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RECOVERABLE S-IB

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Abstract

The paper deals with the selection of a simple recovery system for the Saturn IB first stage.

As an introduction to the discussion on recovery system objectives, a plot of the expected trajectory is presented.

This is followed by a statement which lists the necessary steps which must be followed to develop a recovery program.

An attempt is made to maintain:

- Simplicity of system concept,
- Minimum development time,
- Minimum of changes to the existing S-IB stage,
- Minimum added weight,
- Ease of stoarge and packaging,
- Advanced state-of-the-art,
- Minimum damage to booster integrity in landing
- Minimum of turn around (refurbishment) time.

A brief description of the vehicle is included so that the recovery problems may be more fully appreciated.

Seven recovery system studies are evaluated in terms of weight and include:

(a) Stabilization devices,
(b) Re-Entry,
(c) Recovery, and
(d) Retrieval.

Included are discussions of drag cones, drag balloons, droguechutes, parachutes, retro-rockets, impact problems, and large balloons. Material problems presented by the flight environment are discussed.

A potential schedule for the development of a recovery system is shown in terms of the S-IB program.

Introduction

The feasibility of recovery of space boosters is well documented and much discussed. This paper does not discuss feasibility of any system but rather discusses the design details for recovery systems with established feasibility as related to the S-IB stage, their packaging requirements, and payloads loss. These systems are compared and optimum configurations selected. For the purposes of this paper, a standard boost to 105 nautical mile circular orbit is used.

This paper is limited to those recovery systems which have a potential of being developed to a point where they can be flight tested on the presently programmed Research and Development Flights. These systems will have a clear cut cost advantage over other systems with longer period for development and requiring additional flight test vehicles. Therefore, the systems discussed in this paper are parachutes, balloons, and combinations thereof.

General Recovery Program

The general recovery program for the S-IB consists of a number of logical steps directed towards the development of a practical recovery system for the stage. These steps are:

- System Selection
- Trajectory Measuring
- System Sizing
- Boost Verification
- Recovery System Development
- Sub-system Recycle Testing
- Mission Reliability
- Cost Effectiveness
- Flight Test
- Recycle Inspections
- Re-Flight Test

Most of these steps are interlocking and overlapping.

Program Step Definitions

To further define the development program and the steps necessary to accomplish it, the following descriptions are given:

System Selection. This portion of the program, from which this paper evolves, compares the various methods of recovery. This selection process must include missions and schedules, plus the best cost information available.

Trajectory Measuring. This step is the simplest and the most fundamental requirements for the ultimate design of a recovery system for the stage. To accomplish this, the stage instrumentation is monitored until impact or destruction. A great deal of the required information is being obtained from SA-5, 6, and 7.

System Sizing. Based on data from step one and detailed analyses, the recovery system would be designed in detail to meet technical requirements of loads and temperatures on the stage. This step would include the redesign of the vehicle for any increased loads or change in enviroment.

Boost Verification. This step would include one R&D flight with "boilerplate" fairings required to package the recovery system. This flight would verify analyses and show effects of fairings on boost characteristics. The overall program schedule should be such as to allow use of a programmed R&D flight. This flight could also include development testing outlined in the following phase.

Recovery System Development. This step would develop the individual sub-systems required to effect the recovery of the state. This would include the following as a minimum program:

(a) Wind tunnel and rocket tests to establish required design parameters.

(b) Flight-test of high altitude attitude control system if required. This test should also utilize a programmed flight.

(c) Drop-test of sub-scale models of drag devices to test deployment, interaction, and effectiveness.

(d) Drop-test of single drag device if applicable to test fabrication and deployment.

(e) Drop-test of impact attenuation devices if used.

(f) Handling tests for retrieval portion of program.

Sub-System Recycle Testing. This step would establish those sub-systems of the stage that can be reused, number of cycles for life, and refurbishment requirements. This will be accomplished by sub-system static, dynamic, and immersion tests. These tests would be used to establish design changes and cost effectiveness. Reliability parameters would also be determined in this phase.

