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A STUDY OF THE ROLE OF PYROTECHNIC SYSTEMS ON THE SPACE SHUTTLE PROGRAM

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16. Abstract

Pyrotechnic systems, high burn rate propellant and explosive-actuated mechanisms, have been used extensively in aerospace vehicles to perform a variety of work functions, including crew escape, staging, deployment and destruction. Pyrotechnic system principles are described in this report along with their applications on typical military fighter aircraft, Mercury, Gemini, Apollo, and a representative unmanned spacecraft. To consider the possible pyrotechnic applications on Shuttle the mechanical functions on a large commercial aircraft, similar in scale to the Shuttle Orbiter, were reviewed. Many potential applications exist for pyrotechnic systems on Shuttle, both in conventional short-duration functions and in longer duration and/or repetitive type gas generators.

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FOREWORD

This report presents the results of a twelve-month study conducted by the Pyrotechnic Design Staff of McDonnell Aircraft Company, McDonnell Douglas Corporation, for NASA Langley Research Center, under Contract NAS1-10892.

The authors wish to acknowledge the contributions of the Hydraulic Design Staff, McDonnell Aircraft Company; the technical assistance provided by the Navigation and Controls Division of the Bendix Corporation; the Elkton Division of the Thiokol Chemical Corporation; and other pyrotechnic manufacturers, users, and Government facilities too numerous to mention, who supplied technical information.

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APPENDIXES (Cont.'d)

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SUMMARY

Pyrotechnics have been and will continue to be used extensively aboard aerospace vehicles to perform a multitude of work functions, including crew escape. Mercury, Gemini, and Apollo pyrotechnic systems were surveyed historically, along with a representative unmanned space vehicle and a typical military fighter aircraft. Compiled information reveals that these high-energy, light-weight, minimum-volume pyrotechnic systems have in general been used for relatively short-time duration events. A large commercial aircraft similar in size to the Space Shuttle was reviewed for potential pyrotechnic applications. Aside from the conventional one-shot type function of short duration, considerable emphasis was placed on the possibility of applying pyrotechnics to flight control systems as either primary or backup functions. Analysis showed that although this application to aircraft may be questionable, their consideration for Shuttle use may have merit. The Space Shuttle review from a pyrotechnic application aspect revealed many conventional short-time duration items, plus a potential use for longer duration and/or repetitive type gas generators. These could be used directly with actuators and/or vane motor arrangements.

INTRODUCTION

Space Shuttle, which is presently in the stage of developing initial mission concepts, possesses many characteristics of an enlarged commercial aircraft. In reality it is a hybrid vehicle, encompassing both commercial aircraft and space vehicle requirements. The application of considerable aerospace vehicle pyrotechnic experience to the Space Shuttle could effect significant design simplification in many onboard mechanical systems.

Pyrotechnics, by accepted aerospace terminology, refers to a broad family of sophisticated devices utilizing self-contained energy sources such as explosives, propellants and/or pyrotechnic compositions. These devices have been used since 1945 to perform a variety of work functions aboard aerospace vehicles, including emergency and life-saving applications. The use of pyrotechnics is attractive as they are self-contained energy sources possessing a minimum volume-weight relationship, high reliability, and safety. They provide instantaneous operation on demand plus the added asset of relatively long-term storage capability. The fundamental explosive, propellant and/or pyrotechnic material, when properly utilized or packaged, can be made to accomplish applications of cutting, separation, or pressurization plus numerous other mechanical work functions, such as valving, electrical switching, and personnel ejection.

This study of the role of pyrotechnics on Space Shuttle includes a review of pyrotechnic system principles, a survey of historical aerospace applications, investigation of possible pyrotechnic systems application to a large commercial aircraft, and exploration of possible applications on the Space Shuttle.

The objective of this study is to provide sufficient information to demonstrate the feasibility of utilizing pyrotechnic (explosively actuated mechanical) systems on Space Shuttle mechanical systems. It will also acquaint program administrators with the advantages that can be derived by considering pyrotechnic approaches in system trade studies with the more conventional hydraulic/pneumatic/electrical energy sources.

PROCEDURE

The program was divided into four distinct phases of investigation which are as follows:

Phase I - Pyrotechnic System Principles
Phase II - Historical Applications Survey
Phase III - Possible Pyrotechnic System Applications to Modern Aircraft
Phase IV - Definition of Mechanical Requirements and Possible Pyrotechnic Application to Space Shuttle

Phase I - Pyrotechnic System Principles

Pyrotechnic Definition - Background and generic forms are discussed. The basic pyrotechnic system is presented, along with a discussion of five basic types of initiation stimuli.

Pyrotechnic Reliability - A review from a conceptual standpoint is presented to show the importance of adequately understanding and separating the energy required from energy available at each interface. Redundancy concepts and examples are presented showing typical Apollo criteria. The F-111 crew module redundancy is discussed, along with various methods used to achieve same.

Test Methods - A brief discussion on testing is included. This aspect was reviewed from an improved technique approach to show that pyrotechnics can be evaluated on an engineering basis.

Safety - Some aspects of safety as they relate to a reliable system were reviewed. The relationship to reliability is discussed.

Trade Studies - Criteria for performing a trade study are discussed, especially when the use of a pyrotechnic system is not an obvious choice.

Standardization - The importance of standardization from a system and/or component aspect is presented. Merits of using off-the-shelf hardware are discussed.

Phase II - Historical Applications Survey

Aeronautics - The first usage of pyrotechnics as related to aircraft developments is reviewed. Aeronautic pyrotechnic usage is principally divided between personnel escape systems and weapons deployment. The three principal personnel escape techniques were therefore reviewed; namely, the open ejection seat as found on the F-4, the encapsulated escape seat used on the B-58, and the crew module system as utilized aboard the F-111. Comparisons are presented between escape systems along with unique systems applications.

Small missiles also fall in the aeronautical category and therefore the Shrike air-to-air weapon was examined. A typical F-4 weapons configuration was selected to study weapons and/or stores deployment. From a pyrotechnic standpoint this operation varies very little from aircraft to aircraft.

Astronautics - Pyrotechnic usage on space vehicles centers about manned craft such as Mercury, Gemini, and Apollo. These systems were reviewed from a functional and component aspect. In addition, the Mariner Mars '71 unmanned spacecraft was selected for the survey. To complete the survey of astronautics pyrotechnic applications, the Saturn V launch vehicle was also included as a good example of a booster.

Trade Studies - Three typical trade studies were performed to provide the broadest possible cross-section of depth and complexity. The first study was a comparison of personnel ejection techniques from a hypothetical multicrew aircraft. A second study compared different electrical disconnect methods. A third and final study, under this phase, was a very detailed comparison of stimulus transfer techniques for aircrew ejection from a typical dual-seat fighter.

The trade studies were based on the pyrotechnic principles listed in Phase I and the parameters listed below:

A. Mechanical requirements
B. System weight/volume analyses
C. Energy/power requirements
D. Time required to energize and actuate system
E. Safety factor (design margin)
F. Reliability-confidence levels
G. Passenger protection (safety)
H. Refurbishment
I. Cost to produce an operational system
J. Shelf-life, ruggedness
K. Any trade-off studies, comparing any of the above.

Phase III - Possible Pyrotechnic System Applications to Modern Aircraft

To approach the physical scale of applying pyrotechnic systems to Space Shuttle, a systems analysis was conducted on a large modern commercial transport in which system size, weight, and energy requirements were well established. The analysis was performed to obtain information under the following guidelines:

A. All phases of mechanical operation including control surfaces, landing gear, emergency egress, etc., were examined for possible pyrotechnic systems application.
B. Differentiation was made between single and multi-cycle requirements.
C. Consideration was given to pyrotechnic systems to accomplish primary, secondary, or tertiary functions.
D. Trade-off studies were then conducted, comparing the existing systems to proposed pyrotechnic systems based on the same parameters described in Phase II.

It was necessary to review the methods whereby aircraft power is converted into mechanical work, prior to considering pyrotechnic applications. The application of pyrotechnic energy directly through the use of linear actuators or vane motors was evaluated. Selected mechanical systems from the McDonnell Douglas DC-10 and Boeing 747 aircraft were reviewed.

Phase IV - Definition of Mechanical Requirements and Possible Pyrotechnic Applications to Space Shuttle

In this final phase of the study, both firm and potential pyrotechnic applications are proposed for use on the Space Shuttle, which includes the Orbiter vehicle, the external fuel tank, and the solid propellant boosters. These applications are based on the background data obtained during Phases II and III of this study and the following Space Shuttle study contracts:

(1) NAS 8-26016 and NAS 9-9204 (McDonnell Douglas)
(2) NAS 9-10960 (North American)
(3) NAS 9-11160 (Grumman)

Throughout this phase, the selection or determination of potential applications was related to the work function and the required time of performance. Consideration was also given to primary, secondary, or tertiary Shuttle functions. A single trade study was performed, based on the parameters described in Phase II, wherein a gas generator/vane motor arrangement was compared with a manual back-up system for operating the radiator and payload bay doors.

RESULTS

Phase I - Pyrotechnic System Principles

Pyrotechnic Definition - The word "pyrotechnics" is literally defined as the art of making fireworks; however, in today's aerospace terminology, pyrotechnics refers to a broad family of sophisticated devices utilizing explosive, propellant and/or pyrotechnic compositions. Specifically not included are bombs, warheads, land mines, etc., which are commonly associated with the military term, ordnance. Pyrotechnic devices have seen extensive use on all the manned and unmanned spacecraft where they have been used to perform a very wide variety of mechanical functions. They have been and are continuing to be vital components in all aerospace personnel escape and armament deployment systems.

Pyrotechnics offer the designer the opportunity of employing a self-contained energy source that possesses perhaps the highest work potential (exclusive of nuclear energy) in the smallest volume and with minimum weight. In addition, pyrotechnics provide instantaneous operation upon initiation; they can be designed to provide closely controlled functioning; they are highly reliable, safe to handle; and possess the added asset of a relatively long-term storage capability.

Each pyrotechnic device requires a basic succession of events to assure proper functioning. The basic system, represented graphically in Figure 1, consists of four essential elements; namely, the igniter, a chemical conversion source, the work output mechanism, and the mechanical function required. An initiation stimulus functions an igniter, usually a heat-sensitive pyrotechnic or primary explosive. This material possesses the ability to ignite by heat, shock, or hot particles the chemical conversion material next in the train of events. The chemical conversion involves the release of controlled amounts of gas and heat such that various rates of energy application can be applied. This energy source is generally a propellant of moderate burning rate. The next function is the change from chemical to kinetic energy. The most general form is the acceleration of a mechanical piece, such as a piston/cylinder arrangement. The end item of the basic pyrotechnic system is the work output or actual work performed and can be in the form of cutting, breaking, pressurizing, pushing, and pulling.

As shown in Figure 1, an incoming electric stimulus functions the igniter. This in turn initiates the propellant which produces gas at pressure. This gas pressure then imparts kinetic energy to the guillotine blade which is capable of successfully severing the wire bundle. Although a guillotine was chosen to illustrate this point, all pyrotechnic devices generally contain the same four basic elements and their corresponding interfaces.

While pyrotechnic devices are self-contained and isolated from the fundamental vehicle operation systems, they require an initiation stimulus. Five of the most popular methods, together with their modes of transmission to the igniter, are shown diagrammatically in Figure 1. The fundamentals of each initiation stimulus are briefly as follows:

- o Mechanical - This initiation system relies upon the compression and release of a spring-loaded firing pin to function a percussion primer. Such mechanisms generally employ either a sear or ball release arrangement to free the firing pin at the point of maximum spring compression.
- o Ballistic Hot Gas - This requires a moderate pressure pyrotechnic gas generating source (usually a double base propellant cartridge) to provide the stimulus medium. The ballistic hot gas from such a source is transmitted through a reinforced pneumatic hose to the pyrotechnic device[1,2]. Because of decreasing pressure with increasing length and volume, hose lengths are relatively short.

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[1] The footnotes appearing in the text have been contributed by the NASA technical monitor to provide supplementary information which should be helpful to some sectors of the intended users of this report.

[2] "initiating the devices with percussion primers, as described in the Mechanical ignition section".

Additional in-line gas generators may be added to maintain the operating pressure range. This type stimulus system is unaffected by electromagnetic radiation.

- Electric - This system uses both low and high voltage approaches, both of which require igniters containing[3] bridgewires for termination of the electric circuit. In the low voltage system, the bridgewire, upon passage of the electric current incandesces prior to breaking[4], while in the high voltage EBW approach the bridgewire actually explodes as a result of energy discharge of a capacitor at a high voltage. While the low voltage technique is susceptible to electromagnetic interference, the high voltage method generally avoids this potential problem area, but requires considerably more volume and is heavier than the low voltage system.
- Explosive - This system utilizes detonating cord in the packaged form of either confined detonating fuse (CDF) or shielded mild detonating cord (SMDC) to transmit an explosive signal. Both forms of cord terminate in small explosive charges which can be used directly to function another device. Both CDF and SMDC type stimulus transfer systems are insensitive to electromagnetic

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[3] "thin gage bridgewires for termination of the electrical circuit at the igniter material. In the low voltage system (usually no higher than 40 volts) the high resistance bridgewire in conducting the electrical current is heated to achieve the auto-ignition temperature of the igniter material; thus the reference to hot wire systems."

[4] "however, in the high voltage approach the bridgewire actually explodes as a result of energy discharge of a capacitor, (charged to usually no higher than 2500 volts), igniting an explosive material with the shock wave created; thus the reference to exploding bridgewire, (EBW), systems."

radiation, and provide essentially instantaneous initiation[5]. This method is commonly referred to as explosive stimulus transfer.

- Laser - This new initiation stimulus consists of transmitting coherent light through a fiber optic cable to an igniter. The latter contains an optical window with a heat or light sensitive pyrotechnic composition pressed against it. Because this system is relatively new, system weight has not been optimized. This type stimulus system is unaffected by electromagnetic radiation.

Pyrotechnic devices can perform a variety of functions and are available to the designer in a number of generic forms, (Reference 1). Figures 2 through 8 graphically illustrate some of the more popular pyrotechnic devices found on aerospace systems. Figures 2 and 3 illustrate linear explosives in both shaped and circular form. The explosive cord is a detonating material such as RDX, PETN, or Dipam. The circular cord[6] is also used in stimulus transfer systems providing signals to various events at the rate of about 6100 m/sec (20,000 ft/sec), and is unaffected by electromagnetically induced current.

Figure 4 shows six explosive bolts differing in separation characteristics. They all provide release or separation at a prescribed plane. The selection of one versus another is generally based on a limited trade-off, based on systems requirements.

Explosive valve principles are shown in Figure 5. Gas cartridge pressure moves a spool or plunger to provide a passageway or to obstruct same. The valve on the right has the capability to both open and be reclosed.

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[5] "(transfer rates in the order of 6,100 m/sec - 20,000 feet/sec.)."

[6] "is the material used in the explosive stimulus transfer systems."

Figure 6 shows three fundamental explosive nuts. Type I contains a piston to forcibly eject the bolt, whereas Type II merely releases same. Type III relies on explosive cartridges to force apart the nut halves.

Linear actuators as shown by Figure 7 are straightforward devices to provide a push or pull. Examples are canopy removers or pin pullers.

Guillotines (Figure 8) are widely used to sever wires, tubes, reefing lines, and/or any item requiring quick disconnect.

Pyrotechnic Reliability - The only positive method to determine whether a pyrotechnic device will function satisfactorily is to test fire it. The high reliability and confidence level customarily imposed would require very large numbers of devices to be fired in order to fulfill the requirements. For example, a .999 reliability at a 95% confidence level requires the test firing of 2996 devices without a failure. The cost of this demonstrated reliability generally proves to be prohibitive. Therefore, the alternative is to use a statistical approach which must be based first and foremost on a thorough understanding of the hardware design and its margin.

The philosophy behind this approach is based on simple statistics. As long as these statistics follow a normal distribution, the approach discussed above can be followed. Figure 9 shows two curves depicting normal distribution about a mean for the energy required to perform a particular function and that available in the pyrotechnic cartridge. As long as the two curves remain separated throughout the operating temperature range, satisfactory performance is assured. However, if there should be any overlapping of the two curves then random failures, victims of statistical distribution, can be expected. If a quantitative approach has been followed, there is no reason for ever allowing the latter condition to occur. Both the energy available and energy required can be measured and statistically analyzed.

Redundancy - A definition of redundancy is superfluous repetition, or use of parallel paths to perform a single function. Because of the crucial nature of many aerospace pyrotechnic applications, redundancy is considered necessary to prevent single-point failures. Even with two independent paths, adequate redundancy exists only if proper attention has been given to design margins and quality control, from development through final installation. If redundancy is necessary, however, the depth of implementation must then be determined, for example, from simply redundant initiators to completely redundant systems. In astronautics, specifically the Apollo program, pyrotechnic applications were divided into two principal categories; namely, crew-critical and mission-critical. Premature operation or failure of the pyrotechnic to operate properly was considered crew-critical, since this might result in loss of the crew. The mission-critical category covered those pyrotechnic functions which in the event of failure could result in an aborted mission or an alternate mission. The extremely critical nature of the pyrotechnic functions onboard Apollo dictated a philosophy of maximum redundancy where possible. This is graphically illustrated in Figure 10.

It should be noted that during the early development phases of the Apollo program when the redundancy requirements for the pyrotechnic systems were less clear, redundancy was taken a step beyond that shown in Figure 10; namely, the initiators contained dual circuits, each with a single bridgewire. This was the Apollo Standard Initiator (ASI). As the program progressed, it became apparent that the desired reliability and redundancy could be more readily attained at higher levels of the pyrotechnic assembly; therefore, the ASI was replaced by a cartridge containing a single circuit with a single bridgewire known as the SBASI (Single Bridgewire Apollo Standard Initiator).

Both the F-111 crew module and the F-14 personnel ejection systems are notable aeronautic examples of redundant pyrotechnic applications. Both systems utilize an explosive rather than ballistic hot gas as a stimulus system to sequence the escape functions. This requires the use of a sizable number of shielded mild detonating cord (SMDC) assemblies. Since the F-111 crew module pioneered the use of SMDC, redundancy was initially implemented to provide assurance of firing a system whose reliability of operation had not been proven. In the F-111 and F-14 crew escape systems, redundancy also protects against the possibility of an SMDC assembly being damaged during installation and failing to propagate the explosive signal.

Finally, and most important, redundancy should never be employed in such a manner that will permit introduction of a single-point failure. For example, Figure 11 shows two redundant pyrotechnic time delay columns terminating in explosive tips, which in turn initiate the tips of SMDC lines. For added "redundancy" an explosive cross-over has been added between the two output tips. Because of the nature of pyrotechnic time delays, one delay will most probably burn faster. If the output of this faster delay should initiate low order, then it will fail to initiate the SMDC tip directly facing it. Further, the cross-over will also propagate low order and may very well arrive before the second delay initiates its own output tip. In this case it will destroy both the output tip of the delay as well as the second tip. The result is complete failure of the device.

By omitting the cross-over, as shown in Figure 12, the failure of the first delay cannot interfere with the operation of the second; thereby providing complete redundancy.

Testing - A properly constructed test program to demonstrate all of the requirements of a new design is a vital, non-replaceable portion of the pyrotechnic designer's effort to produce a successful system or device. Improved techniques in the field of testing have provided the designer with the means to obtain quantitative data with a higher degree of accuracy from each test firing than ever before possible. Some examples of these improved techniques are:

- Tapered Plate Test Technique for Linear Explosives (Severance Ability)
- Energy Sensor (Cartridge and/or Detonator Output)
- Dynamic Test Device (Energy-Displacement Performance)

The aforementioned techniques are by no means all that are available for performance monitoring; however, they do represent some of the latest methods, designed to provide engineering type measurement and analysis.

An excellent treatise concerning the above-mentioned test techniques is to be found in Reference 2.

Safety - Pyrotechnic materials such as high explosives or propellants are by definition unstable chemical compounds designed to release energy upon initiation. Pyrotechnic safety must not be viewed only from the inert end of the unstable spectrum since extreme insensitivity imposes severe restrictions on the initiating, or "all fire," reliability[7].

Essentially, it is a balance between how insensitive a device or system can be made compared with its reliability of functioning on command. Safety must be carefully balanced with reliability by the pyrotechnic specialist so that the optimum of both diametrically opposed extremes is realized. The specialist must utilize his knowledge of explosive materials, including such factors as sensitivity, compatibility, performance, environmental ability plus evaluation techniques in order to achieve the necessary reliability within the limits of safe handling and use. This concept is illustrated in Figure 13.

The use of discrete safety devices, known as safe and arm (S & A) mechanisms, is generally restricted to systems that represent extreme hazard to personnel who must work around them. Under these circumstances, S & A's which in essence are simply mechanically interrupted explosive trains, are usually incorporated. Ignition of large rocket motors and initiation of propellant dispersion or destruct systems are examples of applications requiring S & A devices. Since these S & A devices add to the system complexity, part of the functional reliability is compromised.

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[7] "For example, some explosives cannot be initiated to function in their normal mode by direct flame or impact by direct gunfire. However, only a closely controlled, high level explosive input can produce proper initiation."

Trade Studies - The trade study is an analytical process by which selection of an optimum approach, compatible with the specific program requirements, can be determined. Examples are: comparison of pyrotechnic, hydraulic, and pneumatic approaches to determine the best suited for a specific task, or comparison of several different pyrotechnic devices, each capable of providing the desired end result. Frequently, trade studies do not progress beyond a certain point because of an obvious advantage of one approach. However, when this is not the case, a complete study must be made. In performing trade studies, one word of caution is warranted: namely, that it is very easy to allow personal bias to influence the result.

Standardization - Standardization in any system is desirable from a number of aspects, including qualification testing, interface control, reliability analysis, and the logistics of supply. Generally, standardization is limited to initiation and/or the transfer of the initiation stimulus to the end pyrotechnic item. Standardization also permits commonality of design principles in the end item. It is inconceivable to attempt standardization of specific work items such as actuators, explosive bolts, explosive valves, etc., since most items are unique in their geometry and performance requirements. An excellent example of a standardized item of pyrotechnic hardware is the SBASI. This is the standard electrical initiator used throughout the Apollo and LEM vehicles. (References 3 and 4).

The utilization of off-the-shelf hardware should be attempted wherever possible insofar that an item will be compatible with performance and interface requirements. A caution on the use of the off-the-shelf hardware should be made. This hardware should be thoroughly demonstrated in the planned system. Often times, many off-the-shelf items do not meet the unique requirements of individual systems.

Phase II - Historical Applications Survey

Prior to World War II, escape from a disabled aircraft in flight occurred in environments and at speeds that were physiologically tolerable. As speeds increased, the technique of turning the aircraft on its back, releasing one's safety belt, and falling out was no longer feasible. The parachute by itself was not adequate for survival.

The Germans took the first effective action in 1944, requiring all fighter aircraft to be equipped with ejection seats. Some 60 ejections were reportedly made prior to the end of the war. The British and the USA followed with appropriate development programs resulting in some standardized hardware by 1947.

In addition, a 4-gauge blank cartridge was successfully used during World War II to start certain aircraft piston-type engines. The cartridge, containing relatively fast-burning propellant was fired into one of the pistons, thus spinning and starting the engine. This 4-gauge cartridge later was modified and utilized as a stores and/or weapons ejection cartridge.

Aeronautics - Since the initial post-World War II inception, pyrotechnics have been increasingly used aboard military aircraft for many applications including personnel emergency egress and weapons separation. The speed of the aircraft has logically predicated the development of pyrotechnic hardware as to sophistication of performance and design. As an example, the early M-1 personnel catapult is relatively straightforward as compared to the latest rocket catapult for today's high-speed fighter aircraft.

It is beyond the scope of this study to delineate all of the pyrotechnic systems and/or components utilized aboard today's fighter aircraft, not to mention the many now obsolete models. Therefore, selected aircraft or systems were chosen as representative for study. In addition, no attempt is made to show all pyrotechnic hardware ever developed as this can be found elsewhere in vendor or government publications. Table I shows a brief review of some of the more significant and representative applications.

In the military aeronautical field, the use of pyrotechnics is about equally divided between stores or weapons ejection and personnel escape systems. The field of personnel escape is by far the more complex and offers the greater challenge to the pyrotechnics engineer. Study emphasis was therefore placed on escape systems, with limited mention of other pyrotechnic systems and/or components.

The field of personnel escape systems (Reference 5) for military aircraft provides three significantly different approaches; namely, the open ejection seat, an encapsulated ejection seat or a crew module. One each of these systems was selected for study. Appendix I covers the open seat system pyrotechnics as found on the F-4 aircraft. This application is for a dual-place tandem ejection system utilizing sequencing, rocket-assist separation, and a ballistic hot gas stimulus transfer system.

The encapsulated seat pyrotechnic system, as utilized aboard the B-58 bomber, is shown in Appendix II. The pyrotechnic components list, along with a block diagram of the sequence of events, is shown. This encapsulated seat system provides an improved escape capability over the open ejection seat. The stimulus transfer technique employed is a combination ballistic hot gas and electric.

The crew module approach, in which the entire crew compartment is separated from the fuselage, represents the most advanced system from the standpoint of escape envelope and post-escape survival. The crew module system as utilized aboard the F-111 was selected for review. Appendix III delineates the pyrotechnic system and includes a list of the mechanical functions. This pyrotechnic system utilizes a high explosive stimulus transfer system of shielded mild detonating cord (SMDC). The explosive used in the cord is the Naval Ordnance Laboratory (NOL) developed high temperature resistant DIPAM of 2 1/2 grains/ft charge. The system is redundant as shown by the schematic outline.

A trade study was conducted on a hypothetical supersonic bomber relative to selection of open seats, encapsulated seats or a crew module. The results of this study are listed in Appendix IV.

A typical missile, namely the Shrike AGM-45, carried and launched by aircraft is delineated in Appendix V. The pyrotechnic items and sequence of pyrotechnic events are shown to complete the cross-section review of military aircraft.

The use of pyrotechnics aboard civilian or commercial aircraft has been minimal. Some progress has been achieved in recent years aboard the 747 transport. This utilization for door unlatching and slide chute deployment is shown in Appendix VI, entitled "Unique Pyrotechnic Applications." This appendix also includes a number of military pyrotechnic systems which appear unique in application and/or functional accomplishment.

Astronautics - The use of pyrotechnics in the astronautics field parallels somewhat aeronautics in that they were used to some degree during early rocket and missile development. Extensive utilization, however, did not occur until the advent of the more prominent spacecraft, and especially Project Mercury. With the Apollo series, pyrotechnic usage aboard spacecraft reached a new high level. Major past and current pyrotechnic applications in the field of astronautics is shown in Table II.

