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Frank B. Pollard
Aero/Astro Research, California

Edgar Shurtleff
Aerojet-General Corporation, California

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SOLID PROPELLANT SPACE POWER SYSTEMS FOR NORMAL AND EMERGENCY SPACE OPERATIONS

By

Frank B. Pollard,
Aero/Astro Research, California
Edgar Shurtleff,
Aerojet-General Corporation, California

The ability of man to function safely both inside and out of his spacecraft will become even more critical after his pioneering flights such as Gemini and Apollo are completed. As greater numbers of astronauts make flights of long duration, survival may well be a function of a number of extravehicular activities such as routine vehicle inspection, emergency maintenance and repair, erection of structures and platforms, and rescue operations. Current systems remain bulky, heavy, and a possible source of hazard and malfunction. The solid-propellant space power systems examined here are small, light, manually or automatically operated, and have the capability not only to propel and stabilize man in space, but provide a means of power to do an extremely wide variety of critical functions outside or within a spacecraft.

It has often been stated that there is no need to replace a working system. The authors of this paper are in full agreement with this statement. Let us assume for purposes of illustration a simplified spacecraft which requires only two systems for its operation, one in the nose which is hydraulic, and another in the tail which is electrical. Both are well designed and completely workable. As long as they are capable of performing their required function and as long as they are capable of growth to meet additional mission requirements, there should be no valid reason to replace either by a solid-propellant hot gas system. But let us consider further. In the event of a failure of either system during a flight, the parts of one system cannot be used in a repair of the other. It would be very surprising if the motors, switches, etc. of the electrical system could be substituted in any way for any of the valves and cylinders of the various hydraulic devices and vice versa. If, however, both systems were replaced with a compatible gas generator powered system, a failure in either end of the spacecraft could use parts and prime movers from the other.

The present philosophy for space-borne systems and components imposes as criteria of design extremely high standards of operational reliability and there is no quarrel with this doctrine. However, high reliability from the standpoint of completion of a manned space mission does not necessarily imply complete maintenance-free reliability during the entire operating life of the various systems involved.

We are dealing here with a vehicle containing a crew of thinking, random decision making, non-linear operating, human beings rather than an inanimate object which is capable of performing only the actions for which it has been pre-programmed. At the present time, crew members of space vehicles perform a variety of maintenance functions which enhance the operability of themselves and their vehicles. Such simple non-programmed actions as tuning a radio or adjusting a thermostat can be considered as part of the maintenance functions.

Bad communications? A pilot will naturally and instinctively tune his command receiver for increased performance or change to another communications channel where reception might be better.

Too hot? A crew member turns down the thermostat on his suit a couple of notches to compensate for the extra heat load caused by unplanned exertion.

The majority of the space flights in the Mercury and Gemini series could not have been performed with success as unmanned missions. The ability of the crews to react to unplanned situations and apply the necessary corrective action or maintenance was a prime factor in these successful flights. Why then should not the basic systems of the vehicle, the tools with which the spaceman in a very real sense makes his living, be designed for the highest possible degree of onboard maintainability and repair?

The situation is analogous to that of safety in the ordnance industry itself. Realizing that one is working with materials having a great potential for hazard there are two common approaches taken in minimizing this danger.

The first is to be so safe that no accidents can occur. Safety devices and procedures are piled on safety devices and procedures until every conceivable situation has been taken care of. "The operation is absolutely and completely safe." There is no organization which has tried this approach that has not had casualties at some time during its history.

The other approach is to assume that sooner or later the explosion is going to happen. The effort here goes into preparing devices and procedures which will minimize and contain the effects of whatever may happen. There has been broken and melted tooling, partially shattered safety barriers, etc., where a relatively large amount of high energy material had fired without any physical injury to the personnel involved.

In like manner, it is considerably more realistic in the design of a spacecraft and its operating systems to expect the unexpected and make the most rigorous preparations for a serious malfunction whose nature cannot be forecast.

For future manned space missions, those carrying us through the 1980's and beyond, it appears that some new design considerations must be made in space systems. As we pointed out earlier, we are faced today with many systems which are not compatible with one another and as a result we can see some very complex problems related to maintenance, repair, and emergency operations in the space environment. While it will be possible to place resources and supplies in orbit or on the surface of the moon and planets, the task and costs associated with such programs can be considerably reduced if, in fact, our systems are designed for optimum compatibility and the resultant interchangeability of components.

Small solid-propellant devices have much in their favor for use in such systems. While it is true that on a comparative weight basis, solid-propellant and bottled gas or liquid systems are nearly the same, the advantages in size reduction and work performed are enormous and will produce some amazing results when designed into major space systems.

For example, in the large variety of EVA tasks anticipated, solid-propellant gas generating systems designed for complete interchangeability, system-to-system, can produce some extremely interesting results.

