MASSACHUSETTS INSTITUTE OF TECHNOLOGY

APOLLO

GUIDANCE AND NAVIGATION

MIT G&N DESIGN
AND MECHANIZATION
COURSE NOTEBOOK

July 5-9, 1966

MIT INSTRUMENTATION LABORATORY
CAMBRIDGE 39, MASSACHUSETTS

MIT G&N DESIGN AND MECHANIZATION COURSE NOTEBOOK

July 5-9, 1966

MIT. IL G&N DESIGN AND MECHANIZATION COURSE OUTLINE (JULY 5-9, 1966)

TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
8:30 AM Introduction R. Ragan D. Hoag J. Nevins 9:30 AM Basic Concepts R. Battin 11:00 AM G&N Operational Concept J. Dahlen 1:30 PM Optical Subsystem A. Koso 3:00 PM Apollo Guidance Computer C. Muntz	8:30 AM Inertial Subsystem R. Crisp (P01, P02) 10:30 AM System Interfaces R. Larson (P00, P05, P06) 07 2:30 PM IMU Alignment J. Shillingford (P51, 52, 53) 3:30 PM Navigation G. Levine (P22, 23, 27)	8:30 AM Boost Monitor & Abort B. Sokkappa (P04, P11, P12, P17, P71) 9:00 AM Thrust Vector Control, Trajectory Nominal Maneuvers, Deorbit B. Sokkappa (P31-3, 41-3) 2:30 PM Entry D. Lickly (P61-67)	8:30 AM System Testing A. Laats 9:30 AM Nominal Mission Sequence J. Suomala 1:30 PM CM Operations Simulator Demonstration Program P31, P41	8:30 AM General Review

1. ( ): Discussion periods for indicated AGC programs.
2. The Space Navigator will be available for familiarization with LEB operations.
3. Lunch periods 12-1:30.

PRELIMINARY 204 G&N CREW TRAINING PLAN

I. G&N System Design Philosophy and Mechanization
(Hows and Whys) (MIT 1 week) July 5-9, 1966

A. Definition of fundamental problems of guidance and navigation and their solutions as mechanized by the G&N system for 204.

B. G&N system capabilities and limitations as mechanized solutions to these problems; emphasize reasons for particular system mechanizations.

C. Definition of systems interfacing.

D. Introduction to crew procedures and operational control.

E. Introduction to software moding and programming logic as related to mission phasing.

II. Introduction to Hardware (AC/G&C Lab).

A. Physical Exposure to hardware equipment.

B. Operational moding at G&N with flight hardware.

III. Detailed Functional Description (AC 40 hours) March 28 - April 1

1. Introduction to G&N requirements.

2. Systems function (to block diagram level) and relation to mission phases (brief).

3. Equipment construction, mechanization.

4. Modes of operation.

5. Displays and Controls.

   Ref: MIT/IL Report No. E-1899, "Flight Operations Manual for the CM G&N System to be used in Apollo Mission AS204A".

IV. Detailed Procedures (MIT)

Detailed classroom instruction and mockup dry runs of the flight programs and procedures as developed in the computer logic-checklist interface.

Ref: Section 4 of MIT/IL Report No. R-507, "G&N System Operations for Mission AS204A".

V. Simulation (MIT)

1. Real time practice (2 man) with hybrid simulation of major mission phase blocks.

   a. Boost
   b. Thrusting Maneuvers.
   c. Navigation
   d. Entry

2. Skill practice of navigation optics sightings (optically and photometrically correct targets).

OPERATIONAL CONCEPT .

- Flight operations organized into a set of manually-initiated programs and routines

- Self-contained guidance and control

- Self-contained or ground-based navigation - Position/Velocity state vector and guidance targets may be derived using on-board sensors or accepted via the voice or Digital Command System uplinks.

This concept provides maximum flexibility of flight plan and permits maximum continuity of programs and procedures.