Mission Reliability. This step of the development would establish reliability required for the recycled stage based on mission objectives, including level of refurbishment required. This study should also establish the number of flights feasible within the reliability requirements.

Cost Effectiveness. The foregoing studies will furnish the required data to establish initial cost effectiveness. This will be the first estimate of cost effectiveness based on other than extremely rough estimates and virtual guesses.

Flight Test. The flight test will prove the adequacy of the complete recovery system. This program will require a minimum of two flights; one to be completely disassembled and inspected for damage, and the other to be refurbished and flown. These flights should include logical operating payloads.

Vehicle Description

The S-IB booster is the first stage of the Saturn IB vehicle. It is an advanced version of the S-I booster and was made possible by careful analysis of flight data acquired from previously flown Saturn I Research and Development vehicles. The major differences between the two boosters are found in weight reductions created by the removal of redundant system components and reducing gage thickness of the vehicle skin.

The S-IB as shown in Figure 1 is a cluster of eight 70-inch propellant tanks around a 105-inch center tank, and is powered by eight H-1 engines. The center and four outer tanks carry liquid oxygen; the remaining four outer tanks carrying RP-1 fuel. Propellant tanks are interconnected by manifolds to maintain equal levels in the fuel tanks and equal levels in the oxygen tanks during vehicle flight. The tanks are basically those used on the Redstone (70-inch) and Jupiter (105-inch) missiles.

The S-IB stage structural assembly measures 21.4 feet in diameter and 80.3 feet in length, and physically supports all onboard systems and equipment including propellants, rocket engines, pneumatic, hydraulic, electrical and guidance systems, and upper stages are required for each mission. It also supports onboard systems and equipment during ground handling and transportation.

Thrust produced by the eight H-1 engines is transmitted from the engine mounting pads through the thrust support outrigger assembly and the upper and lower ring segment assembly to the center and four outer LOX tanks. These LOX tanks transmit the thrust to the spider beam assembly. The spider beam assembly supports the second stage, the 260-inch diameter S-IVB stage.

Propulsion of the S-IB is provided by eight, 200,000-pound thrust, H-1 engines manufactured by the Rocketdyne Division of North American Aviation, Inc. Total thrust delivered is 1,600,000-pounds. Engines are mounted in an inner and outer square pattern. The four engines making up the outer square are canted outward six degrees from the vertical and are gimbal-mounted to provide a swing of plus or minus $7\frac{1}{2}$ degrees to maintain vehicle stability and controls.

For the recovery program the following facts are pertinent. There is available storage volume between the 70-inch diameter outer tanks and within the interstage structure.

Configuration Studies

This paper outlines the highlights of the preliminary study effort required to select an optimum configuration of recovery system for the S-IB stage. Each recovery system must be individually sized and packaged to produce the best weight and schedule figures for comparison.

Although many configurations are possible and under consideration, only those recovery configurations shown in Figure 2 are discussed in this paper. This diagram shows seven definitive paths to be explored for recovery of the stage, as shown in Figure 3. The interface (timing) between these systems has been selected by standard methods as outlined in the following pages.

The major problem in the selection of a recovery system is the high altitude stabilization of the stage. The performance of drag devices at the altitudes and Mach Numbers experienced by the stage is unknown. Therefore, before any system can be selected this problem must be experimentally studied to arrive at the drag device required to stabilize the stage.

Recovery Technique

For convenience, recovery, as discussed in this paper, is broken into four broad areas - Stabilization, Re-Entry, Recovery, and Retrieval.

The stabilization system maintains the vehicle at a pre-selected angle of attack until subsequent systems can be brought into play. This system must remove any dynamic moments imparted to the vehicle on separation, place the vehicle in the desired attitude, and maintain it as required. For system simplicity, this paper assumes a passive system consisting of an expandable structure. A great deal of testing and analysis must be performed before an optimum configuration for this device can be established. Therefore, three types are considered - drag cone, drag balloon, and balloon.

Re-entry does not actually require an independent system but is only concerned with maintaining stability and absorbing the high deceleration loads of re-entry. In general, this means designing the stabilization and/or recovery systems for these higher loads.