Let us, for purposes of illustration, take a typical solid-propellant gas generator power unit which might be used in a vehicle-borne application. The device has the form of a cylinder, a little under one and one-half inches in diameter and a little under six inches long. This, incidentally, is about the size of a flashlight containing two "D" size batteries and weighs about the same. The propellant in the gas generator is completely self-contained. It has redundant igniters capable of being actuated by electrical, manual, or optical means. It operates at nominal pressure of 1, 000 psi and is controlled by a sonic nozzle built into its end fitting. (Figure 1.).

Let us further assume that this gas generator has been designed for a pressurization application where 1, 000 cubic inches are to be pressurized to 200 psi at a temperature of 400°F. In line with good design practice, a 13% service factor has been placed on this requirement to take care of leakage, low-temperature operation, etc. The device actually produces 955 cubic inches of gas at the standard conditions of 70°F and one atmosphere, neglecting condensation in the exhaust products. This is a relatively routine design problem and application.

Let us investigate briefly and see just what other types of output can be provided from the same package. (Figure 2.). The basic gas generator as outlined above burns for six seconds. During this time it produces approximately 122 gas horsepower. If the LeClanche-type dry cells in the flashlight of comparable size were replaced by high-energy cells such as silver-zinc, and if all the energy in the cells could be delivered to a system, and if the delivery could be made over the same period of six seconds, the battery pack could produce approximately 36 horsepower. On this basis the gas generator is better than three times more efficient as a power source.

Now instead of plugging the gas generator into some system to be operated, let us install an expanding cone auxiliary nozzle onto the gas outlet. Since we are in space we have the potentiality of a very efficient rocket motor. If our rocket motor can produce 95% of its theoretical vacuum thrust, we will get 17. 2 lbs of thrust out of the unit, or a total impulse of 103. 2 lb-sec. This is sufficient to accelerate a man and space suit weighing 250 lbs to 13. 3 ft/sec for example. If we remove the auxiliary nozzle and use the universal gas generator as a heater, approximately 1700 BTU will be produced. The temperature of the exhaust gases as they leave the main nozzle is about 3100°F.

We could continue with calculations of the magnitude of the various outputs which can be obtained, but this much seems adequate for illustrative purposes.

Another typical and more sophisticated design is a hand-held thrust and pressure gun. (Figure 3.). This system contains eight to sixteen gas generators cartridges arranged in an annular space between the outside housing and an accumulator neck connected to an accumulator chamber (see Figure 4). By depressing a firing button in the pistol grip, one of the generators is fired by means of electrical energy from a battery and the gas produced flows into the accumulator. A nozzle on the end of the accumulator controls the outflow of gases. The system is designed to automatically activate the individual gas generators in sequence, however, they will not fire unless there is sufficient pressure drop in the accumulator. Although the reliability of most single-unit gas generators has been established at 99. 98%, one hundred percent reliability of the system is established by simply discharging gas from a second, third, or fourth generator into the system. In the event of single generator failure, the next in the series will be activated and constant accumulator pressure maintained. Sizes of the units vary as a function of the end performance necessary and may be as small as 12 inches long by 8 inches in diameter or as large as 36 inches long by 12 inches in diameter.

The gas generators themselves are quick-disconnect and can be replaced in less than a minute with no tools required.

The applications for this unit are many. The small system, for emergency propulsion in the space environment, will give an acceleration of five ft/sec^2 to a 50th percentile man. Since each pulse can be limited to a maximum duration of one second, the maximum velocity which results is 5 ft/sec or normal walking speed.

This system will also produce, on demand, gas under pressure of 10 to 3500 psi. Gas generators will produce gas which (1) is non-explosive and non-flammable, (2) has a low heat expansion coefficient, (3) is non-condensing, (4) is non-toxic and non-allergic, and (5) is compatible with nylon, neoprene and normal adhesive, zinc-base alloys, copper-base alloys, steel and steel alloys and aluminum and aluminum alloys, etc.

The complete flexibility of this system is unique if spacecraft systems are designed to be totally compatible. In the hands of the astronaut outside the capsule a unit such as this can perform a myriad of functions.

Inflation

Future needs in space will include a variety of inflated structures. They may be inflated units or expandible self-locking structures actuated by inflatable means. These can be repair modules which are attached to the outside of a spacecraft, provided with an oxygen environment from the spacecraft to allow "shirt sleeve" maintenance or repair outside the spacecraft with adequate room to operate (see Figure 5). These structures may be in space or on the surface of the moon or a planet.

The pressures necessary to erect such structures will of necessity be on the order of two to three times those required for a working environment in order to overcome initial loads, dispense plastic foams, extend and lock extendible masts or other structural elements, etc. Providing this pressure from the spacecraft breathing gas could severely overtax the system, particularly in an emergency situation involving repair of puncture damage. By using a gas generator to perform the initial erection function a significant reduction in system requirements could be made.

If the systems were designed and packaged properly, an astronaut would simply be able to place his pressure gun into a connection, initiate it, and inflate the structure within a few seconds. If a form of double-base propellant, which is essentially a mixture of nitrated hydrocarbons, were used, additional advantages would accrue.

