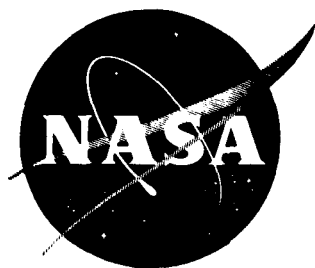


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APOLLO SPACECRAFT PYROTECHNICS

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APOLLO SPACECRAFT PYROTECHNICS

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INTRODUCTION

At the Third Electroexplosive Device (EED) Symposium in Philadelphia in 1963, the author presented a paper entitled "The Apollo Standard Initiator (ASI)." That paper described a modular-cartridge concept using a standard EED which was being adopted for the Apollo spacecraft. Concepts also were presented for the postmanufacture indexing of the initiator, for the anticipated application of pyrotechnic devices to spacecraft functions, and for a computerized data collection storage analysis system.

The pyrotechnic devices and their functions in the Apollo spacecraft on a lunar landing mission (fig. 1) are described in this paper. During the past 6 years, all pyrotechnic devices and systems have been tested extensively on the ground, in unmanned flights, and in manned flights. The last flight test objectives of the pyrotechnics were completed successfully subsequent to the Apollo 10 mission in May 1969.

The term Apollo Standard Initiator (ASI) was applied originally both to the concept of a standard EED for Apollo spacecraft and to the hardware, a specific dual-bridgewire initiator. Subsequently, a single-bridgewire initiator was developed and now is the standard device on the spacecraft; the dual-bridgewire unit is now obsolete in the Apollo program. Therefore, "Apollo Standard Initiator," or "ASI," now represent

the concept, and "Single-Bridgewire Apollo Standard Initiator," or "SBASI," describe the hardware.

Other words and abbreviations used in this paper are clarified below.

1. "Pyrotechnics" is synonymous with "explosive" and "ordnance" (pyrotechnic device).
2. "Explosive" includes both detonating and deflagrating materials. "High explosive" and "propellant" are used to differentiate between the two types of materials, when necessary.
3. "Redundant" is used in the sense of "dual" rather than "superfluous."
4. "Spacecraft" (S/C) (fig. 2) includes the following:
 - a. The command and service modules (CSM), which are abbreviated command module (CM) and service module (SM)
 - b. The lunar module (LM)
 - c. The spacecraft/lunar module adapter (SLA)
5. The Saturn IVB (S-IVB) is the third stage of the launch vehicle (LV) which inserts the spacecraft into translunar trajectory.

GENERAL

The Apollo spacecraft and SLA incorporate over 210 explosively loaded devices (including 143 electrically initiated cartridges of 19 different types) in the most complex pyrotechnic system ever used on any flight vehicle.

Most functions performed by spacecraft pyrotechnics are classified as "crew critical," because premature operation of the pyrotechnics or the failure of the pyrotechnics to operate properly could result in loss of the crew. The few remaining functions are, similarly, "mission critical;" that is, failure could result in an aborted mission or in an alternate mission. The high criticality assigned to spacecraft pyrotechnic functions dictated maximum redundancy in pyrotechnic systems and devices (fig. 3). Where practicable, completely redundant systems or devices are used, as in the apex-cover jettison system. Where completely redundant systems are not possible because of space or weight limitations, redundant cartridges are used, as in the canard thruster. Next in order of desirability is a single cartridge with dual initiators, as in the parachute-riser guillotines. The original dual-bridgewire initiator was developed to provide an additional back-out step, a single initiator with dual bridgewires interfacing the same explosive charge.

The electrical circuitry and associated control components, including the batteries that supply power for logic and firing, are redundant. The pyrotechnic batteries and circuits are used only for pyrotechnic system firing and control. Firing circuits A and B are completely independent and are electrically and physically isolated from each other and from all other spacecraft circuitry. Logic circuits A and B are similar, except in the earth-landing system where additional redundancy is required. In the earth-landing system, although the logic relay contacts are electrically isolated, the relay coils A and B are interconnected so that both contacts are pulled in by either logic A or logic B. This system circumvents a single-point failure in either logic system without compromising the isolation of the firing circuitry.

Early in the Apollo program, the NASA Manned Spacecraft Center (MSC) adopted the concept of modular cartridge assemblies, based on a standardized hot-wire initiator. Whenever possible, this standardization principle has been extended to cartridge assemblies at significant cost and time savings. In addition, the adoption of the modular-cartridge concept has enhanced confidence and reliability of these common components/assemblies through increased testing and use (fig. 4). Components, subassemblies and assemblies were qualified serially (that is, first the EED, then each cartridge, then each higher assembly, and so forth) to complete systems.

Because the most critical area in any EED is the electroexplosive interface, a common interface that is tested in a number of devices increases the confidence in all devices using the interface. The SBASI provides such an interface in a form that can be tested as a separate unit then tested again and again in higher devices, assemblies and systems. In addition, because of the necessity to develop and qualify only one EED, it was possible to test and understand more thoroughly the characteristics of that device than would have been possible if a number of different devices had been developed for the spacecraft.

Noninterchangeability of special-purpose cartridges is ensured by using different threads on the output ends and by using on the connector a unique postmanufacture indexing technique which provides for special keyway combinations. The indexing technique is covered by NASA-owned U.S. Patent 3,287,031 and is available on a royalty-free, nonexclusive license basis for commercial use. The technique can be used also on other nonpyrotechnic electrical connectors.

A family of special shielded connectors, which mate with the various SBASI configurations and provide radiofrequency shield continuity, were developed for

the Apollo pyrotechnic systems. On the Apollo spacecraft, these connectors are reserved for use on pyrotechnic circuits to prevent misconnection with other electrical circuitry.

In instances where the common use of hardware was not feasible, common technology was used. For example, the opposing-blade guillotine which severs the CM-SM umbilical (fig. 5) was the basis for the designs of the LM interstage guillotine, of two guillotines for umbilicals between the LM and SLA, and of the LM landing-gear uplock cutter.

To ensure consistent quality and traceability of high-explosive materials, only newly manufactured RDX and HNS high explosives are used. These bulk explosives are government-furnished material. RDX is supplied to NASA by the Army, and HNS is supplied by the Navy. The materials are shipped directly to the using supplier of explosive assemblies upon request to MSC by North American Rockwell and Grumman Aircraft Engineering Corporation.

Neutron radiography (N-ray) is a relatively new technique used to ensure high quality of assemblies. In a number of instances, such as examining the explosive core in a mild detonating fuse (MDF) for discontinuities, this technique is superior to X-ray. The relative opacity of the lead sheath and of the explosive core to thermal neutrons is the reverse of that with X-rays. However, the advantage is lost when the MDF is bonded into a charge holder with a hydrogenous material such as epoxy. Therefore, the N-ray technique is applied selectively to Apollo pyrotechnics to supplement X-rays where appropriate.

All lots of all explosively loaded components and assemblies are non-destructively tested and inspected on a 100-percent basis. The lots then are sampled at random for destructive testing at each level of assembly. In addition, one unit from each lot of each device to be installed on a spacecraft is

fired at the Kennedy Space Center before each flight to ensure that there has been no deterioration caused by shipping, handling, or storage subsequent to lot acceptance.

The Apollo Pyrotechnic Data System (APDS) was established to collect and analyze data on the spacecraft pyrotechnics. The system uses the computer complex at MSC and is now being modified to increase the capabilities. When fully operational, the APDS will be capable of storing and analyzing data pertaining to the logistics, quality, and engineering aspects of all Apollo devices by serialized parts, by lots, and by total population.

The inputs to the computer system are reports submitted on MSC Form 1275 by all Government and Contractor activities which manufacture, test, ship, install, or handle Apollo pyrotechnic devices. Each report identifies the reported devices by part, lot, and serial number. Parametric data on performance and tests are reportable, as are shipping destinations, receiving inspections, allocation to specific spacecraft, and so forth.

A typical logistics study from the stored data could be a printout of the location of every cartridge in existence; such a report could be used to locate all units of a specific lot to provide a basis for additional procurement or to "freeze" a lot pending investigation of an anomaly related to that lot or part. Engineering studies of specific performance parameters can be made to investigate lot-to-lot variations and trends.

PYROTECHNIC FUNCTIONS ON A NORMAL MISSION

Pyrotechnic devices perform many and varied functions on a spacecraft. A total of 218 explosively loaded parts, including 143 cartridges, are installed on each spacecraft. The first pyrotechnic function in a normal mission, jettison of the launch escape system (LES), occurs approximately 3 minutes after launch, and the last pyrotechnic function, main parachute disconnect, occurs after splashdown. The pyrotechnic devices and locations in the spacecraft are shown in figure 6. In this paper, the devices are discussed first as used in a normal lunar landing mission (fig. 1) and then as used in aborted missions.

Launch Escape System (LES) Jettison

In a normal mission, the LES is not used and is jettisoned immediately after second-stage booster (S-II) ignition (fig. 7). Simultaneously with ignition of the tower-jettison motor by dual igniter cartridges, a frangible nut in the base of each tower leg (used to secure the tower to the command module structure) is fractured by dual detonators (fig. 8).

CSM-Launch Vehicle Separation

The next pyrotechnic event, CSM separation from the launch vehicle, occurs after translunar injection by the third (S-IVB) stage of the launch vehicle (fig. 9). The four SLA panels are separated by redundant explosive trains on the forward, aft, and inner and outer longitudinal splice plates (fig. 10). Pyrotechnic thrusters powered by dual cartridges rotate each panel outwardly around a center hinge. After a rotation of approximately 45° , the panel hinges separate and spring thrusters jettison the panel. At the time of splice-plate separation, a

high-explosive-operated guillotine severs an umbilical between the LM and one SLA panel, a spring reel then retracts the umbilical arm to the panel for jettison with the panel, and a high-explosive charge in a frangible-link disconnect separates the SM-SLA umbilical just aft of the SM. The entire system is explosively interconnected, with dual detonators initiating the separation trains and confined detonating cords connecting these trains to the SM-SLA umbilical disconnect and to the LM-SLA guillotine.

LM-SLA Separation

After separation from the S-IVB, the CSM returns and docks with the LM, an electrical umbilical is attached to the LM separation firing circuits through the docking interface, and the four frangible links that attach the LM to the fixed portion of the SLA are fired (figs. 11 and 12). Because the detonators in the links are located on the SLA side of the LM-SLA interface, a high-explosive guillotine severs this umbilical bundle 30 milliseconds after the frangible-link detonators are fired.

LM Pyrotechnics

All LM pyrotechnic functions occur during the next phases of the mission which involve lunar descent, landing, and ascent. The LM devices and locations are shown in figure 13. The relatively new explosive hexanitrostilbene (HNS) is used in all LM high-explosive devices and in the docking ring separation system of the CM. In all other CSM and SLA high-explosive applications, cyclotrimethylene trinitramine (RDX) is used because, at the time of initial system development, relatively little information on HNS was available and the supply of HNS was limited.

LM Landing Gear Deployment

In lunar orbit and prior to separation of the LM from the CSM, the LM landing gear is deployed by firing guillotines (fig. 14) which sever tension straps that hold the gear in the retracted position. When the straps are severed, springs deploy the gear to the downlocked position.

LM Main Propulsion and Reaction Control Systems

(MPS and RCS) Pressurization

A number of normally closed explosive valves (fig. 15) are used in the LM main propulsion system and in the reaction control system (RCS). The valves pressurize propellant tanks by opening the lines to ambient and supercritical helium storage vessels, provide for propellant tank venting, and perform compatibility functions. The valves are used singly or in pairs, depending on their function; redundant cartridges are used when valves are not redundant. A total of 16 valves and 22 cartridges are used for these functions.

The explosive valves in the descent propulsion system (DPS) and in the RCS are functioned and the systems are checked out prior to undocking of the LM for descent to the lunar surface. The valves in the ascent propulsion system (APS) are fired during preparation for launch from the lunar surface.

LM Staging

On the lunar surface and prior to launch of the ascent stage, the LM stages are separated by an explosive nut and bolt (fig. 16) at each structural attachment point. The interstage electrical circuits are deadfaced by two electrical-circuit interrupters (fig. 17), and the interstage umbilical (electrical and fluid lines) is severed by a guillotine (fig. 18).

In an abort during descent to the lunar surface, actuation of the "Abort Stage" switch initiates the staging and the pressurization of the ascent section of the main propulsion system in an electrically timed sequence, the descent stage is jettisoned, and the ascent stage then returns to lunar orbit to rendezvous with the CM.

LM Jettison

After rendezvous, docking, and LM crew transfer to the CM in lunar orbit, the LM is jettisoned by severing the docking-tunnel structure with redundant explosive trains (fig. 19). The docking-ring separation charges and associated long-reach detonators are the only CSM devices which use HNS high explosive.

CM-SM Separation and SM Jettison

Before the spacecraft enters the atmosphere of the earth at approximately 400 000 feet, the CM RCS propellant tanks are pressurized by helium which is released by explosive valves of the same configuration as that shown in figure 15. By using the RCS, the crew then orients the CSM to separation attitude. At separation (fig. 20), the critical electrical circuits between the CM and the SM are deadfaced by electrical-circuit interrupters (fig. 21), the CM-SM umbilical is severed by a high-explosive-operated guillotine (fig. 5), and structural separation is accomplished by dual linear-shaped charges (fig. 22) on each of the three tension ties between the modules. The SM backs away from the CM using the +X thrusters of the SM RCS.

Earth Landing System (ELS) Operation

Approximately 8 minutes after atmospheric entry (fig. 23), the spacecraft has descended to approximately 24 000 feet where the CM apex cover is jettisoned by a redundant thruster system (fig. 24). As the cover separates from the CM, a lanyard-operated switch fires a drag parachute mortar in the cover. The parachute prevents the cover from recontacting the CM or interfering with drogue parachute deployment.

Two seconds after cover jettison, the two reefed drogue parachutes are deployed by mortars (fig. 25). At "line stretch," the time-delay reefing-line cutters in each parachute (fig. 26) are actuated and disreef the drogues 10 seconds later.

Approximately 40 seconds after deployment, the drogues are disconnected by severing the risers with propellant-gas-operated guillotines (fig. 27) and the three pilot parachutes are deployed simultaneously by mortars (fig. 25). The pilot parachutes deploy the main parachutes, which inflate to a full-reefed condition. Main parachute riser deployment actuates six 8-second-delay line cutters which release spring-loaded deployment mechanisms on two VHF antennas and on a flashing beacon light to assist in recovery operations. At line stretch of the main parachutes, four 6-second and two 10-second-delay reefing-line cutters are actuated on each parachute, effecting disreef in two stages to lower the inflation shock loading on the parachutes.

Immediately after splashdown, the three main parachutes are disconnected by guillotines in the parachute disconnect assembly (the "flowerpot") (fig. 27).

