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Presentation Title: Parachute Recovery Systems Design and Development Efforts Expended on MERCURY-REDSTONE Booster And SATURN S-1 Stage

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PARACHUTE RECOVERY SYSTEMS DESIGN AND DEVELOPMENT EFFORTS EXPENDED ON MERCURY-REDSTONE BOOSTER AND SATURN S-1 STAGE

I. INTRODUCTION

The George C. Marshall Space Flight Center's (MSFC) presentation will be given in four steps. The four presentations will cover separate but related areas of effort expended by the MSFC.

I will give a rundown on the early research and development of two parachute recovery systems - one being for the MERCURY-REDSTONE booster, the other being the SATURN S-1 stage. I will also give a short rundown on two other related programs done parallel with the recovery system developments - these being the MERCURY-REDSTONE booster retrieval exercises and the salt water immersion of the H-1 engine.

Mr. Lewis McNair will summarize the Rogallo Flexible Wing feasibility studies for the first stage recovery on the C-1 and C-2 SATURN programs.

Mr. Dietrich Fellenz will give a short review of study results, both in-house and out-of-house, on recovery of an upper stage from orbit employing a Rogallo Flexible Wing.

Mr. Luke Spears will cover the parametric studies that the MSFC has underway now and planned. He will outline performance penalties, operational considerations, and economic trade-offs. Mr. Spears will also summarize the future effort on Booster Recovery by the MSFC.

II. RECOVERY PROGRAM

The Recovery Project Office, Propulsion and Vehicle Engineering Division, MSFC, has been conducting studies on first stage recovery since February, 1959. Some feasibility studies were conducted as early as June 11, 1958, by the Future Projects Office, MSFC.

Two contracts for the design and development of a recovery system for the SATURN C-1 booster and the MERCURY-REDSTONE booster, respectively, have been supervised by the Recovery Project Office. The two recovery systems employed the same basic technique since the requirements outlined for both of the contractors stated that the system be highly reliable and simple, avoiding in so far as possible, the use of techniques and/or components which would require extensive development. Also, a major requirement imposed on the contractors was that the system be designed such that it would not interfere with, or compromise the vehicle design. With the above requirements and limitations, the only recovery system conceivable was one employing parachutes.

Following the basic requirements that the booster recovery system be highly reliable, simple, and avoiding in so far as possible the use of techniques and/or components requiring extensive development work, a brief outline of the MSFC's approach in determining the initial design of the recovery system for SATURN C-1 S-1 stage is as follows:

1. Approaches that were considered.

Various approaches to the recovery problem were considered in view of the foregoing requirements and limitations. The approaches were generated by variations of the following parameters:

a. Booster cutoff conditions: velocity, altitude, and angle.

b. Booster re-entry: structural loads and temperature capabilities.

c. Booster attitude: either broadside or end-on, during re-entry and impact.

d. Terminal recovery parachute: type, size, and number.

e. Terminal decelerating rocket: thrust, burning time, and number.

2. Having given careful consideration to the above mentioned parameters, it was decided that the simplest and quickest approach for initial deceleration would be by ribbon parachute. Dive brakes were undesirable for reasons of required size and complexity. The use of retro-rockets for initial deceleration, in addition to being inefficient weight wise, would require close attitude control of booster in order to align thrust vector with the velocity vector. Use of parachutes for initial deceleration required only quasi-stability of the booster permitting angles of yaw up to ninety degrees at parachute deployment.

3. After the initial deceleration by the ribbon parachute, further deceleration of the booster to water entry velocity could be accomplished by the following: (1) parachutes, (2) retro-rockets, or (3) combination of parachutes and retro-rockets.

Making the proper selection required consideration of reliability, simplicity, weight, volume, and cost of each alternative. The use of only retro-rockets would mean that the stabilization of the booster with the initial parachute would be ineffective at lower velocities, and the thrust and velocity vector would not be aligned so as to provide predictable deceleration. The use of only parachutes to accomplish recovery appeared very attractive at first glance; but because of booster weight such as the SATURN, the water impact velocity would be too high. Also, the complexity of a parachute system would increase and the reliability would decrease as the parachutes increased in size and number. The conclusions were that neither the retro-rocket system nor the parachute system was capable of performing the terminal deceleration phase by themselves.

With the above observation, it was decided that the most efficient deceleration system would be to combine the use of a few parachutes for the high velocities, and other means, such as retro-rockets for the lower velocities.

The immediate advantages of the combination system over the system using the retro-rockets only were (1) booster attitude stabilized by parachutes during retro-rocket firing, and (2) reduced weight and cost. The combination system advantages over the system using only parachutes were (1) greatly reduced complexity, (2) increased reliability, (3) reduced weight, and (4) reduced parachute stowage volume requirement.

The booster attitude at water impact was considered for both the end-on and horizontal positions. The horizontal position presented the following problems: (1) placement of retro-rockets, (2) the possibility of impacting on top of a wave with the center section, and (3) the possible misfiring of retro-rockets, thus, providing an unpredictable attitude at water impact. It was therefore decided that the end-on position would have a definite advantage, and the booster was far more capable of standing heavy loads in the end-on position than the horizontal. As a result, the method and sequencing of the system selected was (1) initial deceleration by ribbon parachute, (2) terminal deceleration by parachutes and retro-rockets, and (3) end-on attitude at water impact.

The control system (sequencing system) was not finalized at the termination of the studies, but the method of initiating the operation of the system would most probably have been to use either a barometric switch, deceleration switch, or the control timer on the booster, or any combination of the three to have given greater reliability.

After having made some preliminary investigations and selecting the recovery system design approach as outlined above, a contractor proposal was accepted and funded by MSFC in February, 1959.

The recovery system consisted of a deceleration system and a control system that provided for recovery of the booster from the ocean. The deceleration system consisted of parachutes which deployed after re-entry, and a retro-rocket system which decelerated the booster to a safe velocity for water impact. The control system consisted of the devices which determined the initiation of the recovery events. This system located the parachutes and control unit in a cylindrical shaped container at the top of the stage and the retro-rockets on the periphery of the tail structure.

During the course of the recovery system development, preliminary investigations indicated that the ability of the SATURN booster structure to withstand re-entry and impact loads was marginal, but acceptable, since no reuse of components was planned. A damaged booster was acceptable provided the booster would float so as to allow retrieval.

As the development program progressed, changes in the vehicle configurations and in the cutoff conditions were made. This necessitated further investigations into the ability of the booster structure to withstand re-entry and impact loads. After careful evaluation, it was concluded that the booster could not reasonably be expected to survive re-entry without the incorporation into the recovery system of special means to stabilize the booster attitude prior to re-entry and during re-entry.

Studies made of the additional recovery system requirements and the various design constraints, imposed as a result of the specific nature of the SATURN vehicle, led to the adoption of a recovery system concept incorporating the following features:

1. Spatial attitude control of the booster from separation to the start of re-entry by means of vernier rockets, which were to be located near the forward end of the booster. This system incorporated its own independent stable reference system and the necessary associated hardware.

