Apollo Spacecraft & Saturn V Launch Vehicle Pyrotechnics / Explosive Devices

Objectives

- Identify critical performance, design requirements and safety measures used to ensure quality, reliability and performance of the pyrotechnic/explosive devices
- List and understand the major components and functions of a typical Apollo pyrotechnic/explosive device:
  - Initiators
  - Cartridge Assemblies
  - Detonators
  - Core charge
- Identify the major locations/uses for the devices on:
  - Command & Service Module (CSM)
  - Lunar Module (LM)
  - Launch Vehicle (all stages)

Overview

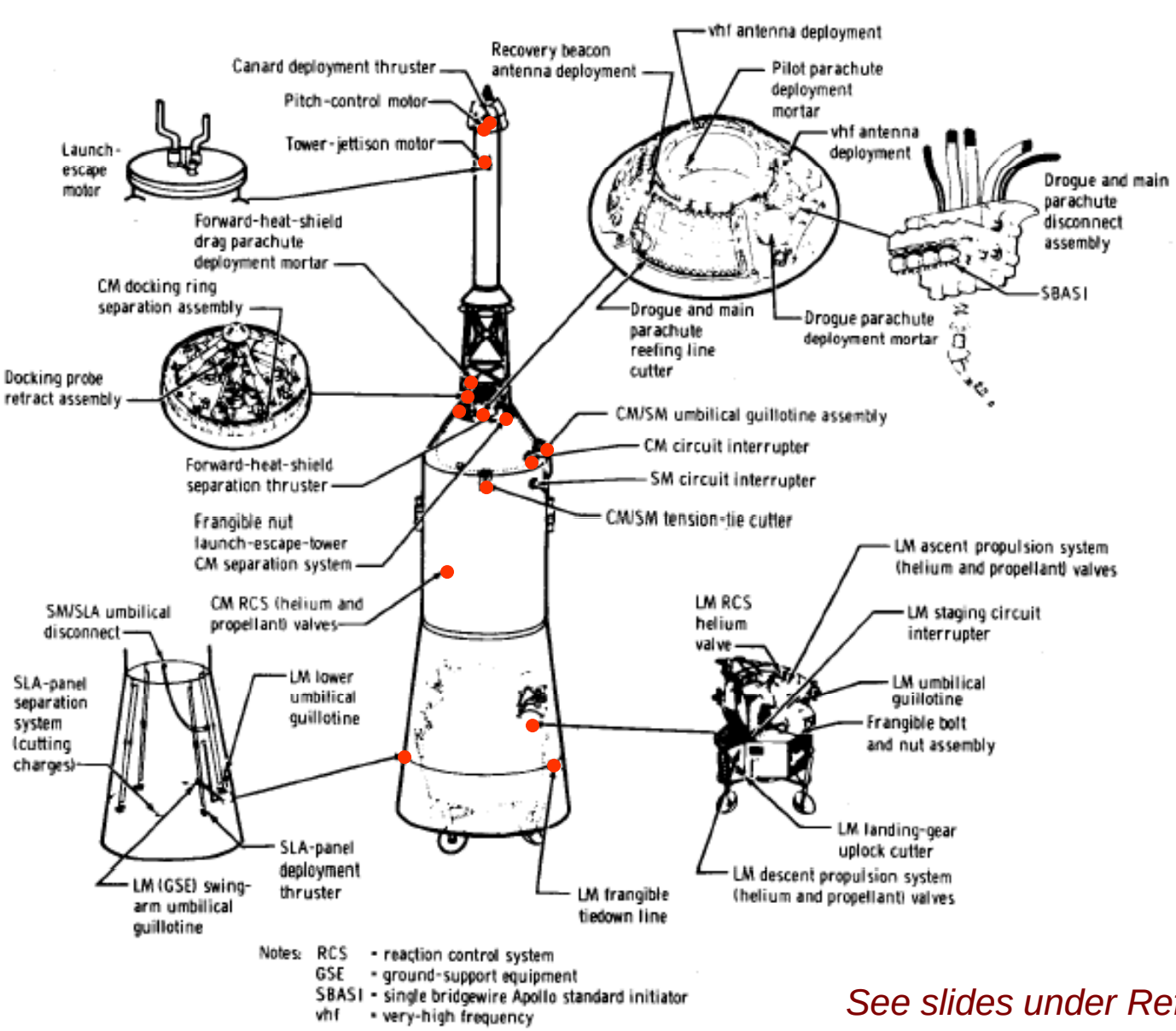
- More than 210 pyrotechnic devices per Apollo Mission
- Automatically or commanded from the Apollo spacecraft systems
  - Onboard
  - In-flight
  - Timed
  - Controlled
- All devices required high reliability and safety
- Most devices were classified as either crew safety critical or mission critical

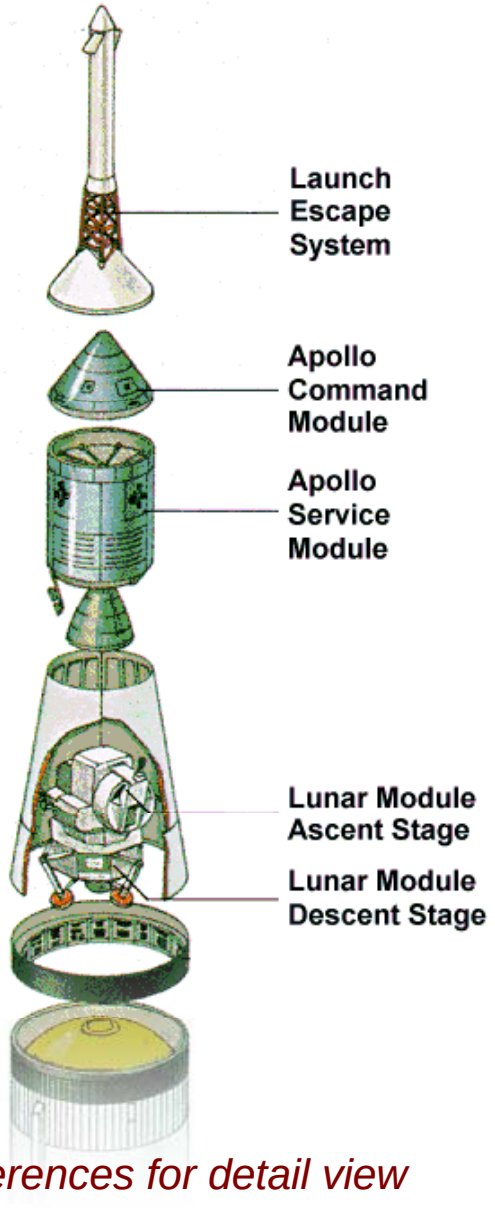
Common Uses of Pyrotechnic Devices

Pyrotechnic devices had a wide variety of applications:

- Launch Escape Tower (LET) separation
- Separation rocket ignition
- Booster stage/Lunar Module separation
- Forward heat shield jettison
- Spacecraft/Lunar Module Adapter panel separation
- Lunar Module landing gear deployment
- Lunar Module propulsion systems pressurization and activation
- Parachute deployment and release
- Electrical circuit opening and closing
- Line/cable cutting – timed & delayed-time
- Spacecraft vehicle destruction, if loss of control or other catastrophe

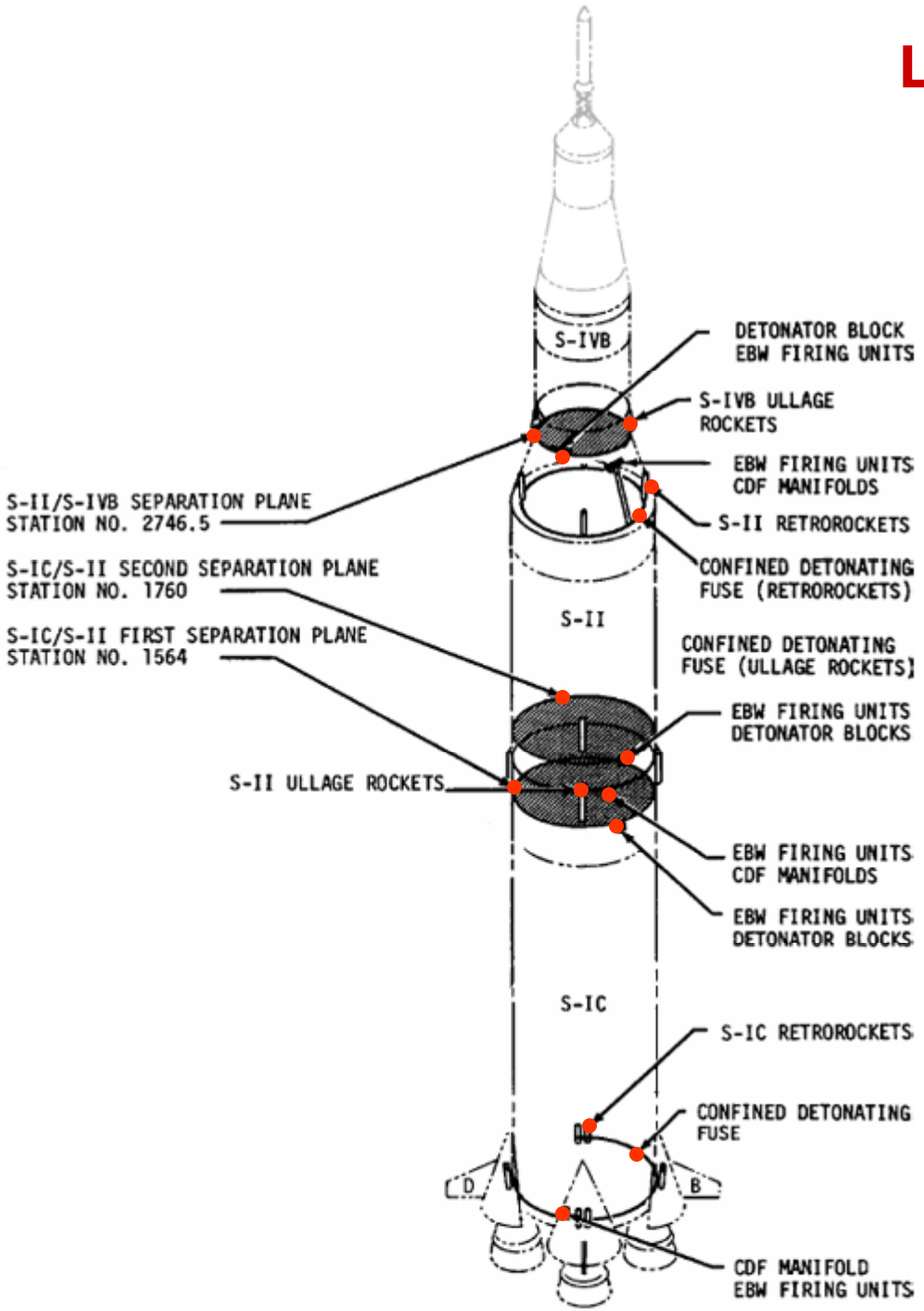
Locations – Apollo Spacecraft





See slides under References for detail view

Locations – Launch Vehicle



- Saturn V Launch Vehicle Pyrotechnics components
  - Stage separation
    - Retrorockets
    - Ullage rockets
    - Detonator blocks
    - Firing Units
  - Propellant Dispersion System
    - Not shown – discussed later

See slides under References for detail view

Requirements, Design / Safety Philosophy

- The high specific energy of pyrotechnic materials provides a large energy source in a small package
- Functions were accomplished reliably and safely with minimum weight and space limitations
- These properties made wide acceptance of pyrotechnics in the Apollo Program a natural result
- Conventional electrical and mechanical components were used, when possible, to minimize potential design problems
- The quality of explosive materials was crucial - only newly-manufactured, specification-controlled Cyclotrimethylenetrinitramine (RDX), Hexanitrostilbene (HNS), and Lead Azide were used to ensure consistent quality of the high-explosive materials

Requirements, Design / Safety Philosophy

- To ensure non-interchangeability of similarly-shaped cartridges, an indexing technique which provided special keyway combinations was developed, and different size threads were used on the output ends of the cartridges.
- When complete system redundancy was not possible, redundant cartridges or single cartridges with dual initiators were used.
- Typically, two separate and electrically independent systems operated in parallel and provided complete redundancy in the firing circuitry.
- Apollo pyrotechnic devices ranged from low-energy charges for puncturing gas bottles to high-energy charges for cutting 0.153-inch-thick steel.

Reliability

- The pyrotechnic safety design reliability goal was established to be 0.9999 at the 95 % confidence level
- Tests of the initiators were performed in all applicable types of environment & storage conditions to obtain information on the safety aspects or the no-fire capabilities of a particular device
- No failures of any pyrotechnic device were ever detected during any of the Apollo missions

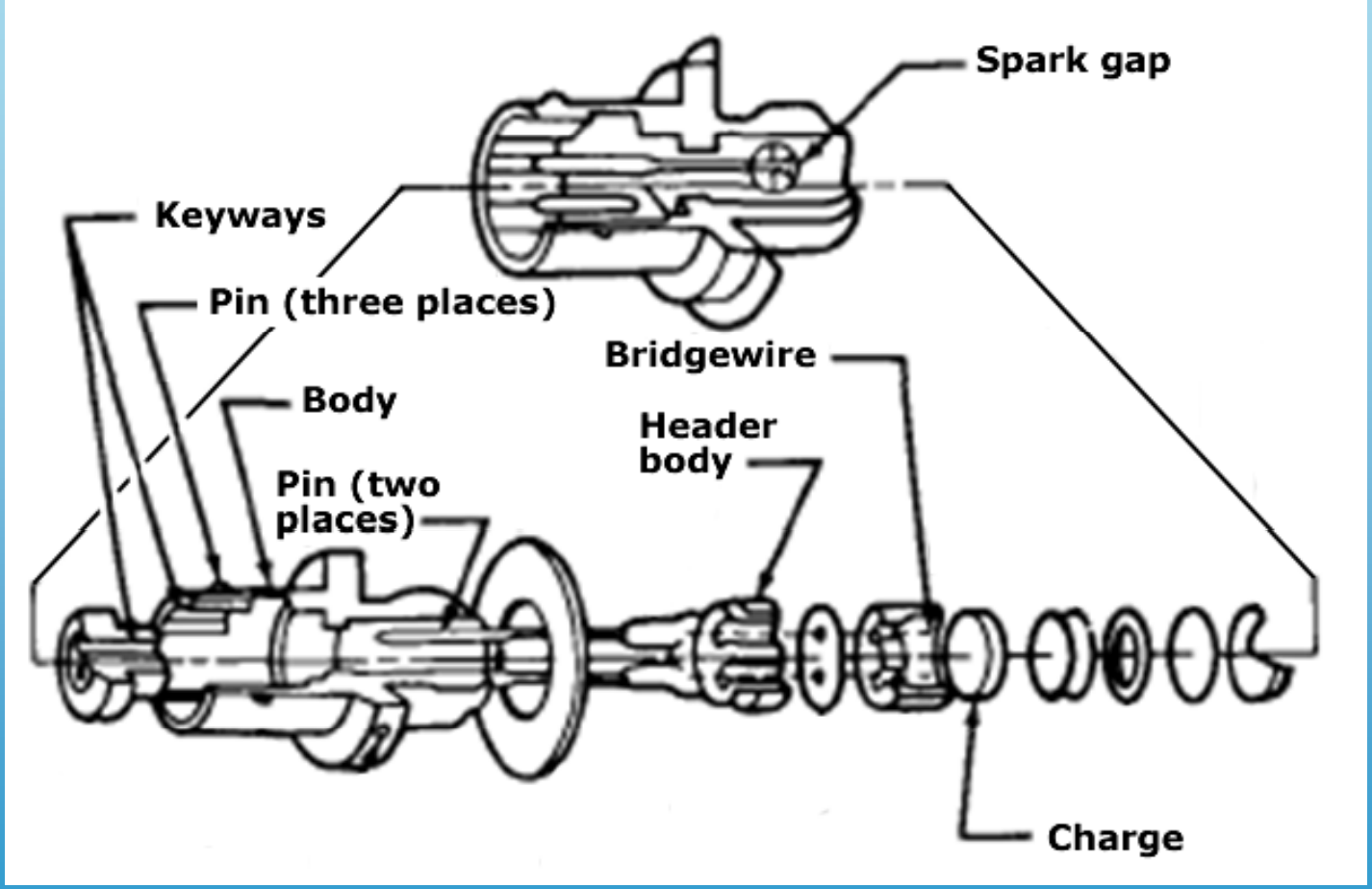
Major Components

- A typical Apollo explosive device system (or “train”) generally consisted of:
  - Initiators - started “first fire”
    - Apollo Standard Initiator & Single Bridgewire Apollo Standard Initiator
  - Cartridge assemblies - increased the power of the initiator
    - Electrically Initiated & Spacecraft/LM Adapter Thruster
  - Detonator - initiated the core charge
    - Apollo Standard Detonator, End-Detonating Cartridge, & Long-Reach Detonator
  - Core charge - completed the explosion started by the detonator (big explosion)
    - Mild Detonating Fuse, Confined Detonating Cord, & Linear Shaped Charge