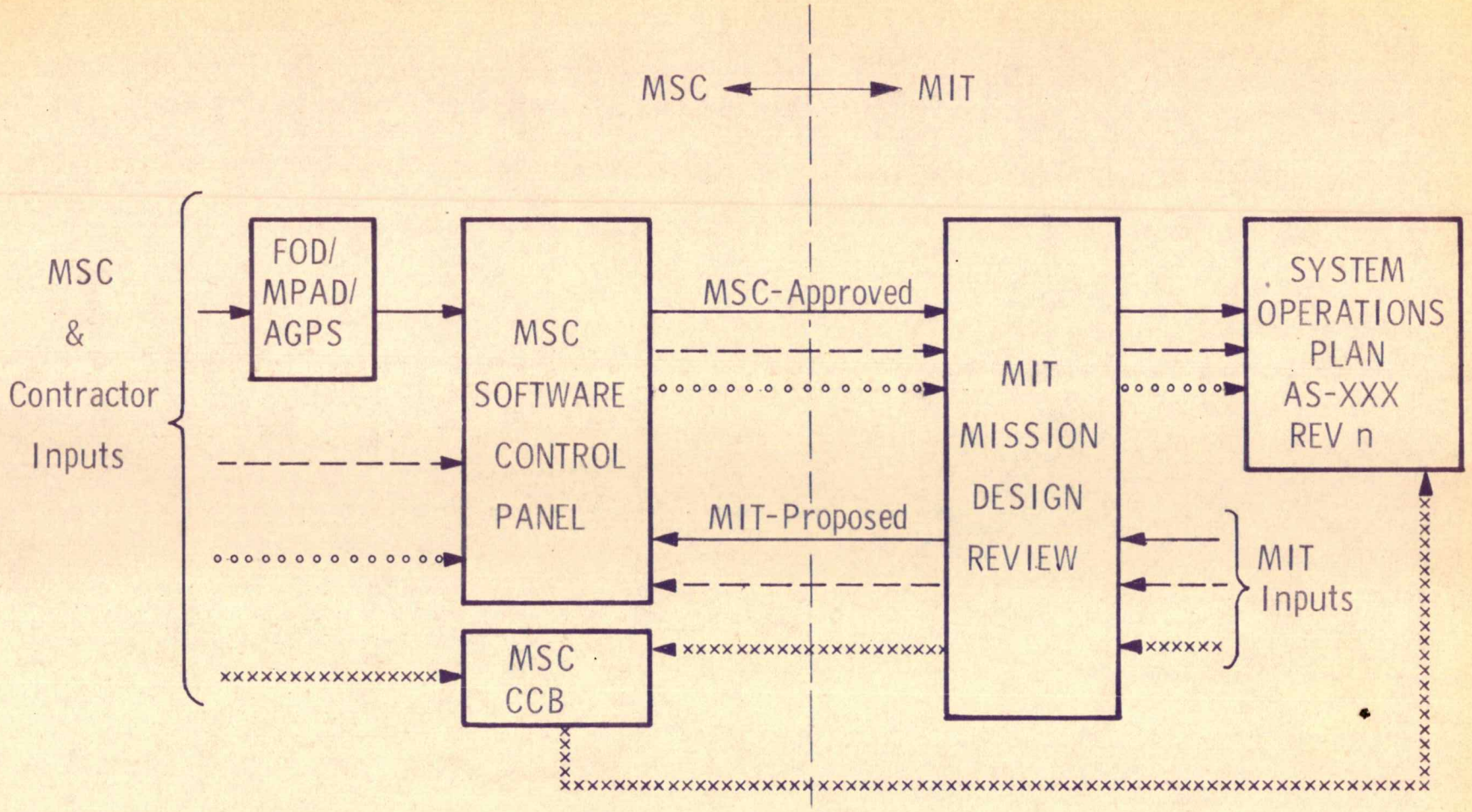
FLIGHT-READY SYSTEM

- Basic Block Configuration of Equipment

PLUS

- Computer Programs
- Crew Procedures and Training
- Flight Data (Maps, Checklists, etc)
- Signal Conditioning Equipment
- Required System Hardware Mods

MISSION SOFTWARE DESIGN CONTROL



Key:

- Program Reqmts
- Procedure Reqmts
- Spacecraft/Trajectory Data
- G&N Hardware Changes

JOB NO. TP# PROJ. # FIG. NO. CLASS

TYPE I CONTROL DOCUMENT FOR:

- Guidance and Navigation Equations
- MSC/Crew/Computer Interface for S/C & Mission Control
- Computer Logic & Timeline for S/C & Mission Control (Unmanned)
- RTCC/Computer Interface (Digital Uplink and Downlink)
- Spacecraft & Trajectory Data Stored in Computer and Used in Simulations

INFORMATION DOCUMENT FOR:

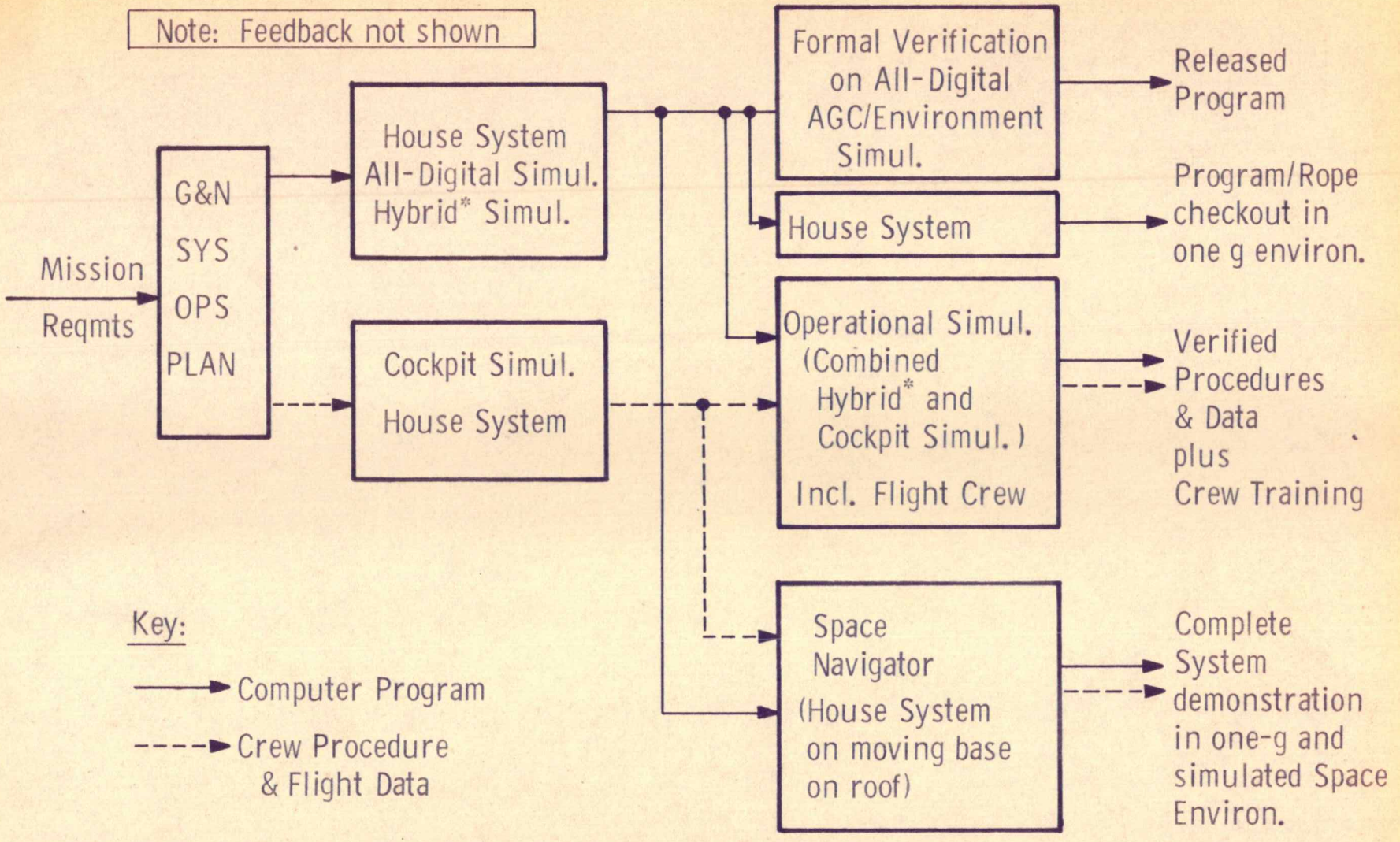
- G&N Configuration
- Error Analysis (Effect of G&N errors)
- Performance Analysis (Effect of L/V dispersions and S/C performance variations)
- Telemetry and Recording Instrumentation
- MSFN Tracking Requirements

SUPPORT DOCUMENT FOR:

- Mission ΔCDR, S/C CARR, FRR

SOFTWARE DEVELOPMENT AND TEST AT M. I. T.
(Programs - Procedures - Flight Data)

Note: Feedback not shown



*Hybrid Simul contains computer, CRS, CDUs, Beckman Analog Comp., SDS 930 Dig. Comp., Interface Equip., and Downlink Recorder

