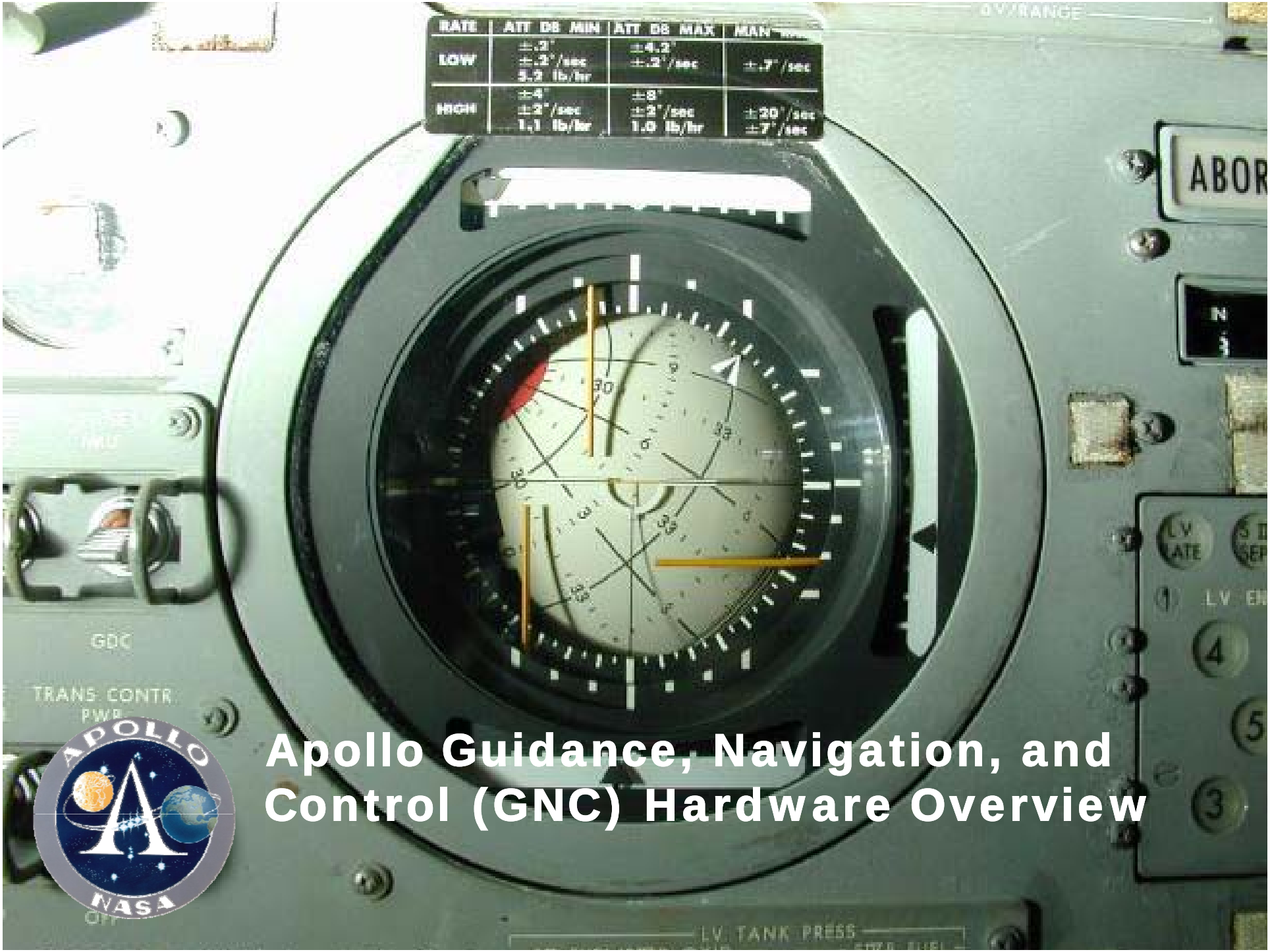

Apollo Guidance, Navigation, and Control (GNC) Hardware Overview

Topics

- Terminology familiarization
- Top-level organization of the GNC system
- Caveats
  - Terminology not always consistent between various organizations (Program Office, Flight Ops, North American, Grumman, MIT, TRW)
  - Prime contractor terminology (North American, Grumman) used here

Agenda

- Review of basic GNC concepts
- Command and Service Module (CSM)/Lunar Module (LM) GNC organization
- Primary Guidance, Navigation, and Control (PGNCS) (mostly common to CSM and LM)
- CSM Stabilization and Control System (SCS) and other CSM-specific hardware
- LM Abort Guidance System (AGS), Control Electronics System (CES), and other LM-specific hardware
- Other common hardware
- Summary
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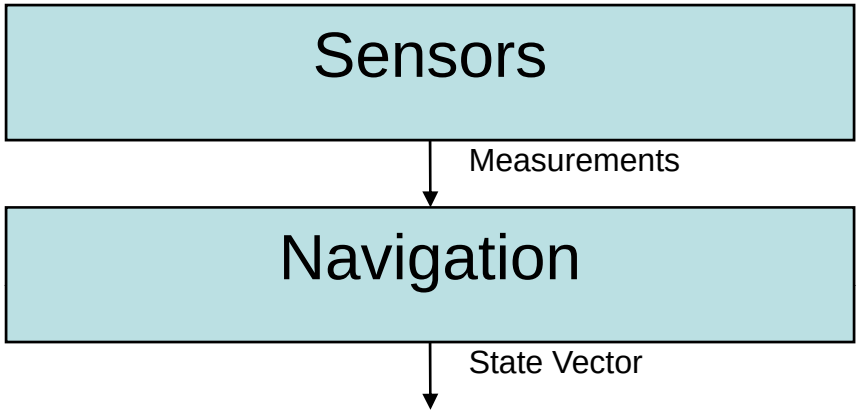
Review of Basic GNC Concepts

- Navigation: “Where am I?”
  - Inputs: sensor measurements
  - Outputs: vehicle state vector (position & velocity at a given time)



Review of Basic GNC Concepts

- Navigation: “Where am I?”
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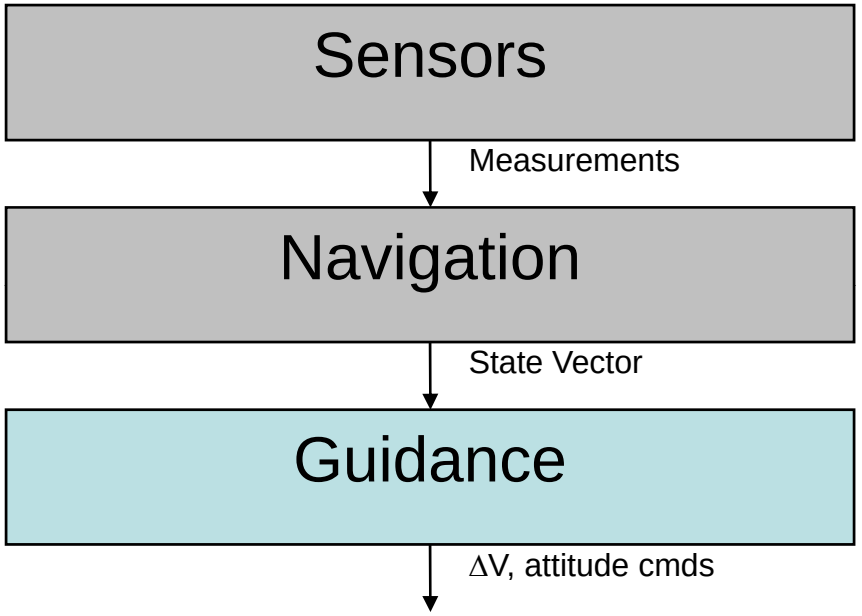
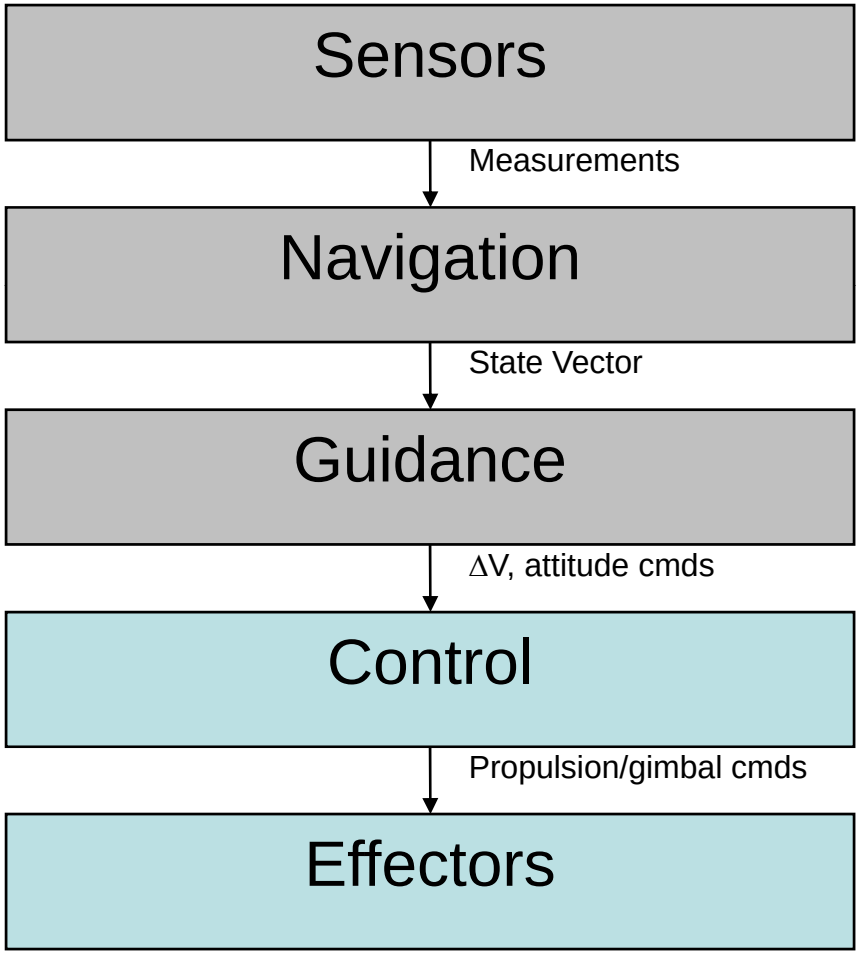
  - Outputs: vehicle state vector (position & velocity at a given time)
- Guidance: “Where am I going?”
  - Inputs: state vector from navigation
  - Outputs: required change in velocity, required attitude (for powered flight)



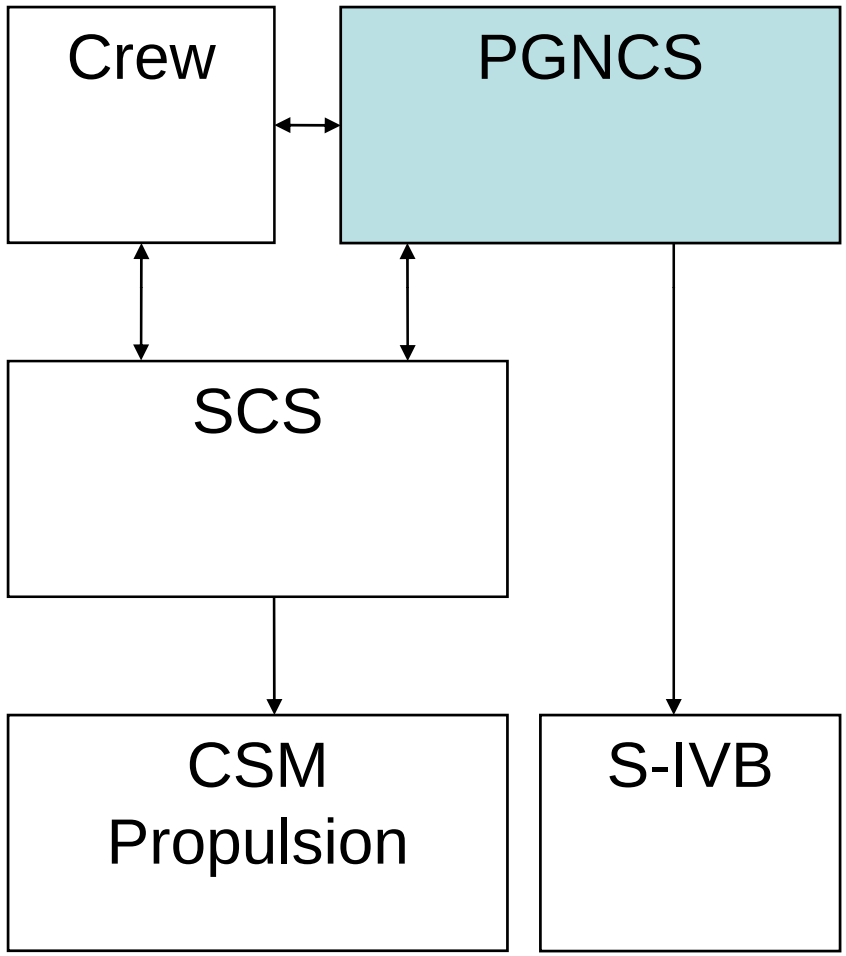
Review of Basic GNC Concepts

- Navigation: “Where am I?”
  - Inputs: sensor measurements
  - Outputs: vehicle state vector (position & velocity at a given time)
- Guidance: “Where am I going?”
  - Inputs: state vector from navigation
  - Outputs: required change in velocity, required attitude (for powered flight)
- Control: “How do I get there?”
  - Inputs: required change in velocity and/or attitude
  - Outputs: commands to flight control effectors (Reaction Control System (RCS) thrusters, engine gimbals, etc)



Command & Service Module (CSM) GNC Organization

- Primary Guidance, Navigation, and Control System (PGNCS)
  - All guidance and navigation functions
  - Primary control functions
  - Takeover capability for Saturn S-IVB stage



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- Primary Guidance, Navigation, and Control System (PGNCS)
  - All guidance and navigation functions
  - Primary control functions
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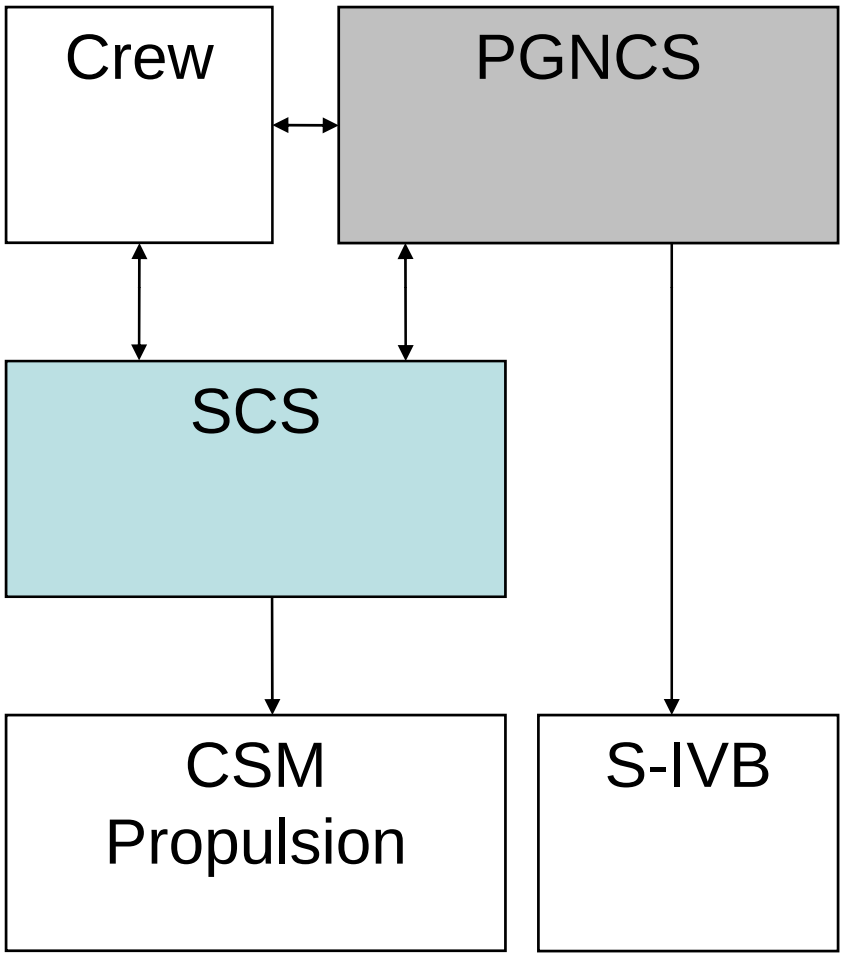
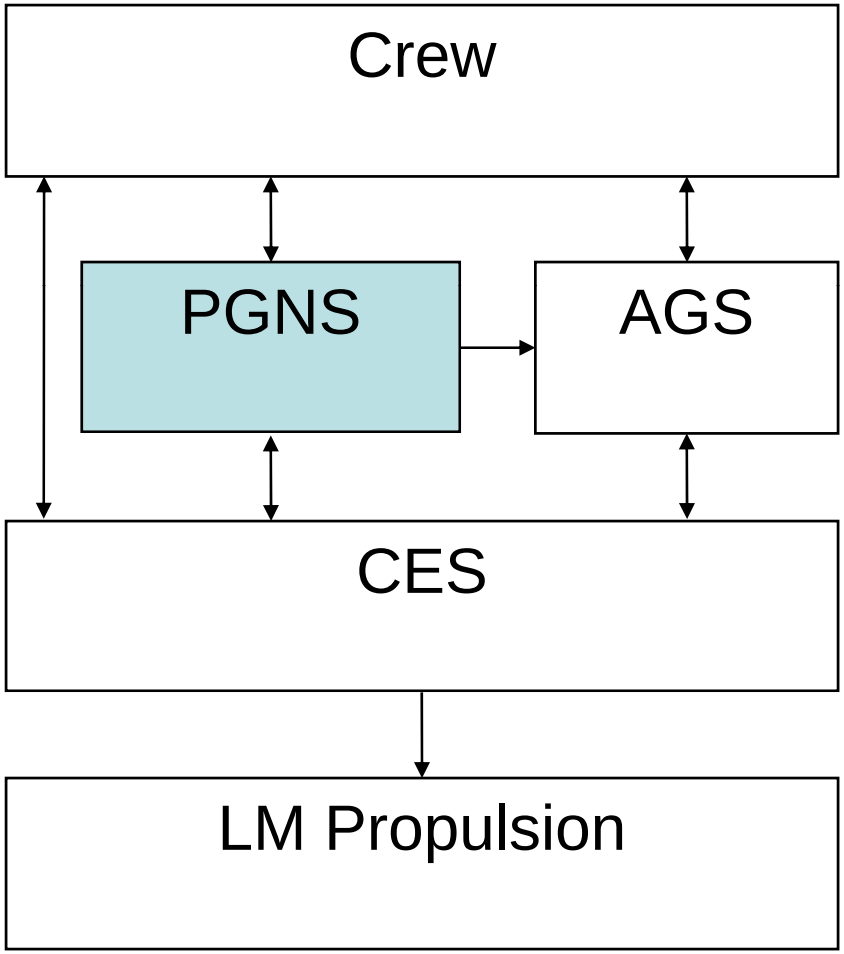
- Stabilization and Control System (SCS)
  - Backup control functions
  - Crew displays and manual controls
  - Interface between PGNCS and propulsion system