Such propellants can be completely burned so that their products of combustion are N_2, H_2O and CO_2, with proper control of oxygen balance. This is not normally done for propulsive applications since thrust is inversely proportional to the molecular weight of the exhaust gases. Normal propellants are therefore made "fuel rich" so that a much greater proportion of carbon monoxide, which has a lower molecular weight than carbon dioxide, results. An additional one to two percent of other combustion products, depending on propellant formulation, usually solids, would also be produced.

After inflation of a structure, the H_2O would condense into liquid water and then ice, and could be collected for other uses. The CO_2 would then be absorbed or otherwise purged from the system, as would the other trace gaseous constituents, resulting in a completely non-toxic gas. Sufficient oxygen would be added to form a breathable mixture. This could be taken from the spacecraft or, if total independence from that source were desired, from the burning of an alkali chlorate yielding the chloride plus gaseous oxygen. Another source is the reaction of calcium permanganate and hydrogen peroxide, which yields potable water in addition to oxygen.

Spacecraft Systems

Gas generators may also be used in any system that operates pneumatically, hydraulically or by pressure. The design of systems to accept solid-propellant gases as a source of emergency or boost pressurization could increase reliability and maintenance factors radically. Most present systems have built-in redundancy at a sacrifice in weight and space. This essentially necessitates carrying "backup" or duplicates of each system critical to spacecraft operation. With the solid-propellant system, optimized in design for compatibility in all systems, it is necessary only to "plug in" power units at a specific location in the system and at the time dictated by the existent condition.

Attitude control is an excellent example. A gas generator is for all practical purposes a small rocket motor which can be very closely controlled with respect to output. In the event of failure of thrust systems for attitude control, gas generator units could be connected by the astronaut to each of these systems and replace or effect a method of operation in emergency conditions.

Rescue

The ability to function outside the space vehicle during an emergency may become critical during long-duration flights when an astronaut is forced out of his capsule for emergency repair, hull inspection, maintenance, for rescue or by accident. It will be imperative for man to have a simple, portable, reusable and extremely light system to propel, orient, and stabilize himself when by accident or carelessness he drifts beyond the limits of his capability to effect physical contact with the vehicle or his normal maneuvering system malfunctions. One approach is the use of the thrust gun which he might carry much as we carry a pistol here in the earth environment. While not the most sophisticated method of propulsion it would provide an excellent backup system. In addition, if the maneuvering units were designed for emergency operations from solid-propellant gas generators, a belt of such cartridges could be an integral part of the system, again, giving a tremendous flexibility of operation.

In the aforementioned explosive forming activity for example, the way is now open for actuation of high explosives remotely from a nearby spacecraft through laser energy. Dangerous by-products of high explosive operations are in this way removed as a source of hazard to man and machine. (Figure 7).

Each of the operations outlined here is within the state of current technology and is now being accomplished. It is true that to modify existing systems for this kind of activity would be totally impossible. However, as new generations of spacecraft are conceived some of these concepts can and should be designed into the systems.