STATE VECTOR IMPROVEMENT

SPS MANEUVER TARGETTING

SPS THRUST VECTOR CONTROL

ENTRY GUIDANCE

IMU ALIGNMENT

RCS ATTITUDE CONTROL

P11 PRE-LET JET BOOST MONITOR

DISPLAY γ_i, V_i, h

(INERTIAL PATH ANGLE, VELOCITY AND ALTITUDE)

DRIVE CDU'S SO ATTITUDE ERROR DISPLAYED ON FDAI

P12 POST-LET JET BOOST MONITOR

DISPLAY g_{max}, h_{per}, T_{ff}

(MAXIMUM "g", PERIGEE ALTITUDE AND FREE-FALL TIME ASSOCIATED WITH INSTANTANEOUS BOOSTER CUTOFF)

CONTINUE CDU HOLD FOR ATTITUDE ERROR DISPLAY FOR FIVE SECONDS

P71 CSM ABORT FIRST BURN MONITOR

DISPLAY ΔR, h_{per}, T_{ff}

(ΔR IS MISS DISTANCE FROM ATLANTIC RECOVERY AREA)

P22 LANDMARK TRACKING

NAVIGATOR KEYS IN LANDMARK COORDINATES

AUTOMATIC OR MANUAL OVERRIDE ACQUISITION

SMOOTH TRANSITION TO ALTERNATE LANDMARK OR TO SXT TRACKING OF UNKNOWN LANDMARK

NAVIGATOR KEYS IN IDENTIFICATION AFTER MARK

P24 GROUND TRACK DETERMINATION ROUTINE

AGC PROVIDES LAT(t), ALT(t), LONG(t), MAX DECL, t(MAX DECL), t(LONG)

P27 AGC UPDATE

PROVIDES FOR GROUND UPDATE OF STATE VECTOR AND/OR GUIDANCE AIM POINTS VIA VOICE OR DCS UPLINK

P 31 Pre-Thrust - Orbit Change

Aim Point Load:

Crew selects: T_{IGN}, orbit period
LAT, LONG, h over point
$\Delta V_{tail\ off}$, SPS trim angles

AGC displays: $\Delta V_{req'd}$, h_{ap}, h_{per}

P 27 can be initiated during this program

Program calls for IMU alignment which includes maneuver to thrust attitude (Also done in P32, 33)

P 32 Pre-Thrust - Deorbit

Same as P 31 except for Aim Point Load

Crew selects: LAT, LONG of splash point,
ΔV, $\Delta V_{tail\ off}$, SPS trim angles,
Earliest T_{IGN}

AGC displays: T_{IGN}, miss distance (no out-of-plane steering),
γ_{entry}, V_{entry}

P41 ORBIT CHANGE BURN

GOVERNS COUNT-DOWN, DISPLAYS AND CONTINGENCIES

GUIDANCE LAW STEERS FOR A AND PLANE CONTAINING TARGET VECTOR

DISPLAYS TTI (CHANGES TO T_G AT IGNITION), V_G, $|\Delta V|$

P42 DEORBIT BURN

GOVERNS COUNT-DOWN, DISPLAYS AND CONTINGENCIES

GUIDANCE LAW HOLDS FIXED ATTITUDE W.R.T. VISIBLE HORIZON WITH THRUST VECTOR IN TRAJECTORY PLANE

DISPLAYS TTI (CHANGES TO T_G AT IGNITION), V_G, $|\Delta V|$ (CHANGES TO T_{ff} AT IGNITION)

P51 IMU ORIENTATION DETERMINATION

MANUAL ATTITUDE CONTROL AND STAR ACQUISITION

P52 IMU ALIGN ON SIVB

FINE ALIGNMENT WHEN SIVB ATTACHED

AUTO STAR SELECTION AND ACQUISITION WITH MANUAL OVERRIDE

P53 IMU/CSM ALIGN

FINE ALIGNMENT WHEN CSM FREE

AUTOMATIC STAR SELECTION AND ACQUISITION WITH MANUAL OVERRIDE

AUTOMATIC ATTITUDE MANEUVERS WITH MANUAL OVERRIDE

PROGRAM TERMINATES WITH CSM AND IMU IN ATTITUDE REQUIRED BY GOVERNING MAJOR PROGRAM

P54 IMU REALIGNMENT

MANUAL ATTITUDE CONTROL AND STAR ACQUISITION

P61 MANEUVER TO CM/SM SEPARATION ATTITUDE

DISPLAY g_{max}, γ_{entry}, T_{ff}

P62 CM/SM SEPARATION AND PRE-ENTRY MANEUVER

CREW INPUTS SPLASH POINT AND LIFT UP OR DOWN

P63 ENTRY INITIALIZATION

DISPLAY β, g, R_{targ}

HOLD ATTITUDE (LIFT UP OR DOWN)