PYROTECHNIC FUNCTIONS FOR ABORTS

Missions may be aborted at any time. However, special pyrotechnic functions or sequences are involved only in the aborts occurring between crew insertion (man-ning of the spacecraft on the pad) and orbital insertion of the spacecraft. Aborts from the launch pad and at low altitudes require highly complex sequences of pyro-technic events; the combination and sequence of events are functions of altitude. To minimize risk to the crew, onboard automatic control, onboard manual control, and ground control of abort initiation is provided.

From the pad to approximately 30 000 feet (fig. 28), abort begins with the following essentially simultaneous pyrotechnic functions ($T = 0$).

1. CM-SM electrical circuit deadfacing (four circuit interrupters)
2. CM RCS propellant pressurization (four explosive valves)
3. CM RCS helium, fuel, and oxidizer interconnects (four explosive valves)
4. CM RCS oxidizer dump (two explosive valves)
5. CM-SM structural separation (three dual linear-shaped charges)
6. CM-SM umbilical separation (one guillotine)
7. Launch escape motor ignition (two cartridges)
8. Pitch control motor ignition (two cartridges)

At $T + 5$ seconds, the CM RCS fuel dump is initiated by firing two more ex-plosive valves. At $T + 11$ seconds, a thruster deploys canards in the LES to re-verse the attitude of the CM for LES jettison and parachute deployment (fig. 29), and at $T + 14$ seconds, the docking ring is explosively separated and jettisoned with the launch escape tower to which it is attached by a tension tie.

At approximately T + 14.5 seconds, the apex cover is jettisoned as in normal landing, and at T + 16 seconds, the drogues are deployed. At T + 18 seconds, the RCS fuel and oxidizer lines are purged, and the residual helium pressurant is dumped through four explosive valves.

The drogues disreef at approximately T + 27 seconds and are disconnected simultaneously with main parachute deployment at T + 28 seconds. Recovery-aid deployment, descent, and landing are the same as in a normal mission.

30 000 Feet to Normal LES Jettison

In an abort from 30 000 feet to LES jettison, the pyrotechnic functions are similar to the abort described previously. However, rapid jettison of RCS propellant is inhibited, and the propellants are disposed of as in a normal mission. The time interval between events is changed slightly, and above 100 000 feet, the crewmen may elect to jettison the LES and follow normal landing procedures.

LES Jettison to Normal CSM Launch Vehicle Separation

After tower jettison and prior to normal CSM separation from the launch vehicle, missions are aborted by using the SM service propulsion system (SPS). The CSM is separated from the launch vehicle as in a normal mission and, at crew option, either normal entry and landing procedures are followed or the CSM aborts into orbit with the SPS.

EED AND CARTRIDGE ASSEMBLIES

Three general types of cartridges are used in the spacecraft: igniter cartridges in rocket motors, pressure cartridges in mechanical devices, and detonator

cartridges in high-explosive systems. The number of special-purpose cartridges has been minimized, and all but one type of cartridge electrically initiated.

To achieve high confidence in the critical electroexplosive interface, a standard EED, the SBASI, was developed and qualified as an independent module. By adding booster modules containing various types of charges, special-purpose cartridge assemblies are obtained. The resulting spacecraft cartridge family is shown in figure 30. The only nonelectric cartridge, that used to operate the SLA panel thrusters is fired by confined detonating cords to minimize the electrical circuitry and to ensure simultaneity in SLA panel separation.

The EED Module

The heart of the Apollo spacecraft pyrotechnic systems is the SBASI. Early in the Apollo program, a dual-bridgewire four-pin initiator was developed as the standard unit and was used in the early development and qualification of CSM and LM pyrotechnic systems. During the development of the device and system, the following limitations of the dual-bridgewire initiator became apparent.

1. Low interbridge electrical resistance (characteristic of conductive mixes) imposed limitations on electrical systems design.
2. The body material (17-4PH steel) had inadequate impact resistance in detonator applications at low temperatures (below -65° F).
3. In the detonator and in some high-pressure cartridge applications, the electrical pins in the EED could be blown out.
4. In the circuit-to-circuit mode, the initiator had high sensitivity to electrostatic discharge.

It also became apparent that the dual-bridgewire feature of the device was not required because the necessary redundancy could be better achieved at higher levels of assembly and, as a result, it was possible to eliminate one bridgewire. Thus, the SBASI came into existence. The SBASI retains the performance and desirable electrical characteristics of the original unit and incorporates the following improvements.

1. The body material was changed to Inconel 718 for improved impact resistance at cryogenic temperatures.

2. The wall thickness was increased for higher internal pressure capability.

3. The electrostatic discharge survival capability was increased from 9000 to 25 000 volts, and the spark gap providing this capability was moved to the interior of the unit for environmental and contamination protection.

4. A stepped Inconel 718 header was incorporated, with the contact pins glassed to the header and the header welded to the body. This design, together with the increased wall thickness, raised the internal pressure capability to over 35 000 psi.

5. The technique for postmanufacture indexing of the connector was incorporated.

In development of the SBASI, the body-header assembly was hydrostatically tested, after repeated thermal shocks from -320° F to 500° F, to over 100 000 psi without failure. In production, all units are tested to 35 000 psi. All production units are also tested for electrostatic survival capability and leak tested with helium to ensure proper hermetic sealing. Sectioned and exploded views of the SBASI are shown in figure 31. The technical requirements and the physical

configuration of the SBASI and the component parts are defined in NASA/MSC documents which comprise the SBASI procurement package. Space Ordnance Systems, Inc., developed the dual-bridgewire unit and the SBASI. Subsequently, Hi Shear Corporation was qualified as a second source of the SBASI. The units produced by these two manufacturers have been tested extensively to ensure complete interchangeability.

The capability of indexing the connector end of the SBASI after manufacture is a unique and important feature which permits manufacture and stocking of the unit in a general-use configuration and subsequently configuring any unit to any of nine special keyway combinations to meet special requirements. This technique eliminates the need for stocking the various indexed configurations which may be needed on short notice. With this technique, indexed SBASI can be reconfigured if required.

The indexing technique consists of broaching two (or more) additional keyways in the connector at the time of manufacture. In the SBASI, the two additional keyways are in the 1 o'clock and 11 o'clock position with the master keyway at 12 o'clock and the other four ways at the normal positions of 3, 5, 7, and 8 o'clock (fig. 32). SBASI are procured and stocked in U.S. government-bonded storage in the "all open" (xx0) configuration. However, no SBASI may be shipped in that configuration without special MSC authorization because such a unit will mate with any connector. Prior to shipment, two keyways are blocked by staking appropriate keyways inwardly to within 0.001 inch of the inner surface of the connector. Configuration xx1 is normally found on initiators, but that configuration is prohibited on the Apollo spacecraft; it is reserved for developmental, experimental, nonflight, and rejected flight units. SBASI which are rejected at any time can be restaked to this nonspacecraft xx1 configuration to prevent mating of any firing circuit on the spacecraft if a rejected

unit is installed by mistake. The special indexing system on the Apollo spacecraft may not be used in any system other than pyrotechnics, thus preventing possible mixups in the connection of circuits.

The complete part numbering system for the SBASI is shown in figure 32. The first digit of the dash number indicates the flight status, the second digit indicates whether a weld washer is installed on the part, and the third digit indicates the keyway indexing combination.

Another unique feature of the SBASI is the spanner-type torquing section that is used instead of the usual hexagonal section (fig. 33). This feature is used to prevent applying torque to the SBASI, with attendant damage to the hermetic seal, when a cartridge assembly is installed in the spacecraft. Because a special tool is required to install or remove a SBASI, only authorized personnel possessing this tool can perform this operation.

A third feature is the method of hermetically sealing the SBASI into a cartridge assembly. A thin metal washer is welded to the underside of the torquing section (fig. 33) during the preshipment configuration operations. After installation of the SBASI into the cartridge, this washer is welded around the outer edge to the top of the cartridge body.

For the Apollo spacecraft program, the SBASI is government-furnished equipment to all cartridge manufacturers upon request to MSC by North American Rockwell Corporation and Grumman Aircraft Engineering Corporation. MSC stocks the unit in the xx0 configuration with only the basic part number marked on the unit (in addition to lot, serial, and so forth). Prior to each shipment, the required quantity of units are staked, fitted with washers if required, marked with the appropriate dash number, and tested nondestructively. Units which

fail the shipping tests are reconfigured to xx1, color coded as rejected flight units, and shipped to MSC for removal from the flight stock. Any SBASI or cartridge assembly which becomes nonflightworthy at any time can be handled similarly.

The SBASI has a perfect reliability record to date; the SBASI and its predecessor unit has not been known to have failed to fire when subjected to the recommended minimum all-fire current pulse. The Inconel 718 body and header resists high-explosive shock loading at cryogenic temperatures, and the autoignition (cookoff) temperature of the explosive mix is well over 600° F.

The SBASI and its predecessor unit have undoubtedly undergone more exhaustive and extensive testing than any other initiators. More than 20 000 dual-bridgewire units were used in the Apollo spacecraft development, followed by perhaps 5000 to 6000 SBASI units. The extent of testing and use of the units in non-MSC programs is not known with any degree of exactness; however, it is known that the SBASI is being tested and used elsewhere in a variety of programs and is being considered for even wider use. MSC is vitally interested in acquiring such information, especially test results which indicate areas where improvements are desirable or which demonstrate acceptable characteristics under extended environmental conditions.

The personnel of the MSC believes strongly in the standard initiator concept and encourages the use of the SBASI, within the limits of its capabilities, on other programs. The advantages of standardization have been clearly demonstrated on the Apollo program where significant reductions in cost and development time were realized. In addition, the demonstrated reliability and confidence level in the SBASI are being significantly increased as the Apollo flight program progresses because approximately 140 SBASI are flown on each Apollo mission.

The present SBASI design represents a stage in the evolutionary process and will undoubtedly undergo modifications as necessary improvements are uncovered for future programs. The present SBASI will be used in the Apollo Applications Program. Each new MSC program will start with the then-current SBASI configuration, with improvements being incorporated as required. Thus, the SBASI and the ASI concept are dynamic rather than static end-of-the-line devices and concepts.

Cartridge Assemblies

Modular cartridges (incorporating the SBASI as a component) are used throughout the spacecraft and are designed for common-use where possible.

The physical configuration, performance, and spacecraft usage of the Apollo cartridge assemblies are shown in table 1. The SBASI is included because it is used as a pressure cartridge in one application. The indexing of the SBASI in the cartridges is also shown. Cartridges with different outputs have different threads where necessary to prevent improper installation, and those having the same output but which are located close to each other in the spacecraft and are fired at different times are differently indexed. Thus, the same thread and indexing may be used in various locations on the spacecraft.

Each cartridge assembly (except the SLA thruster cartridge) consists of one or two SBASI and a cartridge body hermetically sealed together by the weld washer. The Type 100 pressure cartridge contains no charge other than that in the SBASI; the cartridge module is an adapter necessary to install the SBASI in a small explosive valve. Right- and left-hand threads are used on variations of these, and other, cartridges because of installation near other cartridges with different functions or different firing times.

The parachute disconnect assembly (figs. 27 and 34), known as the flowerpot, provides an excellent example of the need for indexing initiators. Because of the limited space available, only one cutter blade, powered by one cartridge, could be used for each of the five risers. The maximum attainable redundancy was to install two SBASI in each cartridge, one connected to each of the two electrical systems. In figure 35, the connectors are shown mated to the SBASI and the figure clearly illustrates the space problem often encountered in the spacecraft. In this one case, the space was so limited that weld washers could not be used because the washers would overlap. Therefore, the SBASI are epoxied in place and lockwired together. The necessity for correct connection of firing leads is apparent because a mistake could result in disconnecting a main parachute before deployment. To ensure circuit redundancy in each cartridge, both system A and system B must be connected to each cartridge. As a result, five cartridges with ten SBASI are in proximity where proper cartridge installation and connector mating is mandatory. The solution to this problem is shown in figure 36. Proper cartridge installation is ensured by different threads on the two cartridges, and proper connector mating is ensured by four different indexing combinations.

CONCLUSION

The Apollo spacecraft has a pyrotechnic system which is undoubtedly the most complex ever used on any flight vehicle.

Undoubtedly the greatest innovation in the Apollo spacecraft pyrotechnic systems is the use of a standardized initiator. This technique, with modular cartridges and postmanufacture indexing of the initiator, resulted in significant cost reductions, shorter development times for higher assemblies, and higher demonstrated reliability of the most critical area, the electroexplosive interface.

TABLE 1.- APOLLO SPACECRAFT CARTRIDGES

Cartridge type	Variations, (cartridge dash number)	SBASI dash number	Cartridge thread (a)	Nominal performance			Use	Number on each spacecraft
				psi	Bomb			
					Volume	Type (b)		
Pressure cartridges								
Canard	None	216	1-1/2 × 12 RH	13 500	20 in ³	C	Canard thruster	2
Type I	None	216	7/8 × 14 RH	14 500	52 cc	V	Drogue parachute mortar	4
Type II	None	216	11/16 × 12 RH	11 200	8.9 cc	V	Pilot and drag parachute mortar	8
Type IV	0034	218	15/16 × 16 RH	2 250	8.8 cc	C	CM RCS propellant valve	5
Type IV	0054	216	15/16 × 16 RH	2 250	8.8 cc	C	SM circuit interrupter	4
Type IV	1034	217	15/16 × 16 LH	2 250	8.8 cc	C	CM RCS propellant valve	1
Type VI	None	216	1-1/16 × 18 RH	14 500	4.8 in ³	V	Apex cover thruster	4
Type 100	0121	216	11/16 × 24 RH	9 000	0.5 cc	C	CM and LM RCS helium valve	12
Type 100	0122	212	11/16 × 24 LH	9 000	0.5 cc	C	CM RCS helium valve	2
Type 200	None	216	3/4 × 16 LH	12 900	7.0 cc	C	CM circuit interrupter	4
Drogue disc	None	252/253 (c)	13/16 × 20 RH	5 800	0.9 in ³	C	Drogue parachute disconnect	2
Main disc	None	258/259 (c)	1 × 16 RH	10 500	1.9 in ³	C	Main parachute disconnect	3
LM valve	None	216	3/8 × 24 LH	1 600	10 cc	C	LM propulsion system	22
Electrical circuit interrupter	None	216	7/16 × 24 RH	1 000	10 cc	C	LM circuit interrupter	4
Explosive nut	None	216	9/16 × 24 RH	6 800	2.7 cc	C	LM interstage separation	4
Explosive bolt	None	216	1-1/16 × 18 RH	23 000	2.5 cc	C	LM interstage system	4
SBASI	Many	256	3/8 × 24 RH	650	10 cc	C	Docking probe retraction	4
SLA thruster	None	(d)	1-1/16 × 18 RH	4 200	4 in ³	C	SLA panel deployment	8
Igniter cartridges								
Type I	None	216	5/8 × 18 RH	2 100	10 cc	C	Launch escape/ pitch control motors	4
Type II	None	218	3/14 × 16 RH	2 100	10 cc	C	Tower jettison motor	2
Detonator cartridges								
CSM standard	0007	216	9/16 × 18 RH	0.045 dent in aluminum		Various on CSM		26
CSM standard	0008	218	9/16 × 18 LH	0.045 dent in aluminum		SLA separation		2
End type	None	216	9/16 × 18 RH	0.018 dent in steel		LM guillotine and landing gear uplocks		10
Long reach	None	216	5/8 × 18 RH	0.022 dent in steel		Docking-ring separation		2

^aRH, right hand; LH, left hand.