Initiators

- The Apollo Standard Initiator (ASI), was originally developed/qualified for Apollo electrically-initiated pyrotechnic devices - electrical sensitivity problems with the double-bridgewire design were discovered
- In response, the Single-Bridgewire Apollo Standard Initiator (SBASI) was developed/qualified in 1966 as the initiating element for all electrically-initiated pyrotechnic devices
- The SBASI is a two-pin, electrically-activated, hot wire, electro explosive – translates an electrical stimulus into a pyrotechnic action or “train”
- The SBASI was adopted and used as the NASA Standard Initiator (NSI) on the Space Shuttle, Shuttle payloads, & other NASA programs

Initiators



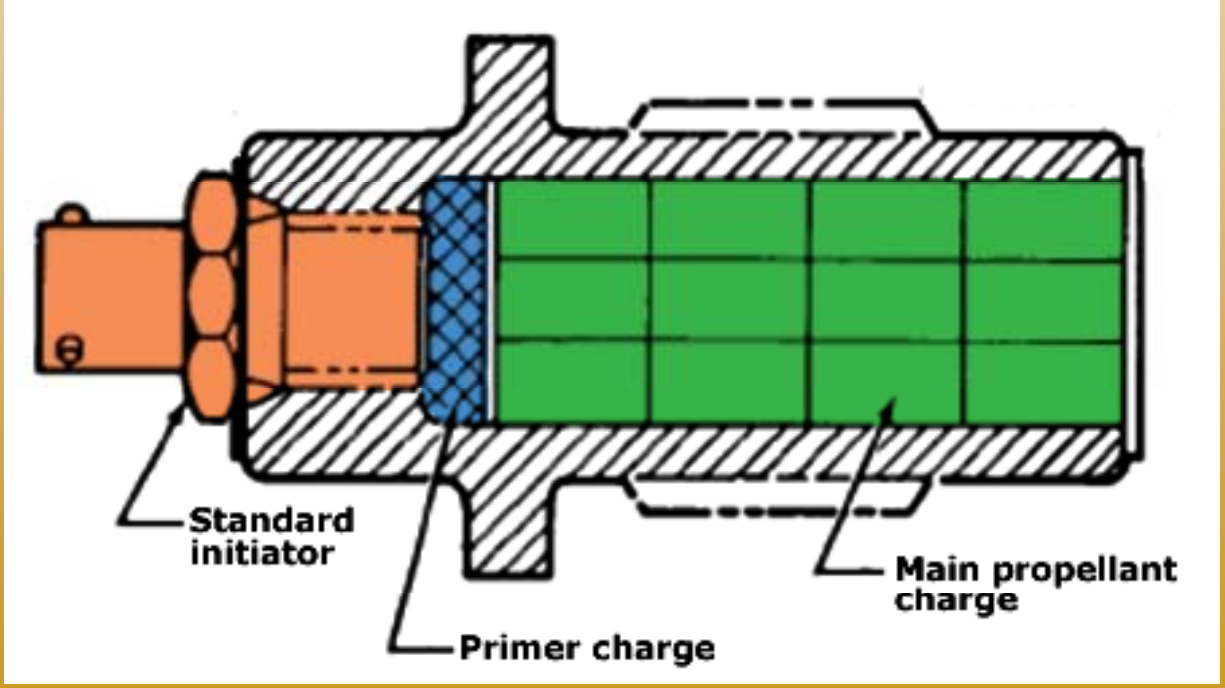
Single Bridgewire Apollo Standard Initiator (SBASI)

Cartridge Assemblies

- Typical applications
  - Actuating electrical circuit interrupters and disconnects
  - Thruster operation
  - Parachute deployment
  - Valve operations
  - Served as separation systems component parts

Cartridge Assemblies

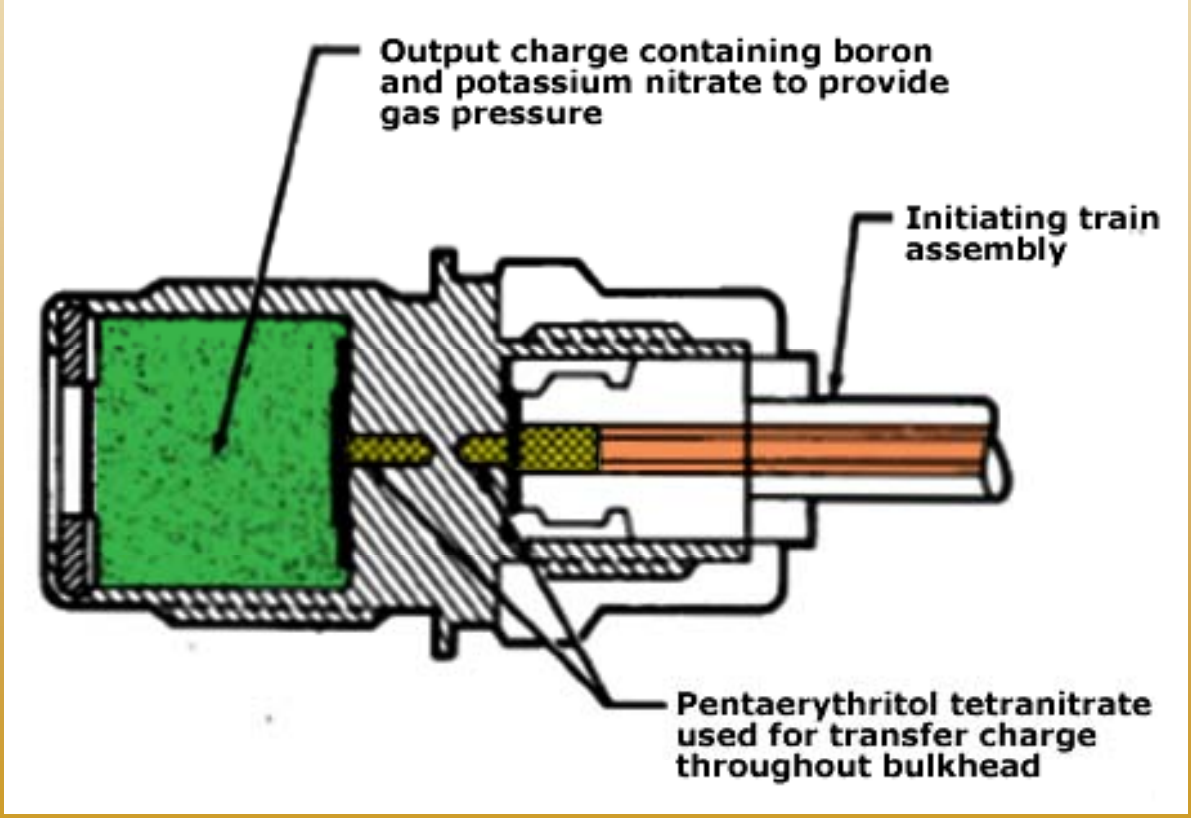
- Most cartridge assemblies were similarly constructed, but differed in thread size and in amount of output charge
  - Cartridges with different outputs had different thread size to prevent installation in the incorrect pyro train
  - Cartridges with the same output, but located close together and fired at different times, were keyed (or indexed) differently
- Most were electrically initiated by an SBASI (exception noted on next slide)



Electrically-Initiated Cartridge

Cartridge Assemblies

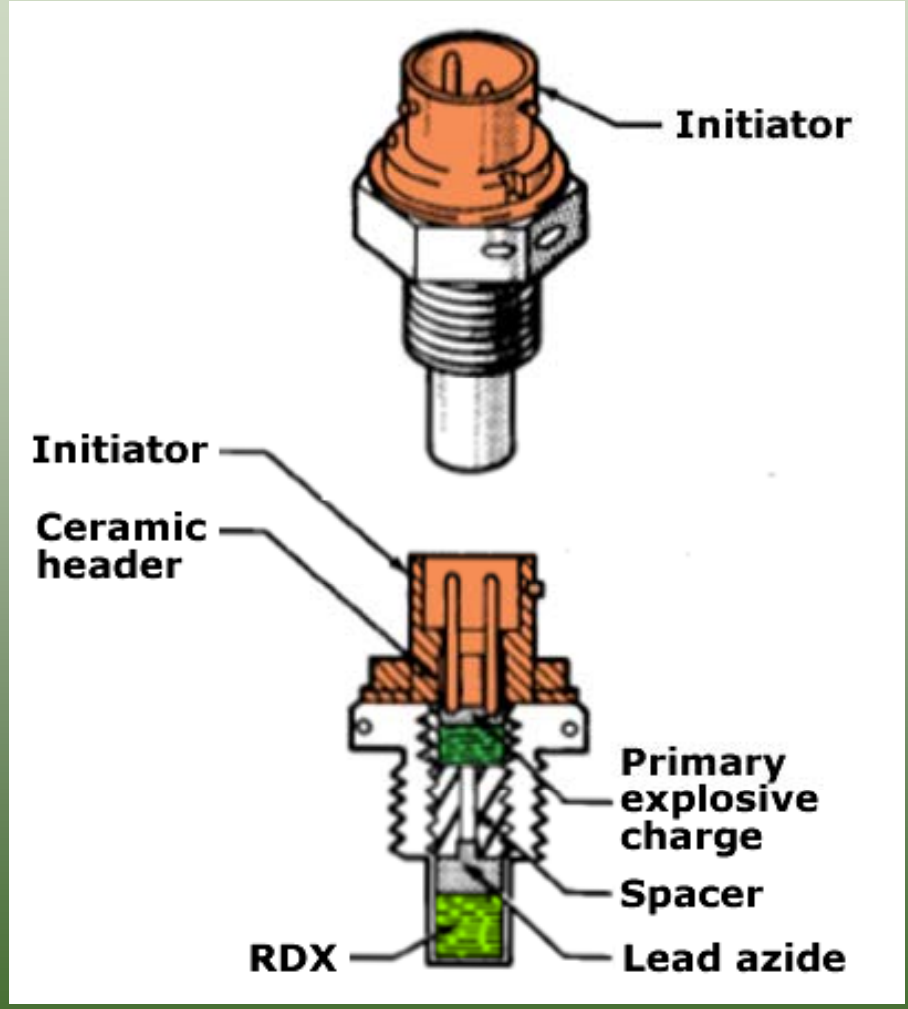
- The only non-electrically initiated cartridge was initiated by Confined Detonating Cord (CDC)
- Use to operate the Spacecraft/Lunar Module Adapter (SLA) panel adapters



Spacecraft/Lunar Module Adapter Thruster Cartridge

Detonators

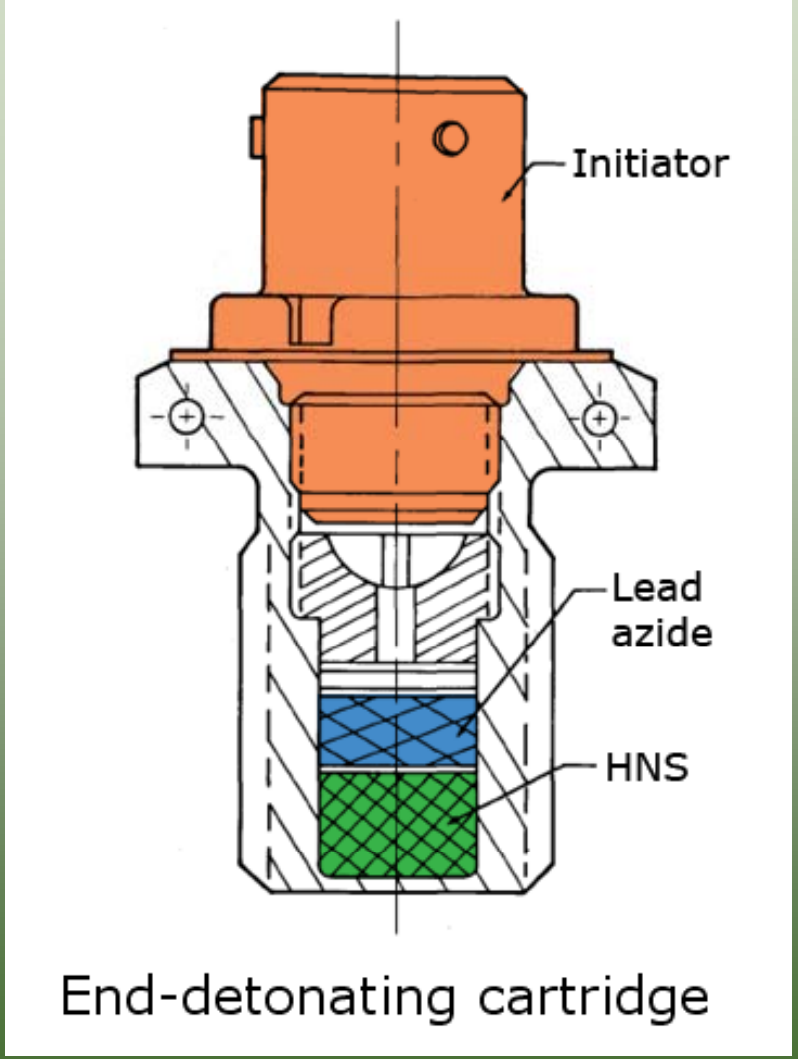
- **Type 1- Apollo Standard Detonator (ASD) – typical uses:**
  - **LES tower-separation frangible nut**
  - **CM/SM guillotine**
  - **Tension-tie cutter**
  - **Lower LM guillotine**
  - **SLA-panel separation**
  - **LM/SLA separation**



Type 1 – Apollo Standard Detonator (ASD)