Mercury, the first U.S. manned spacecraft (Reference 6), utilized a relatively large quantity of pyrotechnic items, a number of which were redundant because of the many functional and environmental unknowns and the strong desire to assure mission success. Project Mercury was unique in that electrical initiation was used rather extensively along with ballistic hot gas. Mercury also perhaps accomplished the earliest use of linear explosive cord. Two strands of 5 grain/ft cord were used to break 70 titanium bolts around the periphery of the entrance hatch, which provided emergency and routine egress. Appendix VII provides a summation of all the pyrotechnic functions and items utilized aboard Mercury.

Project Gemini (Reference 7) pyrotechnic usage is shown in Appendix VIII and demonstrates the increased usage of pyrotechnic items over Mercury. Project Gemini pioneered the use of shielded mild detonating cord (SMDC) and the use of the high temperature resistant explosive DIPAM (Reference 8). It is interesting to note that Gemini, unlike Mercury or Apollo, utilized open ejection seats for escape from the craft while on the launching pad or at some low level after launch. Both Mercury and Apollo included a large rocket capable of lifting the complete capsule to a safe height in the event of a pad abort.

Project Apollo pyrotechnic utilization is shown in Appendix IX and represents an advanced system. Significant in the Apollo pyrotechnic systems is the use of the Apollo Standard Initiator (ASI). In terms of reliability this represents one of the better pyrotechnic accomplishments in the industry.

The Saturn V launch vehicle was also included, because it reflects typical functions that are found on larger booster systems (Appendix X), but is unique in its use of exploding bridgewire (EBW) devices in conjunction with explosive stimulus transfer for initiation of all pyrotechnic functions. The review of pyrotechnic usage in astronautics was completed with a tabulation of pyrotechnic functions on a typical unmanned satellite. The Mariner Mars '71 spacecraft, Appendix XI, was selected as representative of this category.

Phase III - Possible Pyrotechnic System Application to Modern Aircraft

The study of possible pyrotechnic applications for Space Shuttle would not be complete if only the obvious typical applications were included. The Space Shuttle is unique in that it combines many aspects of space and aeronautical design and function. The dual role of spacecraft and aircraft, along with mission objectives and size of the Orbiter vehicle, resulted in the obvious similarity to a large modern widebody aircraft. Therefore this phase of the study was directed toward a theoretical consideration of pyrotechnic applications to a modern aircraft. Since an abundant supply of power and redundancy exists on today's modern aircraft; it must be pointed out that the items studied for possible application of pyrotechnics are not to be interpreted as recommended conversions for the aircraft, but should be considered merely as functional considerations for the Space Shuttle where different power sources and philosophies of redundancy may exist.

Figure 14 depicts a typical large jet transport and identifies various mechanical functions for possible pyrotechnic consideration. Availability of detailed information relative to weight and energy requirements of mechanical systems prompted the selection of the DC-10 as the study baseline.

The initial step in this analysis was to review the methods whereby aircraft power is converted into mechanical work. Methods of energy conversion differed sufficiently between aircraft manufacturers to make it necessary to also include certain Boeing 747 mechanical systems in order to be fully representative. This review revealed the fact that the DC-10 (Figures 15 and 16) uses hydraulically powered linear actuators exclusively for operation of all control surfaces. The Boeing 747, on the other hand, utilizes hydraulically powered ball screw actuators for operation of control surfaces, except for the leading edge flaps, which are powered by pneumatics.

In order to understand and compare proposed systems with existing hydraulic and/or pneumatic applications, a comparison was made as shown in Appendix XII. Since pyrotechnics normally produce hot gas as the result of an exothermic reaction, their application as a power source can be referred to as hot gas pneumatics or pyro-pneumatics. The principal advantages of pyro-pneumatics is simplicity in that only a single energy conversion is required. Three basic energy sources for pyro-pneumatic power were considered: solid propellants, liquid mono-propellants, and liquid bi-propellants with specific impulse ranges of 160-250 seconds, 130-250 seconds, and 200-390 seconds, respectively.

The methods of generating pyro-pneumatic power are shown in Figure 17. The simplest approach is obviously a solid propellant generator (Reference 9) applied directly to a hot gas operated actuator. A typical application of an existing generator as found on the Sidewinder missile is shown schematically in Figure 18. Solid propellants are generally limited to relatively short operating times. A start-stop capability or sequential firing of additional units could extend this time.

Liquid mono-propellants do increase the operation time. They do, however, possess limitations in that they require (1) initial pressurization of the propellant storage tank, (2) a thermal decomposition chamber or catalyst bed for propellant combustion or decomposition, and (3) a solid propellant initiator for each start when thermal decomposition chambers are used.

Aircraft mechanical systems can be grouped in two categories; namely, those requiring continuous operation, such as elevators, and those operated infrequently or only once per flight, such as landing gear extension. Because of the current limitations on time duration and start-stop capability, the continuous operation functions were not considered for detailed study.

Table III shows a summary of the mechanical systems considered and their potential for pyrotechnic application.

Systems requiring either single-shot or relatively short-duration energy were reviewed. Typical of these type applications is the emergency slat actuation system as shown in Appendix XIII along with a brief comparison of physical characteristics.

Phase IV - Definition of Mechanical Requirements and Possible Pyrotechnic Applications to Space Shuttle

Shuttle pyrotechnic applications are unique in that most Shuttle components are to be recovered, refurbished, and used again. Pyrotechnic systems selected for Shuttle use, will consider refurbishment and/or replacement as related to the turnaround time required and economics. In some instances, it will be more economical and quicker to replace an item rather than removal, teardown, and replacement of expended parts.

The mechanical functions aboard Shuttle that can most logically be accomplished with pyrotechnics will probably fall into one of two categories. The first category of applications is that of a relatively short-time duration and of a one-shot-only nature. The second category of potential pyrotechnic items will include longer-duration functions.

Category I pyrotechnic applications will include many basic functions such as severance, separation, initiation or ignition, stimulus transfer, valving, and switching. Although a large variety of designs and hardware exist, it is probable that Shuttle requirements will necessitate modification, redesign, and/or new hardware. This is especially true with respect to the quick turnaround concept.

Appendix XIV contains a pictorial schematic of the location of a number of potential pyrotechnic applications, along with a list of some of those showing suggested units for functional accomplishment. The schematic and list, mostly covering category I applications, does not necessarily represent all of the possible applications that may ultimately be used on Space Shuttle.

Two of the most important pyrotechnic systems utilized will be the initiation and signal transfer systems. With respect to ignition, the Apollo Standard Initiator (ASI) will be used for many applications. Care should be exercised, however, in using any electric initiator in simultaneous multitudinous events which could over-tax the supply of available electric energy and affect the system's reliability. To preclude this possibility, it is good design practice to combine the ASI with shielded mild detonating cord (SMDC). SMDC is widely used in a number of forms (rigid and flexible). The use of the ASI and SMDC will provide an interface control for the many individual pyrotechnic items to be found.

The second category of potential pyrotechnic items will include a somewhat longer-duration function. Shuttle mechanical functions to be considered in this category include orbiter gear extension, air-breathing engine starting, pressurization of hydraulic accumulators, pneumatic system pressurization, vane motor actuation for miscellaneous work functions, and large actuator separation systems.

A relatively large number of gas generators utilizing solid propellants is in existence. These gas generators, having a nominal operating time of up to 60 seconds, may have considerable merit for adaption to a number of mechanical functions on the Space Shuttle. They have been developed to power turbine-driven auxiliary power units (APU's), hot-gas servos, piston motors, turbine pumps, turbine starters, and nutating disc actuators. It should be noted that some gas generators have been developed, with a continuous burning time of up to six minutes.

A trade study considering the use of a gas generator/vane motor combination, in place of a manual back-up system for operating the radiator and payload bay doors, is shown in Appendix XV. The weight reduction realized might be further increased if one of the electric motors (and parts of the differential gear associated with it) could be eliminated.

CONCLUSIONS

Pyrotechnics have been and will continue to be widely used aboard aerospace vehicles to perform a wide variety of work and emergency functions wherever independent, reliable, self-contained energy systems are required.

Many unique advancements have been made in pyrotechnic utilization and understanding. Aeronautics have produced personnel-escape and weapons-release systems. Astronautics have produced pyrotechnic systems to accomplish nearly all major mechanical functions of space missions, such as personnel escape, staging, hatch removal, and valving. Engineering analysis, design, development, and performance demonstration testing can now be accomplished in a routine manner.

The most proficient usage of pyrotechnic systems and/or devices must involve the technical specialist in this field in the system design. Since pyrotechnic technology is largely unpublished and represents an expertise held by a relatively small number of people, dissemination of important experience and data from other projects and industry can only be achieved by involvement of the technical specialist at an early stage.

Pyrotechnics are generally utilized as short-duration, one-shot devices. However, they do have potential for repetitive functioning and for relatively long function times, based on existing gas generator technology. These concepts were theoretically demonstrated by considering possible pyrotechnic applications on a large commercial aircraft which approaches the scale of the Shuttle Orbiter. The study showed that although pyrotechnic applications for functions such as the operation of flight control surfaces and landing gear, do not appear practical on an aircraft due to the availability of surplus power, their consideration for similar Shuttle functions should have merit. The technology to accomplish these large-scale functions will require study and possible advancement of the state-of-the-art.

Pyrotechnic applications for the Space Shuttle should occupy a prominent role in the successful accomplishment of the overall mission. The potential applications are numerous, drawing heavily on experience derived from previous aerospace programs. Many new pyrotechnic concepts will undoubtedly be conceived out of necessity. In many applications where the choice of a mechanical system is not obvious, objective trade studies should include pyrotechnics as well as other mechanisms to provide the required information for optimum selection. The Apollo Standard Initiator (ASI) and shielded mild detonating cord (SMDC) should find extensive use. Both the ASI and SMDC will provide an excellent degree of standardization and interface control.

This study, in providing a summary of the state-of-the-art of pyrotechnic technology, and the consideration of pyrotechnic applications on a large aircraft and on the Shuttle itself, now affords the Shuttle designer a wider area of consideration through the use of pyrotechnic energy sources for a wide variety of mechanical functions.

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TABLES

TABLE I
MAJOR PAST AND CURRENT PYROTECHNIC APPLICATIONS IN AERONAUTICS

PROGRAM	NUMBER OF AIRCRAFT INSTALLED PYROTECHNIC DEVICES USED
F-4 (DUAL PLACE) (EXCLUDING ARMAMENT REQUIREMENTS)	31
F-111 CREW MODULE	315
F-14 (DUAL PLACE) (EXCLUDING ARMAMENT REQUIREMENTS)	211
F-15 (SINGLE PLACE) (EXCLUDING ARMAMENT REQUIREMENTS)	44
F-4 ARMAMENT CARTRIDGE REQUIREMENTS FOR A MISSION CONFIGURATION OF (24) 500 LB BOMBS AND 4 SPARROW MISSILES	42

TABLE II
MAJOR PAST AND CURRENT PYROTECHNIC APPLICATIONS IN ASTRONAUTICS

PROGRAM	NUMBER OF SPACECRAFT INSTALLED PYROTECHNIC DEVICES USED
MERCURY	46
GEMINI	139
SATURN	APPROX. 150
APOLLO (CSM/SLA/LM)	314
APOLLO (CSM/SLA) FOR SKYLAB	249

TABLE III
OPERATION OF AIRCRAFT MECHANICAL SYSTEMS

	SYSTEM	DUTY CYCLE REQUIREMENTS	TYPE OF CONTROL	PYROTECHNIC CONSIDERATIONS
CONTROL SURFACES	AILERONS			
	INBOARD	CONTINUOUS	MULTI-POSITION	NOT PRACTICAL
	OUTBOARD	TAKEOFF & LANDING	MULTI-POSITION	**POSSIBLE APPLICATION**
	ELEVATORS	CONTINUOUS	MULTI-POSITION	NOT PRACTICAL
	FLAPS	TAKEOFF & LANDING	TWO POSITION (MIN)	**POSSIBLE APPLICATION**
	HORIZONTAL STABILIZERS	CONTINUOUS	MULTI-POSITION	NOT PRACTICAL
	RUDDER	CONTINUOUS	MULTI-POSITION	NOT PRACTICAL
	SLATS	TAKEOFF & LANDING	TWO POSITION	**POSSIBLE APPLICATION**
	SPOILERS	CONTINUOUS	MULTI-POSITION	NOT PRACTICAL
OTHER OPERATIONS	LANDING GEAR	TAKEOFF & LANDING	SINGLE POSITION	**POSSIBLE APPLICATION**
	PASSENGER DOORS	TAKEOFF & LANDING	SINGLE POSITION	**POSSIBLE APPLICATION**
	ENGINE STARTING	TAKEOFF	SINGLE POSITION	**POSSIBLE APPLICATION**
	WHEEL BRAKES	TAKEOFF & LANDING	MULTI-POSITION	**POSSIBLE APPLICATION**

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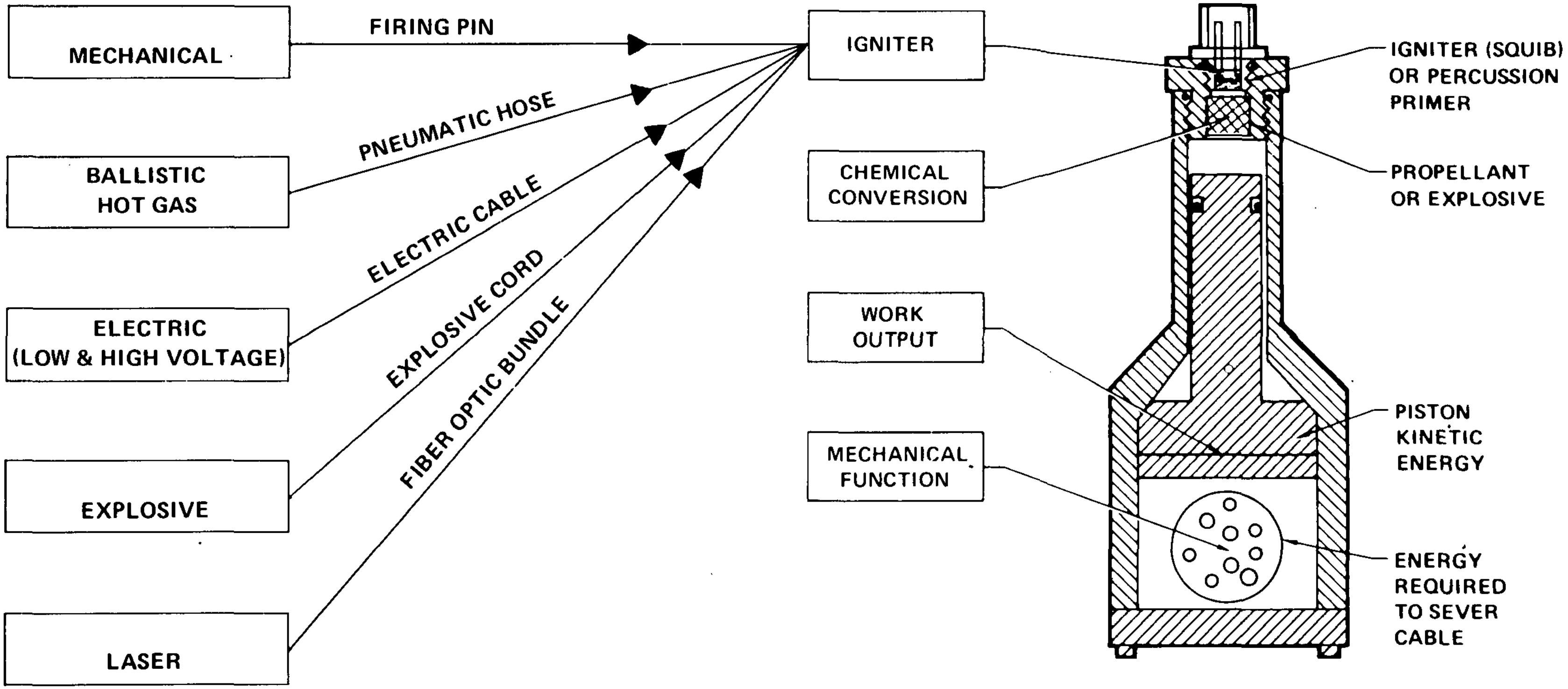


FIGURE 1
BASIC PYROTECHNIC SYSTEM

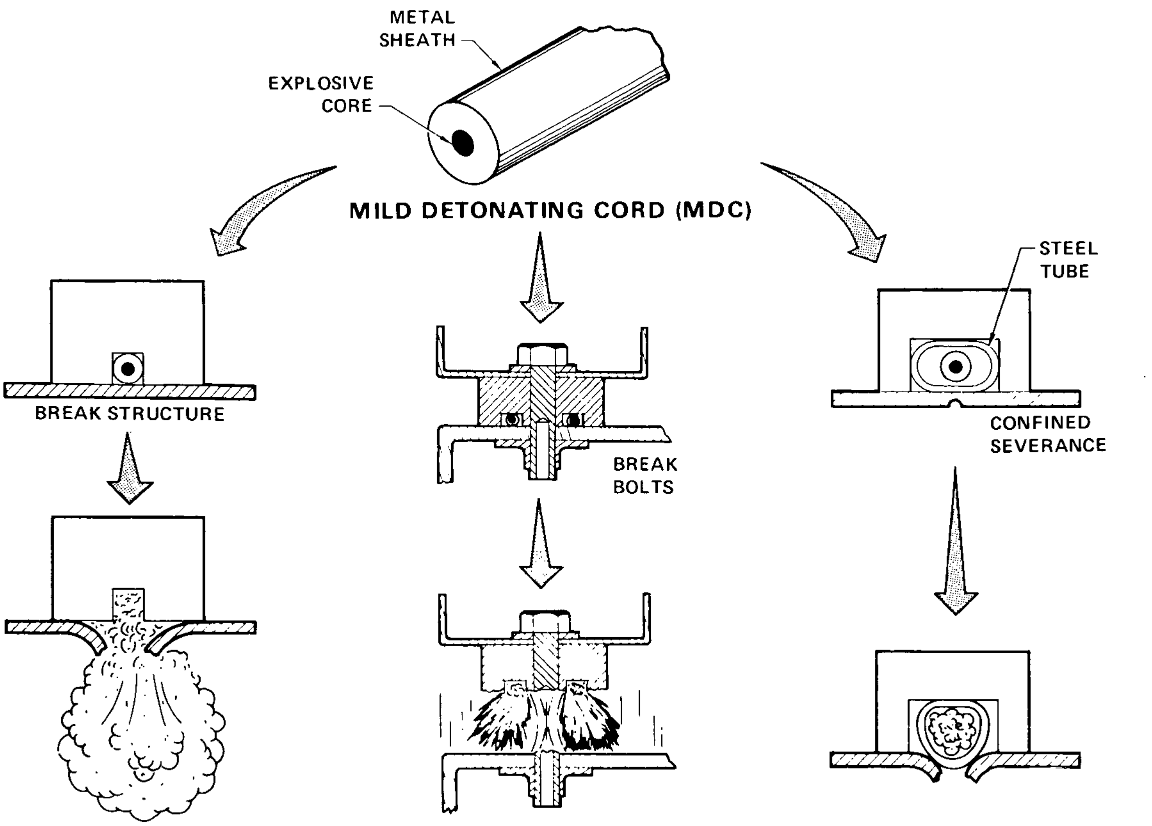


FIGURE 2
LINEAR EXPLOSIVES

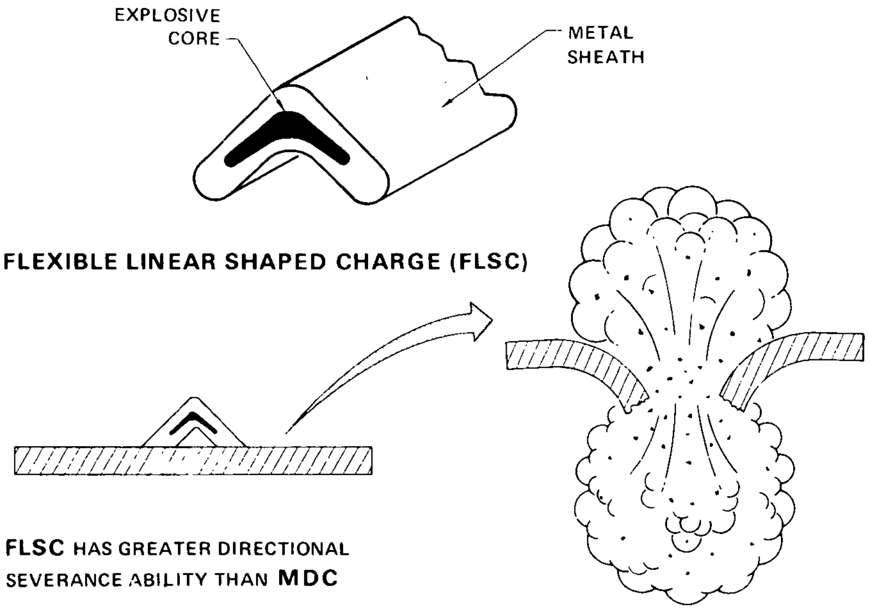
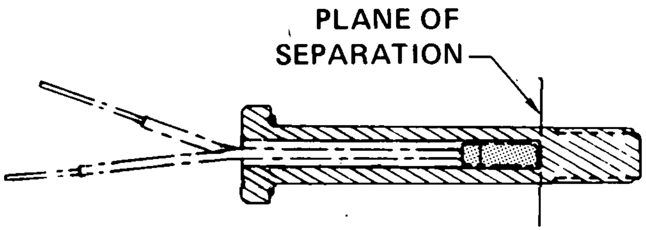
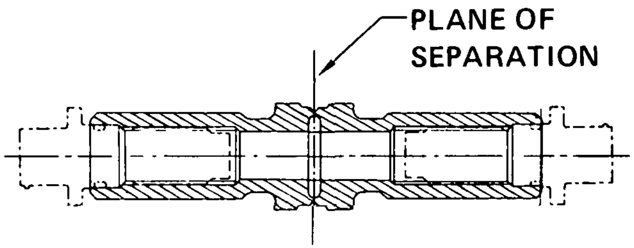


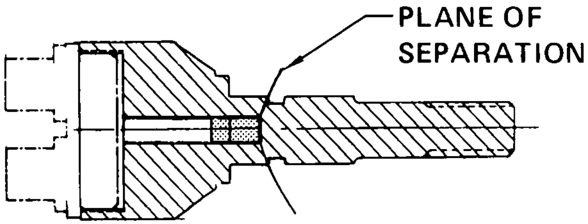
FIGURE 3
LINEAR EXPLOSIVES



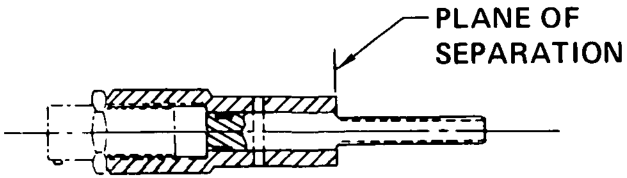
FRAGMENTING (STRUCTURAL BREAKUP)



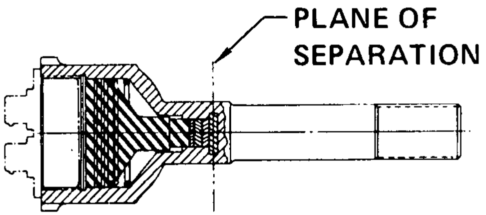
PRESSURE (TENSION FAILURE)



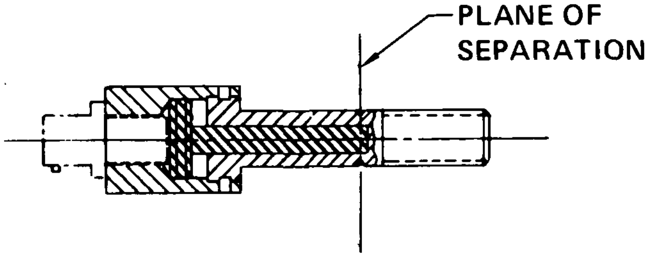
RIDGE CUT (SHOCK WAVE FAILURE)



SHEAR (SHEAR PIN FAILURE)



HYDRAULIC (HOOP/TENSION FAILURE)



PISTON (TENSION FAILURE)