^cTwo SBASI per cartridge.

^bC, closed; V, vented.

^dNonelectric cartridge initiated by confined detonating cord.

LUNAR LANDING MISSION PLAN

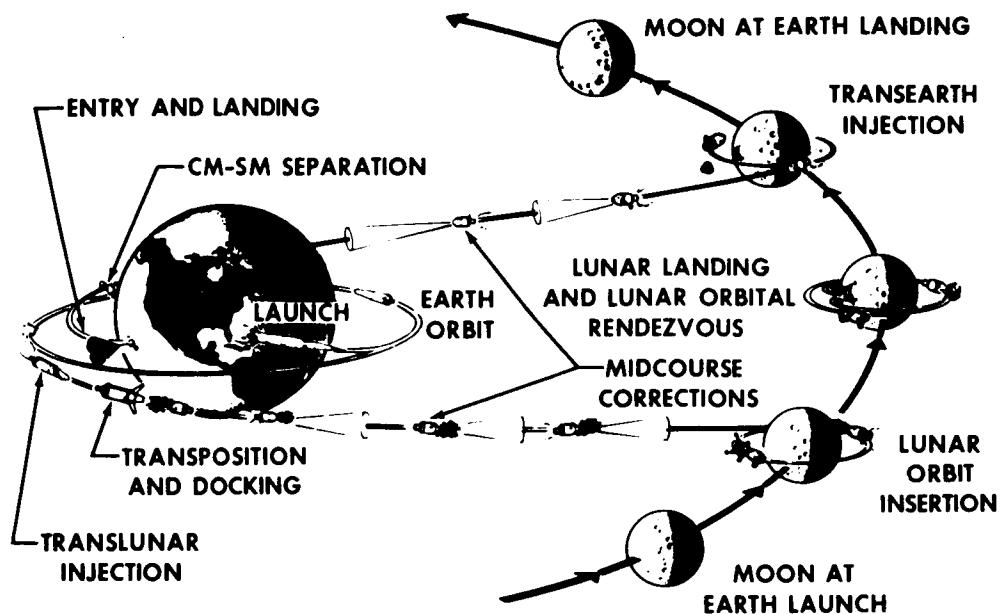


Figure 1

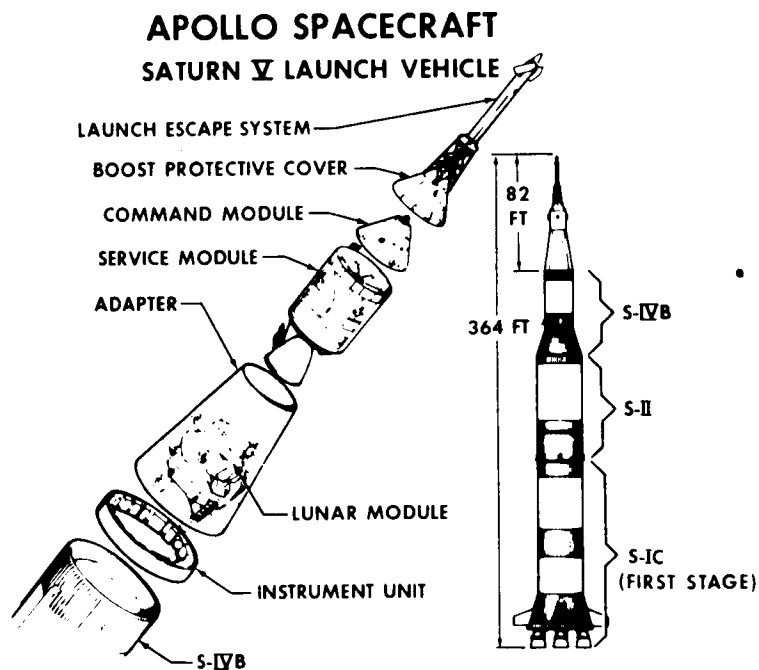
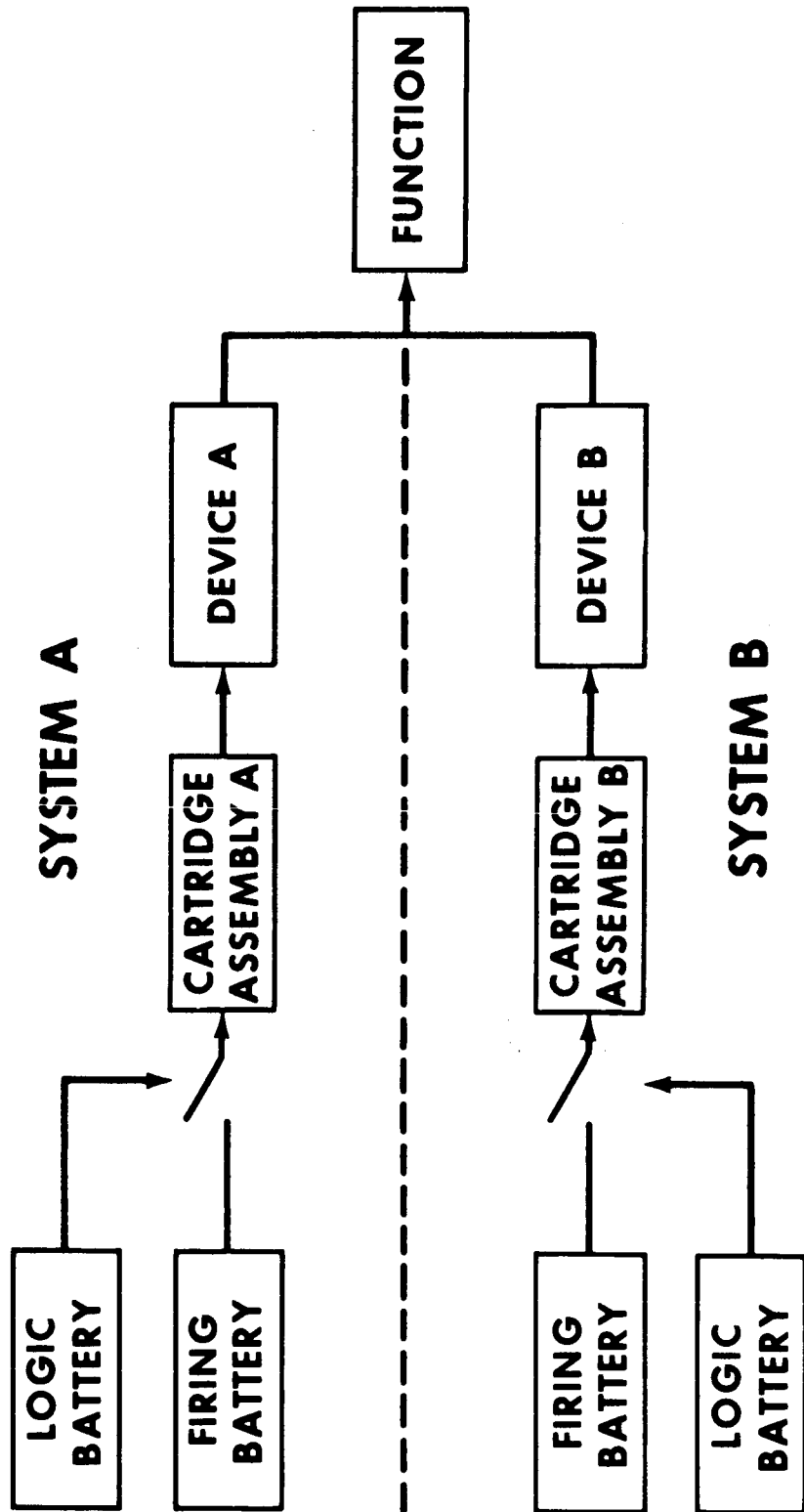
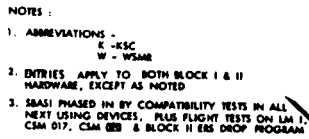


Figure 2

SYSTEM / DEVICE REDUNDANCY



TEST SUMMARY

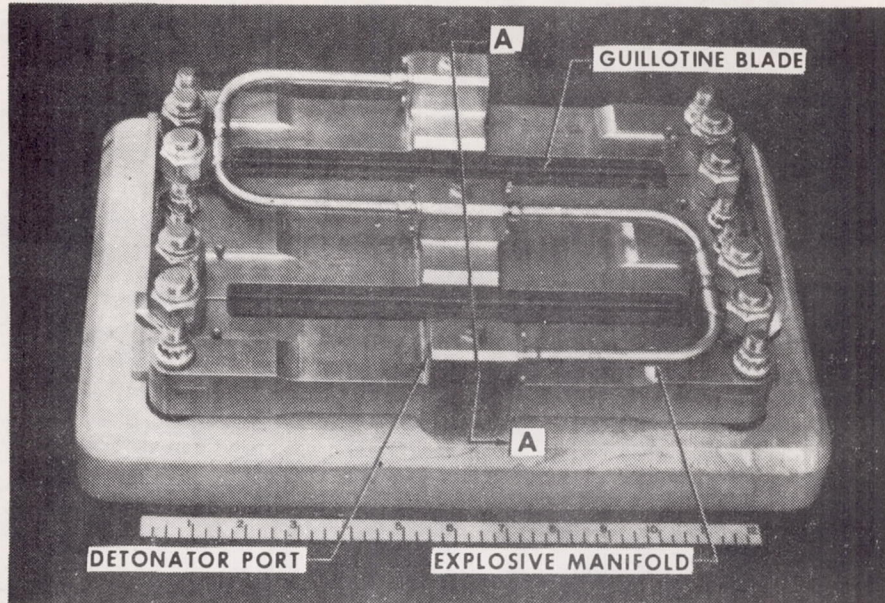


KEY :

- ENVIRONMENTAL TESTING
- OTHER THAN ENVIRONMENTAL TESTING
- UNMANNED FLIGHT TESTING
- ===== END OF TEST PROGRAM (BLOCK / HOWE)

Figure 4

CM-SM UMBILICAL GUILLOTINE ASSEMBLY



CM-SM UMBILICAL GUILLOTINE, (CONT)

