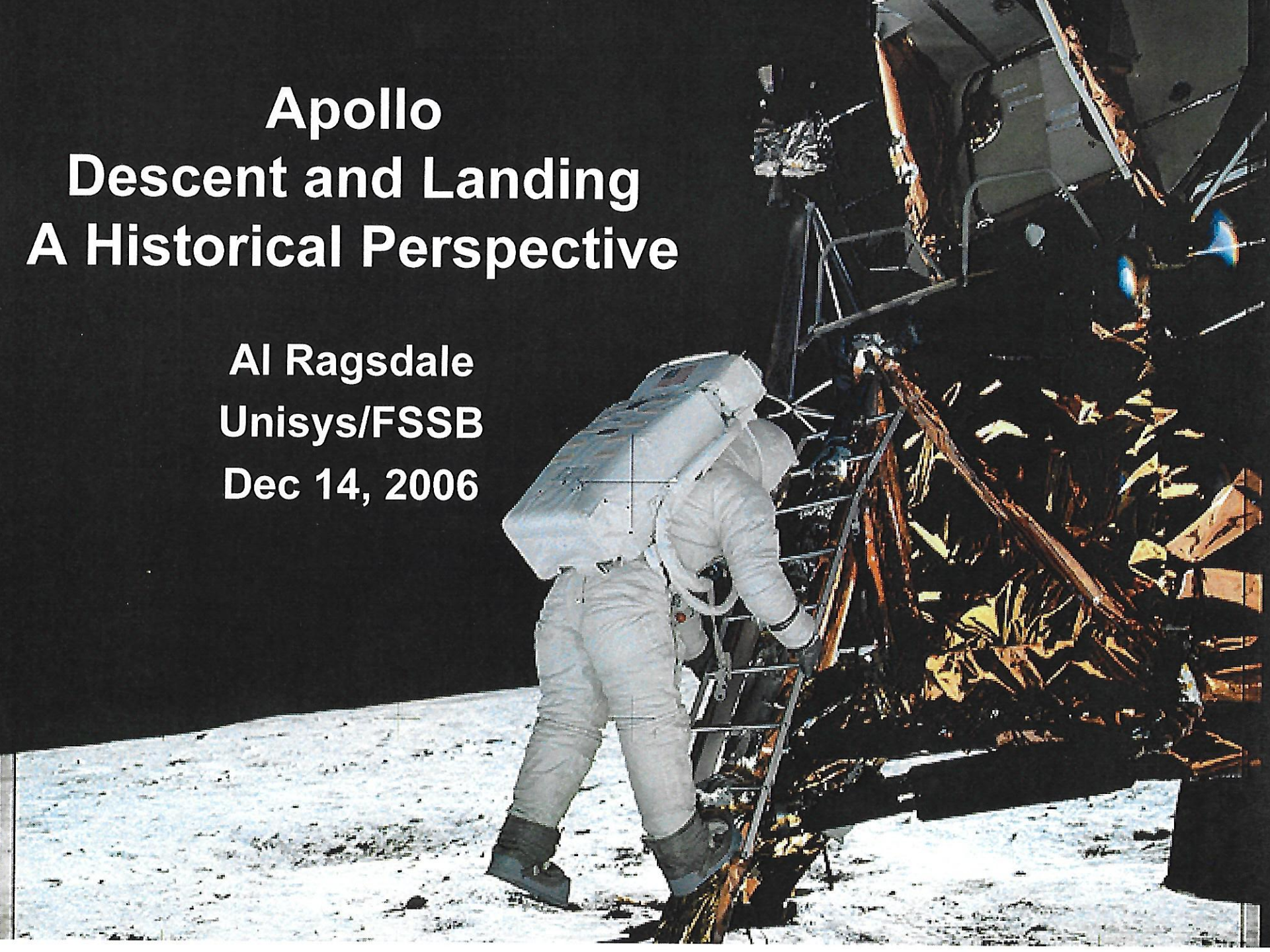


# **Apollo Descent and Landing A Historical Perspective**

**Al Ragsdale  
Unisys/FSSB  
Dec 14, 2006**



# Overview

*Apollo Descent and Landing*

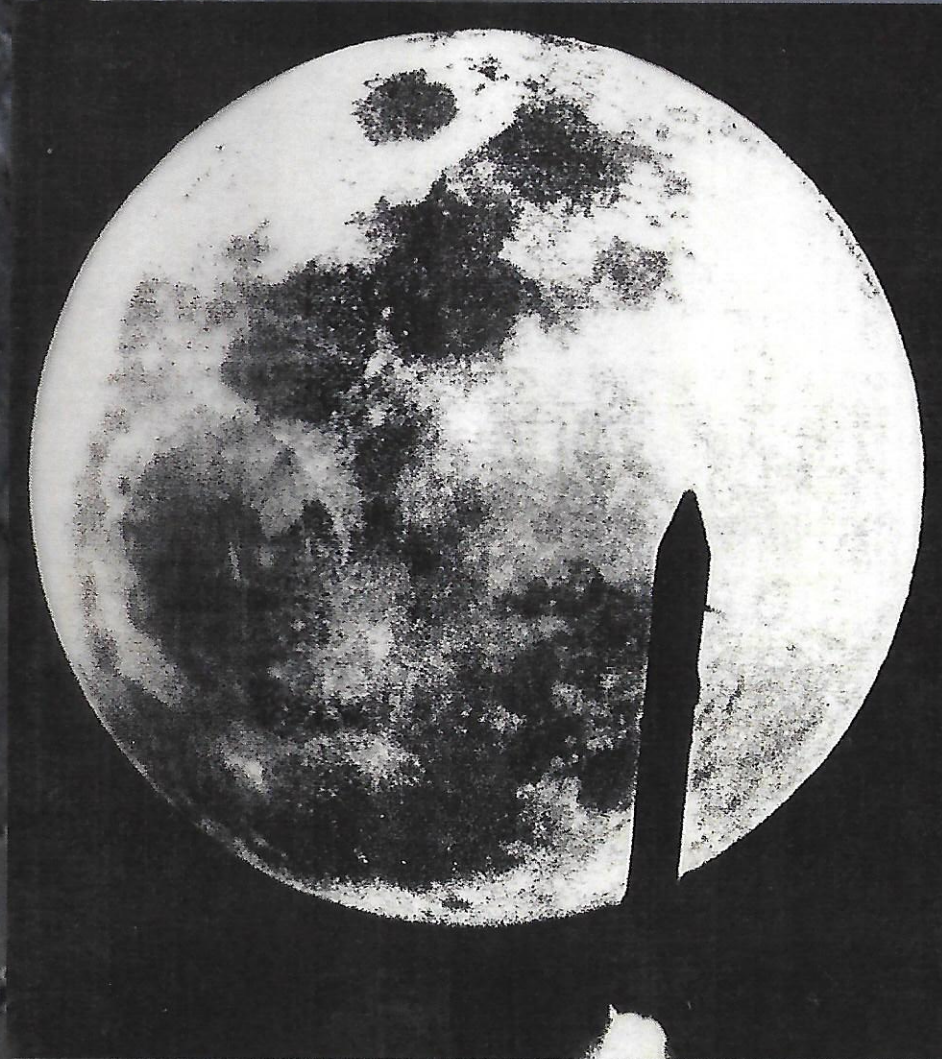
- **Lunar Module (LM) Descent Trajectory**
- **LM Vehicle (Descent & Ascent Stages)**
- **Reaction Control System (RCS)**
- **Cockpit & Instrument Panels**
- **Primary Guidance Navigation & Control System(PGNCS)**
- **Abort Guidance System (AGS)**
- **Apollo 11 Landing Video**
- **Apollo 11 Memories**
- **Selected References**