2. During the free space portion of the flight, an inflatable drag device initially housed within the recovery package was to be inflated and deployed so that it would help stabilize the booster and augment its aerodynamic drag during the re-entry period with a resultant reduction in the peak aerodynamic loads on critical areas.

3. The terminal portion of the recovery was to be accomplished by the original system which deployed a 57-foot-diameter first stage parachute; the first stage parachute in turn would deploy a cluster of

three 108-foot-diameter parachutes which decelerated the booster to a terminal velocity of 100 ft/sec. A series of landing rockets were to be ignited to reduce the booster water entry velocity to theoretically zero.

To accommodate the modification, two design layouts were proposed. Figure 1 shows the proposed layout of components which would have required modifications to the existing front I-beam structure. Figure 2 shows the layout which required minimum modifications to existing structure by providing a wafer or spacer for installation of the attitude control system and sub-systems. This allowed more time to test and qualify the complete recovery system by requiring a later delivery date for installation.

Figures 3 through 9 give typical cutoff conditions investigated and illustrate the sequence of events of the revised recovery system.

With the proposed incorporation of the above mentioned features, additional funds were requested by the contractor. The overall SATURN program at the time was having funding problems; and since recovery was not a primary mission, the booster recovery program was postponed to later vehicles in order to make funds available for other necessary flight hardware required on early flights.

The MERCURY-REDSTONE Recovery Program was an outgrowth of a feasibility study initiated by the Future Projects Office of this Center. In June, 1958, a feasibility study contract on booster recovery was initiated by the Future Projects Design Branch (presently Advanced Flight Systems Branch), Propulsion and Vehicle Engineering Division, with Aeronautical Equipment Research Corporation, a Division of M. Steinthal and Company, Inc.

During the time this study was being conducted, the MERCURY Program came into existence. The Future Projects Branch having supervision over the study contract, requested, received, evaluated, and accepted the contractor's proposal on a recovery system applicable to the MERCURY-REDSTONE booster. After acceptance of the proposal, the technical supervision was transferred to the Recovery Project Office. The basic scope of work covered design and development, bench testing of components, aerial testing of parachutes and overall system, finalization of design and drawings, and finally fabrication and delivery of five systems.

The recovery package (Figure 10) is a self-contained unit. It is installed in the booster by joining two mating structural rings, one an integral part of the booster, the other a part of the recovery system structure. Installation of the package is accomplished by bolt attachments through the mating rings, and attachment of the power supply and telemetry network plugs. All components of the recovery system are installed in the package prior to installation on the booster.

Parachute recovery is accomplished in the order shown in Figures 11 through 14. The first-stage parachute is deployed in a reefed condition to limit the possible bending moment on the booster within its structural capability. When sufficient time to orient the booster in a vertical tail-down attitude has passed, the parachute is disreffed to allow greater deceleration. When the first stage parachute has brought the booster below a 5000-foot altitude, and has been deployed for more than 15 seconds, the rate of descent will be in the range of 300 to 350 feet per second, and within the design capability of the final recovery parachutes. At that time the first-stage parachute will be disconnected, and acting as a pilot parachute will then extract and deploy the final recovery parachutes. The final recovery parachutes will deploy reefed to limit the load on the booster, and progressively open through a second step of reefing to their full size. When the final parachutes are fully deployed, terminal velocity at sea level is approximately 40 feet per second.

During the time the contract was in effect, the recovery system conceptual design was established, and fabrication of three systems initiated (one of which is approximately 95% complete). The other two are approximately 40% completed. The drop test program, although difficulties were encountered in the first drops, was progressing satisfactorily at termination of contract. Several times during the development, changes to the recovery system had to be made to guarantee no interference or compromises to the primary mission of the booster. The final design, both mechanically and electrically, was approved by the Manned Spacecraft Center (MSC) and the MSFC.

The end of the program came when contractor and funding problems were encountered. The MSFC was unable to obtain additional funds to complete the development program and delivery of flight hardware.

A major problem in the water recovery program for the MERCURY-REDSTONE booster is the determination of possible damage sustained upon water impact, the angle of flotation, and the depth of submersion. The solution to the problem was of great interest as the solution of these unknown factors determined the method for safing and retrieval employed in floating the booster into the recovery vessel. The tests were conducted at Madkin Mountain quarry, Redstone Arsenal, with a booster approximately four years old, i.e., the REDSTONE RS-33, which was used by the Army as a back-up in the REDSTONE program and also as a troop training missile at the Ordnance Guided Missile School. RS-33 was altered in weight and configuration so as to simulate MERCURY-REDSTONE booster retrieval conditions.

In parallel to the impact and flotation tests, the proper procedures were established for safing the booster prior to floating aboard the recovery vessel. During the performance of this exercise, handling procedures were also studied and later applied during the rehearsals in the Atlantic Ocean.

Results obtained from prior investigations indicated that the use of an LSD as a recovery vessel was the most practical method of recovering a MERCURY-REDSTONE booster. A two-day training exercise was conducted, about 50 miles out at sea from Norfolk, Virginia, to ascertain the capabilities of the LSD and to provide training for the underwater demolition team and LSD crew.

Special recovery equipment was used by the UDT in preparing the booster for towing aboard ship and for receiving and securing the booster to the saddles.

Prior to bringing the booster aboard the LSD, the saddles in which it was to be set were positioned and anchored in the ship's well. The saddles were used and were placed 36 feet 4 inches apart along the ship's centerline. The rear skid was placed 19.5 feet from the stern gate allowing about 10 feet of working area between the tail of the booster and the stern gate. Since six connecting points were established on the booster for handling purposes, six 175-foot-long lines were made up, with quick fastening snaps, and numbered for identification.

There were four retrieval exercises conducted. Figures 15 through 19 illustrate the position of the saddles in the well of the LSD and operational procedure in towing the booster into the well of the LSD and placed on the saddles.

The primary objective of this first retrieval attempt was to check out the proposed handling procedures. As the first step, the booster, swimmers and their rubber boat, and the towing crew aboard the LCVP were launched. The LSD drained the well and moved away several thousand yards. The swimmers then approached the booster and went through the safing procedures without any difficulty, and also installed the handling connections.

After the safing operation was completed the booster was taken in tow by the LCVP and positioned astern the LSD which was maintaining a constant heading into the sea. The LSD was ballasted so as to have 8 feet of water in the well at the stern gate sill. The LCVP continued towing until its bow was over the LSD stern gate, then reversed, disconnected its tow line, and moved off to the port side and stood by. Swimmers with lines from the LSD attached lines to prescribed connections on the booster, and the booster was positioned over saddles. Once the booster was positioned, deballasting of the well proceeded until booster rested firmly on saddles. After the well was drained, the booster and recovery equipment were checked for damage.

The second operation omitted the safing procedure, but went through with towing booster out and back into LSD with the LSD maintaining a heading of 2 to 3 knots into the waves. The third operation was very similar to the second. A change on the tiedown location of the nylon restraining slings was made.