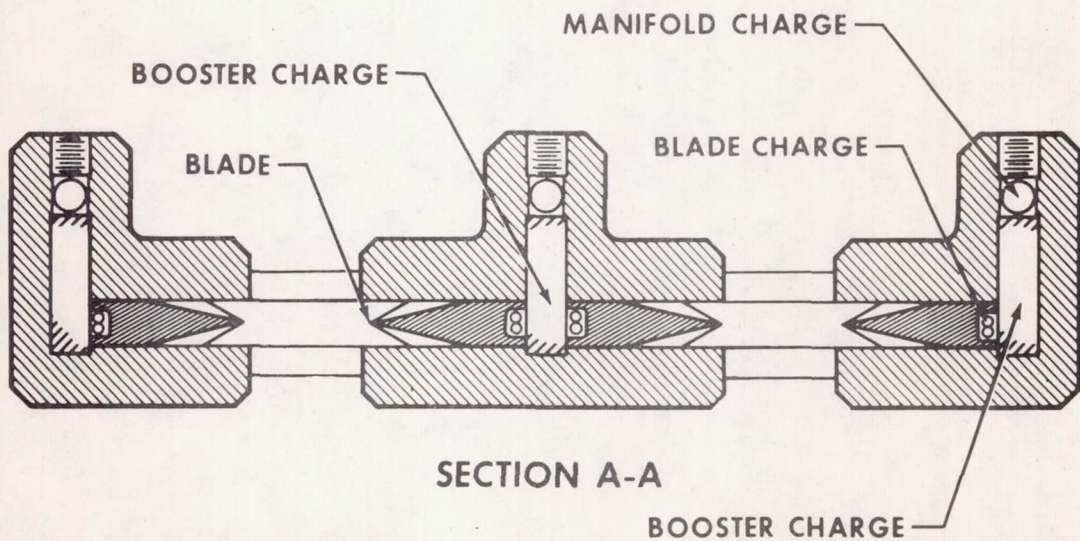


Figure 5

APOLLO PYROTECHNICS AND THEIR LOCATIONS ON THE SPACECRAFT

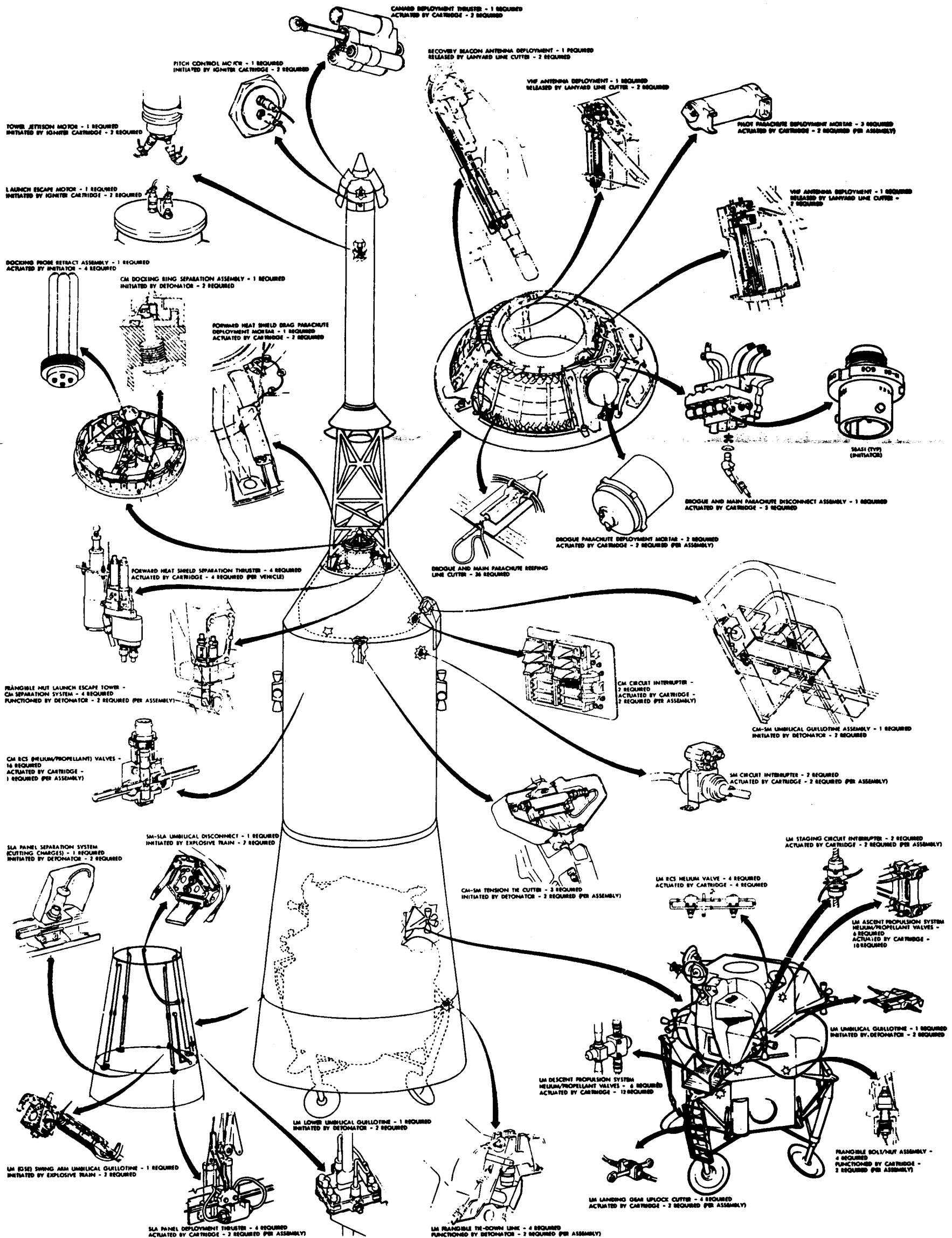


Figure 6

NORMAL TOWER JETTISON

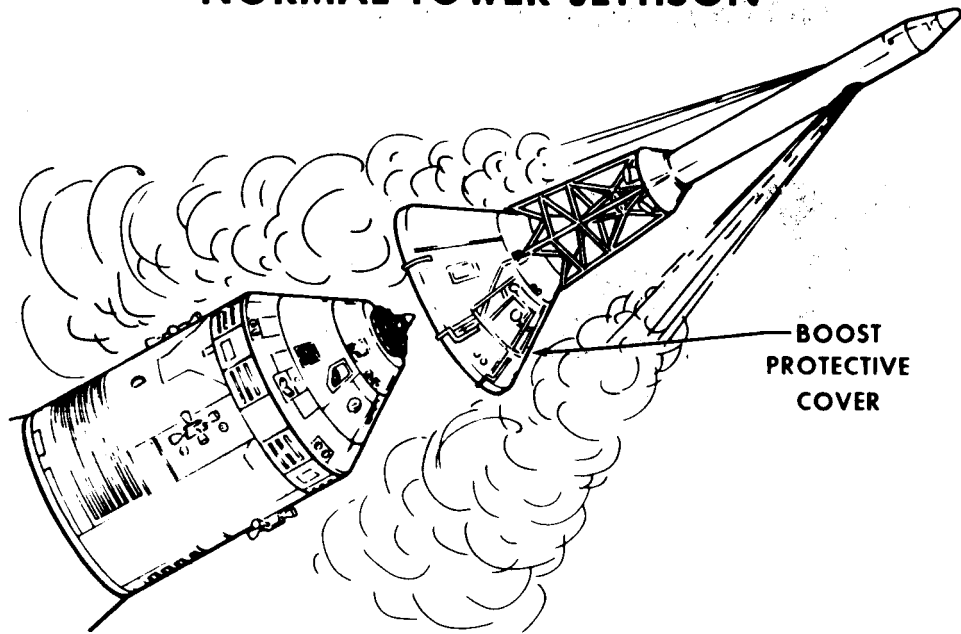


Figure 7

TOWER SEPARATION SYSTEM

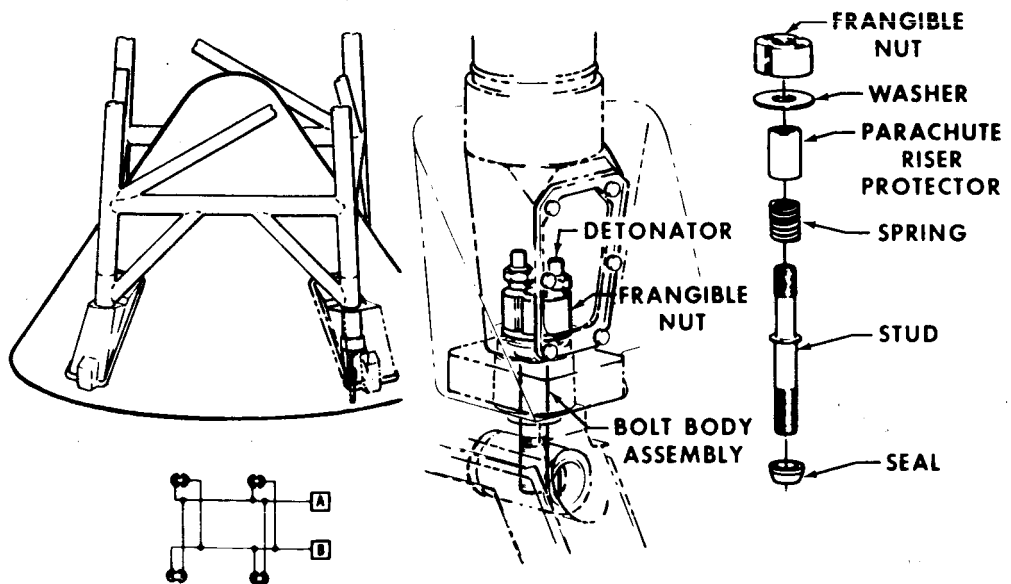


Figure 8

NORMAL CSM/LV SEPARATION

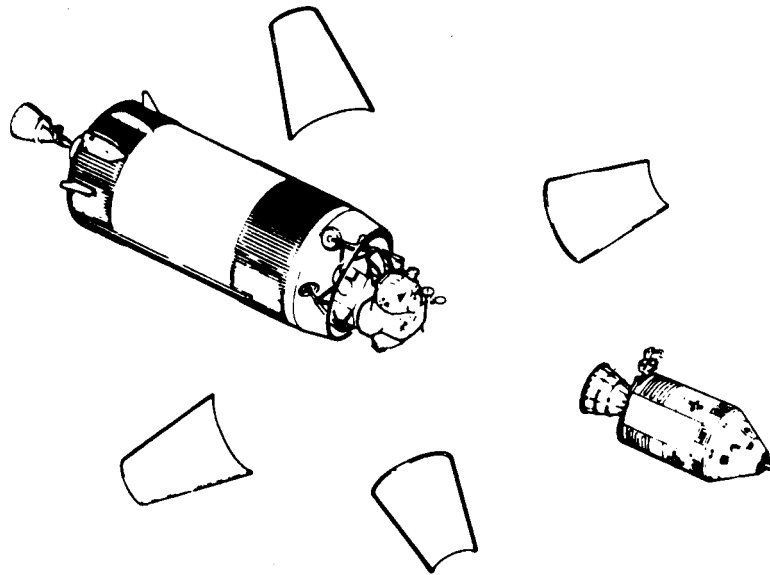


Figure 9

SEPARATION OF THE SLA PANELS

PANEL DEPLOYMENT

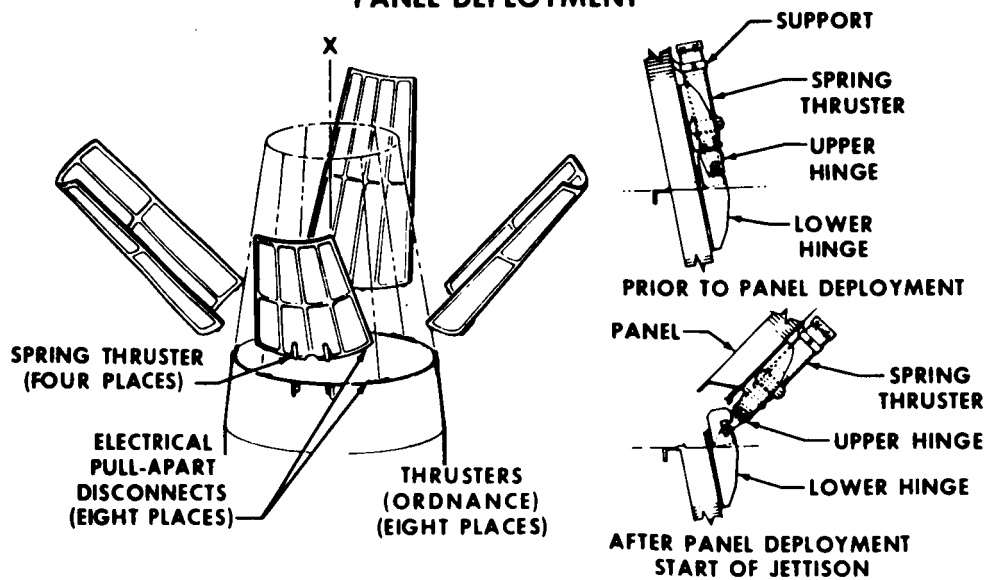


Figure 10(a)

SEPARATION OF THE SLA PANELS, (CONT)

PANEL SEPARATION

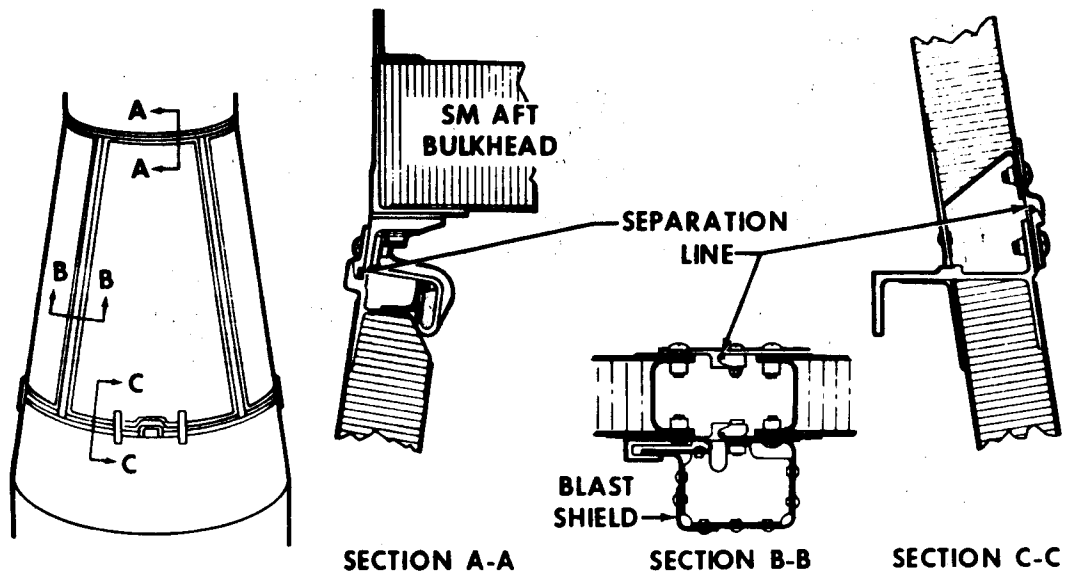


Figure 10(b)

SEPARATION OF THE SLA PANELS, (CONT)

EXPLOSIVE TRAINS

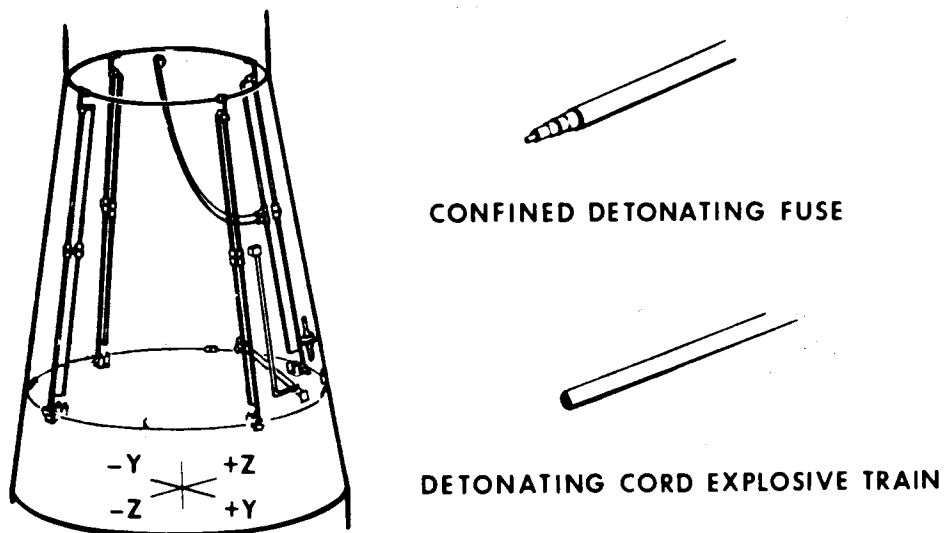


Figure 10(c)

SEPARATION OF THE SLA PANELS, (CONT)

ASSOCIATED DEVICES

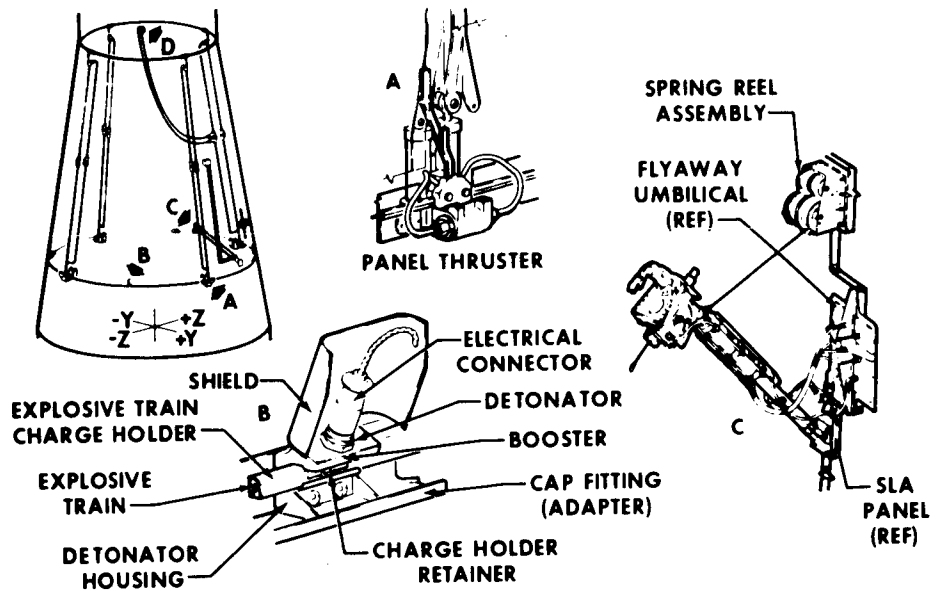


Figure 10(d)