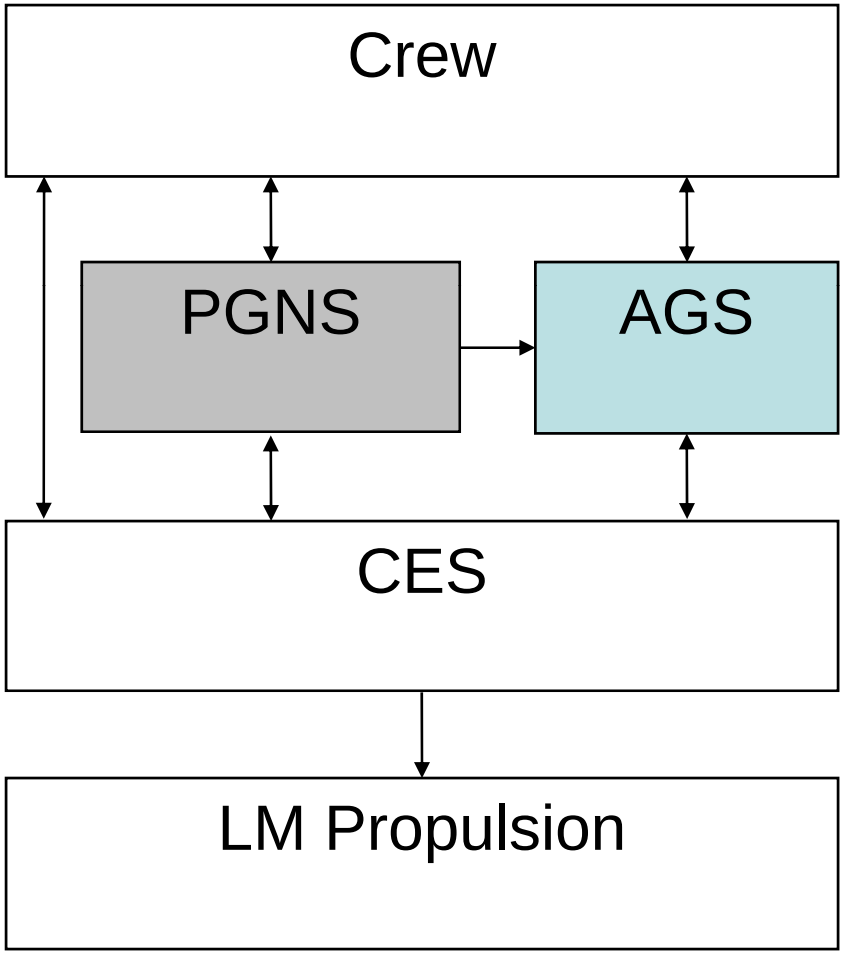
Lunar Module (LM) GNC Organization

- Primary Guidance and Navigation Section (PGNS)
  - Primary guidance, navigation, and control functions



Lunar Module (LM) GNC Organization

- Primary Guidance and Navigation Section (PGNS)
  - Primary guidance, navigation, and control functions
- Abort Guidance Section (AGS)
  - Backup guidance and (rudimentary) navigation functions for lunar descent aborts, powered ascent, and rendezvous with CSM



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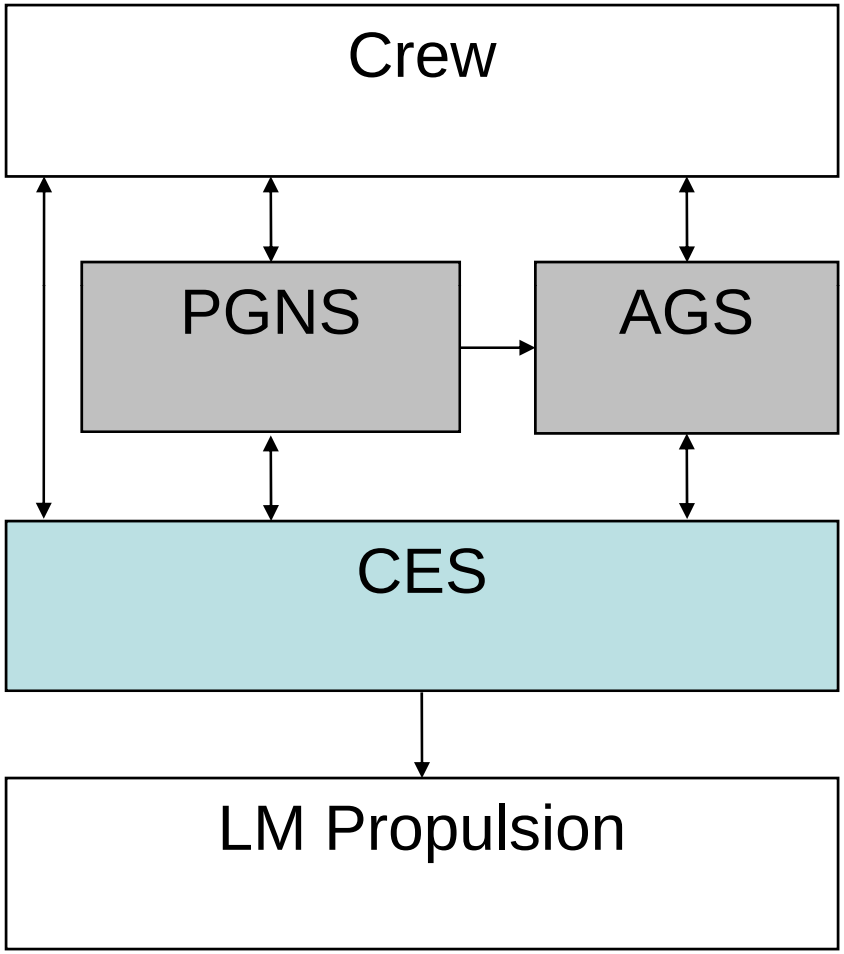
  - Backup guidance and (rudimentary) navigation functions for lunar descent aborts, powered ascent, and rendezvous with CSM
- Control Electronics Section (CES)
  - Backup control functions for PGNS
  - All control functions for AGS
  - Crew displays and manual controls
  - Interface to propulsion system for both PGNS and AGS



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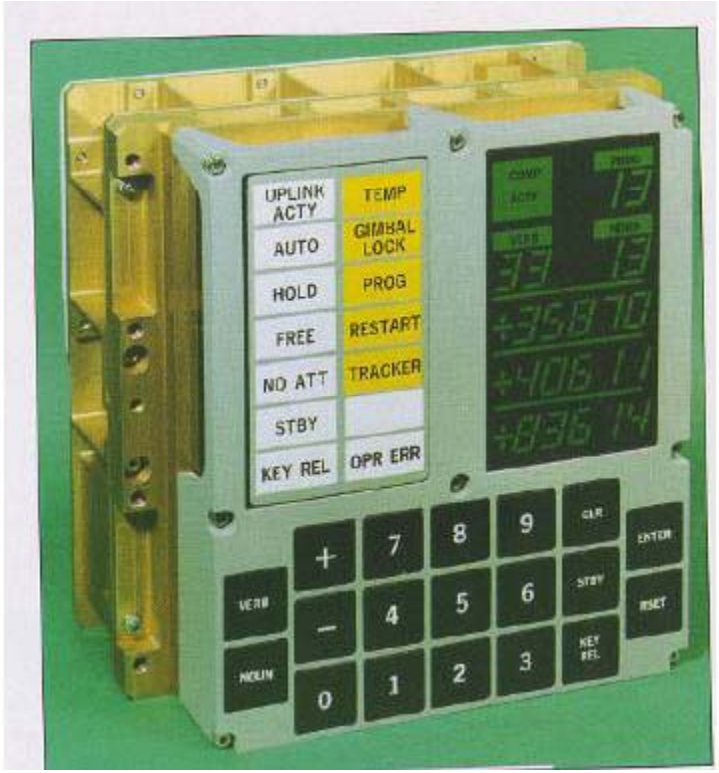
PGNCS/PGNS Hardware

- Three subsystems on each vehicle
  - Designed to operate independently
  - Computer and inertial subsystems almost identical between CSM and LM
- Computer Subsystem (CSS)
- Inertial Subsystem (ISS)
- Optical Subsystem (OSS)

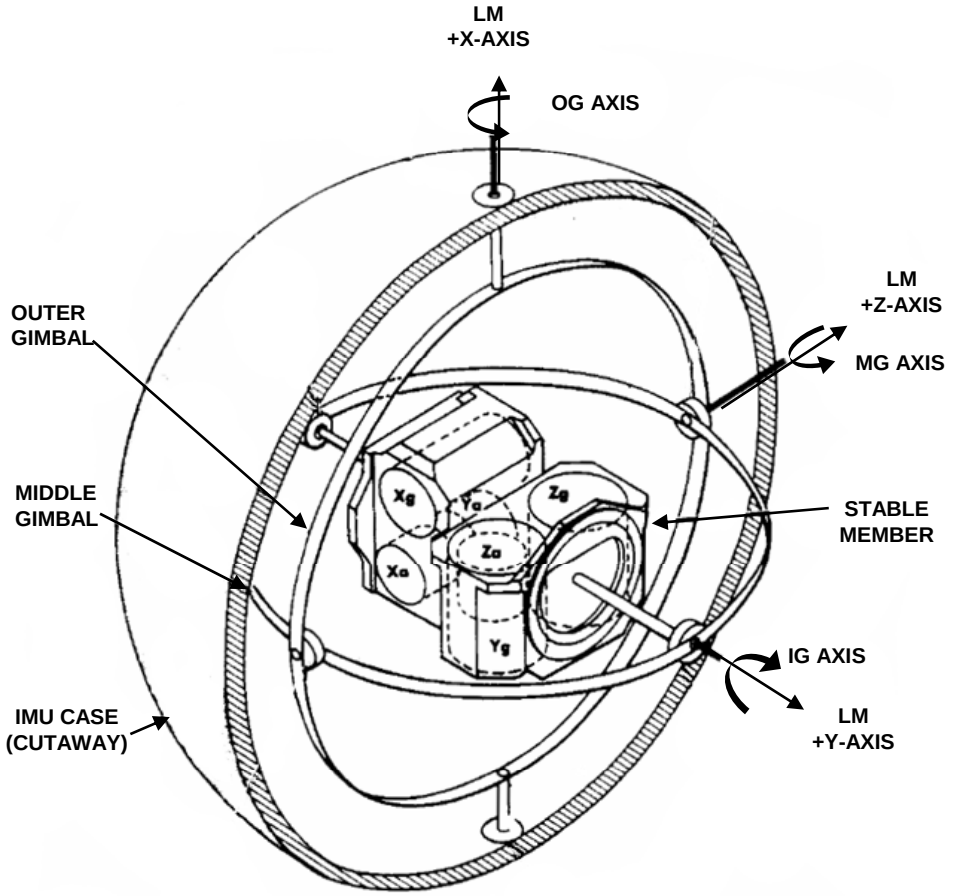
Computer Subsystem

- Apollo Guidance Computer (AGC)
  - Command Module Computer (CMC) on CSM
  - LM Guidance Computer (LGC) on LM
  - Identical hardware, different software (Colossus for CSM, Luminary for LM)
- Display and Keyboard (DSKY)
  - Two CSM DSKYs, one on main panel and one in Lower Equipment Bay (LEB)
  - One LM DSKY, on main panel
  - Only difference between CSM and LM are caution/status indicator lights (LM shown)



Inertial Subsystem

- **Inertial Measurement Unit (IMU)**
  - Stable platform for measurement of attitude and acceleration, isolated from case by three gimbals



Inertial Subsystem

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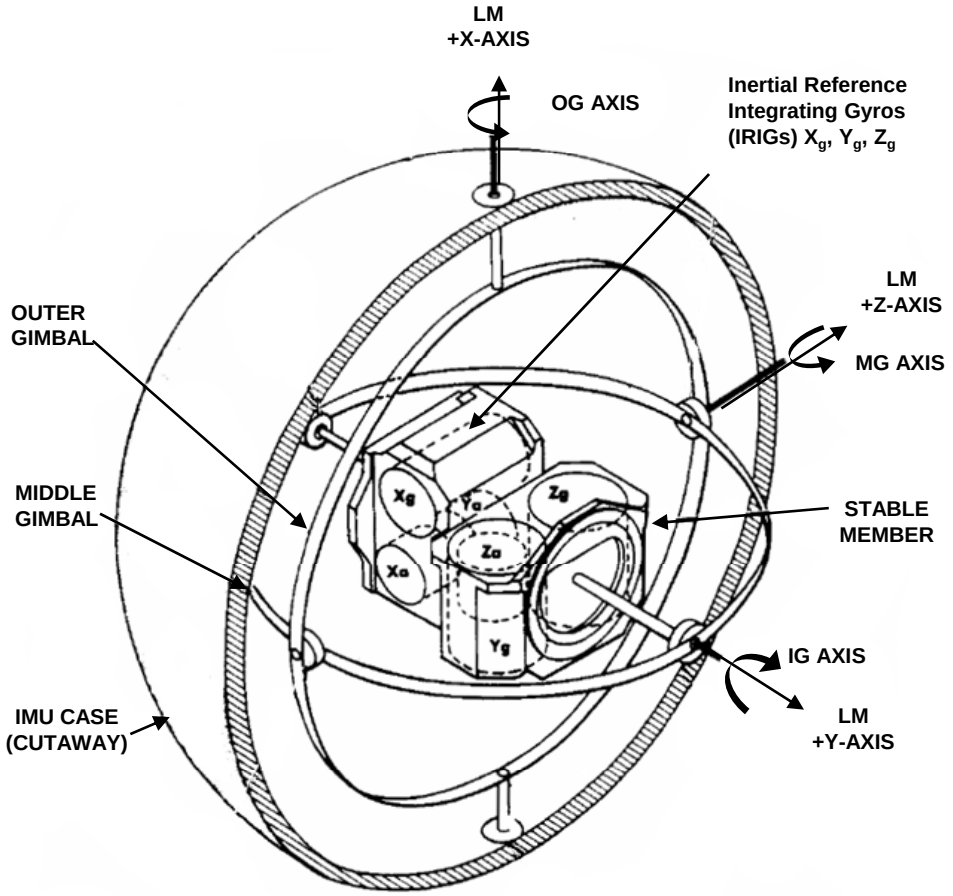
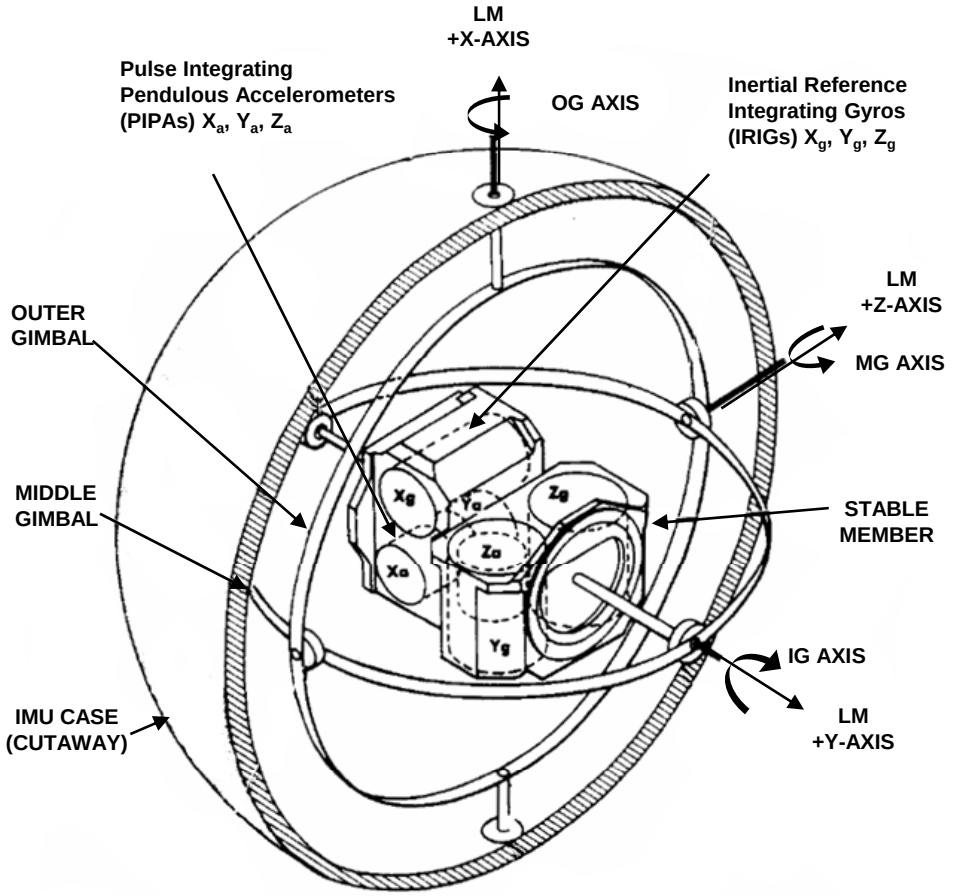
  - Stable platform for measurement of attitude and acceleration, isolated from case by three gimbals
  - Inertial Reference Integrating Gyros (IRIGs) sense attitude changes