# DESTINATION MOON



*Apollo Descent and Landing*



NASA Langley Research Center  
Flight Research Services Directorate  
Flight Simulation and Software Branch

- 3 -

December 5, 2006

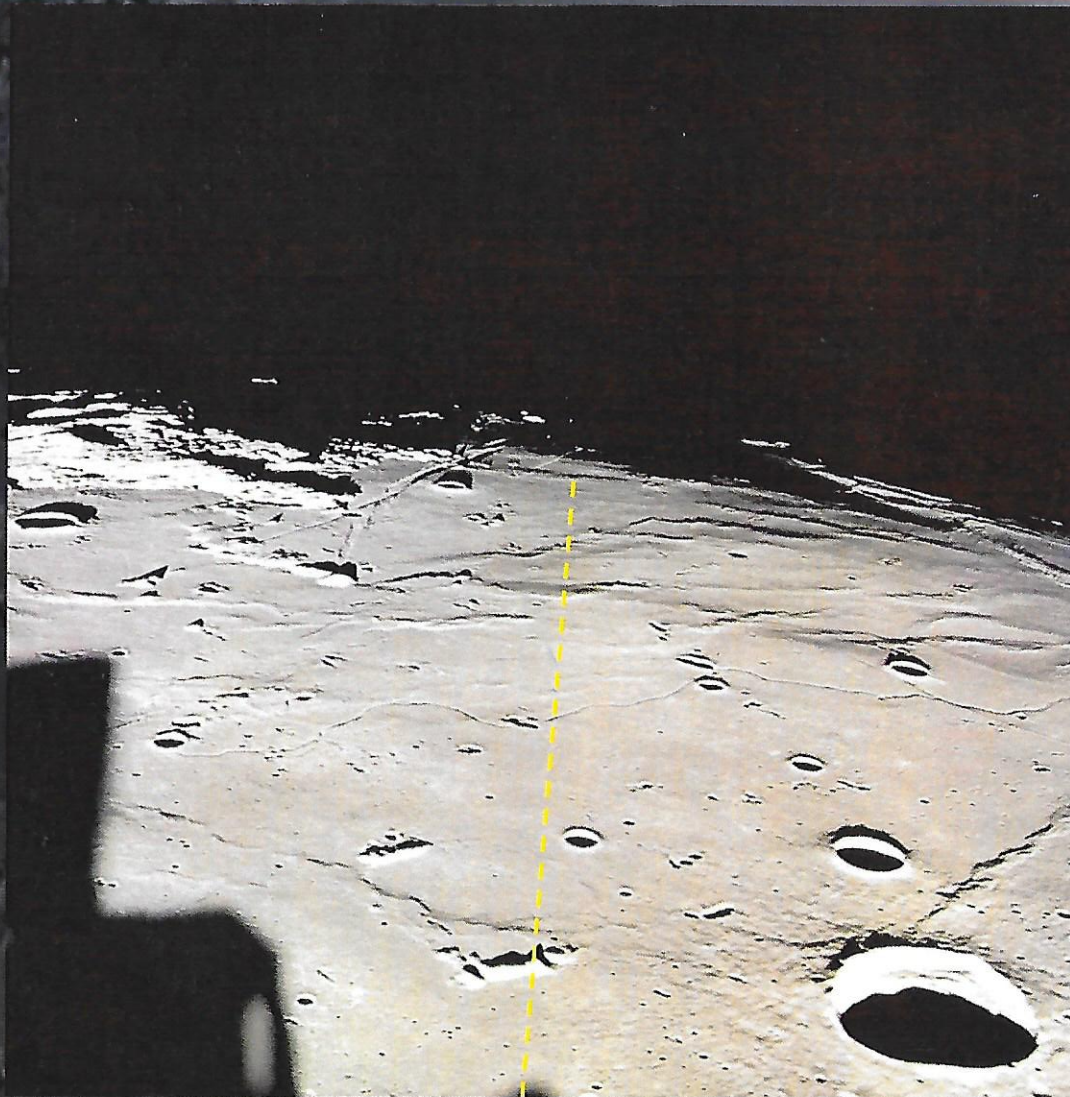
UNISYS



# SEA OF TRANQUILITY



*Apollo Descent and Landing*



# LM DESCENT TRAJECTORY



Apollo Descent and Landing

POWERED  
DESCENT  
INITIATION  
(PDI)

40K YAW 180  
Windows Up  
Landing Radar  
Lockon

12 MIN FROM PDI TO LANDING

TYPICAL VALUES

NOT DRAWN TO SCALE

P63 BRAKING  
50K Alt  
250 nmi Range  
 $V_H$  5560 Hdot 0

THROTTLE DOWN  
to 60% at 27K Alt

ARROWS SHOW  
THRUST DIRECTION

P64 APPROACH  
8K Alt 28K Range  
 $V_H$  450 Hdot -150

APPROACH ANGLE  
about -16 deg

LANDING  
P65 AUTO 500'  
P66 MANUAL  
Hdot < -3% of Alt  
-15at500 -6at200

Hdot -3  
below 100'