Detonators

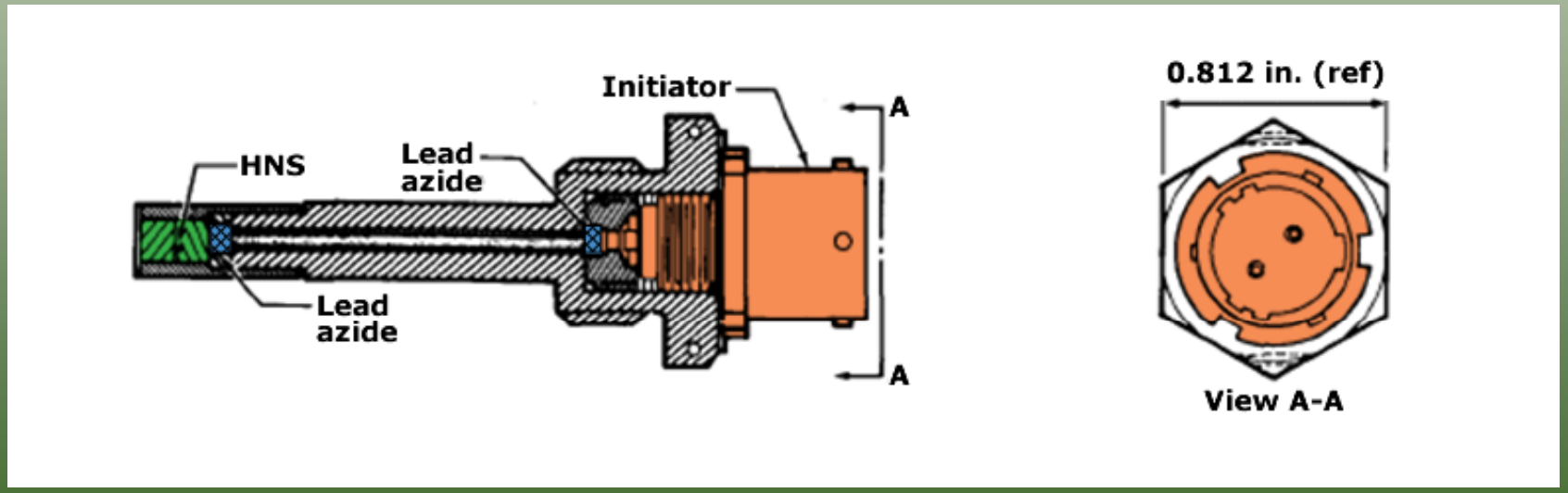
- **Type 2 - End - Detonating Cartridge (EDC)**
  - Used for high-temperature applications where a directional shock was needed to initiate high-explosive elements
  - Had an intermediate charge of lead azide and an output charge of HNS



Type 2 – End-Detonating Cartridge (EDC)

Type 3 – Long Reach Detonator (LRD)

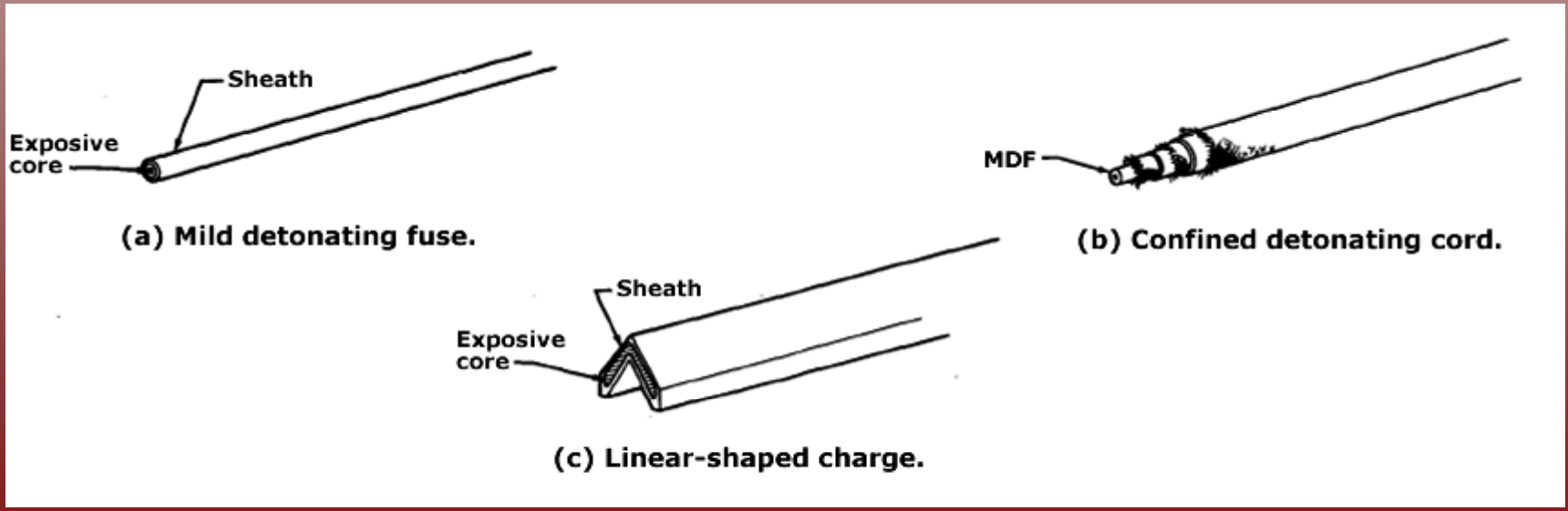
- The Long-Reach Detonator (LRD) was only used in the docking ring assembly
- This configuration was necessary to extend the output charge to an interface area not accessible with either the Apollo Standard Detonator (ASD) or the EDC (previous slide)



Type 3 – Long Reach Detonator (LRD)

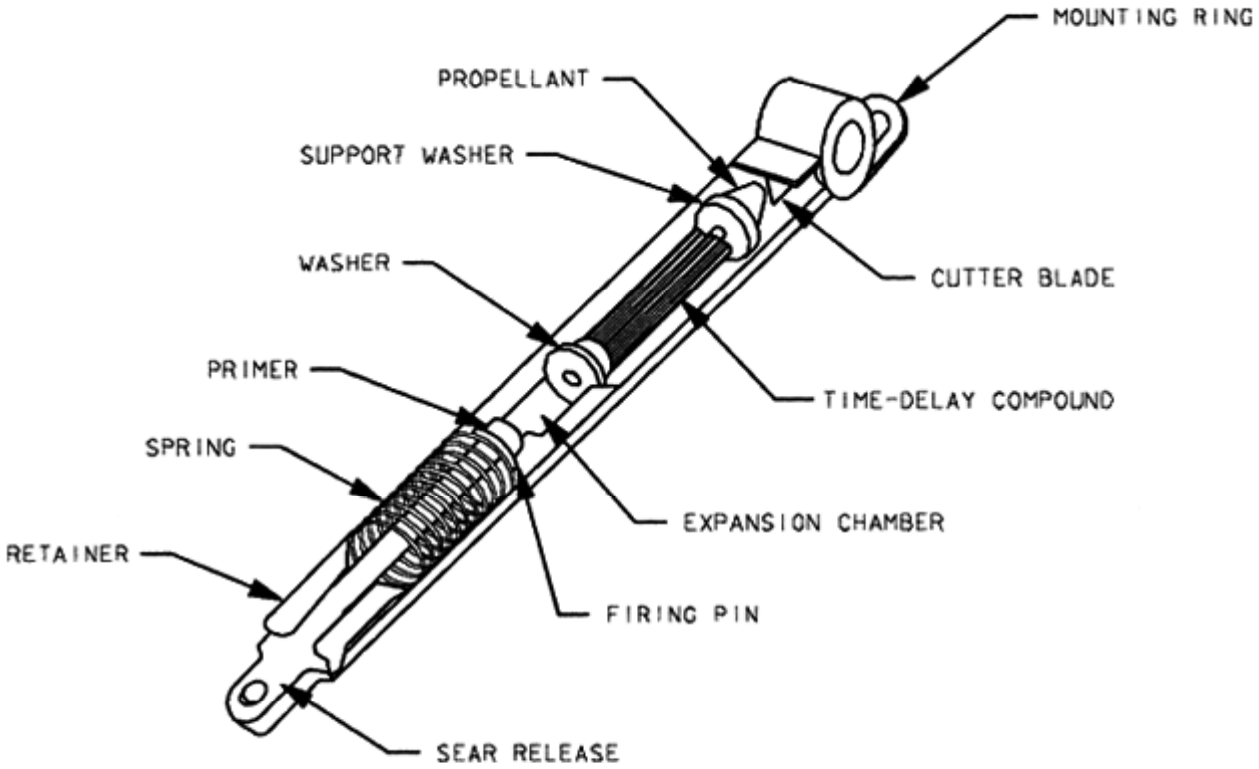
Core Charges

- Mild Detonating Fuse (MDF) – two primary uses
  - On the SLA and for CM/docking separation
  - As the explosive element that drove the guillotine blades when cutting umbilicals
- Linear-Shaped Charge (LSC)
  - Sever tension ties connecting the SM and CM
- Confined Detonating Cord (CDC)
  - Detonation transfer in the SLA separation system



Reefing Line Cutters

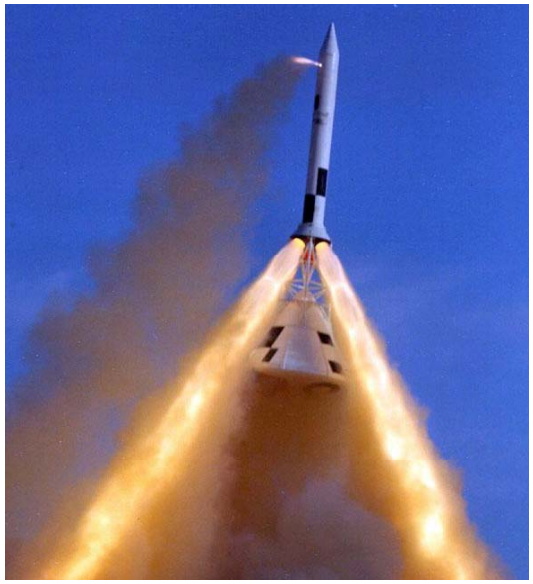
- Time-delay line cutters were used for:
  - Deploying recovery aids (e.g. VHF and HF antennas and the recovery beacon)
  - Cutting parachute reefing lines (drogue and main chutes)

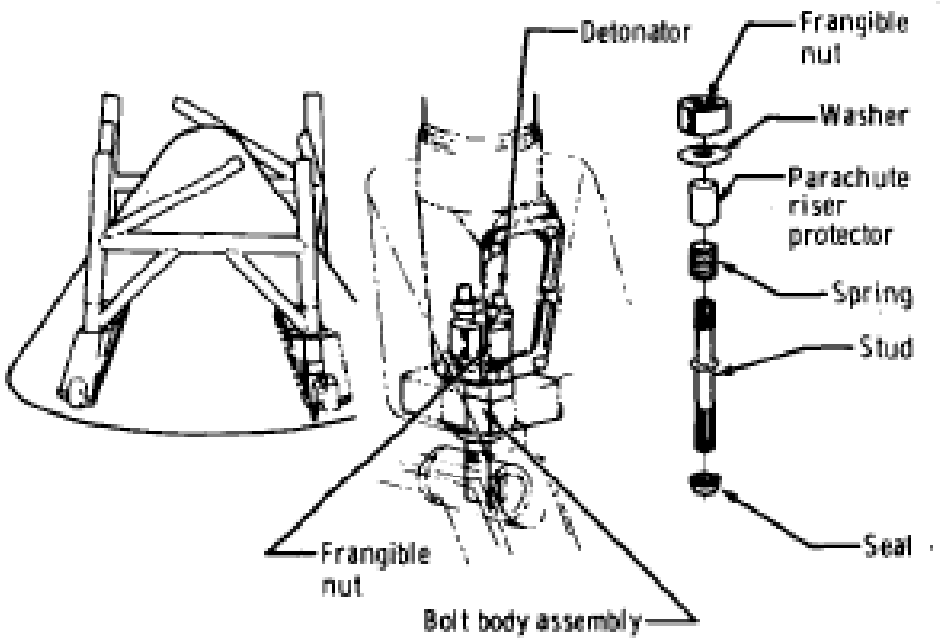


Time-delay Reefing Line Cutters

Launch Escape System (LES) Explosive Devices

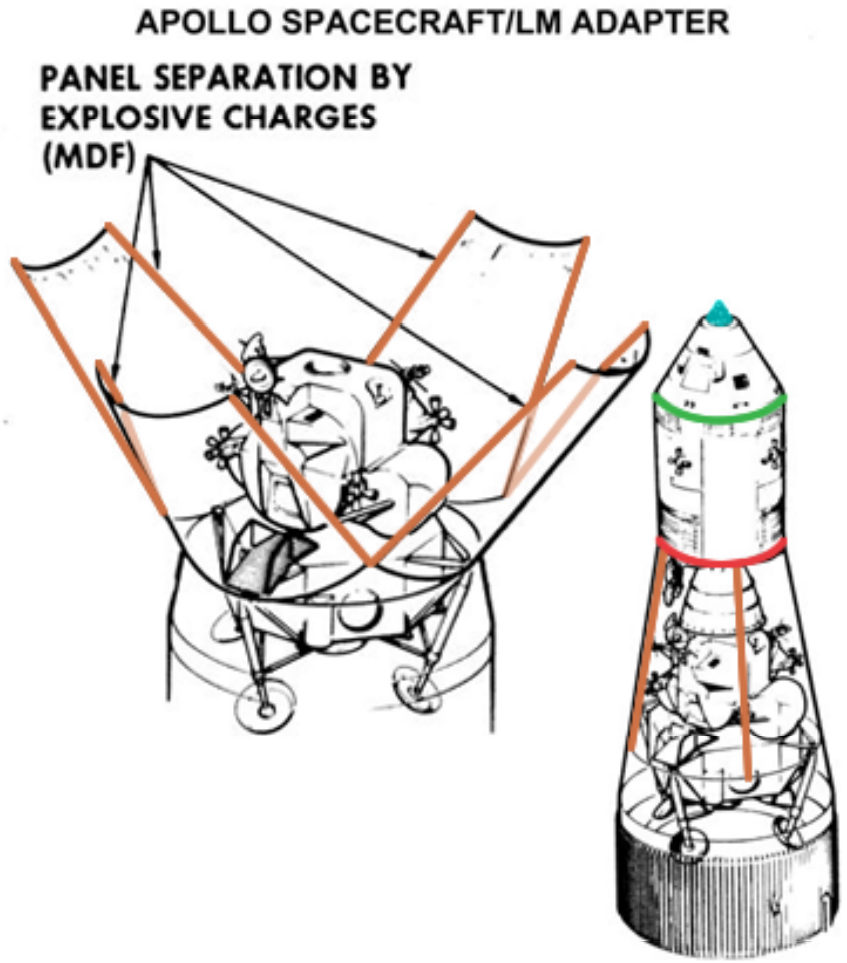
- **Purpose of LES explosive devices:**
  - Separate the Command Module (CM) from the Launch Vehicle (LV) in the case of a Pad Abort or 1st Stage Abort
- **Emergency separation:**
  - The LES was activated immediately before an abort was initiated to ensure crew was clear of explosive debris or an out-of-control launch vehicle
- **Nominal separation:**
  - If no abort declared, the Launch Escape Tower (LET) was separated from the CM at L/O + 2:50 and approximately 260K ft/ 79K m altitude
  - Accomplished by switch throws by the crew - the tower jettison motor and the frangible nuts at that base of each tower were ignited simultaneously



