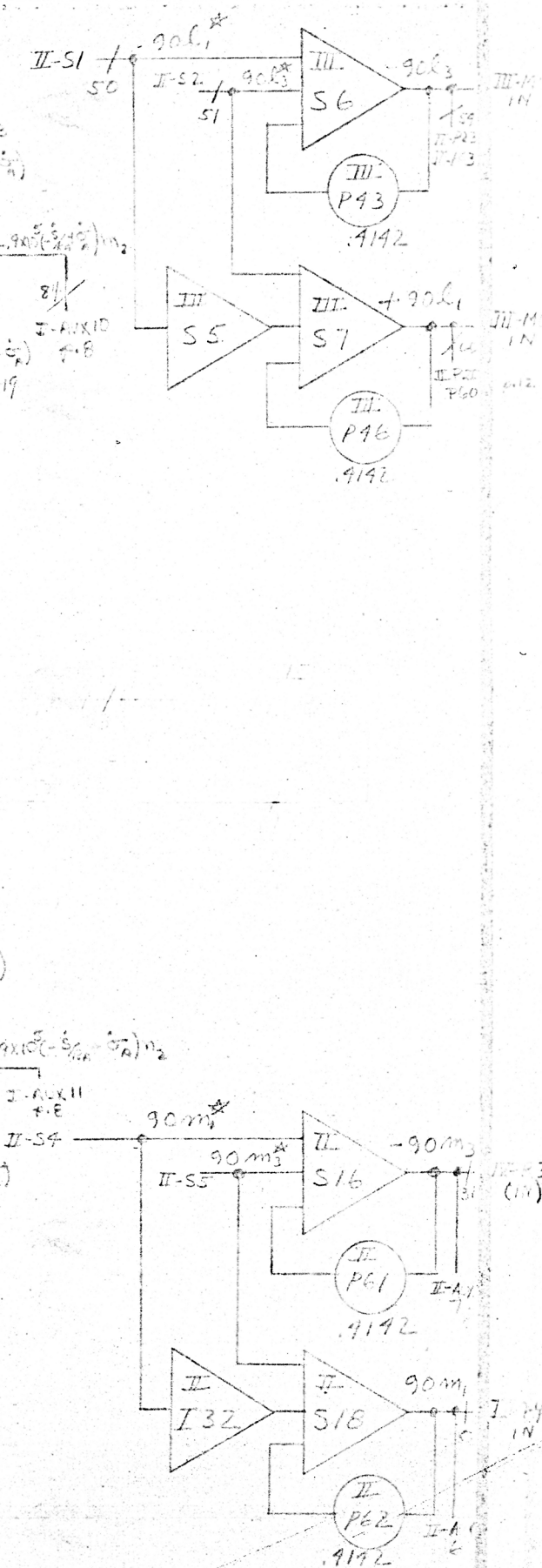
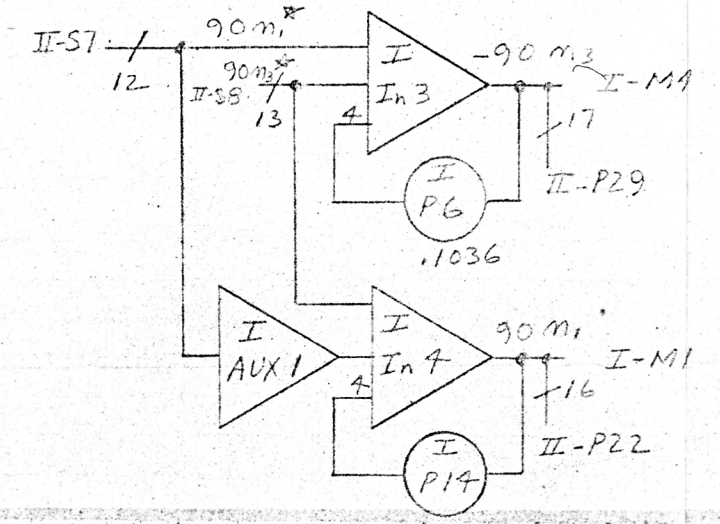
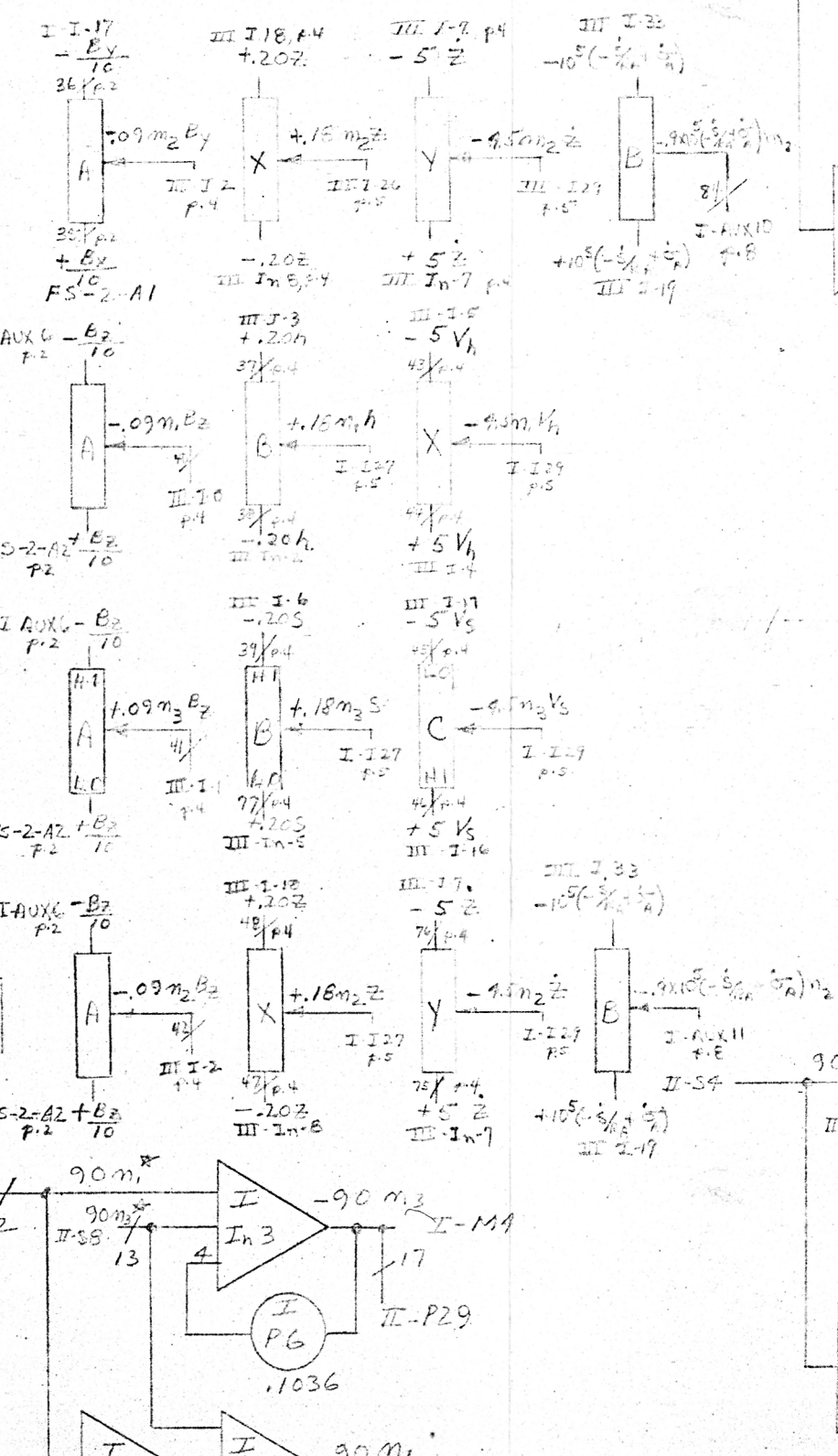
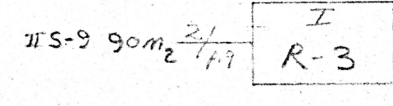
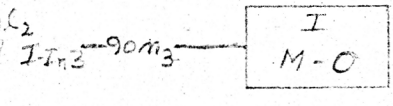
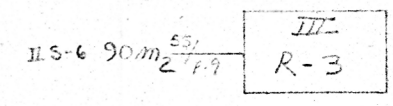