The final operation was a complete simulated recovery. The booster was set free and all personnel stayed aboard the LSD. The LSD deballasted and steamed off ten miles from booster. At ten miles the booster was held on surface radar while the P2V tracked it 50 miles from 1500 feet.

Once the tracking exercises were over, the LSD started toward the booster. Ballasting of LSD and preloading of LCVP were performed while enroute. When the LSD was approximately 1000 yards from booster, the LCVP was launched and proceeded to the booster. Upon arriving at the booster, the swimmers went through the safing operation; the booster was taken in tow, and brought into the well of LSD and positioned as before.

Sea water immersion tests were conducted on a Rocketdyne H-1 engine in order to evaluate the corrosive effects of sea-water recovery on the engine and to define the procedures necessary to restore the engine for flight service. This program involved a series of tests in which the H-1 engine was immersed in sea water for given periods of time, followed by various post treatments designed to minimize the corrosive effect of sea water. The engine was then disassembled, evaluated for corrosion damage, reassembled, and test fired.

f. Hot fired short duration and full duration (150 sec.).

2. Second test - June 1961

a. Immersed H-1 engine to a depth of 10 feet for one hour, half submerged for three hours, and on the surface for three hours.

b. Waited twelve hours before purging, and applying minimum preservatives.

c. Upon arrival at the MSFC, it was dismantled, inspected, cleaned, replaced damaged parts and assembled.

d. Hot fired short duration and full duration.

3. Third test immersion in August 1961 - Hot fired in March 1962

a. Dropped H-1 engine into water to simulate water entry conditions, immersed it, held it half submerged, and on the surface for a total of nine hours.

b. Washed it with fresh water, no preservative compounds were used.

c. Upon arrival at the MSFC, it was dismantled, inspected, and partially cleaned, and left in storage.

d. Six months later the engine was assembled and hot fired, short duration and full duration.

The two reasons for delay on the third test are as follows:

1. The Test Division was over loaded with work.

2. The first two tests were so successful that the Recovery Project Office had difficulty justifying the manhours required to complete the hot firings, especially since the engine was dismantled, and the components looked as good as the previous two times.

In order to establish an approximate cost factor, a log was kept of the procedures, reconditioning manhours, materials, and an itemized list of replaced engine parts. The cost to recover and recondition the H-1 engine was approximately 5% of the cost of a new one.

In closing, it should be stated that the selection of the recovery systems employing parachutes was primarily brought about by the requirements and limitations previously stated, and possibly early availability. Also, the MSFC saw no need in duplicating study efforts by other government agencies that were investigating the economics and feasibility of other recovery system concepts. Aware that the studies were giving varying results, the MSFC preferred to develop a simple recovery system capable of recovering the SATURN S-1 stage and actually recover the first flight vehicles. Having actual post-flight hardware on hand would provide factual data and define precisely the economics, feasibility, and practicability of booster recovery. This would be accomplished without having to develop a new recovery technique. However, during the parachute recovery system development program on both the SATURN and MERCURY-REDSTONE vehicle programs, funding problems were encountered; and in both cases, the first program to be canceled was recovery.

Between the termination of the SATURN parachute recovery system and parallel with the H-1 salt water exercise, several proposals with different recovery system concepts were received and reviewed by the MSFC. Among these proposals were two similar techniques utilizing the Rogallo Flexible Wing concept. Approximately six months after termination of SATURN recovery program, funds were again made available. At this time, the concept that looked the most promising was the Rogallo Wing; and a decision was made to investigate the feasibility of the Rogallo Wing to recover a SATURN S-1 stage of the C-1 or C-2 program. Mr. McNair will present the result of the studies.