P64 POST 0.05g

DISPLAY β, g, R_{targ}

HOLD ATTITUDE

P67 FINAL PHASE

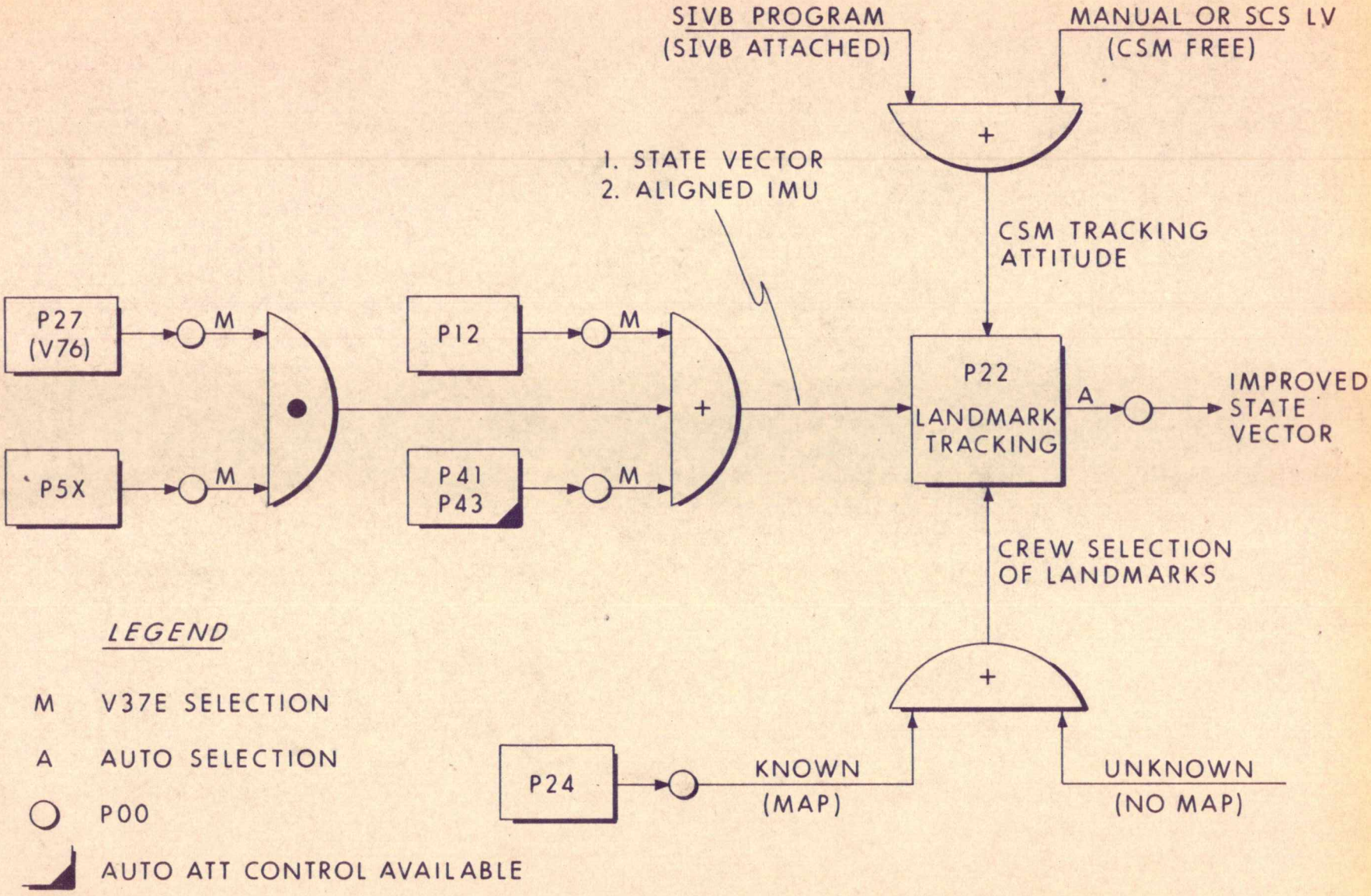
INITIATED WHEN g = 0.2

DISPLAY β, g, $R_{pred} - R_{targ}$

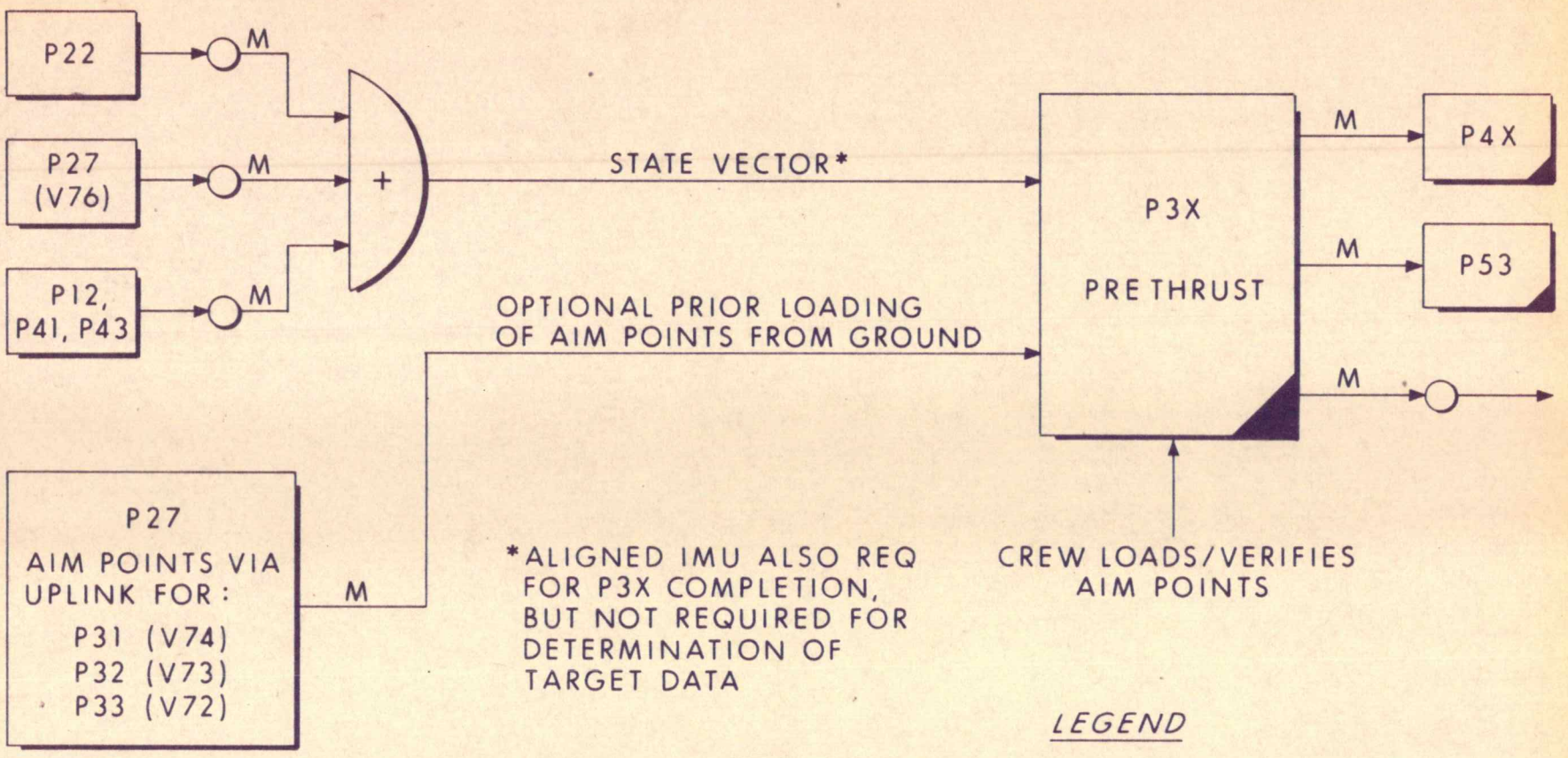
ROLL FOR LANDING AREA CONTROL

JOB NO. TP# _____ PROJ. # _____ FIG. NO _____ CLASS _____

AS-204 LANDMARK TRACKING (P22)



AS-204 SPS BURN TARGETTING (P31-33)