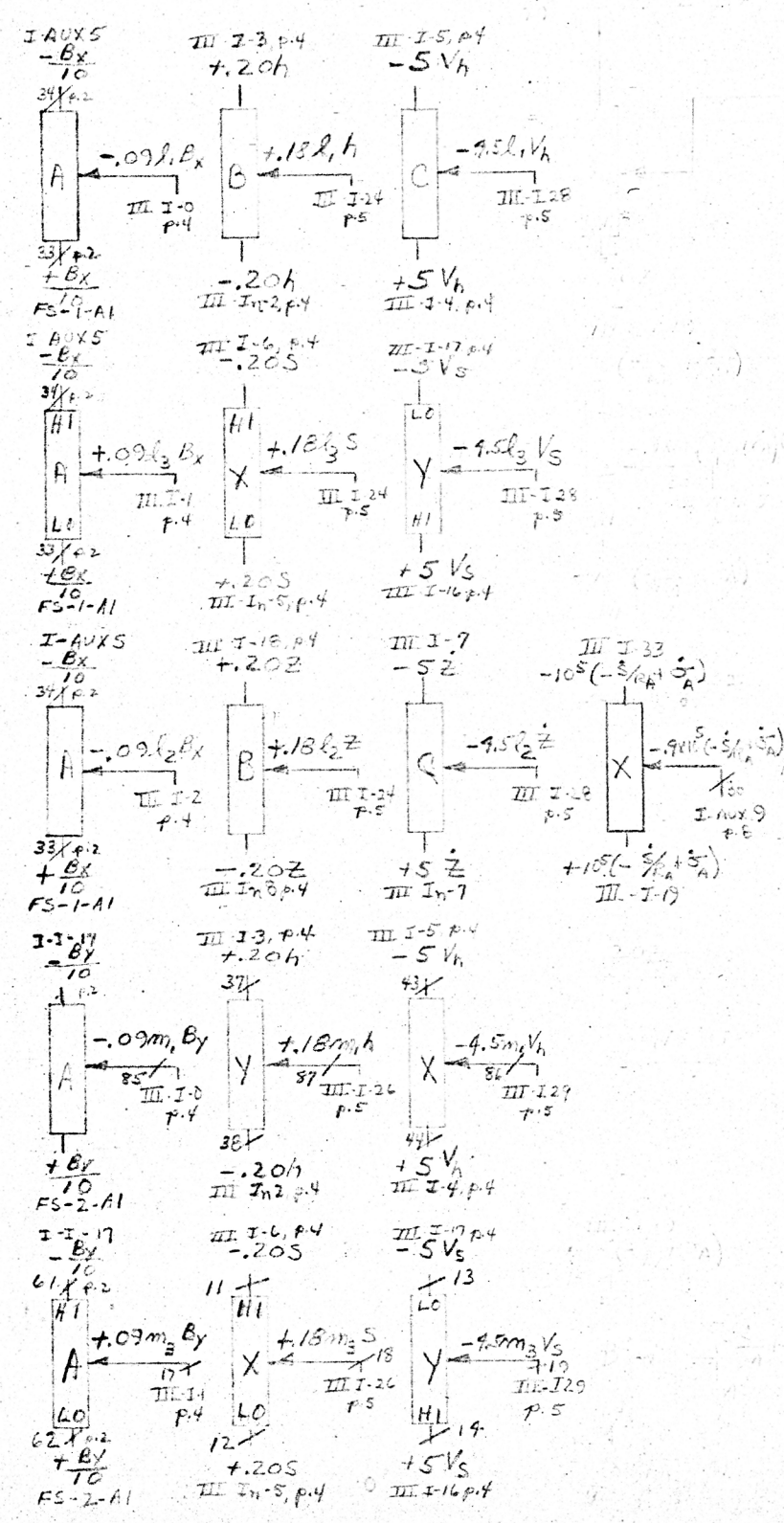
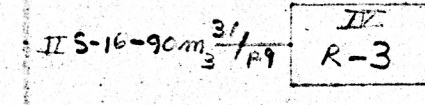
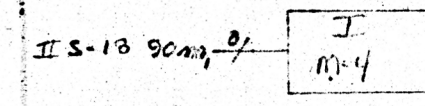
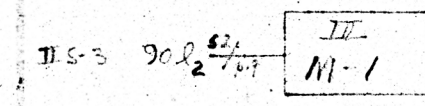
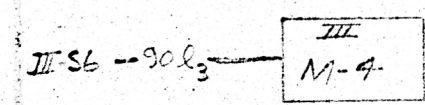
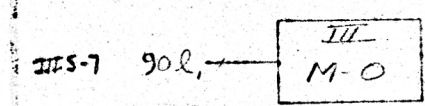