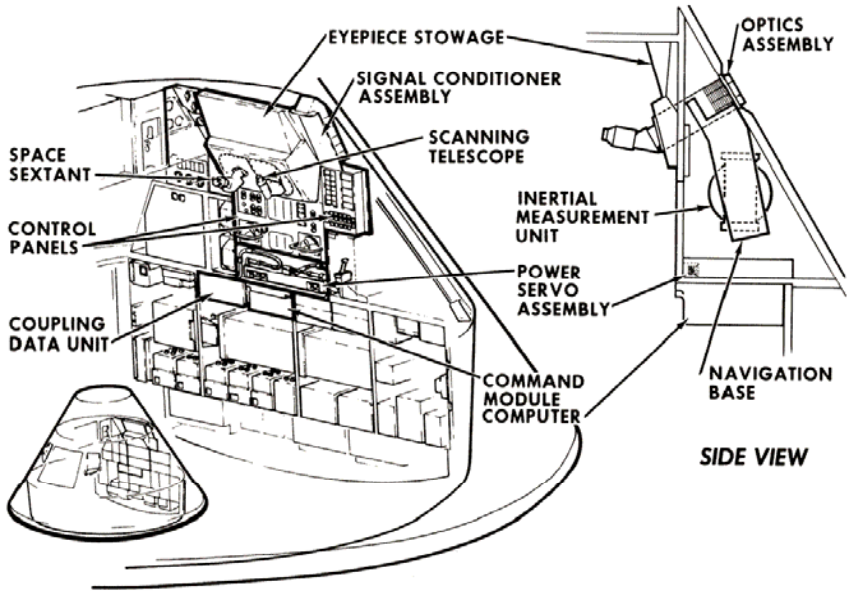
Inertial Subsystem

- **Inertial Measurement Unit (IMU)**
  - Stable platform for measurement of attitude and acceleration, isolated from case by three gimbals
  - Inertial Reference Integrating Gyros (IRIGs) sense attitude changes
  - Pulse Integrating Pendulous Accelerometers (PIPAs) sense velocity changes



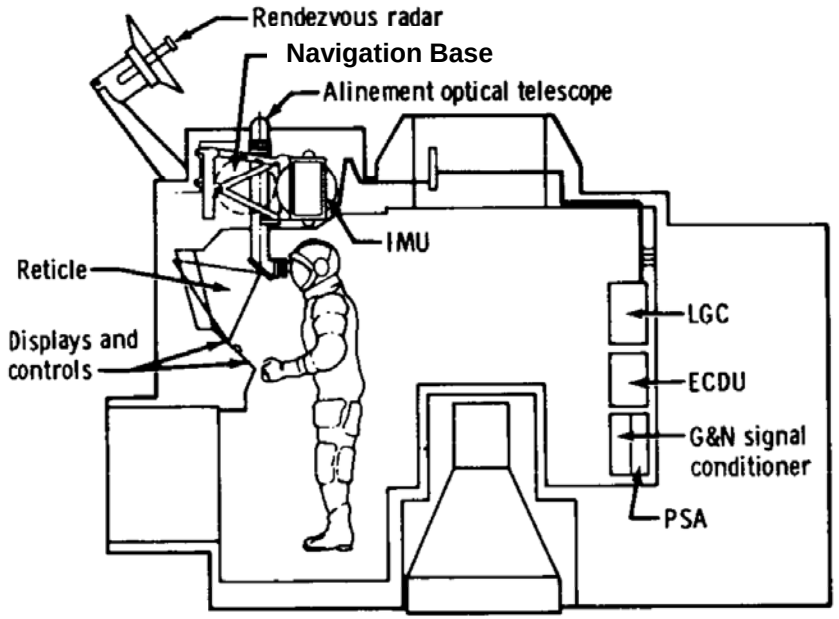
Inertial Subsystem

- Navigation Base (NB)
  - Rigid mounting point for IMU, optics
  - CSM NB located in Lower Equipment Bay (LEB)



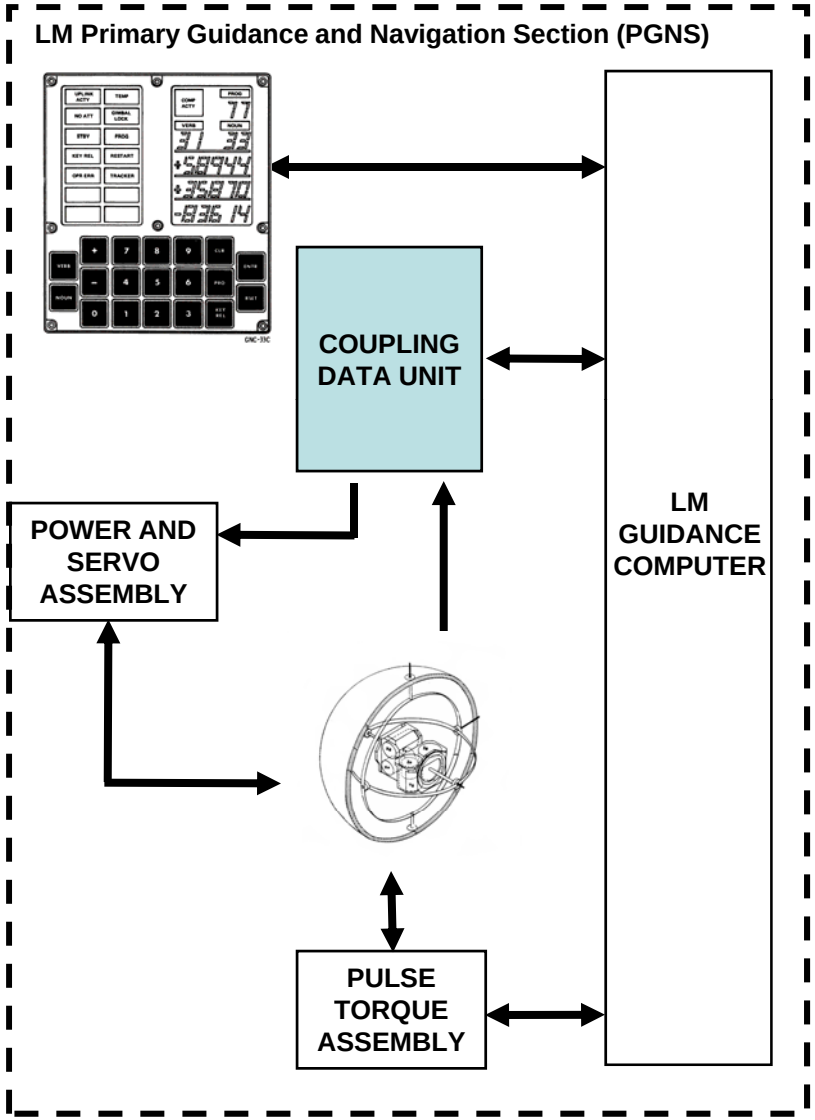
Inertial Subsystem

- Navigation Base (NB)
  - Rigid mounting point for IMU, optics
  - CSM NB located in Lower Equipment Bay (LEB)
  - LM NB located at top forward of LM ascent stage



Inertial Subsystem

- Coupling Data Unit (CDU)
  - 5-channel Analog-Digital and Digital-Analog converter
  - Data interface between computer and IMU, optics, and various controls and displays



Inertial Subsystem

- Coupling Data Unit (CDU)
  - 5-channel Analog-Digital and Digital-Analog converter
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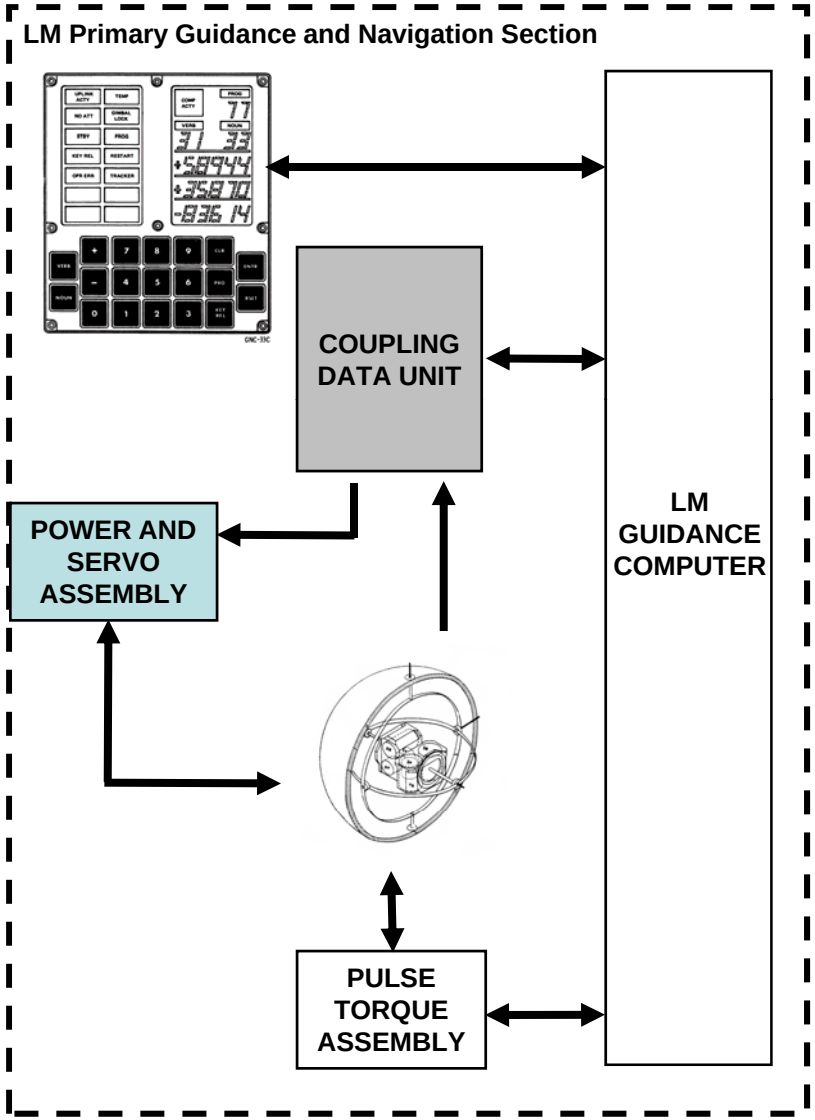
  - Central mounting point for power supplies, amplifiers, and other electronics



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- Power and Servo Assembly (PSA)
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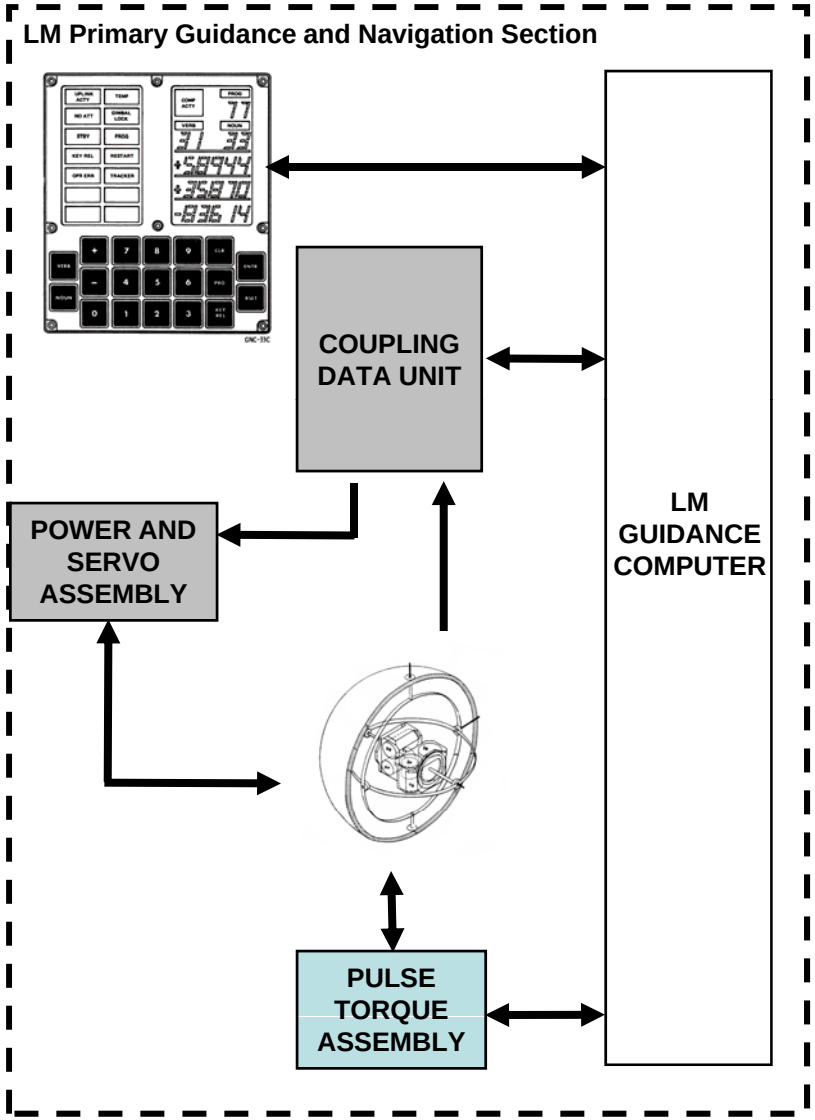
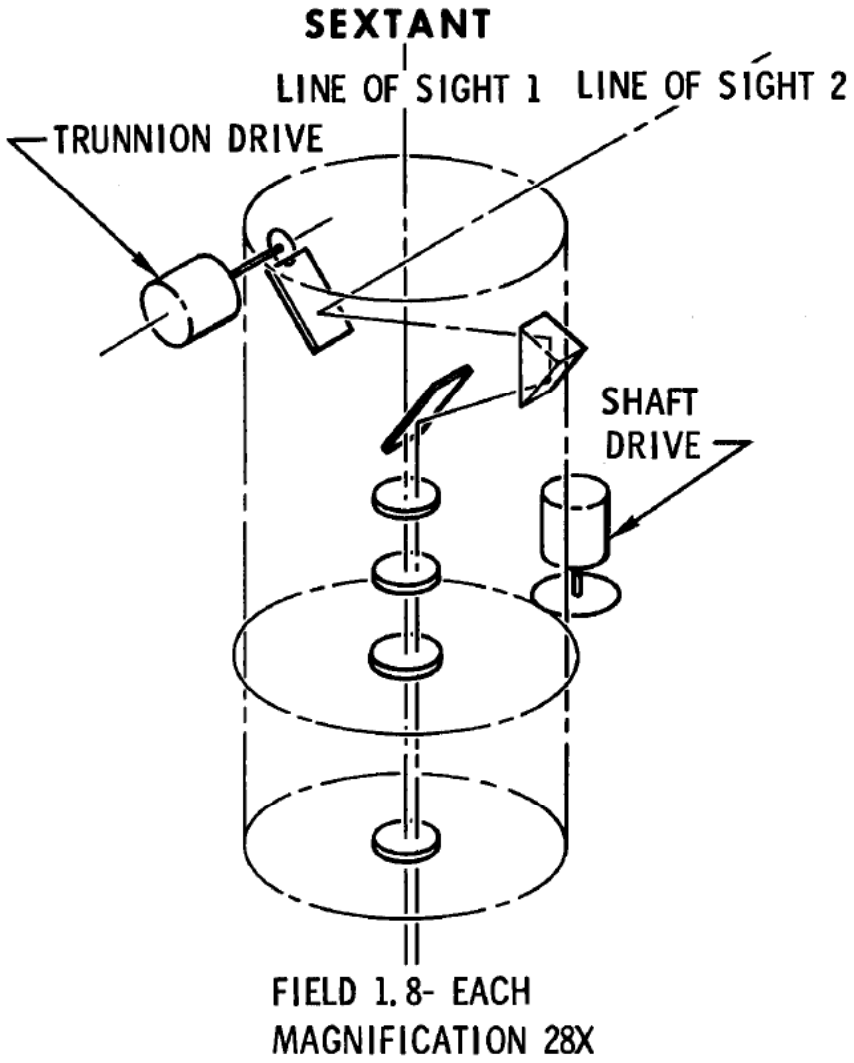
- Pulse Torque Assembly (PTA)
  - Command/data interface to IMU accelerometers
- Signal Conditioner Assembly (SCA) (not shown)
  - Interface to instrumentation system



CSM Optical Subsystem

- Sextant (SXT)
  - 28x magnification, 1.8 degree field-of-view (FOV), dual lines-of-sight (LOS)
  - Collect star LOS data for IMU align
  - Collect star/horizon LOS data for cislunar navigation
  - Collect LM LOS data for rendezvous navigation