TYPICAL GAS GENERATOR

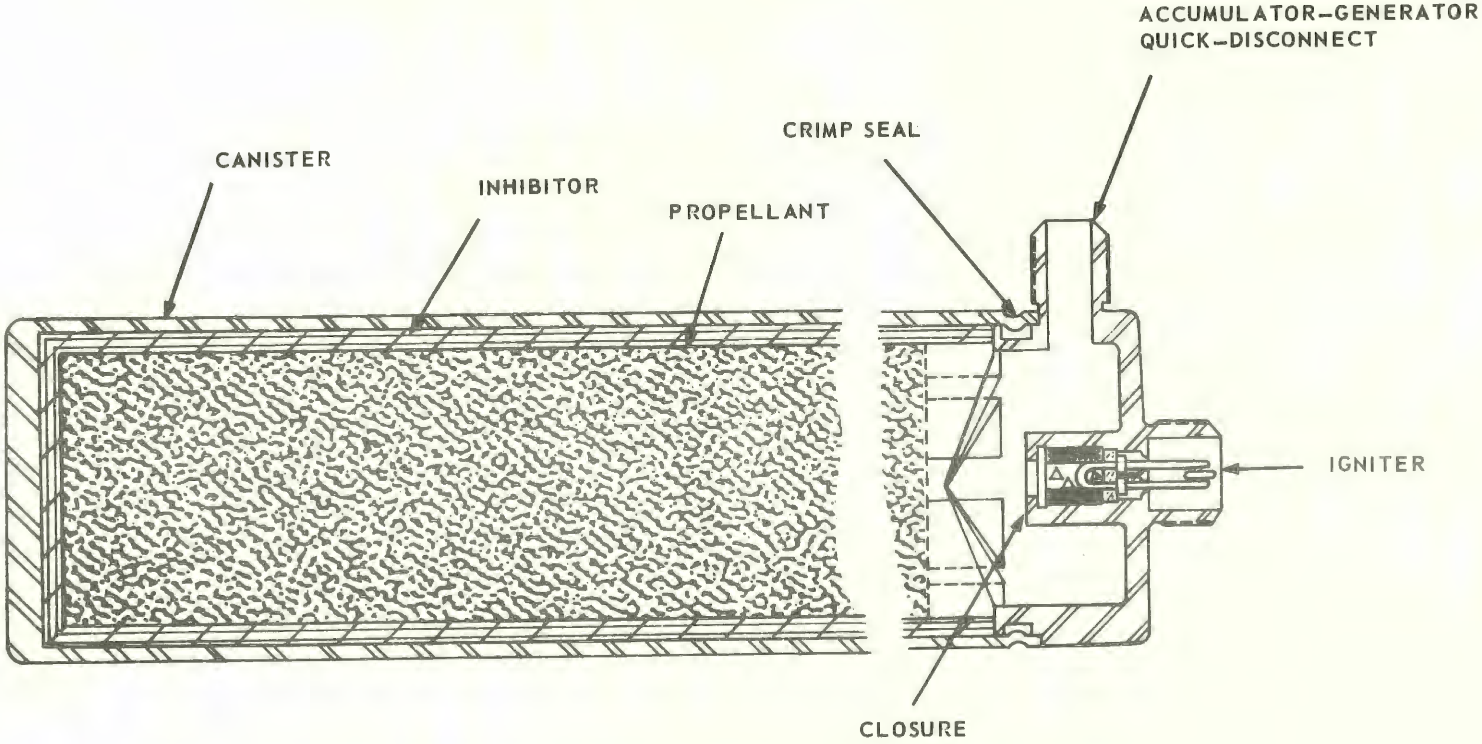


Figure 1. Typical Gas Generator.

COMPARATIVE OUTPUTS OF GAS GENERATOR

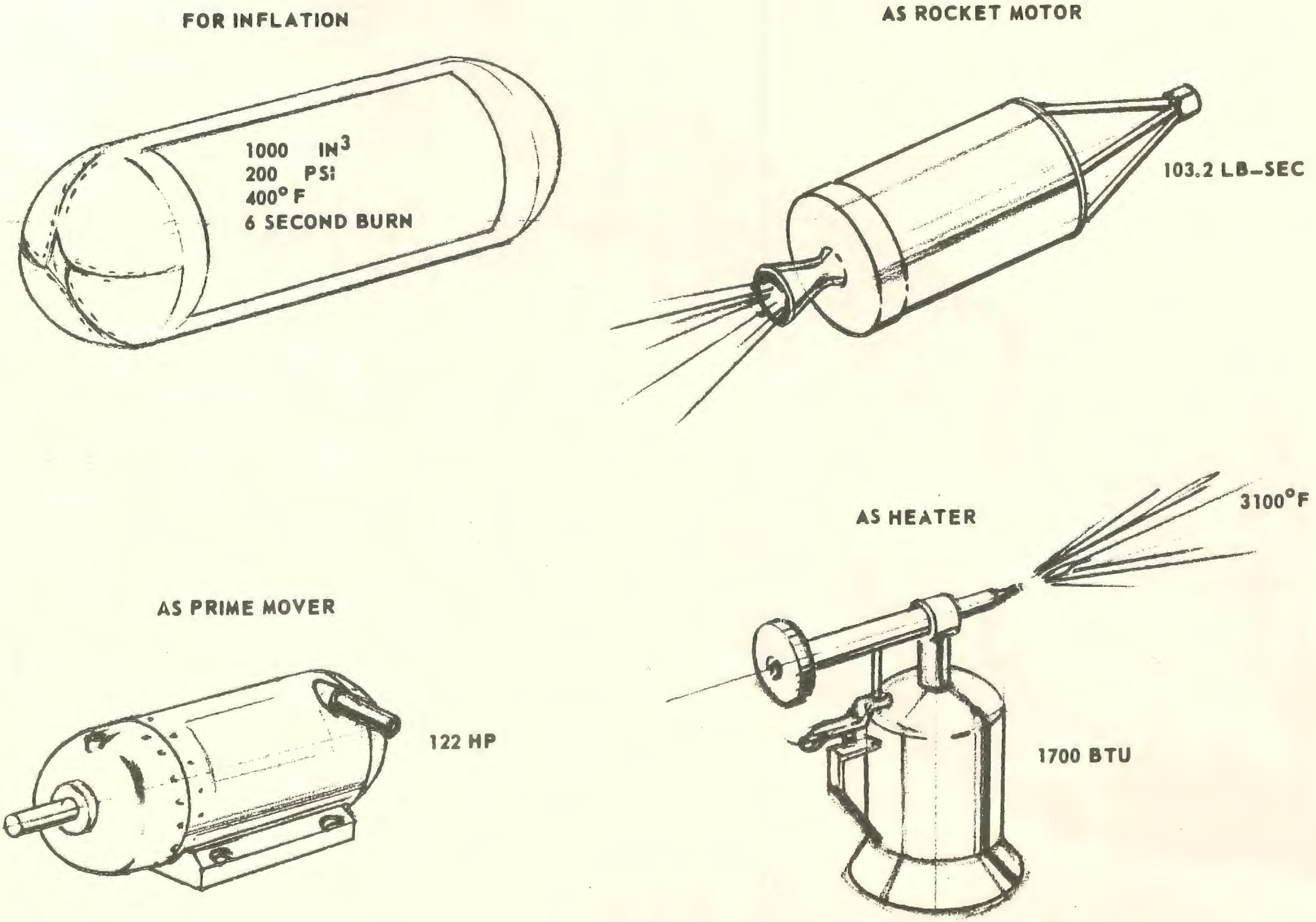


Figure 2. Comparative Outputs of Gas Generator.