Rodolfo M. Barraza

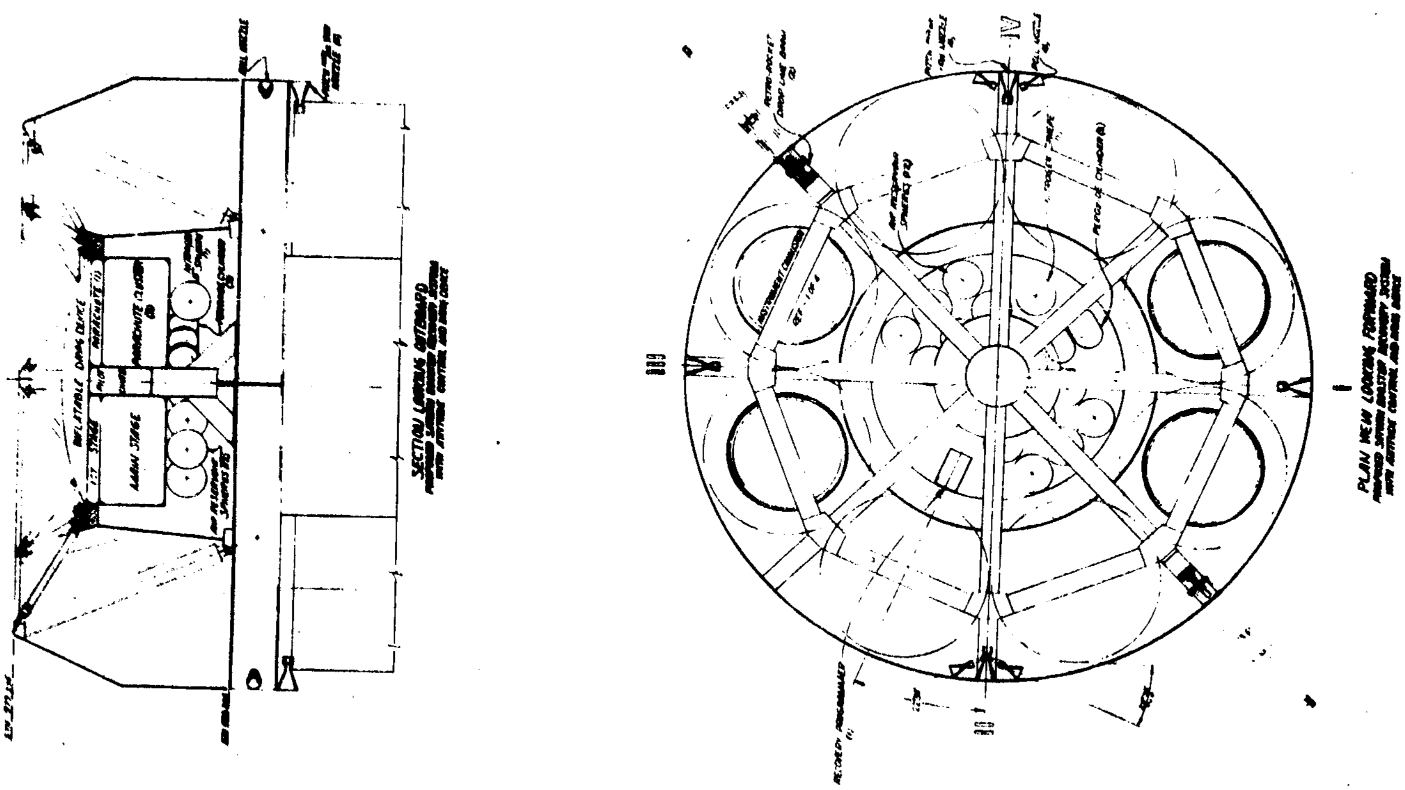


Fig. 1

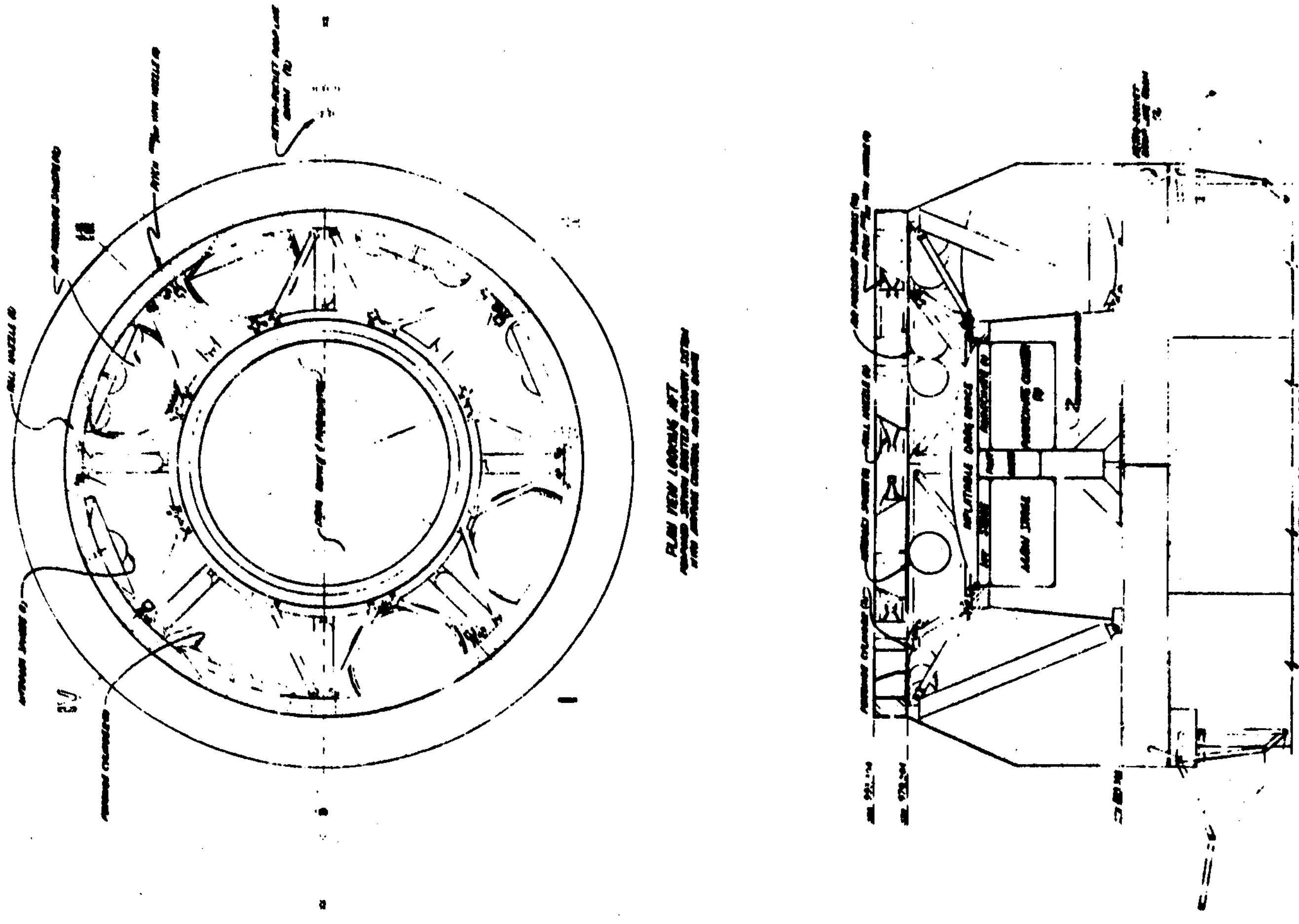
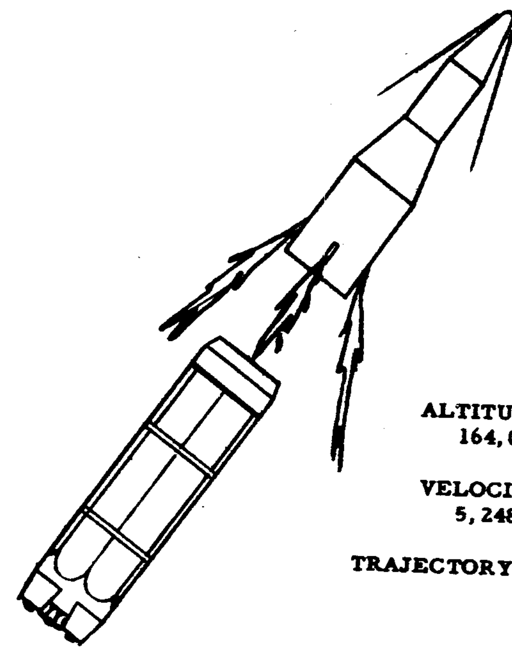