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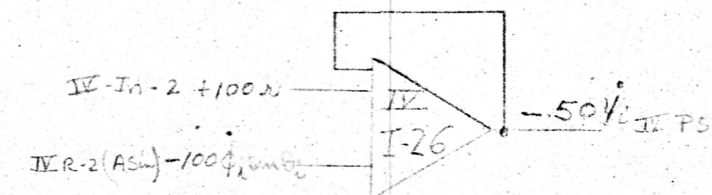
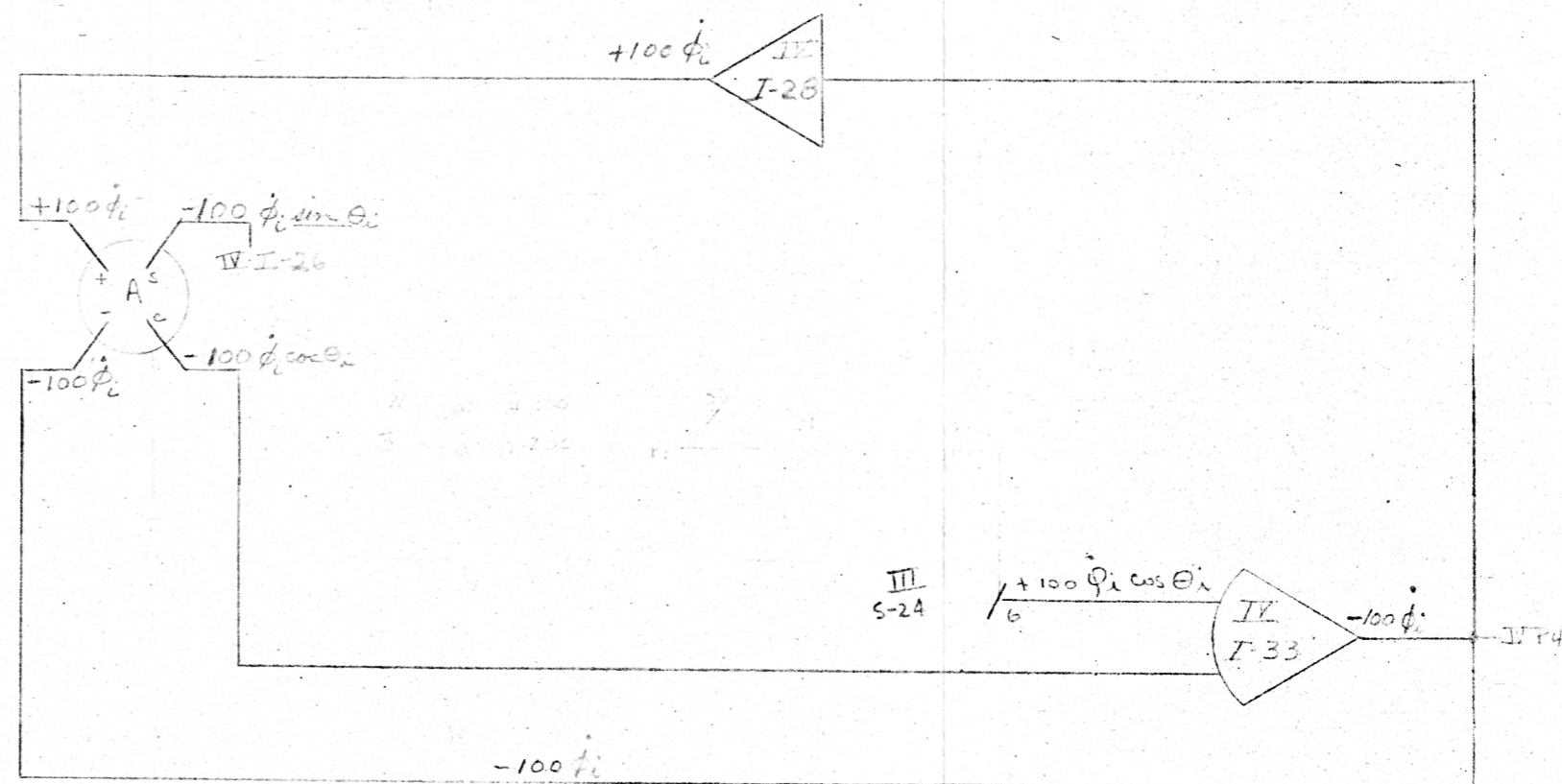
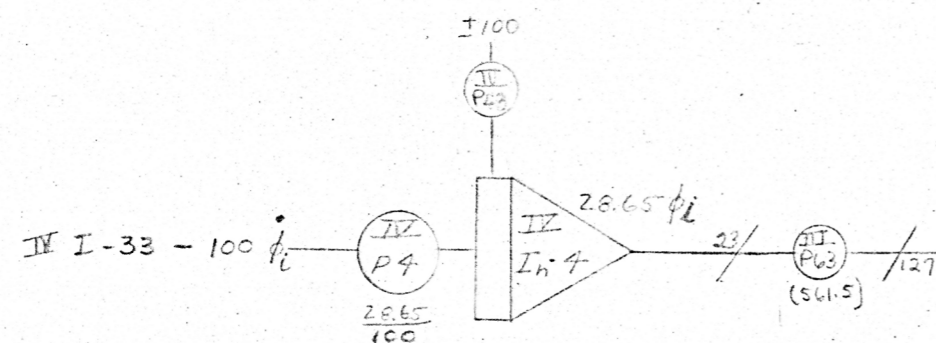
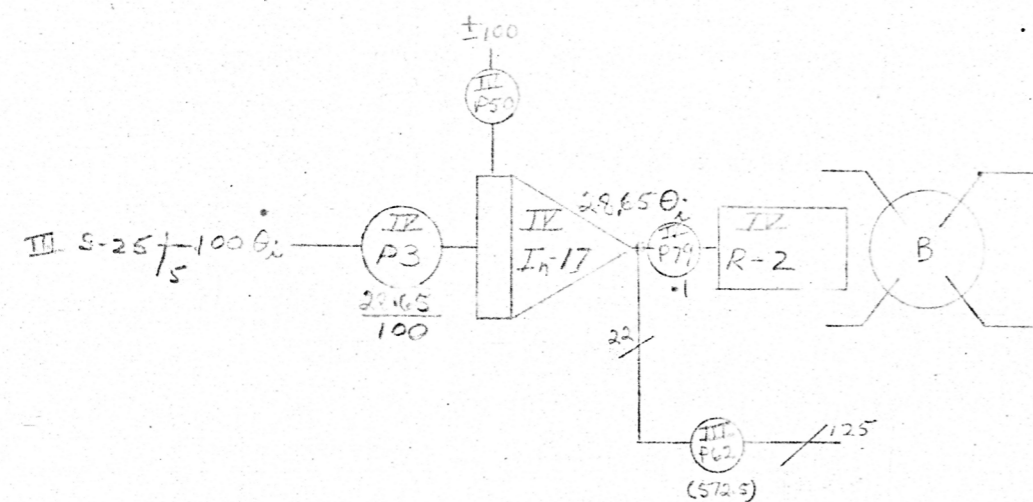
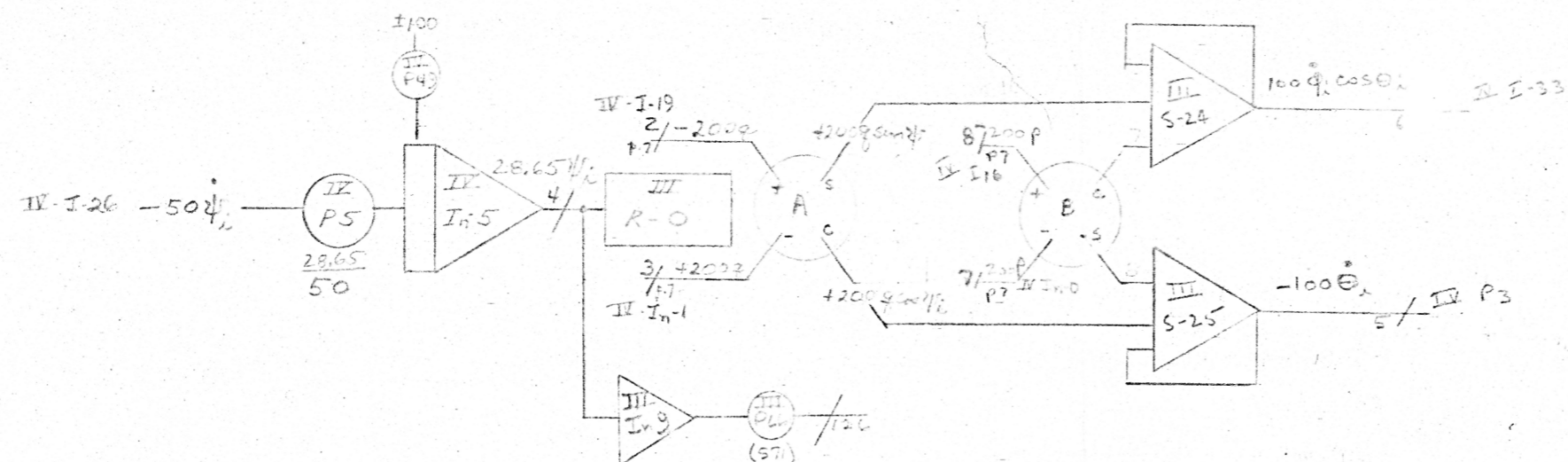