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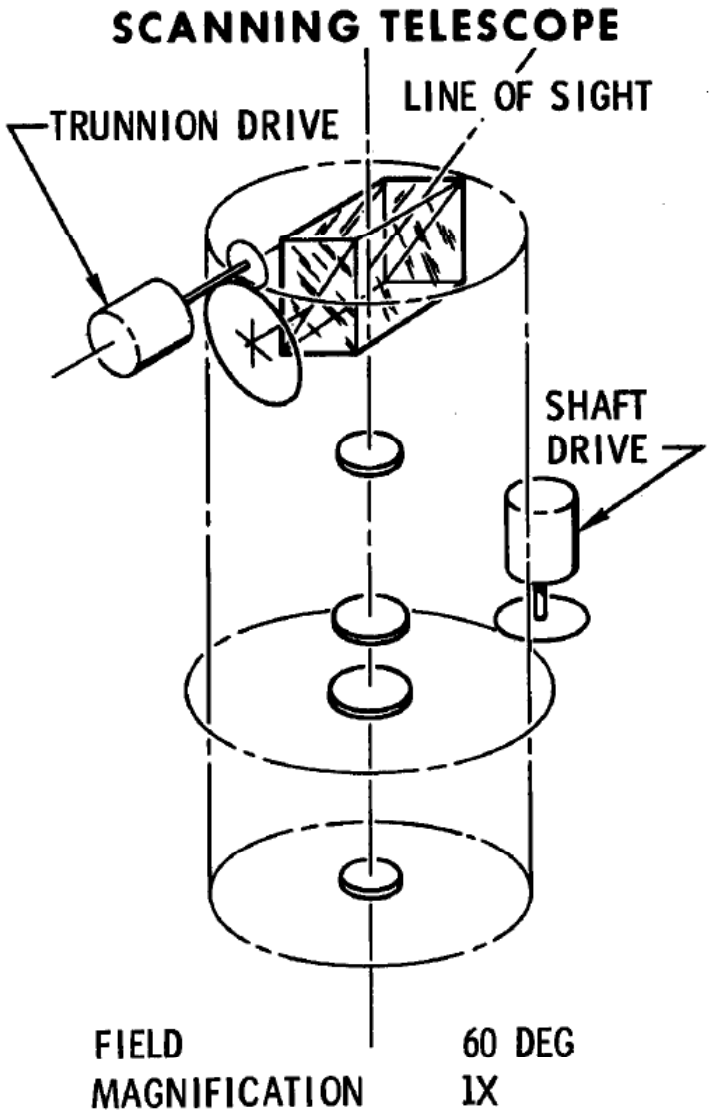
  - 1x magnification, 60 degree FOV
  - Locate stars for subsequent SXT sightings
  - Collect landmark LOS data for orbital navigation



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  - 1x magnification, 60 degree FOV
  - Locate stars for subsequent SXT sightings
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- Minimum Impulse Controller (MIC)
  - Located in LEB with optics
  - Mini-rotational controller provides fine RCS pointing control for optics sightings

LM Optical Subsystem

- Alignment Optical Telescope (AOT)
  - 1x magnification, 60 degree FOV
  - Collect star LOS data for IMU align

LM Optical Subsystem

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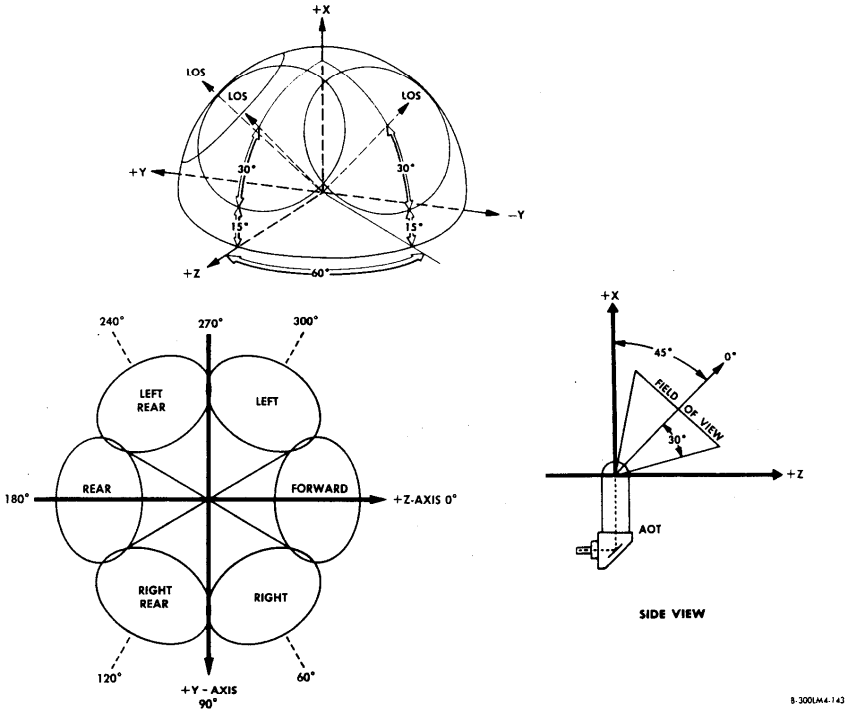
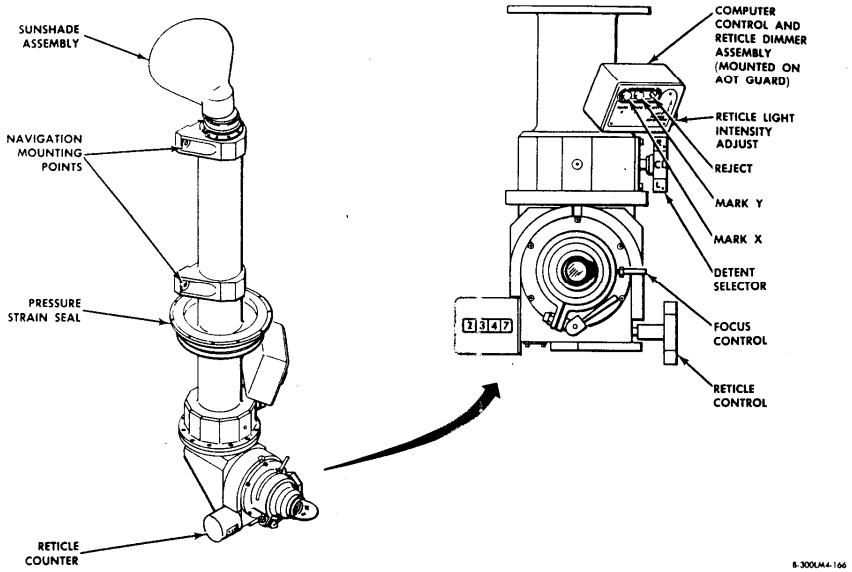
  - Fixed elevation, movable in azimuth to six detent positions for sky coverage while on lunar surface



LM Optical Subsystem

- Alignment Optical Telescope (AOT)
  - 1x magnification, 60 degree FOV
  - Collect star LOS data for IMU align
  - Fixed elevation, movable in azimuth to six detent positions for sky coverage while on lunar surface
- Computer Control and Reticle Dimmer (CCRD) Assembly
  - MARK and REJECT pushbuttons for AOT sightings
  - Reticle light intensity adjust



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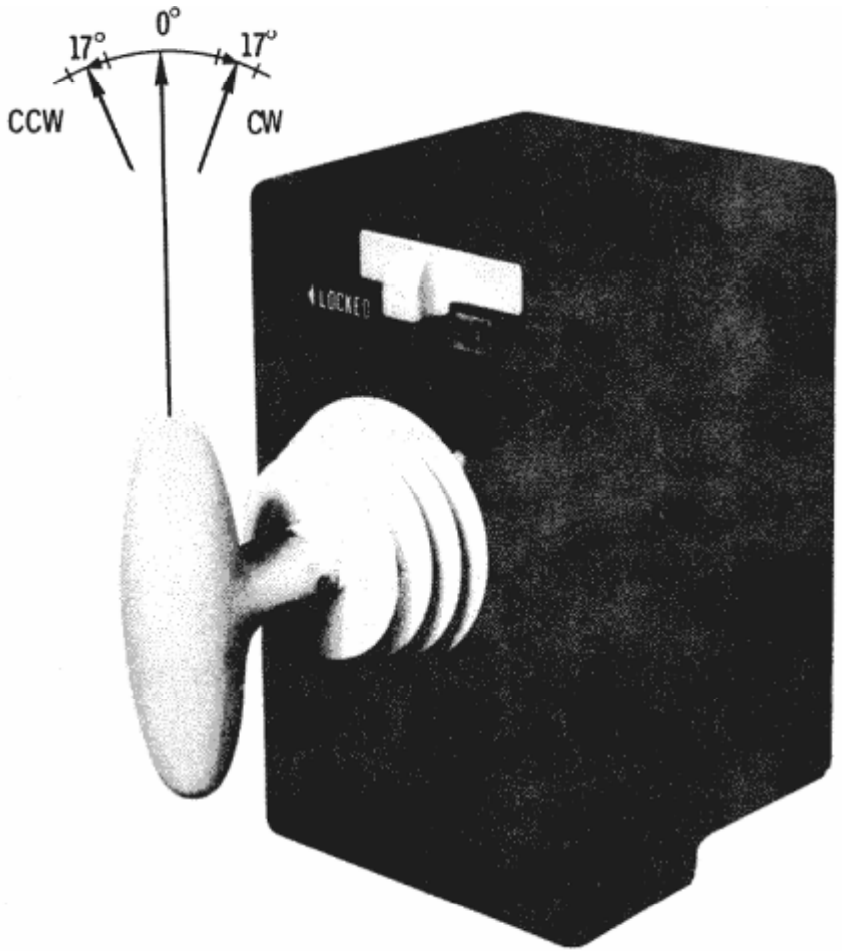
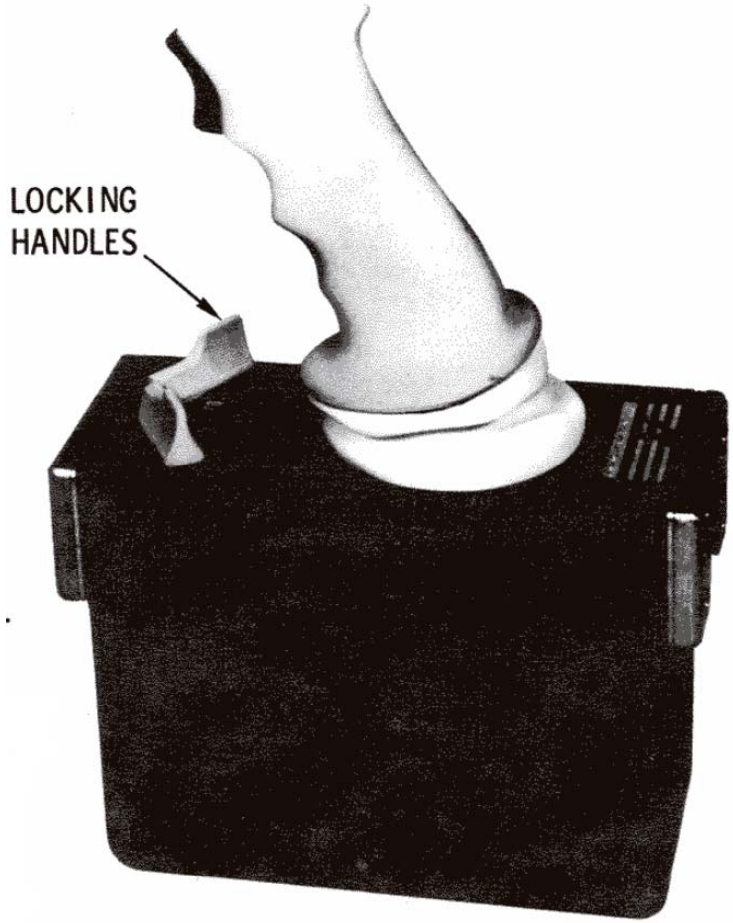
CSM SCS Hardware

- Translation Control (TC)
  - Three-axis CSM RCS translation control
  - Rotate T-handle counterclockwise to initiate launch abort
  - Rotate T-handle clockwise to switch from PGNCS to SCS control



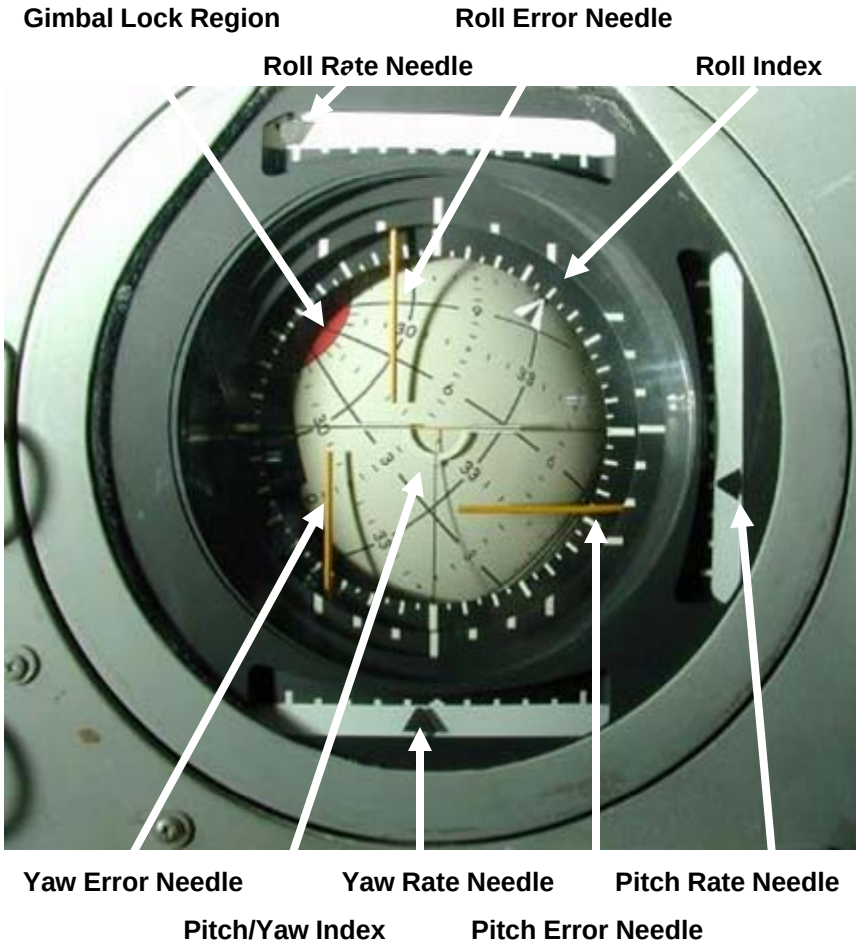
CSM SCS Hardware

- Rotation Controls (RC)
  - Three-axis CSM RCS rotation control or Thrust Vector Control (TVC)
  - Push-To-Talk (PTT) trigger



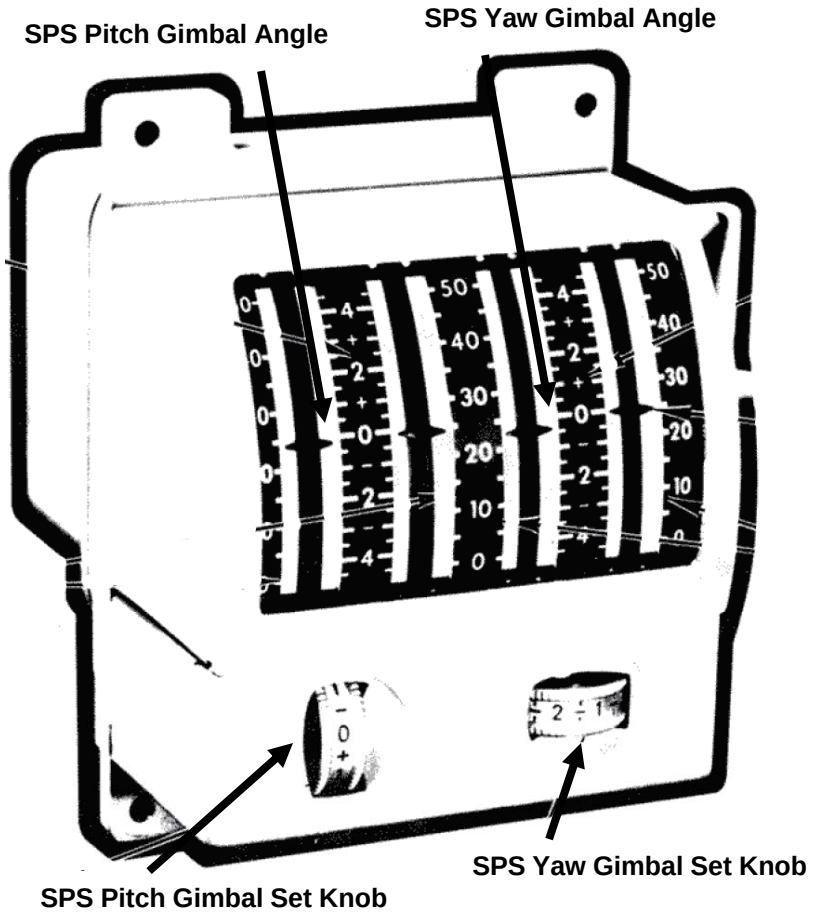
CSM SCS Hardware

- Gyro Assemblies (GA1, GA2)
  - Each contains three Body Mounted Attitude Gyros (BMAGs)
  - Can provide output signals proportional to either angular rate or angular displacement
- Gyro Display Coupler (GDC)
  - Integrates GA data to produce backup attitude reference
- Flight Director Attitude Indicators (FDAI)
  - Display of CSM attitude, attitude errors, and rates
  - Rates from BMAGs, attitude from either IMU or GDC



