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

- **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
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
- 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
• 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
• 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 Measurement Unit (IMU)
  – Stable platform for measurement of attitude and acceleration, isolated from case by three gimbals
• 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
• **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
• **Navigation Base (NB)**
  – Rigid mounting point for IMU, optics
  – CSM NB located in Lower Equipment Bay (LEB)
• 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
• Coupling Data Unit (CDU)
  – 5-channel Analog-Digital and Digital-Analog converter
  – Data interface between computer and IMU, optics, and various controls and displays
• Coupling Data Unit (CDU)
  – 5-channel Analog-Digital and Digital-Analog converter
  – Data interface between computer and IMU, optics, and various controls and displays

• Power and Servo Assembly (PSA)
  – Central mounting point for power supplies, amplifiers, and other electronics
• Coupling Data Unit (CDU)
  – 5-channel Analog-Digital and Digital-Analog converter
  – Data interface between computer and IMU, optics, and various controls and displays

• Power and Servo Assembly (PSA)
  – Central mounting point for power supplies, amplifiers, and other electronics

• Pulse Torque Assembly (PTA)
  – Command/data interface to IMU accelerometers

• Signal Conditioner Assembly (SCA) (not shown)
  – Interface to instrumentation system
• 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
• Sextant (SXT)
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  – Collect star/horizon LOS data for cislunar navigation
  – Collect LM LOS data for rendezvous navigation

• Scanning Telescope (SCT)
  – 1x magnification, 60 degree FOV
  – Locate stars for subsequent SXT sightings
  – Collect landmark LOS data for orbital navigation
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
- **Scanning Telescope (SCT)**
  - 1x magnification, 60 degree FOV
  - Locate stars for subsequent SXT sightings
  - Collect landmark LOS data for orbital navigation
- **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
• 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
• 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
• 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
• 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
• Rotation Controls (RC)
  – Three-axis CSM RCS rotation control or Thrust Vector Control (TVC)
  – Push-To-Talk (PTT) trigger
• 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 (FDAl)
  – Display of CSM attitude, attitude errors, and rates
  – Rates from BMAGs, attitude from either IMU or GDC
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
• **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

• **Attitude Set Control Panel (ASCP)**
  - Thumbwheels to set pitch, yaw, and roll attitudes
  - Attitude error reference for display on FDAI
  - Attitude reference for GDC
- Electronic Display Assembly (EDA)
  - Interface between various data sources and FDAIs/GPI
• Electronic Control Assembly (ECA)
  – Analog autopilot logic
- Thrust Vector Servo Amplifier (TVSA)
  - Interface to SPS gimbal actuators
• 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
- $\Delta V$ 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
• 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
• **Abort Electronics Assembly (AEA)**
  - AGS computer

• **Data Entry and Display Assembly (DEDADA)**
  - 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
• **Attitude Controller Assemblies (ACAs)**
  - Manual attitude control
  - Landing point redesignation capability during final approach phase
  - Push-To-Talk (PTT) trigger
• 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

Up deflection: +X RCS translation

Down deflection: -X RCS translation

THROTTLE/JETS lever in JETS
• **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
• Attitude and Translation Control Assembly (ATCA)
  – RCS logic and drivers
  – Analog autopilot for AGS
- Rate Gyro Assembly (RGA)
  - Vehicle attitude rate data when under AGS control
- Descent Engine Control Assembly (DECA)
  - Controls descent engine ignition, gimbaling, and throttling
- Gimbal Drive Actuators (GDAs)
  - Drive descent engine pitch/roll gimbals
- Ascent Engine Arming Assembly (AEAA)
  - Arm/fire ascent engine remotely for LM disposal
- 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
LM Radar Subsystem Hardware

- **LM Landing Radar (LR)**
  - Slant range and velocity data for control of descent to lunar surface
• 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
Orbital Rate Display – Earth And Lunar (ORDEAL)

• FDAO 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
• **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
• 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
• 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 Training: Guidance and Control Systems - Block II S/C 101*, 15 September 1967.