FIGURE 4
EXPLOSIVE BOLTS

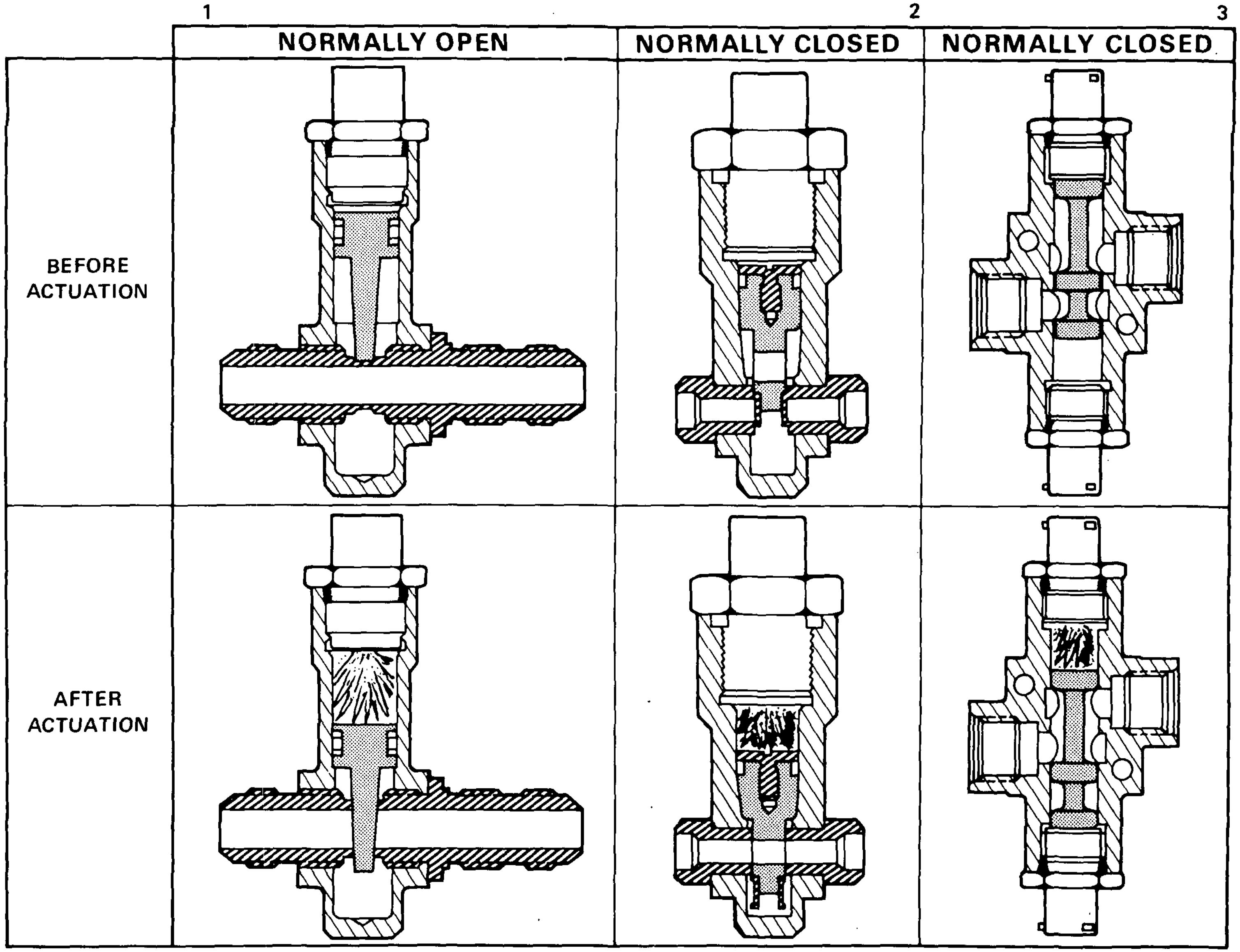


FIGURE 5
EXPLOSIVE VALVES

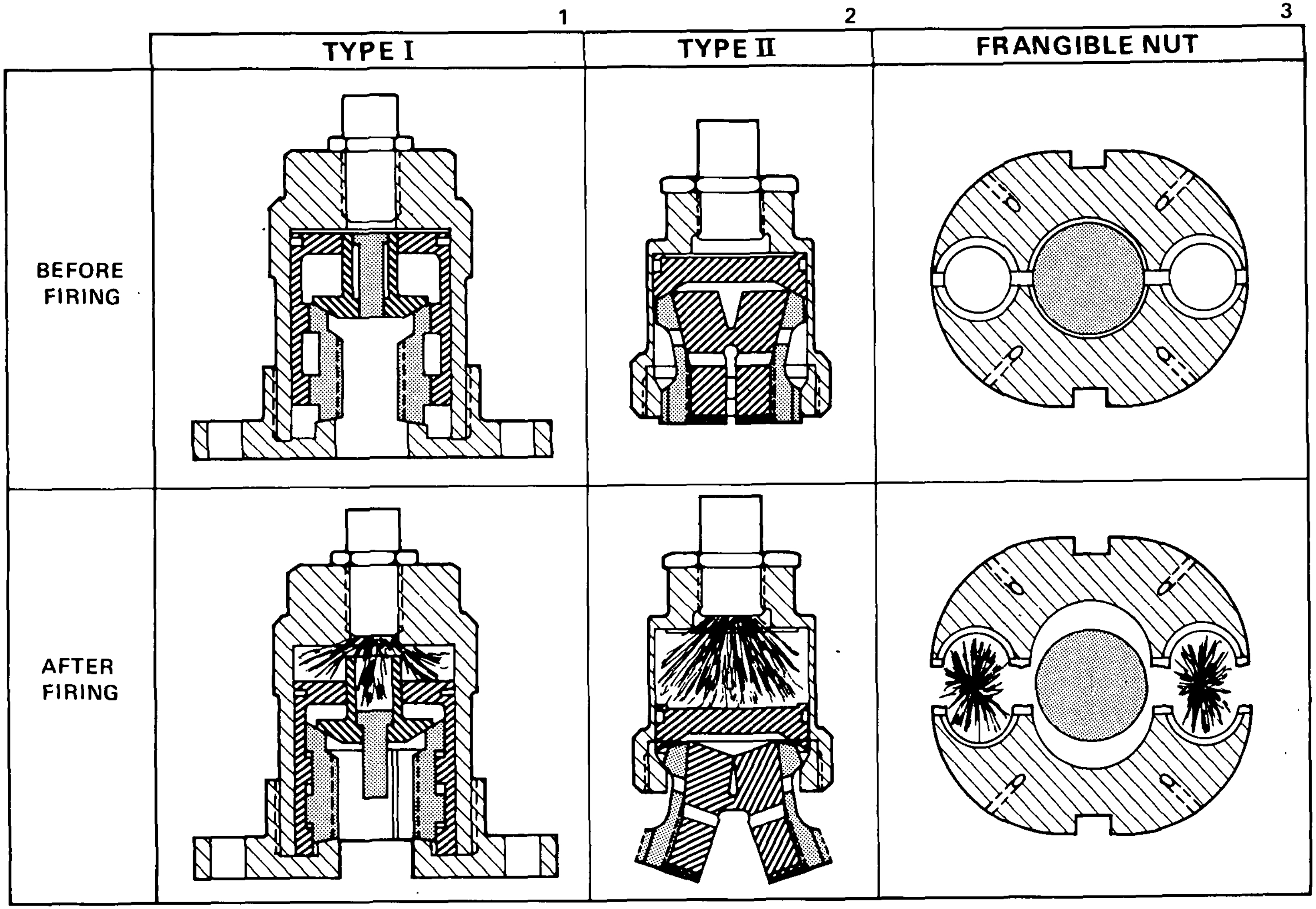
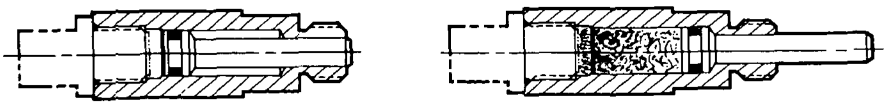


FIGURE 6
EXPLOSIVE NUTS

THRUSTER



RETRACTOR OR PIN PULLER

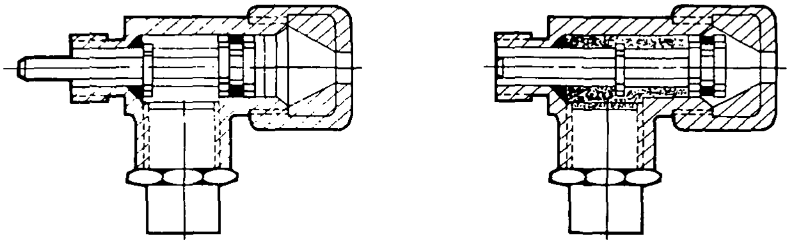
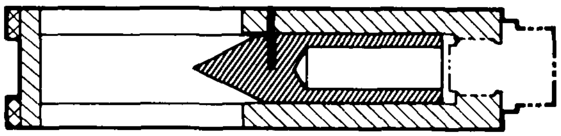
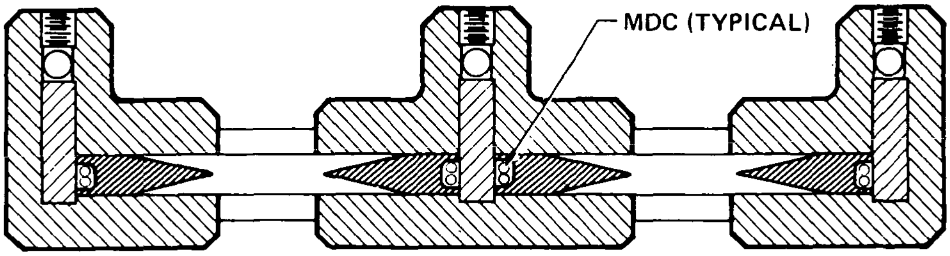


FIGURE 7
LINEAR ACTUATORS
(PROPELLANT ACTUATED DEVICES)



PROPELLANT ACTUATED



EXPLOSIVE ACTUATED

FIGURE 8
GUILLOTINES

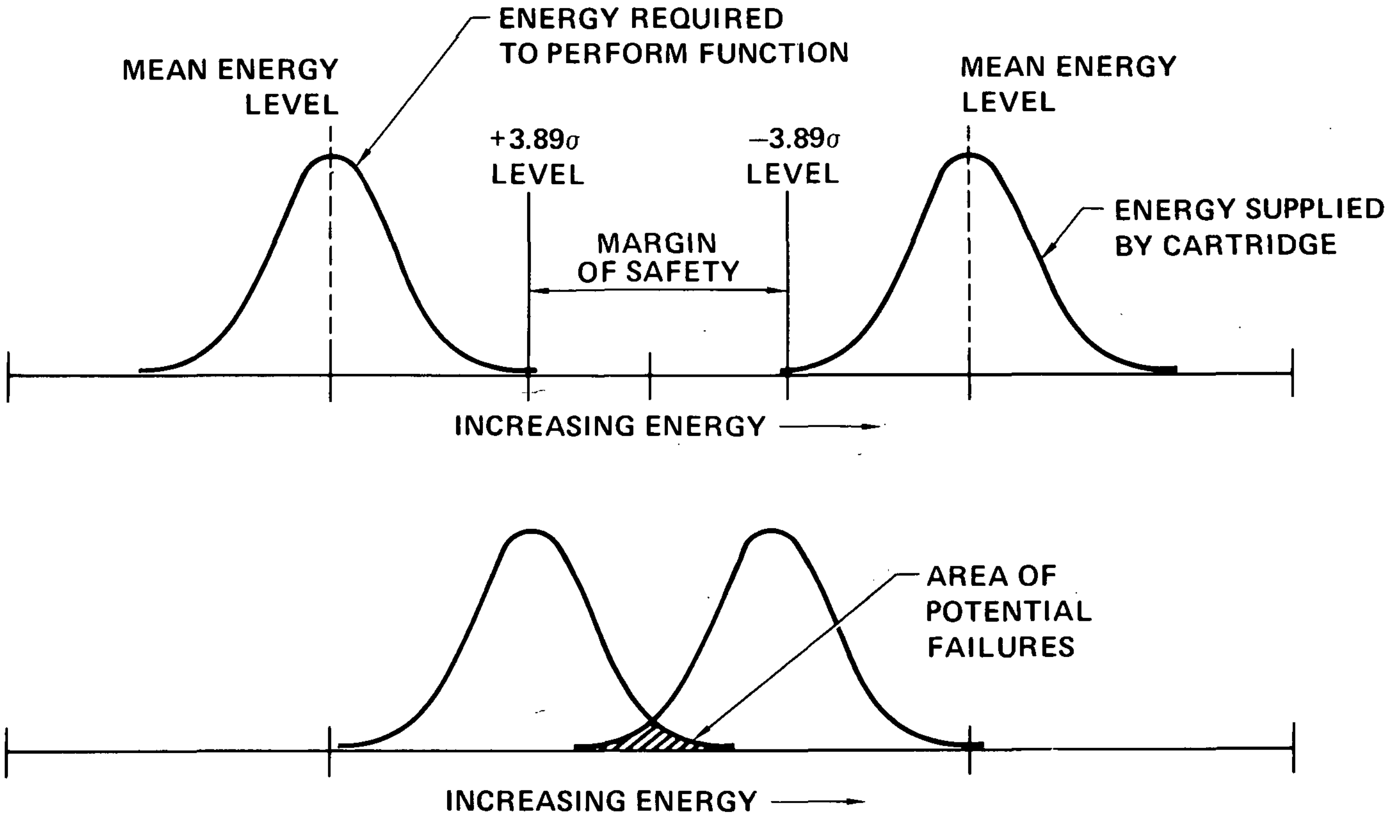
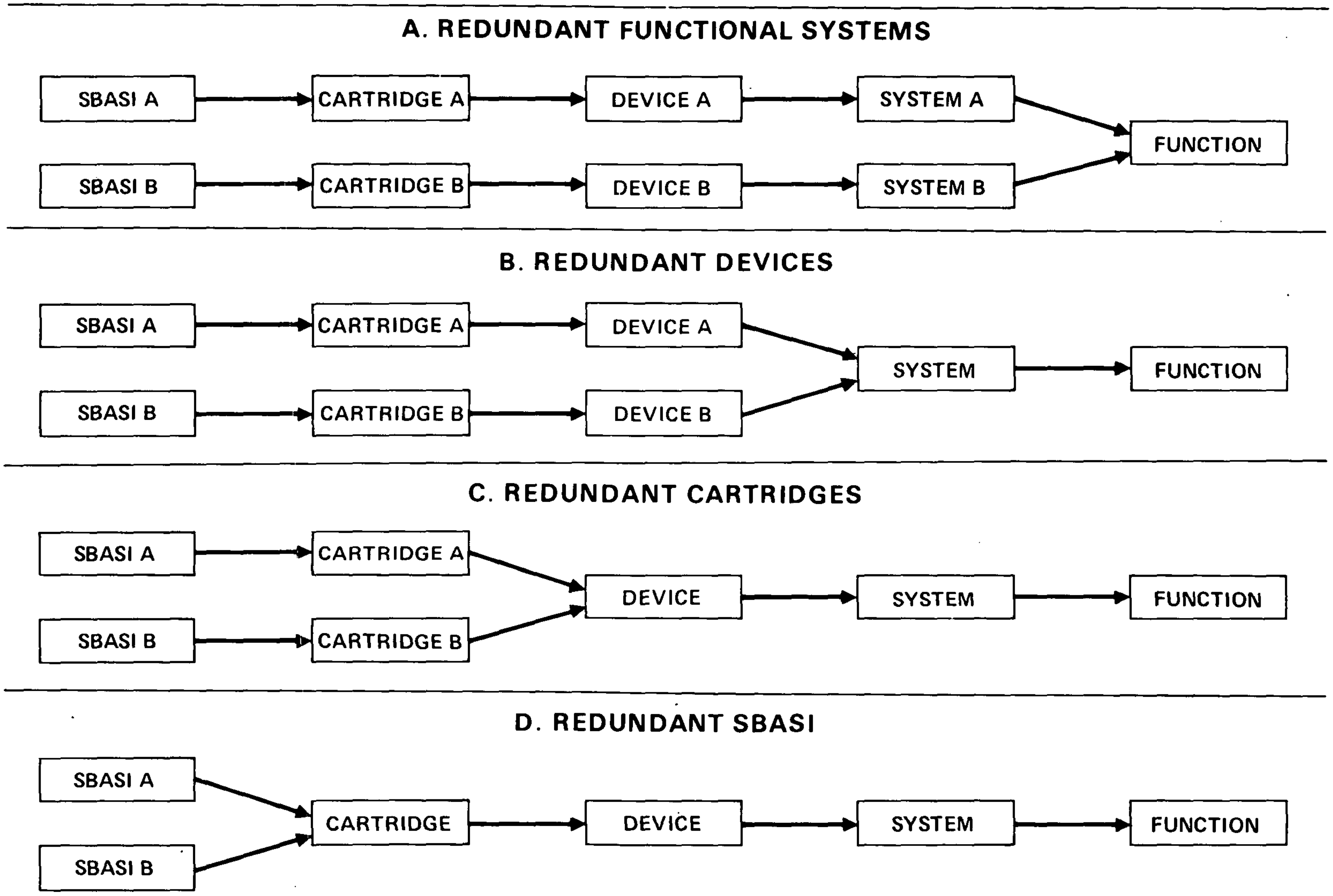