CSM SCS Hardware

- Gimbal Position/Fuel Pressure Indicator (GP/FPI)
  - Thumbwheels to manually trim Service Propulsion System (SPS) pitch and yaw gimbals prior to burn
  - Needles display gimbal angles
  - Also displays fuel/oxidizer pressures for Saturn S-II and S-IVB stages



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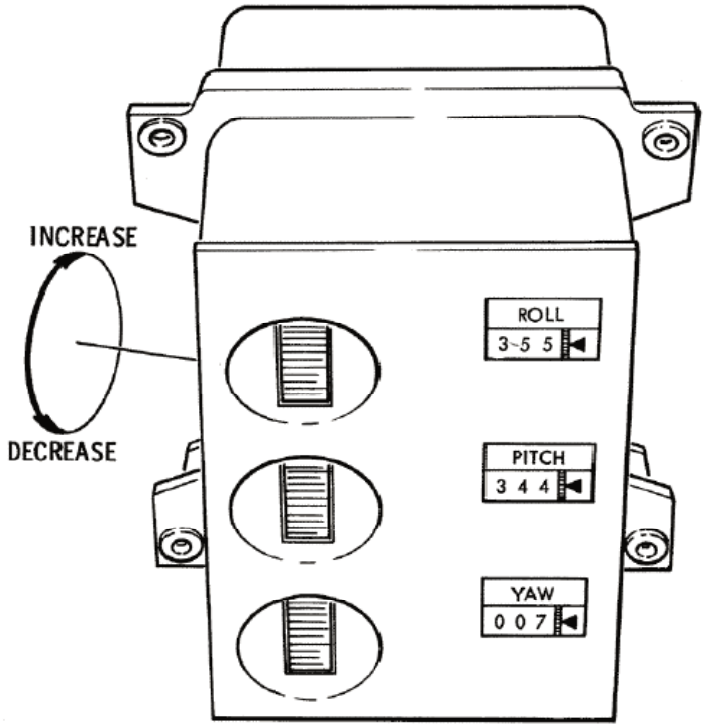
  - Needles display gimbal angles
  - Also displays fuel/oxidizer pressures for Saturn S-II and S-IVB stages
- Attitude Set Control Panel (ASCP)
  - Thumbwheels to set pitch, yaw, and roll attitudes
  - Attitude error reference for display on FDAI
  - Attitude reference for GDC



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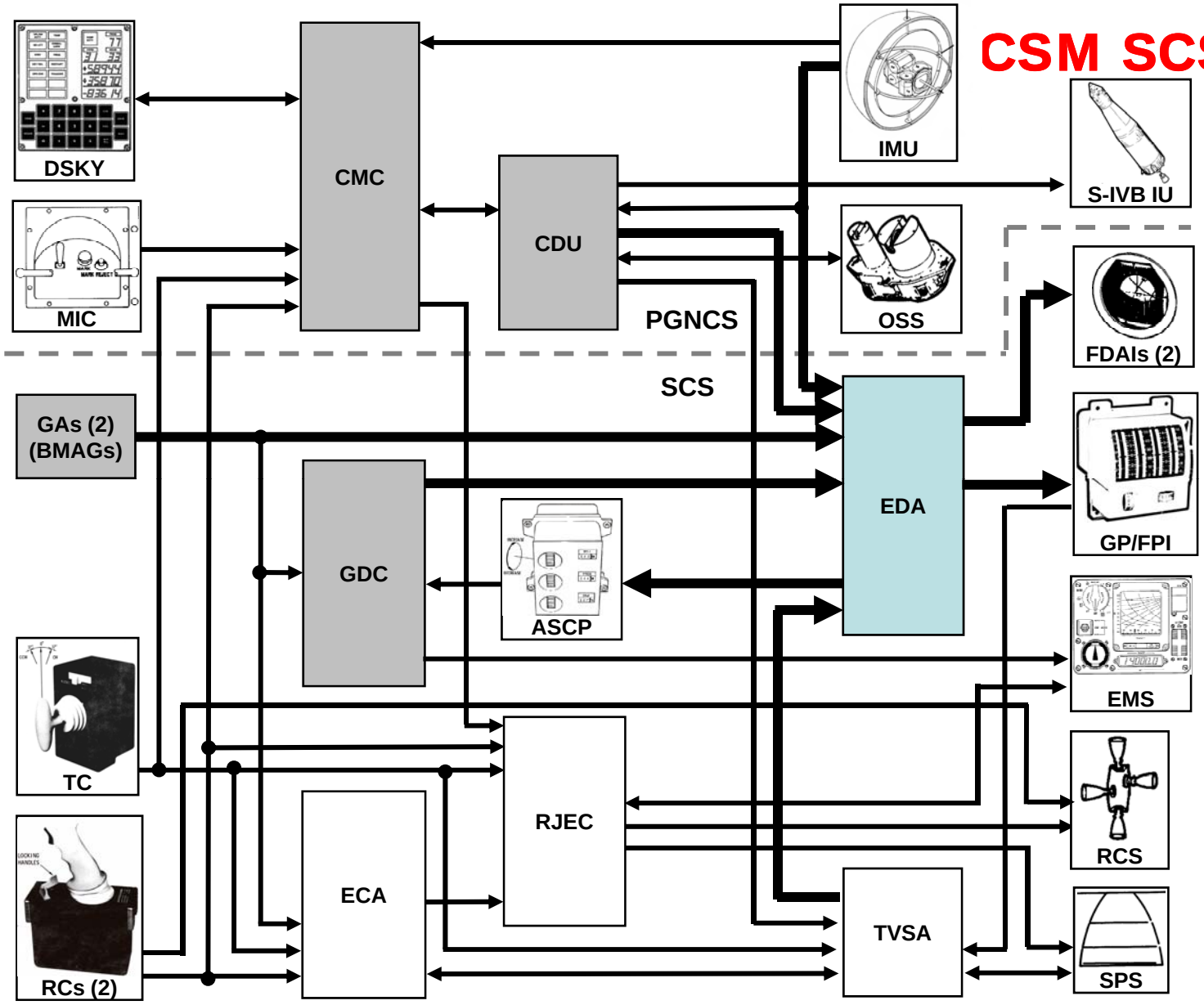
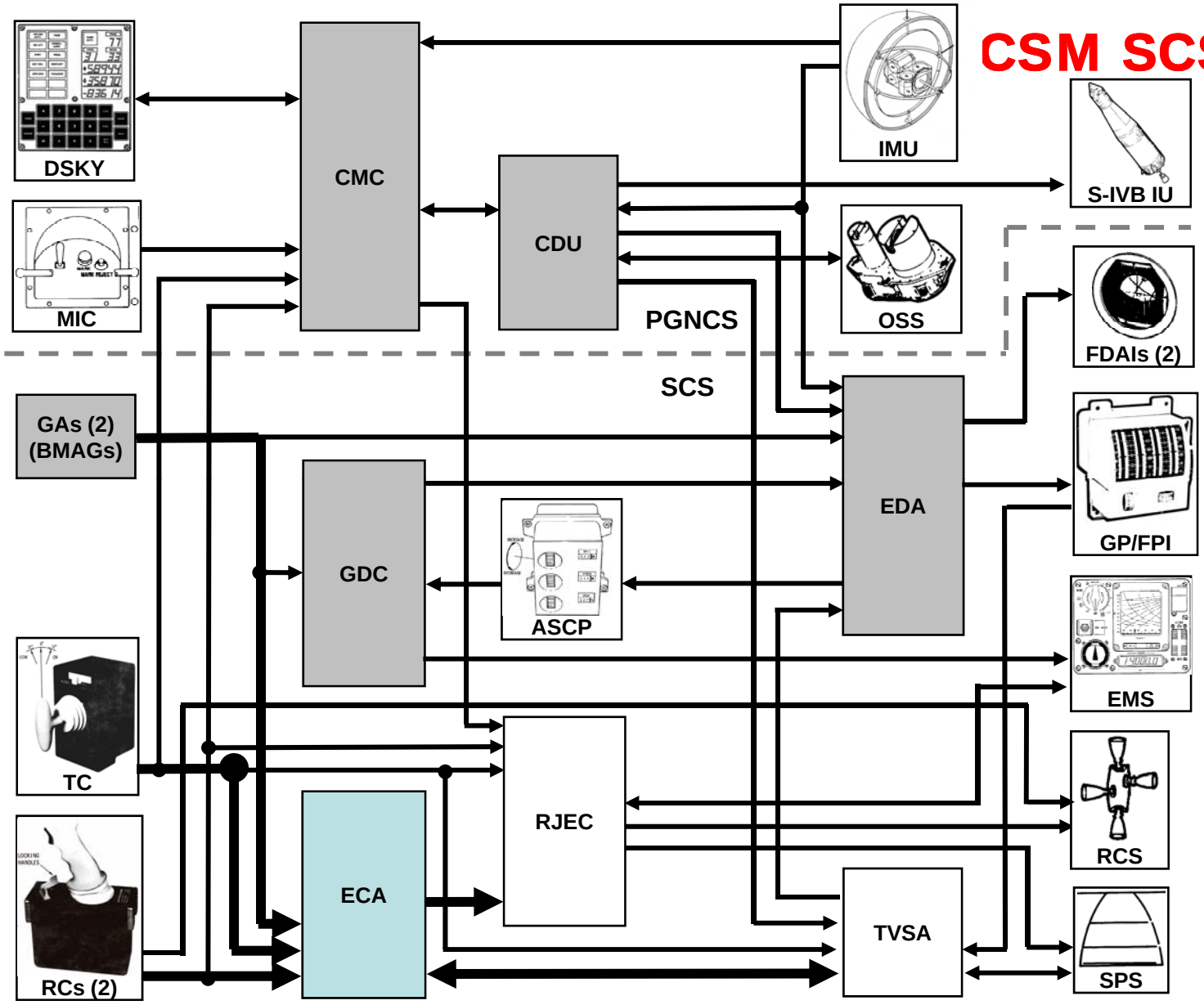


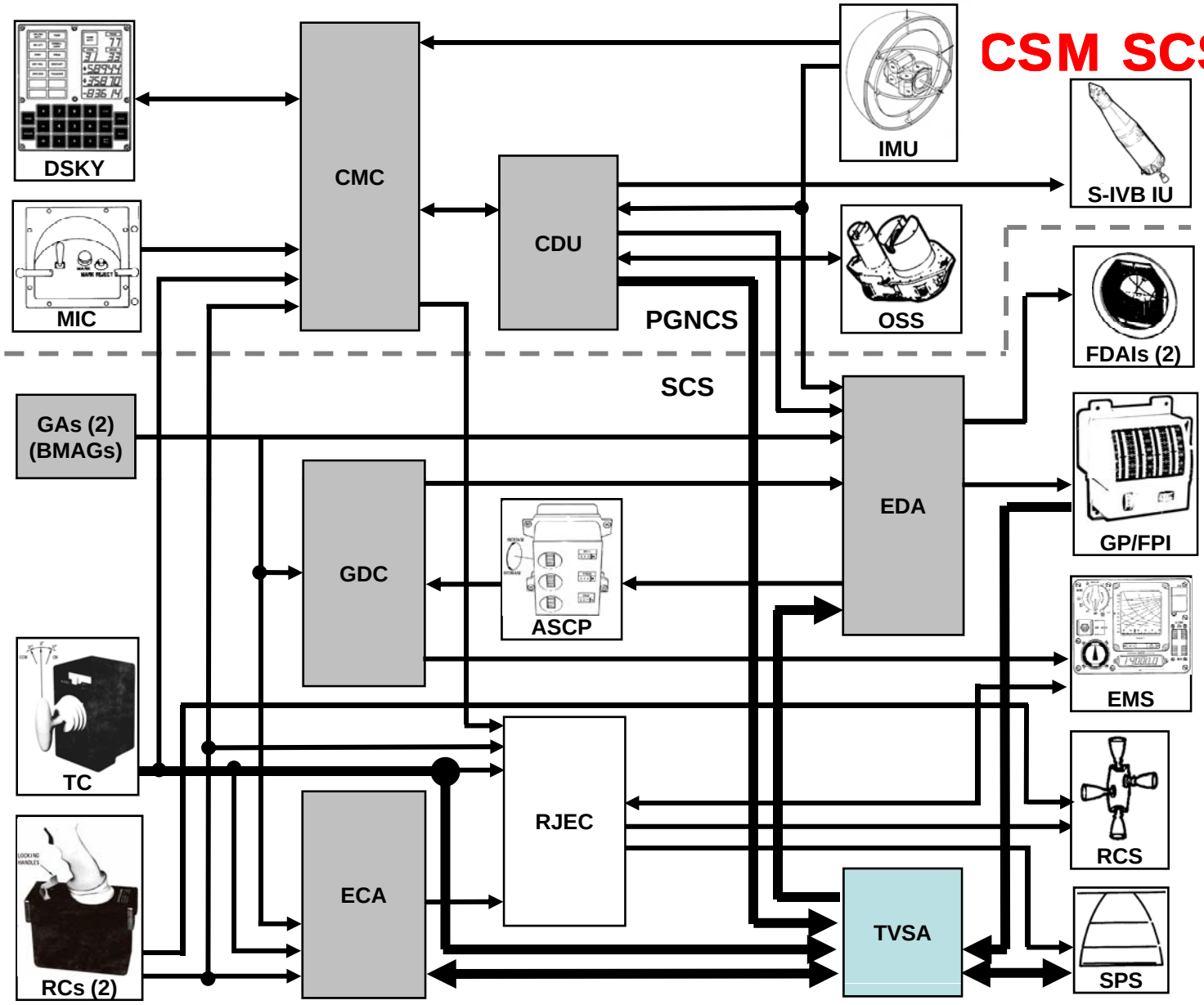
- Electronic Display Assembly (EDA)
  - Interface between various data sources and FDAIs/GPI

CSM SCS Hardware



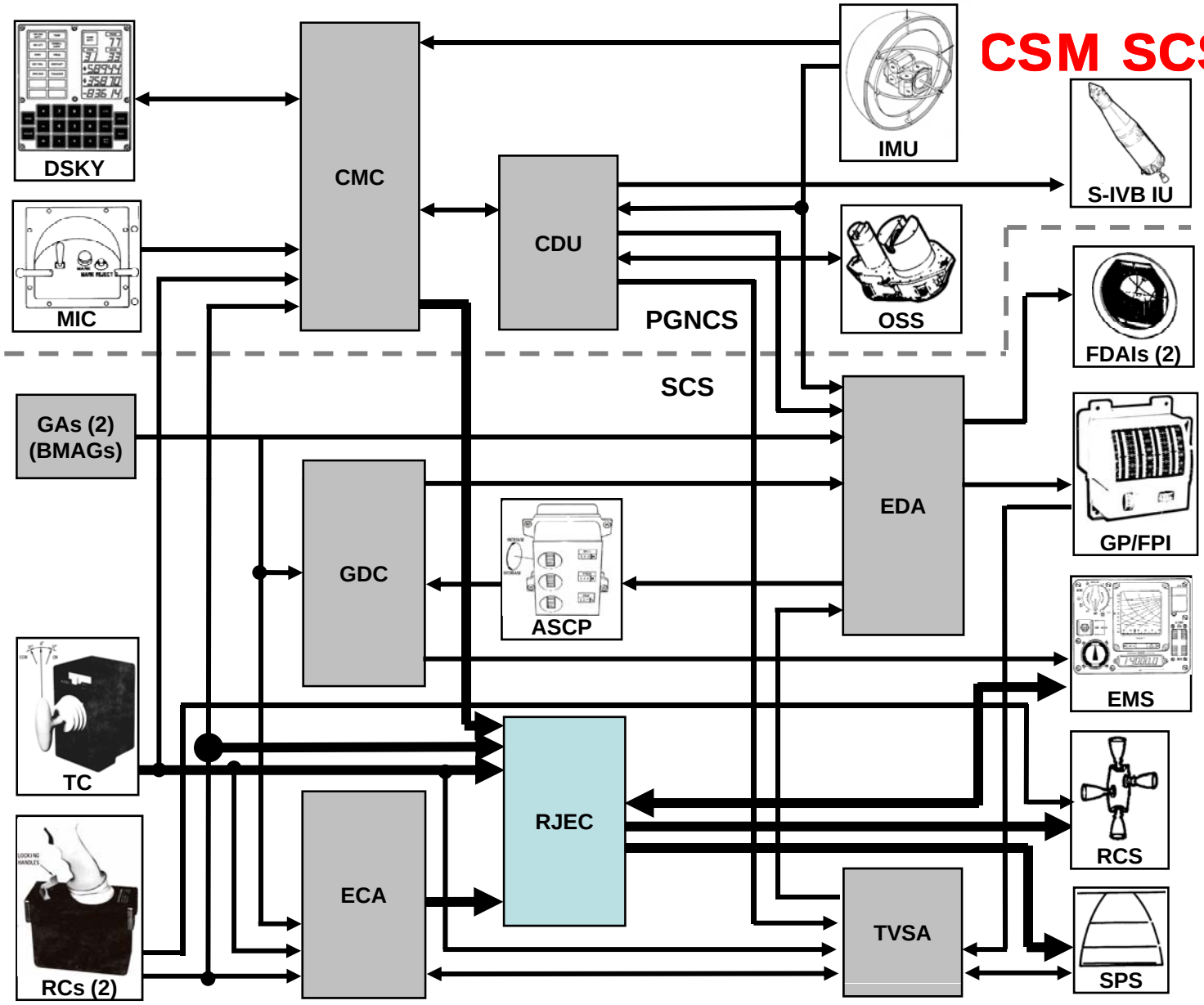
- Electronic Control Assembly (ECA)
  - Analog autopilot logic