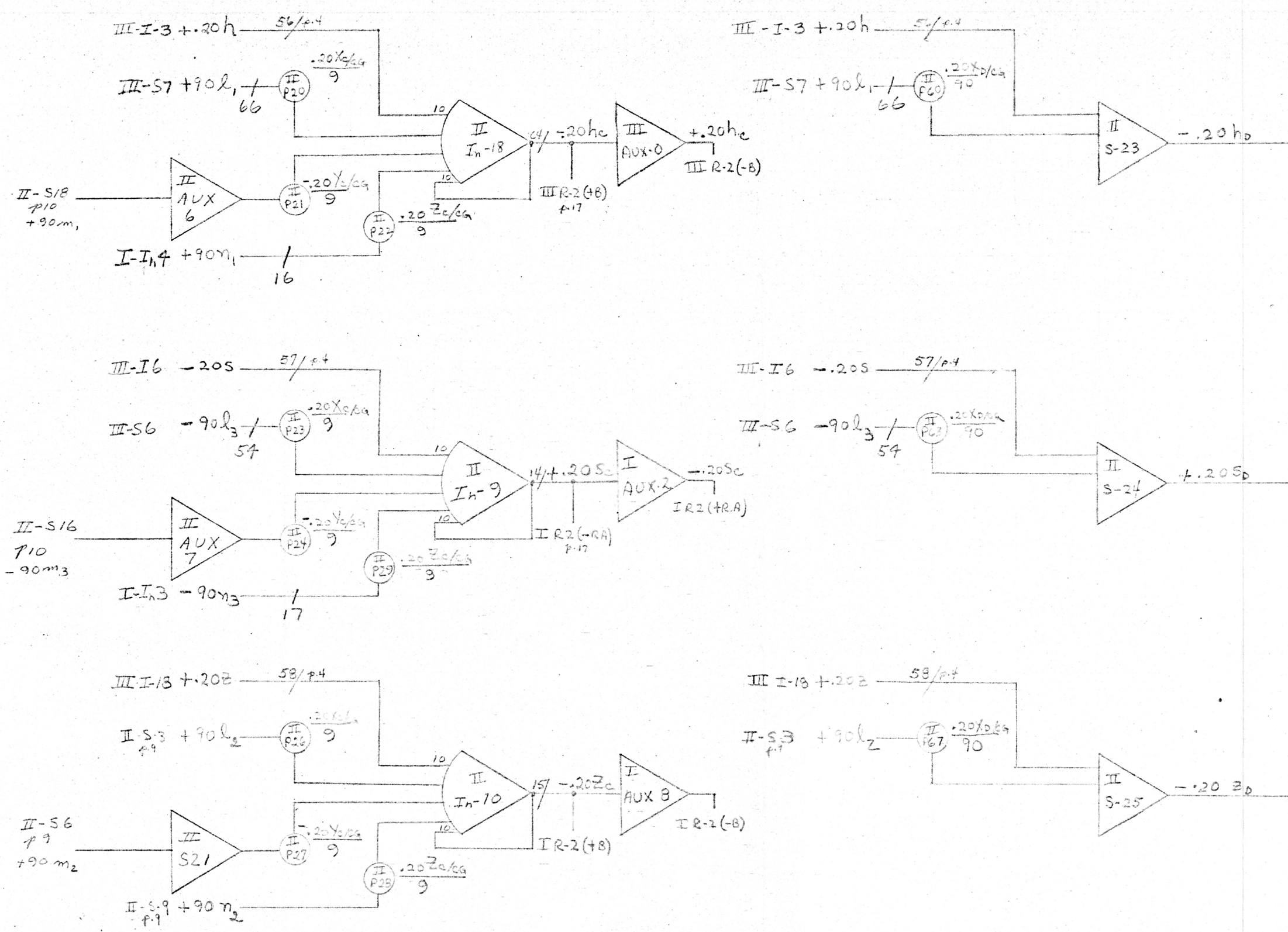




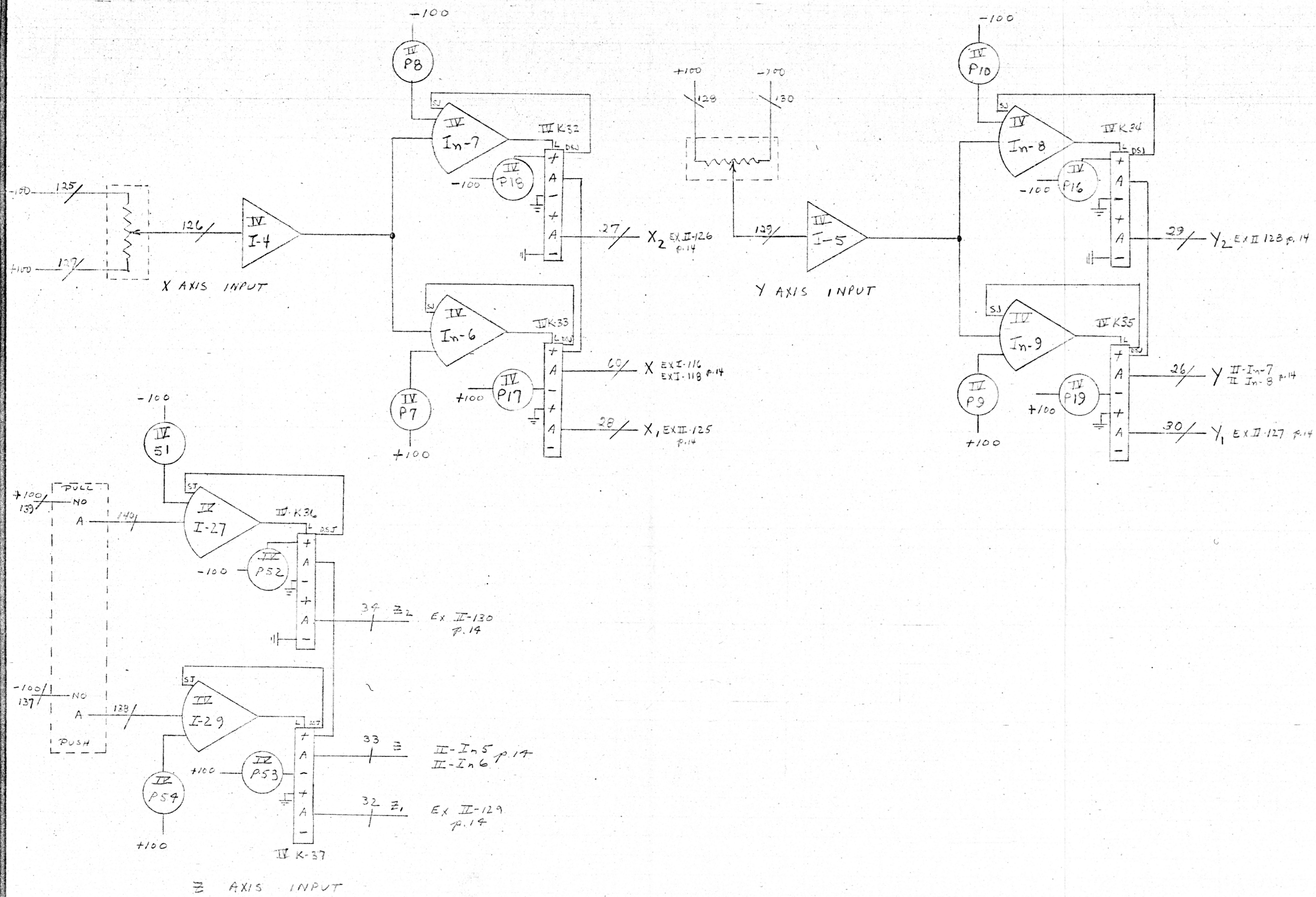