# LM DESCENT TRAJECTORY

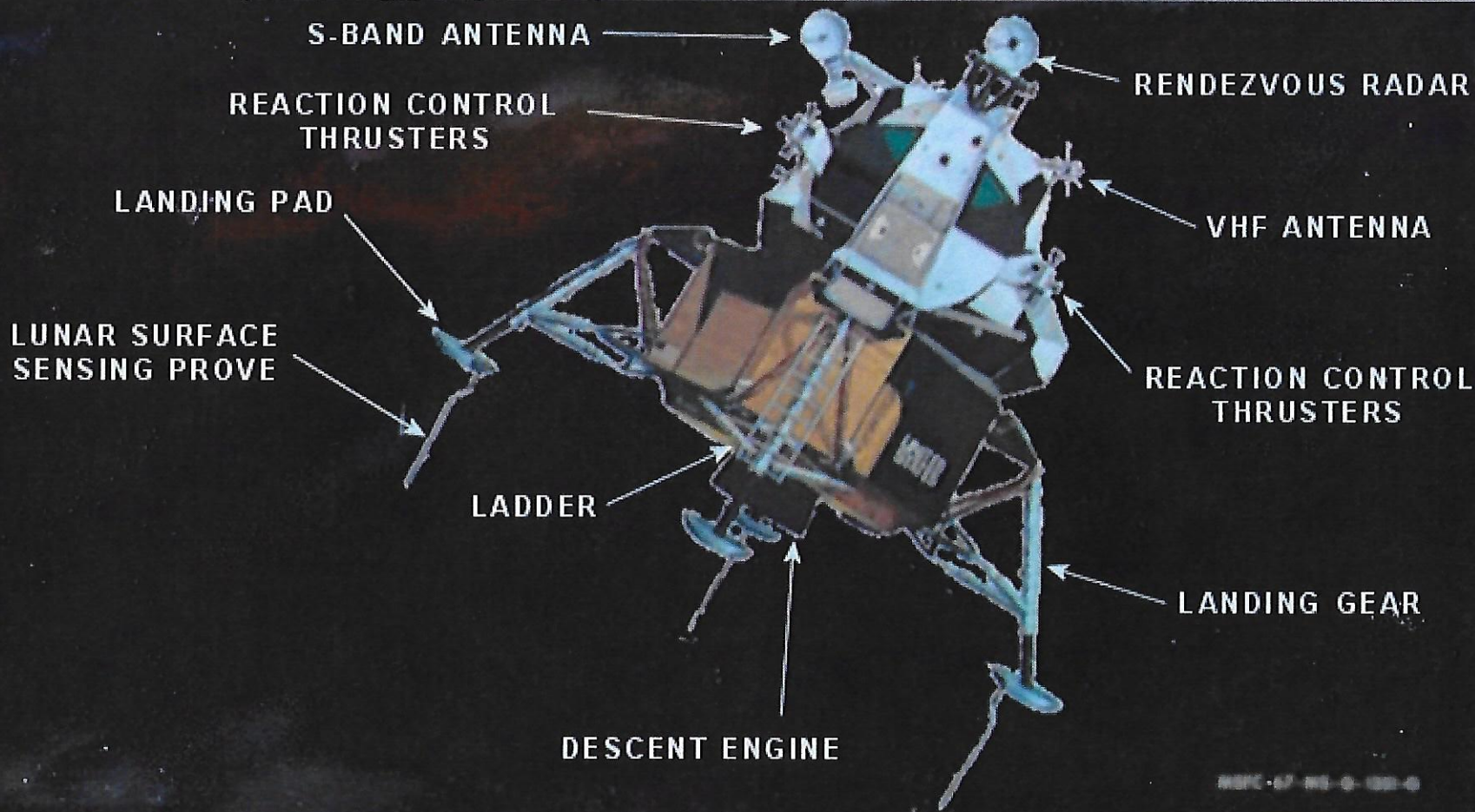


*Apollo Descent and Landing*

- **DOI Descent Orbit Insertion** 60 nmi x 50Kft orbit
- **PDI Powered Descent Initiation** 250 nmi range, 5560 fps
- **P63 Braking Phase**
  - Thrust vector approximately opposite velocity vector (gravity turn)
  - At 40K yaw 180 deg from windows down to windows up/forward
  - Landing radar provides nav updates for altitude & velocity below 35K
- **P64 Approach Phase** 8K alt, 28K range, target visible
  - Pilot could redesignate automatic landing target with joystick
- **P65 Automatic Landing** 500 ft to landing (never used!)
- **P66 Rate of Descent Landing (all Apollo landings)**
  - Zero forward/lateral velocity, 3 fps rate of descent last 100 ft
  - Auto thrust holds rate of descent, pilot changes ROD by 1 fps delta
  - Pilot controls forward & lateral velocity via pitch, roll, yaw rate cmds
- **P67 Manual Throttle (never used!)**