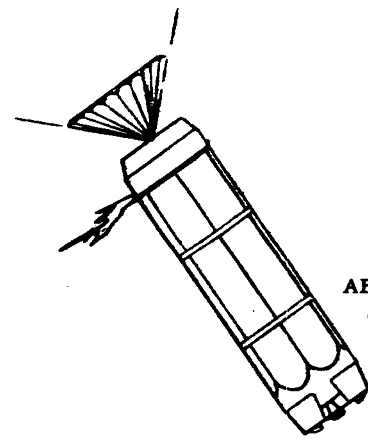
Fig. 2



SECOND STAGE SEPARATION

FIG. 1

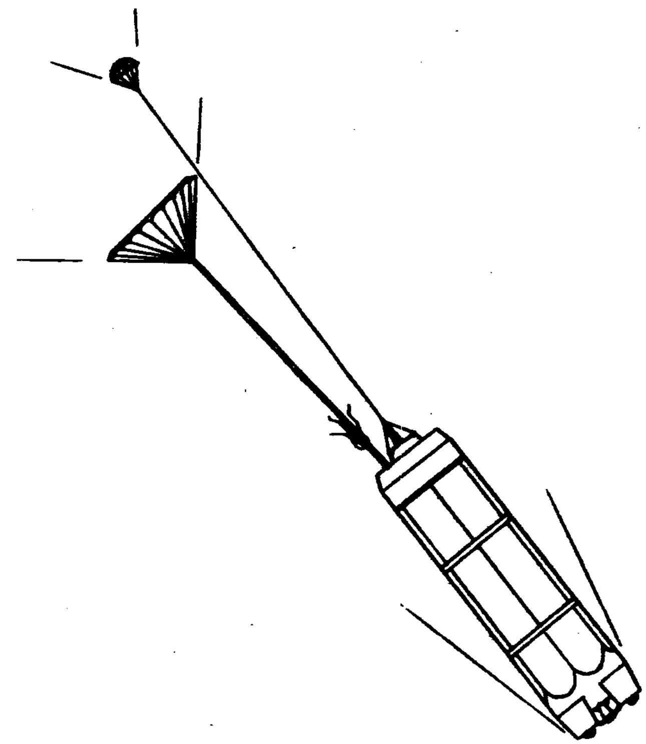
Fig. 3



DRAG DEVICE INFLATING CLOSE TO BOOSTER AND
ATTITUDE CONTROL JETS TRIMMING ATTITUDE OF BOOSTER

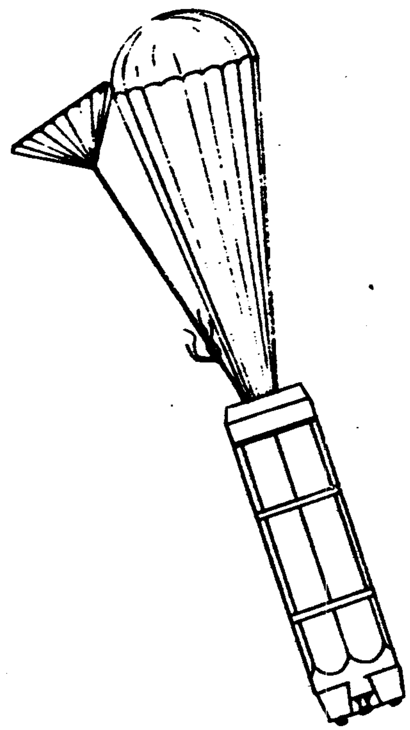
FIG 3

Fig. 4



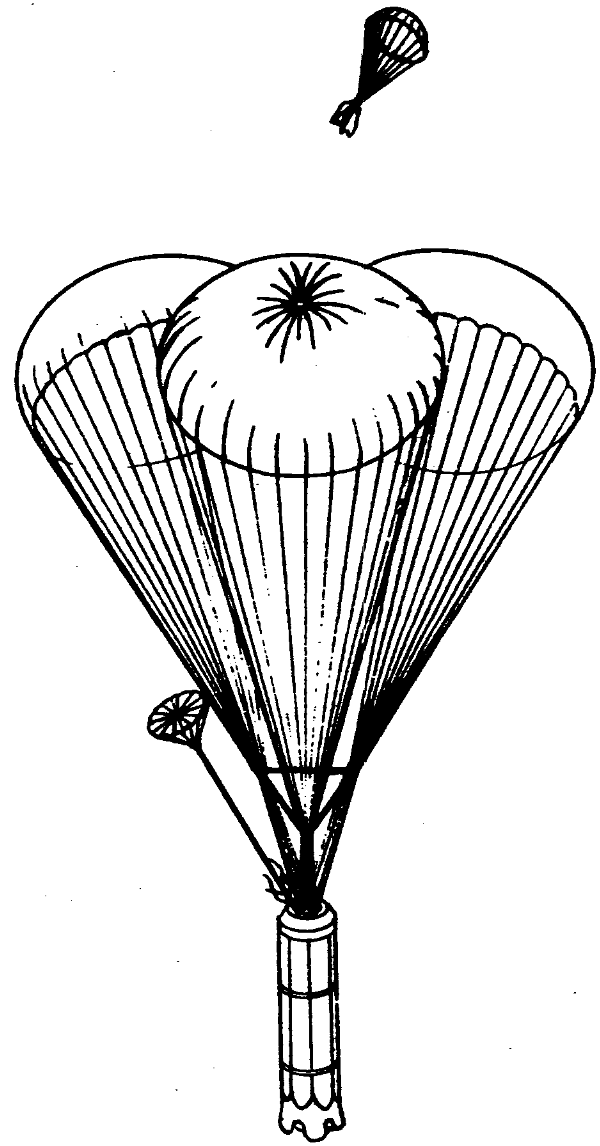
MAJOR NUMBER OF DRAG DEVICE LINES CUT LOOSE TO ALLOW PARACHUTE DEPLOYMENT OPERATION.
DRAG DEVICE RETAINED OFF CENTER AND PILOT PARACHUTE DEPLOYED. PILOT PARACHUTE WILL EXTRACT FIRST STAGE PARACHUTE IN REEFED CONDITION.

FIG. 5



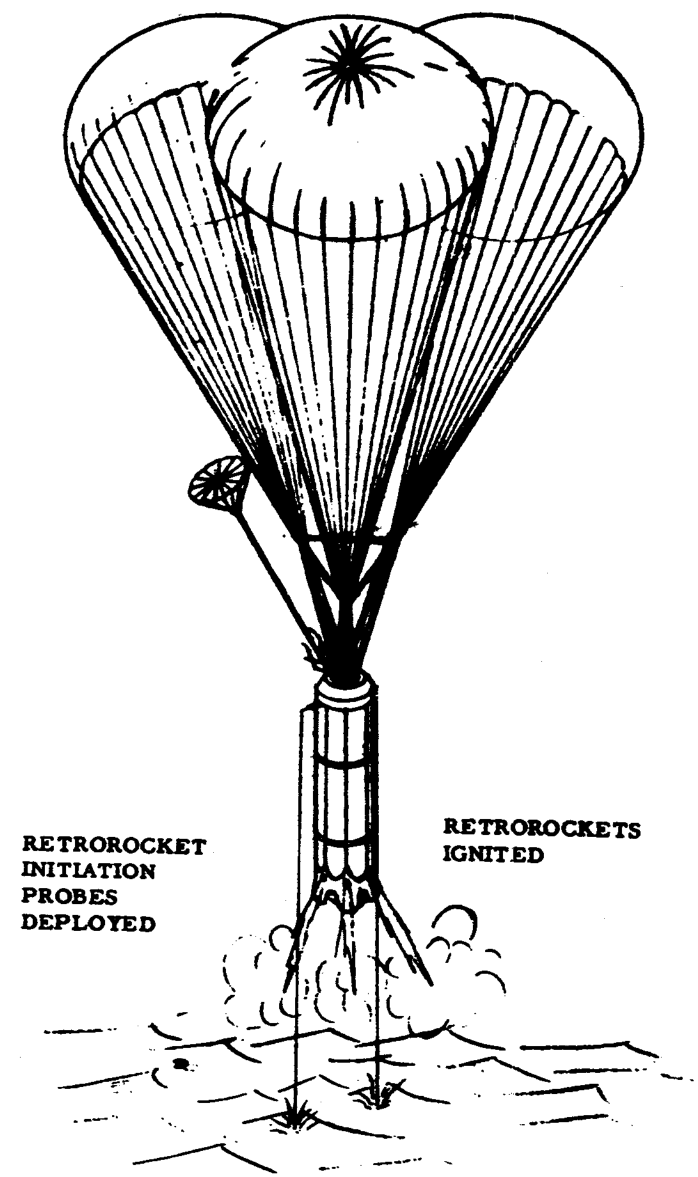
FIRST STAGE PARACHUTE
DISREEFED AND FULLY INFLATED.