The recovery system delivers the stage to the ground or maintains it at a pre-selected altitude for retrieval. This system consists of parachutes or floatation balloons.

The onboard retrieval system is only required for balloon systems and consists of a sea anchor that would be required to keep the buoyant stage from being carried away from the recovery ship by local winds.

The individual components of these systems are:

Drag Cone

The drag cone is deployed after separation to stabilize the stage as it penetrates the increased density of the lower altitudes. This cone is packaged on the outside of the S-IB/S-IVB interstage and is inflated by compressed gas from high-pressure bottles stored in the forward skirt of the LOX tanks. A conceptual drawing of this cone is shown in Figures 4 and 5.

Drag Balloon

The drag balloon is basically a close-coupled balloon of large diameter to develop stabilizing forces in the upper atmosphere. A 100-foot diameter balloon is arbitrarily chosen to fill the gap between the drag cone and the floatation balloon.

Droguechute

The droguechute is a standard FIST ribbon chute deployed at a maximum Mach Number 1.5 and requiring no advance in the state-of-the-art. Three different siting techniques would be used for this chute.

Parachutes

Parachutes are sized by a trade-off study with retro-rocket weight to provide a minimum system weight. Standard nylon ribbon chutes are used for this study.

Retro-Rockets

Standard solid propellant motors are used to reduce vehicle velocities to an acceptable level.

Impact

The impact problem can be conveniently divided into land and water retrieval. For water recovery, this study uses thirty feet per second or an acceptable velocity for the booster to impact in profile. Of course, a land recovery impact velocity must be more restrictive but is not considered in this study due to the launch trajectory.

Balloon

Balloons considered in this study are zero pressure mylar balloons. They have an aerodynamic shape consistant with their deployment requirements. Both gas and hot air balloons are considered. A sketch of the stage supported by a hot air balloon is shown in Figure 6.

Sea Anchor

The sea anchor consists of a water immersed drag device with an attaching steel cable. This device could be attached to the stage after floatation is achieved by parachute.

Interim Air Recovery

This is the temporary stabilization of the neutrally buoyant stage until descent and retrieval can be accomplished. For this study a floatation altitude of 5,000-feet is assumed with subsequent control to lower levels.

Water Retrieval

This retrieval phase assumes the floating stage is towed to a docking area.

Ship Retrieval

This phase assumes the stage is hauled on board an L.S.M. for return to land.

Land Retrieval

For this recovery the airborne stage is towed to a ground station for lowering. No land retrieval is considered in this study due to the trajectory of the stage.

Trajectories

Boost and re-entry trajectories were simulated on the IBM 7094 using the TRACER (Trajectory Routine for Advanced Conceptual Engineering Research) two-dimensional trajectory program.

Basic data inputs (weights, propulsion characteristics, aerodynamic characteristics, etc.) used were those for the nominal Saturn IB except for a 20,000-pound increase in booster inert weight for recovery gear and recovery stress requirements.

The boost phase shpaing was determined for maximum payload to 105 n. mi. orbit (34,522 pounds). The re-entry trajectories were then simulated from lift-off to impact using the boost parameters from the orbital run, and a re-entry drag coefficient for the stage with a zero angle of attack.

The vehicle flight trajectory, and terminal velocity are shown for the unassisted vehicles in Figures 7A and B. The change in q with change in the vehicle ballistic coefficient are shown in Figure 7C.

Recovery System Sizing

The various portions of the recovery system are individually sized for trade-off purposes. This sizing exercise is for purposes of packaging and comparison only.

Drag Cone

The drag cone is sized to create a stable configuration for the vehicle. Using a design diameter of fifty feet, the cone must be designed for q of 400 psf (Reference Figure 7). This would require an expandable structure weighing approximately 2,200 pounds, including supporting systems.

Drag Balloon

The drag balloon is sized to furnish greater stabilization to the vehicle and give response at higher altitudes. The balloon used in this study is one hundred feet in diameter and must be designed for a q of 100 psf (Reference Figure 7). Using Nomex this balloon would weigh approximately 3500 pounds, including support system.