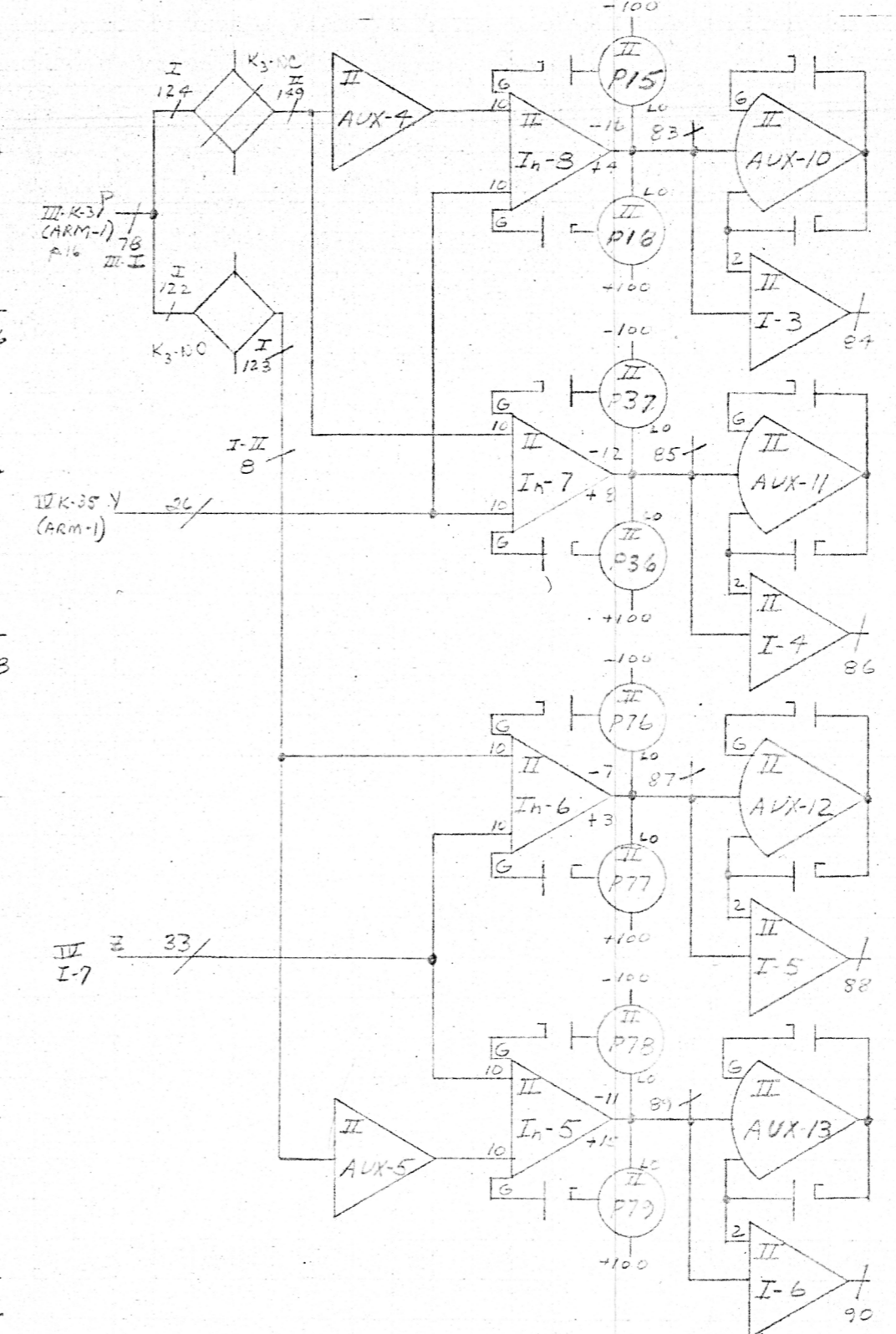
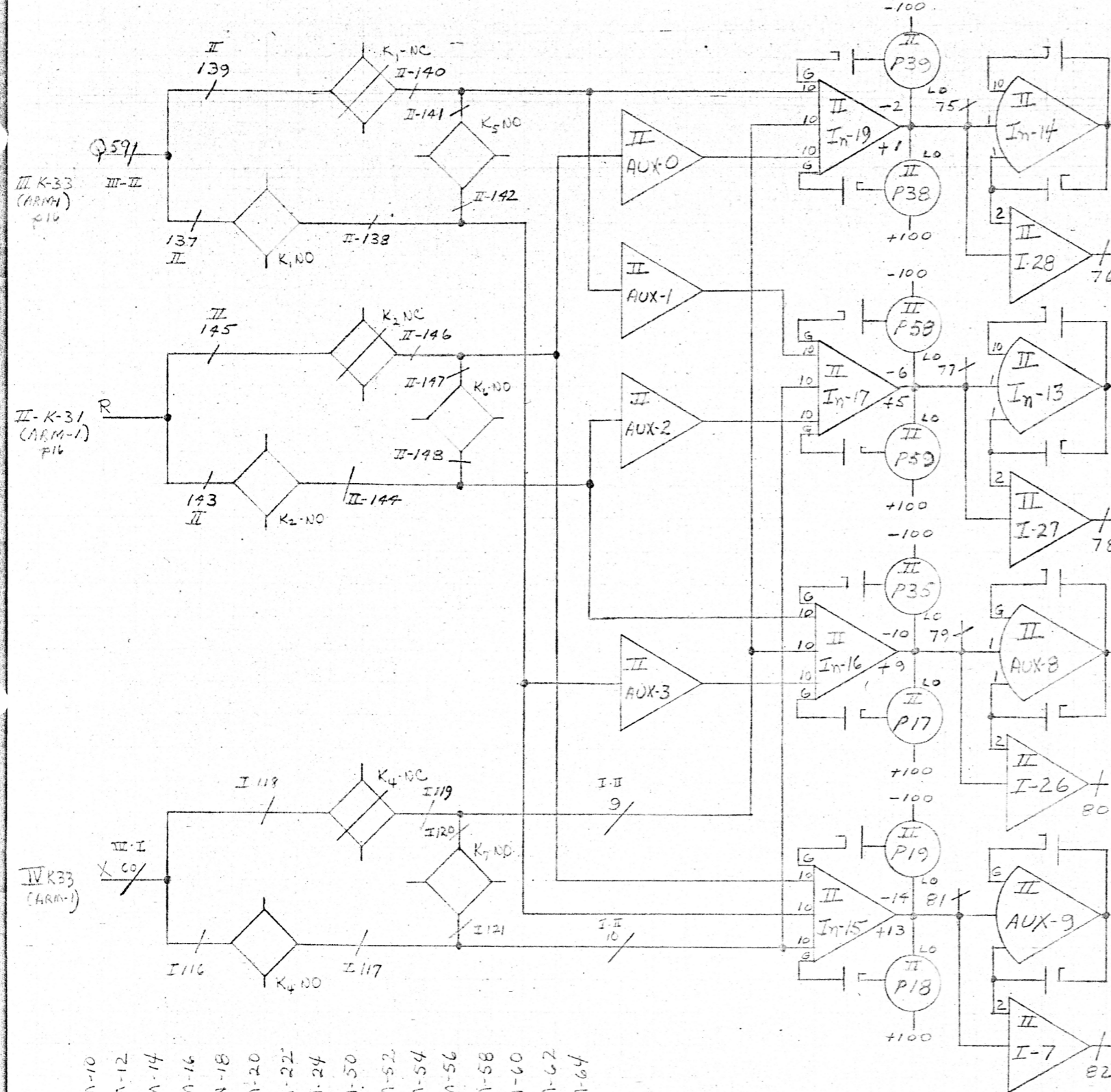