FIGURE 9
GRAPHIC REPRESENTATION OF DESIGN MARGIN



A. REDUNDANT FUNCTIONAL SYSTEMS

B. REDUNDANT DEVICES

C. REDUNDANT CARTRIDGES

D. REDUNDANT SBASI

FIGURE 10
APOLLO SPACECRAFT – LEVELS OF PYROTECHNIC REDUNDANCY

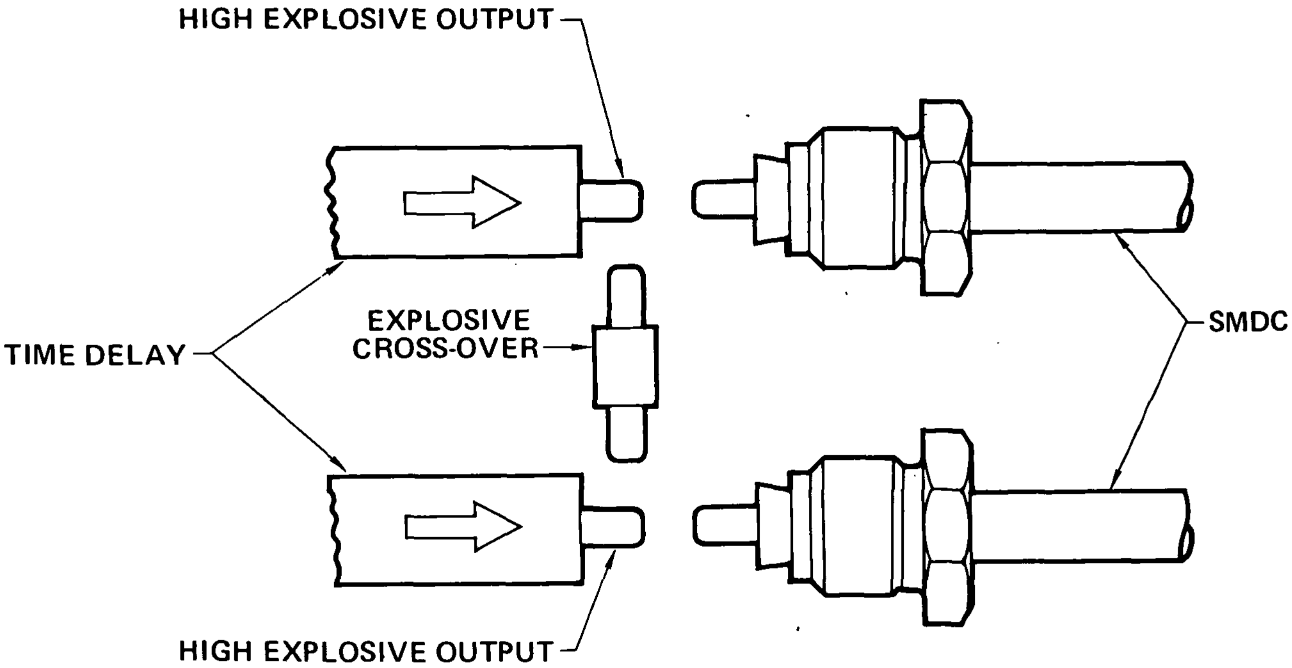


FIGURE 11
FALSE REDUNDANCY

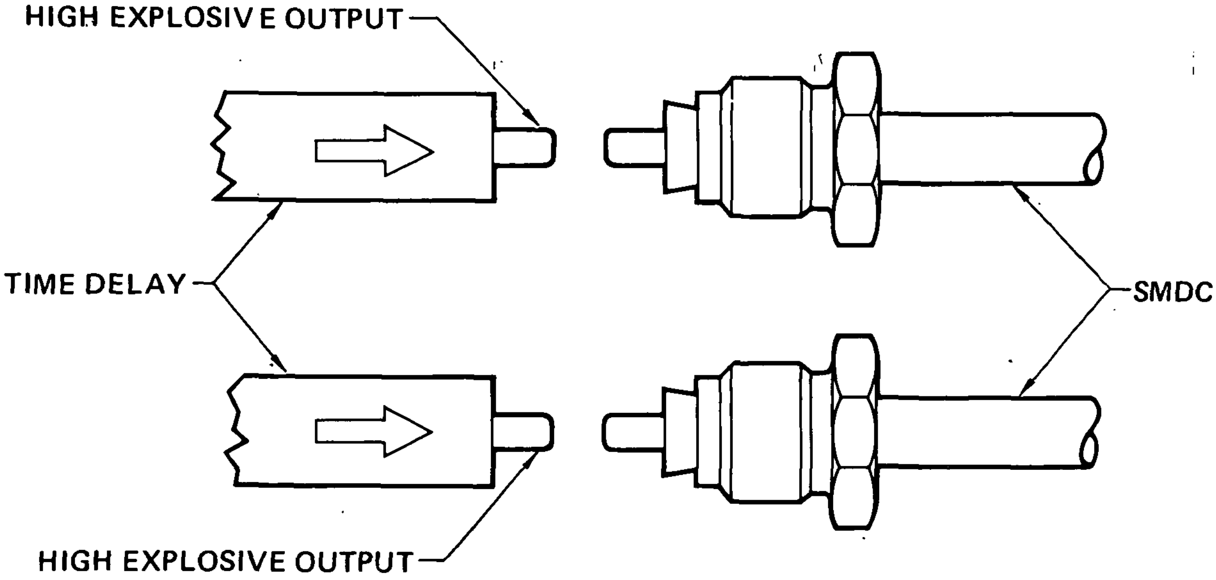


FIGURE 12
TRUE REDUNDANCY

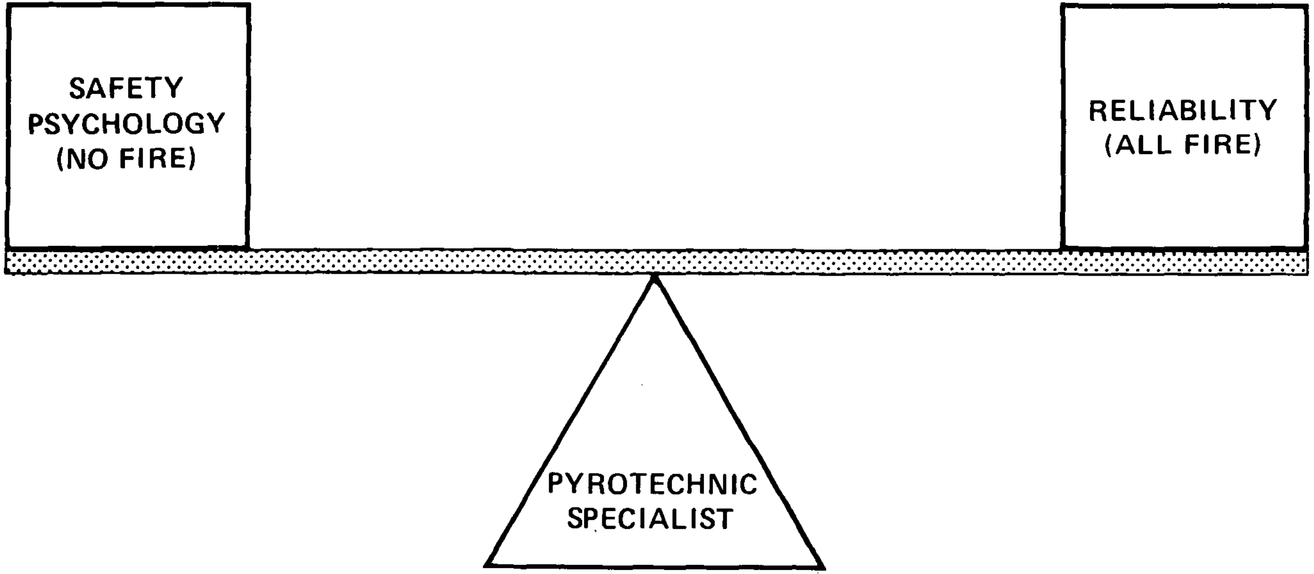


FIGURE 13
SAFETY CONSIDERATIONS

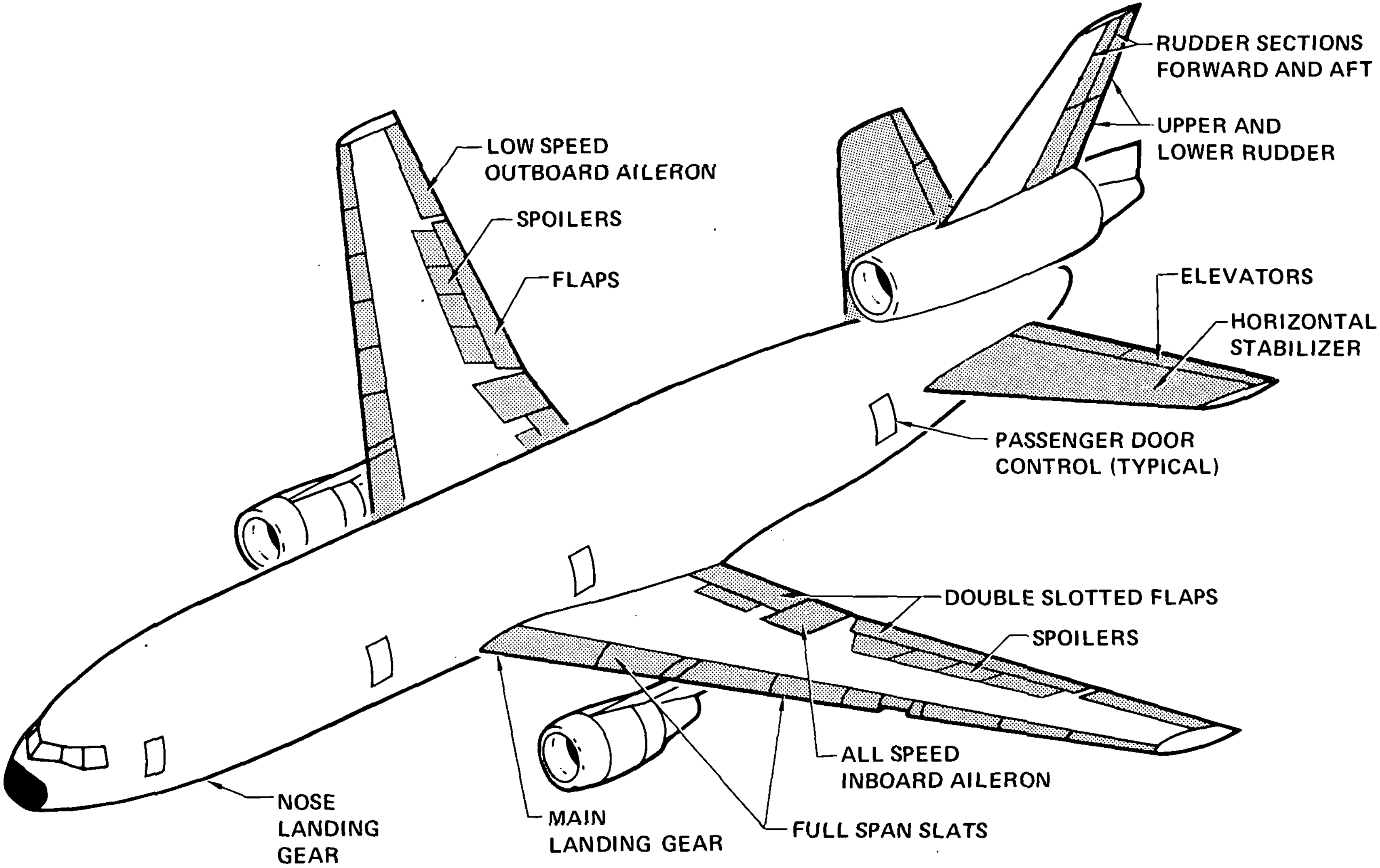
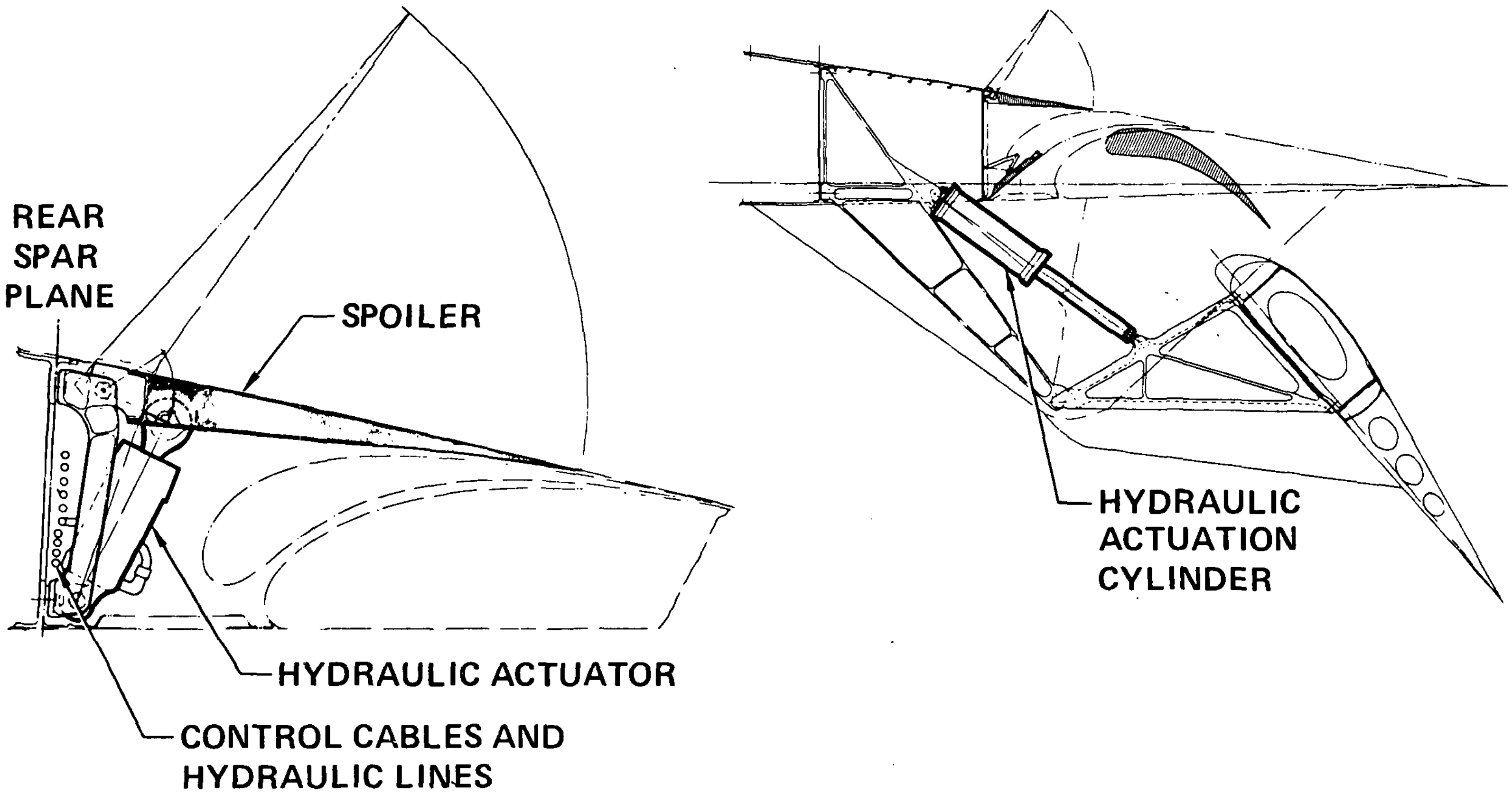


FIGURE 14
TYPICAL LARGE BODIED JET TRANSPORT
Identification of Mechanical Functions for Possible Consideration


DC-10 Outboard Spoiler

DC-10 Typical Flap Drive Hinge

FIGURE 15
TYPICAL HYDRAULIC/LINEAR ACTUATOR DESIGN CONFIGURATIONS

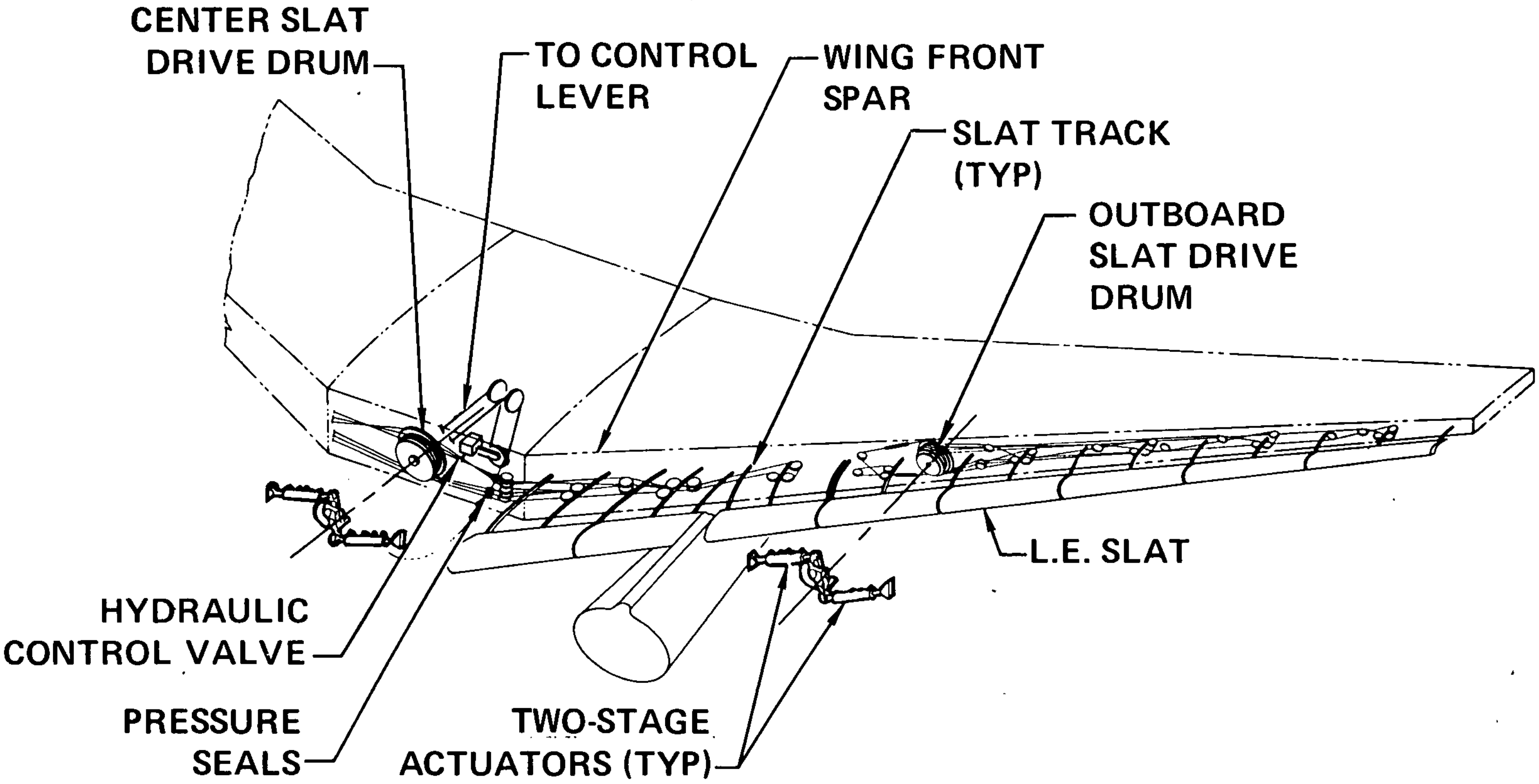
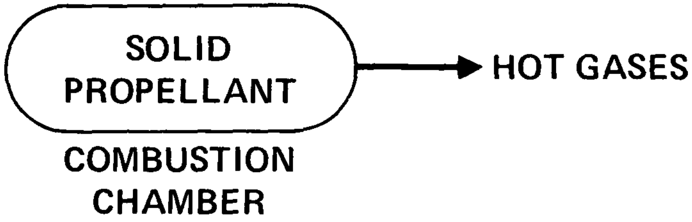
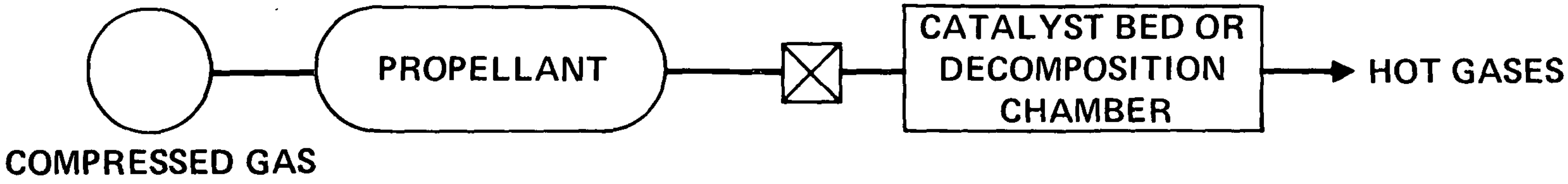


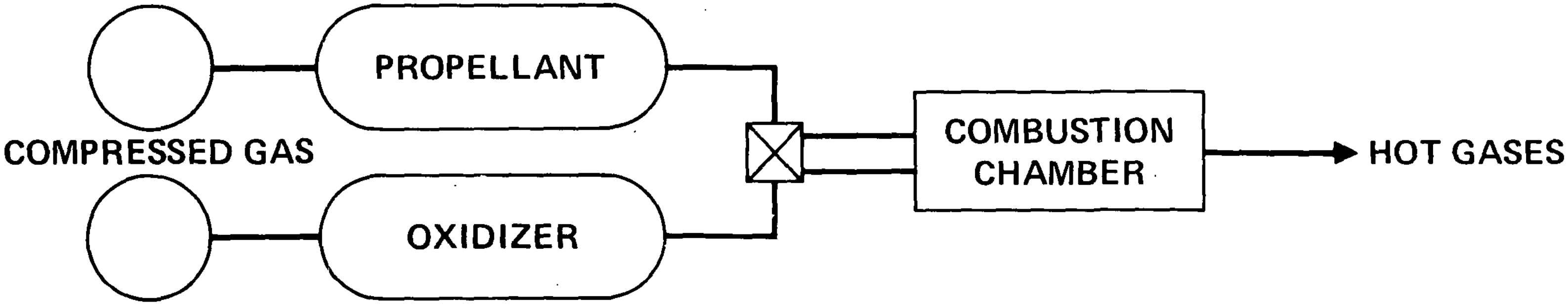
FIGURE 16
TYPICAL HYDRAULIC/LINEAR ACTUATOR DESIGN CONFIGURATIONS
DC-10 Slat Actuation Schematic



Solid Propellant



Liquid Mono-Propellant



Liquid Bi-Propellant

FIGURE 17
METHODS OF GENERATING PYRO-PNEUMATIC POWER

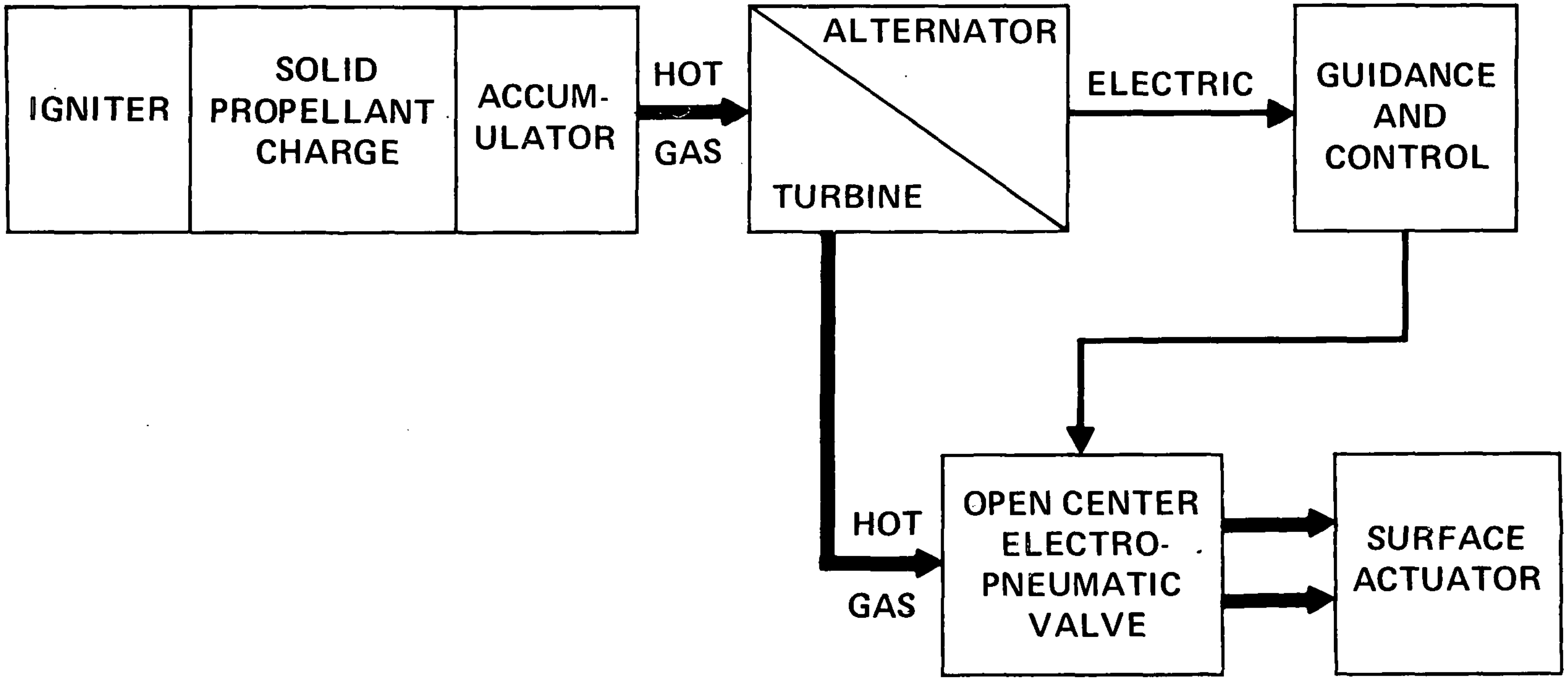


FIGURE 18
TYPICAL SOLID PROPELLANT GAS GENERATOR
(Sidewinder Air-to-Air Missile)

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APPENDIX I
TYPICAL TWO PLACE AIRCRAFT (F-4)

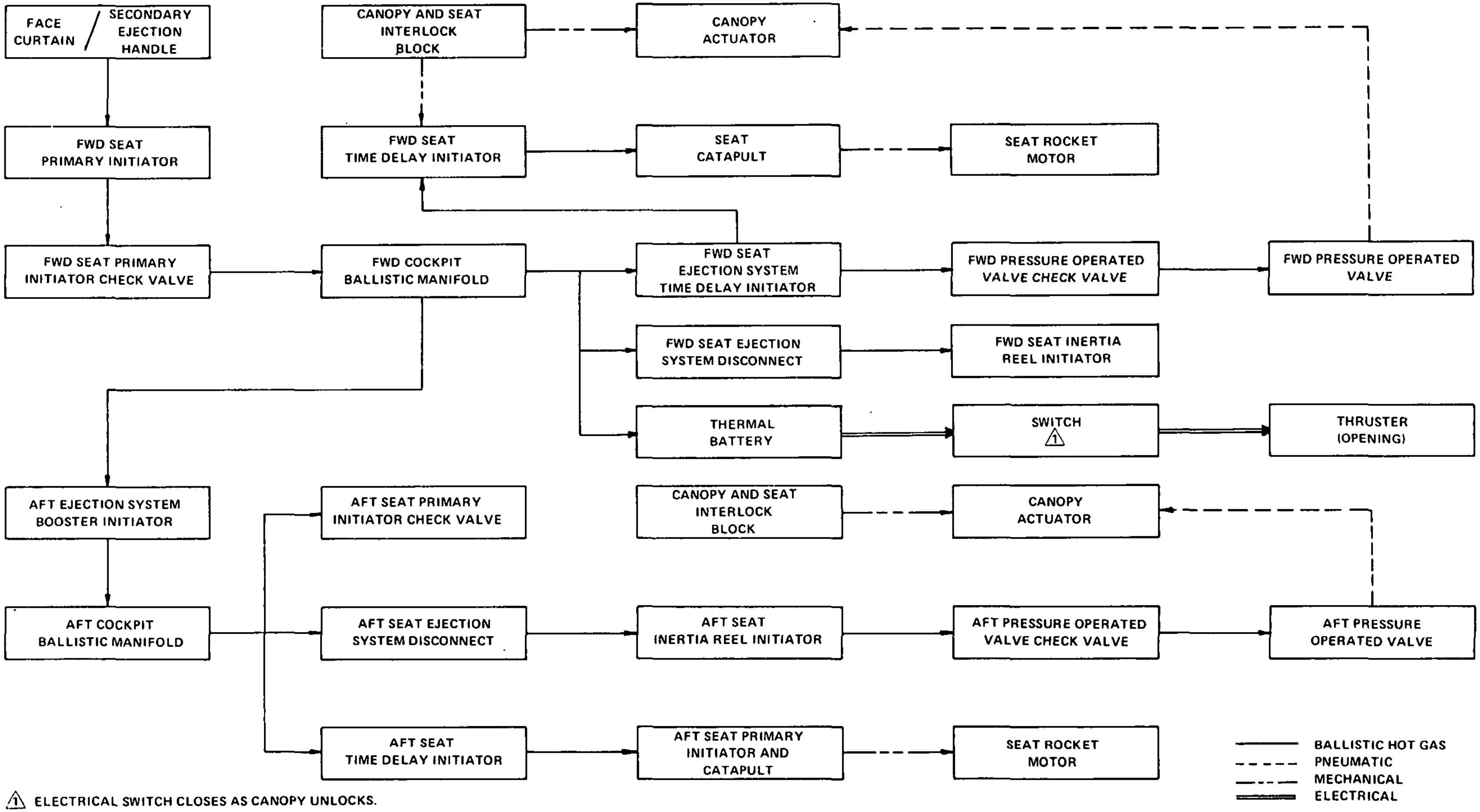
MECHANICAL FUNCTION	PYROTECHNIC APPROACH	NO. OF PYROS USED PER VEHICLE	INITIATION METHOD	PYROTECHNIC OUTPUT	COMMENTS
Ejection - Sequence System	Initiators - Gas Actuated	5 Total number required for sequencing and dual ejection	Mechanical and Ballistic Gas	Propellant Powder/ Pressure Generation	Initiators supply and maintain ballistic hot gas necessary to perform all sequence operations for ejection.
	Initiator - Mechanically Actuated	1			
	Initiator - Delay	2			
Jettison - Forward Canopy	Linear Actuator (Thruster)	2 Thrusters, 1 Pressure Cartridge/ Thruster	Electrical	Propellant Powder/ Pressure Generation	Initiation of thermal battery provides electric power to fire thruster cartridges. Rear canopy ejected by pneumatics produced by ballistic hot gas sequencing system.
	Initiator, Thermal Battery	1 Thermal Battery	Ballistic Gas	Heat Powder	
Ejection - Personnel Seat	Catapult	1 Primary and 2 Auxiliary Pressure Cartridge/Seat	Ballistic Gas	Propellant Powder/ Pressure Generation	Primary cartridge provides initial operation of catapult, auxiliary cartridges provide sequenced boost to catapult during stroking. Rocket motor is ignited at "line stretch" of lanyard. Drogue gun deploys drogue chute 0.75 sec. after ejection is initiated. Guillotine severs drogue chute from main chute.
	Rocket Motor	1 Igniter - Pressure Cartridge/Seat	Ballistic Gas	High Velocity Hot Gas	
	Drogue Gun	1 Pressure Cartridge/ Seat	Ballistic Gas	Propellant Powder/ Pressure Generation	
	Guillotine	1 Pressure Cartridge/ Seat	Ballistic Gas	Propellant Powder/ Pressure Generation	
Positioning - Personnel	Inertia Reel	1 Pressure Cartridge Seat	Ballistic Gas	Propellant Powder/ Pressure Generation	
Separation - Radar Pod	Guillotine	1 Pressure Cartridge/ Seat	Electrical	Propellant Powder/ Pressure Generation	Large Gemini wire bundle guillotine used to sever aluminum wave guides.
Shut Off - Coolant	Explosive Valve	1 Pressure Cartridge/ Seat	Electrical	Propellant Powder/ Pressure Generation	
Armament Applications					
Ejectors - Bomb Racks	Ballistic Gas Actuated Mechanical Linkage Linear Actuator (Thruster)	See Comments and Note	Electrical	Propellant Powder/ Pressure Generation	Aero 27A bomb rack, MAU-12B/A rack, A/A 37 B-6 Multiple Ejection Rack (MER), A/A 37 B-5 Triple Ejection Rack (TER).

APPENDIX I (Continued)
TYPICAL TWO PLACE AIRCRAFT (F-4)

MECHANICAL FUNCTION	PYROTECHNIC APPROACH	NO. OF PYROS USED PER VEHICLE	INITIATION METHOD	PYROTECHNIC OUTPUT	COMMENTS
Armament Applications (Cont'd)					
Launcher - Missile	Ballistic Gas Actuated Mechanical Linkage	See Comments and Note 1	Electrical	Propellant Powder/ Pressure Generation	Aero 7A, LAU 34A
Ejector Pylon - Wing Tank	Ballistic Gas Actuated Mechanical Linkage	2 Pressure Cartridges	Electrical	Porpellant Powder/ Pressure Generation	
Ejection - Missile Launcher/Pylon	Explosive Bolt	1 Pressure Cartridge	Electrical	Propellant Powder/ Pressure Generation	LAU 17/A - Housing around explosive bolt provides for thrusting away of severed bolt section and attached pylon. <u>Note 1</u>: A particular mission configuration carries 24 each 500 pound bombs and 4 Sparrow missiles requiring 1 and 2 cartridges respectively to eject each store. In addition 10 cartridges are available for release of the racks and/or their respective pylons in the event the aircraft must be aerodynamically cleaned.

APPENDIX I (Continued)

FRONT SEAT INITIATED DUAL EJECTION SCHEMATIC



⚠1 ELECTRICAL SWITCH CLOSES AS CANOPY UNLOCKS.