SEPARATION OF THE SLA PANELS, (CONCL)

ASSOCIATED DEVICES, (CONCL)

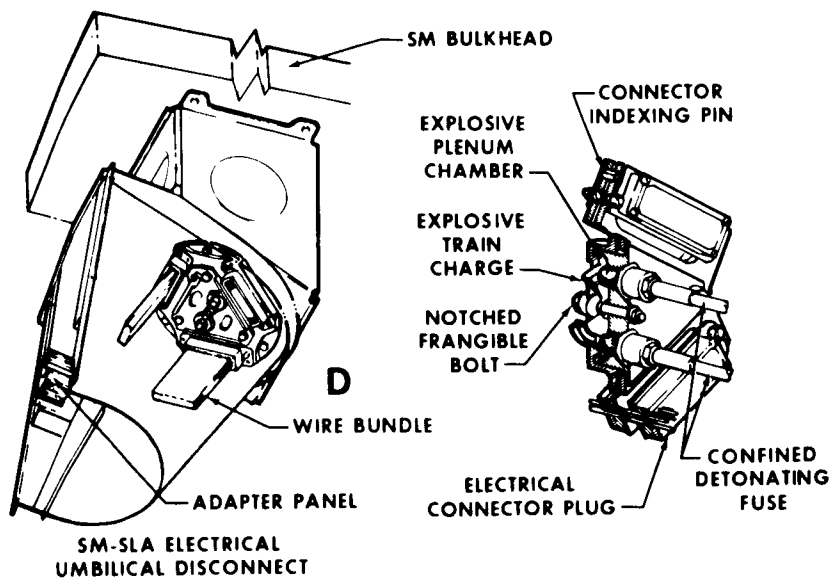


Figure 10(e)

TRANSPPOSITION, DOCKING, AND SPACECRAFT SEPARATION

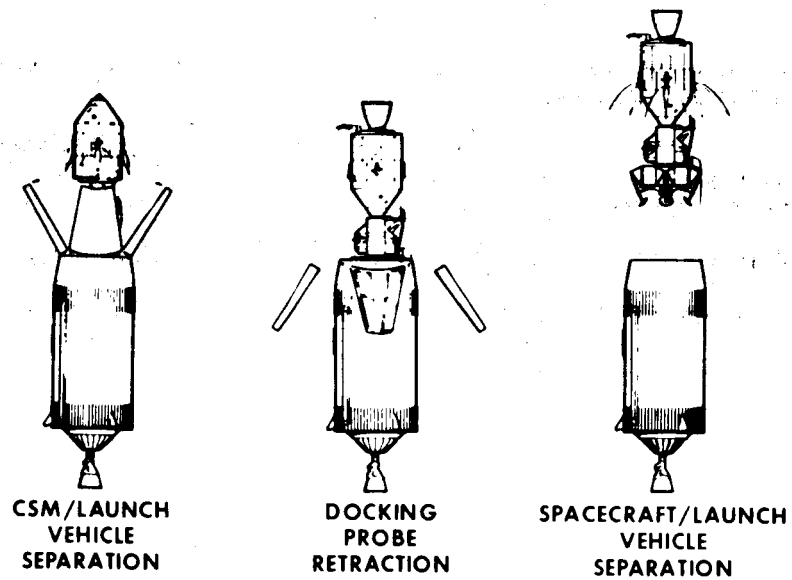


Figure 11

LM-SLA SEPARATION SYSTEM

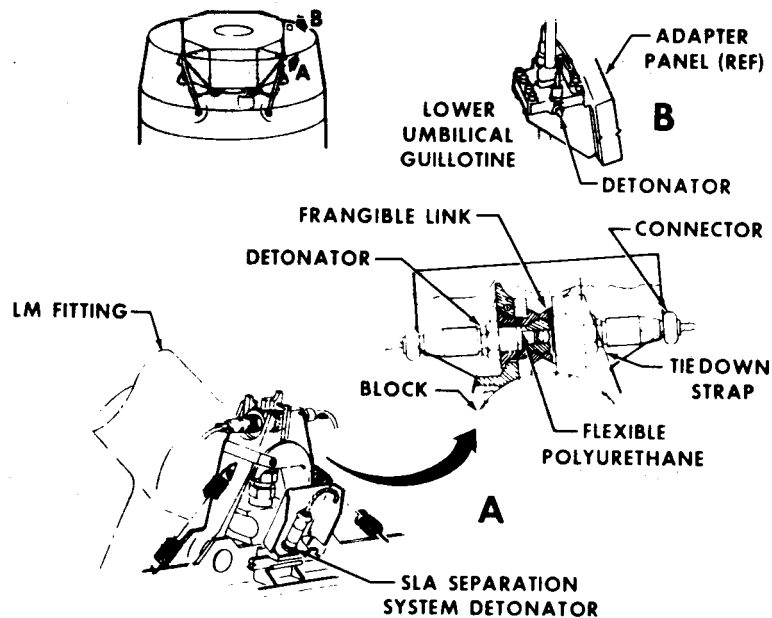


Figure 12

LM PYROTECHNICS - COMPONENT LOCATION

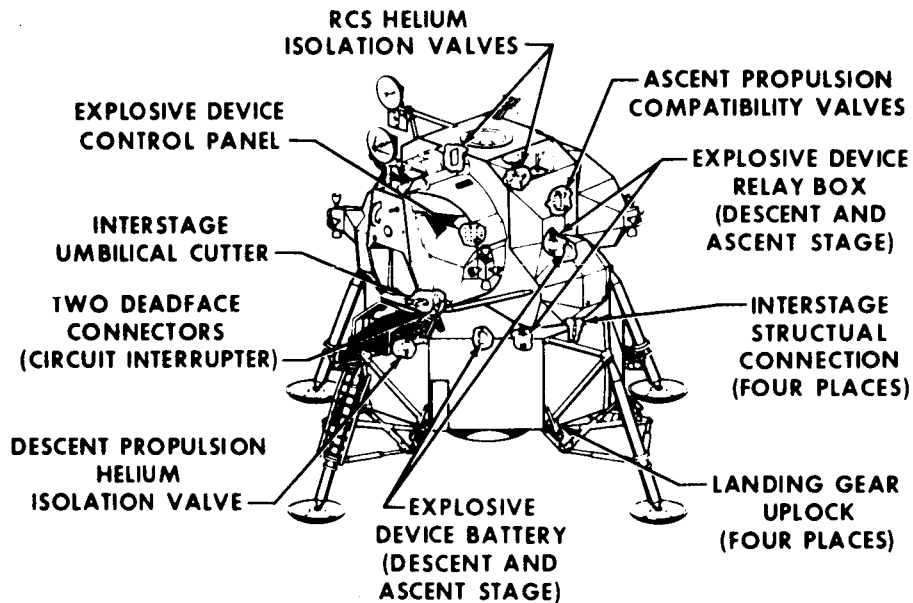


Figure 13

LM LANDING GEAR UPLOCK AND CUTTER ASSEMBLY

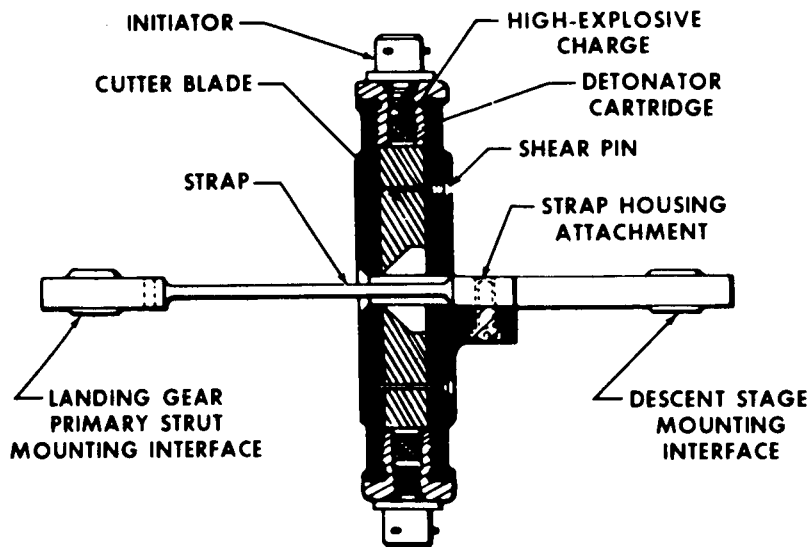


Figure 14

LM EXPLOSIVE VALVES

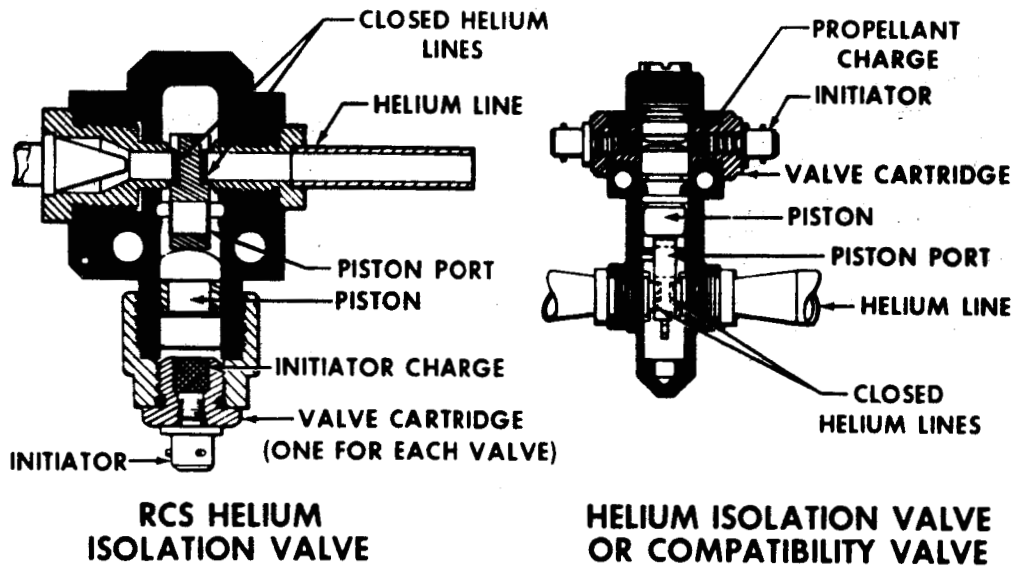


Figure 15

INTERSTAGE STRUCTURAL CONNECTION NUT AND BOLT ASSEMBLY (LM)