CSM SCS Hardware



- Thrust Vector Servo Amplifier (TVSA)
  - Interface to SPS gimbal actuators

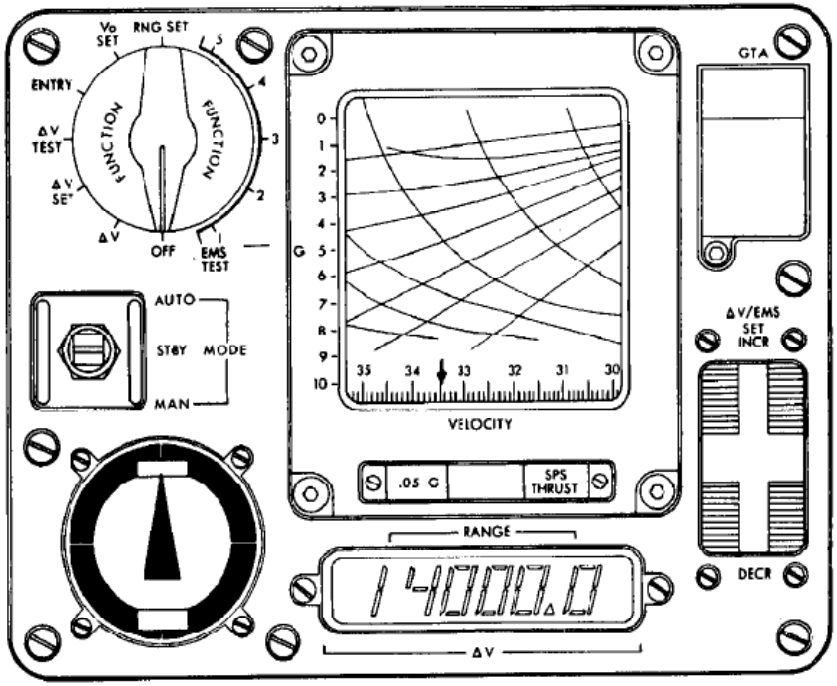
CSM SCS Hardware



- Reaction Jet and Engine Control (RJ/EC)
  - RCS solenoid drivers and logic circuits, SPS ignition control

CM Entry Monitor System (EMS)

- Displays data for monitoring a PGNCS entry and/or manual control of a PGNCS-fail entry
- ΔV monitoring and backup shutdown during SPS burns
- Raw display of VHF ranging data during rendezvous



CSM Very High Frequency (VHF) Ranging

- VHF ranging developed to supplement sextant (SXT) data for CSM rendezvous navigation at ranges up to 606 km (327 nmi)
  - Used existing VHF comm system for duplex link
  - Used Entry Monitor System (EMS) for data display
  - First flight Apollo 10 in 1969
- Prime sensor in the event of LM RR fail or CSM active rendezvous

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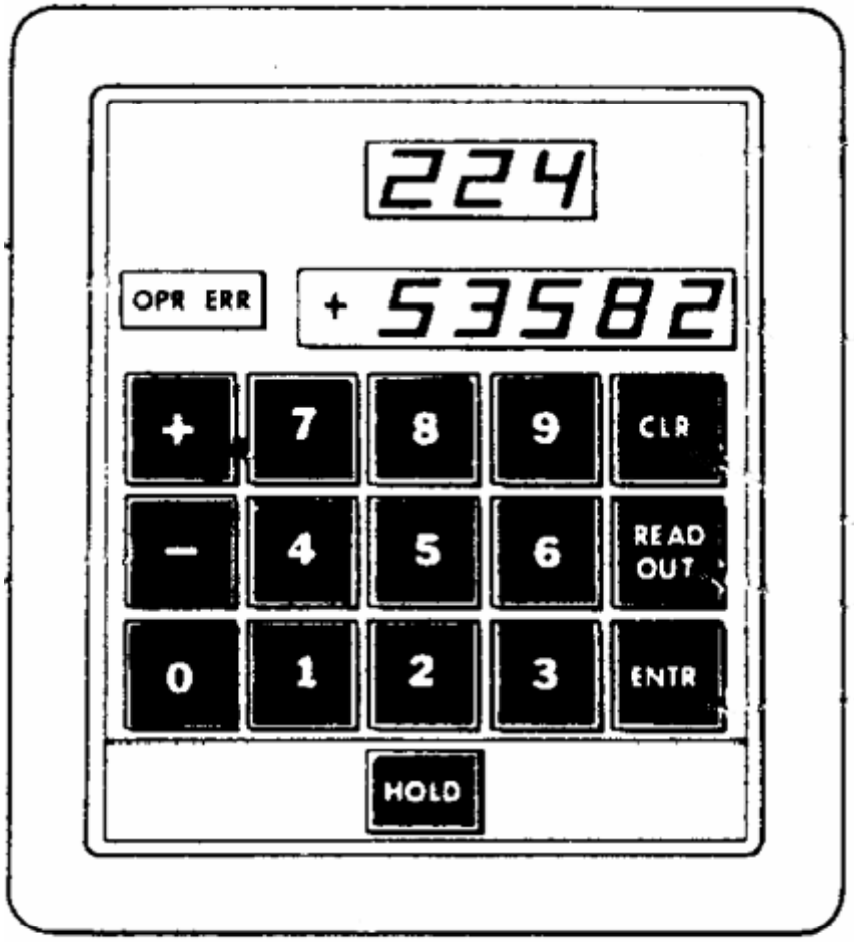
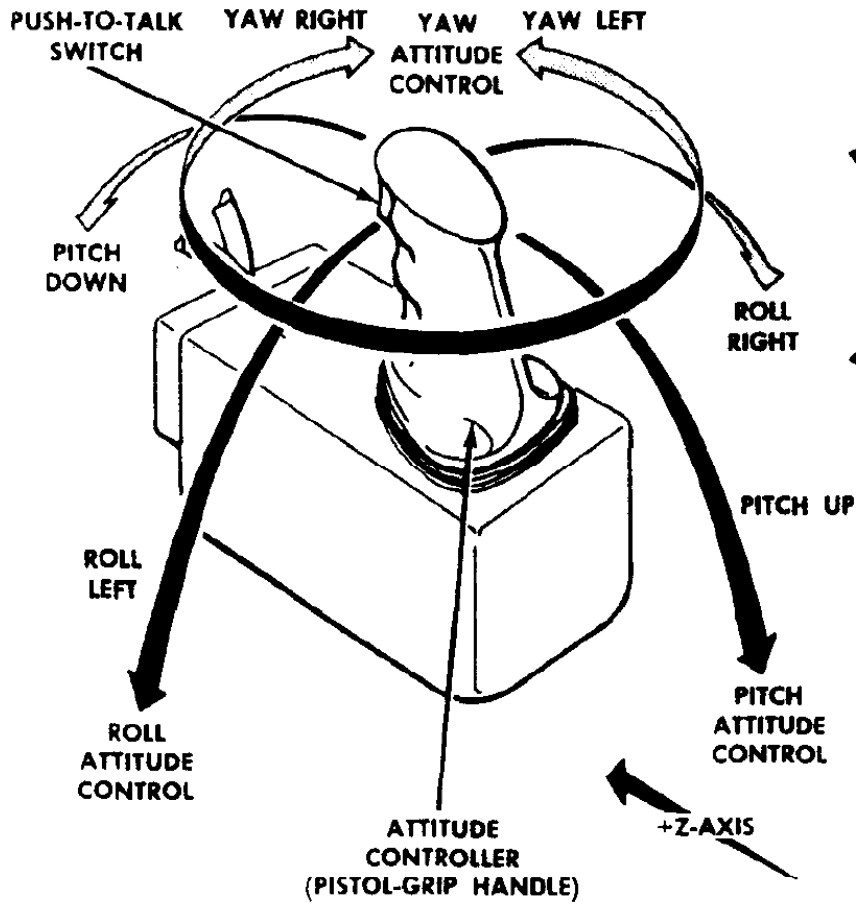
LM AGS Hardware

- Abort Electronics Assembly (AEA)
  - AGS computer
- Data Entry and Display Assembly (DEDA)
  - Display/keyboard
- Abort Sensor Assembly (ASA)
  - Strapdown (fixed to LM body) inertial navigation system
  - Attitude and velocity data to AGS
  - Mounted to nav base with IMU and AOT



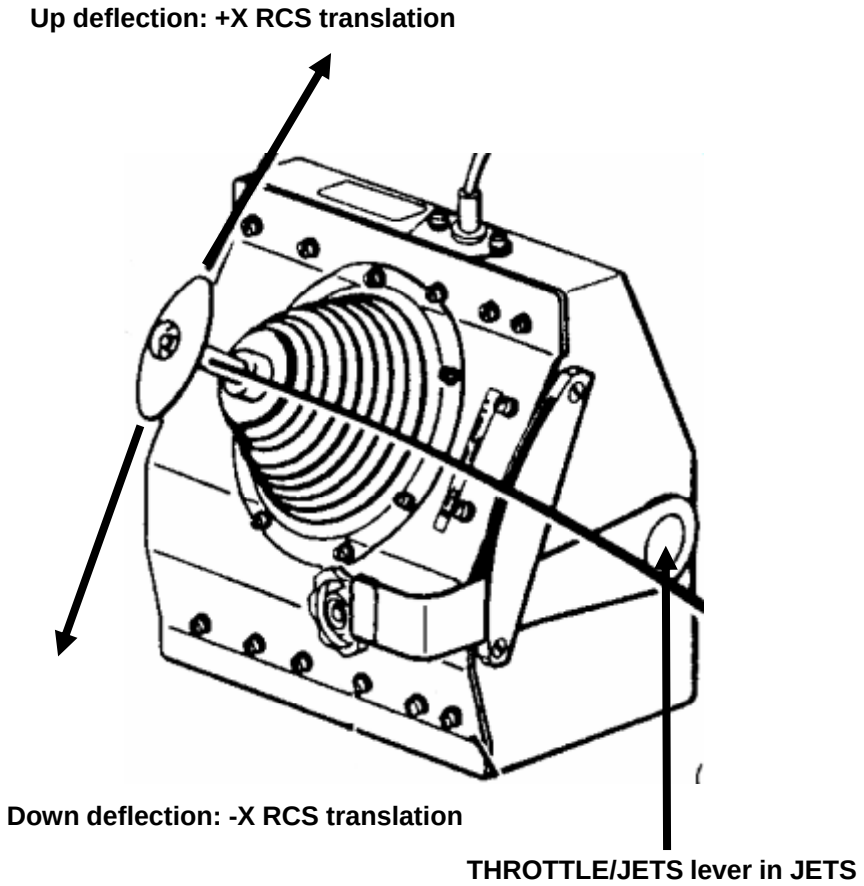
LM CES Hardware

- Attitude Controller Assemblies (ACAs)
  - Manual attitude control
  - Landing point redesignation capability during final approach phase
  - Push-To-Talk (PTT) trigger



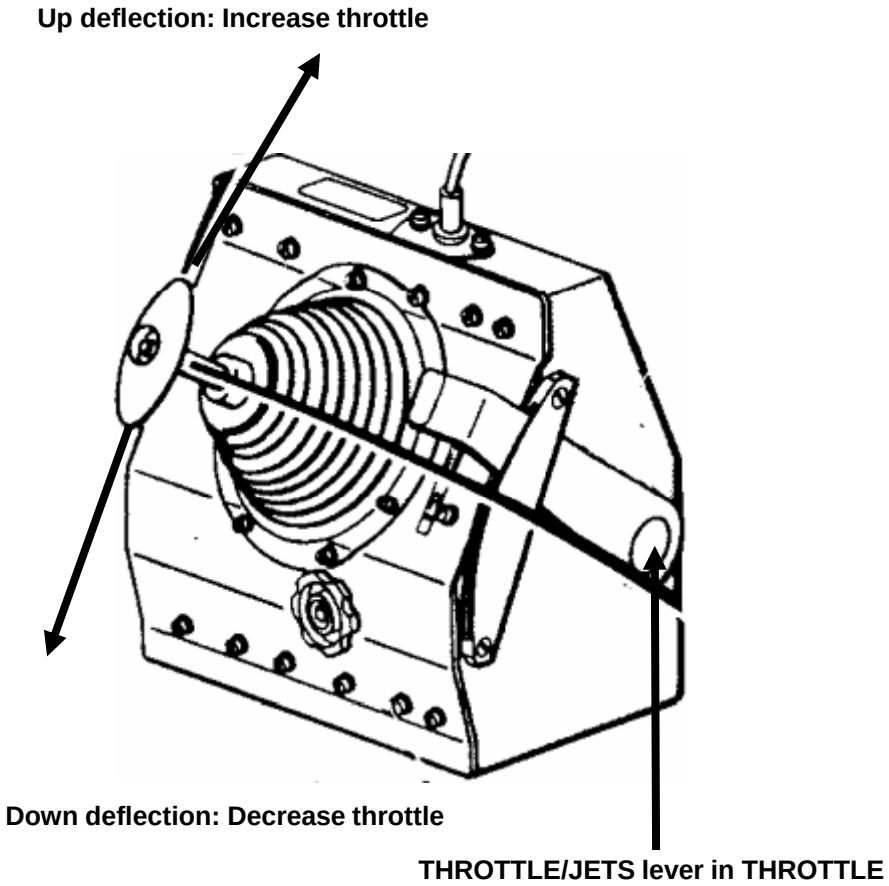
LM CES Hardware

- Thrust/Translation Controller Assemblies (TTCAs)
  - Left-right and in-out deflection: provide Y and Z axis RCS translation
  - Up-down deflection:
    - X axis RCS translation when THROTTLE/JETS lever in JETS position

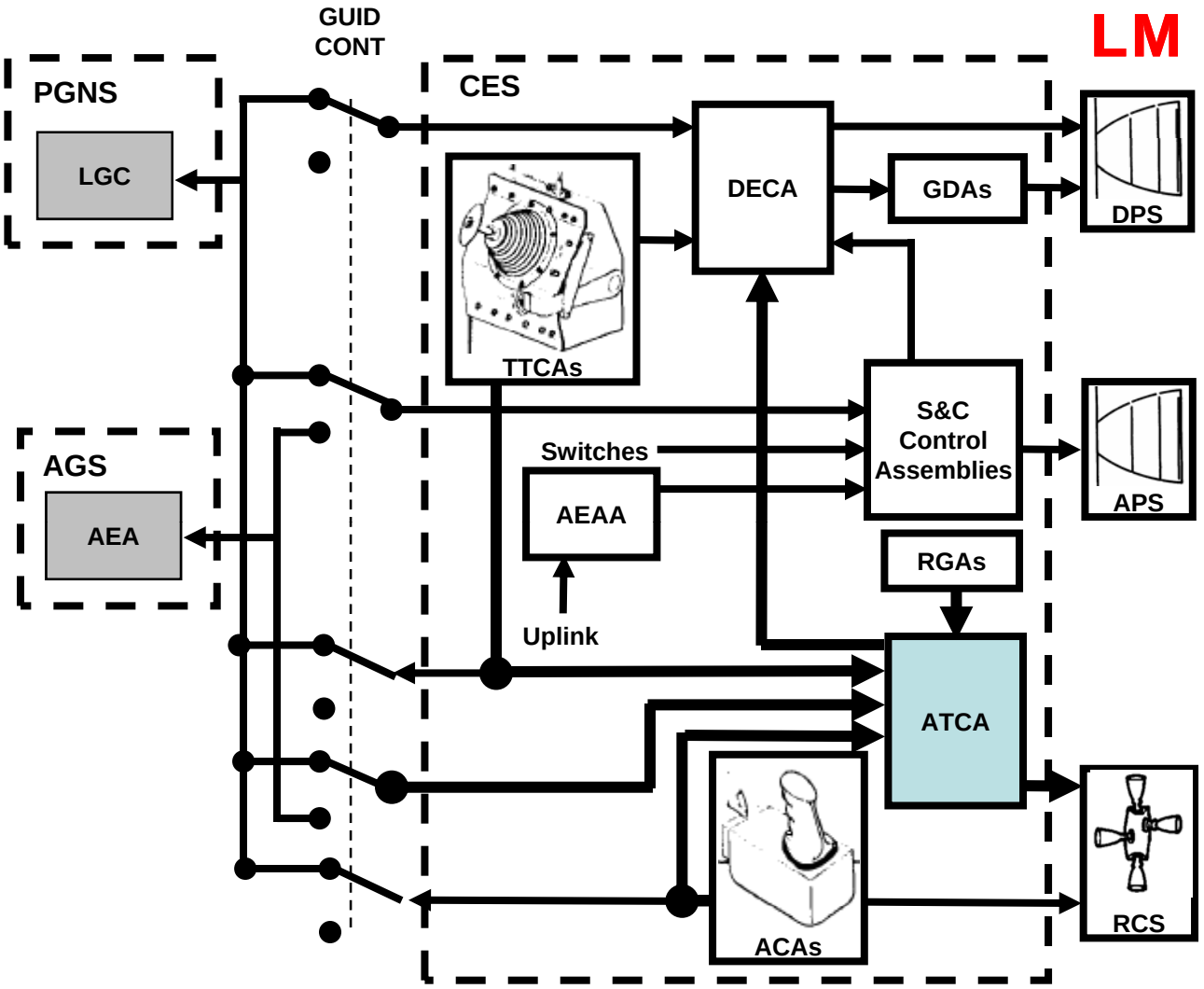


LM CES Hardware

- Thrust/Translation Controller Assemblies (TTCAs)
  - Left-right and in-out deflection: provide Y and Z axis RCS translation
  - Up-down deflection:
    - X axis RCS translation when THROTTLE/JETS lever in JETS position
    - Descent Propulsion System (DPS) throttle control when THROTTLE/JETS lever in THROTTLE position