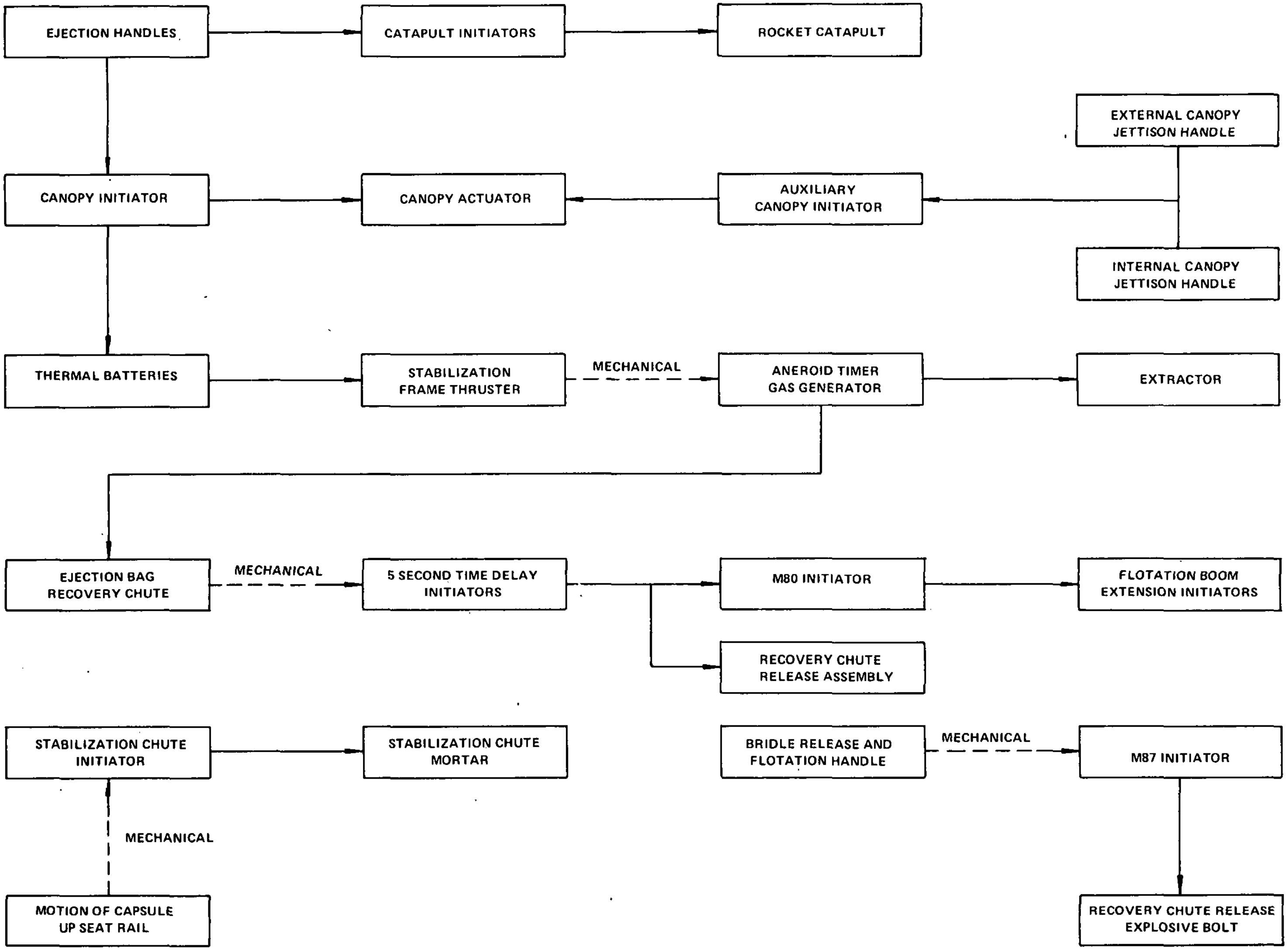
APPENDIX II
B-58 ENCAPSULATED EJECTION SEAT

MECHANICAL FUNCTION	PYROTECHNIC APPROACH	NO. OF PYROS USED PER VEHICLE	INITIATION METHOD	PYROTECHNIC OUTPUT	COMMENTS
Jettison - Canopy	Mechanical Initiator	1 per System	Mechanical/ Percussion Primer	Propellant Powder/ Pressure Generation	Actuation of the ejection triggers fires the canopy jettison and rocket catapult initiators simultaneously.
	Linear Actuator (Thruster)	1 per System	Ballistic Gas	Propellant Powder/ Pressure Generation	
Initiation - Rocket Catapult	Mechanical Initiator	2 per System	Mechanical/ Percussion Primer	Propellant Powder/ Pressure Generation	A .3 sec. delay is built into the rocket to allow for canopy jettison. In the event the canopy is not jettisoned during the normal sequence of events the first movement of the seat up the rail unlocks the canopy which is then pushed off by the seat.
	Solid Propellant Rocket	2 per System	Ballistic Gas	High Velocity Hot Gas	
Deployment - Stabilization Chute	Mechanical Initiator	2 per System	Mechanical	Propellant Powder/ Pressure Generation	As the seat moves up the rail the stabilization chute initiators are mechanically fired initiating the stabilization chute mortars.
Deployment - Stabilization Frame	Thermal Batteries	2 per System	Ballistic Gas	Heat Powder	The same initiator that fires the canopy actuator activates the thermal batteries. The current from the thermal batteries ignites the thrusters located on the stabilization frame which is deployed for capsule stability.
	Linear Actuator (Thruster)	2 per System	Electric	Propellant Powder/ Pressure Generation	
Deployment - Recovery Chute	Gas Generator	1 per System	Atmospheric Pressure	Propellant Powder/ Pressure Generation	As the stabilization frame deploys it arms the aneroid assembly by mechanically extracting two arming pins. Once armed, the assembly is fired by a barostat when the correct atmospheric pressure is attained. Recovery chute deployment is accomplished by rapid inflation of an ejection bag.
Extension - Flotation Booms	Mechanical Initiator (5 sec. Delay)	1 per System	Mechanical	Propellant Powder/ Pressure Generation	Deployment of recovery chute initiates this system in preparation for capsule landing.
	Gas Actuated Initiator (Instantaneous)	1 per System	Ballistic Gas	Propellant Powder/ Pressure Generation	
	Gas Actuated Initiator (2 sec. Delay)	2 per System	Ballistic Gas	Propellant Powder/ Pressure Generation	

APPENDIX II (Continued)
B-58 ENCAPSULATED EJECTION SEAT

MECHANICAL FUNCTION	PYROTECHNIC APPROACH	NO. OF PYROS USED PER VEHICLE	INITIATION METHOD	PYROTECHNIC OUTPUT	COMMENTS
Release - Recovery Chute Hard Point	Mechanical Initiator (5 sec. Delay)	1 per System	Mechanical	Propellant Powder/ Pressure Generation	The shock of recovery chute deployment is taken at a single point on the capsule during ejection; after a 5 sec. delay the capsule is repositioned. Both the flotation boom delay and the recovery chute hard point release are fired simultaneously by the action of the pendant.
Release - Recovery Chute Bridle	Mechanical Initiator	1 per System	Mechanical	Propellant Powder/ Pressure Generation	Manual actuation of the bridle release and flotation handle fires a mechanical initiator which in turn fires the two explosive bolts.
	Explosive Bolts	2 per System	Ballistic Gas		
Jettison - Canopy (Auxiliary)	Mechanical Initiator	1 per System	Mechanical	Propellant Powder/ Pressure Generation	Manual actuation of the external or internal canopy jettison handle initiates this system.
Disreefing - Recovery Chute	Reefing Cutter, Propellant Actuated	3 per System	Percussion Fired Primer	Propellant Powder/ Pressure Generation	Recovery chute is deployed in reefed condition and at line stretch the two sec. delay reefing line cutters are fired.

APPENDIX II (Continued)
B-58 ENCAPSULATED SEAT EJECTION SCHEMATIC



APPENDIX III
F-111 CREW MODULE

MECHANICAL FUNCTION	PYROTECHNIC APPROACH	NO. OF PYROS USED PER VEHICLE	INITIATION METHOD	PYROTECHNIC OUTPUT	COMMENTS
Ejection - Initiation	Manual Initiator	2 per Module	Manual/ Percussion Primer	Explosive	Pilot or Co-Pilot can initiate ejection.
Stimulus Transfer	Shielded Mild Detonating Cord (SMDC)	258 Individual SMDC Assemblies of Varying Lengths and Configurations	Explosive	Explosive	Stimulus system interconnects all sequenced functions required for complete recovery of module.
Positioning - Personnel	Inertia Reel	2 per Module	Explosive		
Sequencing - Initial	Pyrotechnic Time Delay	1 - 0.350 sec. Delay per Module (Dual Delay Columns)	Explosive/ Percussion Primer	Explosive	Inhibits stimulus signal to rocket igniters and structural severance system until inertia reels have completed their function. Time delay contains crossover on output end to assure initiation of both SMDC outputs.
Separation - Rocket Motor Ignition	Igniter (Pencil Tube)	1 Igniter per Module (Dual Primer)	Explosive/ Percussion Primer	Pressure/Temp./Flame	
Severance - Structure	Flexible Linear Shaped Charge (FLSC)	13 Individual FLSC Assemblies of Varying Lengths and Configurations	Explosive (SMDC)	Explosive	FLSC is initiated at each end and is not redundant.
Severance - Stabilization Brake Chute Cover	FLSC	1 FLSC Assembly	Explosive (FLSC)	Explosive	FLSC is initiated at each end and is not redundant.
Severance - Secondary Controls and Antenna Leads	Guillotine	3 per Module	Explosive/ Percussion Primer	Propellant Powder/ Pressure Generation	
Actuation - Emergency Oxygen Valve and Radio Beacon	Linear Actuators (Thruster)	2 per Module	Explosive (SMDC)/ Percussion Primer	Propellant Powder/ Pressure Generation	The functions shown here, with the exception of emergency oxygen, can be switched in and out by a manual selector.
	Pyrotechnic Time Delay	1 per Module - 3.0 Sec. (Single Delay Column)	Explosive (SMDC) Percussion Primer	Propellant Powder/ Pressure Generation	
Deployment - Chaff	Chaff Dispenser	1 per Module	Explosive (SMDC)		
Sequencing - Stabilization	Pyrotechnic Time Delay	1 per Module - 0.150 Sec. (Dual Delay Column)	Explosive/ Percussion Primer	Explosive	Time delay required to delay deployment of stab-break chute.

APPENDIX III (Continued)
F-111 CREW MODULE

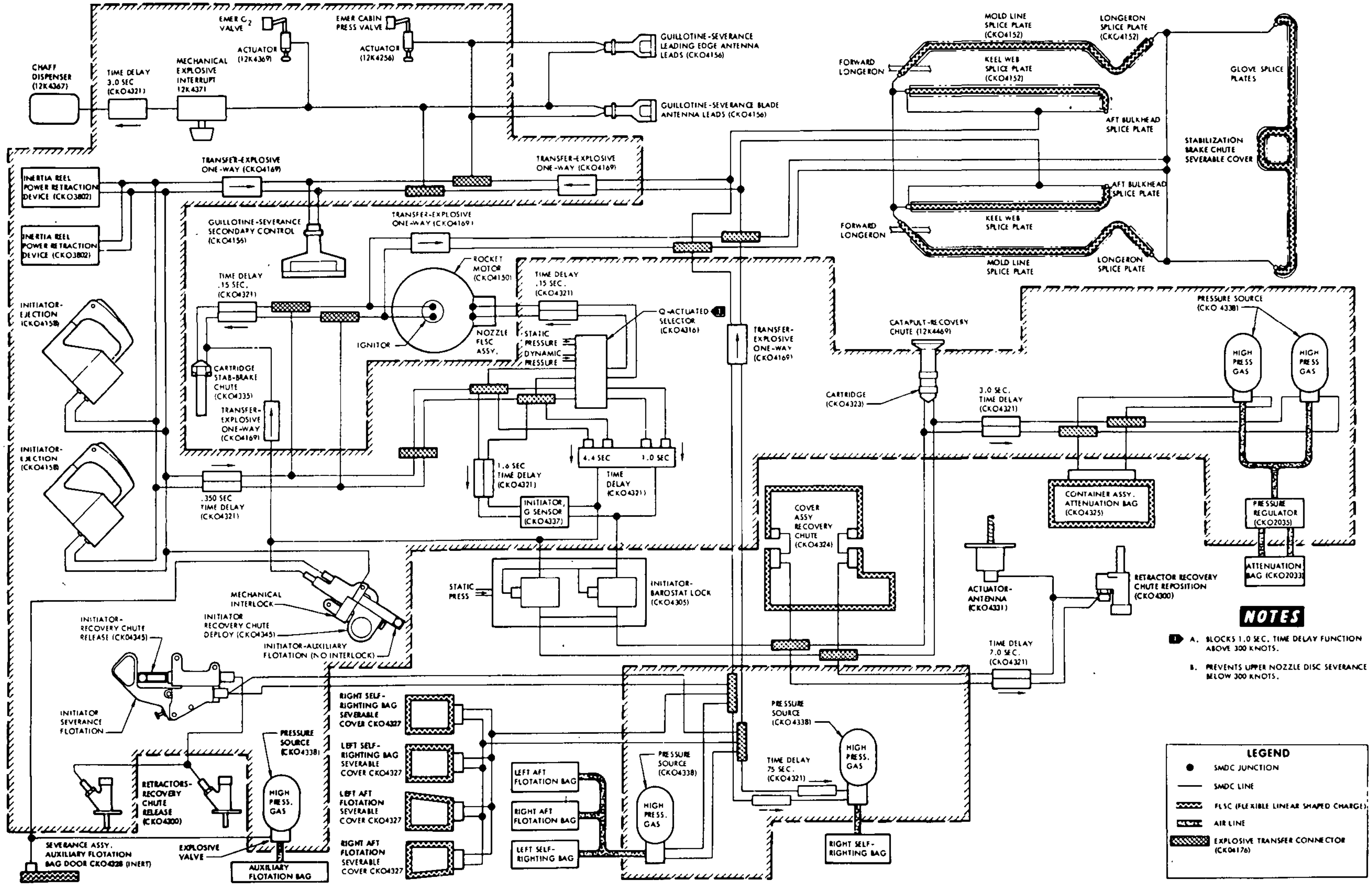
MECHANICAL FUNCTION	PYROTECHNIC APPROACH	NO. OF PYROS USED PER VEHICLE	INITIATION METHOD	PYROTECHNIC OUTPUT	COMMENTS
Mode Selection - Rocket Motor	Q-Activated Sensor	1 per Module	Barometric Pressure	Non-Explosive - Selects SMDC Path	Q-sensor determines whether FLSC for rocket motor upper nozzle severance should be fired for high speed ejection or selects 1.0 sec time delay for low speed ejection.
	Pyrotechnic Time Delay	1 per Module - 0.150 Sec. (Dual Delay Column - Upper Rocket Nozzle Only)	Explosive/ Percussion Primer	Explosive	
	FLSC Upper Nozzle Severance	1 per Module	Explosive (SMDC)	Explosive	
Sequencing - Recovery Mode	Pyrotechnic Time Delay	1 ea. 1.6 sec., 1 ea. 4.4 sec. and 1 ea. 1.0 sec. (Dual Delay Column)	Explosive/ Percussion Primer	Explosive	Signal from 1.6 sec. time delay unlocks G-sensor initiator. Barostat lock initiator can receive signal from output of G-sensor, 4.4 sec. or 1.0 sec. time delays. Barostat lock initiator inhibits SMDC signal for completion of recovery functions until module is at a safe altitude. Redundant SMDC signal is maintained by crossover in Barostat and G-sensor.
	G-Sensor Initiator	1 per Module Dual Pyro Train	Explosive/Stab. Primer	Explosive	
	Barostat Lock Initiator	1 per Module Dual Pyro Train	Explosive/ Percussion Primer	Explosive	
Severance - Recovery Chute Ass'y, Cover and Antenna Blade Panel	FLSC	2 FLSC Assemblies	Explosive SMDC	Explosive	
Deployment - Recovery Chute	Catapult	1 per Module	Explosive/Dual Percussion Primers	Propellant Powder/ Pressure Generation	
Sequencing - Completion of Recovery Mode	Pyrotechnic Time Delay	1 ea. 3.0 sec. and 1 ea. 7.0 sec. (Dual Delay Columns)	Explosive/ Percussion Primer	Explosive	Output signal from 3.0 sec. delay initiates attenuation bag deployment. Output signal from 7.0 sec. delay operates both a retractor for recovery chute repositioning and an antenna actuator.
Repositioning - Recovery Chute	Linear Actuator (Retractor)	1 per Module	Explosive/ Percussion Primer	Propellant Powder/ Pressure Generation	
Separation - Antenna Actuator Cover	SMDC End Tip	1 per Module	Explosive Stimulus	Explosive	Energy from SMDC end tip fails and blows off cover to release spring loaded antenna.

APPENDIX III (Continued)
F-111 CREW MODULE

MECHANICAL FUNCTION	PYROTECHNIC APPROACH	NO. OF PYROS USED PER VEHICLE	INITIATION METHOD	PYROTECHNIC OUTPUT	COMMENTS
Deployment - Recovery Chute Initiation	Dual Mode Manual Initiator	1 per Module	Manual	Explosive	Actuation of the initiators "D" handle initiates all functions required for deployment of recovery chute downstream of *Barostat*. Actuation of the initiators "T" handle deploys the auxiliary flotation bag.
Severance - Auxiliary Flotation Initiation	FLSC	1 Per Cover 5 Covers/Module	Explosive (SMDC)	Explosive	
Release - Recovery Chute Initiation	Dual Mode Manual Initiator	1 per Module	Manual	Explosive	Actuation of the "D" handle not only initiates the devices required for deployment of the self-righting and flotation bags but also the guillotines that severs the control and antenna leads and the FLSC that severs the structure necessary to affect a safe landing. Actuation of the "T" handle fires the recovery chute release retractors.
	Linear Act. (Retractor)	2 per Module	Explosive/ Percussion Primer	Propellant Powder/ Pressure Generation	

APPENDIX III (CONTINUED)

F-111 CREW MODULE



NOTES

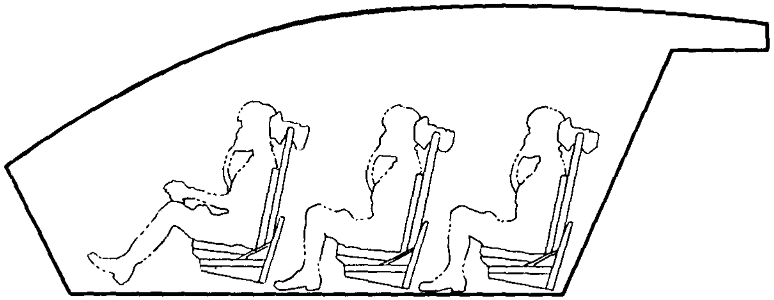
1 A. BLOCKS 1.0 SEC. TIME DELAY FUNCTION ABOVE 300 KNOTS.

B. PREVENTS UPPER NOZZLE DISC SEVERANCE BELOW 300 KNOTS.

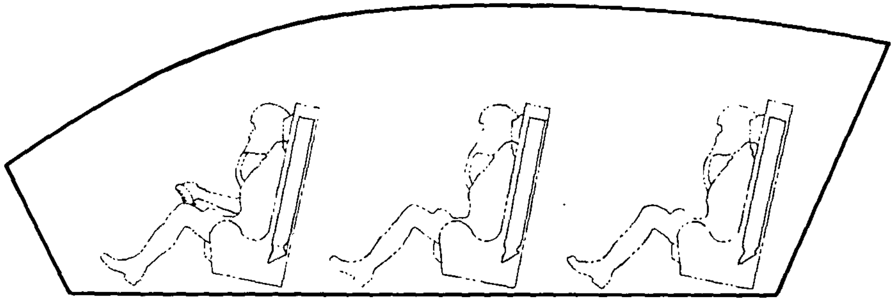
APPENDIX IV

TRADE STUDY FOR AIRCREW EJECTION METHODS FROM A HYPOTHETICAL MULTICREW (6), MULTIENGINE SUPERSONIC BOMBER

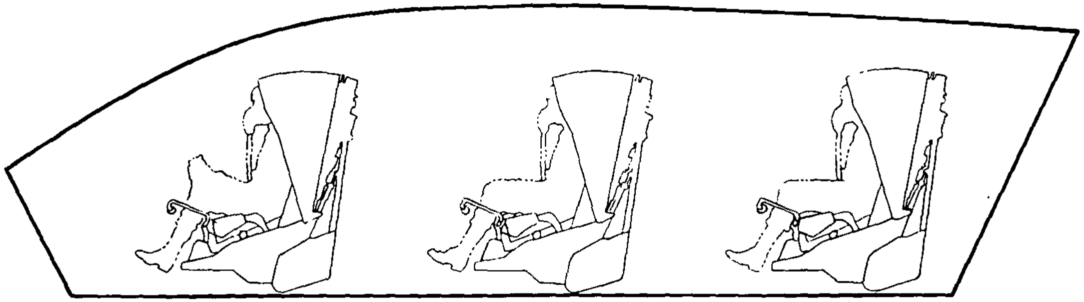
Cabin Size Comparison



CREW MODULE



OPEN EJECTION SEATS



ENCAPSULATED EJECTION SEATS

APPENDIX IV (Continued)

TRADE STUDY FOR AIRCREW EJECTION METHODS FROM A HYPOTHETICAL MULTICREW (6), MULTIENGINE SUPERSONIC BOMBER

EJECTION METHOD	WEIGHT OF SYSTEM COMPONENTS	AIRCRAFT GROSS WEIGHT DELTA POUNDS (KILOS) [2]	COST ESTIMATE (DOLLARS) [3]		CREW SAFETY - PROTECTION CAPABILITY & OTHER CONSIDERATIONS										CREW SURVIVAL		PERFORMANCE	RELIABILITY		MAINTAINABILITY
			ACQUISITION	10 YEAR OPERATION & MAINTENANCE	WIND & HAIL	LANDING ON LAND	LANDING ON WATER	PARACHUTE DRAGGING	POST LANDING SURVIVAL ON LAND	POST LANDING SURVIVAL ON WATER	VISION	COMFORT, MOBILITY & EFFICIENCY	EJECTION HATCH REQUIRED	PRESSURE SUIT REQUIRED	ESCAPE & SURVIVAL POTENTIAL (PERCENTAGE)	FATALITIES PER 100,000 HOURS		OPERATIONAL (RATING)	HARDWARE MEAN TIME BETWEEN FAILURE -HOURS PER SYSTEM	MEAN MAINTENANCE HOURS PER FLIGHT HOUR PREDICTION
CREW MODULE	CREW SEATS (6) 440.0 MECHANISM & STRUCTURE 50.0 SEVERANCE SYSTEM 150.0 ROCKET SEPARATION SYSTEM 440.0 PARACHUTES 270.0 IMPACT ATTENUATION 90.0 FLOTATION SYSTEM 120.0 STABILIZATION SYSTEM 155.0 SURVIVAL EQUIPMENT 170.0 TOTAL 1885.0 CREW COMPARTMENT WEIGHT GROWTH = 0 TOTAL SYSTEM WEIGHT 1885.0	1885x7.8 = 14,703 (6,669)	92,000,000	32,500,000	1	1	1	1	1	1	1	1	No	No	85.71	1.482	ESCAPE CAPABILITY o ZERO ALTITUDE/ ZERO SPEED o AIRCRAFT MAXIMUM VELOCITY o AIRCRAFT MAXIMUM ALTITUDE	1	69	.4116
OPEN EJECTION SEAT	SEAT STRUCTURE 72.2 MECHANISM & EQUIPMENT 50.9 PARACHUTE ASSY. 17.5 ROCKET CATAPULT 19.0 SURVIVAL EQUIPMENT 40.4 ESCAPE HATCH 50.0 PRESSURE SUITS & SYSTEM REVISIONS 30.0 280.0 TOTAL = 280 x 6 (Crew)= 1680.0 CREW COMPARTMENT WEIGHT GROWTH [1] = 728.0 2408.0	2408x7.8 = 18,782 (8,520)	59,000,000	62,500,000	4	3	4	3	3	4	1	3	Yes	Yes	81.0 [4]	1.750	ESCAPE CAPABILITY o ZERO ALTITUDE/ ZERO SPEED o 600 KEAS (MAX.) o 50,000 FEET ALTITUDE (PRESSURE SUIT REQUIRED ABOVE THIS ALTITUDE).	2	102	1.629
ENCAPSULATED EJECTION SEAT	SEAT STRUCTURE 150.5 MECHANISM 107.6 SURVIVAL EQUIPMENT 52.6 RECOVERY SYSTEM 106.7 STABILIZATION SYSTEM 48.1 ROCKET 40.7 ESCAPE HATCH 70.0 576.2 TOTAL = 576.2x6 (Crew) = 3457.0 CREW COMPARTMENT WEIGHT GROWTH [1] 728.0 4185.0	4185x7.8 = 36,643 (16,621)	122,000,000	84,800,000	1	1	1	3	3	2	3	2	Yes	No	85.23	1.499	ESCAPE CAPABILITY o ZERO ALTITUDE/ ZERO SPEED o AIRCRAFT MAXIMUM VELOCITY o AIRCRAFT MAXIMUM ALTITUDE	2	93	1.938

NOTES:

[1] 52 INCH LENGTH PENALTY TO INSTALL INDIVIDUAL EJECTION SEATS WEIGHT PENALTY FOR THIS INCREASED LENGTH EQUALS 14 LBS/INCH (2.5 kg/cm).

[2] GROSS WEIGHT FACTOR = 7.8 (TOTAL SYSTEM WEIGHT).

[3] COST ESTIMATED UPON ACQUISITION OF 250 PRODUCTION AIRCRAFT & 5 DEVELOPMENT/TEST AIRCRAFT.

[4] THIS FIGURE IS SOMEWHAT MISLEADING, SPECIFICALLY IN THE AREA OF LOW ALTITUDE, ADVERSE ATTITUDE WHEREIN OPEN EJECTION SEATS UNDER SOME CIRCUMSTANCES MAY HAVE AN ADVANTAGE.

RATING CODE

1. EXCELLENT
2. GOOD
3. FAIR
4. POOR

APPENDIX V
SHRIKE AGM-45

MECHANICAL FUNCTION	PYROTECHNIC APPROACH	NO. OF PYROS USED PER VEHICLE	INITIATION METHOD	PYROTECHNIC OUTPUT	COMMENTS
Ignition - Motor	Igniter	1 per Motor	Electric	Propellant Powder/ Pressure Generation	
Switching	Squib Switches	3 per Missile	Electric	Not Applicable	The switches are of different designs and associated with engine start up of the missile.
Electric Power Generation	Thermal Batteries	2 per Missile	Electric	Gasless Heat Powder	
Pressurization	Gas Generator	2 per Missile	Electric	Propellant Powder/ Pressure Generation	

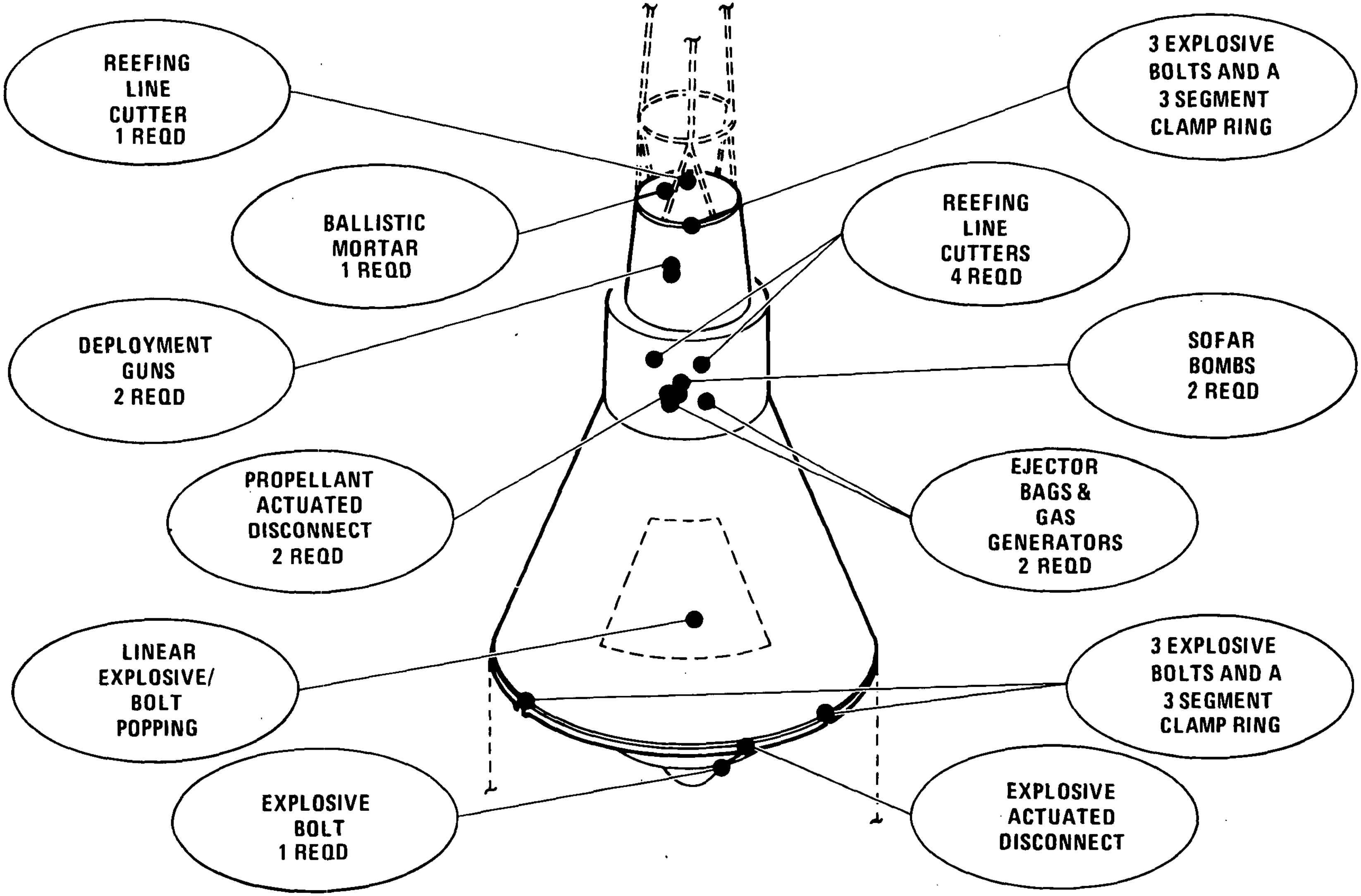
APPENDIX VI
UNIQUE PYROTECHNIC APPLICATIONS

	MECHANICAL FUNCTION	PYROTECHNIC APPROACH	NO. OF PYROS USED PER FUNCTION	INITIATION METHOD	ENERGY FORM	COMMENTS
F15 Air Superiority Fighter	Emergency Deployment of Aerial Refueling Cover	Linear Actuator (Thruster)	1 Thruster/Retractor 1 Pressure Cartridge per Thruster/Retractor	Electric	Propellant Powder/ Gas Generation	Function is to open and lock the aerial refueling slipway door in the event of a hydraulic failure. Small thruster piston operates hydraulic dump valve to dump hydraulic system pressure. When this piston has stroked approx. 60%, ballistic gas pressure is applied to larger retractor piston which in turn unlocks and opens the aerial refueling slipway door.
		Thermal Battery	1 Thermal Battery	Percussion Primer	Gasless Heat Powder	Supplies electric power to fire pressure cartridge in the aerial refueling thruster/ retractor. NOTE: It is unique in that it is a totally redundant and independent system. Aeronautically, it is the first known back-up of aircraft electric power by a thermal battery.
Boeing 747 Jet Transport	Off Wing Escape Chute Door Unlatch	Linear Actuator (Thruster)	1 Pressure Cartridge Per Thruster	Percussion Primer	Propellant Powder/ Gas Generation	Escape chute door is located in wing fairing. Unlatching and opening of door mechanically fires the two thrusters for deployment of escape slide.
	Off Wing Escape Chute Deployment	Linear Actuator (Thruster)	2 Pressure Cartridges Per Thruster	Percussion Primer	Propellant Powder/ Gas Generation	Note: First known application of a pyrotechnic operated thruster on a commercial aircraft.
	Inflation of Escape Slides	Cool Gas Generators	1 Cool Gas Generator & 2 Two-Stage Aspirators	Percussion Primer	Propellant Powder and Freon Provide Gas Source to Operate Aspirators which Compress Atmospheric air.	Each cool gas generator supplies necessary power to drive two aspirators which in turn provides rapid inflation of the escape slide. Eight main doors have cool gas generators located in door, above the window & escape slides are stored below window. Two overwing exits have gas generators stored in wheel wells & the escape slides are stored in the wing fairing. NOTE: This is first application of cool-gas generation systems to an aerospace application.