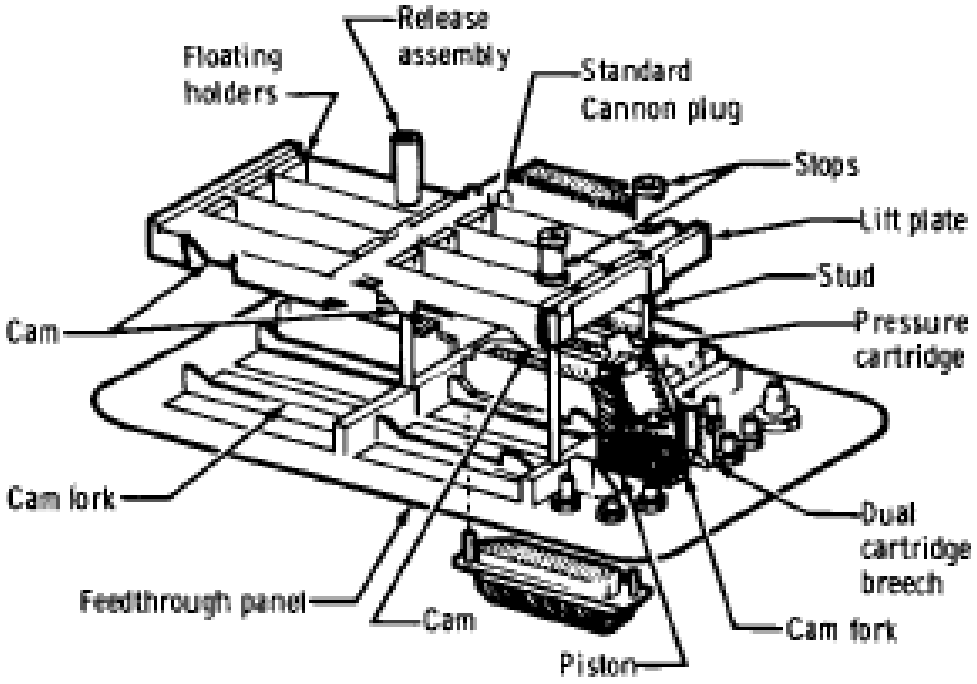


Command & Service Module (CSM) Pyro Systems

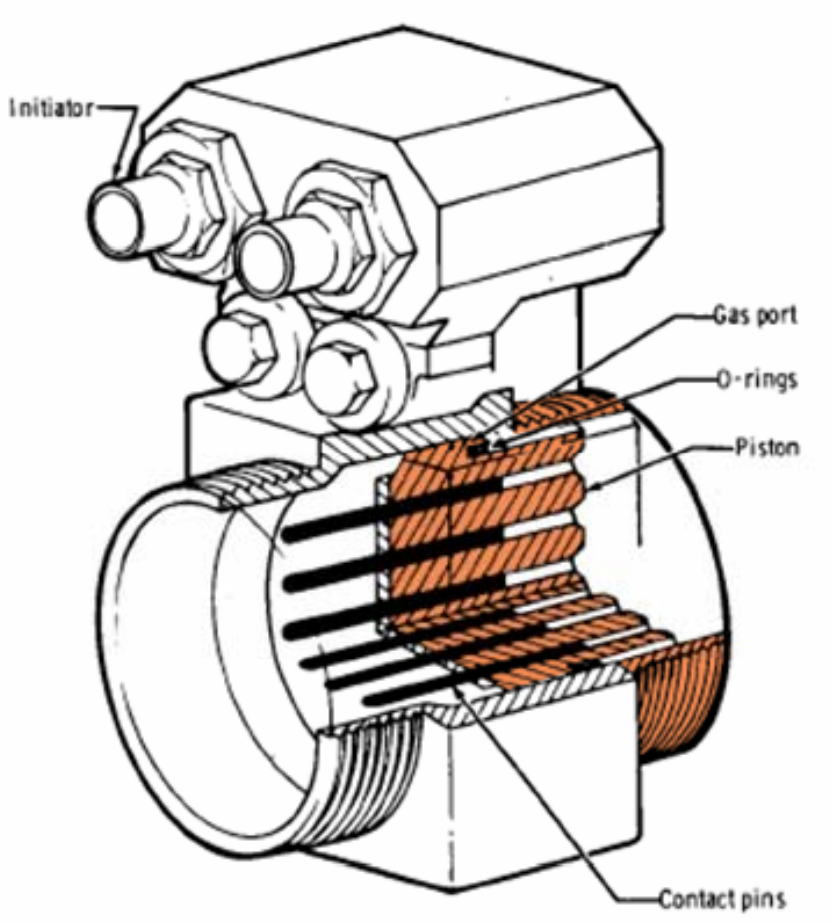
- **Major Command (CM) & Service Module (SM) pyrotechnic devices/uses**
  - CSM and Spacecraft/Lunar Module Adaptor (SLA) separation
  - Lunar Module Separation System
  - Adapter Panel Explosive Train System
  - SLA Panel separation
  - SLA and Lunar Module (LM) separation
  - Docking probe retraction
  - Docking ring retraction
  - CM and SM separation
  - Circuit interruption in the CM and SM
  - Fuel and oxidizer dump/purging functions



CSM Pyrotechnic Circuit Interrupters



Command Module

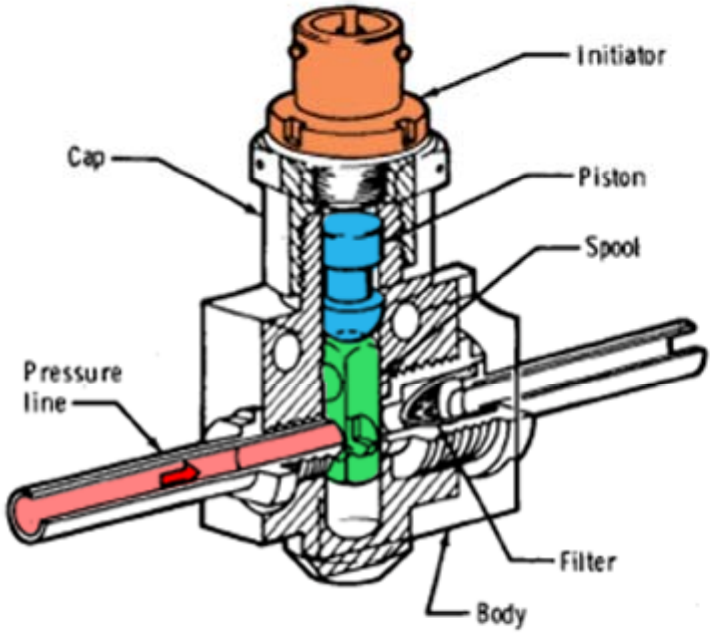


Service Module

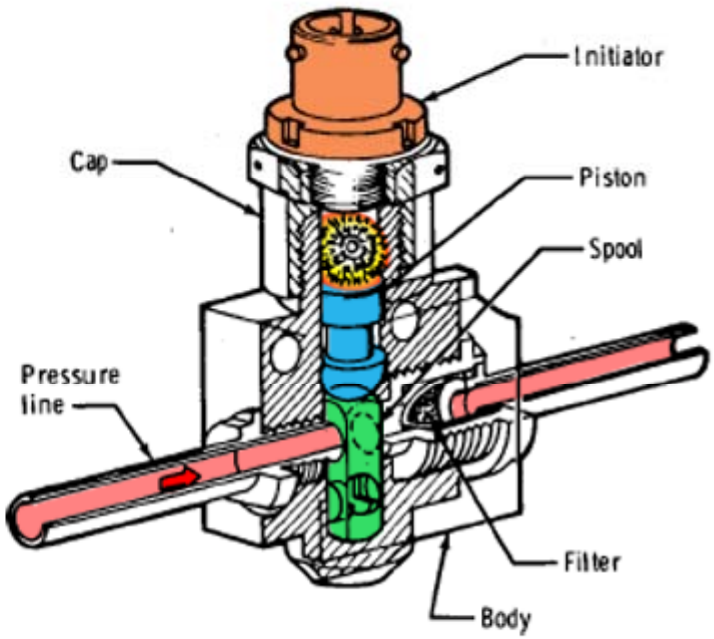
Electrical Circuit Interrupters

CSM Pyrotechnically Operated Valves

- These pyrotechnically operated valves were used to control the distribution of helium & propellants
- Each valve (normally closed) was actuated by an electrically-initiated cartridge
- Upon firing, the valves remained open permanently



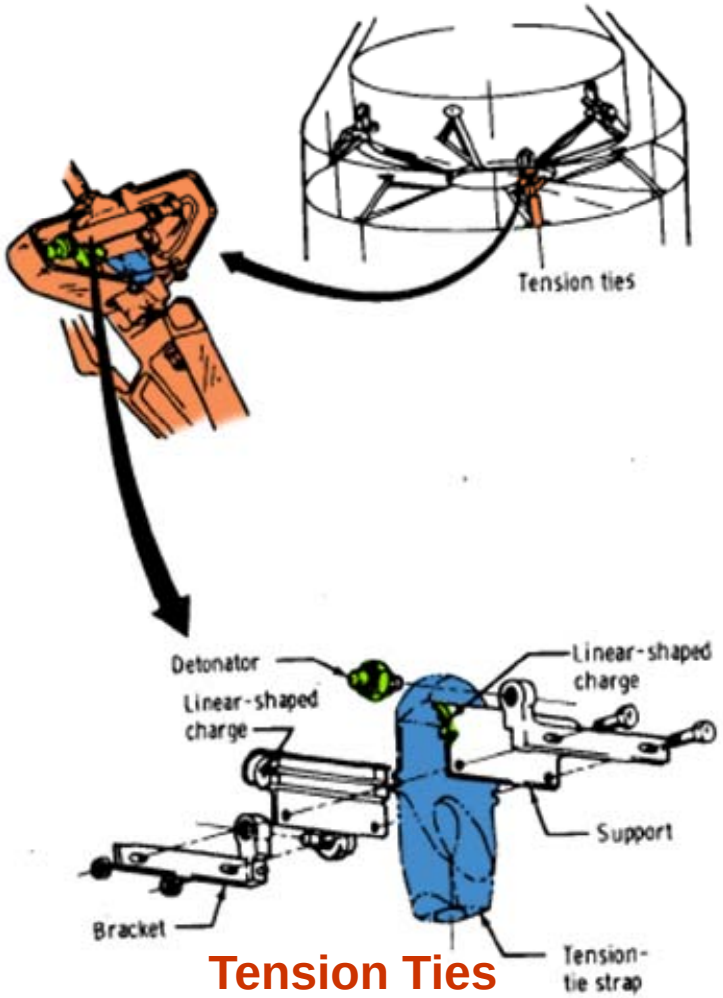
Closed Position



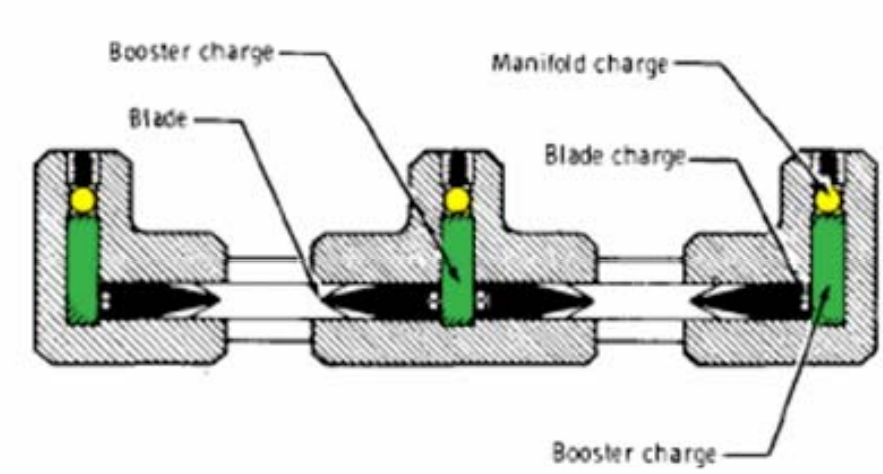
Open Position

CSM Structural Separation System & Guillotine

- Tension ties connecting the SM & CM were cut with linear shaped charges
- The CM/SM guillotine cut the umbilical between the CM & SM thus allowing CM/SM separation



Tension Ties



CM/SM Guillotine

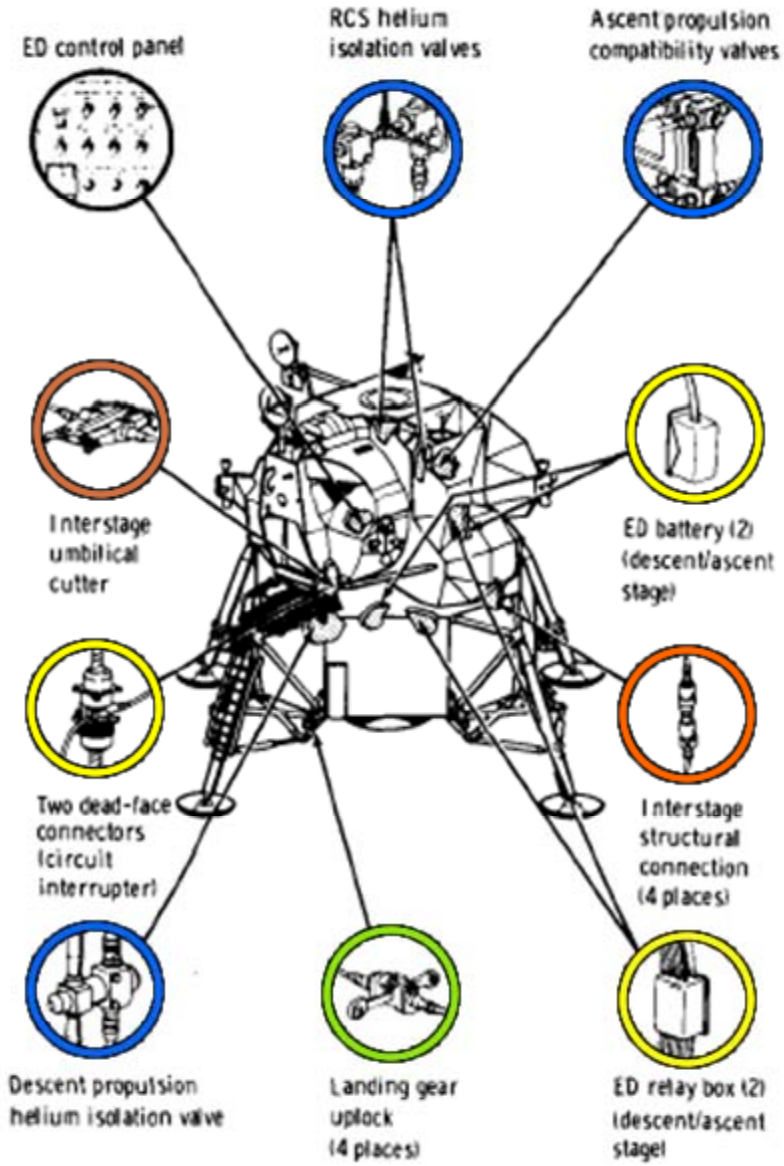
Earth Landing System

- Apex cover was jettisoned when the spacecraft had descended to 24,000 ft (7315 m)
- Drogue parachute deployment followed two seconds after apex cover jettison
- At 10,000 feet (3048 m) the drogue parachutes were released by severing the risers with cartridge-actuated guillotines
- The main parachutes were deployed in the reefed condition using mortar ejected pilot parachutes
- Immediately after splashdown, the main parachutes were released by cartridge-actuated blades

Lunar Module (LM) Pyrotechnic Systems

LM pyro devices/uses:

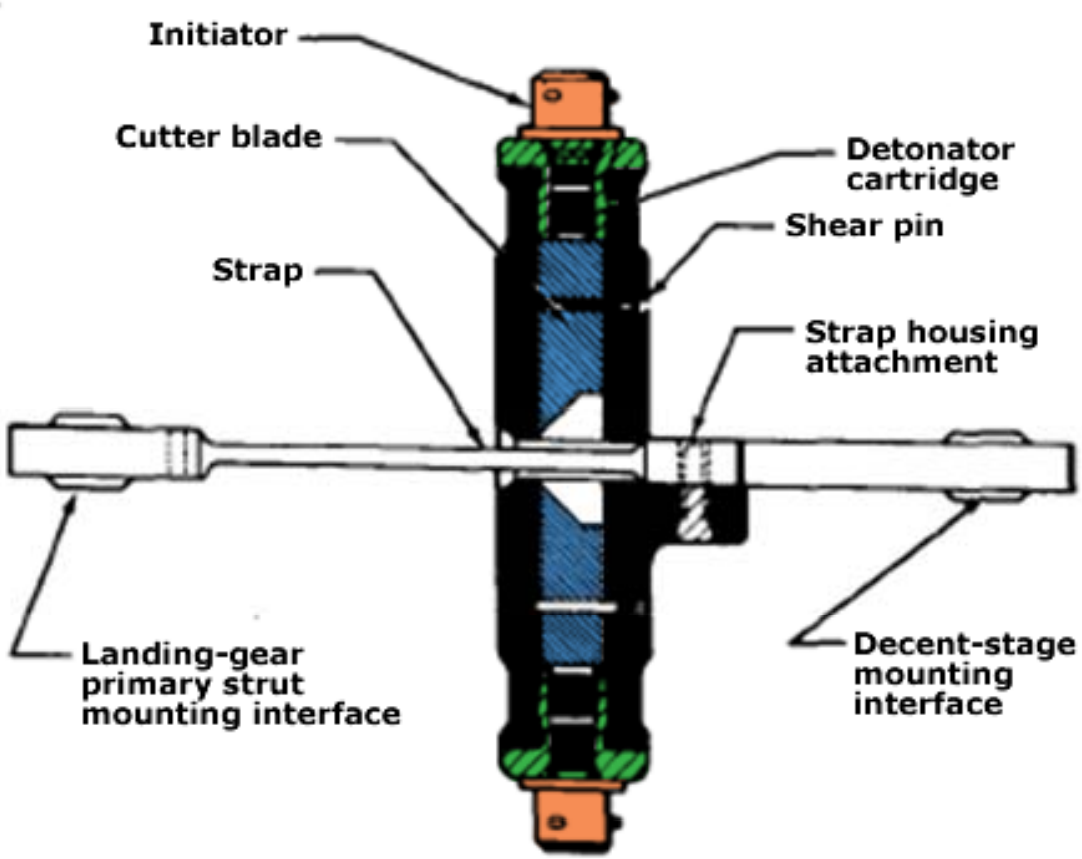
- Landing gear deployment
- Valve opening to pressurize descent, ascent, & RCS propellant tanks
- Descent propellant tank venting
- Electrical circuit interruption
- Interstage umbilical severance
- Ascent & descent stage separation



See slides under References for detail view

LM Landing Gear Extension

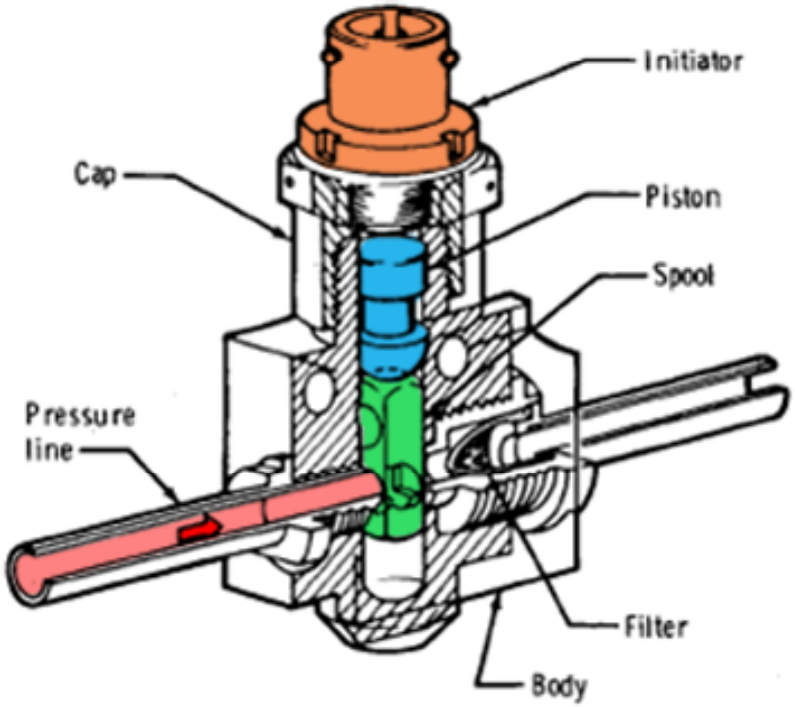
- Landing gear uplock detonators were fired, driving a blade to sever the strap - this allowed deployment mechanism springs to extend the LM landing gear



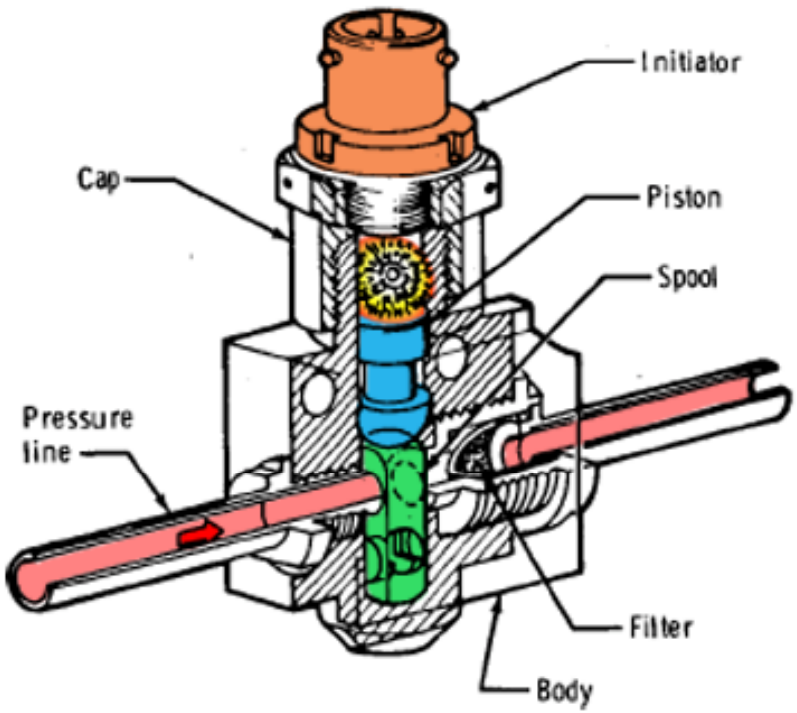
LM Landing-gear Uplock & Cutter Assembly

LM Pyrotechnically Operated Valves

- LM pyrotechnic valves operated instantaneously by firing self-contained explosive charges for valve functioning
- Upon firing, the valves remained open permanently
- Allowed descent propellant tank pressurization/venting, ascent propellant tank pressurization, & RCS propellant tank pressurization



Closed Position

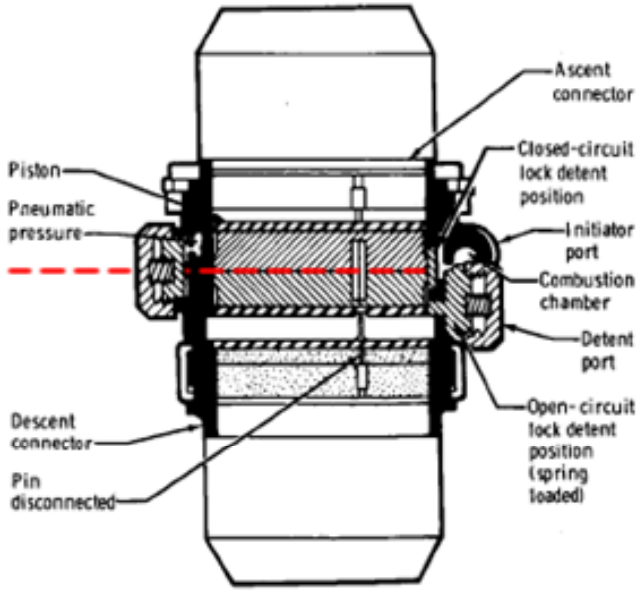


Open Position

LM Ascent Stage Pyrotechnic Separation

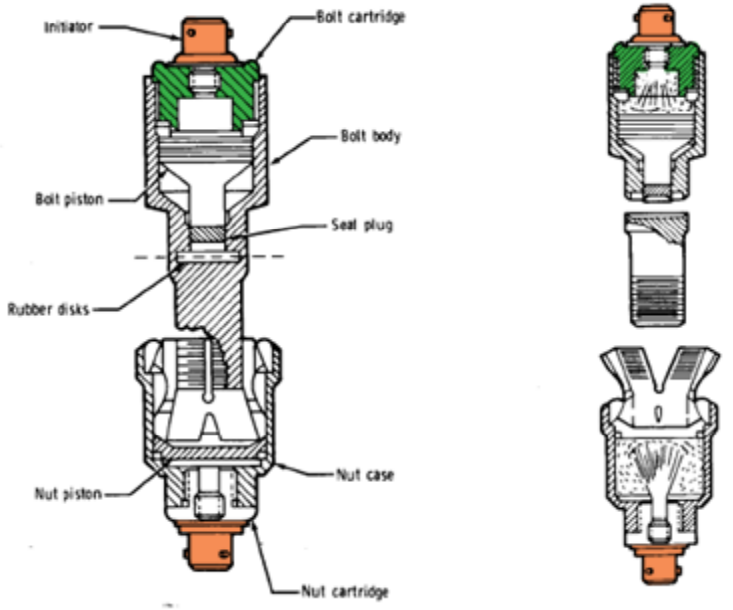
Separation of the LM ascent & descent stages has three steps (all involving pyrotechnics):

Step 1 - Break all interstage electrical circuits



LM Electrical Circuit Interrupter

Step 2 - Separate all four insterstage nuts & bolts



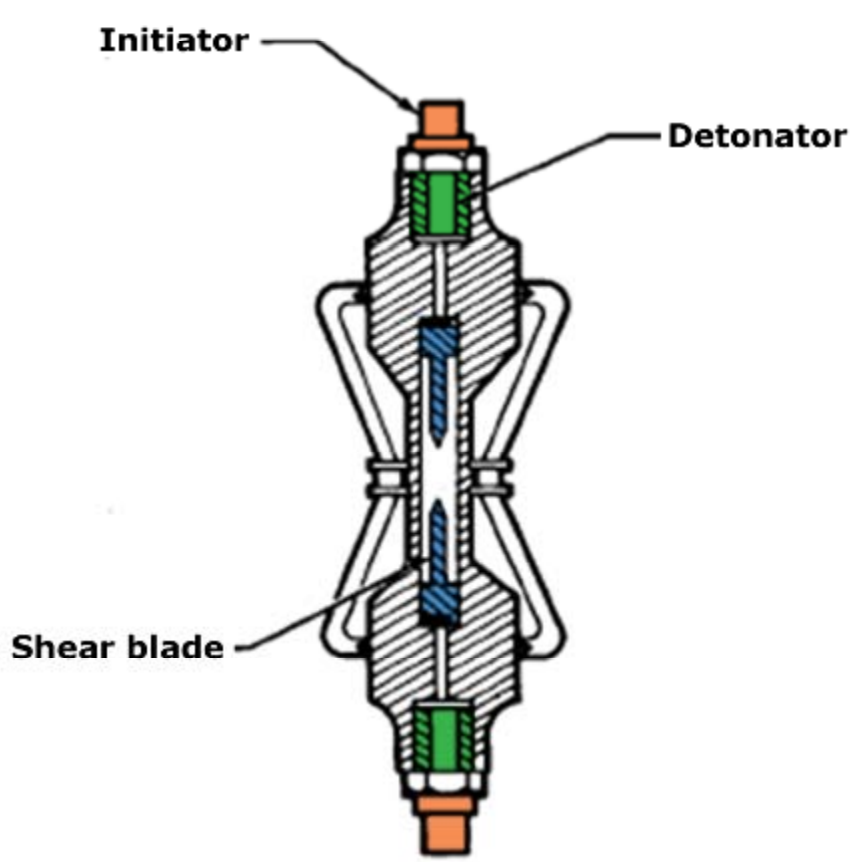
Before firing

After firing

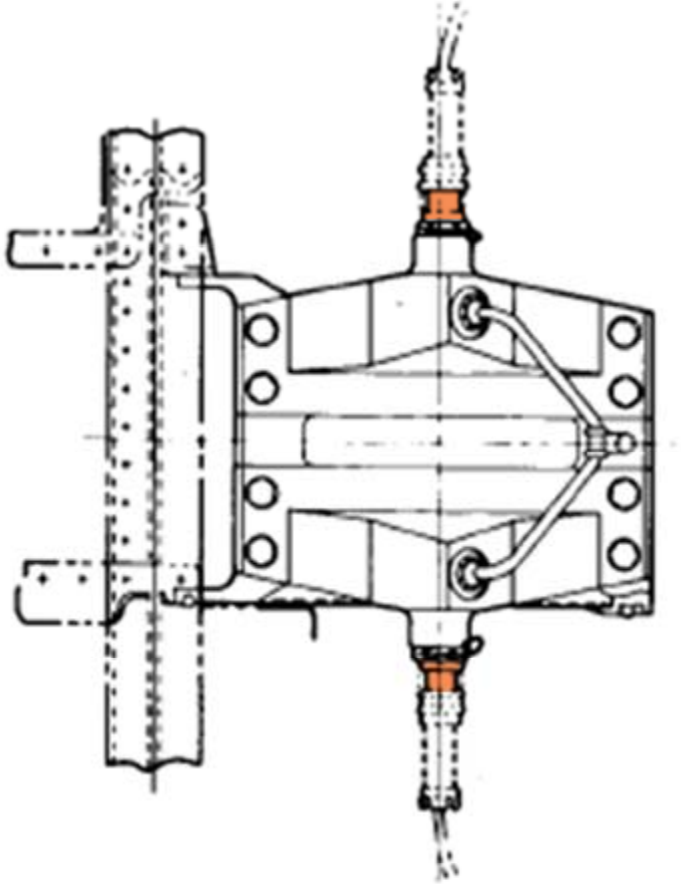
LM Interstage Nut & Bolt Assembly

LM Ascent Stage Pyrotechnic Separation, cont'd

Step 3 – Sever the umbilical and water line between the ascent & descent stages with the interstage umbilical guillotine