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REPORT
DATE



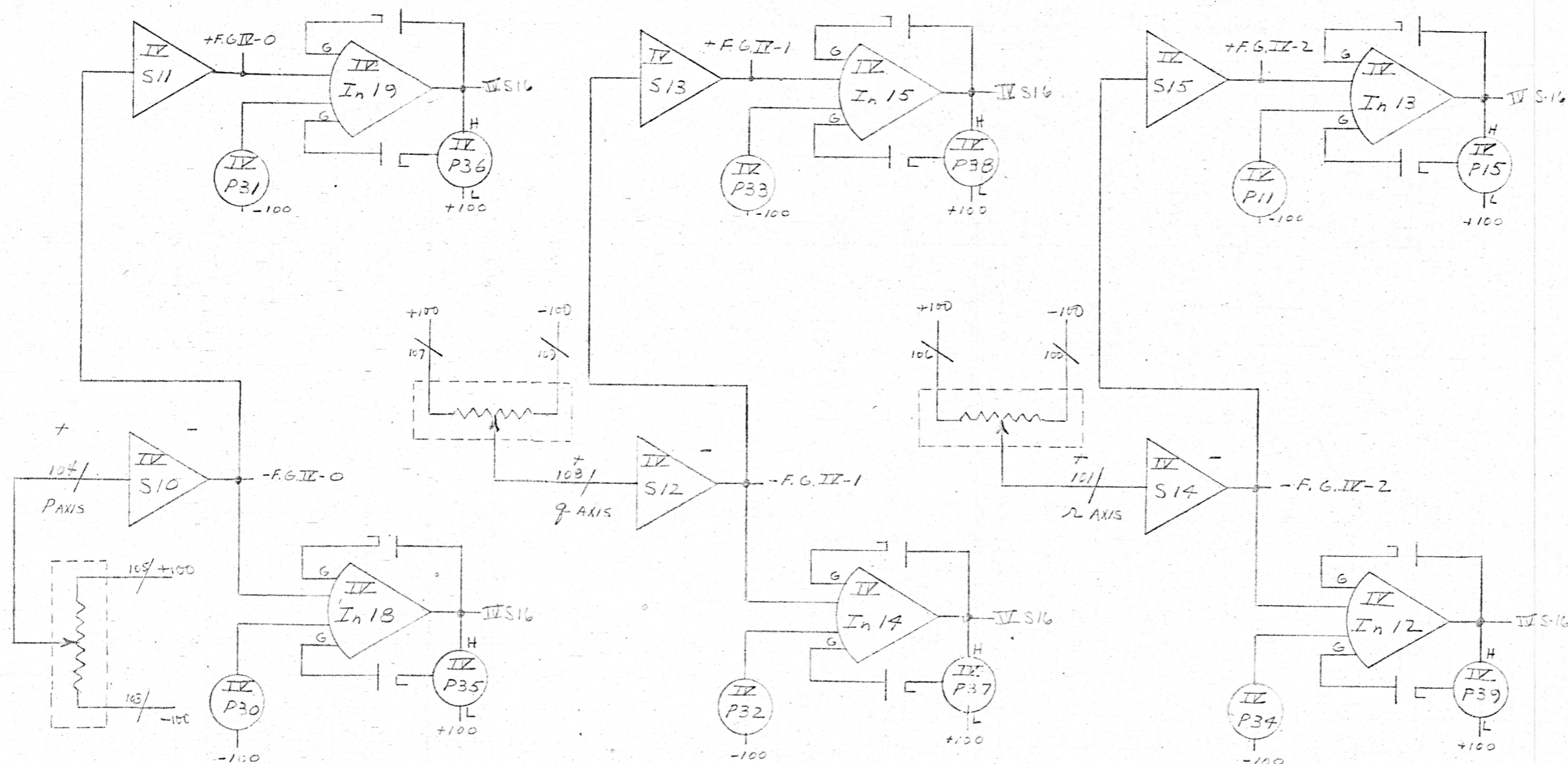
II EXT.	PLUG #	II
125	X1	
126	X2	
127	X1	
128	X2	
129	X1	
130	X2	
131	P1	60
132	P2	61
133	S1	62
134	S2	63
135	R1	
136	R2	
137	K1-NO	
138	K1-NC	
139	K1-NC	
140	K1-NC	
141	K5-NO	
142	K5-NO	
143	K2-NC	
144	K2-NO	
145	K2-NC	
146	K2-NC	
147	K6-NO	
148	K6-NO	
149	K3-NC	

PLUG #	II EXT.	II
100	T1	
101	T2	
102	T3	
103	T4	
104	T5	
105	T6	
106	T7	
107	T8	
108	T9	
109	T10	
110	T11	
111	T12	
112	T13	
113	T14	
114	T15	
115	T16	
116	K4-NO	
117	K4-NO	
118	K4-NC	
119	K4-NC	
120	K7-NO	
121	K7-NO	
122	K3-NC	
123	K3-NO	
124	K3-NC	

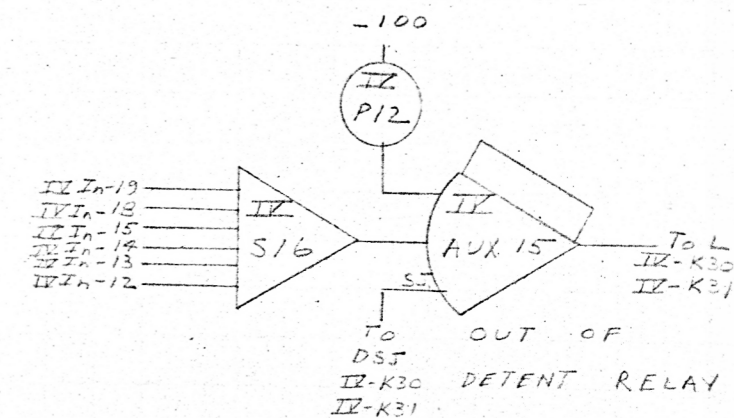
PLUG #	II EXT.	II
75	S1	
76	S1	
77	S2	
78	S2	
79	S3	
80	S3	
81	S4	
82	S4	
83	S5	
84	S5	
85	S6	
86	S6	
87	S7	
88	S7	
89	S8	
90	S8	
91	S9	
92	S9	
93	S9	
94	GND	
95		
96		
97		
98		
99		