X = 1 ORBIT CHANGE
X = 2 DEORBIT
X = 3 MINIMUM IMPULSE

LEGEND

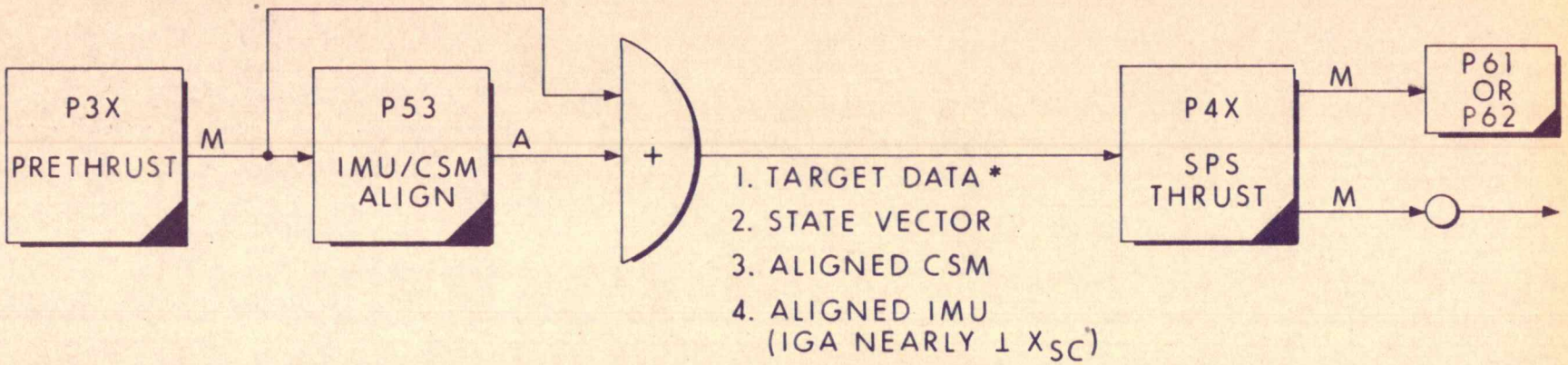
M V37E SELECTION

A AUTO SELECTION

○ P00

◢ AUTO ATT CONTROL AVAILABLE

AS-204 SPS THRUST VECTOR CONTROL (P41-43)



*TARGET DATA ARE PARAMETERS NECESSARY FOR COMPUTATION OF V_{REQD} IN STEERING EQUATIONS

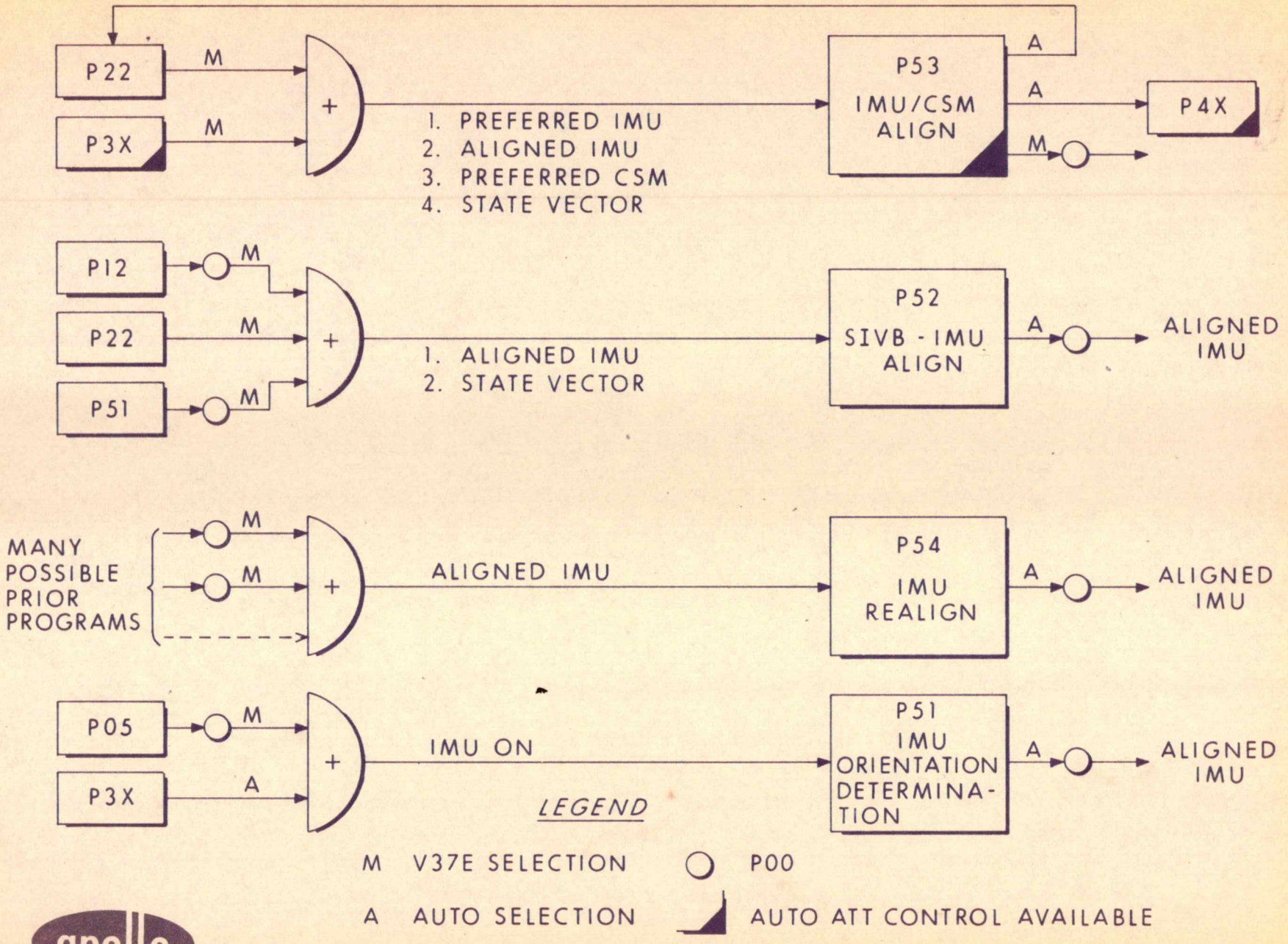
X = 1 ORBIT CHANGE
X = 2 DEORBIT
X = 3 MINIMUM IMPULSE