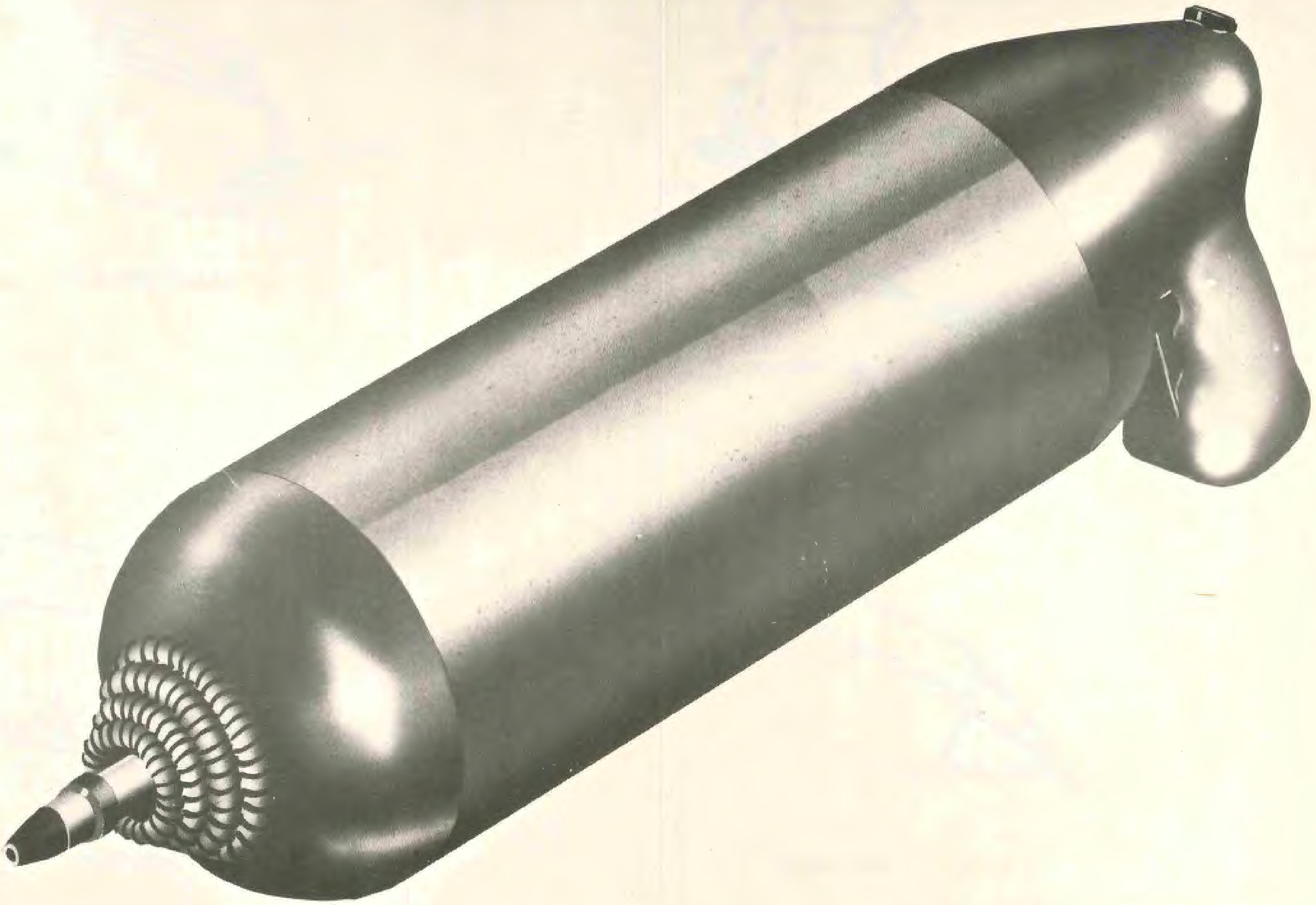


Figure 3. Thrust Gun.