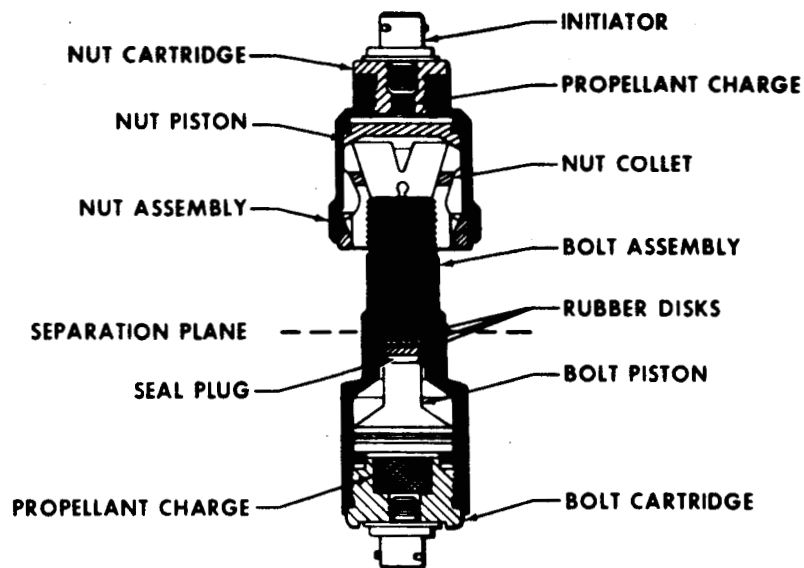


Figure 16

LM ELECTRICAL CIRCUIT INTERRUPTER

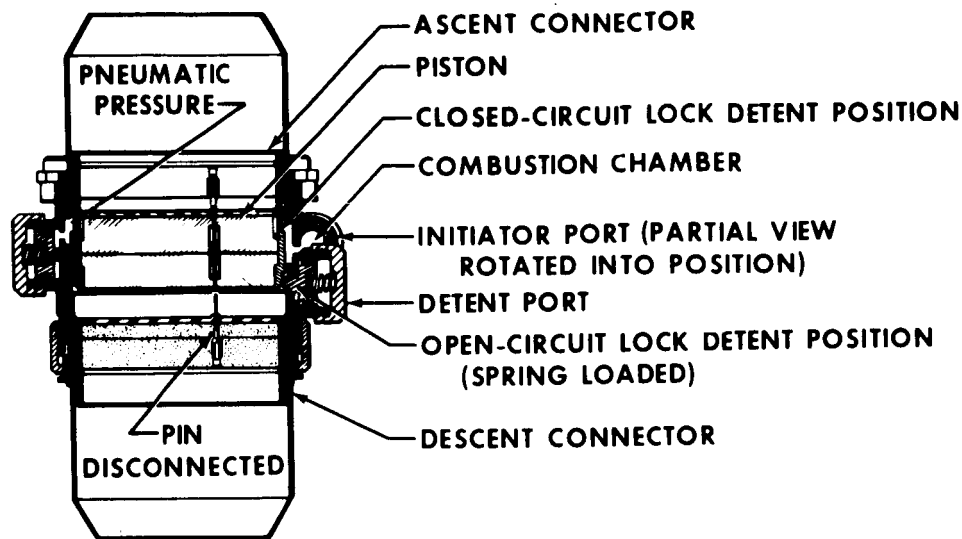


Figure 17

LM INTERSTAGE GUILLOTINE ASSEMBLY

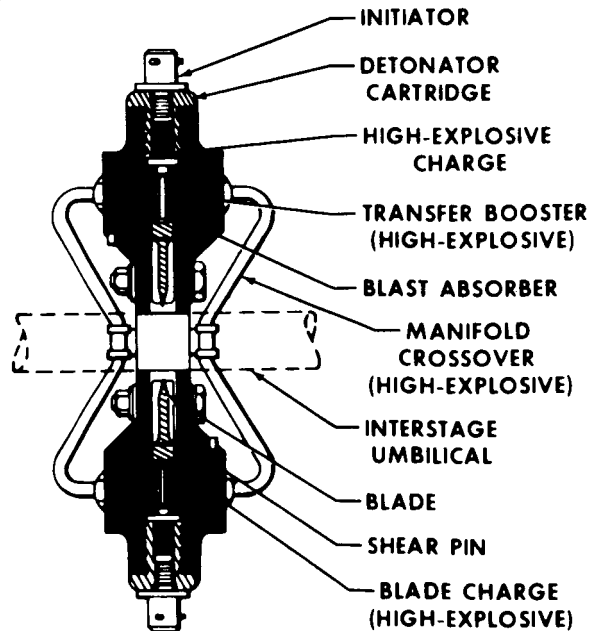


Figure 18

LM JETTISON SYSTEM

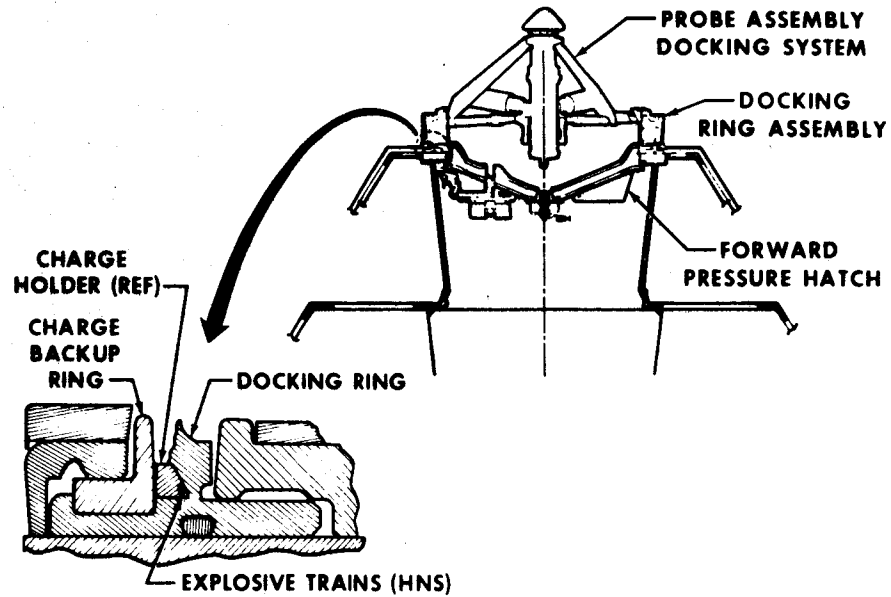


Figure 19

CM-SM SEPARATION AND SM JETTISON

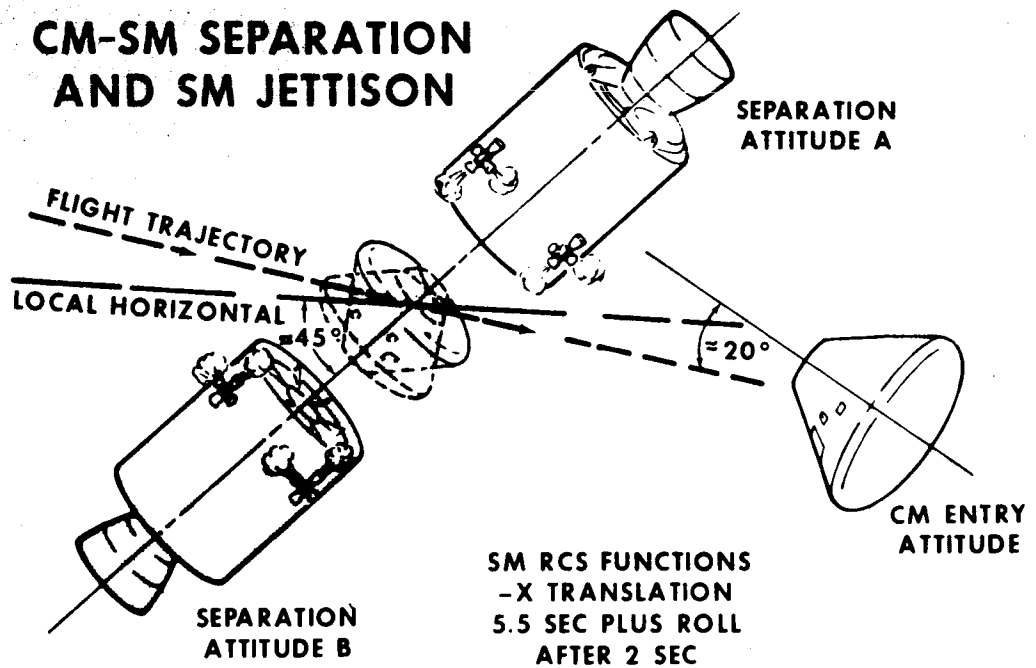


Figure 20

CSM ELECTRICAL CIRCUIT INTERRUPTER COMMAND MODULE

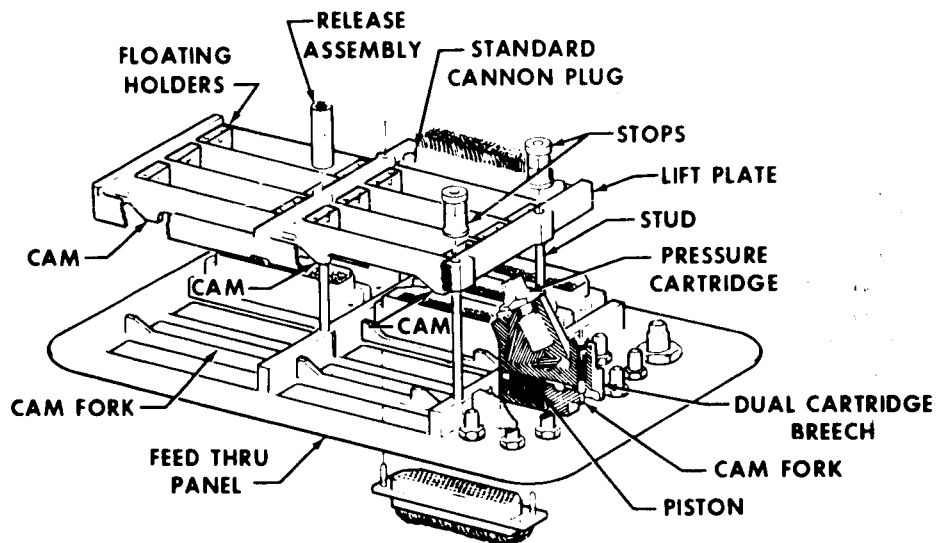


Figure 21(a)

CSM ELECTRICAL CIRCUIT INTERRUPTER, (CONT) SERVICE MODULE

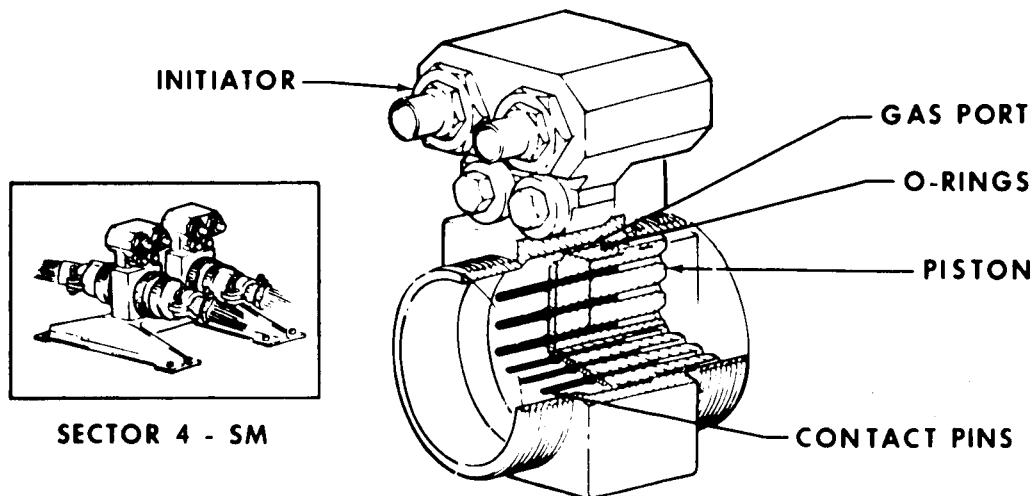


Figure 21(b)

CM-SM STRUCTURAL SEPARATION SYSTEM

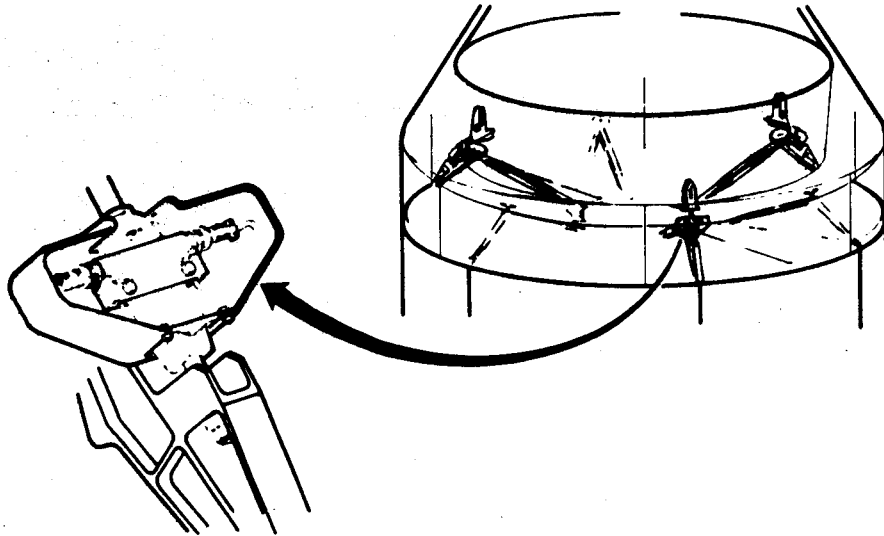


Figure 22(a)

CM-SM STRUCTURAL SEPARATION SYSTEM, (CONT)

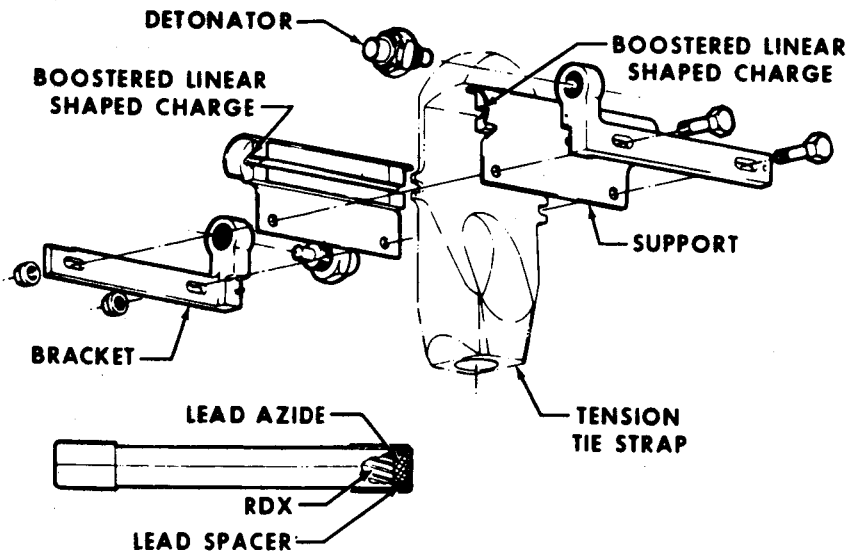


Figure 22(b)

EARTH LANDING SYSTEM

NORMAL SEQUENCE

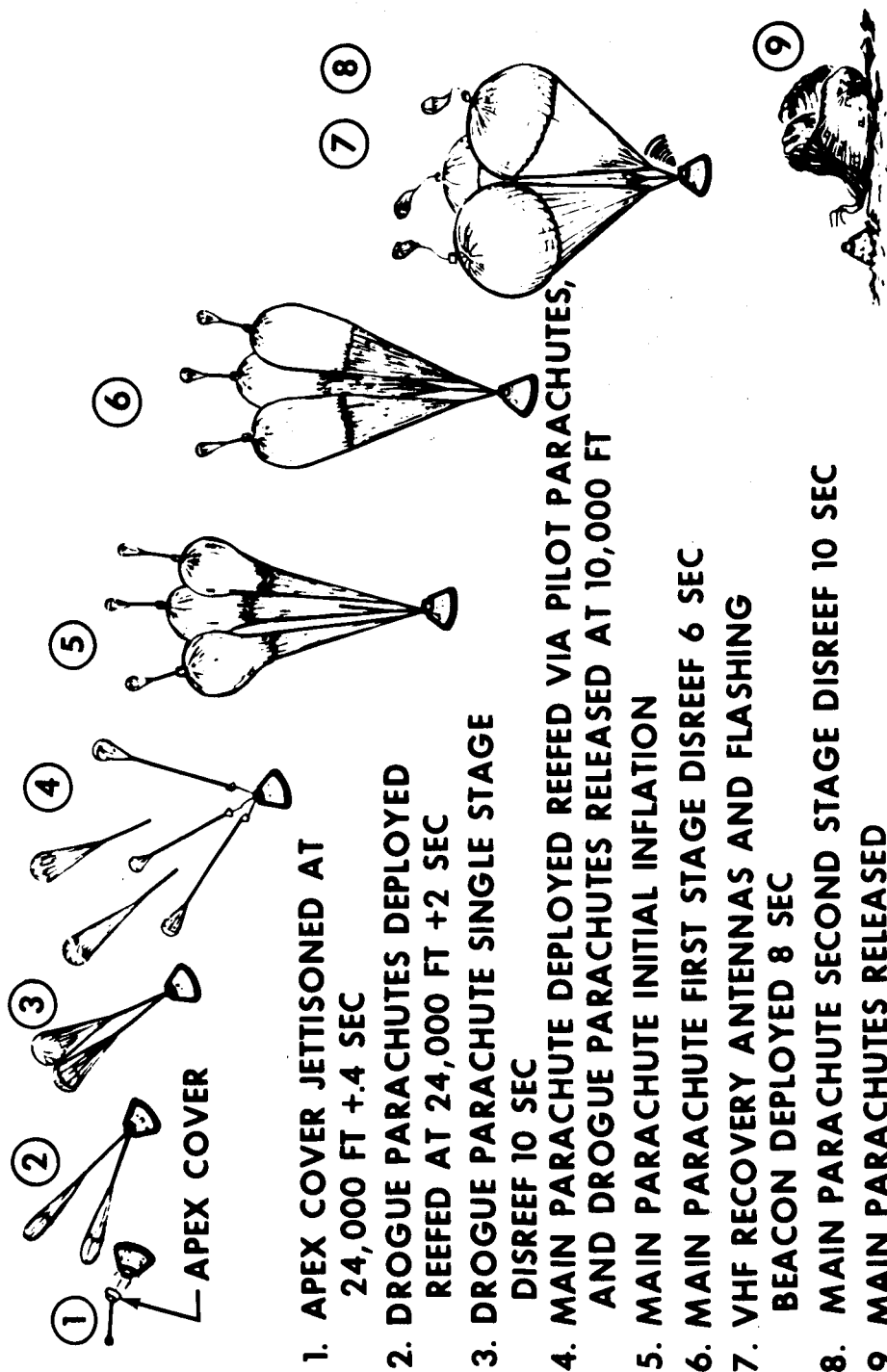


Figure 23

APEX COVER JETTISON SYSTEM THRUSTER SYSTEM

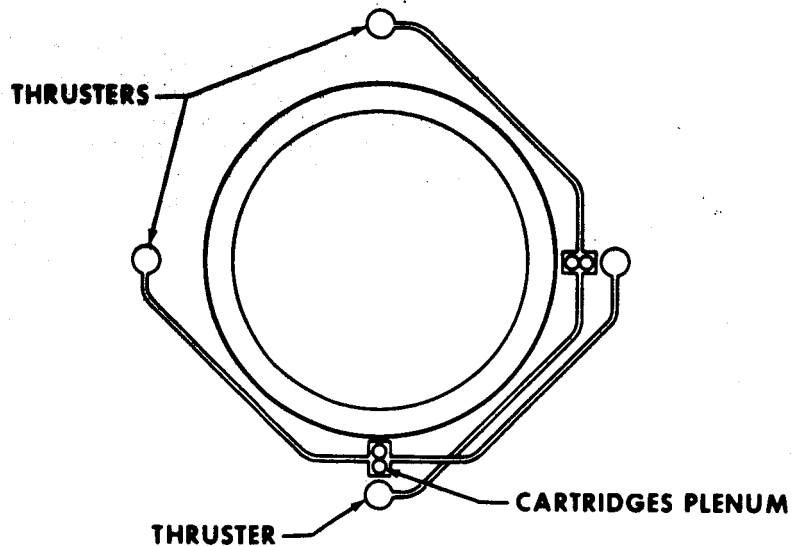


Figure 24(a)