Cross Section

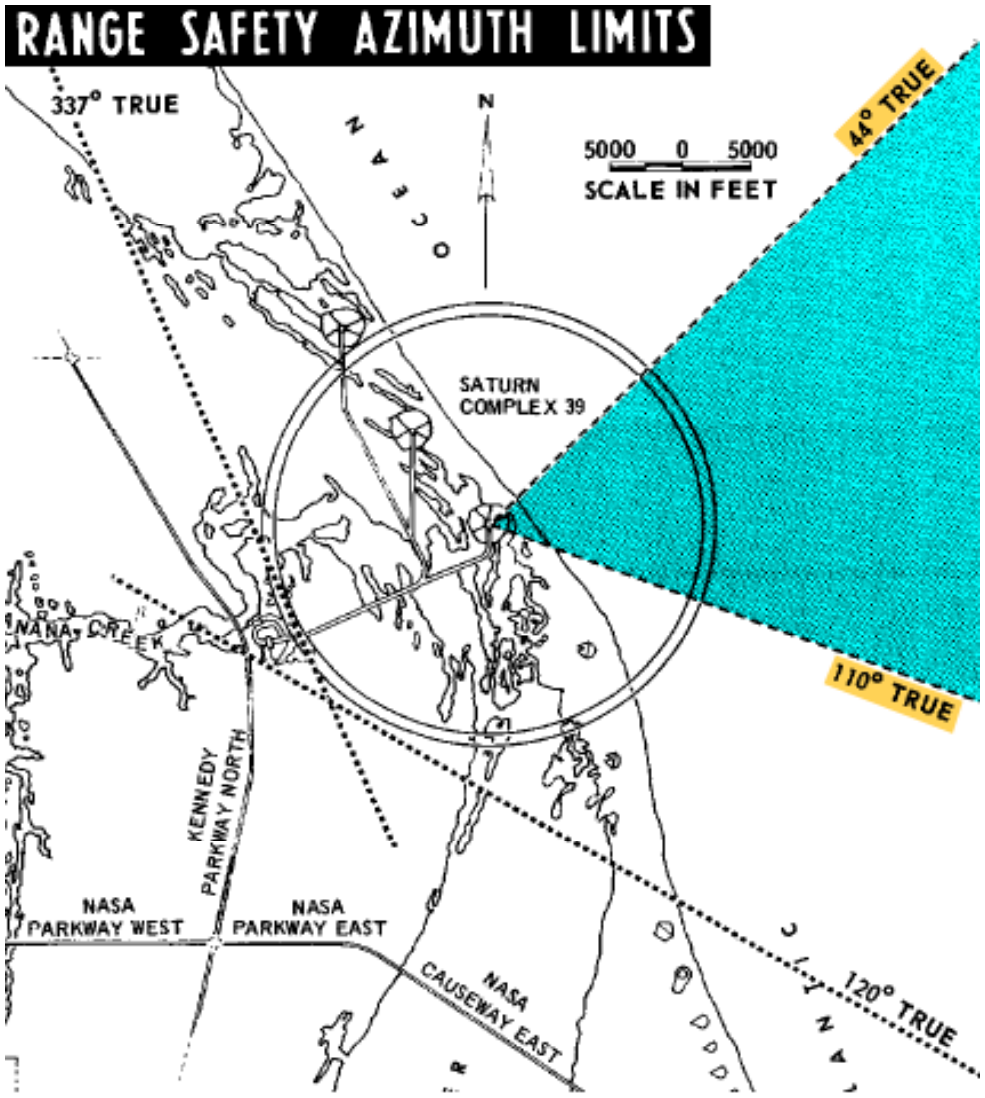


Installed

LM Interstage Umbilical Guillotine

Saturn V Pyro Systems

Saturn V Launch Vehicle Range Safety Operations

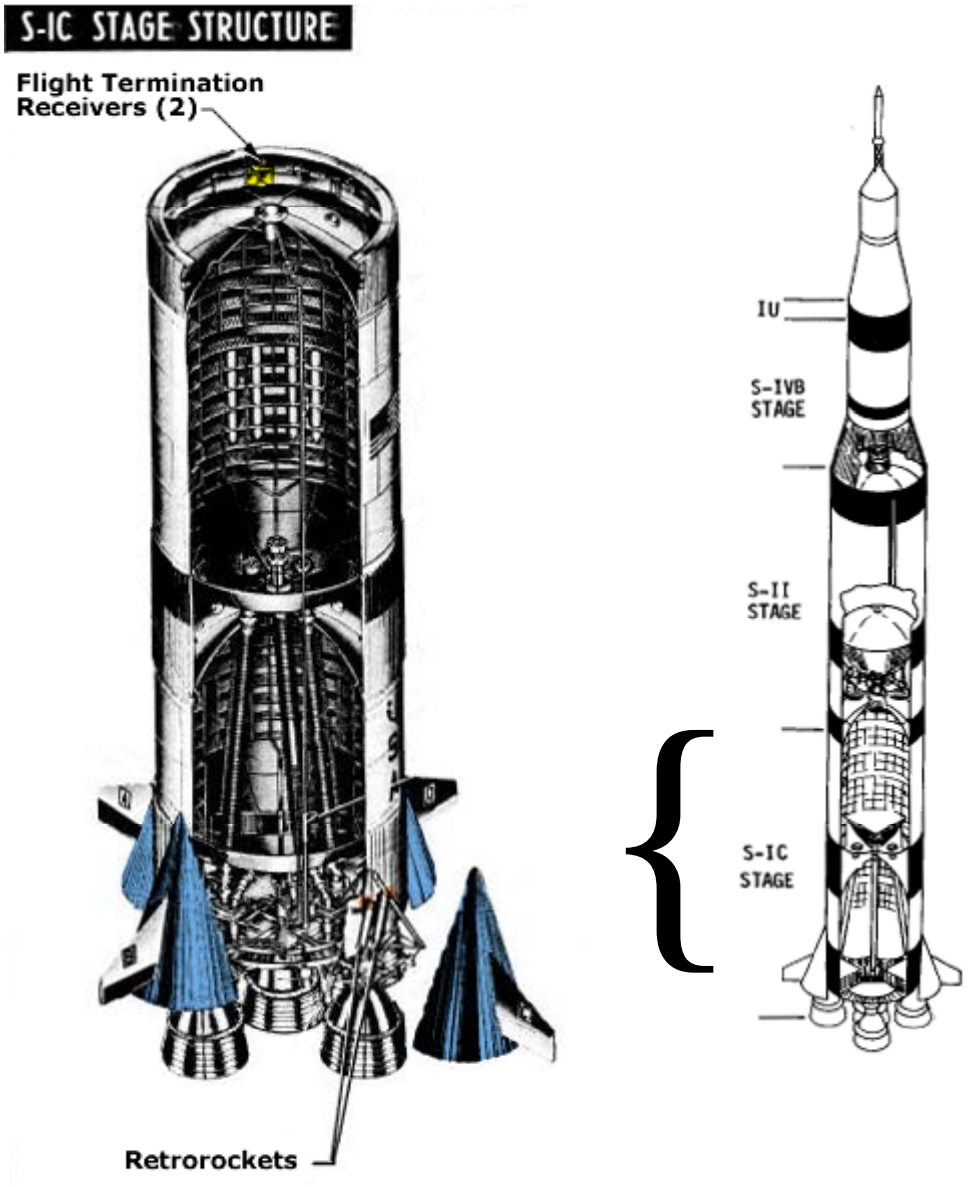


Air Force Eastern Test Range

- The Saturn V Launch Vehicle had a predetermined launch trajectory
- If it deviated from this trajectory, to the degree that it could endanger life or property (shown in the blue band)…
- The Range Safety Officer (RSO) would send a command to the vehicle's Propellant Dispersion System (PDS) to destroy the vehicle
- PDS is described per stage on the following slides
- This operation was never needed during the Apollo Program

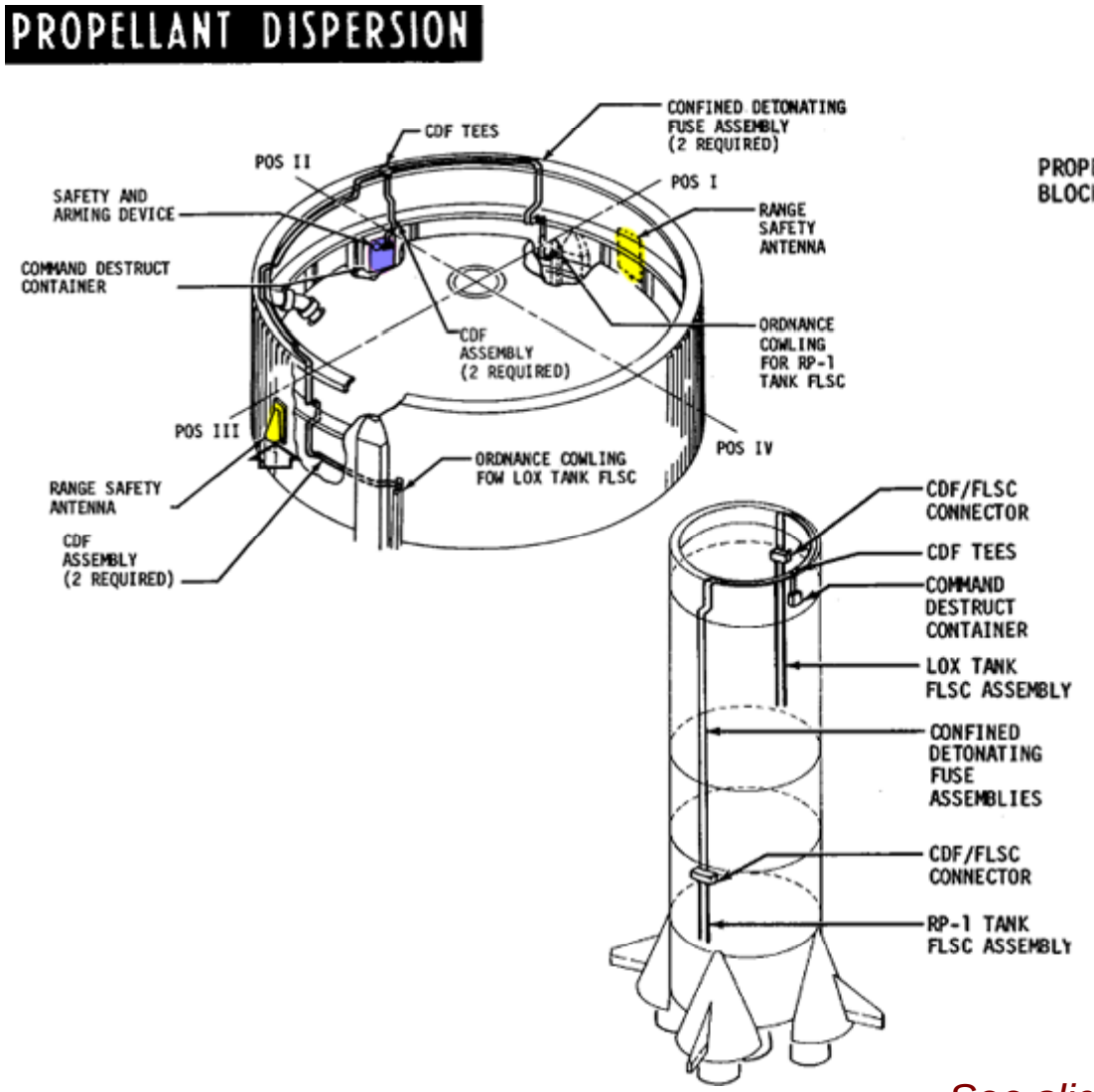
Stage S-IC Ordnance

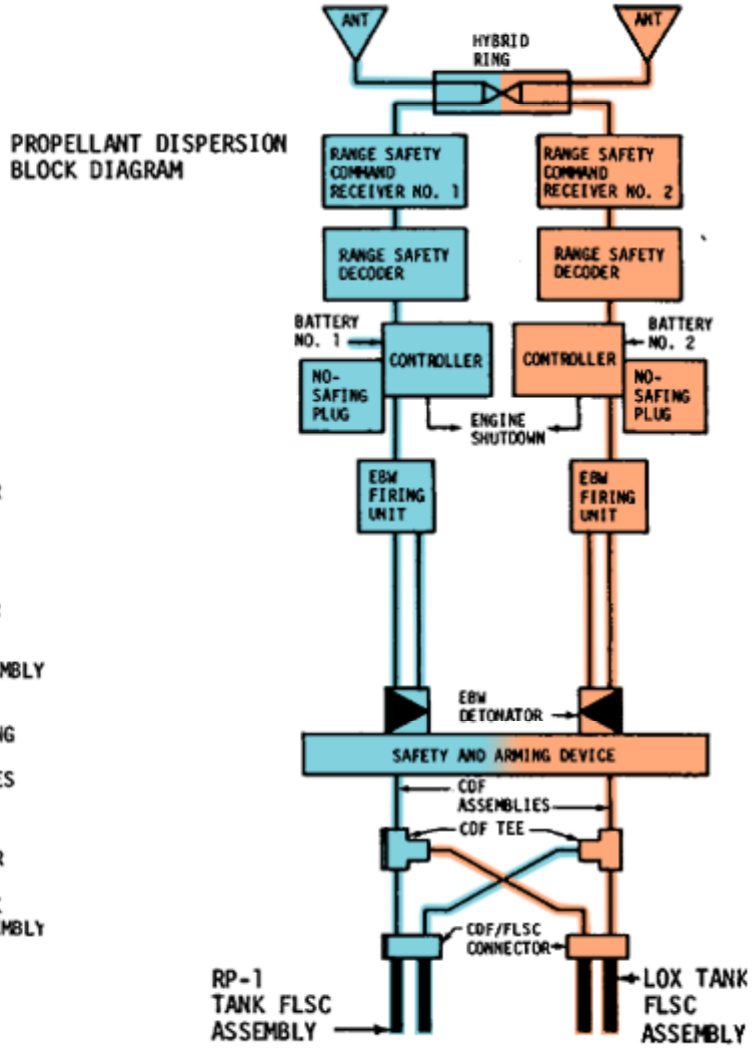
- **Stage S-IC (also called 1st Stage) had two pyrotechnic systems:**
  - **Propellant Dispersion System (PDS)** provided for flight termination (vehicle destruction) if the Launch Vehicle trajectory deviated beyond the prescribed limits of its flight path (previous slide)
  - **Retrorocket System** had 8 rockets to provide separation thrust (deceleration) after S-IC burnout to support staging to Stage II