# LUNAR MODULE (LM) VEHICLE

*Apollo Descent and Landing*



# LUNAR MODULE VEHICLE



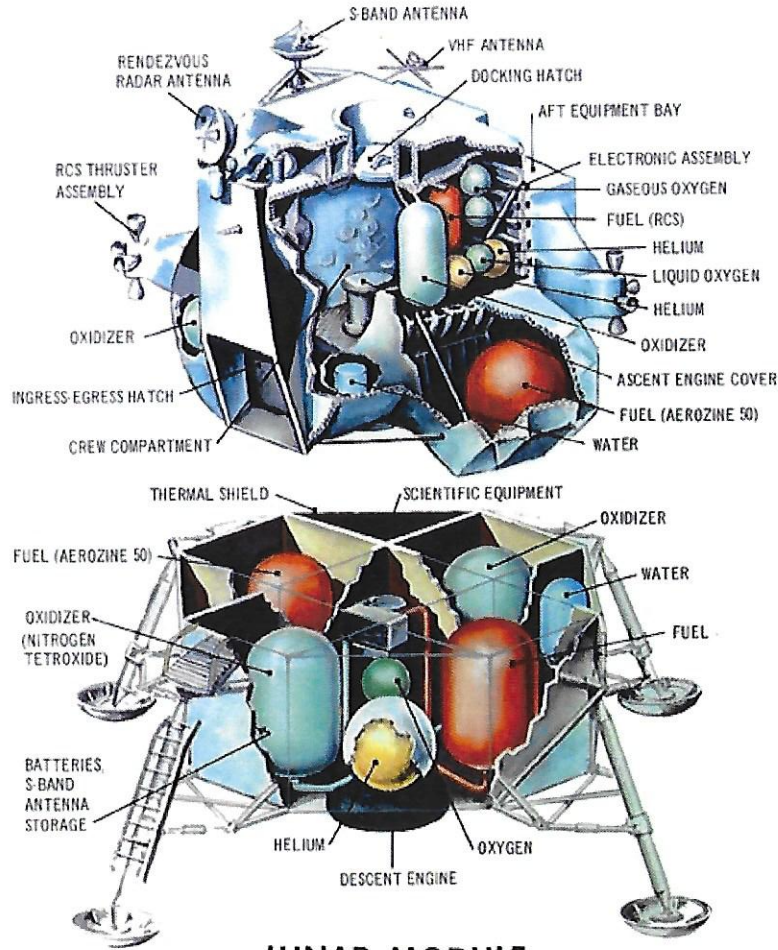
*Apollo Descent and Landing*

- **Descent Stage** for landing
- **Ascent Stage** for launch and rendezvous
- **Propellants** **Unsymmetrical Dimethyl Hydrazine (UDMH)**  
**Nitrogen Tetroxide ( $N_2 O_4$ )**
  - Storable and hypergolic (and toxic)
  - Isp about 305
- **Total weight** 33680 lb
- **Height** 23 ft
- **Width** 14 ft
- **Legs span** 31 ft

# LM DESCENT & ASCENT STAGES



*Apollo Descent and Landing*



**LUNAR MODULE**

MSFC 69-MS-G-1300-27





# LM DESCENT STAGE



*Apollo Descent and Landing*

- **Total Weight**      **22910 lb**
  - Dry Weight              4726 lb
  - Propellants              18184 lb
  
- **Descent Propulsion System (DPS) Engine**
  - Thrust      10000 lb
  - Throttleable      10 to 60 %
  - Engine gimbaled in pitch and roll axes
  - Thrust / Lunar Weight
    - 1.7 full to 3.7 dry
    - 27% thrust at landing weight





# LM ASCENT STAGE



*Apollo Descent and Landing*

- **Contained crew, computers, GN&C equipment**
- **Total Weight            10777 lb**
  - Dry Weight                4905 lb
  - APS Propellants         5238 lb
  - RCS Propellants         634 lb
- **Ascent Propulsion System (APS) Engine**
  - Thrust    3500 lb
  - Not throttleable or gimbaled
  - Thrust / Lunar Weight 1.8 full to 3.6 dry

# LM REACTION CONTROL SYSTEM (RCS)

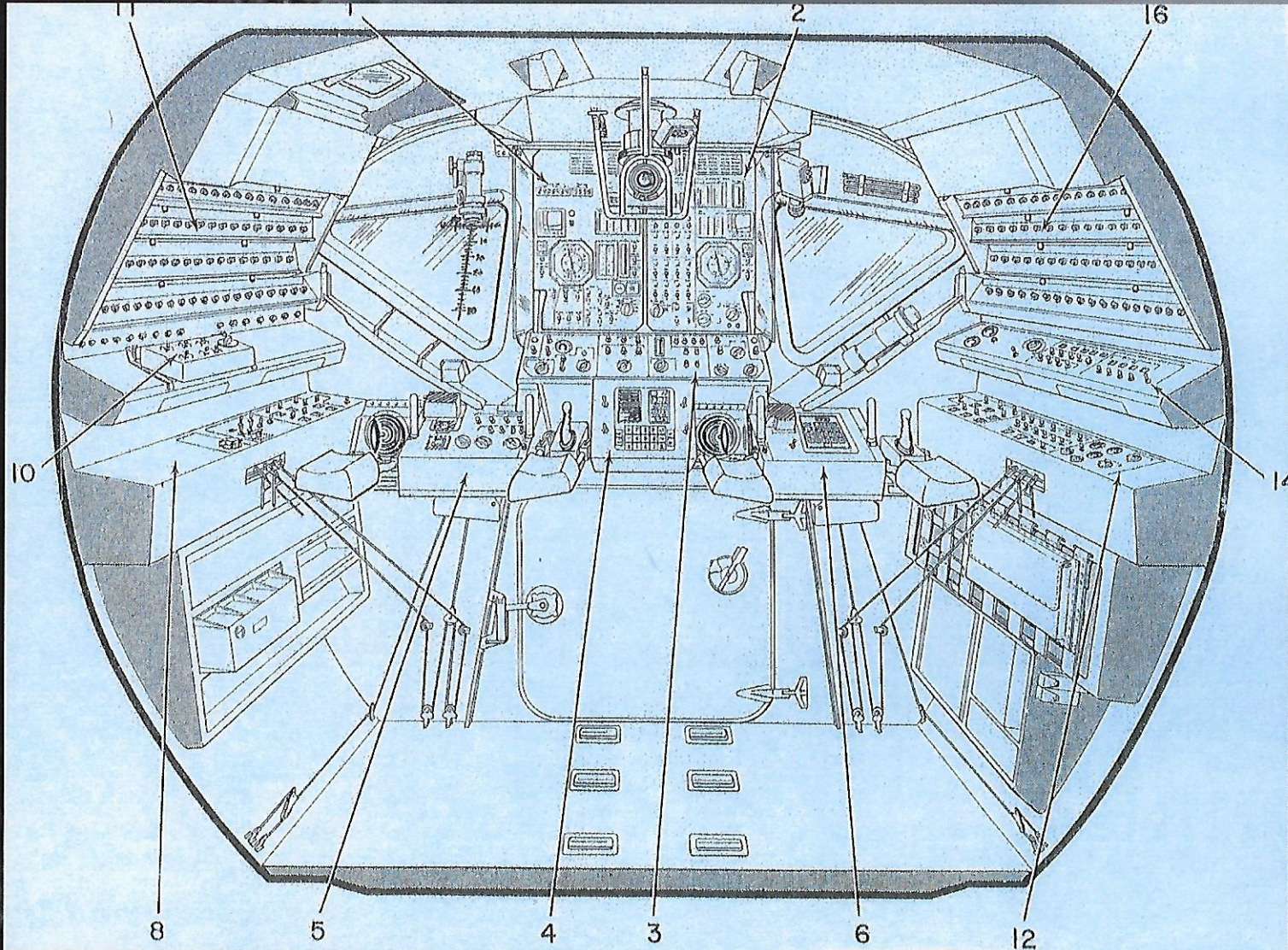


*Apollo Descent and Landing*

- **4 Quads of 4 mutually perpendicular Jets each (16 total)**
- **Provide 6 DOF Rotation and Translation**
- **Thrust 100 lb each**
  - Two jet translational acceleration (Ascent Stage) about 1.1 fps/sec
  - Two jet rotational acceleration about 8 to 28 deg/sec/sec
- **Minimum firing duration 14 msec (0.014 sec)**
  - Minimum rotation rate change about to 0.12 to 0.40 deg/sec
- **Usually fired in pairs (balanced couple)**
- **Four-jet option except longitudinal & lateral translation**
- **Systems A & B for redundancy (8 jets each)**
- **Option to crossfeed from APS propellant**