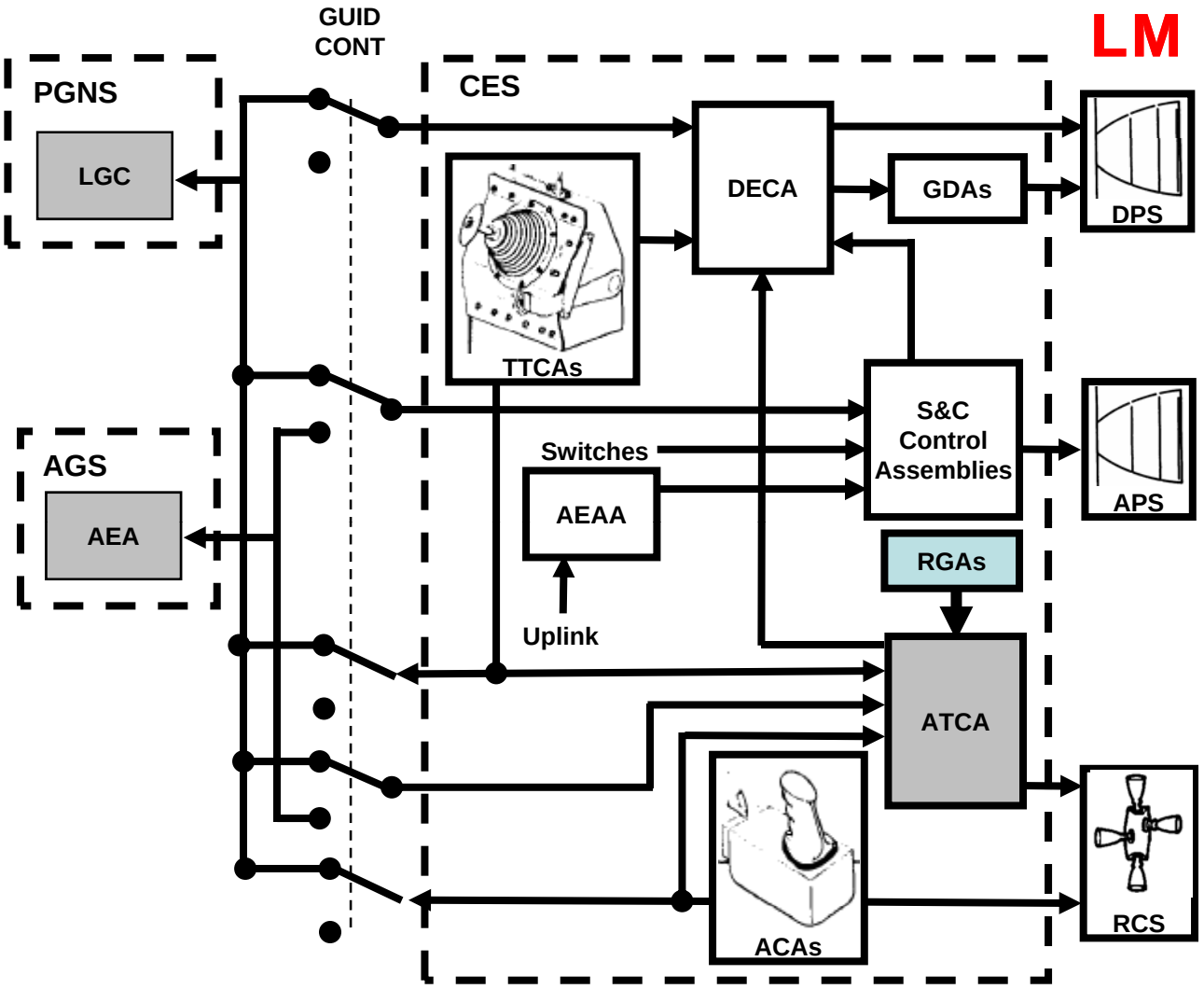


LM CES Hardware



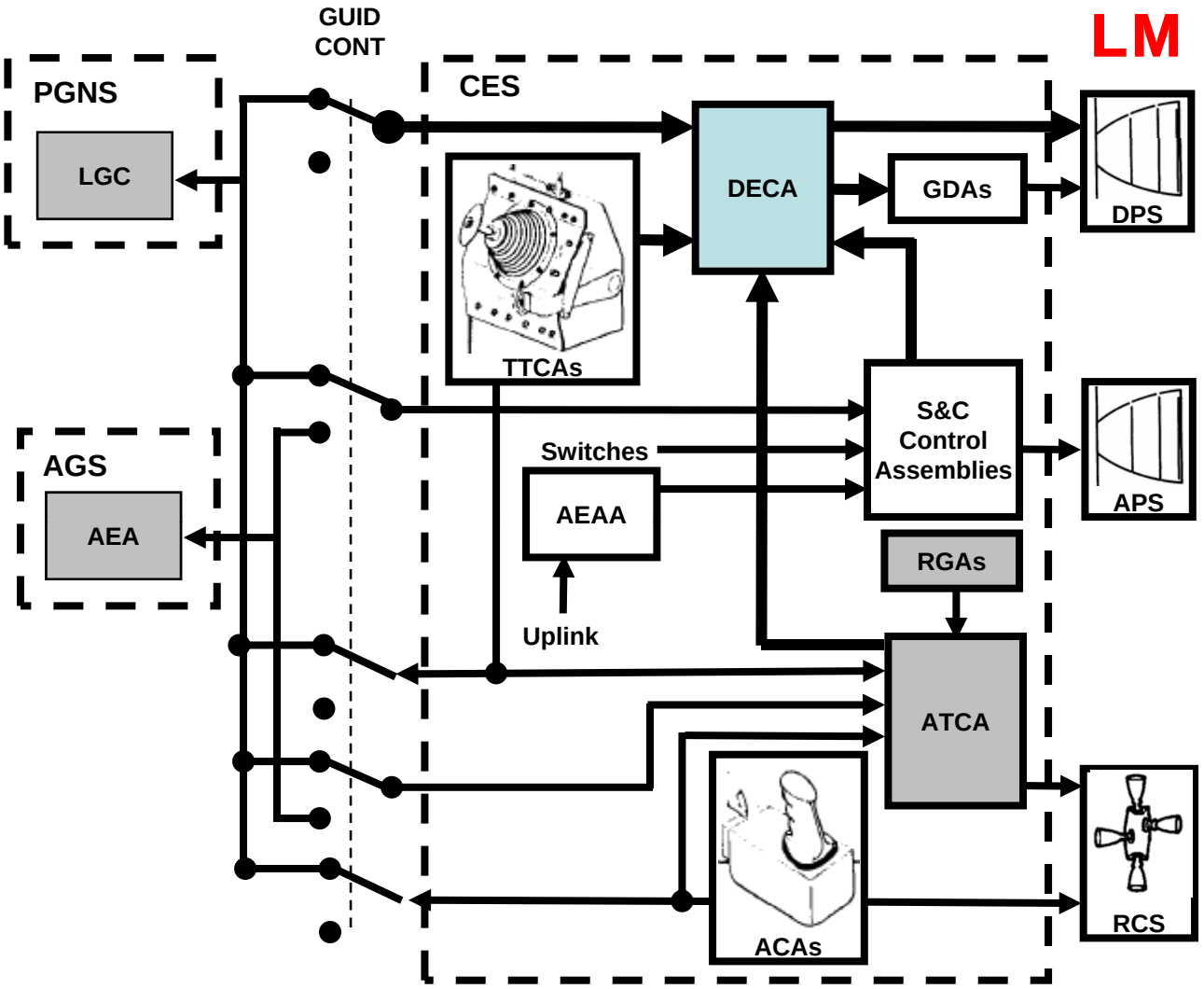
- Attitude and Translation Control Assembly (ATCA)
  - RCS logic and drivers
  - Analog autopilot for AGS

LM CES Hardware



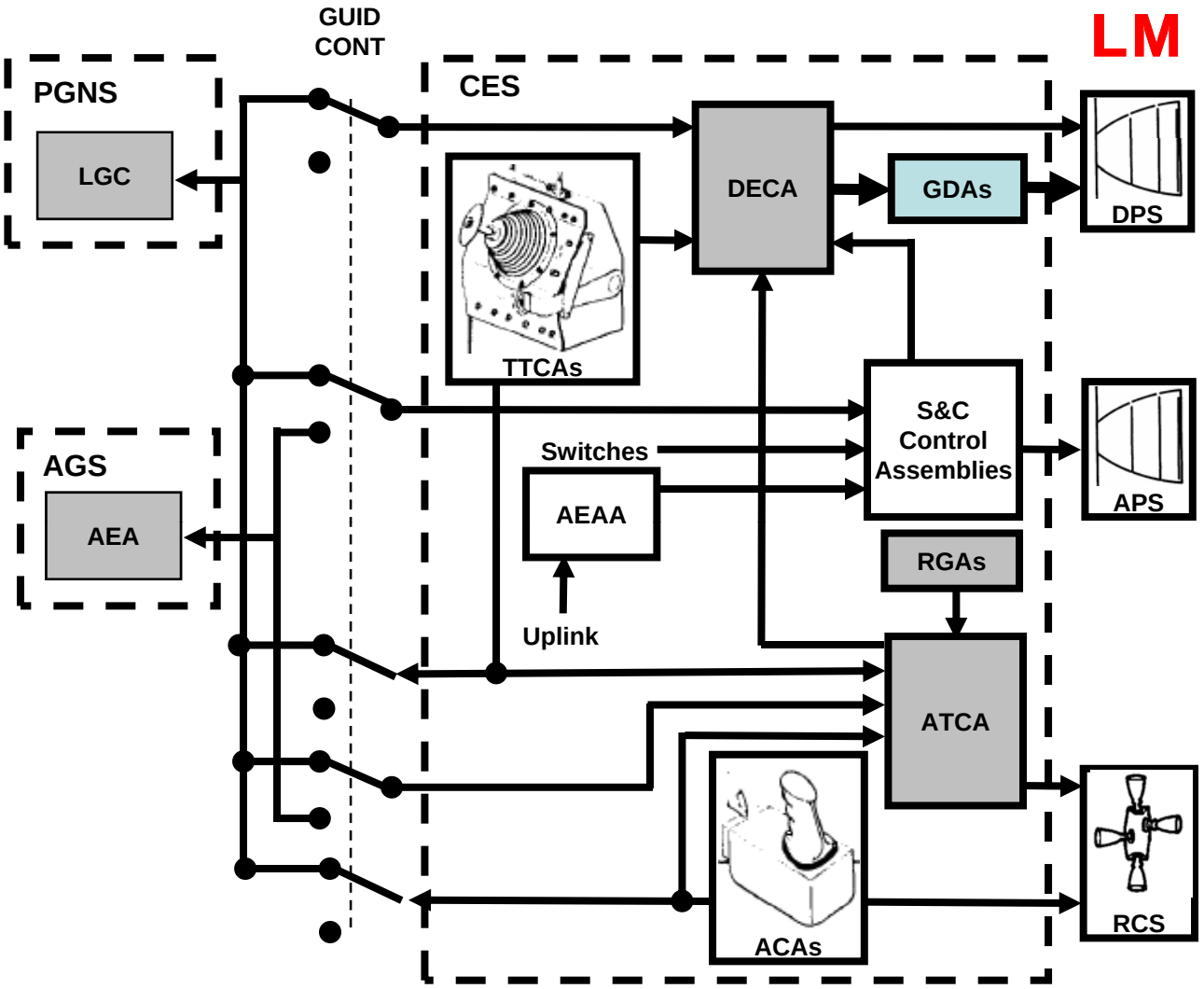
- Rate Gyro Assembly (RGA)
  - Vehicle attitude rate data when under AGS control

LM CES Hardware



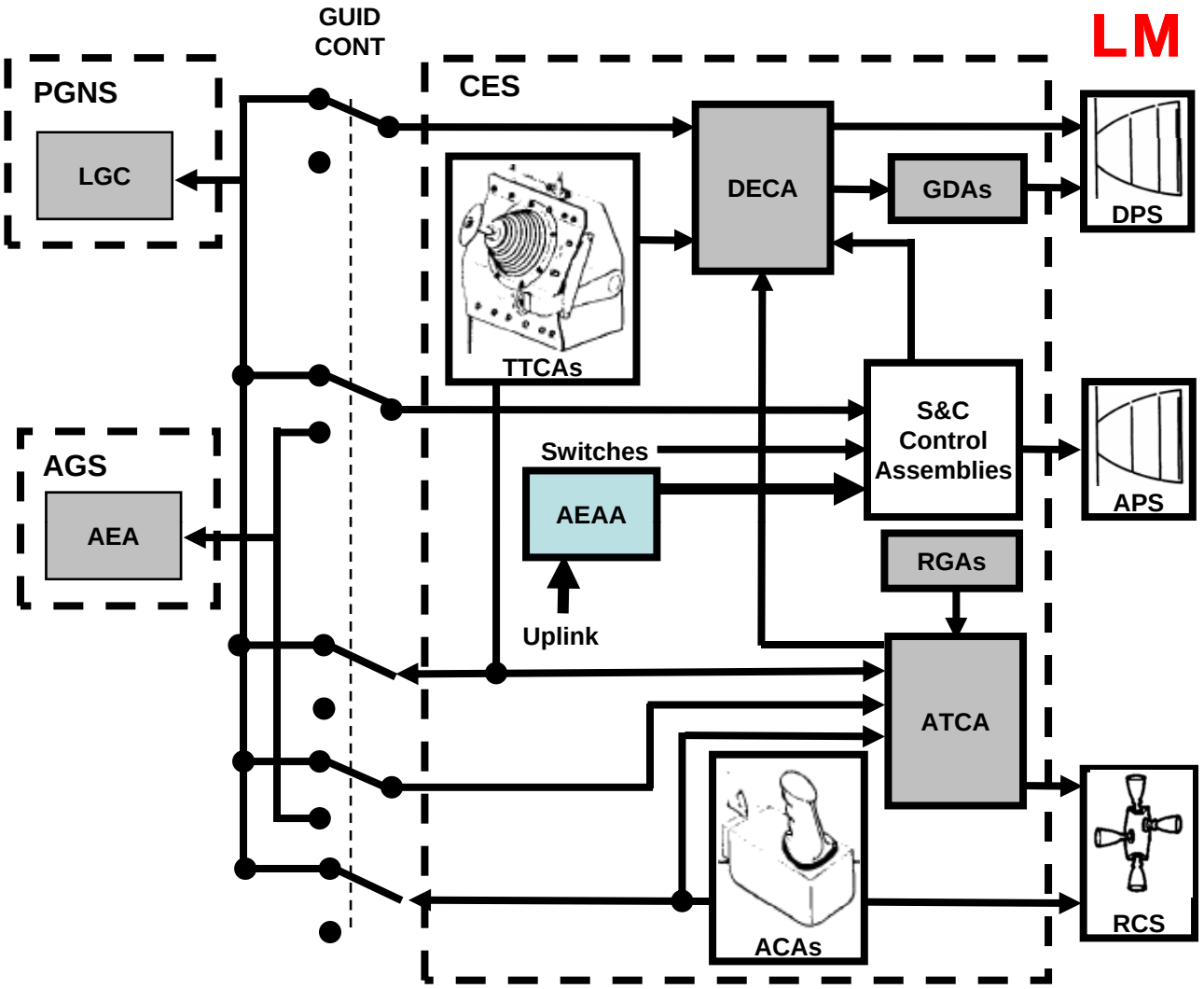
- Descent Engine Control Assembly (DECA)
  - Controls descent engine ignition, gimbaling, and throttling

LM CES Hardware



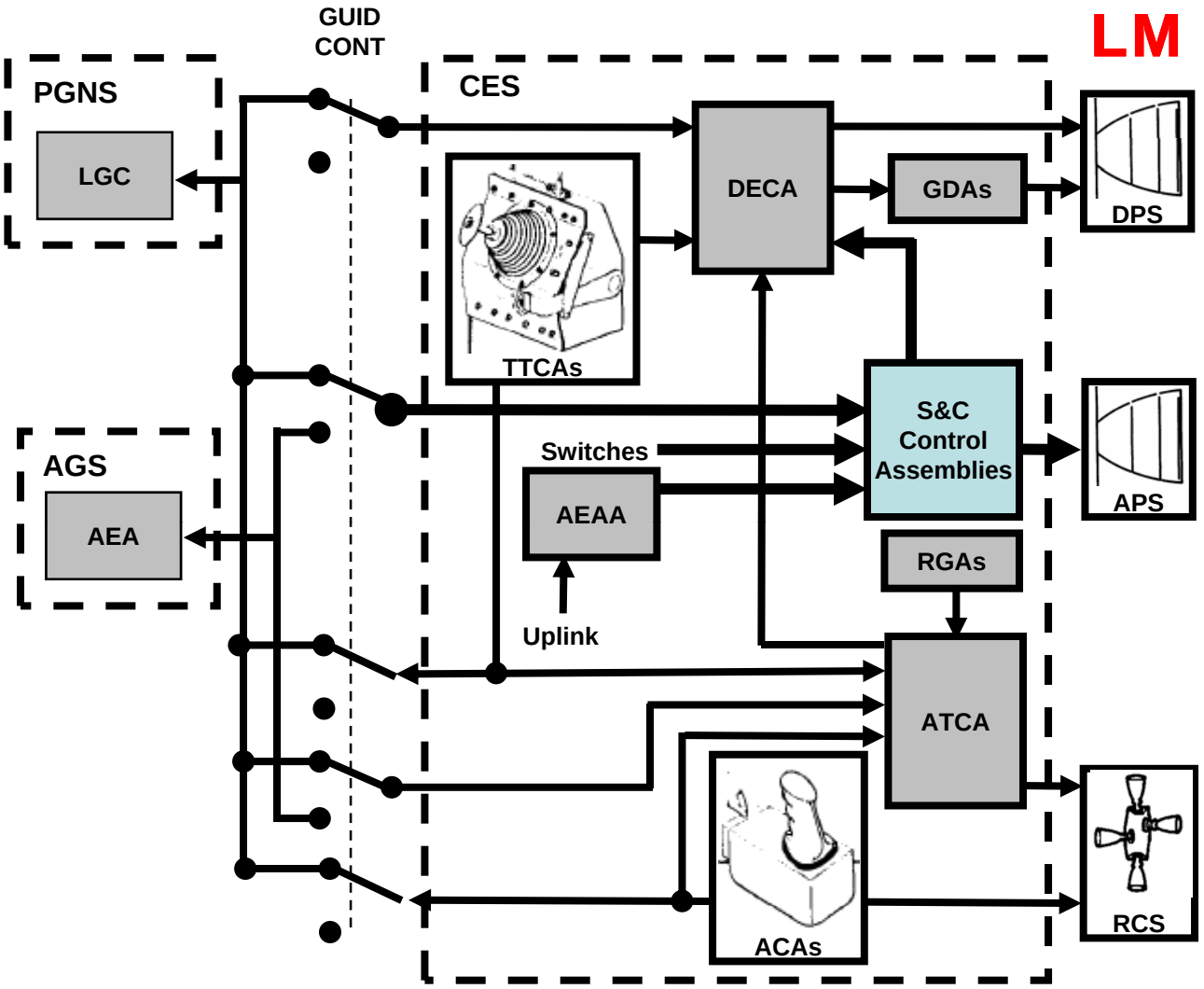
- Gimbal Drive Actuators (GDAs)
  - Drive descent engine pitch/roll gimbals