APEX COVER JETTISON SYSTEM, (CONT) DRAG PARACHUTE MORTAR

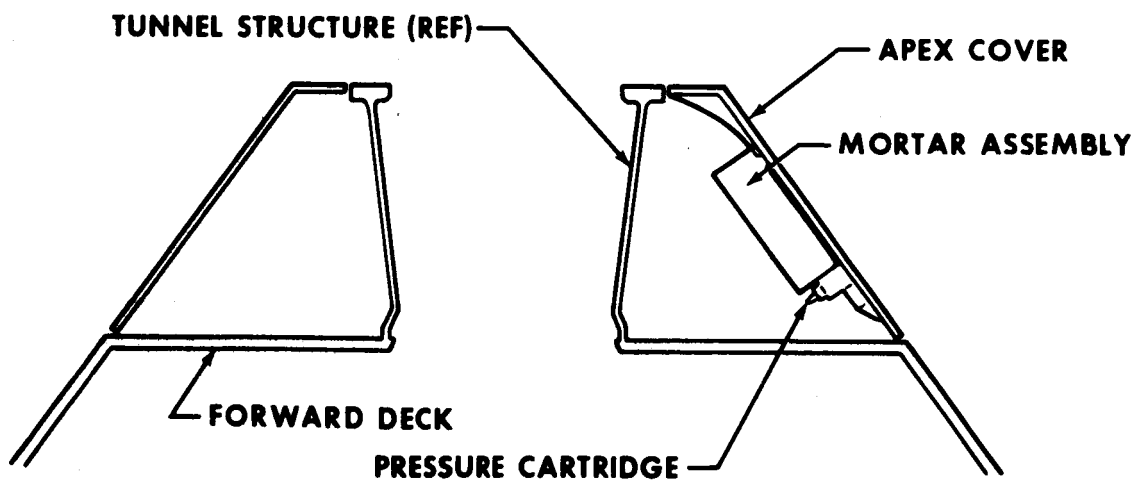


Figure 24(b)

PARACHUTE MORTAR ASSEMBLIES

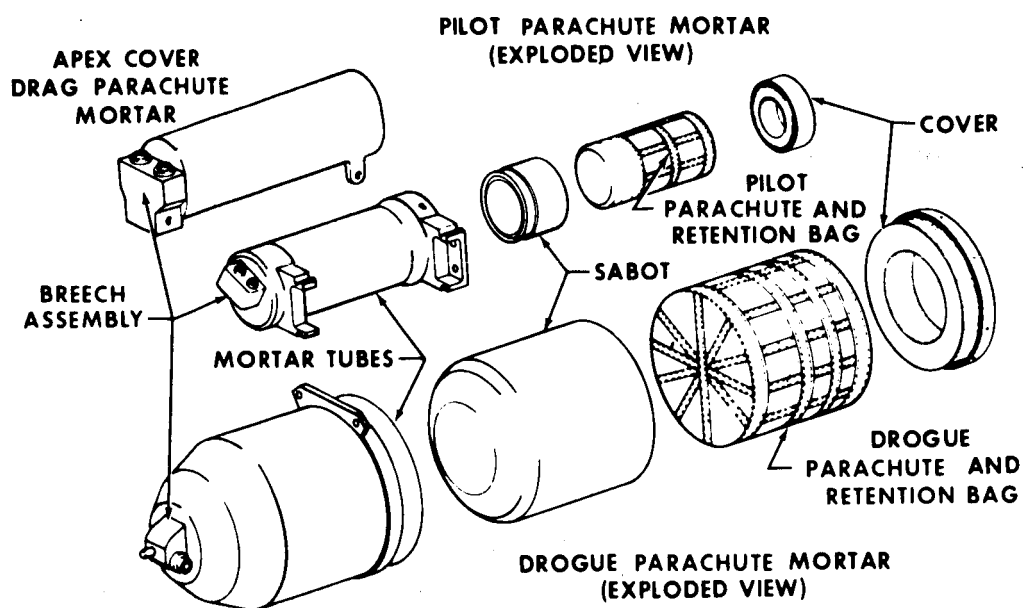


Figure 25

REEFING LINE CUTTERS (6, 8, AND 10 SECOND)

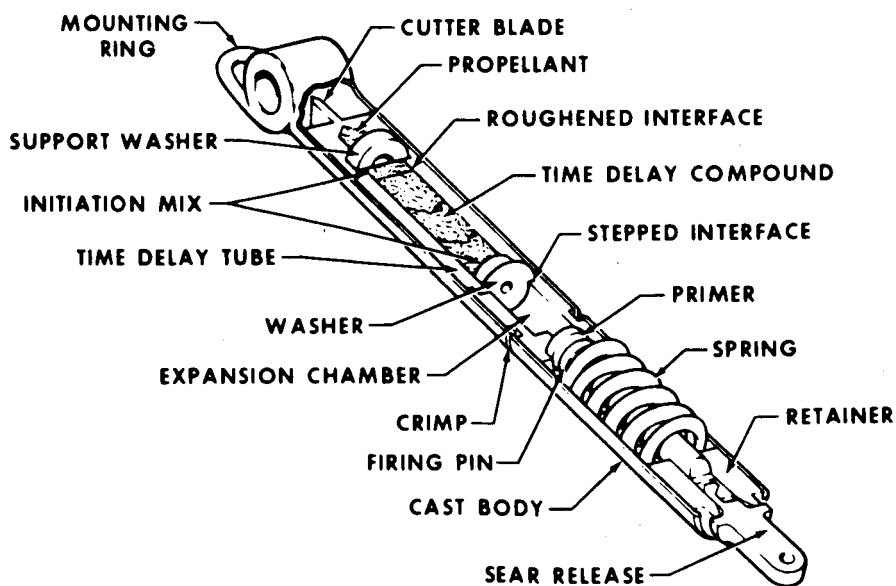


Figure 26

PARACHUTE DISCONNECT (FLOWER POT)

NOTE: ALL RISERS SHOWN ARE
BUNDLES OF STEEL CABLES

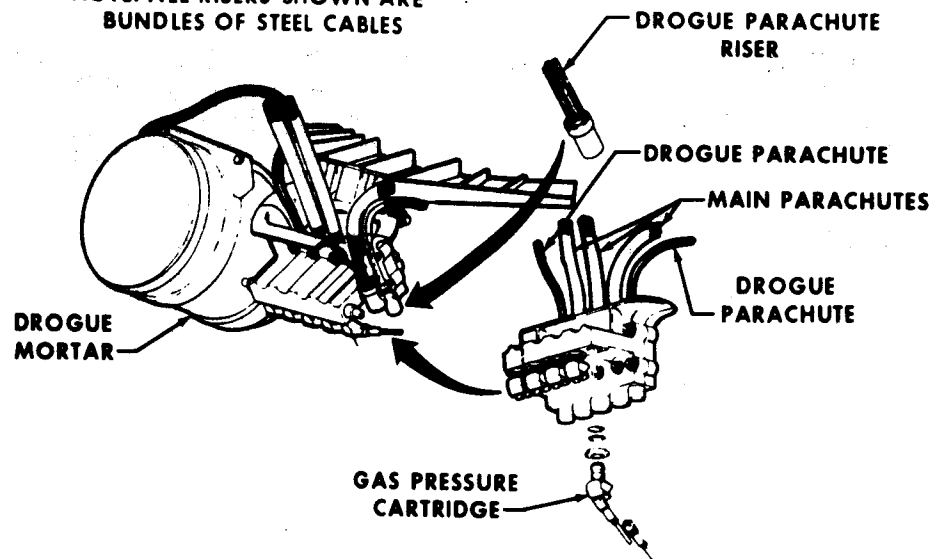


Figure 27(a)

PARACHUTE DISCONNECT (FLOWER POT), (CONT)

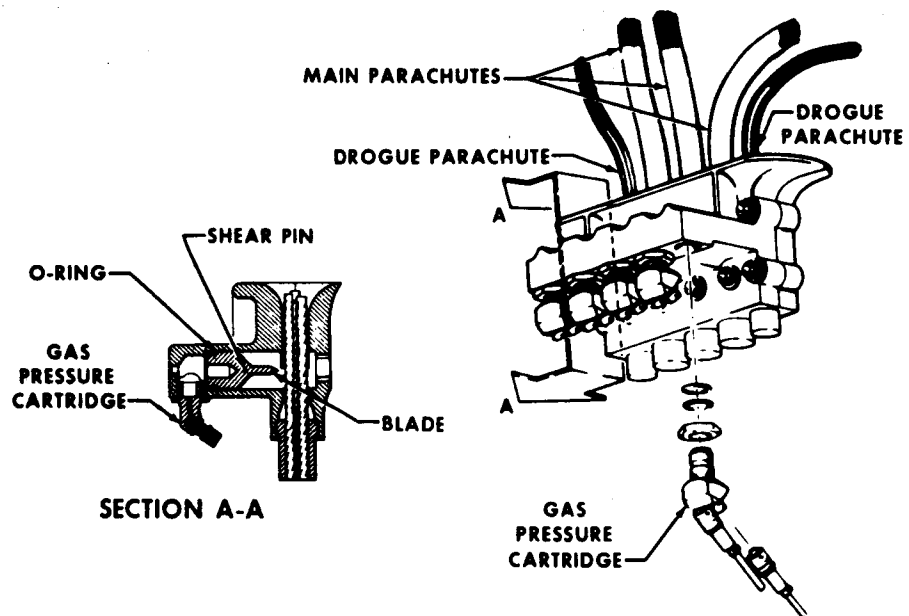


Figure 27(b)

ABORT PROFILE - PAD TO ~30,000 FEET

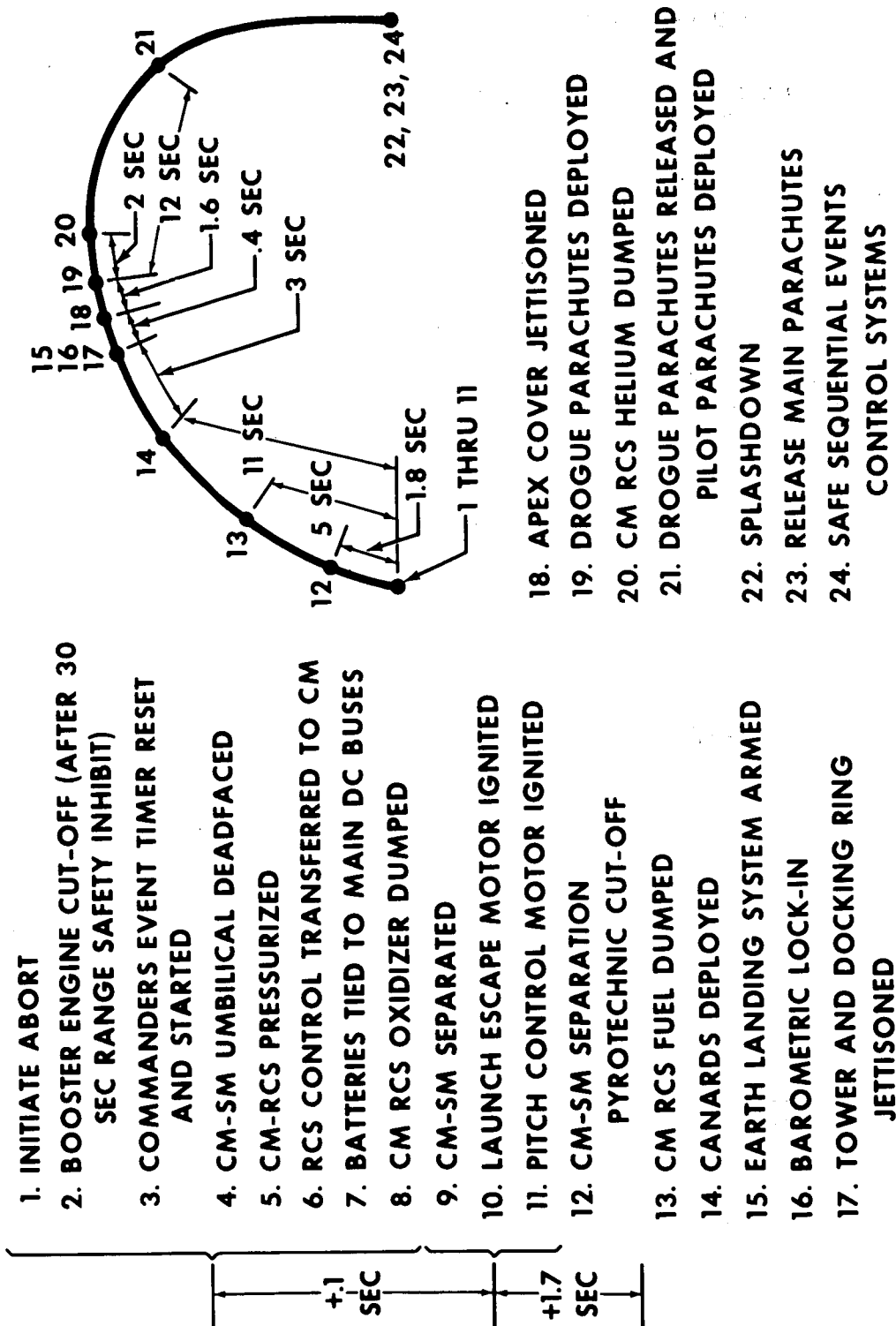


Figure 28

CANARD DEPLOYMENT SYSTEM

CANARD THRUSTER AND MOTOR IGNITER CARTRIDGES

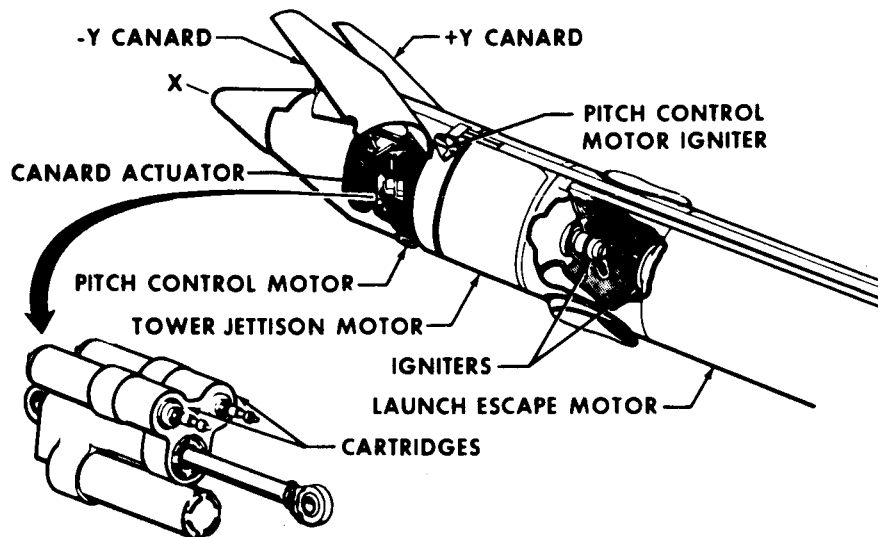


Figure 29(a)