FIG. 6



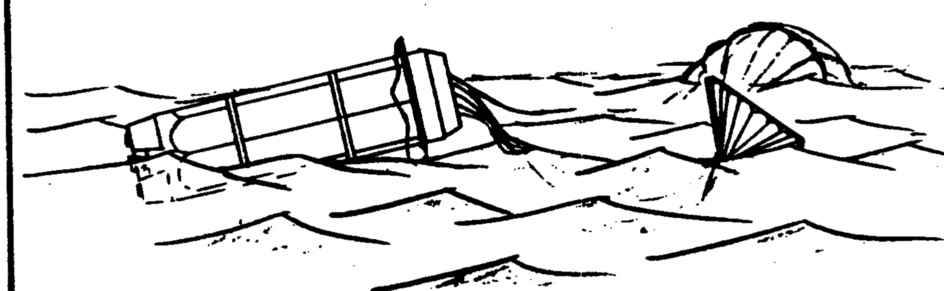
FIRST STAGE PARACHUTE LOOPS SEVERED AND MAIN STAGE PARACHUTES DEPLOYED. DRAG DEVICE RETAINED TO FUNCTION AS BACK-UP FLOTATION SYSTEM.

FIG. 7



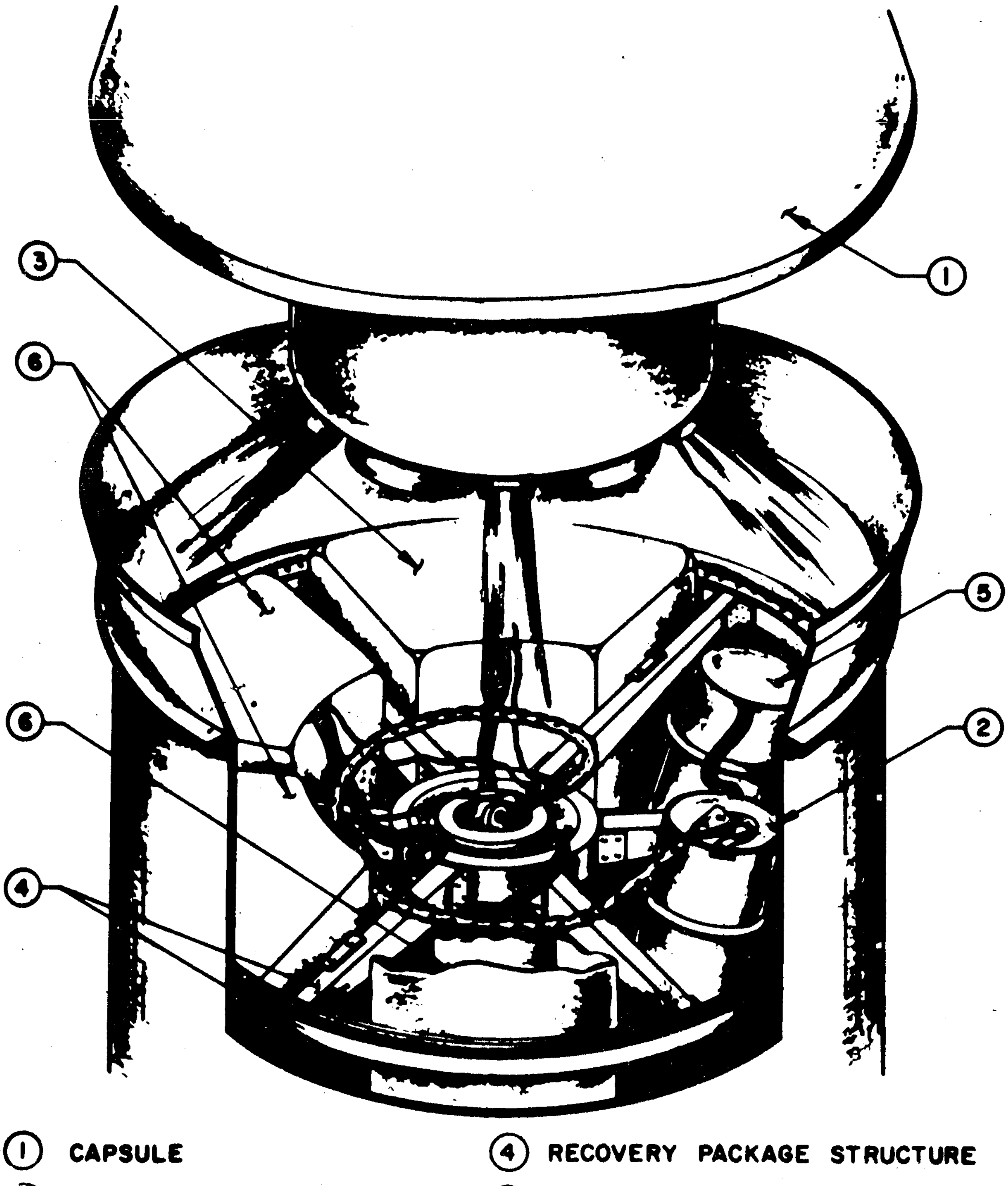
BOOSTER APPROACHING WATER AND RECEIVING FINAL DECELERATION FROM RETROROCKETS

FIG. 8



BOOSTER FLOATING ON WATER
WITH AUXILIARY FLOTATION SYSTEM AND MAIN
STAGE PARACHUTES RETAINED

FIG. 9



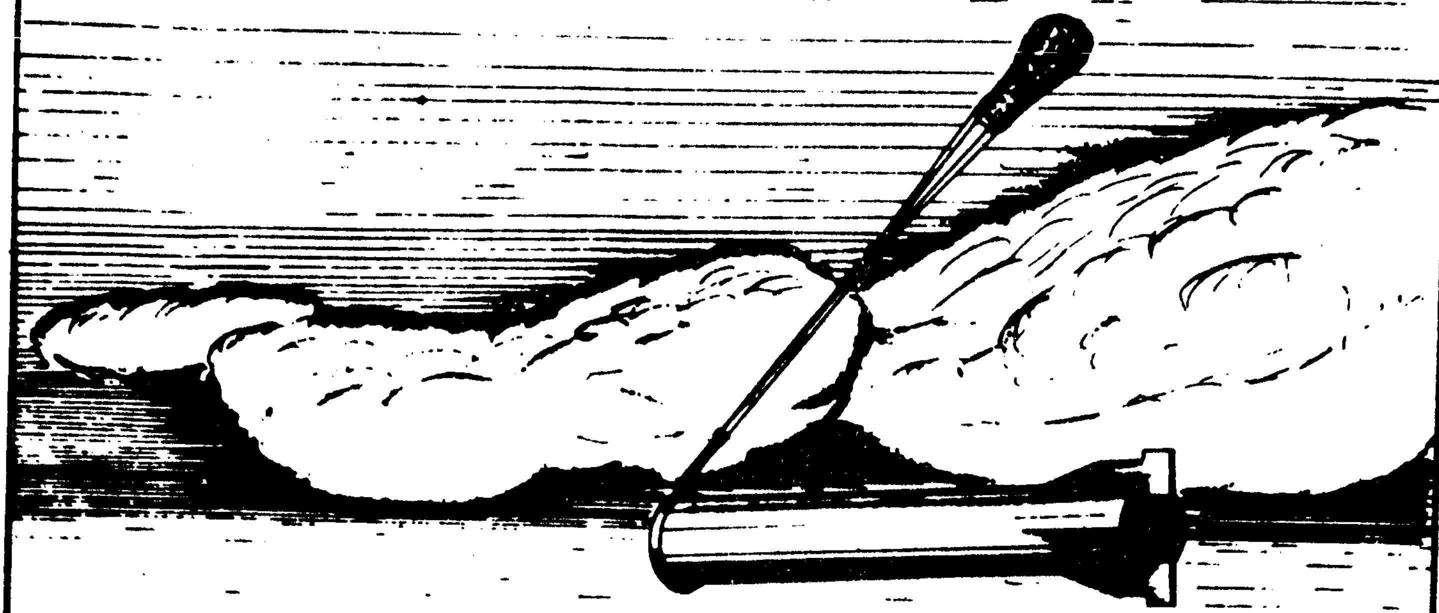
1. CAPSULE
2. RISER MORTAR
3. MAIN PARACHUTE RISERS
4. RECOVERY PACKAGE STRUCTURE
5. DECELERATION PRCHT. MORTAR.
6. FINAL RECOVERY PARACHUTES