THRUST GUN (SECTION)

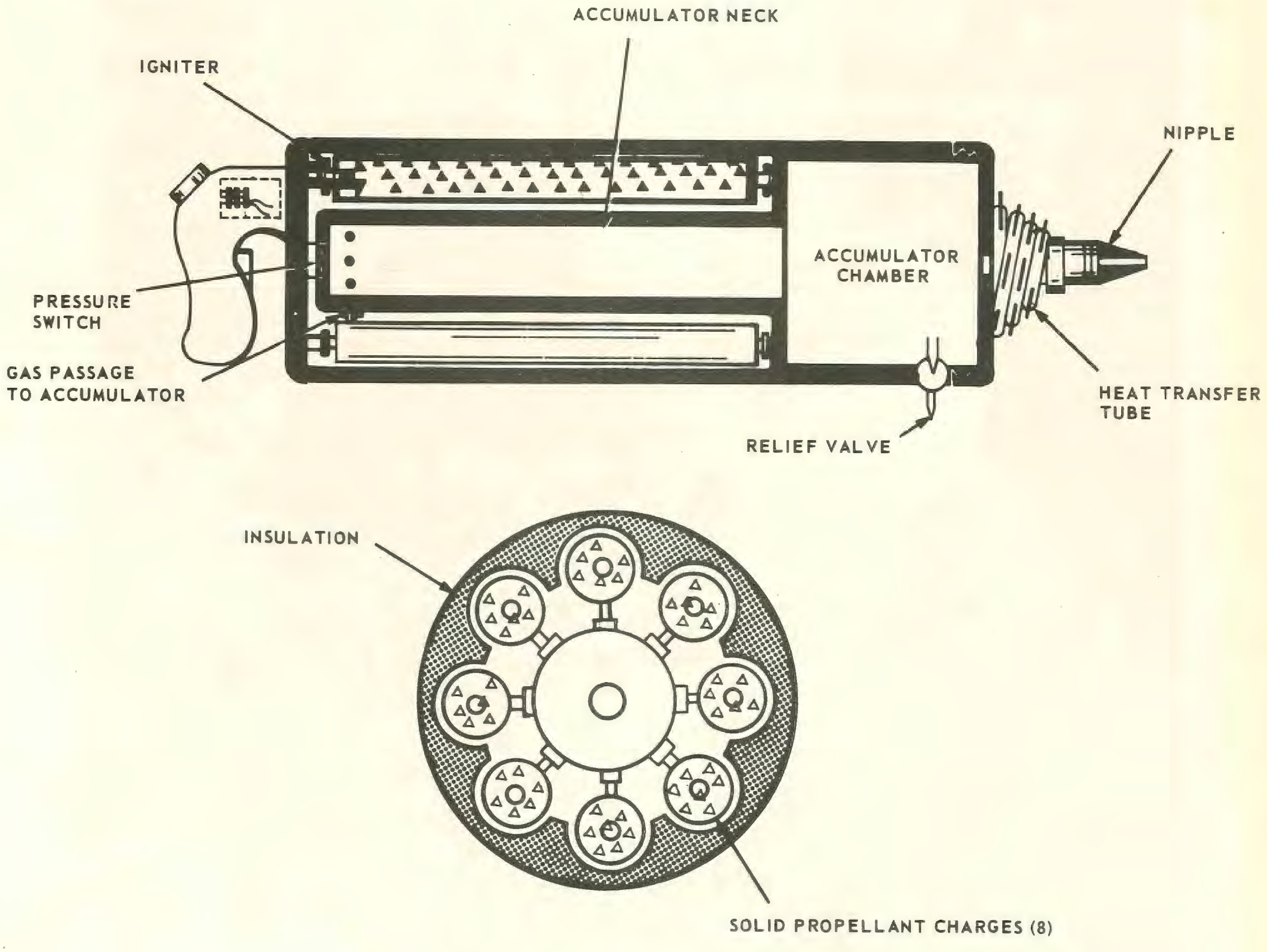


Figure 4. Thrust Gun (Section).