Stage S-IC Ordnance

- **Stage S-IC Propellant Dispersion System (PDS) - Overview**

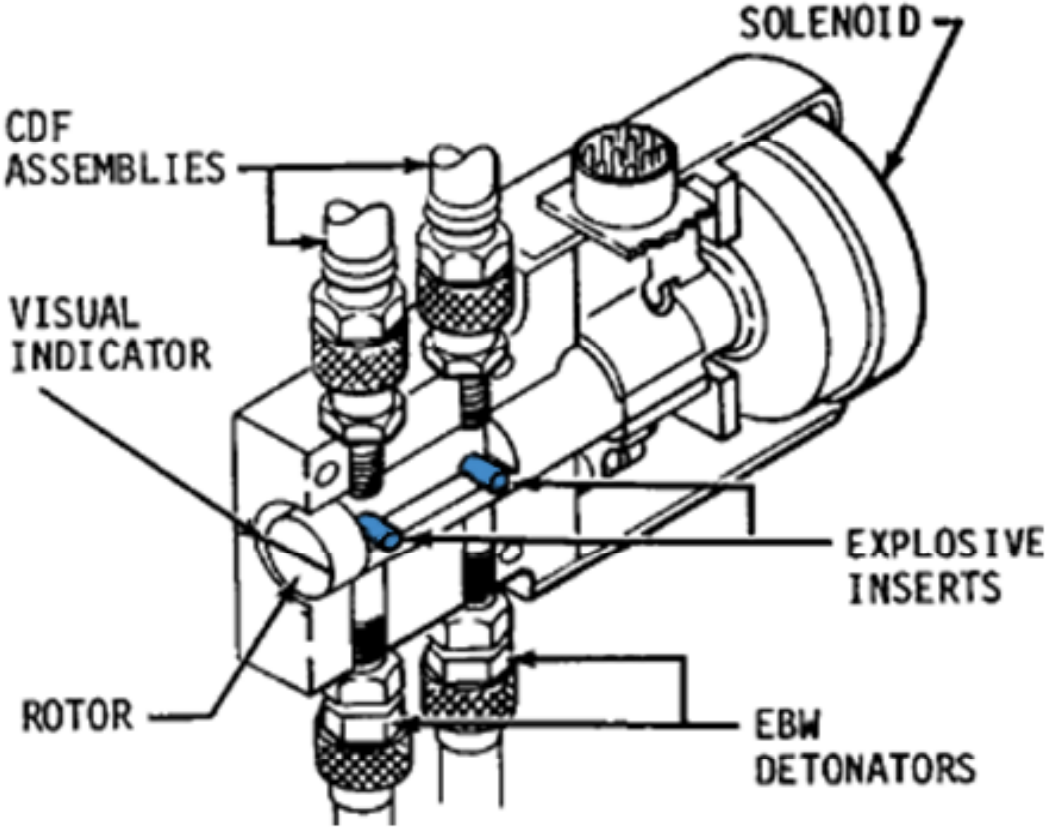




See slides under References for detail view

Stage S-IC Ordnance

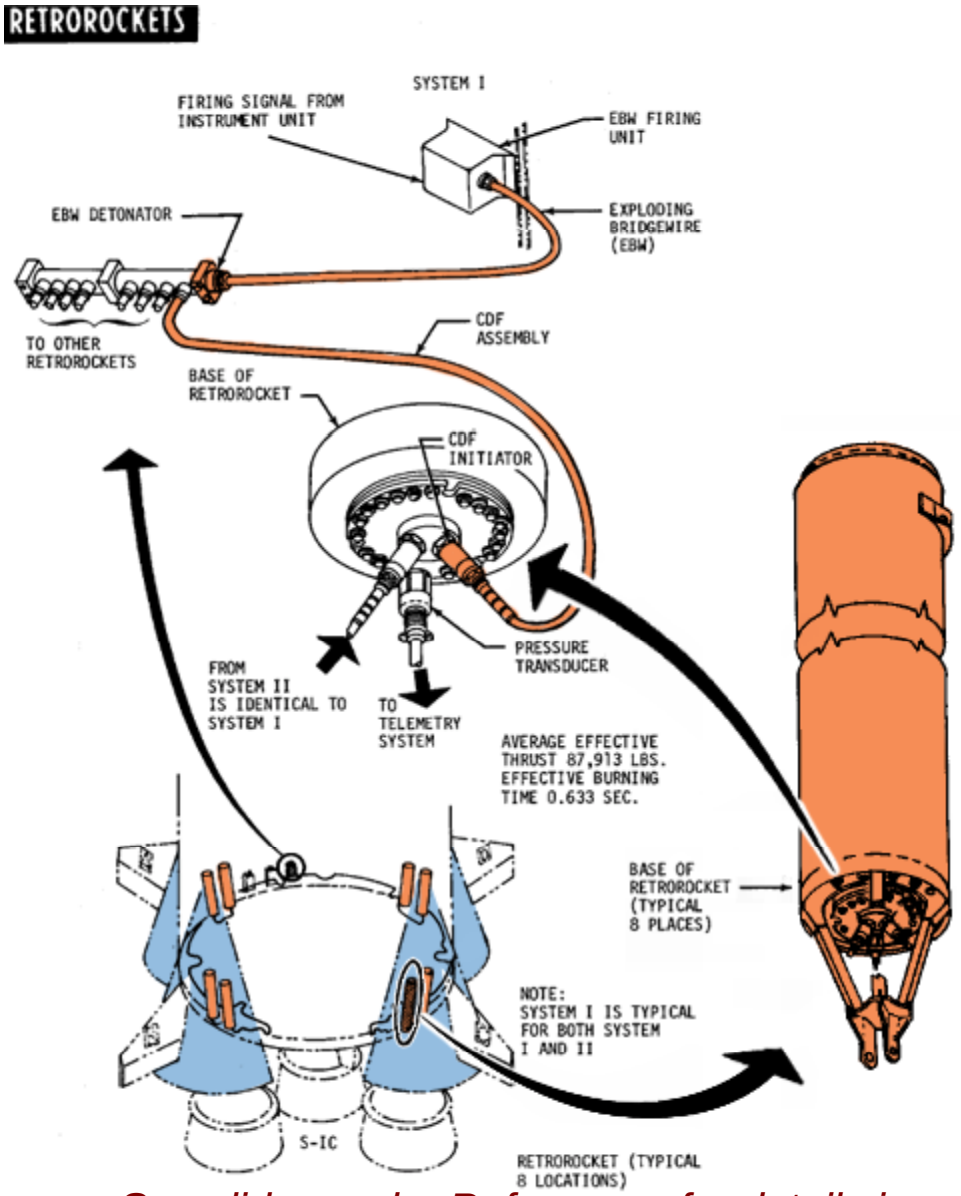
- **Safety & Arming Device – All Stages**
  - Serves as the arm portion of the “arm and fire” technique used for all critical commands to manned space vehicles
  - Used for all Saturn V Propellant Dispersion Systems (PDS) stages
  - The PDS is the system used to destroy the vehicle in case of trajectory diversion or other catastrophic event



Safety & Arming (S&A) Device

Stage S-IC Ordnance

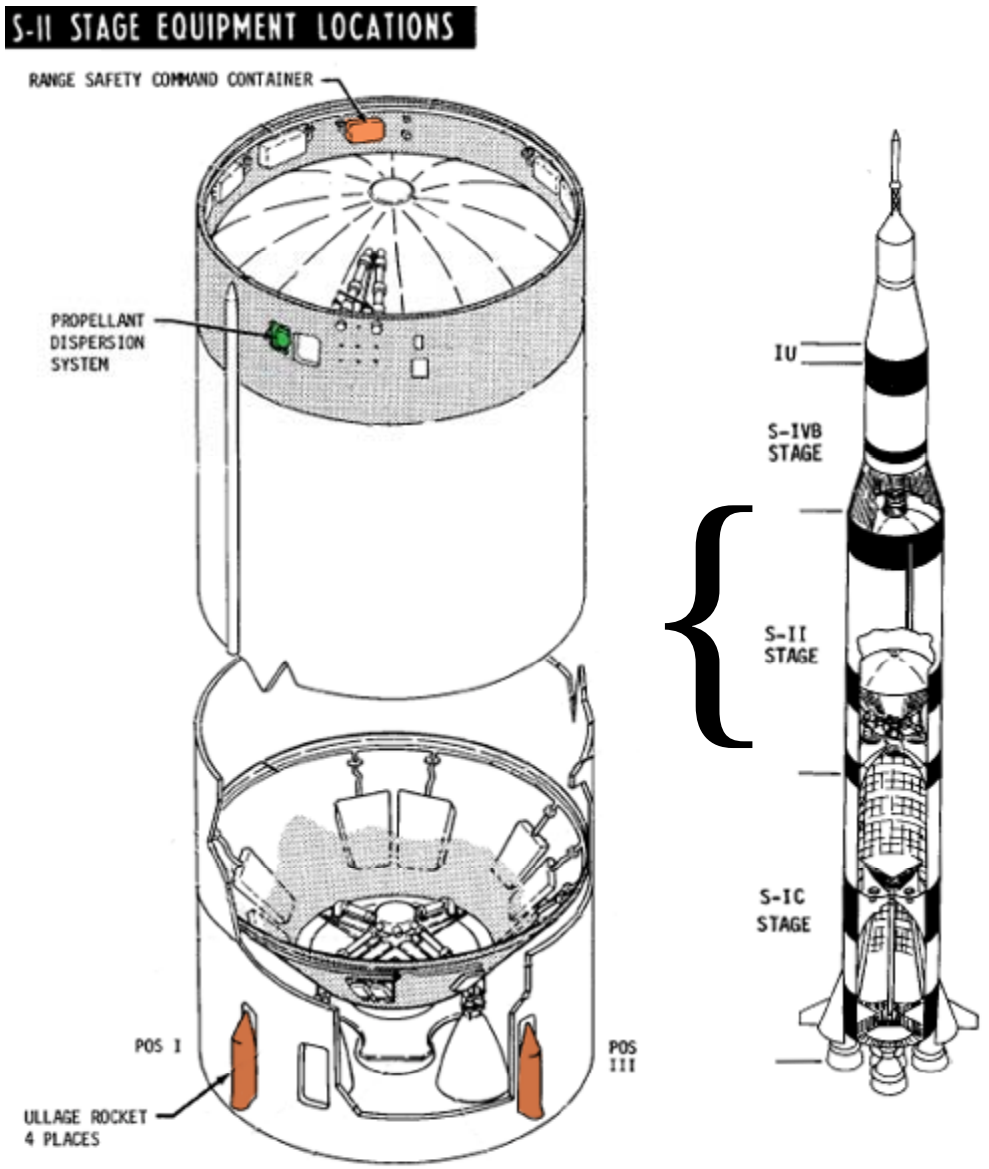
- **Stage S-IC Retrorockets**
  - The 8 retrorockets provide separation thrust after Stage S-IC burnout
  - Propels Stage S-IC away from the rest of the launch stack as it progresses to Stage II



See slides under References for detail view

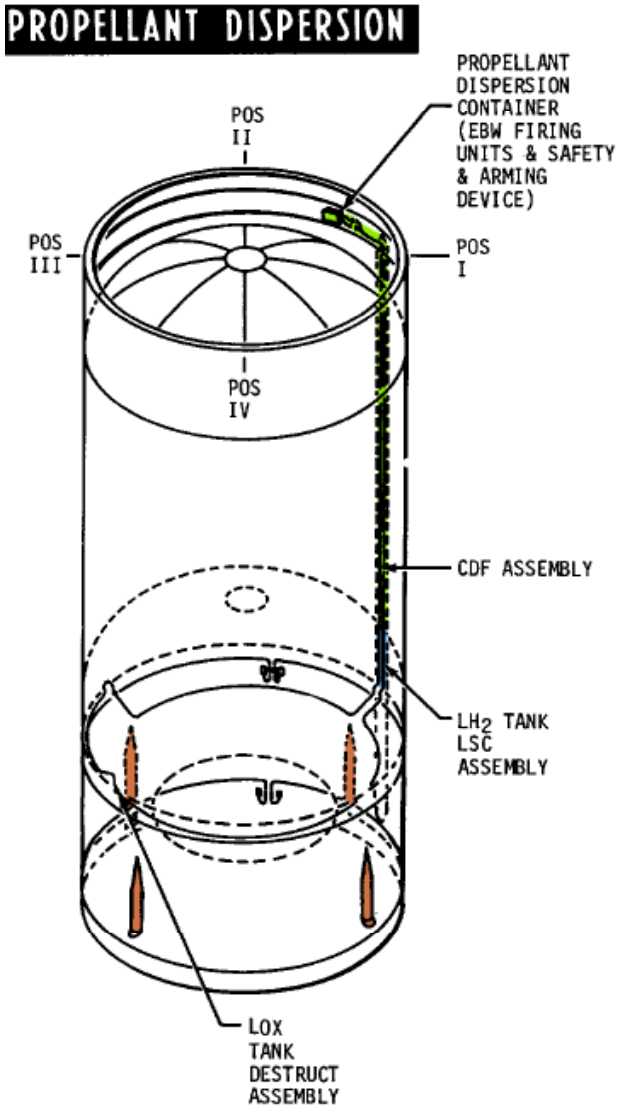
Stage S-II Ordnance

- **Stage S-II (also 2nd Stage) had four pyrotechnic systems:**
  - **Propellant Dispersion System (PDS)** provided for flight termination (vehicle destruction) if the Launch Vehicle trajectory deviated beyond the prescribed limits of its flight path (previous slide)
  - **Separation System** was a dual-plane separation system used to dead face umbilicals, interrupt electrical circuits, etc
  - **Retrorocket System** had 8 rockets to provide separation thrust (deceleration) after S-II burnout to support staging to Stage IV-B
  - **Ullage Rocket System** to ensure stable flow of propellants into the J-2 engines by providing a small forward acceleration to “settle” the propellants



