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)
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.
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 Diagram](image)
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
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 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 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).
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

![Diagram of Mild detonating fuse](image1)
![Diagram of Confined detonating cord](image2)
![Diagram of Linear-shaped charge](image3)
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)
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
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
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 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
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

**Step 2** - Separate all four interstage nuts & bolts
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](image1)

**Cross Section**

![Installed](image2)

**Installed**

LM Interstage Umbilical Guillotine
Saturn V Pyro Systems
Saturn V Launch Vehicle Range Safety Operations

- 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 (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 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 (also 2\textsuperscript{nd} 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 Separation Systems

See slides under References for detail view
Stage S-II Ordnance

- Stage S-II Retrorockets and Ullage Systems

**S-II Ullage and Retrorockets**

Stage S-II Retrorockets

Stage S-II Ullage System
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
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<th>Acronym</th>
<th>Description</th>
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<th>Description</th>
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<tr>
<td>AFETR</td>
<td>Air Force Eastern Test range</td>
<td>LM</td>
<td>Lunar Module</td>
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<tr>
<td>ASD</td>
<td>Apollo Standard Detonator</td>
<td>LRD</td>
<td>Long Reach Detonator</td>
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<tr>
<td>ASI</td>
<td>Apollo Standard Initiator</td>
<td>LSC</td>
<td>Linear-shaped charge</td>
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<td>CM</td>
<td>Command Module</td>
<td>LVDC</td>
<td>Launch Vehicle Digital Computer</td>
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<td>CDC</td>
<td>Confined detonating cord</td>
<td>MDF</td>
<td>Mild detonating fuse</td>
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<td>CDF</td>
<td>Confined Detonating Fuse</td>
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<td>Command Service Module</td>
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<td>Exploding Bridgewire</td>
<td>PIC</td>
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<td>ED</td>
<td>Explosive Device</td>
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<td>End Detonating Cartridge</td>
<td>RFI</td>
<td>Radio frequency interference</td>
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<td>Hexanitrostilbene</td>
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<td>Service Module</td>
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<td>Instrument Unit</td>
<td>ZPP</td>
<td>Zirconium-potassium perchlorate</td>
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<td>LES</td>
<td>Launch-Escape System</td>
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