BOOSTER RECOVERY PACKAGE

(HEAT PROTECTION COVER NOT SHOWN FOR CLARITY)

GE 112-16-5"

S.R. Fig. 10

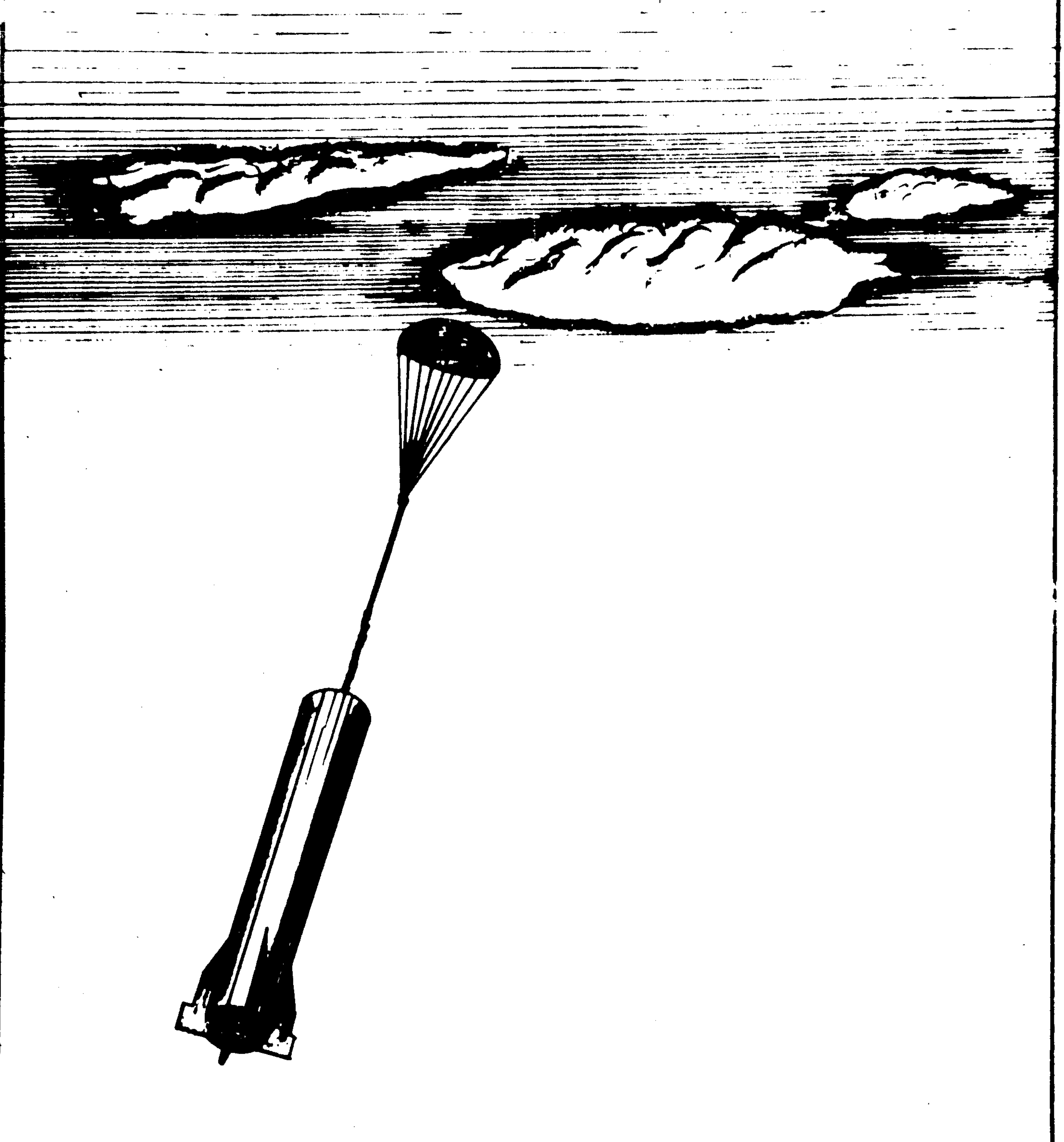


INITIATION OF RECOVERY
DEPLOYMENT OF DECELERATION PARACHUTE

Fig. 11

GE 27-14-60 11 MAR 60

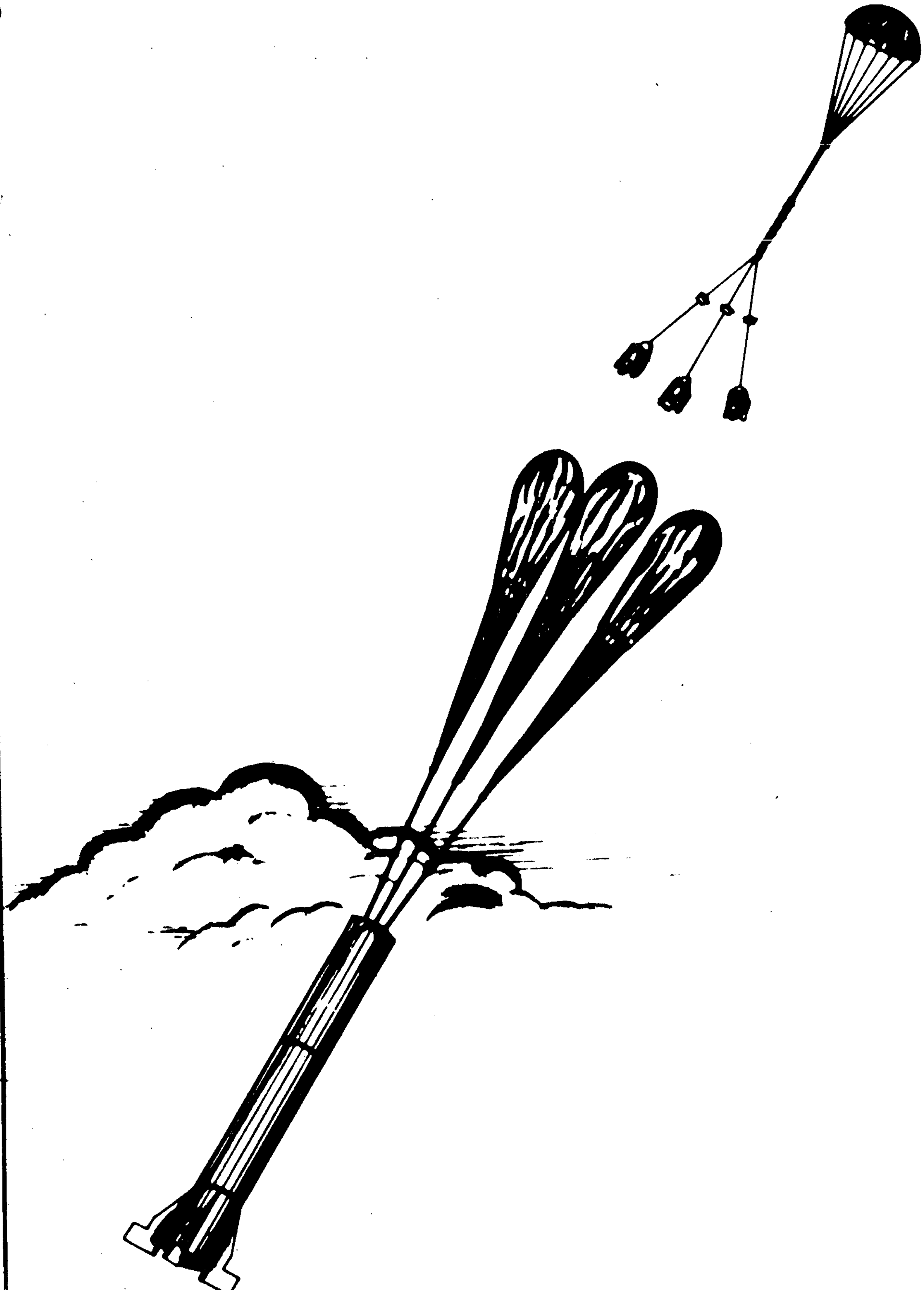
SPACE RECOVERY SYSTEMS INC.



DECELERATION PARACHUTE DISREEFED