# LM COCKPIT

Apollo Descent and Landing





# LM COCKPIT



*Apollo Descent and Landing*

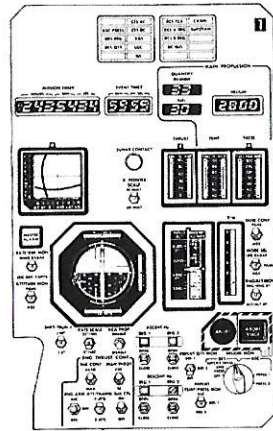
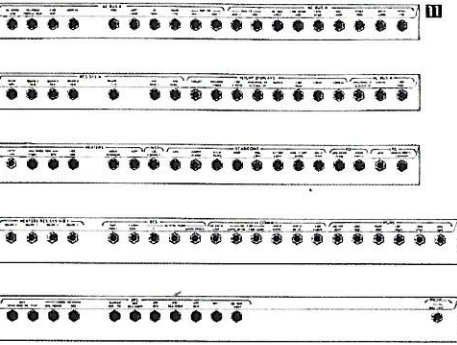
- **Two crew standing, CDR left, LMP right**
  - Note hatch opens from right side
  - Easier for CDR to exit first!
  - Note bungees to hold crew in place!
- **Large triangular forward windows for landing**
  - Field of view down more than 50 deg
  - Scale on CDR window used to determine landing target
- **Overhead window for docking**
- **Crew Optical Alignment Sight (COAS) for rendezvous**
- **Alignment Optical Telescope (AOT) for navigation fixes**
- **Circuit breakers for powering equipment on/off**

# LM CONTROLS & DISPLAYS

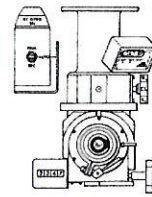


## Apollo Descent and Landing

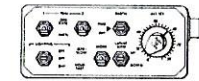
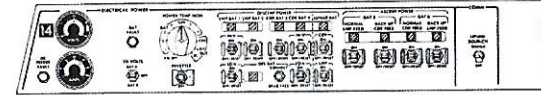
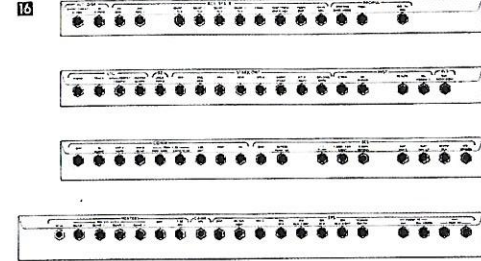
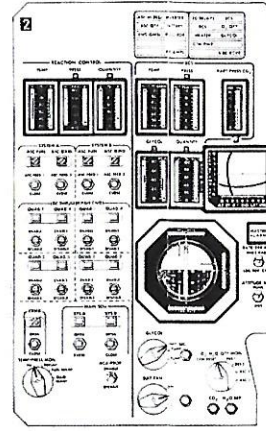
### LUNAR MODULE CONTROLS AND DISPLAYS



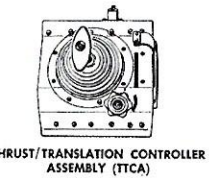
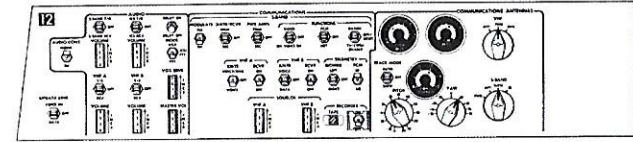
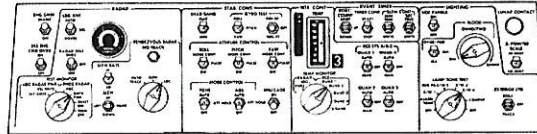
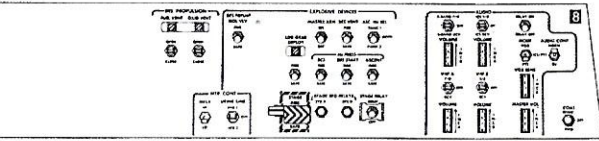
UTILITY LIGHT SWITCH ASSEMBLY



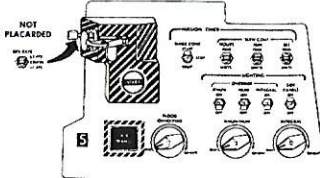
ALIGNMENT OPTICAL TELESCOPE (AOT)



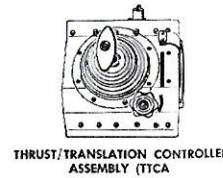
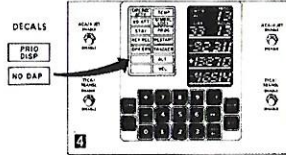
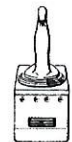
ORBITAL RATE DISPLAY — EARTH AND LUNAR (ORDEAL)



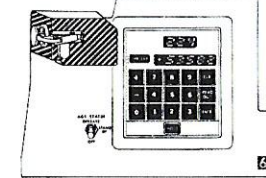
THRUST/TRANSLATION CONTROLLER ASSEMBLY (TTCA)



ATTITUDE CONTROLLER ASSEMBLY (ACA)



THRUST/TRANSLATION CONTROLLER ASSEMBLY (TTCA)



ATTITUDE CONTROLLER ASSEMBLY (ACA)