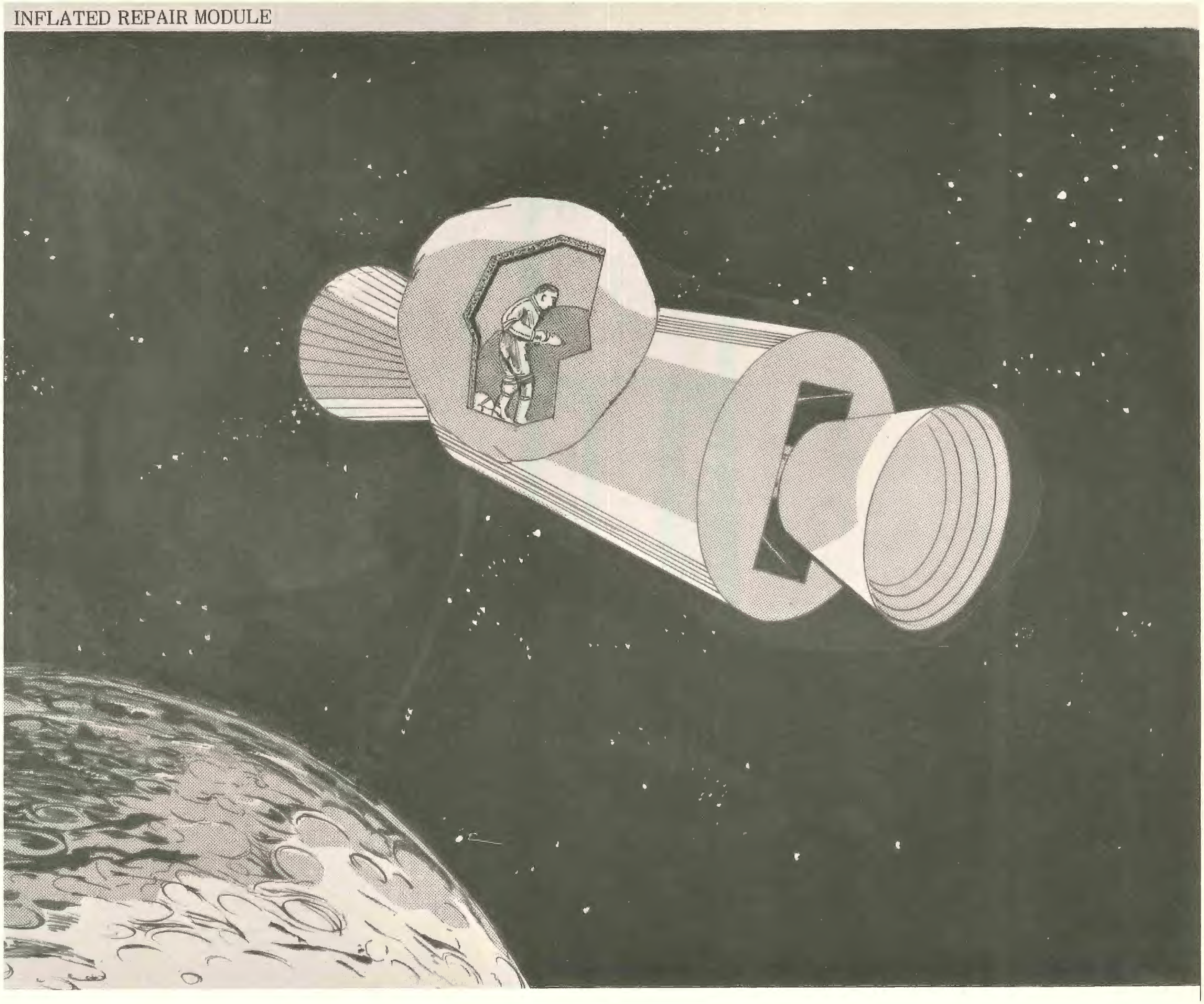
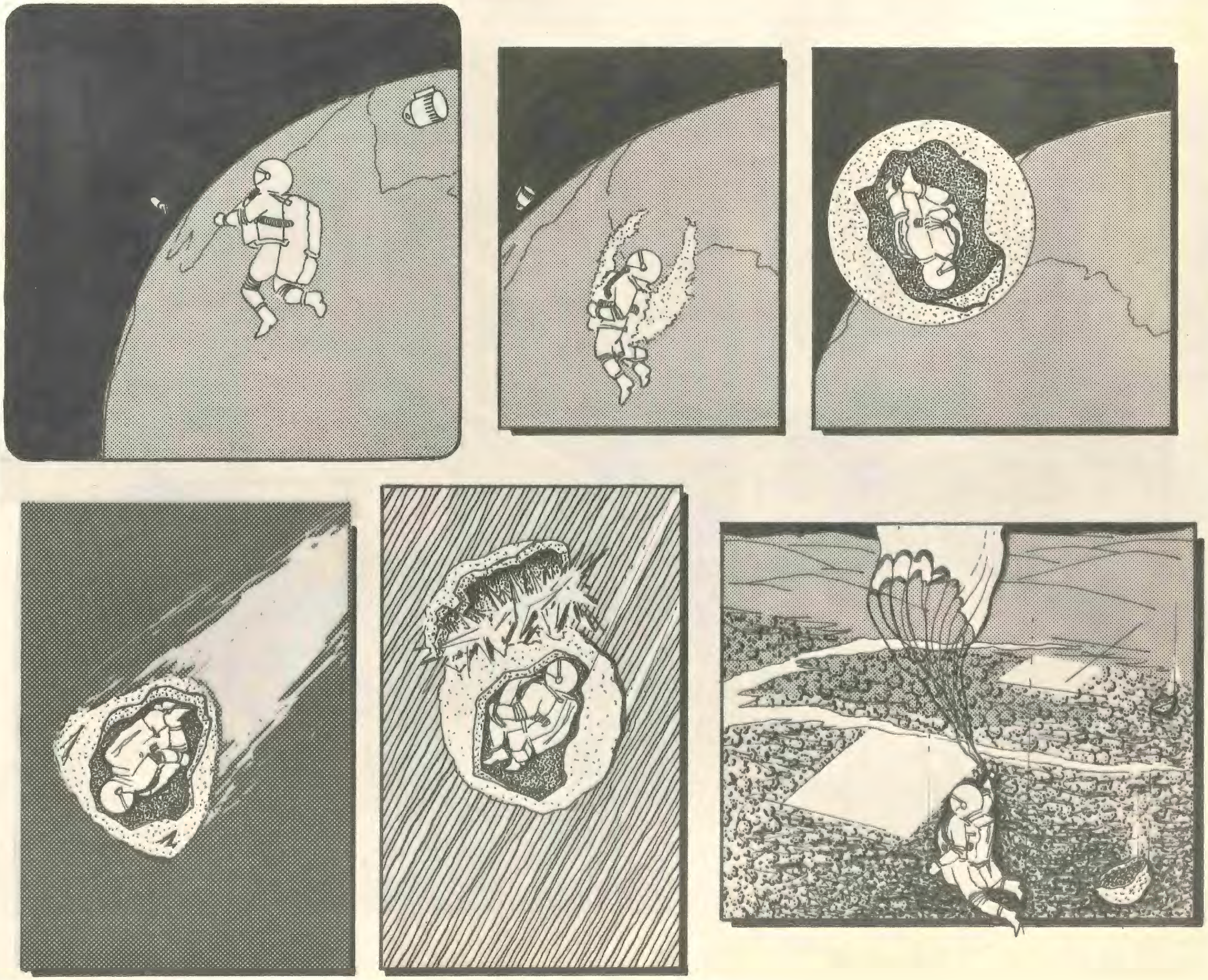