CANARD DEPLOYMENT SYSTEM, (CONT)

CANARD THRUSTER

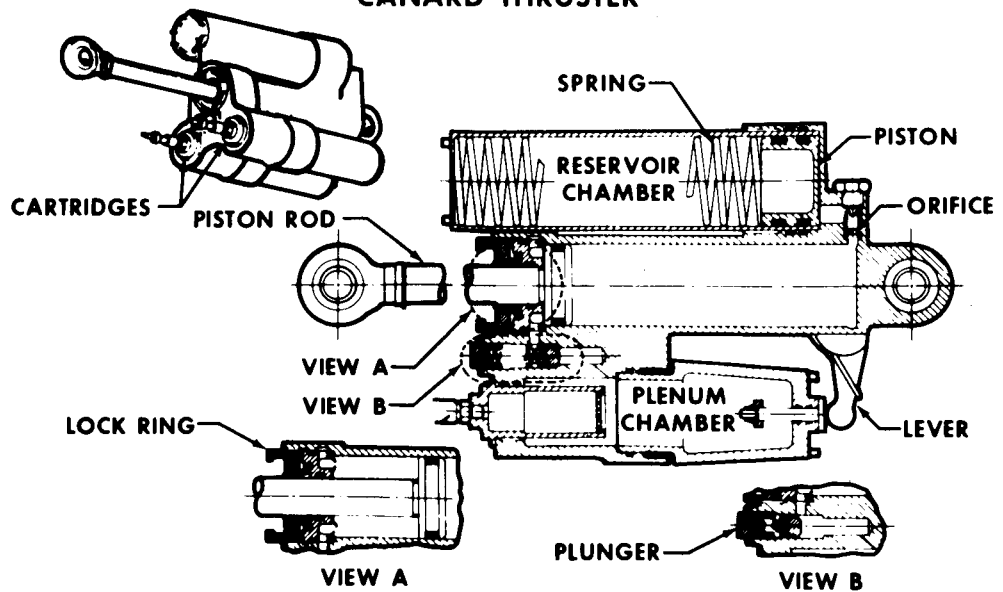


Figure 29(b)

SPACECRAFT CARTRIDGE FAMILY

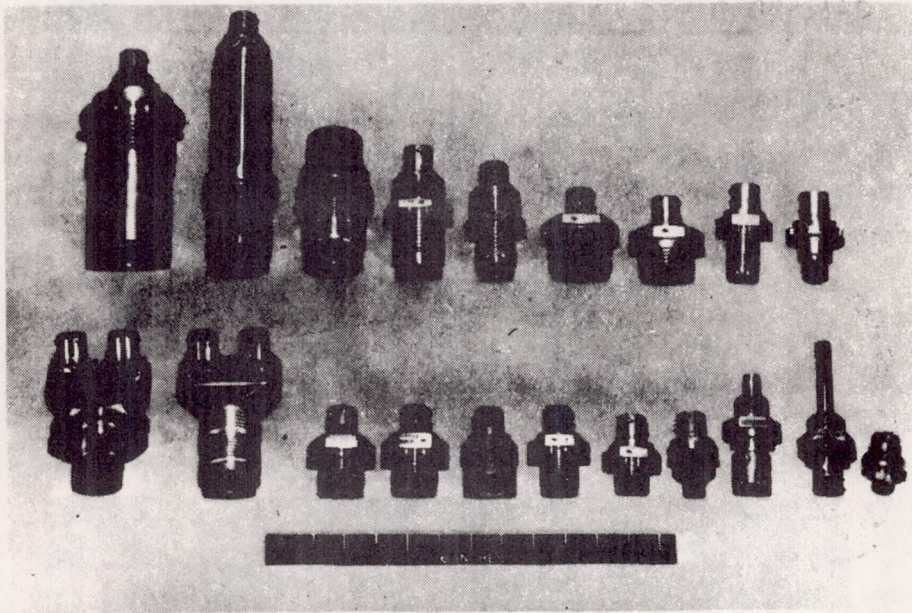


Figure 30

SINGLE BRIDGEWIRE APOLLO STANDARD INITIATOR - EXPLODED VIEW

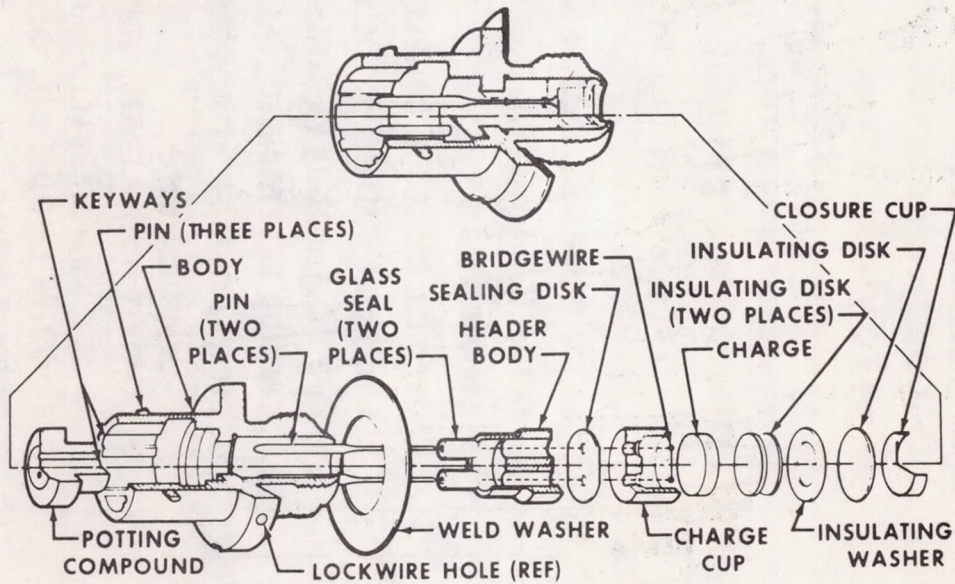
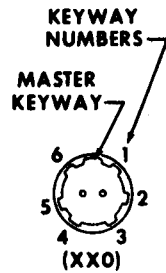
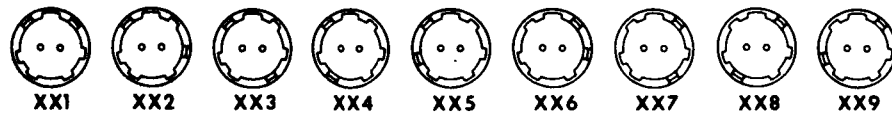


Figure 31

SBASI INDEXING AND DASH NUMBERING



BASIC PART NUMBER	DASH	DESIGNATION
SEB26100001	- 1XX	PROTOTYPE, DEVELOPMENTAL EXPERIMENTAL
	- 2XX	FLIGHT CONFIGURATION, QUALIFIED OR QUALIFIABLE
	- 8XX	INERT DEVICE
	- X1X	WELD WASHER ATTACHED
	- X5X	NO WELD WASHER
	- XX1	KEYWAYS 1 AND 6 CLOSED (NONFLIGHT)
	- XX2	2 6 (FLIGHT)
	- XX3	3 6
	- XX4	4 6
	- XX5	5 6
	- XX6	1 2
	- XX7	1 3
	- XX8	1 4
	- XX9	KEYWAYS 1 AND 5 CLOSED (FLIGHT)
	- XX0	ALL KEYWAYS OPEN (REQUIRES SPECIFIC MSC AUTHORITY FOR USE)

Figure 32

SINGLE BRIDGEWIRE APOLLO STANDARD INITIATOR

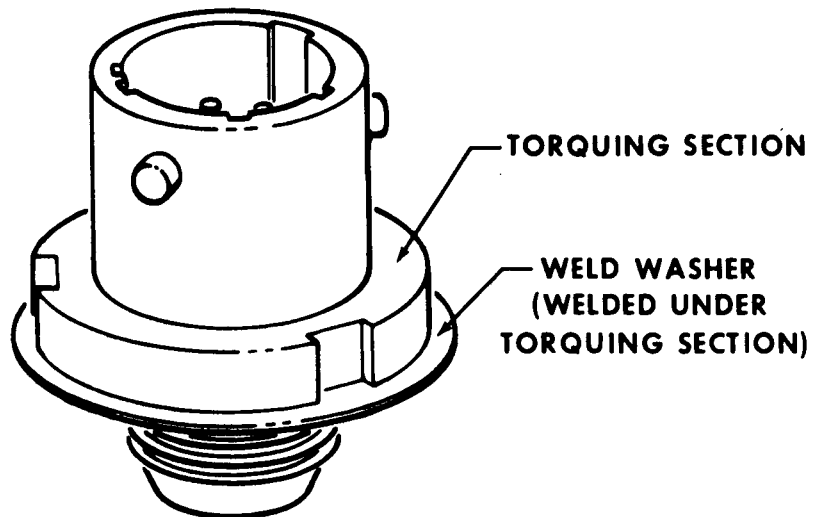


Figure 33

**PARACHUTE DISCONNECT
CARTRIDGE INSTALLATION**

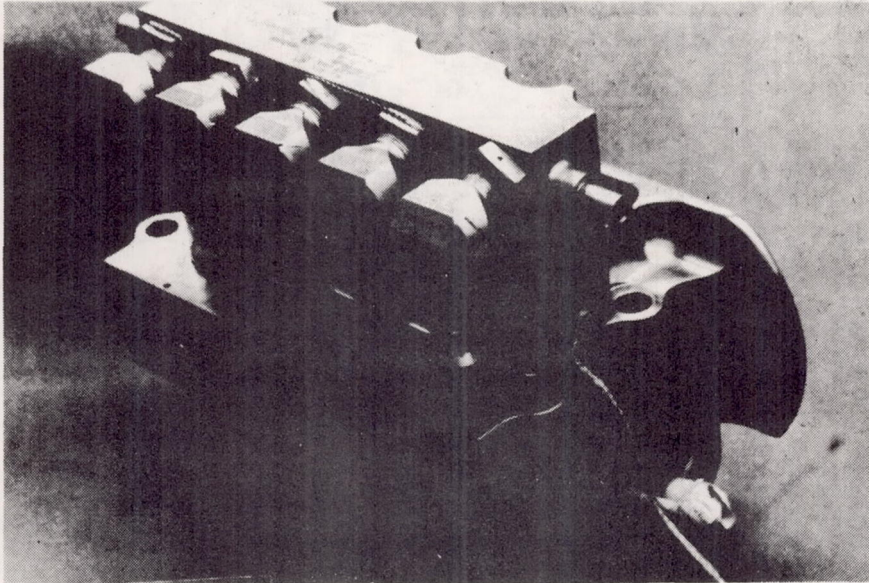


Figure 34

**PARACHUTE DISCONNECT CARTRIDGES WITH
FIRING CIRCUIT CONNECTORS MATED**

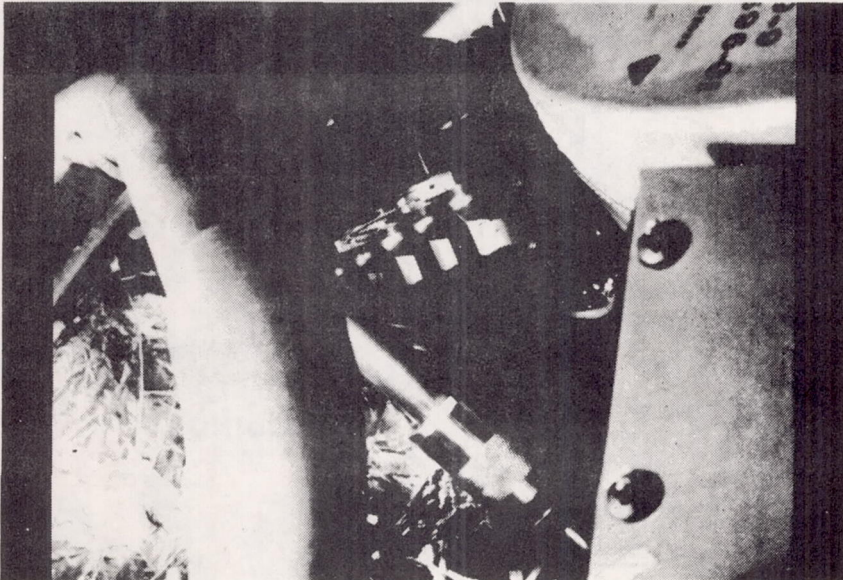


Figure 35

PARACHUTE DISCONNECT CARTRIDGE THREADS/SBASI INDEXING

PARACHUTE		DROGUE		MAIN		MAIN		MAIN		DROGUE	
ELECTRICAL		CIRCUIT		A		B		A		B	
THREAD		13/16 X 20		1 X 16.		1 X 16		1 X 16		13/16 X 20	
SBASI DASH		-252		-253		-258		-259		-252	
NUMBER											

Figure 36