# LM PILOT CONTROLS



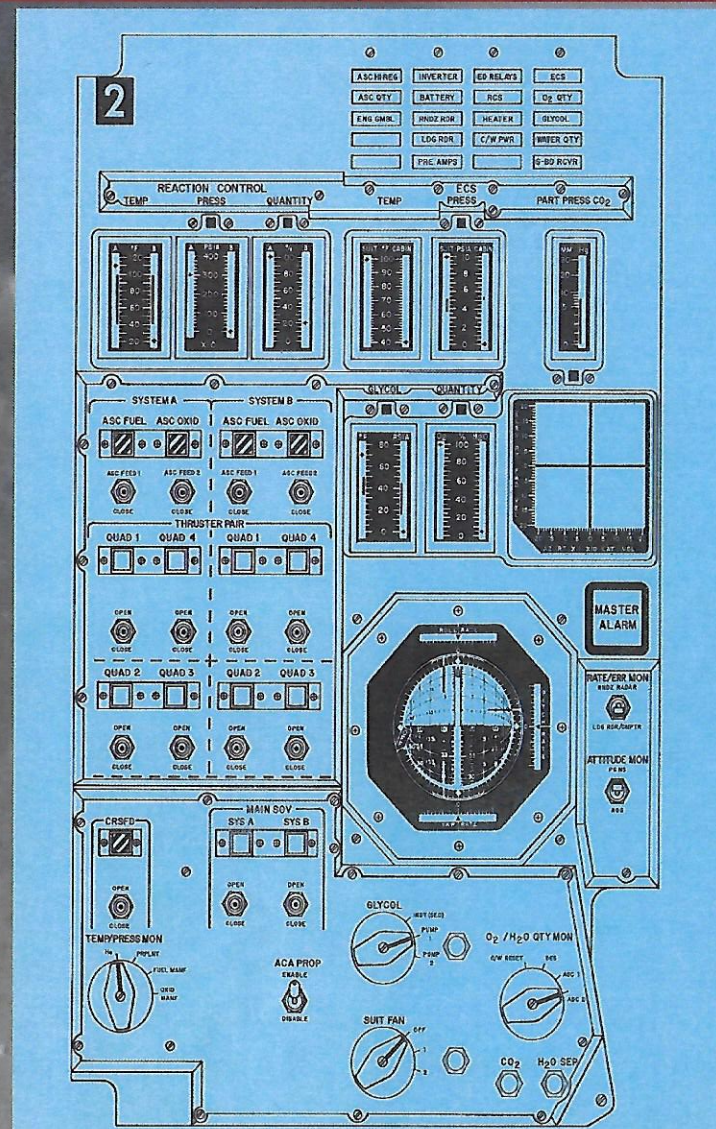
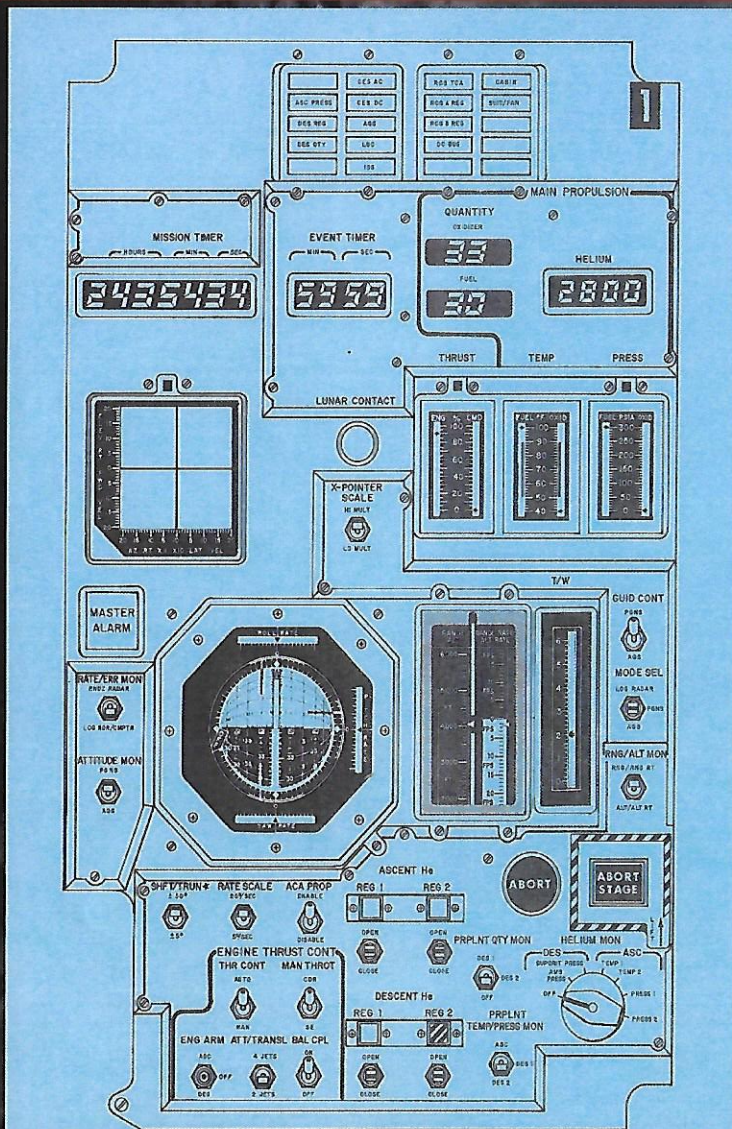
*Apollo Descent and Landing*

- **Attitude Control Assembly (ACA) – ‘Joystick’**
  - 3 Axes joystick for Rotations – Pitch, Roll, Yaw
  - Rate Command, Pulse, Direct Modes
  - Target Redesignation (in P64)
- **Thrust / Translation Hand Controller (TTCA)**
  - 3 Axes translational acceleration (forward/aft, left/right, up/down)
  - Vertical axis could be switched to use as DPS Throttle
- **Engine On/Off and X Translation Pushbuttons**
  - Could be pushed while gripping handle
- **Rate of Descent Switch**
  - Paddle switch with up/down motion while gripping handle
  - Changed vertical velocity by 1 fps (in P66)

# LM MAIN INSTRUMENT PANELS



Apollo Descent and Landing



# CDR INSTRUMENT PANEL

*Apollo Descent and Landing*

- **FDAI – Flight Director, Attitude & Body rotation rates**
- **Altitude/Radar Range and AltRate/Range Rate tapes**
- **Crosspointer – forward / lateral velocity (landing)  
-- elevation/azimuth rates (rendezvous)**
- **Lunar G meter – thrust / lunar weight**
- **Lunar Contact Light (manual engine shutdown reqd)**
- **Thrust / Command and Fuel / Oxidizer / Helium gages**
- **Engine Temperature & Pressure gages**
- **Mission & Event Timers**
- **Abort & Abort Stage (covered!)**
- **Display & Control mode switches**