APPENDIX VI (Continued)
UNIQUE PYROTECHNIC APPLICATIONS

	MECHANICAL FUNCTION	PYROTECHNIC APPROACH	NO. OF PYROS USED PER FUNCTION •	INITIATION METHOD	ENERGY FORM	COMMENTS
Harrier	Severance - Canopy	Mild Detonating Cord		Mechanical	Explosive	Mild detonating cord is directly attached to the inside of the canopy directly above pilots head. Canopy severance initiated by actuation of ejection seat. Explosive shattering of canopy, rather than conventional canopy ejection, selected to reduce functioning time.
C131B Military Air Transport	Emergency Egress Hatch Opening	Flexible Linear Shaped Charge (FLSC)	1 Manual Initiator Containing Dual Explosion Trains Single FLSC Line Initiated at Two Points.	Percussion Primers	Explosive	FLSC built into bailout doors. Electrically operated safe/arm device controlled from cockpit arms system so it can be mechanically fired. This system has been qualified and has successfully passed the explosive atmosphere tests. NOTE: This is unique because it is the first application of FLSC in the aeronautical field for this form of emergency egress.
F14 Air Superiority Fighter	Emergency Canopy Unlock	Confined Explosive Severance			Explosive	Explosively expanded steel tube severs local tabs.
F111 Crew Module	Deployment of Recovery Chute	Catapult	1 Per Module	Explosive/ Percussion Primer		NOTE: The uniqueness of this device is that it contains crushable aluminum honeycomb which is used to control the internal operating pressure of the catapult within narrow limits. This permits higher piezometric propellant efficiency and minimizes the impulsive loading on the associated aircraft structure.
F101	Induce Wing Flutter	Gas Generator - High Thrust, Very Short Duration	1 or more depending upon test requirements	Electric	Propellant Powder/ Gas Generation	Device was mounted on the aircraft wing and initiated to induce wing flutter. Average thrust 300 lbs. (136 kg) duration .030 sec. Two or more could be installed by careful choice of location to induce twist in the wing. Similar devices tested on A3J-1 provided peak thrust in 200 (91 kg) to 800 lbs. (363 kg) range and 7 to 150 millisecond duration. NOTE: Unique use of pyro permits dynamic in flight testing of aircraft structure over large range of speeds.

APPENDIX VII
PROJECT MERCURY
Pyrotechnic Devices



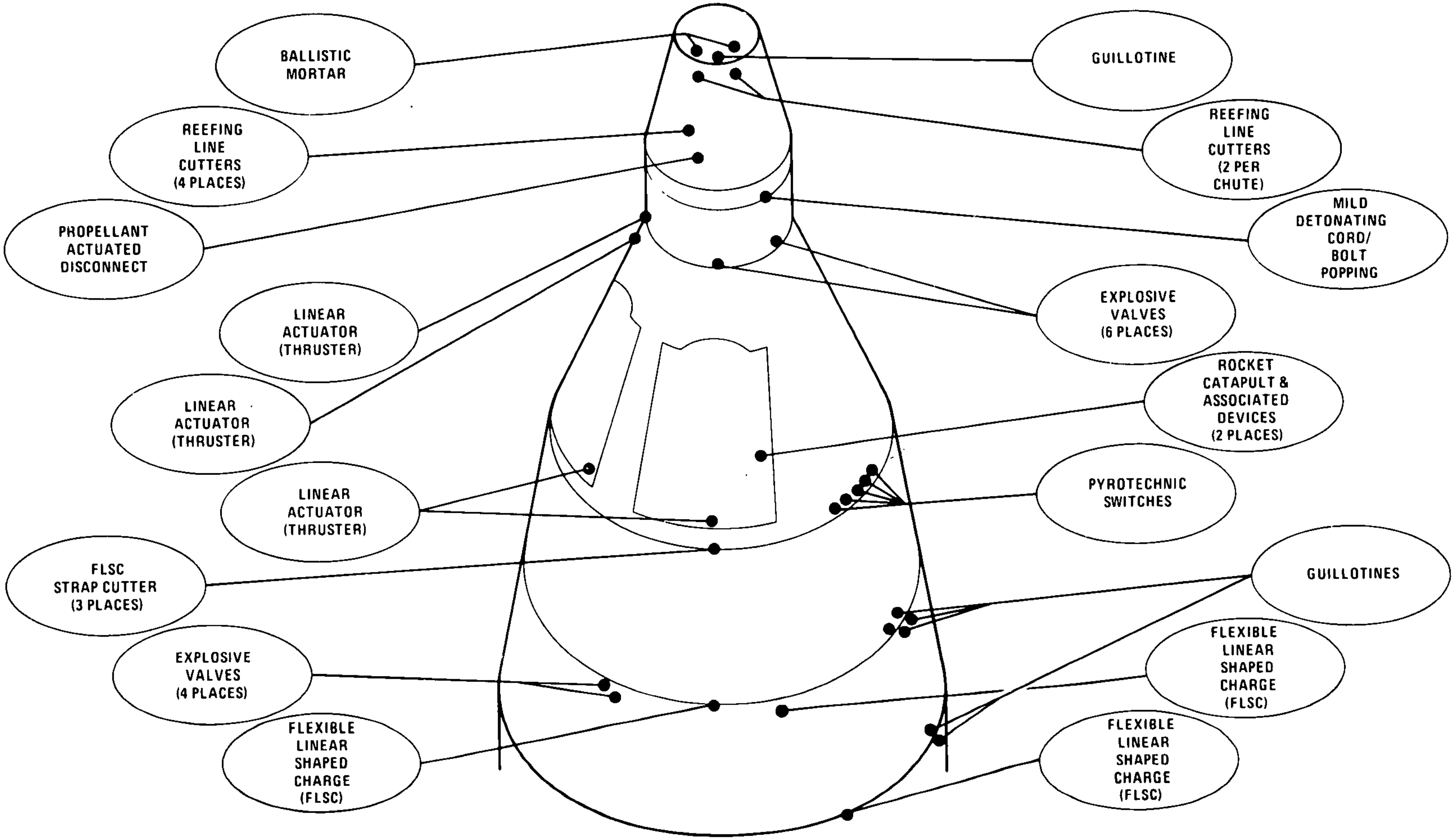
APPENDIX VII (Continued)
PROJECT MERCURY

MECHANICAL FUNCTION	PYROTECHNIC APPROACH	NO. OF PYROS USED PER VEHICLE	INITIATION METHOD	PYROTECHNIC OUTPUT	COMMENTS
Separation - Escape Tower From Capsule	Explosive Bolts - Three Segment Clamp Ring	3 Explosive Bolts	2 Bolts - Electric (Double-Ended) 1 Bolt - Percussion & Electrical	Propellant Powder/ Pressure Generation	Functioning of a single end of any one of the three bolts opens clamp ring. Escape tower rocket removes tower from capsule.
Separation - Capsule From Adapter	Explosive Bolts - Three Segment Clamp Ring	3 Explosive Bolts	2 Bolts - Electric (Double-Ended) 1 Bolt - Percussion & Electric	Propellant Powder/ Pressure Generation	Functioning of a single end of any one of the three bolts opens clamp ring.
Deployment - Drogue Chute	Ballistic Mortar	1 Pressure Cartridge	Electrical	Propellant Powder/ Pressure Generation	
Ejection - Antenna Fairing	Deployment Gun	2 Pressure Cartridges 1 Igniter Cartridge	Electrical Percussion (Back-up)	Propellant Powder/ Pressure Generation	Ejection of antenna fairing assisted by loads imposed by drogue chute.
Deployment - Main Chute	Ejector Bag	1 Pressure Cartridge	Electrical	Propellant Powder/ Pressure Generation	Gas pressure inflates bag causing ejection of chute. Deployment of chute assisted by ejection of antenna fairing.
Release - Main Chute	Disconnect, Propellant Actuated	1 Pressure Cartridge	Electrical	Propellant Powder/ Pressure Generation	
Deployment - Pilot Chute	Deployment Gun	2 Pressure Cartridges (With common time delay)	1 Cartridge - Electrical 1 Cartridge - Percussion	Propellant Powder/ Pressure Generation	
Deployment - Reserve Chute	Ejector Bag	1 Pressure Cartridge (With built in time delay)	Electrical	Propellant Powder/ Pressure Generation	Gas pressure inflates bag causing ejection of chute. Deployment of chute assisted by loads imposed by pilot chute.
Release - Reserve Chute	Disconnect, Propellant Actuated	1 Pressure Cartridge	Electrical	Propellant Powder/ Pressure Generation	
Disreefing - Main & Reserve Chutes	Reefing Line Cutters	1 Pressure Cartridge per reefing line cutter (with built in time delay)	Percussion	Propellant Powder/ Pressure Generation	Two reefing line cutters per chute.
Release - Retro Package	Explosive Bolt	1 Pressure Cartridge	Electrical	Propellant Powder/ Pressure Generation	Failure of bolt to operate and expose heat shield not catastrophic.
Disconnect - Electrical Connectors	Disconnect, Explosive Actuated	2 Pressure Cartridges per Disconnect	Electrical	High Explosive/ Pressure Generation	Ten disconnects used on each manned capsule, twelve disconnects used on each unmanned capsule.

APPENDIX VII (Continued)
PROJECT MERCURY

MECHANICAL FUNCTION	PYROTECHNIC APPROACH	NO. OF PYROS USED PER VEHICLE	INITIATION METHOD	PYROTECHNIC OUTPUT	COMMENTS
Release - Egress Hatch	Mild Detonating Cord (Bolt Popping)	1 Stab. Detonator 2 Strand 5 gr/ft. MDC, lead sheath, RDX	Percussion	High Explosive	Hatch released through tension failure of 70 each 3/16 inch dia. titanium bolts. MDC located on either side of bolts. Either strand capable of breaking bolts.
Erection - Whip Antenna	Linear Actuator (Telescoping)	1 Pressure Cartridge	Electrical	Propellant Powder/ Pressure Generation	
Operation - Fresh Air Inlet Valve	Piston Motor	1 Pressure Cartridge	Electrical	High Explosive/Pressure Generation	
Operation - Fresh Air Vent Valve	Piston Motor	1 Pressure Cartridge	Electrical	High Explosive/Pressure Generation	
Post Landing and Recovery Aid (sound fixing and ranging)	Sofar Bombs	2 bombs per capsule	Percussion (fired by water pressure)	High Explosive	Two bombs deployed. One set to detonate at 3500 ft. (1067m) depth and second to detonate at 4000 ft. (1219m) depth. The first sofar bomb (3500') is tossed overboard by action of reserve chute ejection system. Second bomb is kept in capsule and is only used if capsule starts sinking.
Release - Butterfly Antenna (UHF)	Reefing Line Cutter	1 Pressure Cartridge per Reefing Cutter (With built-in time delay)	Percussion	Propellant Powder/ Pressure Generation	Two reefing line cutters per capsule.
Deployment - Balloon Antenna	Explosive Valve	1 Pressure Cartridge	Electrical	Propellant Powder/ Pressure Generation	Inflated balloon suspends 30 ft. of antenna wire above the capsule.
Release - HF Antenna Tether	Explosive Bolt Cutter	1 Pressure Cartridge	Electrical	Propellant Powder/ Pressure Generation	
Release - HF Balloon Cover	Explosive Bolt	1 Pressure Cartridge	Electrical	Propellant Powder/ Pressure Generation	

APPENDIX VIII
PROJECT GEMINI
Pyrotechnic Devices



APPENDIX VIII (Continued)
PROJECT GEMINI

MECHANICAL FUNCTION	PYROTECHNIC APPROACH	NO. OF PYROS USED PER VEHICLE	INITIATION METHOD	PYROTECHNIC OUTPUT	COMMENTS
Egress - Hatch Actuator Initiation System	Shielded Mild Detonating Cord (SMDC)	8 SMDC Interconnects	Mechanical	Detonation Wave Propagation	Manual translation of the mechanical actuator fires dual percussion primers and a single booster charge which initiates the SMDC. There are 4 rigid and 4 flexible SMDC lines in the system.
Egress - Hatch Actuator	Linear Actuator (Thruster)	1 Pressure Cartridge	MDC Input to Percussion Cartridge	Propellant Powder/ Pressure Generation	The MDC ignites the cartridge which is assembled into a breech assembly loaded with the main propellant charge.
Egress - Seat Ejector Rocket Catapult	Solid Propellant Rocket Motors	2 Integral Explosive Trains	Dual Ballistic Gas Actuated Firing Pins	High Velocity Hot Gas	
Egress - Harness Release Actuator	Retractor	1 Pressure Cartridge	Mechanical	Propellant Powder/ Pressure Generation	The mechanically fired pressure cartridge incorporates a time delay to allow the seat to clear the spacecraft prior to release.
Egress - Thruster Assembly - Seat/Man Separator	Linear Actuator (Thruster)	1 Pressure Cartridge	Ballistic Gas	Propellant Powder/ Pressure Generation	
Egress - Ballute Deploy and Release System	Guillotine	1 Instantaneous and 1 Delay Pressure Cartridge	Mechanical	Propellant Powder/ Pressure Generation	Above 7500 ft. only the delay cartridge is actuated below this altitude this function is instantaneous.
Egress - Drogue Mortar - Backboard Jettison	Ballistic Mortar Mild Detonating Fuse FLSC	1 Pressure Cartridge	Mechanical	Gas Pressure and Detonation Wave Propagation	The initiation of the drogue mortar pressure cartridge fires the MDC which in turn fires the FLSC.
Docking - Docking Bar	Linear Actuator (Thruster)	2 Pressure Cartridges	Electrical	Propellant Powder/ Pressure Generation	One of the pressure cartridges was fired to extend the docking bar and the other was fired to jettison it.

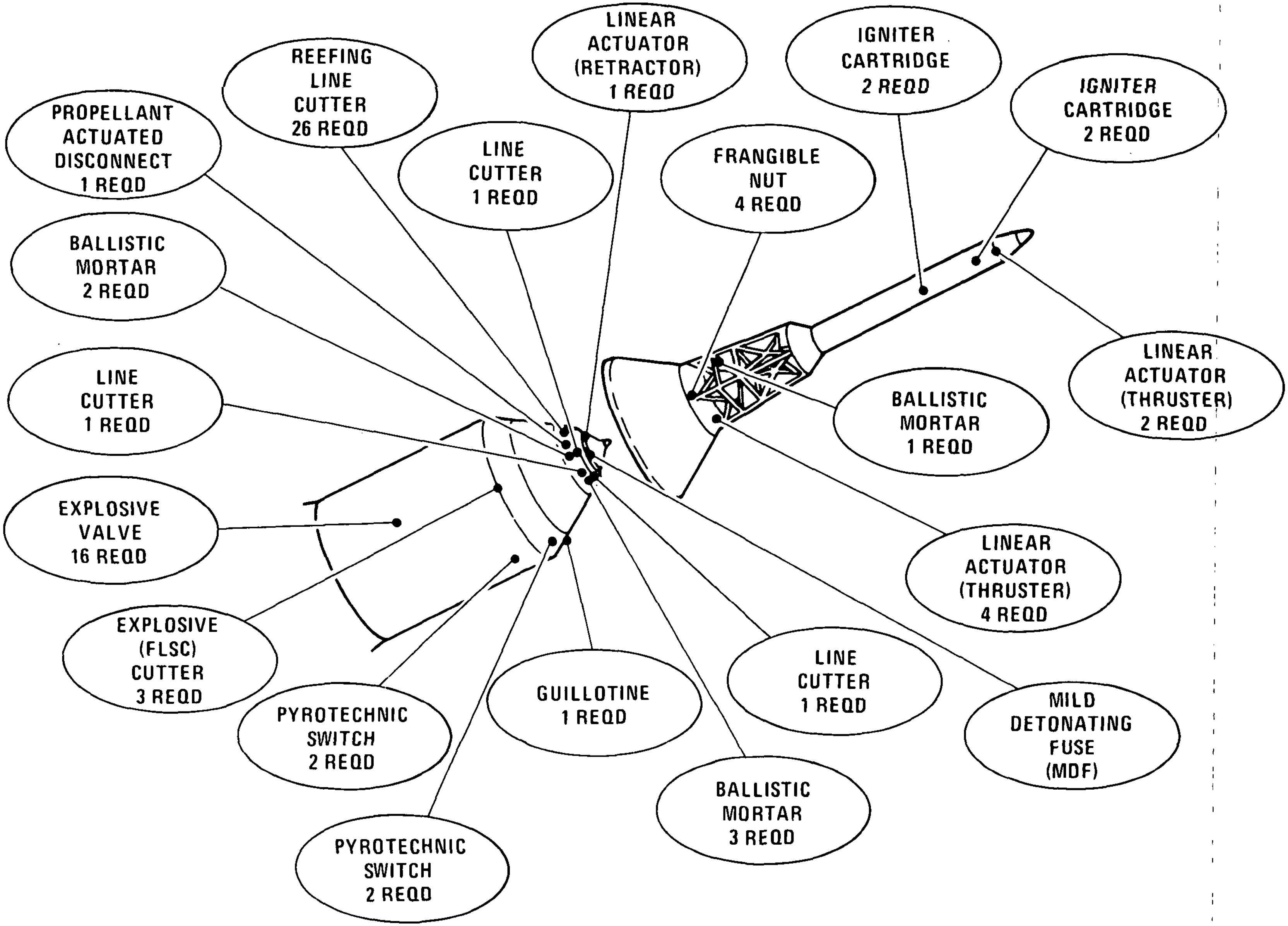
APPENDIX VIII (Continued)
PROJECT GEMINI

MECHANICAL FUNCTION	PYROTECHNIC APPROACH	NO. OF PYROS USED PER VEHICLE	INITIATION METHOD	PYROTECHNIC OUTPUT	COMMENTS
Release - Main Parachute Disconnect	Propellant Actuated Piston	2 Pressure Cartridges	Electrical	Propellant Powder/ Pressure Generation	Initiation of the cartridges produces gas pressure which drives a piston and releases the disconnect.
Control - Orbital Attitude and Maneuvering System	Explosive Valves Normally Open and Normally Closed	1 High Explosive Cartridge Per Valve	Electrical	Primary Explosive/ Pressure Generation	The high explosive cartridge in both the normally open and normally closed valves produces the energy required to actuate a ram which allows the valve to function properly.
Control - Re-entry Control System	Explosive Valves Normally Closed	1 High Explosive Cartridge Per Valve	Electrical	Primary Explosive/ Pressure Generation	The valves used in this system are non-replaceable and in the event the cartridge is fired the entire RCS package must be replaced.
Control - Retrograde Rocket Motor Assembly	Solid Propellant Rocket Motors	2 Igniter Assemblies	Electrical	Hot Gas/Incandescent Particles	The rocket motor contains an internal burning, eight pointed star configuration grain that is cast and cured in the motor.
Control - Retrograde Rocket Igniter Assembly	Solid Propellant Rocket Motor	1 Initiator	Electrical	Hot Gas/Incandescent Particles	Igniter assembly contains booster pellet to assure prompt ignition of rocket motor propellant grain.
Release - Horizon Scanner Fairing	Linear Actuator (Thruster)	2 Pressure Cartridges	Electrical	Propellant Powder/ Pressure Generation	
Release - Horizon Scanner Release Assembly	Gas Actuator	2 Pressure Cartridges	Electrical	Propellant Powder/ Pressure Generation	When initiated the two pressure cartridges produce the gas that unlocks the actuator and jettisons the horizon scanner.
Operation - Fresh Air Door	Linear Actuator (Thruster)	2 Pressure Cartridges	Electrical	Propellant Powder/ Pressure Generation	
Ejection - Nose Fairing	Linear Actuator (Thruster)	1 Pressure Cartridge	Electrical	Propellant Powder/ Pressure Generation	
Disconnect - Pyrotechnic Switch	Explosive Disconnect	1 Pressure Cartridge	Electrical	Propellant Powder/ Pressure Generation	Used in several locations for dead facing electrical circuits.

APPENDIX VIII (Continued)
PROJECT GEMINI

MECHANICAL FUNCTION	PYROTECHNIC APPROACH	NO. OF PYROS USED PER VEHICLE	INITIATION METHOD	PYROTECHNIC OUTPUT	COMMENTS
Separation - Spacecraft/Launch Vehicle	Flexible Linear Shaped Charge (FLSC) 360° Structure Severance	Two Strands of FLSC	3 Electrical Detonators with 3 Dual Explosive Boosters	High Explosive	Either of two 10 gr/ft lead sheathed RDX loaded FLSC capable of achieving separation.
Separation - Equipment Section/Retrograde Section	(FLSC) 360° Structure Severance	Two Strands of FLSC	3 Electrical Detonators, 3 Detonator Blocks containing 3 explosive crossovers and 6 explosive boosters	High Explosive	Either of two 10 gr/ft lead sheathed RDX, loaded FLSC capable of achieving separation.
Separation - Retrograde Section/Re-Entry Module	FLSC 3 Assemblies 120° Apart Interconnected by Shielded Mild Detonating Cord (SMDC)	Four Strands of FLSC Contained in each of 3 Cutter Assemblies	3 Detonators, 3 Detonator Housings 3 Parallel Explosive Booster Columns, and 6 Explosive Interconnects	High Explosive	Either pair of the four 25 gr/ft lead sheathed RDX loaded FLSC capable of cutting 0.100 inch thick titanium straps.
Separation - Rendezvous and Recovery Section	Mild Detonating Cord (MDC)/ Bolt Popping	Two Strands of MDC	Electrical	High Explosive	Detonation of either strand of 5 gr/ft lead sheathed RDX loaded MDC is capable of breaking 24 each 3/16 inch diameter preweakened bolts.
Severance - Electric Wire Bundles/Tubes	Guillotine	1 Pressure Cartridge	Electrical	Propellant Powder/ Pressure Generation	Initiation of the cartridge produces the gas pressure required to actuate the blade. Used in several locations.
Deployment - Drogue and Pilot Parachute	Ballistic Mortar	2 Pressure Cartridges	Electrical	Propellant Powder/ Pressure Generation	Initiation of either cartridge capable of deploying parachute.
Disreefing - Pilot and Main Parachutes	Reefing Cutter	1 Time Delay Cartridge	Percussion Fired Time Delay Cartridge	Propellant Powder/ Pressure Generation	Although there are two units per parachute proper functioning of one is sufficient to perform disreefing.
Release - Drogue Parachute	Guillotine	2 Pressure Cartridges	Electrical	Propellant Powder/ Pressure Generation	Initiation of the cartridges produces the gas pressure required to actuate the anvil thereby severing the cable.
Release - Pilot Parachute (Apex Line)	Guillotine	2 Pressure Cartridges	Electrical	Propellant Powder/ Pressure Generation	Upon initiation of the cartridges the unit functions is identical to that stated above.