LEGEND

M V37E SELECTION
A AUTO SELECTION
○ P00
◢ AUTO ATT CONTROL AVAILABLE

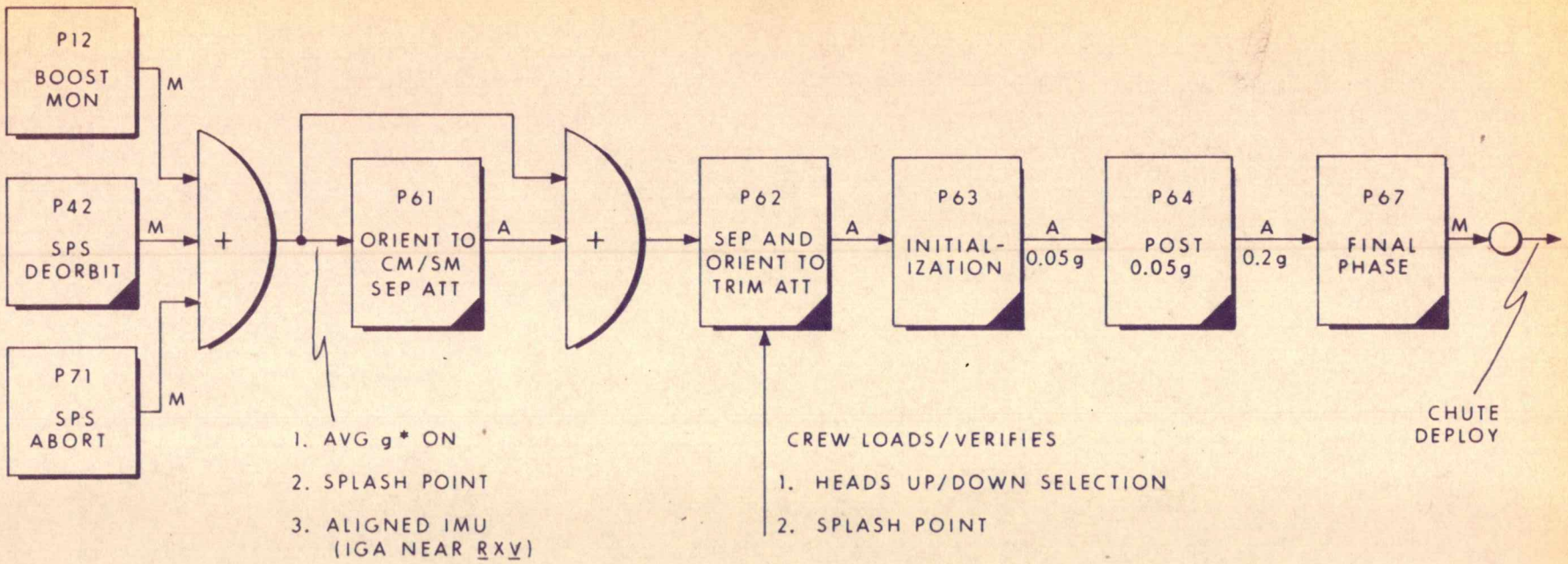
JOB NO. TP# PROJ. # FIG. NO. CLASS.

AS-204 IMU ALIGNMENT (P51 - 54)



JOB NO. TP# PROJ. # FIG. NO. CLASS

AS-204 ENTRY GUIDANCE (P61-67)



LEGEND

M V37E SELECTION

A AUTO SELECTION

○ P00

◢ AUTO ATT CONTROL AVAILABLE

*AVG g UPDATES STATE VECTOR UPDATE EVERY TWO SECONDS USING PIPA ΔV's

JOB NO. TP# PROJ. # FIG. NO. CLASS

OPTICAL SUBSYSTEM FUNCTIONS

1. IMU ALIGNMENT

2. EARTH ORBITAL NAVIGATION

3. MIDCOURSE NAVIGATION

4. LUNAR ORBITAL NAVIGATION

EARTH ORBITAL NAVIGATION

1. TRACKING OF KNOWN LANDMARKS

   FIELD OF VIEW: SUFFICIENTLY LARGE TO RECOGNIZE LANDMARKS FROM 80 TO 150 MILES

   ACCURACY: COMPARABLE TO LANDMARK POSITION UNCERTAINTY (ABOUT 2 MILLIRAD)

   TRACKING RATE: UP TO 3 DEG/SEC

2. TRACKING OF UNKNOWN LANDMARKS

   FIELD OF VIEW: SUFFICIENTLY LARGE TO RECOGNIZE DETAIL

   ACCURACY: COMPARABLE TO IMU ANGLE ENCODING

   TRACKING RATES: UP TO 3 DEG/SEC

3. STAR HORIZON MEASUREMENTS

   FIELD OF VIEW: HORIZON LINE OF SIGHT .1 × 1 MILLIRAD

   ACCURACY: COMPARABLE TO HORIZON KNOWLEDGE (ABOUT 1/2 MILLIRAD)

   TRACKING RATE: 1.5 MILLIRAD/SEC

IMU ALIGNMENT REQUIREMENTS

FIELD OF VIEW : SUFFICIENTLY LARGE TO RECOGNIZE STAR PATTERNS

ACCURACY : COMPARABLE TO IMU ANGLE ENCODING

TRACKING RATE : UP TO 2 MILLIRAD/SEC

SUMMARY OF REQUIREMENTS

FIELD OF VIEW: LARGE FOR ACQUISITION
LARGE FOR LANDMARK MEASUREMENTS

SMALL FOR MIDCOURSE MEASUREMENTS

ACCURACY: 2 MILLIRAD FOR LANDMARK TRACKING
50 MICRORAD FOR MIDCOURSE

TRACKING RATE: ARC SECONDS / SECOND TO 3 DEG/SEC

SUMMARY OF DESIGN

INSTRUMENTS SCT & SXT

	SCT	SXT
FIELD OF VIEW	60 DEG	1.8 DEG
ACCURACY	1/2 MILLIRAD	40 SEC ALIGNMENT 10 SEC MIDCOURSE
TRACKING RATE	50 ARC SEC / SEC TO 10 DEG / SEC	