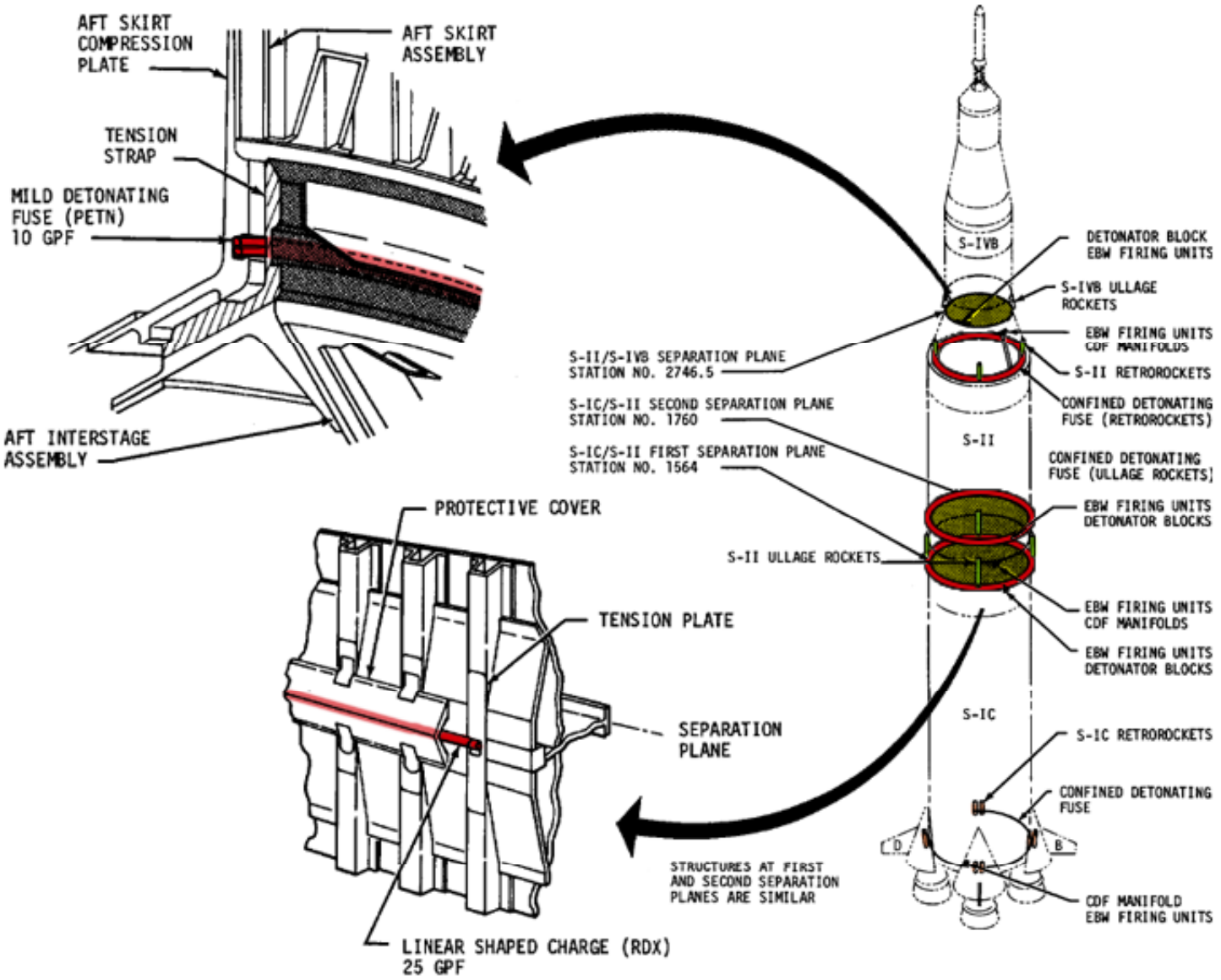
Stage S-II Ordnance

- **Stage S-II Propellant Dispersion System (PDS) - Overview**



Stage S-II Ordnance

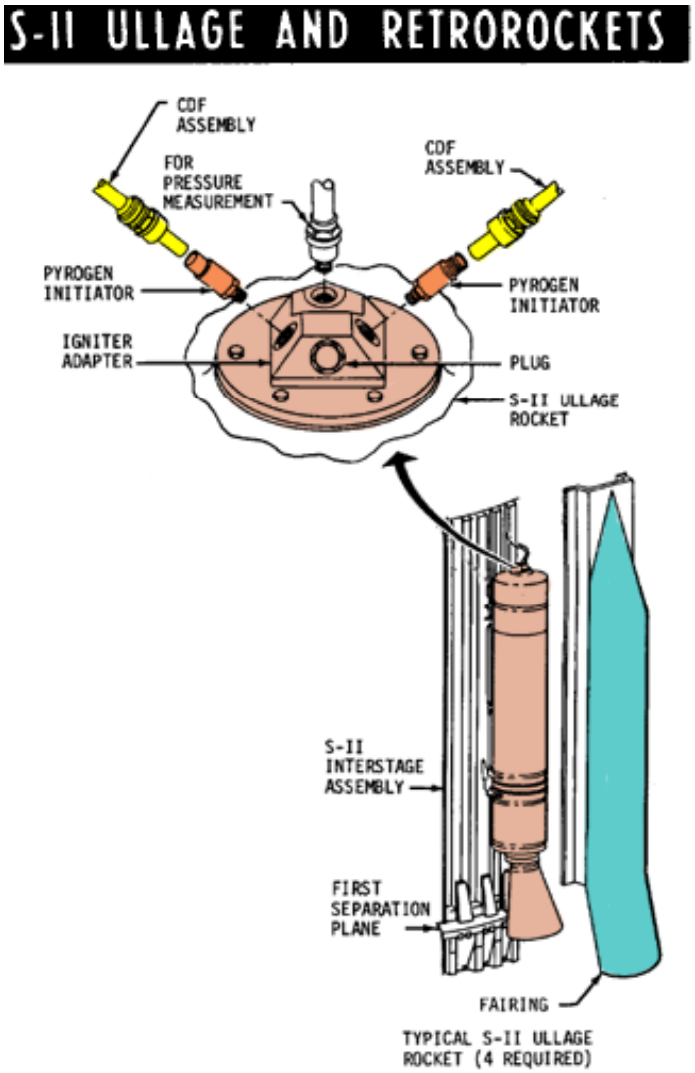
- **Stage S-II Separation Systems**



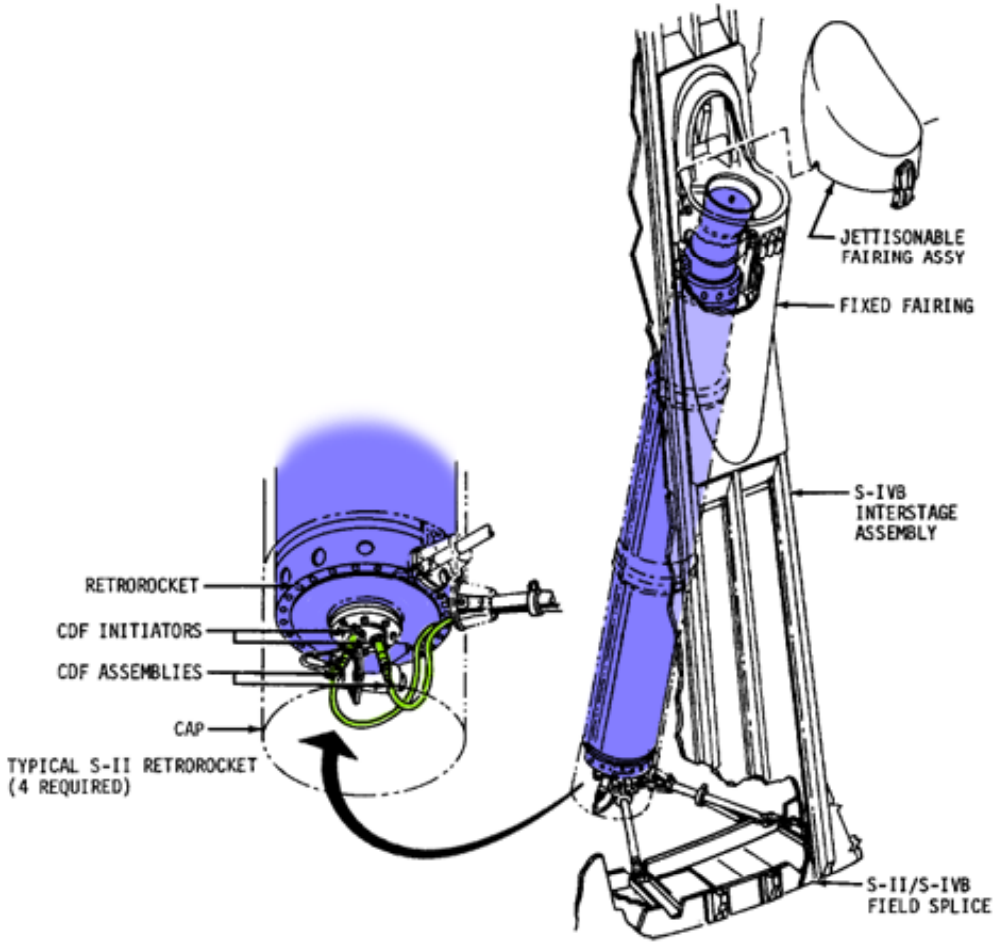
See slides under References for detail view

Stage S-II Ordnance

- Stage S-II Retrorockets and Ullage Systems



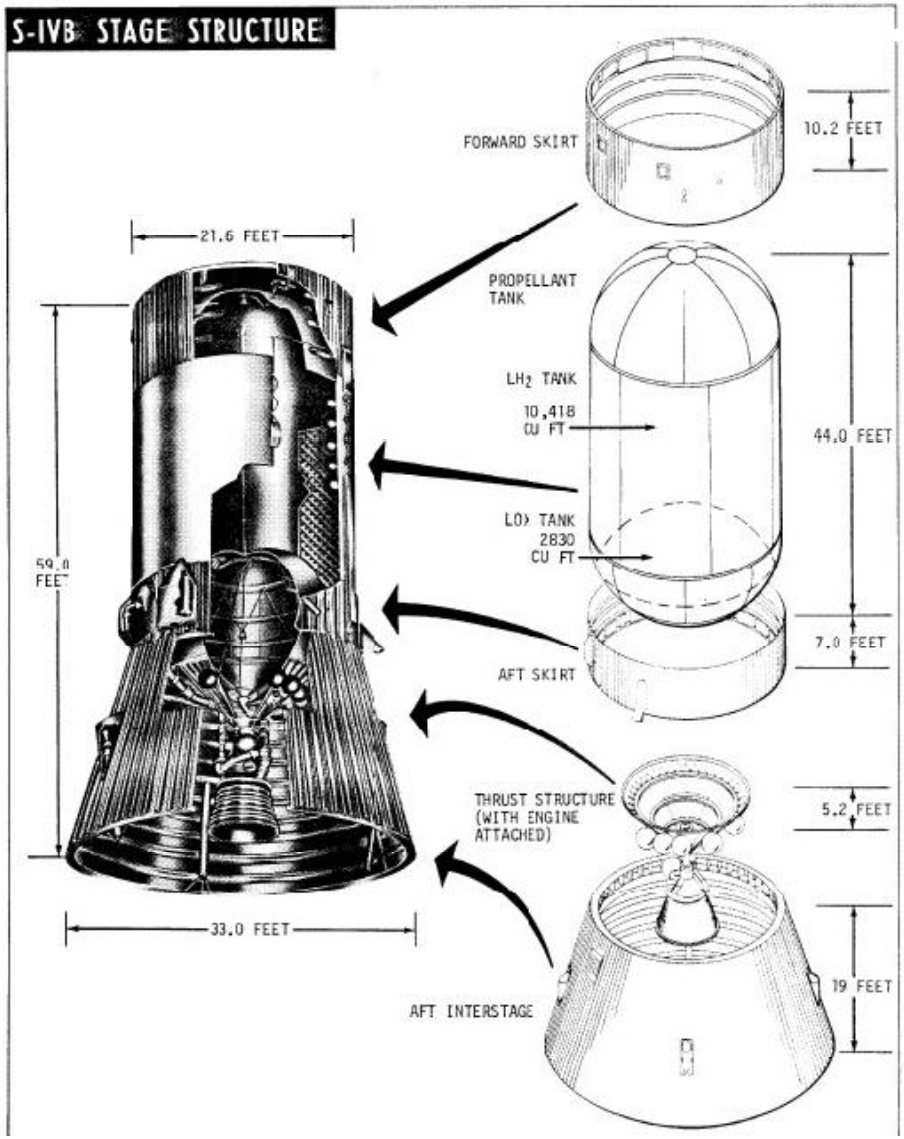
Stage S-II Retrorockets



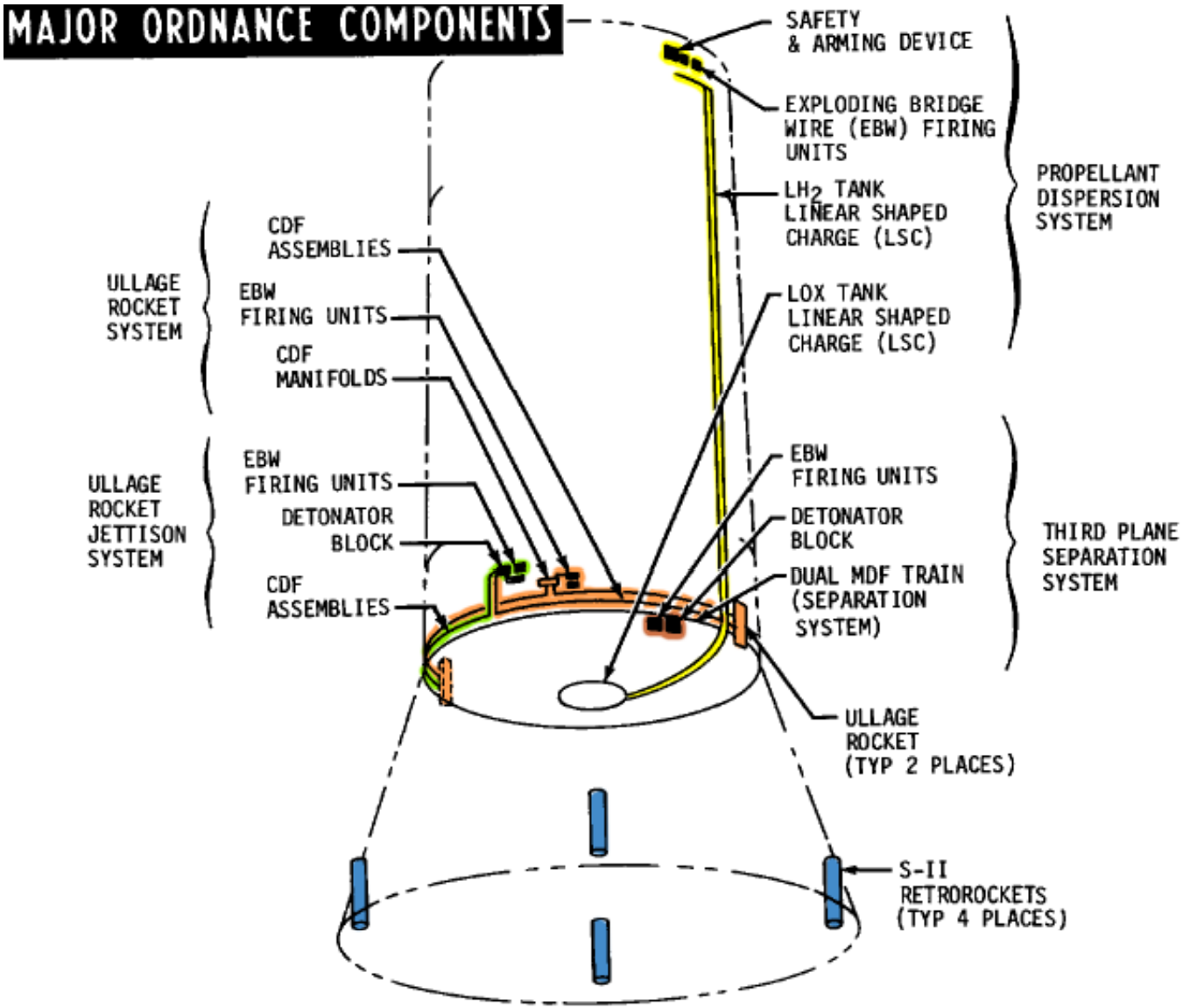
Stage S-II Ullage System

Stage S-IVB Ordnance

- **Stage S-IVB (also called 3rd Stage) had four pyrotechnic systems:**
  - **Propellant Dispersion System (PDS)** provided for flight termination (vehicle destruction) if the Launch Vehicle trajectory deviated beyond the prescribed limits of its flight path (previous slide)
  - **Separation System** was a single-plane separation system used to dead face umbilicals, interrupt electrical circuits, etc
  - **Ullage Rocket System** uses 2 ullage rockets during J2 engine start to ensure stable flow of propellants into the J-2 engine by providing a small forward acceleration to “settle” the propellants
  - **Ullage Rocket Jettison System** jettisons the 2 ullage rockets & fairings following the J2 engine start to reduce weight



Stage S-IVB Ordnance



Stage S-IVB Component Locations

Acronyms

Abbreviations & Acronyms

AFETR	Air Force Eastern Test range
ASD	Apollo Standard Detonator
ASI	Apollo Standard Initiator
CM	Command Module
CDC	Confined detonating cord
CDF	Confined Detonating Fuse
CSM	Command Service Module
EBW	Exploding Bridgewire
ED	Explosive Device
EDC	End Detonating Cartridge
EDS	Explosive Devices Subsystems
ELS	Earth Landing System
EMI	Electromagnetic interference
FLSC	Flexible linear shaped charge
HNS	Hexanitrostilbene
IU	Instrument Unit
LES	Launch-Escape System
LM	Lunar Module
LRD	Long Reach Detonator
LSC	Linear-shaped charge
LVDC	Launch Vehicle Digital Computer
MDF	Mild detonating fuse
NSI	NASA Standard Initiator
PDS	Propellant Dispersion System
PIC	Pyrotechnic Initiator Controller
RDX	Cylotrimethylenetrinitramine
RFI	Radio frequency interference
RSO	Range Safety Officer
S&A	Safety & Arming Device
SBASI	Single bridgewire Apollo standard initiator
SLA	Spacecraft/Lunar Module Adaptor
SM	Service Module
ZPP	Zirconium-potassium perchlorate

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