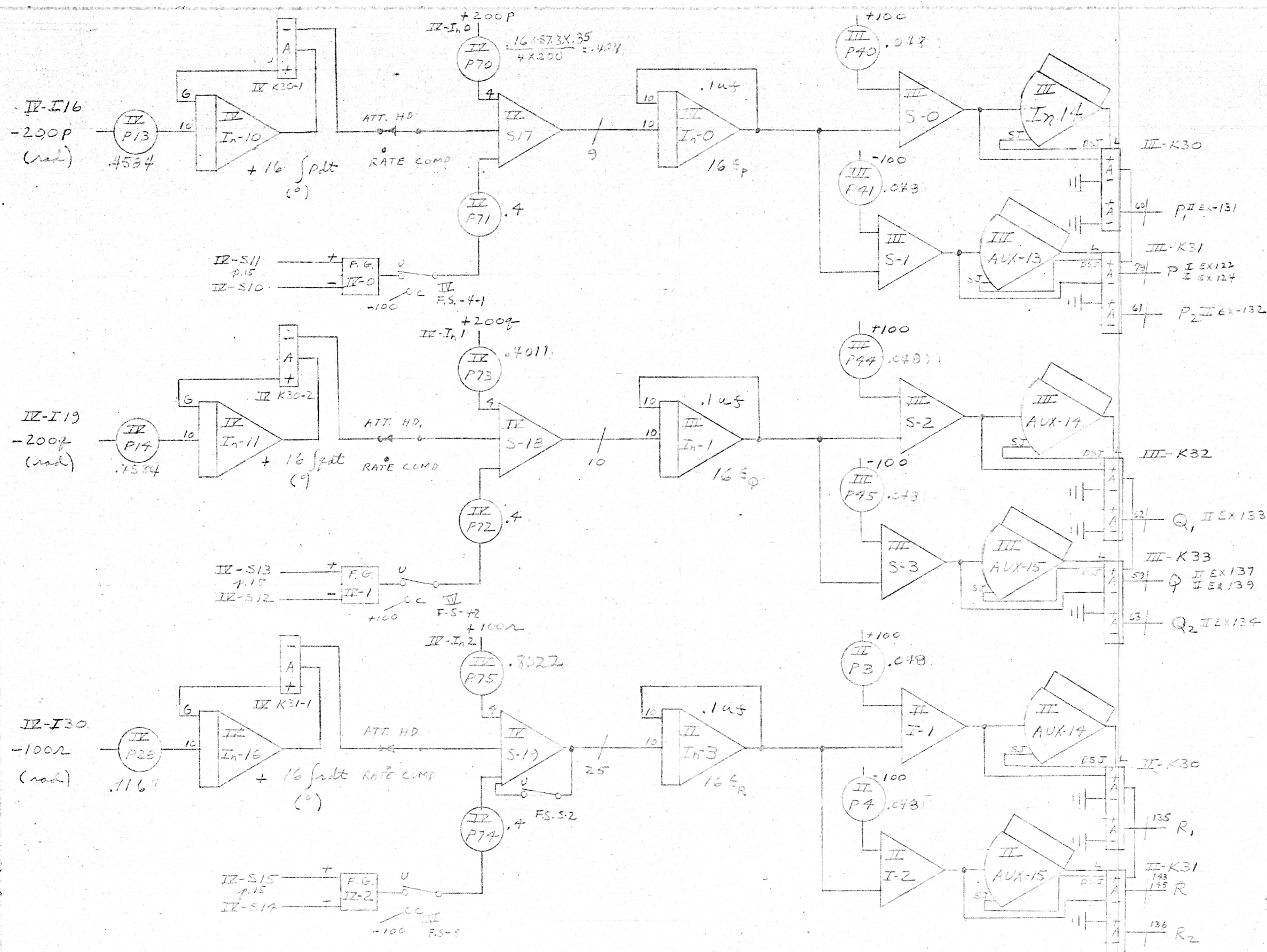
PLUG #4
I-F
MODULATOR
OUTPUTS

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23 October 1961



ROTATION CONTROLLER
DETENT SWITCHES

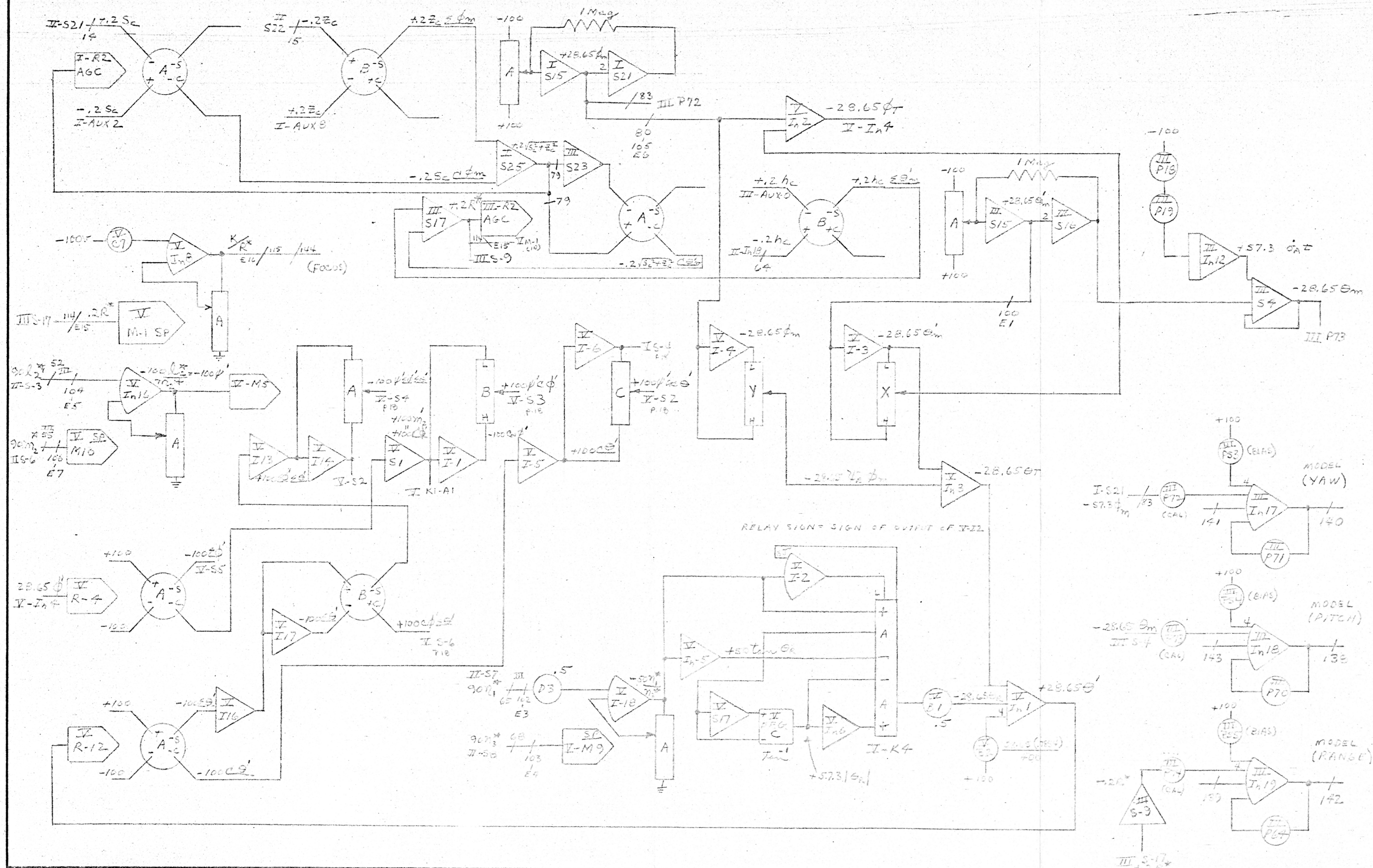




ROTATIONAL CONTROL
IV 100 → 124

TRANSLATION CONTROL
IV 125-149

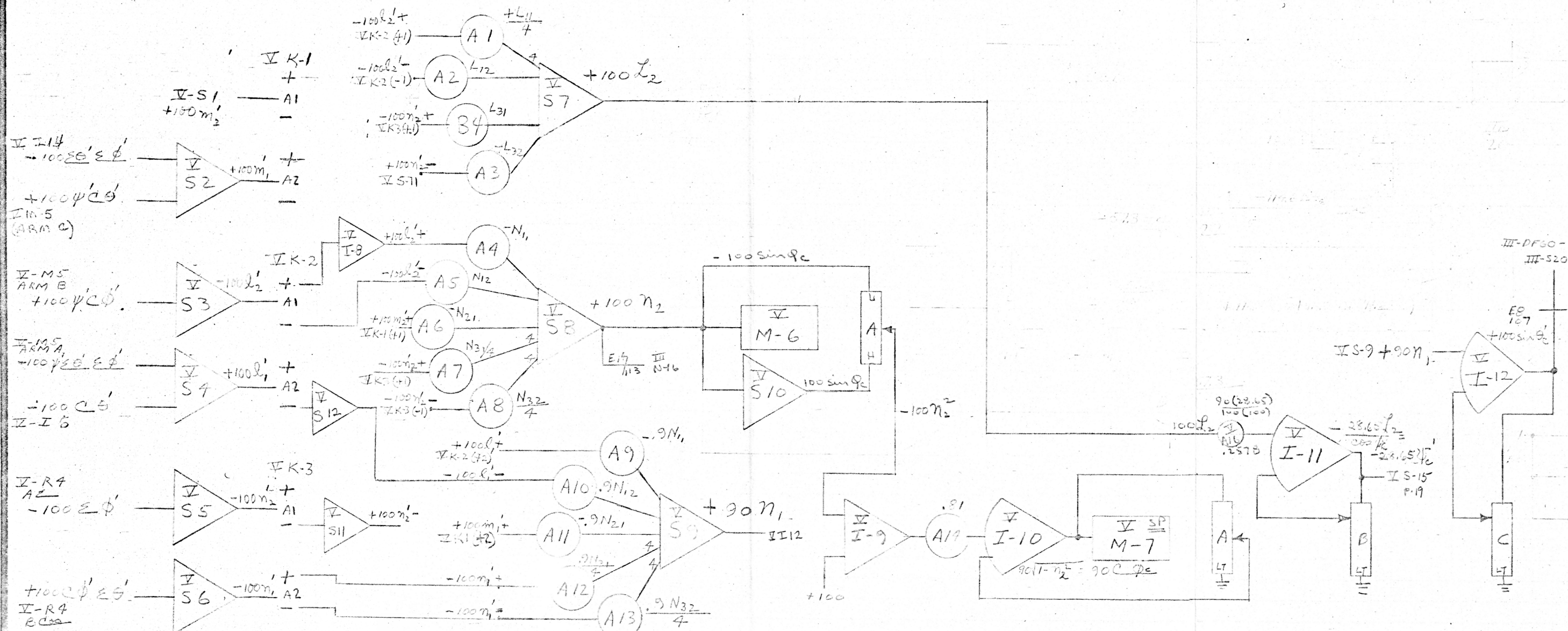