# PRIMARY GUIDANCE, NAV & CONTROL SYSTEM (PGNCS)

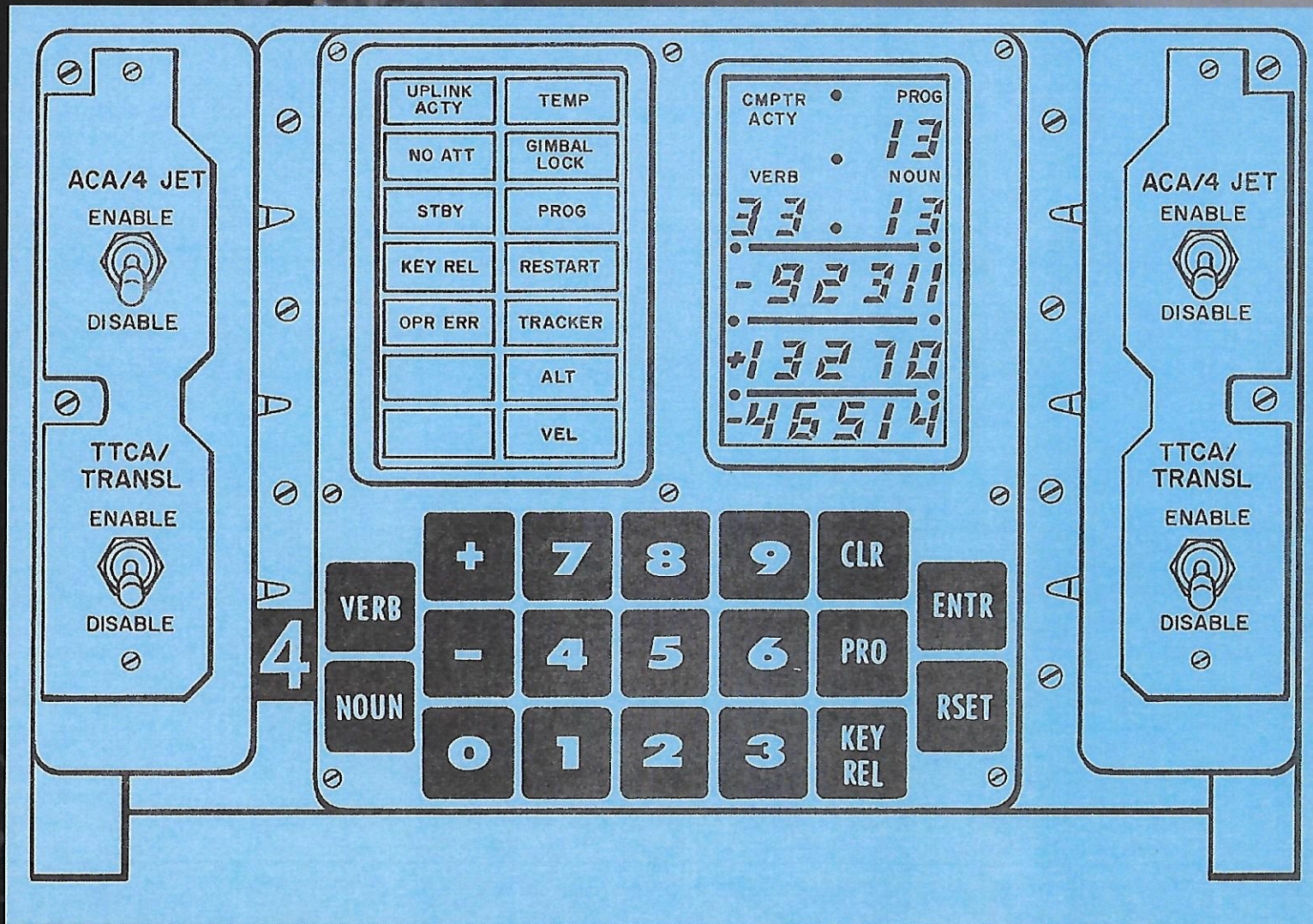


*Apollo Descent and Landing*

- **Program Functionality**
  - Orbital Navigation (based on IMU stable platform & star alignment)
  - Guidance for Deorbit, Landing, Ascent, Rendezvous
  - Digital Autopilot (DAP)
- **Machine Language Programs**
  - Hard wired into core (read only) memory
- **Memory**
  - Read Only Memory 36,864 16-bit words ( = 72 kilobytes ! )
  - Erasable Memory 2048 16-bit words ( = 4 kilobytes RAM ! )
  - Memory cycle time 11.7 microsec ( = 85 kiloHertz ! )
- **Weighed 70 lb, Volume 1.0 cubic foot, 55 Watts**