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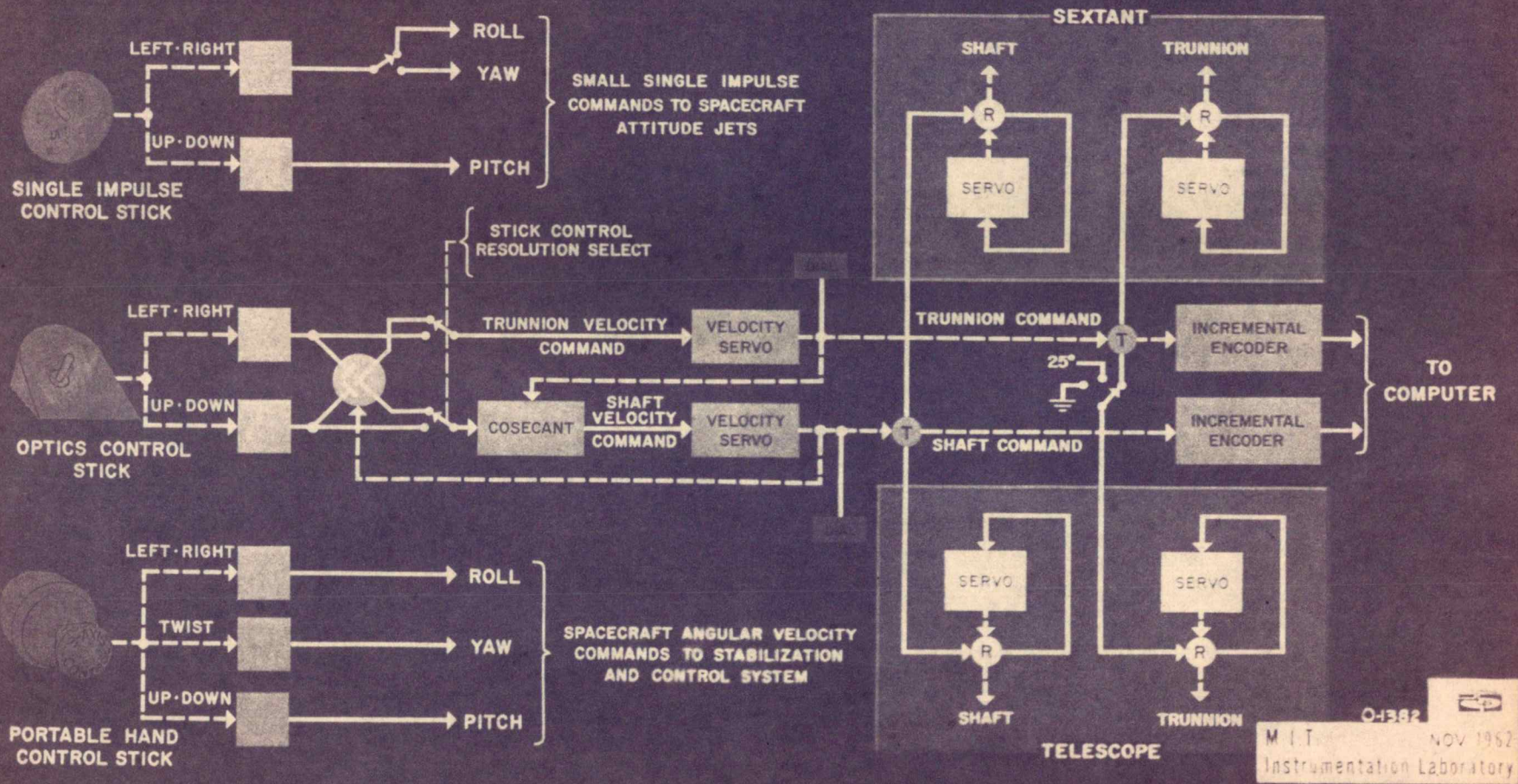
OPTICS CONTROL INSTRUMENTATION — BLOCK DIAGRAM



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SEXTANT FIELD MOTIONS

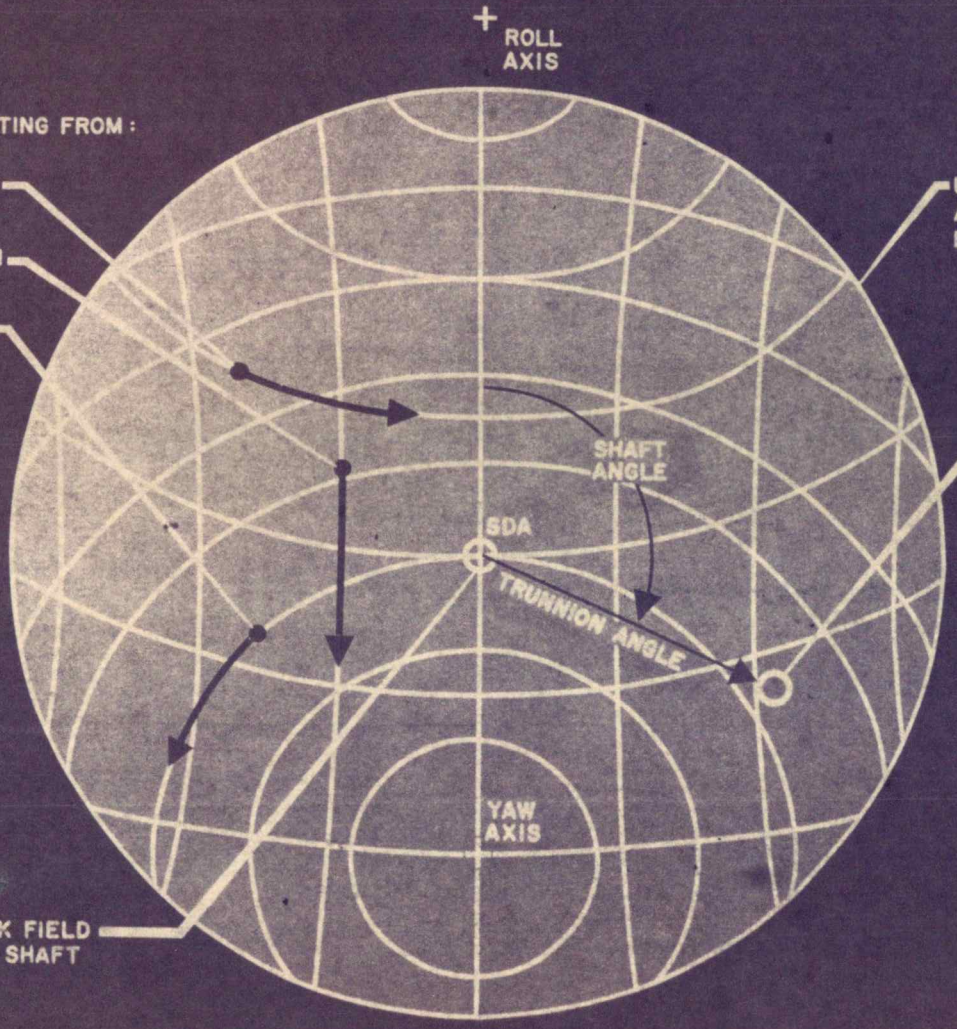


IMAGE MOTION RESULTING FROM:

ROLL MOTION

PITCH MOTION

YAW MOTION

UNOBSTRUCTED SEXTANT FIELD OF VIEW: AT LEAST 50° FROM SHAFT AXIS IN ALL DIRECTIONS

1.9° STAR LINE FIELD

PITCH AXIS +

1.9° LANDMARK FIELD CENTERED ON SHAFT AXIS

D-1375

M.I.T. NOV. 1962

Instrumentation Laboratory

ZERO OPTICS MODE

- CDU'S GO TO ZERO UTILIZING 16X RESOLVER
- OUA FOLLOWS ON COARSE SYSTEM ONLY

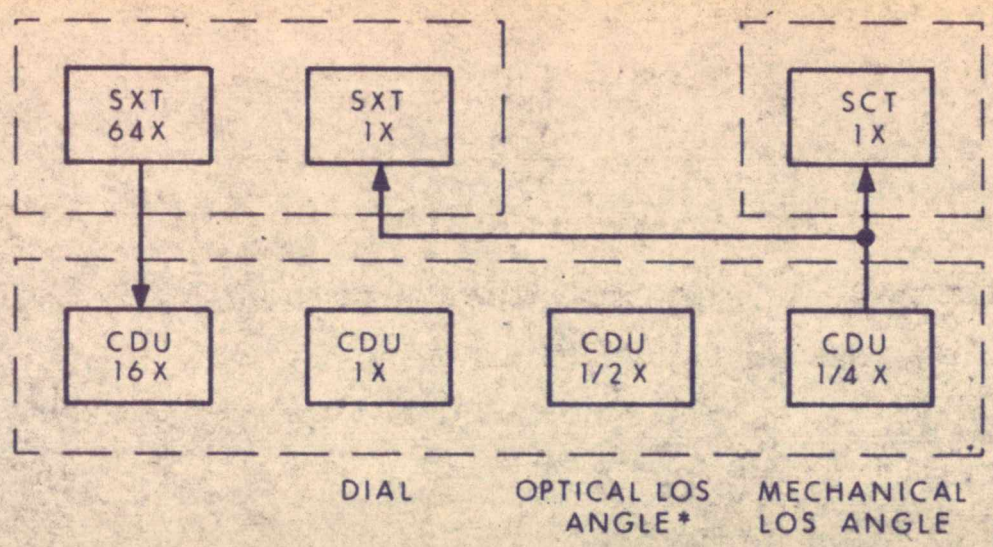
  Thus SXT optical zero (LOS coincidence) will not be good in the zero optics mode.

- COMPUTER RECEIVES DISCRETE FROM MODE SWITCH
- COMPUTER WAITS 60 SECONDS BEFORE COUNTERS ARE SET TO ZERO
- COMPUTER ZEROES COUNTERS
- COMPUTER HEREAFTER HAS CORRECT ANGLES UNTIL OSS POWER IS TURNED OFF

NOTE : THE MODE SWITCH HAS TO REMAIN IN THE ZERO POSITION SECOND OR AN ALARM WILL BE GENERATED

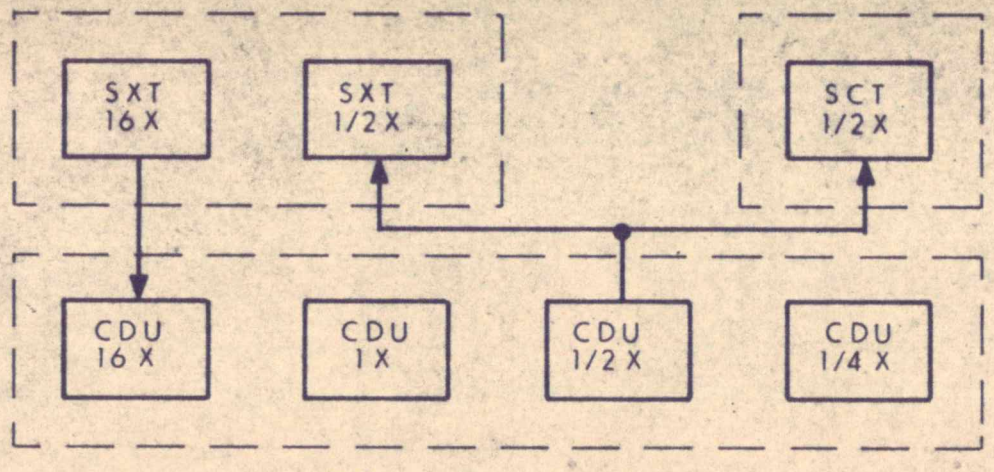
JOB NO. TP# PROJ. # FIG. NO CLASS

RESOLVERS USES FOR THE 2-SPEED SERVO SYSTEM



TRUNNION

*USED IN CSC GENERATOR CIRCUIT RESOLVED MODE



SHAFT

*USED IN SHAFT RESOLUTION RESOLVED MODE

MECHANICAL LIMITS

- CDU — NONE
- SCT — NONE
- SXT TRUNNION — - 5° TO + 95° LINE OF SIGHT
- SXT SHAFT — -270° TO +270° LINE OF SIGHT

RESOLVED MODE LIMITS

- SHAFT — NONE
- TRUNNION — + 5° TO + 90° LINE OF SIGHT

JOB NO. TP# PROJ. # FIG. NO. CLASS

ANGULAR DISPLAYS

1. DIALS ONSET - INDICATE SCT LINE OF SIGHT.

   SINCE SCT SHAFT ALWAYS FOLLOWS CDU, SCT SHAFT DIAL AND SHAFT CDU READ THE SAME ANGLE.

   SCT TRUNNION DIAL READS SCT TRUNNION LOS.
   WHEN THE SCT MODE SW IS IN THE STAR LOS POSITION.

   SET TRUNNION DIAL ALSO READS SXT LOS.
   THUS WHEN THE LOS IS AT 20^{0} THE SCT COUNTER READS 20^{0} BUT THE TRUNNION CDU READS 40^{0}.

2. DIALS ON CDU

   SHAFT DIAL READS TRUE SHAFT ANGLE.

   TRUNNION DIAL READS 2X TRUNNION ANGLE.

3. COMPUTER ANGLE COUNT

   TRUE SHAFT ANGLE AND TRUE TRUNNION ANGLE IF PROPERLY ZEROED.

JOB NO. TP# _____ PROJ. # _____ FIG. NO _____ CLASS _____
DOC NO. _____ FOR _____ BY _____ DATE _____