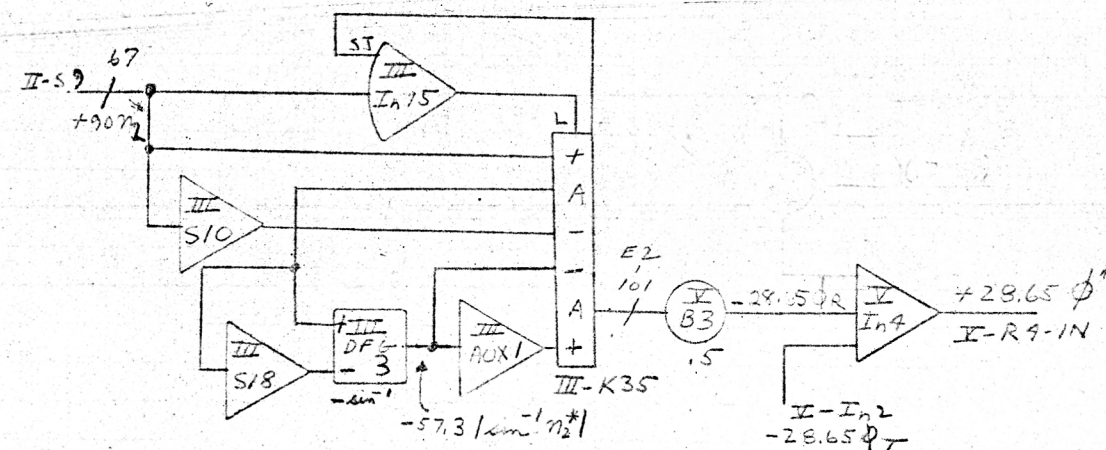
DISPLAYS
III 125-149



REPORT
DATE
CODE 38213

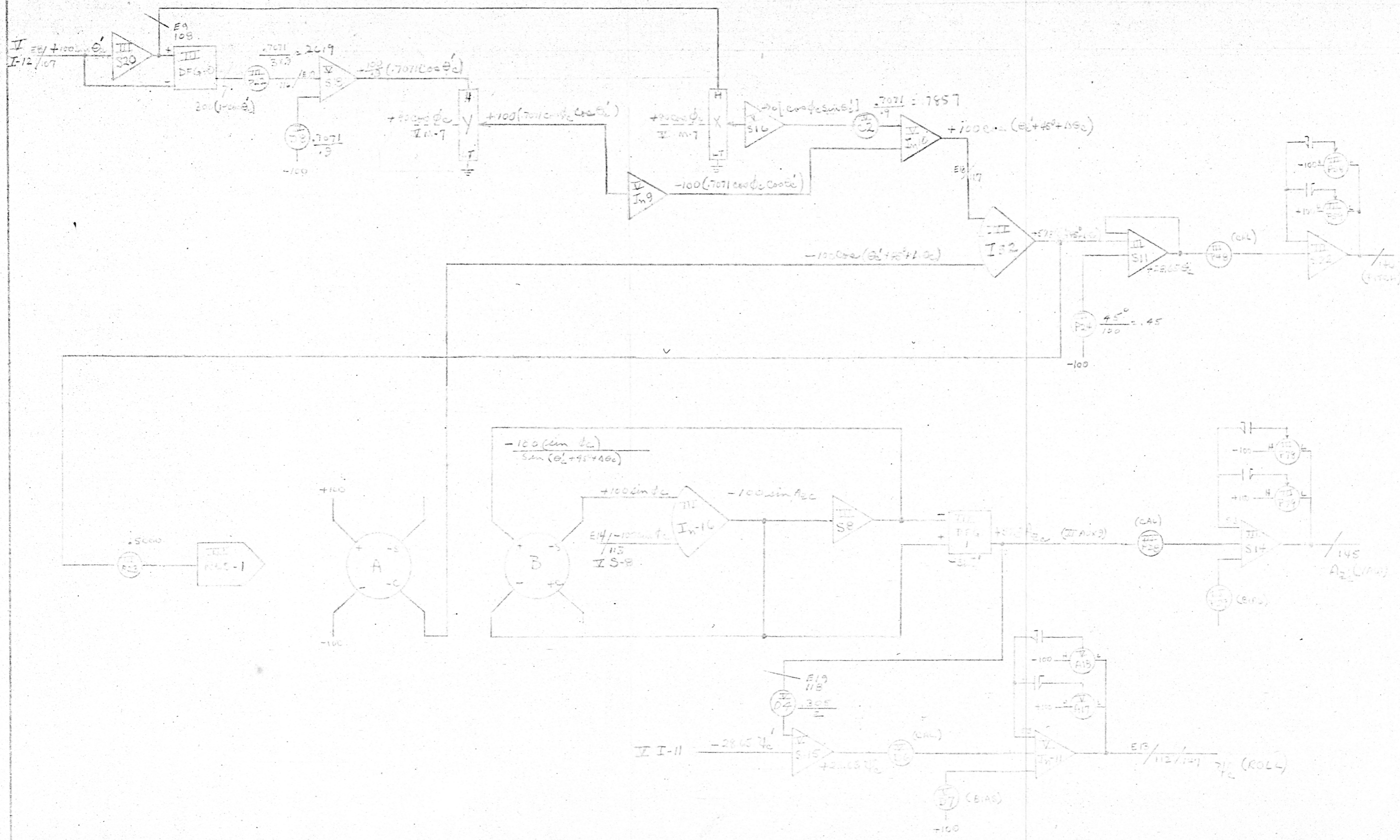
GRUMMAN AIRCRAFT ENGINEERING CORPORATION

REPORT: LED-570-10
DATE: 23 October 1964



REPORT
DATA

REPORT: LED-570-10
DATE: 23 October 1964



FORM G332 5-63 (ENG 72)