Figure 5. Inflated Repair Module.



CONCEPT OF SPACE RESCUE AND RE-ENTRY

Figure 6. Concept of Space Rescue and Re-Entry.

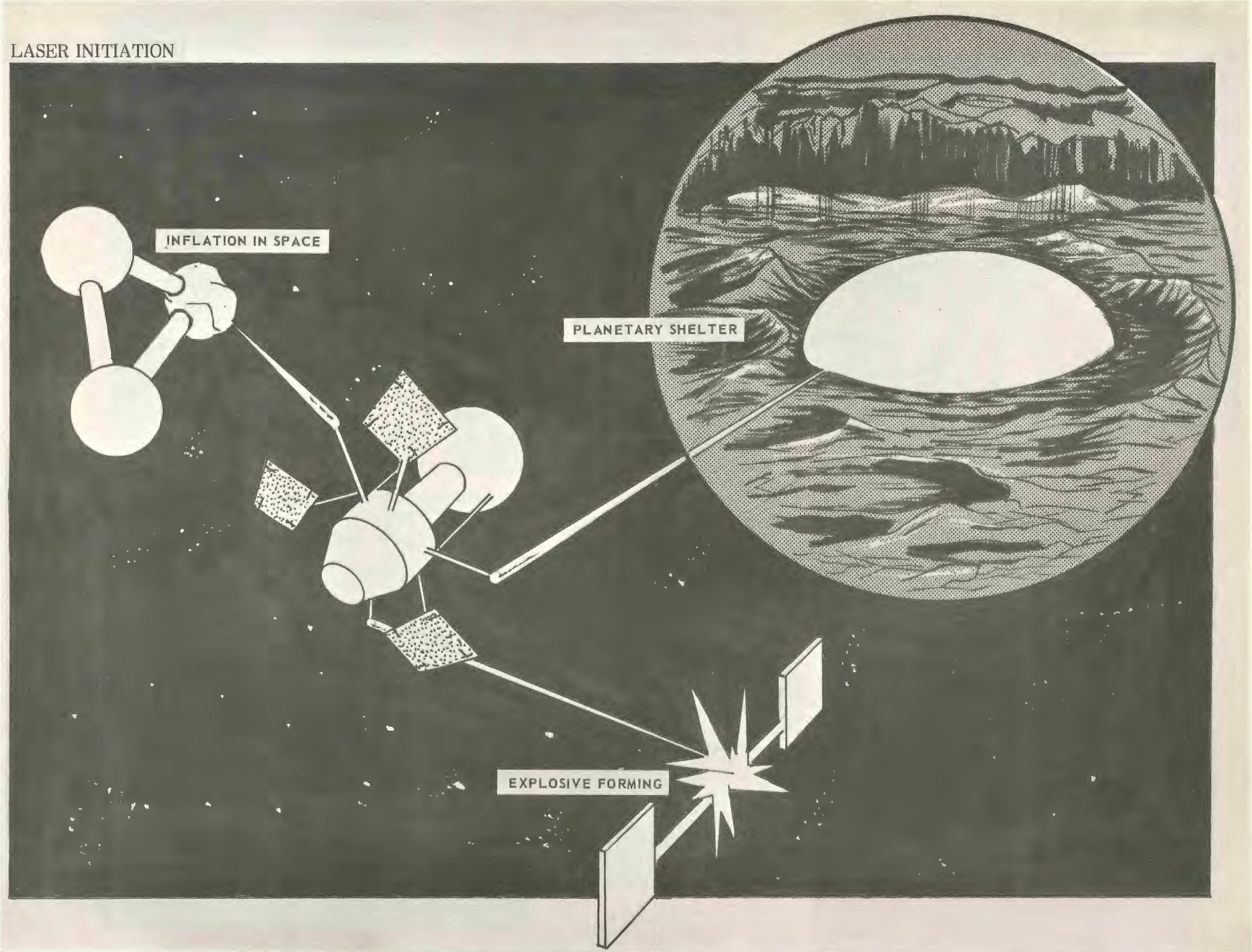


Figure 7.   Laser Initiation.