LM CES Hardware



- Ascent Engine Arming Assembly (AEAA)
  - Arm/fire ascent engine remotely for LM disposal

LM CES Hardware



- S&C Control Assemblies
  - Process ignition commands for descent and ascent engines
- Gimbal Angle Sequencing Transformation Assembly (GASTA)
  - Transforms IMU gimbal angles for display on FDAI (not shown)

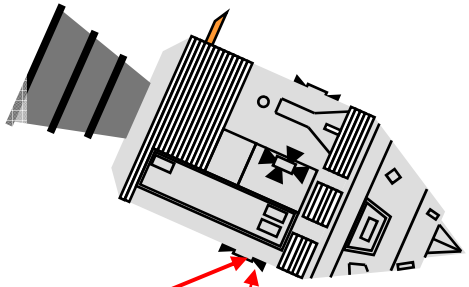
LM Radar Subsystem Hardware

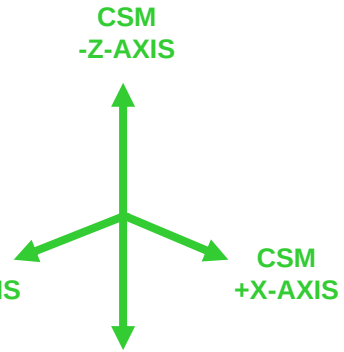
LM Rendezvous Radar (RR)

Range, range rate, and angle (shaft & trunnion) data automatically to LGC, manually to AGS

CSM RR Transponder

Increases RR range capability to max 750 km (405 nmi) compared to skin-track





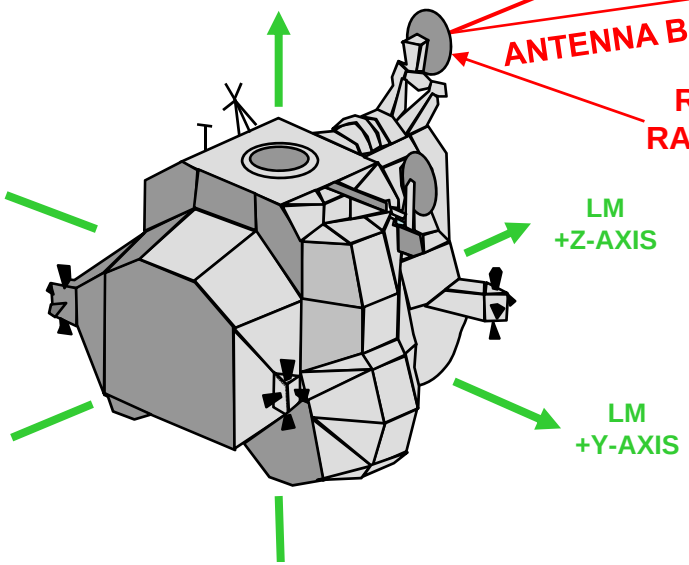
TRANSPONDER

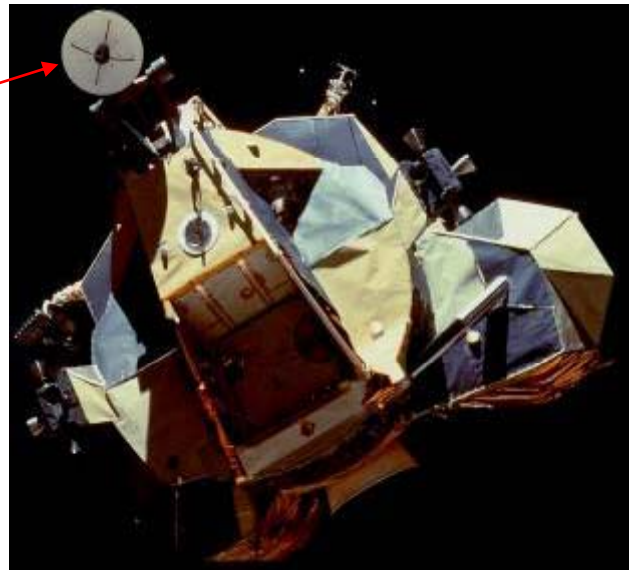
LINE-OF-SIGHT

ANTENNA POINTING ERROR ANGLE
(SHAFT AND/OR TRUNNION)

ANTENNA BORESIGHT

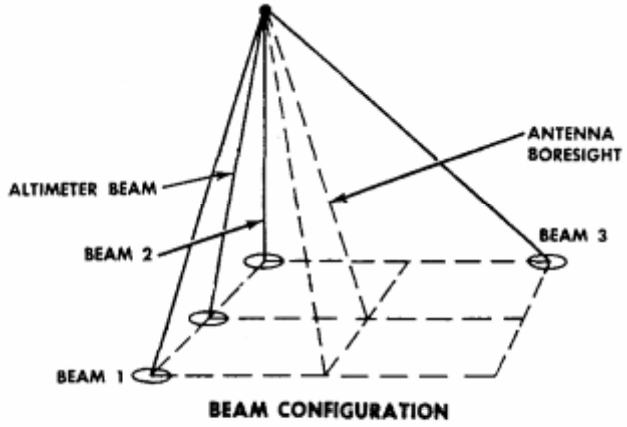
RENDEZVOUS
RADAR ANTENNA





LM Radar Subsystem Hardware

- **LM Landing Radar (LR)**
  - **Slant range and velocity data for control of descent to lunar surface**



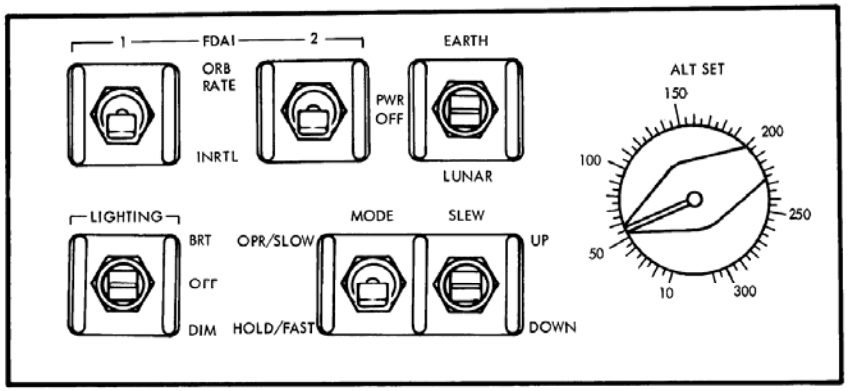
BEAM CONFIGURATION

Agenda

- Review of basic GNC concepts
- Command and Service Module (CSM)/Lunar Module (LM) GNC organization
- Primary Guidance, Navigation, and Control (PGNCS) (mostly common to CSM and LM)
- CSM Stabilization and Control System (SCS) and other CSM-specific hardware
- LM Abort Guidance System (AGS), Control Electronics System (CES), and other LM-specific hardware
- **Other common hardware**
- Summary
- References

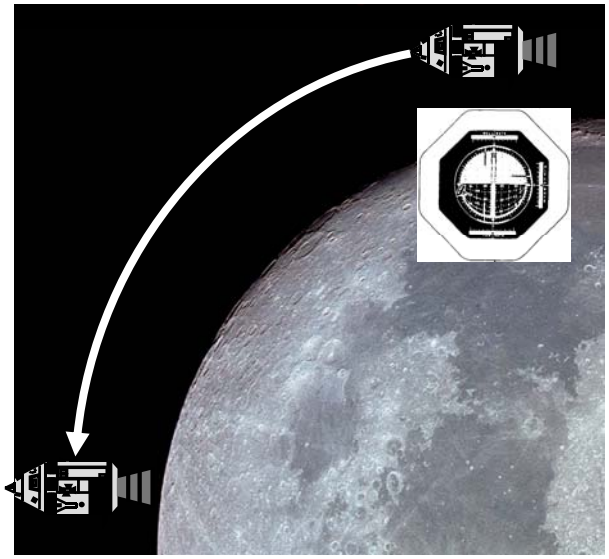
Orbital Rate Display – Earth And Lunar (ORDEAL)

- FDAI display of pitch attitude with respect to local horizontal
- Not tied to nav state - uses altitude rotary knob and earth/lunar switch to determine orb rate



No ORDEAL

No ORDEAL



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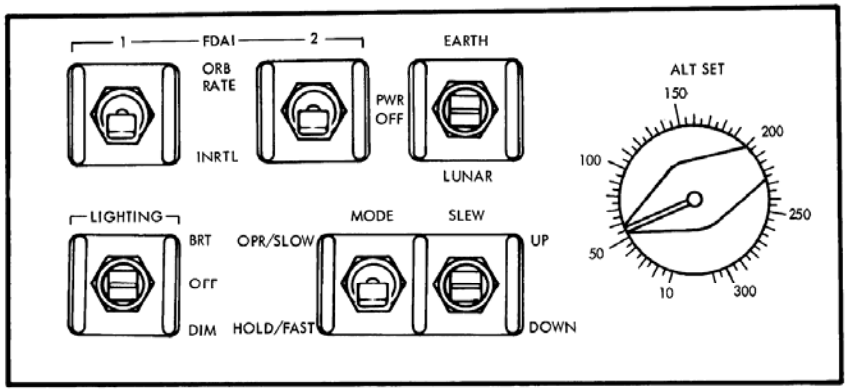
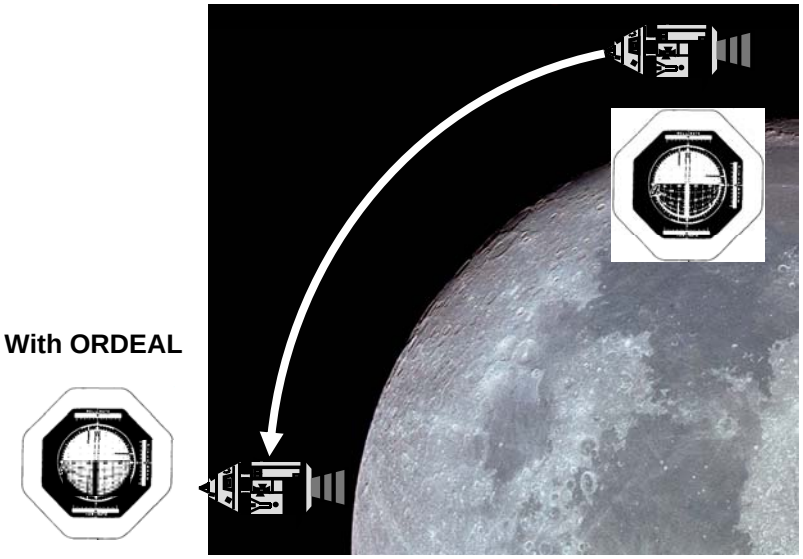


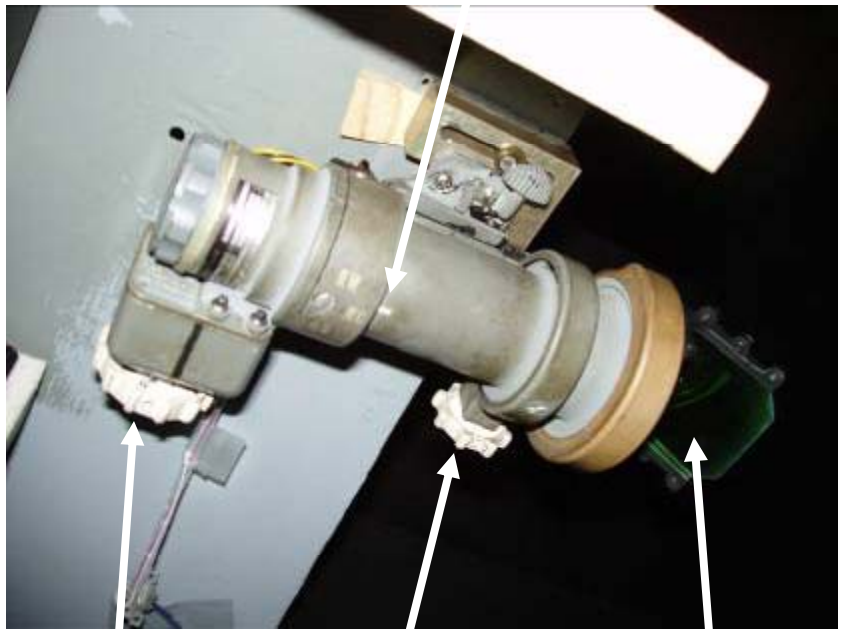
With ORDEAL

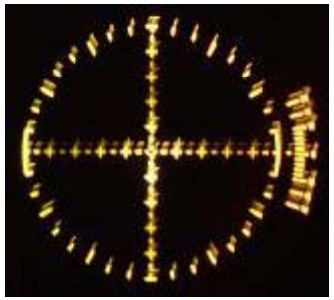
With ORDEAL



Docking Aids

- Crewman Optical Alignment Sight (COAS)
  - Line-of-sight (LOS) reference and gross range/range rate cues during final approach and docking
  - Could be used as backup to optics for navigation sightings

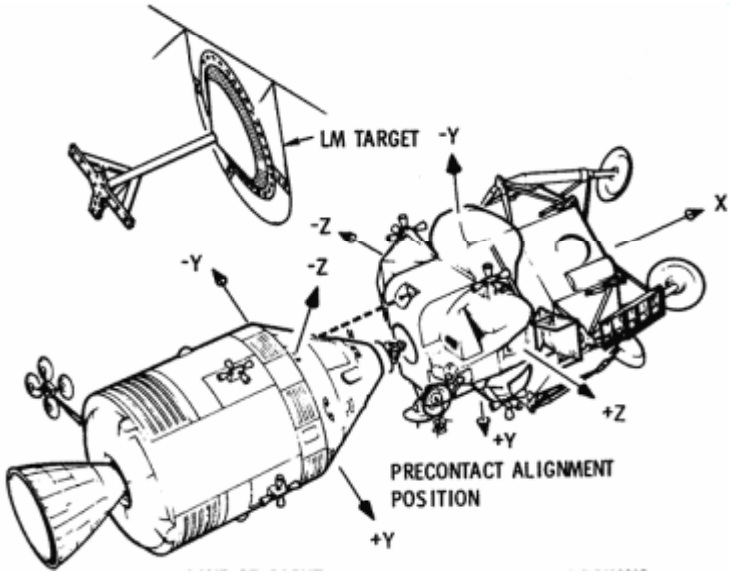


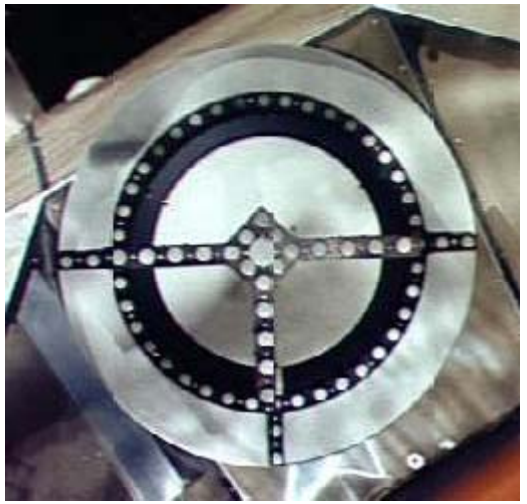


Reticle Pattern

Docking Aids

- Docking Targets
  - Lateral/angular alignment cues during final approach
  - Exterior LM-mounted target for CSM-active docking (nominal)
  - Interior CSM-mounted target for LM-active docking





Summary

- Primary guidance and navigation systems were mostly common to both vehicles
- Almost no redundancy in CSM guidance and navigation (mostly in optics subsystem)
- LM had redundant guidance for aborts
- Redundant control systems on both vehicles allowed manual and limited automatic control in the event of primary system failure
  - Mission Control Center provided guidance and navigation functions for this case

References

- *Apollo Operations Handbook, Block II Spacecraft, Volume I: Spacecraft Description*. SM2A-03-Block II-(1), 15 January 1970.
- *Apollo Operations Handbook, Lunar Module, LM 10 and Subsequent, Volume I: Subsystems Data*. LMA790-3-LM 10, 1 April 1971.
- *Apollo Training: Guidance and Control Systems - Block II S/C 101*, 15 September 1967.
- *Apollo Experience Report – Guidance and Control Systems. NASA TN D-8249*, June 1976.
- *Apollo Experience Report: Very-High-Frequency Ranging System*. NASA TN D-6851, June 1972.
- *Apollo Experience Report – Guidance and Control Systems: Orbital-Rate Drive Electronics for the Apollo Command Module and Lunar Module*. NASA TN D-7784, September 1974.