Fig. 12

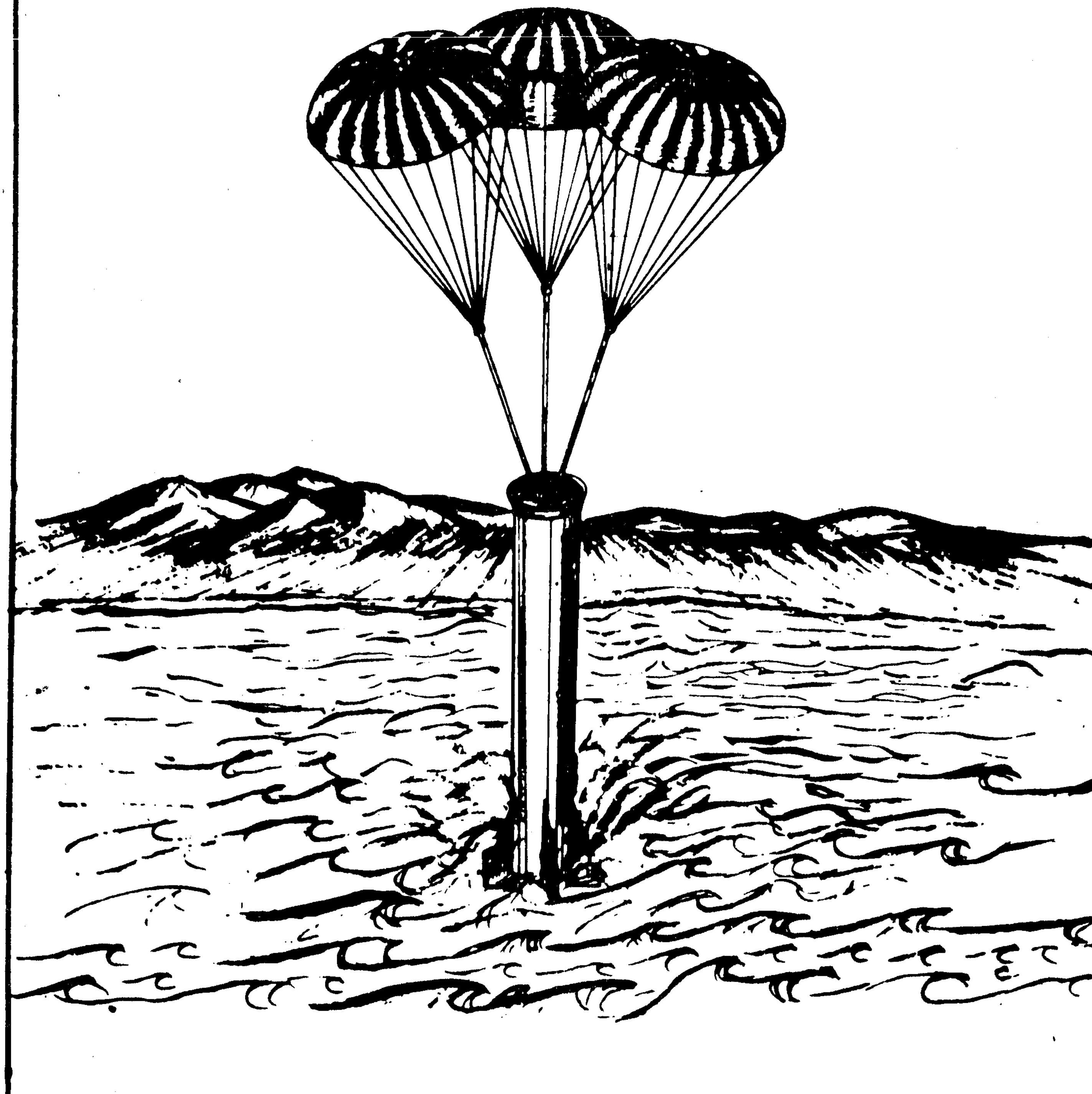
GE 27-15-60 11 MAR 60 SPACE RECOVERY SYSTEMS INC.



DISCONNECT OF DECELERATION PARACHUTE
DEPLOYMENT OF FINAL RECOVERY PARACHUTES Fig. 13

GE 27-16-60 11 MAR 60

SPACE RECOVERY SYSTEMS INC.



WATER IMPACT

Fig. 14

GE27-17-60 11 MAR 60

SPACE RECOVERY SYSTEMS INC.