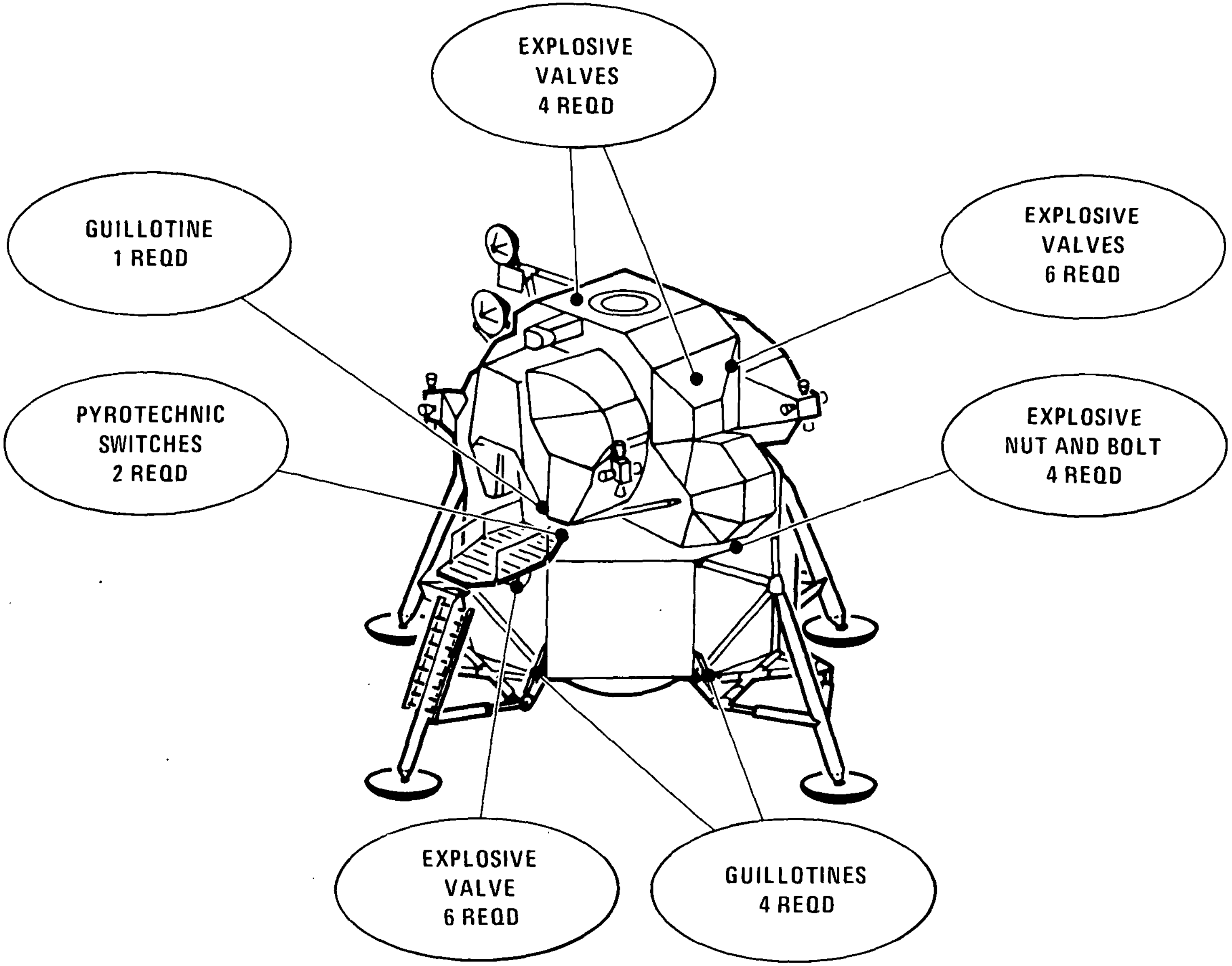
APPENDIX IX
PROJECT APOLLO
Pyrotechnic Devices



APPENDIX IX (Continued)

LUNAR EXCURSION MODULE PYROTECHNICS

Pyrotechnic Devices



APPENDIX IX (Continued)
PROJECT APOLLO

MECHANICAL FUNCTION	PYROTECHNIC APPROACH	NO. OF PYROS USED PER VEHICLE	INITIATION METHOD	PYROTECHNIC OUTPUT	COMMENTS
Jettison - Launch Escape System	Frangible Nuts	4 Frangible Nuts 2 Detonators/Nut	Electrical (SBASI)	High Explosive	
	Igniter Cartridge	2 Cartridges	Electrical (SBASI)	Pressure/Temp/Flame	
Separation - Command Service Module (CSM) from Spacecraft - Lunar Module (LM) Adapter (SLA)	Mild Detonating Cord (MDC)	42 Charge Holders	Explosive	High Explosive	
	Interconnects - High Explosive	24 Interconnect Charge Holders	Explosive	High Explosive	
	Linear Actuators (Thrusters)	8 Thrusters, 2 Pressure Cartridges/Thruster	Explosive	Propellant Powder/ Pressure Generation	Thru-bulkhead CDC initiated pressure cartridge.
	Explosive Disconnect	1 Disconnect/ 1 High Explosive Charge	Explosive	High Explosive	
	Guillotine - High Explosive	1 Guillotine, 2 CDC/ Guillotine	Explosive	High Explosive	LM-SLA GSE Unbilical
	Confined Detonating Cord (CDC) Transmission Line	6 Flexible CDC 8 SMDC	Explosive	High Explosive	
	Detonators	2 Detonators	Electrical (SBASI)	High Explosive	
Docking - CSM to LM	Pressure Cartridge	4 SBASI	Electrical	Pressure/High Explosive	SBASI operates N/C valve on helium bottle to retract probe to hard dock.
Separation - CSM/LEM from Launch Vehicle	Frangible Links	4 Frangible Links, 2 Detonators/Link	Electrical (SBASI)	High Explosive/ Pressure Generation	
	Guillotine - High Explosive	1 Guillotine 2 Detonators/ Guillotine	Electrical (SBASI)	High Explosive	One detonator per blade, fired simultaneously.
Deployment - LM Landing Gear	Guillotine - High Explosive	4 Guillotines, 2 Detonators/ Guillotine	Electrical (SBASI)	High Explosive	Each detonator functions an individual blade in the guillotine. Initially only one blade is actuated. If any landing gear strut (tension tie) remains uncut all second blades are fired.
Pressurization - LM Reaction Control System	Explosive Valves	4 Helium Valves, 1 Pressure Cartridge/ Valve	Electrical (SBASI)	Propellant Powder/ Pressure Generation	Two valves used on each helium high pressure vessel. Same as CM RCS Helium valves.

APPENDIX IX (Continued)
PROJECT APOLLO

MECHANICAL FUNCTION	PYROTECHNIC APPROACH	NO. OF PYROS USED PER VEHICLE	INITIATION METHOD	PYROTECHNIC OUTPUT	COMMENTS
Pressurization - LM Descent Propulsion Section (DPS)	Explosive Valves	6 Valves, 10 Pressure Cartridges	Electrical (SBASI)	Propellant Powder/ Pressure Generation	Two valves open the ambient and supercritical helium vessels. Two valves permit the helium to pressurize the oxidizer and fuel tanks. Two valves vent residual helium from DPS after lunar landing.
Pressurization - LM Ascent Propulsion Section	Explosive Valves	6 Valves, 2 Pressure Cartridges/Valve	Electrical (SBASI)	Propellant Powder/ Pressure Generation	The valves both open the lines from the helium tanks and allow the helium to enter the fuel and oxidizer tanks.
Separation - LM Ascent Stage from Descent Stage	Explosive Nut/ Bolt Combination	4 Explosive Nuts and Bolts, 1 Pressure Cartridge/Nut and 1 Pressure Cartridge/ Bolt	Electrical (SBASI)	Nuts - Propellant Gas Bolts - High Explosive Pressure	Each assembly had a redundant mode in that either nut release or bolt separation would effect staging.
	Electrical Circuit Interupters	2 Interupters, 2 Pressure Cartridges/ Interupter	Electrical (SBASI)	Propellant Powder/ Pressure Generation	Circuits deadfaced before guillotine operation.
	Guillotine	1 Guillotine, 2 Detonators/Guillotine 2 High Explosive/Manifold Crossovers/ Guillotine	Electrical (SBASI)	High Explosive/ Pressure Generation	Guillotines deadface all electrical circuits and two fluid lines between stages. Each detonator functions an individual blade and two high explosive crossovers provide redundant paths to assure functioning of both blades.
Jettison - LM from CSM	Mild Detonating Cord	2 Strands of MDC 6 gr/ft HNS 2 Detonators	Electrical (SBASI)	High Explosive	Initiated with special "long reach" detonator loaded with HNS.
Jettison - Scientific Instrument Module Door	Mild Detonating Cord	4 Charge Holders, each with 2 Strands of MDC, 2 Detonators	Electrical (SBASI)	High Explosive	
Separation - Preparation for CM-SM Separation (CM-RCS Pressurization)	Explosive Valves	10 Helium Valves, 1 Pressure Cartridge/ Valve	Electrical (SBASI)	Propellant Powder/ Pressure Generation	The valve and cartridge used in the helium pressurization system is the same as used in the LM RCS. Two types of valves are used and different cartridge configurations are used in the valves.
		2 Propellant Valves, 1 Pressure Cartridge/ Valve	Electrical (SBASI)	Propellant Powder/ Pressure Generation	

APPENDIX IX (Continued)
PROJECT APOLLO

MECHANICAL FUNCTION	PYROTECHNIC APPROACH	NO. OF PYROS USED PER VEHICLE	INITIATION METHOD	PYROTECHNIC OUTPUT	COMMENTS
Separation - CM-SM Separation					
Circuit Deadfacing	Explosive Disconnect	4 Disconnects, 2 Press. Cart./Disconnect	Electrical (SBASI)	Propellant Powder/ Pressure Generation	Both cartridges are fired simultaneously to achieve disconnect.
Umbilical Severance	Guillotine	1 Per System, 20 gr/ft MDC, 2 Detonators 2 SMDC	Electrical (SBASI)	High Explosive	Either of the two detonators will detonate both cutters. Four blades, 2 per umbilical section. There are two umbilical sections and either blade will sever the umbilical section.
Structural Separation	Linear Shaped Charge (LSC)	6 Strands of LSC, 6 Detonators	Electrical (SBASI)	High Explosive	2 FLSC per tension tie (3 tension ties), 2 detonators per tension tie.
Earth Landing Operations					
Apex-Cover Jettison	Linear Actuators (Thrusters)	4 Thrusters, 2 Breechs with 2 Cartridges/ Breech	Electrical (SBASI)	Propellant Powder/ Pressure Generation	The jettison system consists of two pairs of thrusters each of which is powered by a common breech housing two cartridges. All cartridges are fired simultaneously.
Drogue Parachute Deployment	Ballistic Mortars	2 Mortars, 2 Cartridges/Mortar	Electrical (SBASI)	Propellant Powder/ Pressure Generation	The drogue parachutes are ejected by their mortars and when the retention bags strip off the parachutes the reefing line cutters are fired.
	Reefing Line Cutter	8 10 sec. Delay Cutters	Mechanical	Propellant Powder/ Pressure Generation	
Drogue Parachute Release and Main Parachute Deployment	Cutter, Parachute Disconnect	1 Disconnect, 5 Press. Cart.	Electrical (SBASI)	Propellant Powder/ Pressure Generation	The drogue parachutes are released by cutting forty seconds after deployment; simultaneously the pilot parachute mortars are fired. As the main parachutes deploy to a full-reefed configuration and the risers deploy the 8 second delay line cutters are fired. At "line-stretch" of main chute suspension lines the 6 and 10 second delays are fired. Immediately after splashdown the main chutes are disconnected by the same cutter that released the drogue chutes.
	Ballistic Mortars	3 Pilot Chute Mortars, 2 Press. Cart./Mortar	Electrical (SBASI)	Propellant Powder/ Pressure Generation	
	Reefing Line Cutters	6-8 Sec. Delay Cutters	Mechanical		
		12-6 Sec. Delay Cutters			
		6-10 Sec. Delay Cutters			
Experiments - Appolo Lunar Surface Experiments Package (ALSEP) Pyrotechnics					
Active Seismic Experiments	Linear Actuator (Thumper)	21 Initiators	Electrical 4 pin ASI	Propellant Powder/ Pressure Generation	The seimic experiments are conducted using the hand operated thumper during the astronauts walk on the surface of the moon and the rocket powered grenade launching mortar that is remotely controlled from earth at any time up to 1 year after the astronaut's return to earth.
	Ballistic Mortar	4 Grenades, 1 SBASI and 1 Detonator per Grenade	Electrical (SBASI)	High Explosive	

APPENDIX IX (Continued)
PROJECT APOLLO

MECHANICAL FUNCTION	PYROTECHNIC APPROACH	NO. OF PYROS USED PER VEHICLE	INITIATION METHOD	PYROTECHNIC OUTPUT	COMMENTS
Particles and Fields Subsatellite	Explosive Bolt Cutters	2 Bolt Cutters, 1 Pressure Cartridge/ Cutter	Electrical (SBASI)	Propellant Powder/ Pressure Generation	The same cartridge used for the LM propulsion valve is used for this device.
Lunar Surface Profiling Experiments	High Explosive Charge	8 Charges, 1 Detonator Per Charge	Electrical (SBASI)	Explosive	
Abort - Launch Escape System (LES)					
Rocket Motor Ignition	Igniter Cartridge	4 Cartridges	Electrical (SBASI)	Pressure/Temp./Flame	
CM RCS Propellant Dump	Explosive Valves	4 Valves/4 Pressure Cartridges	Electrical (SBASI)	Pressure Generation	

APPENDIX X
SATURN V LAUNCH VEHICLE

MECHANICAL FUNCTION	PYROTECHNIC APPROACH	NO. OF PYROS USED PER VEHICLE	INITIATION METHOD	PYROTECHNIC OUTPUT	COMMENTS
Ignition - F-1 Engine System	High-Voltage Igniter	5 Engines, 4 Igniters/ Engine	Electrical	Explosive	
Ignition - S-IC Retrorocket System	Exploding Bridgewire (EBW) Detonator	2 CDF Manifolds, 1 Detonator/Manifold	Electrical	Explosive	Initial configuration incorporated 4 pairs of retrorockets mounted in F-1 engine compartment. Forward end of fairing is burned and blown through by the exhausting gases upon retrorocket ignition.
	Confined Detonating Fuse (CDF)Manifold	2 per System	Explosive	Explosive	
	CDF Assemblies	9 per System Various Lengths	Explosive	Explosive	
	CDF Pyrogen Initiators	4 Retrorockets 2 Initiators/Rocket	Explosive	Explosive	
	Solid Propellant Rockets	2 Pairs per System	Explosive/Pyrogen	High Velocity Hot Gas	
Ignition - S-IC Propellant Dispersion System (PDS) (Destruct)	EBW Detonators	1 S&A Device, 2 Detonators/Device	Electrical	Explosive	The PDS is used to destruct the vehicle in the event the flight has to be terminated. The S & A device contains a metal rotor shaft, loaded with two explosive inserts, which is rotated electrically by remote control in order to complete or interrupt the explosive path between the EBW detonator and the CDF. The S & A device contains no provisions for initiating the explosive train.
	Safe and Arm (S & A) Device	1 per System	Electrical	Explosive	
	CDF Assemblies	6 per System Various Length	Explosive	Explosive	
	CDF Tees	2 per System	Explosive	Explosive	
	CDF/Flexible Linear Shaped Charge (FLSC) Connector	2 per System	Explosive	Explosive	
	FLSC Assemblies	9 per System Various Lengths	Explosive	Explosive	
Separation - S-II First Plane Separation System	EBW Detonators	2 Detonator Blocks, 1 Detonator/Block	Electrical	Explosive	The LSC assembly consists of a piggy-back arrangement with a strand of 10 gr/ft mounted on top of a 15 gr/ft lead sheathed RDX FLSC terminated at each end in a detonator block that is an integral part of the assembly.
	Linear Shaped Charge (LSC) Assembly	2 Strands/System	Explosive	Explosive	
Separation - S-II Second Plane Separation System	EBW Detonators	2 Detonator Blocks, 1 Detonator/Block	Electrical	Explosive	The LSC assembly consists of a piggy-back arrangement with a strand of 10 gr/ft mounted on top of a 15 gr/ft lead sheathed RDX FLSC terminated at each end in a detonator block that is an integral part of the assembly.
	LSC Assembly	2 Strands/System	Explosive	Explosive	

APPENDIX X (Continued)

SATURN V LAUNCH VEHICLE

MECHANICAL FUNCTION	PYROTECHNIC APPROACH	NO. OF PYROS USED PER VEHICLE	INITIATION METHOD	PYROTECHNIC OUTPUT	COMMENTS
Ignition - S-II PDS (Destruct)	EBW Detonators	1 S & A Device, 2 Detonators/Device	Electrical	Explosive	The preliminary functions of the S-II PDS are the same as the S-IC PDS. The LH_2 LSC assembly uses aluminum sheathed 600 gr/ft RDX and the LOX tank destruct charge consists of two strands of rayon braid covered 800 gr/ft RDX contained in a common aluminum mounting tube.
	S & A Device	1 per System	Explosive	Explosive	
	CDF Assemblies	6 per System Various Lengths	Explosive	Explosive	
	CDF Tee	2 per System	Explosive	Explosive	
	LH_2 LSC Assembly	1 per System	Explosive	Explosive	
	LOX Tank Destruct Charge Adapter	2 per System	Explosive	Explosive	
	LOX Tank Destruct Charge Assembly	1 per System	Explosive	Explosive	
Ignition - S-II Retrorocket System	EBW Detonators	2 CDF Manifolds, 1 Detonator/Manifold	Electrical	Explosive	The four retrorockets are spaced evenly around the interstage of the vehicle and contain a case bonded, single-grain, solid-propellant in a tapered, five-point star configuration.
	CDF Manifolds	2 per System	Explosive	Explosive	
	CDF Assemblies	9 per System Various Lengths	Explosive	Explosive	
	CDF Pyrogen Initiators	4 Retrorockets, 2 Initiators/Rocket	Explosive	Explosive	
	Solid Propellant Rockets	4 per System	Explosive/Pyrogen	High Velocity Hot Gas	
Separation - S-IVB Third Plane Separation System	EBW Detonators	1 Detonator Block, 2 Detonators/block	Electrical	Explosive	Both ends of the detonating fuse assembly are installed in a common detonator block assembly and initiated simultaneously by individual EBW detonators.
	Detonating Fuse Assembly	1 Detonating Fuse Assembly	Explosive	Explosive	
Ignition - S-IVB Ullage Rocket System	EBW Detonators	2 CDF Manifolds, 1 Detonator/Manifold	Electrical	Explosive	The rockets are mounted 180° apart and are used for propellant settling thus ensuring stable flow of LOX and LH_2 during J-2 engine start.
	CDF Manifold	2 per System	Explosive	Explosive	
	CDF Assemblies	9 per System, Various Lengths	Explosive	Explosive	
	CDF Pyrogen Initiators	2 Rockets, 2 Initiators/Rocket	Explosive	Explosive	
	Solid Propellant Rockets (Ullage)	2 per System	Explosive/Pyrogen	High Velocity Hot Gas	

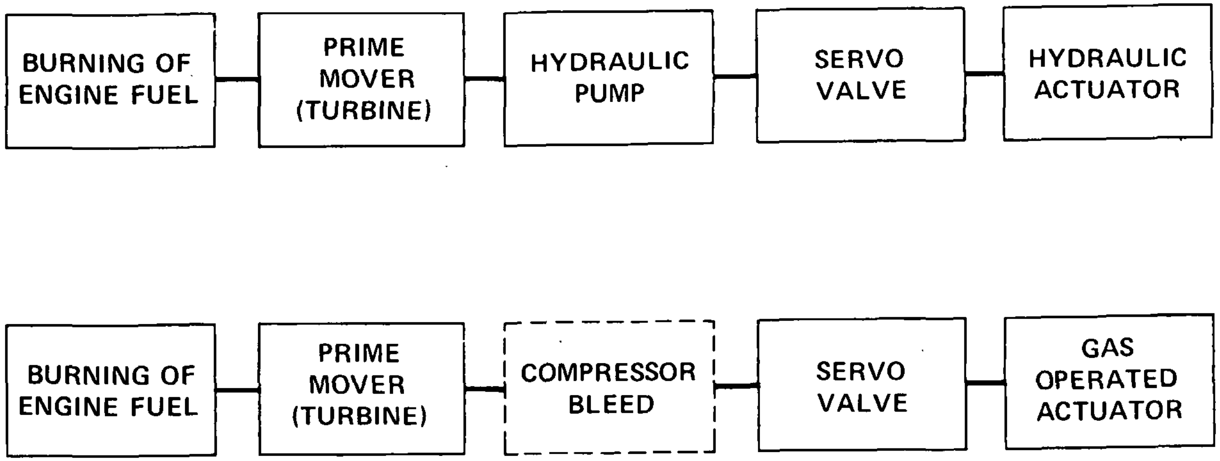
APPENDIX X (Continued)
SATURN V LAUNCH VEHICLE

MECHANICAL FUNCTION	PYROTECHNIC APPROACH	NO. OF PYROS USED PER VEHICLE	INITIATION METHOD	PYROTECHNIC OUTPUT	COMMENTS
Jettison - S-IVB Ullage Rocket Jettison System	EBW Detonators	1 Detonator Block, 2 Detonators/Block	Electrical	Explosive	The spent rockets and their fairings are propelled away from the vehicle by a spring-loaded jettison assembly when the frangible nuts separate.
	Explosive Fuse Assembly	2 per System	Explosive	Explosive	
	Frangible Nuts	2 Rockets, 2 Frangible Nuts/Rocket	Explosive		
Ignition - S-IVB Propellant Dispersion System (PDS) (Destruct)	EBW Detonators	1 S & A Device, 2 Detonators/Device	Electrical	Explosive	The preliminary functions of the S-IVB PDS are the same as the S-IC and S-II propellant dispersion systems. The LSC used throughout the S-IVB PDS is 150 gr/ft aluminum sheathed RDX.
	S & A Device	1 per System	Electrical	Explosive	
	CDF Assemblies	7 per System Various Lengths	Explosive	Explosive	
	CDF Tees	2 per System	Explosive	Explosive	
	LH_2 LSC Assembly	2 per System	Explosive	Explosive	
	LOX LSC Assembly	1 per System	Explosive	Explosive	

APPENDIX XI
MARINER MARS 1971

MECHANICAL FUNCTION	PYROTECHNIC APPROACH	NO. OF PYROS USED PER VEHICLE	INITIATION METHOD	PYROTECHNIC OUTPUT	COMMENTS
Separation - Spacecraft from Booster	Release Device	2 Devices 2 Squibs per Device	Electric	Propellant Powder/ Gas Pressure	Releases V-Band which allows spacecraft separation from Centaur. Device can be exercised with pneumatic pressure during pre-launch check out. (No thrust)
Deployment - Solar Panels and High Gain Antenna	Linear Actuator (Pin Puller)	5 Devices, 2 Squibs per Device	Electric	Propellant Powder/ Gas Pressure	Four pinpullers deploy the four solar panels, one pinpuller deploys the high-gain antenna.
Unlatch - Scan Platform Unlatch Valve	Explosive Valve	1 Device, 1 Squib per Device	Electric	Propellant Powder/ Gas Pressure	Valve releases high pressure gas used to maintain positive pressure on locking clamps.
Control - Propulsion Explosive Valve	Explosive Valve	15 Devices, 1 Squib per Device	Electric	Propellant Powder/ Gas Pressure	Start-Stop regulation of propellant flow.