# DSKY

Apollo Descent and Landing



# DISPLAY AND KEYBOARD (DSKY)



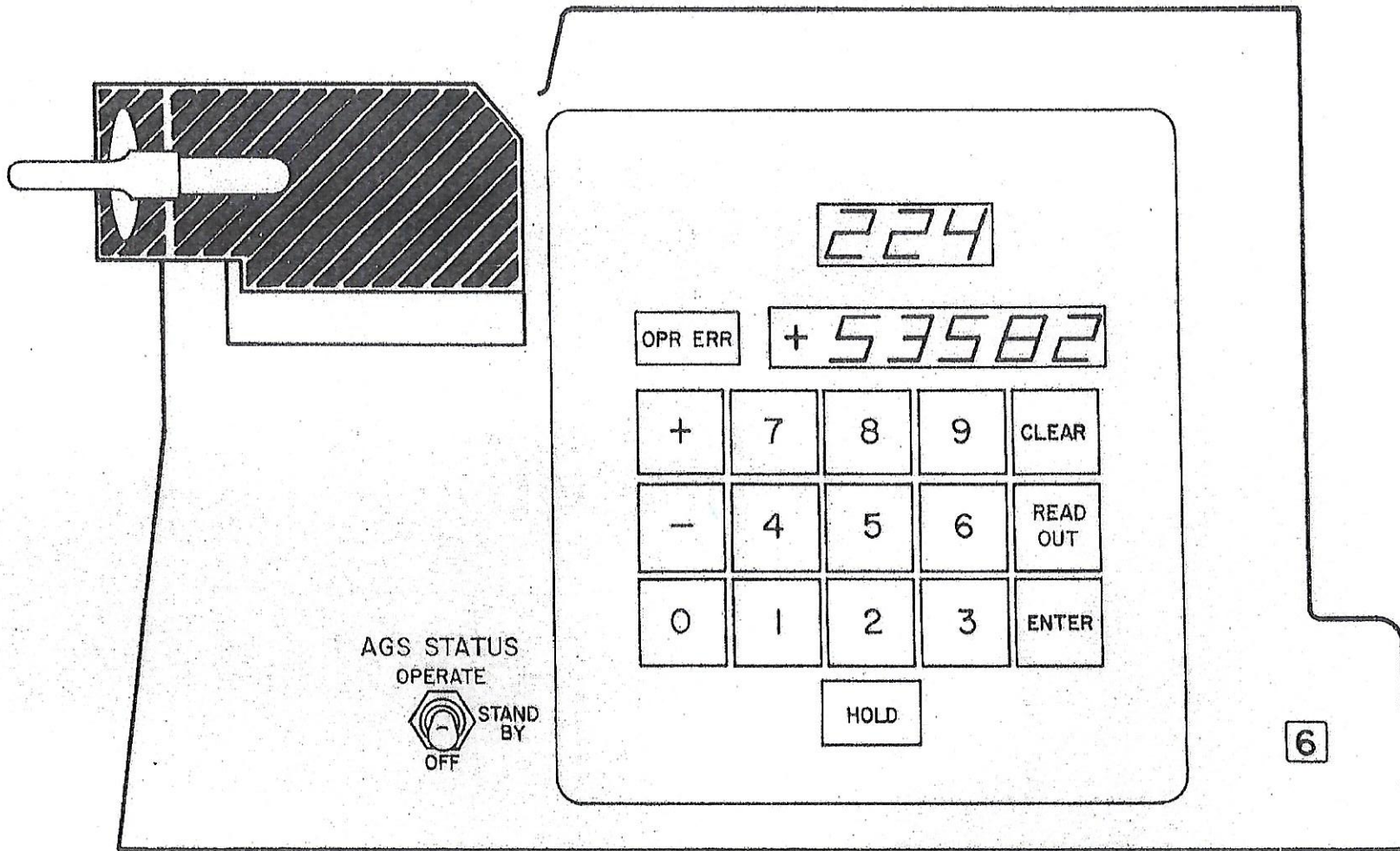
*Apollo Descent and Landing*

- **Crew Inputs via Keyboard (19 keys)**
  - Example Verb 57 Enter → permit landing radar nav updates
- **Computer Outputs via Program, Verb, Noun**
  - Three 5-digit data registers (no decimal point!)
  - Programs were numbered 00 (idle) to 99
  - Example Verb 16 Noun 60 Enter → display decimal data
    - Horizontal velocity    xxxx.x ft/sec
    - Altitude rate            xxxx.x ft/sec
    - Computed altitude    xxxxx ft
- **Computer Activity Light**
- **Error Codes (5-digit integers – took over the display!)**
- **Alarm Lights**

# DATA ENTRY & DISPLAY ASSY (DEDA)



*Apollo Descent and Landing*



# ABORT GUIDANCE SYSTEM (AGS)



*Apollo Descent and Landing*

- **Program Functionality**
  - Orbit Insertion, Rendezvous
- **Strapdown Inertial Navigation System**
  - Body Mounted Accelerometers & Rate Gyros
  - Needed initialization / updates from PGNCS, crew or ground
- **Crew Interface via Data Entry & Display Assembly**
  - Input desired data address (3 digits)
  - One 5-digit data display / entry register
- **Memory**
  - 2048 ROM and 2048 RAM (18 bit words)
  - Memory Cycle time 5 microsec (200 kiloHertz)

# APOLLO 11 VIDEO



*Apollo Descent and Landing*

- Filmed from LMP window looking down during landing
- Image is tilted about 45 deg (top is upper right corner)
- Last eight minutes of descent, about 45K to landing
- Time-lapse running about 8 x real-time
- Highlights
  - Boot Hill, Maskelyne W, Diamondback Rille
  - Yaw around at 40K (note it stops then yaws faster, switch moved)
  - Horizon below field of view for awhile
  - Boulder field around West Crater (West Crater left of field of view)
  - Landed just past 'East Crater' (about 80 ft diameter)
  - Dust and leg shadow, still moving forward at touchdown

# APOLLO 11 MEMORIES



## *Apollo Descent and Landing*

- **Nomograph of nominal trajectory**
- **My personal notes recorded during landing**
- **About 25 fps velocity & 2900 ft altitude initial navigation errors**
  - caused by undocking, unbalanced RCS couples with average G off
- **Program Alarms 1201 and 1202**
  - caused by having both Landing & Rendezvous Radar turned on
- **Landed about 4 miles past original target**
  - result of actual orbit lower than navigated estimate at ignition
  - landing radar corrected altitude and velocity errors, but not position
- **Manual takeover at 500 ft to avoid West Crater**
  - flew manually about 2500 ft forward, level off at 300 ft and at 70 ft
- **Fuel slosh bigger than expected**
- **3 percent fuel left at landing**
  - about 60 sec (Capcom had called Bingo decision in 30 sec)

# SELECTED REFERENCES

*Apollo Descent and Landing*

- **Apollo 11 Mission Report (MSC-00171)**
  - [www.hq.nasa.gov/alsj/a11/a11mr.html](http://www.hq.nasa.gov/alsj/a11/a11mr.html)
- **Apollo 11 Surface Journal**
  - [www.hq.nasa.gov/alsj/a11/a11.html](http://www.hq.nasa.gov/alsj/a11/a11.html)
- **Apollo 11 Video Library**
  - [www.hq.nasa.gov/alsj/a11/video11.html](http://www.hq.nasa.gov/alsj/a11/video11.html)
- **Radar Section Study Guide, LM-5**
  - by Elling Melle, Grumman LSG 770-154-5, April 1969
- **LMS ISLGC Reference Information, Luminary 96**
  - General Electric Apollo Systems Dept, Houston, April 1969
- **Eagle Lander 3D**
  - excellent free download of Apollo 11 P66, 600 ft to landing
  - [eaglelander3d.com](http://eaglelander3d.com)