APPENDIX XII
COMPARISON OF HYDRAULICS vs PNEUMATICS FOR CONVENTIONAL ACTUATOR CONTROL SYSTEMS



APPENDIX XII (Continued)
ADVANTAGES OF CONVENTIONAL HYDRAULIC AND PNEUMATIC APPROACHES

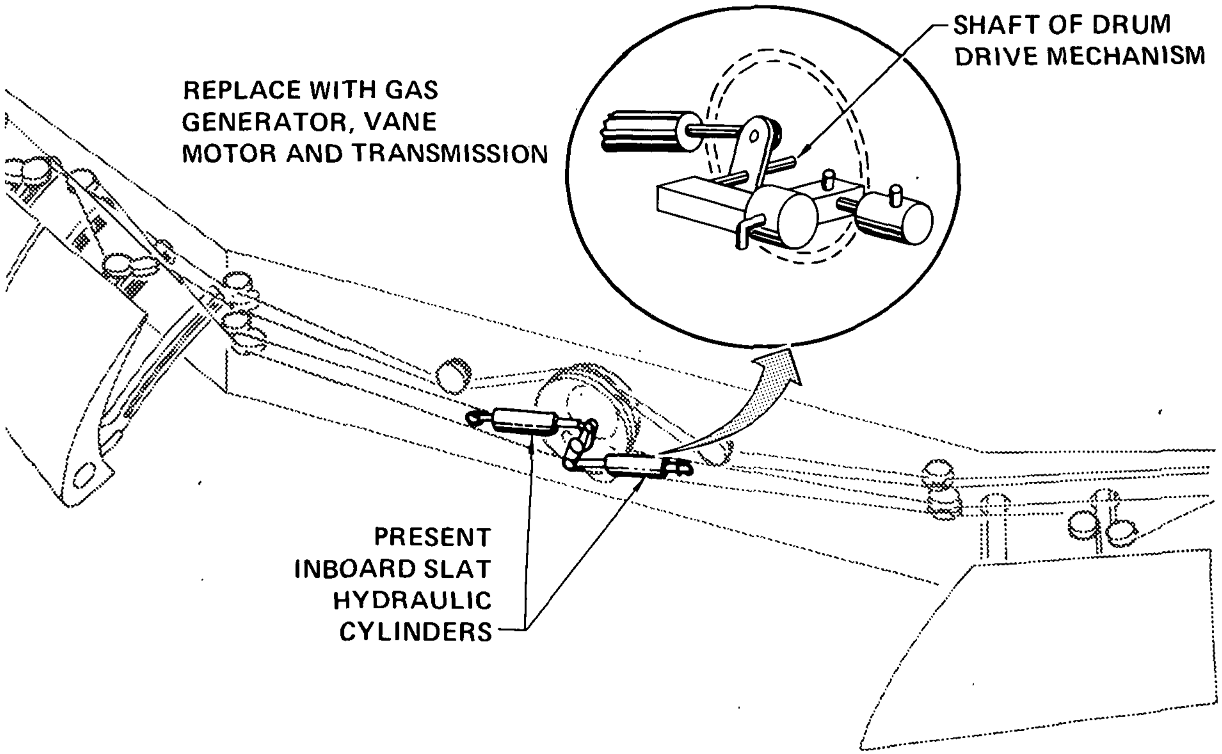
HYDRAULICS

- LONG LIFE
- GOOD LUBRICATION OF COMPONENTS
- SIMPLE TO USE
- SIMPLE ACTUATION METHODS
- FEW CONTAMINATION PROBLEMS
- EXTENSIVE EXPERIENCE
- STIFFNESS

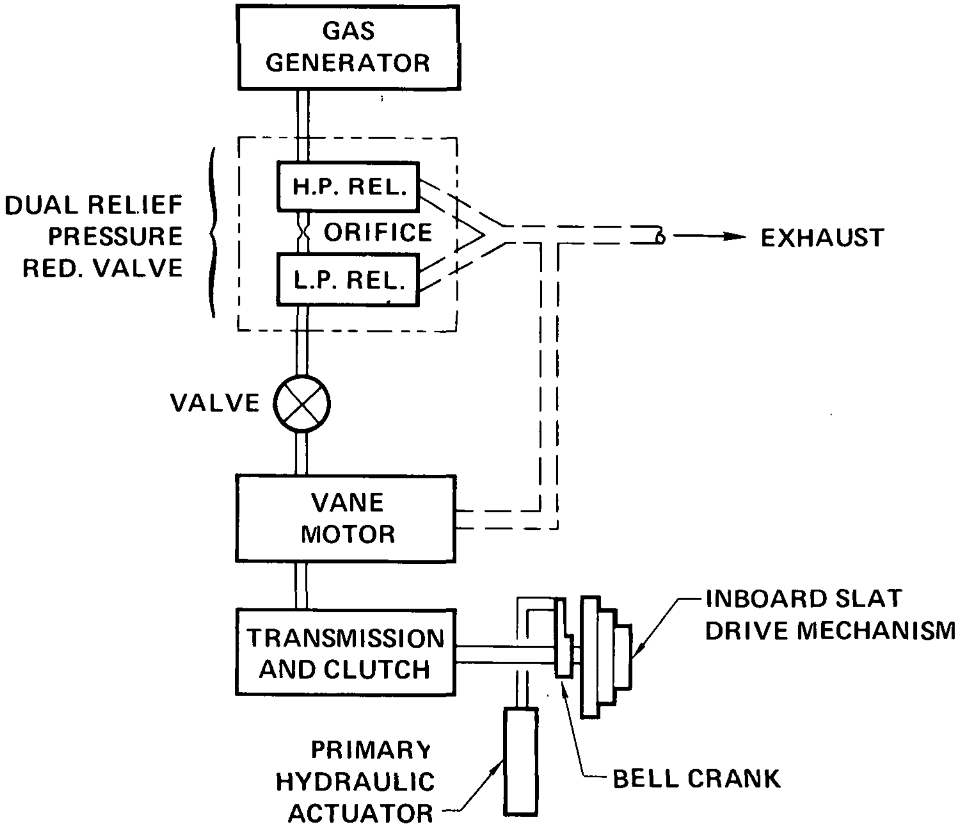
PNEUMATICS

- ONE-WAY ENERGY TRANSFER
- LOW TRANSMISSION LOSSES
- HIGH TEMPERATURE OPERATION
- SIMPLE BACK-UP METHODS AVAILABLE
- INSENSITIVE MINOR LEAKS
- NO WORKING FLUID STORAGE REQUIRED
- POTENTIAL WEIGHT ADVANTAGE (SHORT DUTY CYCLES)
- NO STEADY LOSSES FOR UTILITY FUNCTIONS

APPENDIX XIII
TYPICAL INSTALLATION OF EMERGENCY SLAT ACTUATION SYSTEM



APPENDIX XIII (Continued)
EMERGENCY DEPLOYMENT
Solid Propellant Operated Servo System



APPENDIX XIII (Continued)
SOLID PROPELLANT OPERATED SERVO SYSTEM
Physical Characteristics

WEIGHT (LB) ADDED

GAS GENERATOR CARTRIDGE		2.7
SERVO ASSEMBLY		34.0
VANE MOTOR	4.5	
TRANSMISSION	29.0	
LOCK	0.5	
RELIEF VALVE		1.8
TOTAL		38.5 lb (17.5 kg)

WEIGHT (LB) REMOVED

LINEAR ACTUATOR (HYDRAULIC LINES AND FLUID NOT INCLUDED)	24.0
NET WEIGHT INCREASE	14.5 lb (6.6 kg)

FOR COMPARISON

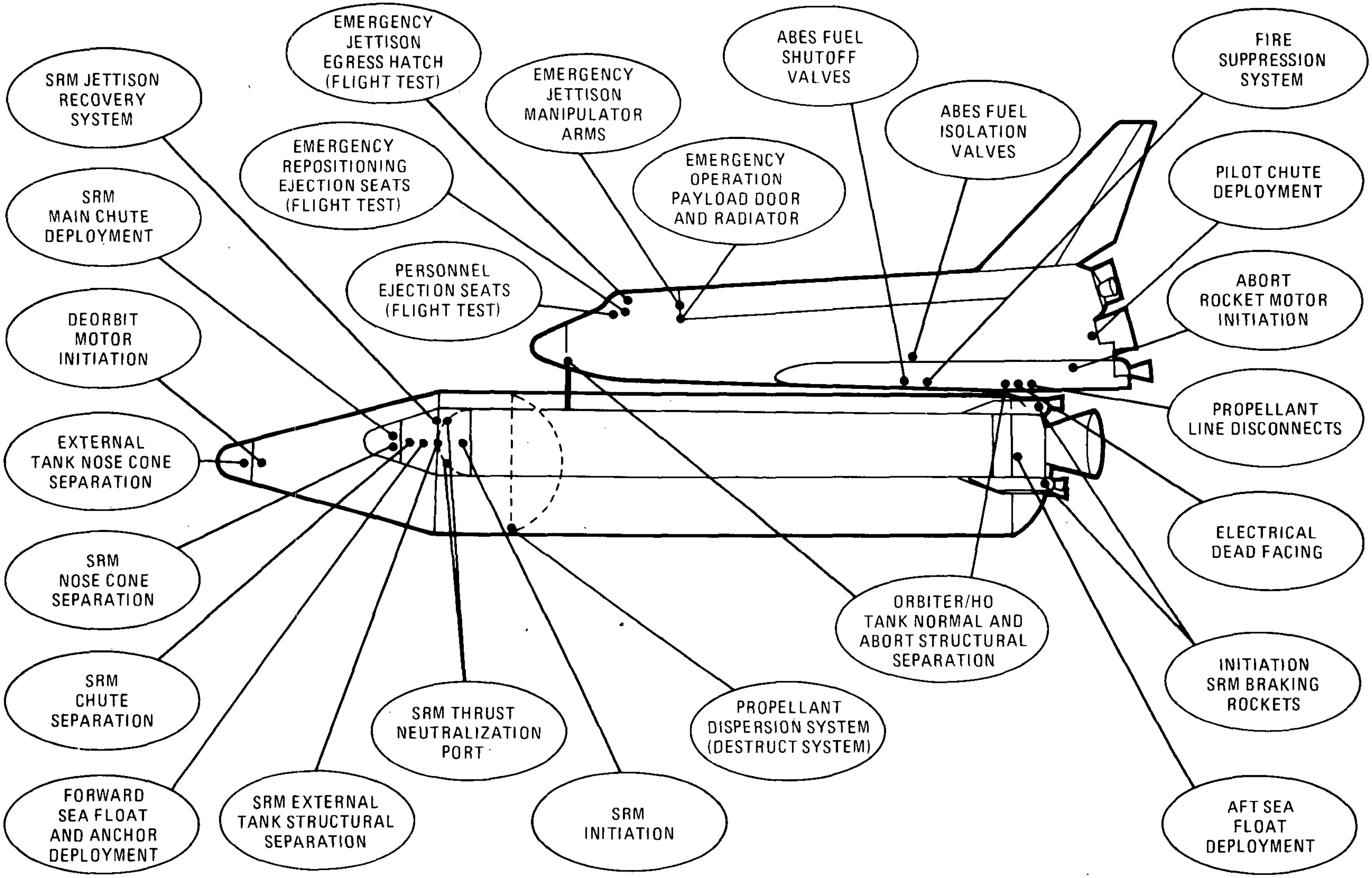
COMPRESSED GAS SUPPLY TO PERFORM EQUIVALENT FUNCTION AS SOLID PROPELLANT SOURCE WOULD REQUIRE:

GAS BOTTLE	10.0
120 CU IN. NITROGEN AT 3000 PSI	0.7
PRESSURE REGULATOR (REPLACES RELIEF VALVE)	0.75
	11.45 lb (5.2 kg)
NET WEIGHT INCREASE	6.95 lb (3.15 kg)

ESTIMATED COST

SERVO ASSEMBLY AND RELIEF VALVE	$1500 TO 1800
GAS GENERATOR CARTRIDGE	$200

APPENDIX XIV
SPACE SHUTTLE
POTENTIAL PYROTECHNIC FUNCTIONS



APPENDIX XIV (Continued)
SELECTED POTENTIAL PYROTECHNIC APPLICATIONS FOR SPACE SHUTTLE

FUNCTION	POTENTIAL PYROTECHNIC DEVICES	FUNCTION	POTENTIAL PYROTECHNIC DEVICES
EMERGENCY JETTISON EGRESS HATCHES	CONFINED EXPLOSIVE SEVERANCE, EXPLOSIVE BOLTS, NUTS, OR THRUSTERS	SEPARATION, ORBITER-EXTERNAL TANK	EXPLOSIVE BOLTS, NUTS OR PIN PULLERS
PERSONNEL EJECTION SEATS	TYPICAL SEAT AND HOT GAS OR SMDC SIMULUS SYSTEM	PROPELLANT LINE DISCONNECT	SEGMENTED CLAMP RING AND EXPLOSIVE BOLTS
ABES* ISOLATION AND FUEL SHUT-OFF VALVES	EXPLOSIVE VALVES	PROPELLANT DISPERSION SYSTEM	LINEAR SHAPED CHARGES
ABES FIRE SUPPRESSION SYSTEM	EXPLOSIVE VALVES OR COOL GAS GENERATORS	SRM** NOSE JETTISON AND DEPLOYMENT OF RECOVERY SYSTEM	CONFINED EXPLOSIVE SEVERANCE OR EXPLOSIVE BOLTS, MORTAR OR CATAPULT
ABORT ROCKET MOTOR IGNITION	PYROGEN IGNITER	SRM CHUTE SEPARATION	EXPLOSIVE BOLTS, PIN PULLERS, DISCONNECTS OR BALL RELEASE SYSTEM
PILOT CHUTE DEPLOYMENT	PROPELLANT ACTUATED MORTAR OR CATAPULT	SRM-EXTERNAL TANK SEPARATION	SEGMENTED CLAMP RING AND EXPLOSIVE BOLTS, EXPLOSIVE NUTS OR PIN PULLERS

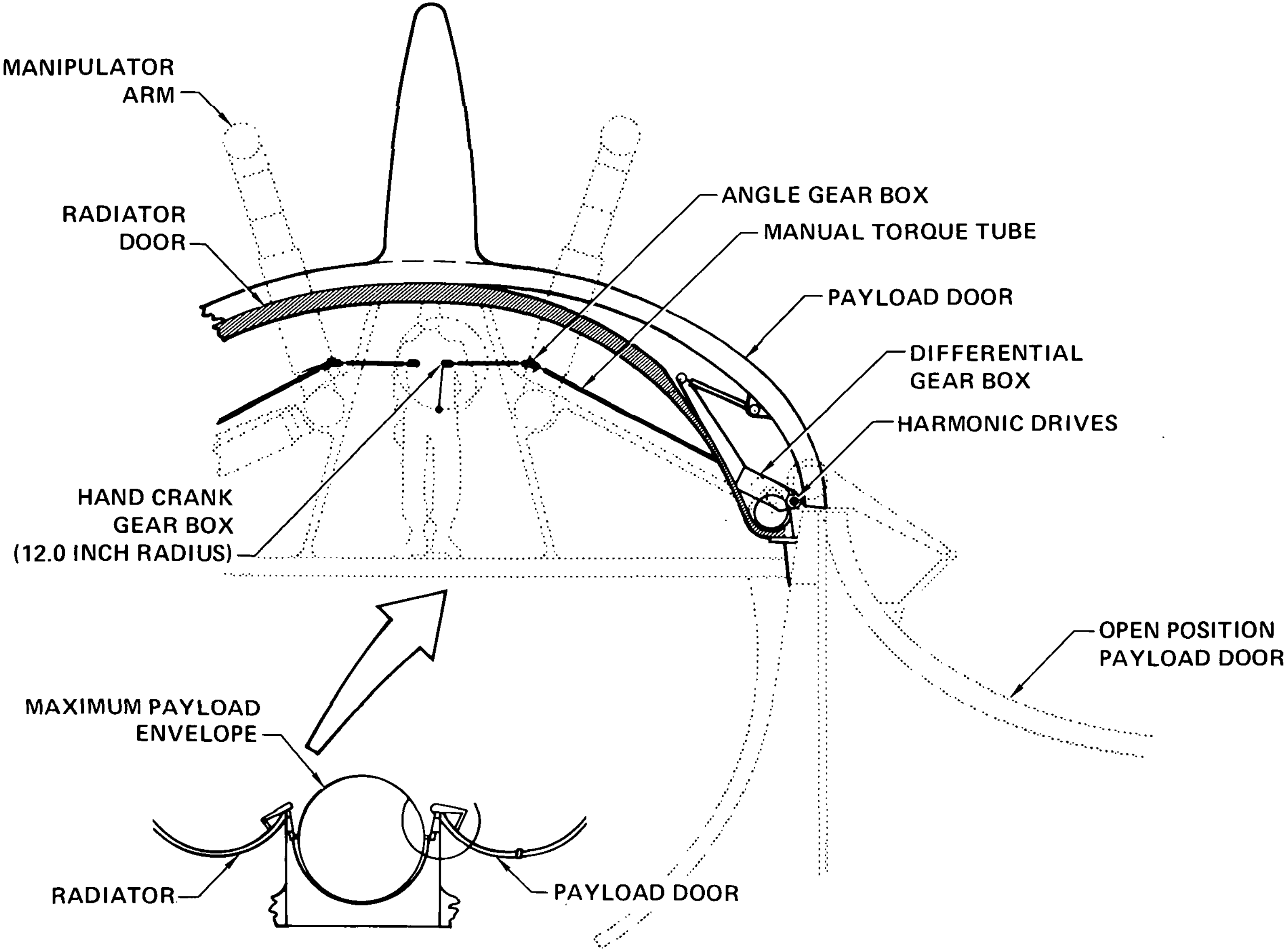
* AIR BREATHING ENGINE SYSTEM
**SOLID ROCKET MOTOR

APPENDIX XV
PAYLOAD DOOR AND RADIATOR DRIVE MECHANISM

TRADE STUDY TO DETERMINE
EFFECT OF POSSIBLE ELIMINATION OF MANUAL BACKUP SYSTEM AND SUBSTITUTION BY A PYROTECHNIC SYSTEM FOR EMERGENCY DOOR CLOSING.

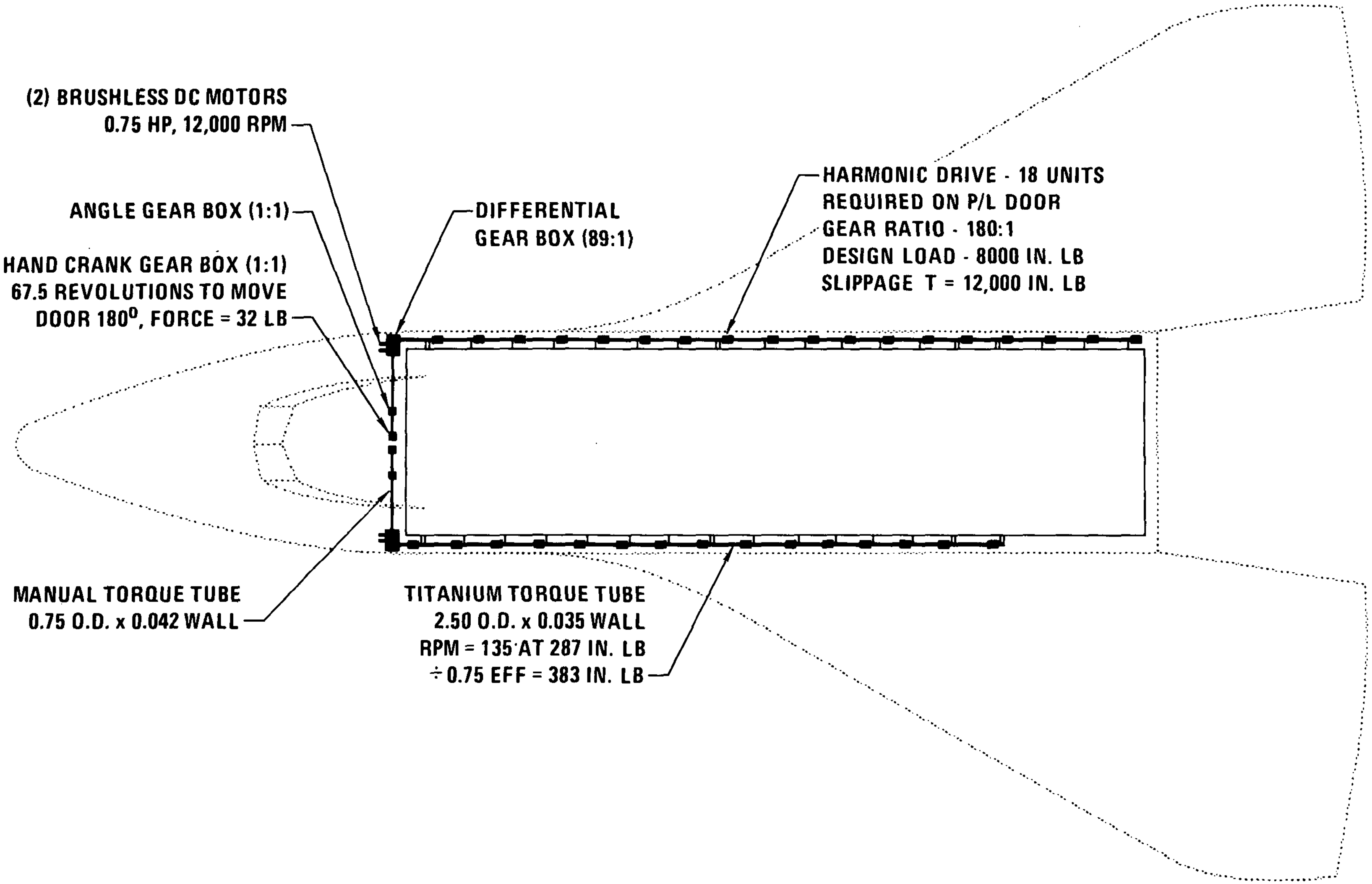
APPENDIX XV (Continued)

PAYLOAD DOOR AND RADIATOR DRIVE MECHANISM

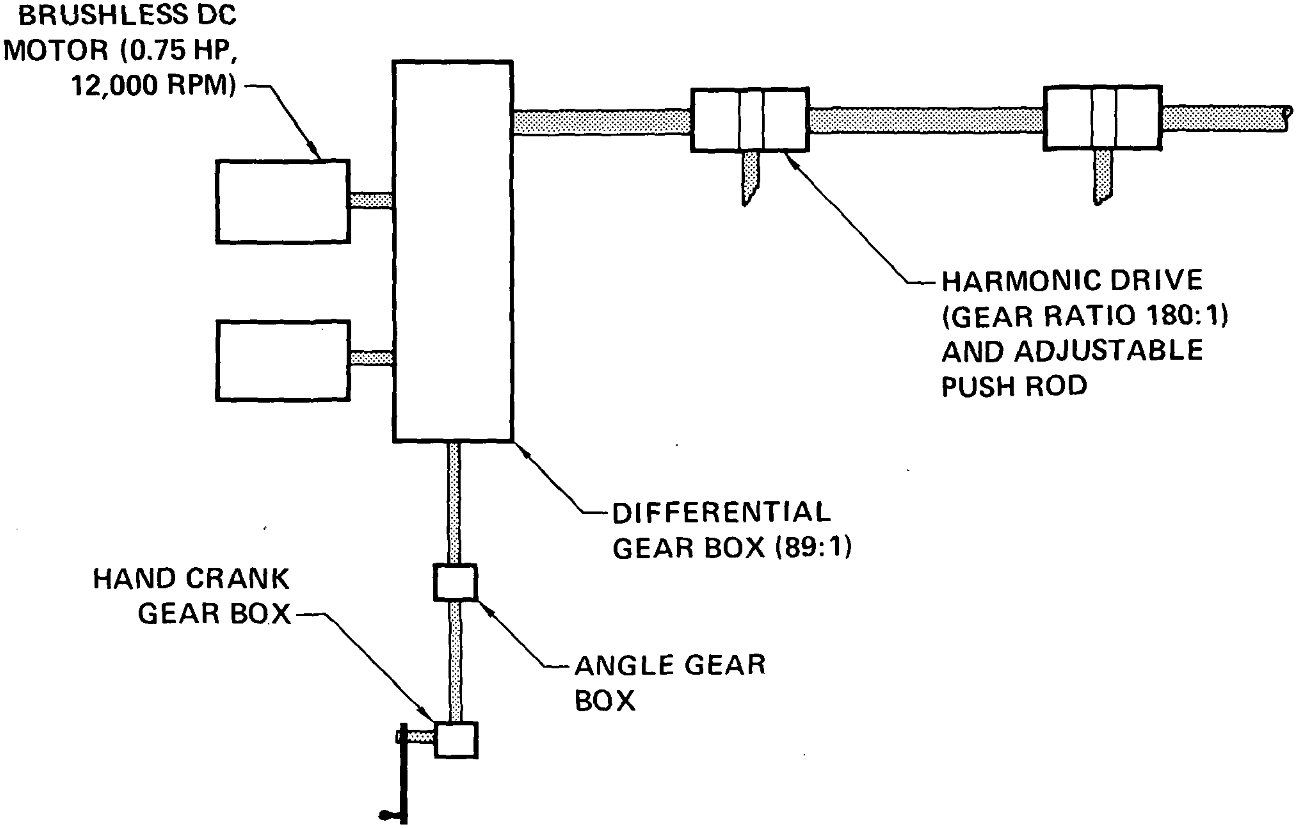


APPENDIX XV (Continued)

PAYLOAD DOOR AND RADIATOR DRIVE MECHANISM



APPENDIX XV (Continued)
PAYLOAD DOOR AND RADIATOR DRIVE MECHANISM
OPERATIONS SCHEMATIC

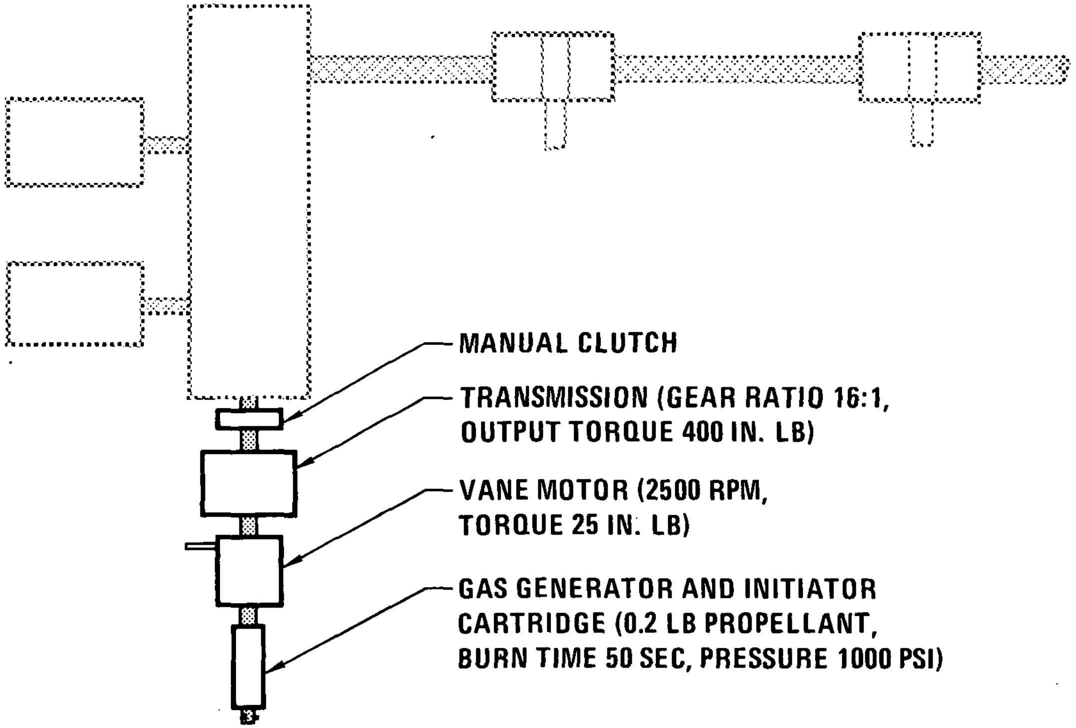


(OPERATION TIME: 40 SECONDS TO OPEN OR CLOSE)

APPENDIX XV (Continued)

PAYLOAD DOOR AND RADIATOR DRIVE MECHANISM

PYROTECHNIC BACK-UP SYSTEM SCHEMATIC



NASA-Langley, 1973 — 31

APPENDIX XV (Continued)
PAYLOAD DOOR AND RADIATOR DRIVE MECHANISM
WEIGHT EFFECT OF SUBSTITUTING PYROTECHNIC BACK-UP FOR MANUAL SYSTEM

ADDED

PYROTECHNIC BACK-UP SYSTEM
(PER DOOR)

	WEIGHT (LB)
GAS GENERATOR	0.7
VANE MOTOR	2.0
TRANSMISSION	2.0
MANUAL CLUTCH	0.5
TOTAL	5.2 (2.36 kg)

REMOVED

MANUAL BACK-UP SYSTEM
(PER DOOR)

	WEIGHT (LB)
TORQUE SHAFT	1.2
ANGLE GEAR BOX	1.5
HAND CRANK GEAR BOX	3.0
HAND CRANK (STOWABLE)	1.0
TOTAL	6.7 (3.04 kg)

NET WEIGHT DECREASE PER DOOR = 1.5 LB (0.68 kg)

IF PYROTECHNIC BACK-UP IS REQUIRED FOR BOTH DOOR OPENING AS WELL AS DOOR CLOSING, THEN AN ADDITIONAL GAS GENERATOR AND SIMPLE, MANUALLY OPERATED SELECTOR VALVE ARE REQUIRED PER DOOR.

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