Parachute

The parachutes are sized by optimizing the relationship between parachute and retro-rocket. The standard equation found in Reference 1 used to size the parachutes is:

$$D_o = \frac{32.724}{V_e}\sqrt{\frac{W_t}{C_{D_o}}} \qquad (1)$$

in which D_o = diameter,

V_e = equilibrium velocity,

C_D = drag coefficient, and

W_t = total weight.

This equation simplifies to

$$D_o = \frac{6540}{V_e} \qquad (2)$$

where C_D + .5 and W_t = 120,000/6 = 20,000 when six parachutes are used. This formula can be combined with the relation for weight of parachute using 4.5 oz. nylon (Reference 1)

$$W_s = .058\, D_o^2, \qquad (3)$$

where W_s is the weight, and the result is

$$W_s = \frac{14,880,000}{V_e^2} \qquad (4)$$

To the parachute weight is added the weight of retro-rockets which would reduce the impact velocity to 30 feet per second. The retro-rockets are sized using the following equation from Reference 2.

$$\Delta V_B + gt = I_s\, g \ln\left(1 + \frac{W_p}{W_{BO}}\right) \qquad (5)$$

where I_s = specific impulse,

g = gravitational constant,

W_p = weight of propellants,

W_{BO} = burnout weight,

ΔV_B = change in velocity, and

t = time.

Noting that the retro-rocket propellant weight is only a small fraction of the burnout weight the approximation

$$\frac{W_p}{W_{BO}} \approx \frac{1}{I_s\, g}\,(\Delta V_B + gt)$$

can be made. Making the following assumptions

I_s = 250 sec.,

t = 2 sec.,

W_{BO} = 100,000 lbs., then

$W_p = 12.4\,(\Delta V_B + 64.4)$.

Assuming that the system weight is 1.15 W_p and substituting $\Delta V_B = V_e - 30$ where this now reflects the difference between parachute equilibrium velocity and 30 feet per second,

$$W_s = 14.3\,(V_e + 34.4).$$

Adding the weights of the parachute and retro-rocket and differentiating with respect to V_e,

$$\frac{dW_{total}}{dV_e} = 14.3 - \frac{29.76 \times 10^6}{V_e^3}$$

Setting this equal to zero and solving for V_e, we find the optimum velocity equal to 128 fps. This produces a total system weight of 3200 pounds.

Gas Balloon

Two gases are of interest for floatation of the stage; these are helium and hydrogen. The calculations for these follow. Basic data are from References 3 and 4.

	Helium	Hydrogen
Density of air (5000 ft)(psf)	.0660	.0660
Density of gas (lb/ft2)	.0091	.0046
Difference in Density(lb/ft2)	.0569	.0614
Volume to support 120,000 lb(ft3)	2,110,000	1,960,000
Weight of gas (lb)	19,200	9,000
Density of liquid (lb/ft3)	9.18	4.43
Volume of liquid (ft3)	2,090	2,030
Heat to 500°R (BTU/lb)	622	1,591
Total heat (BTU)	11,950,000	14,300,000
Propane heat of burning(BTU/lb)	21,700	21,700
Weight of Propane (lb)	550	659
Density of liquid Propane(lb/ft3)	33.2	33.2
Volume of Propane (ft3)	16.6	20.1
Volume of Balloon(ft3)	2,110,000	1,960,000
Radius of Balloon(ft)	79.5	77.5
Surface Area (ft2)	81,100	75,400
Equivalent Thickness (in.)	.005	.005
Material Volume (in.3)	117,000	103,000
Material Density (lb/in.3)	.07	.07
Weight Balloon (lb)	4,100	3,800

This calculation gives only a minimal system and does not include heat losses of the burner and various other simplications. However, it does give the general order of magnitude of the necessary system.

Hot Air Balloon

There are two parts to this system sizing. First the initial stabilization of the balloon and then the sustained flight sizing.

The nominal atmosphere at 5000 ft. altitude has the following characteristics:

Temperature	500°R, 40°F,
Pressure	12.23 psia,
Density	.0660 lb/ft3. (Ref. 5)

Changing temperature to 250°F lowers the density to .0465 lb/ft3

$$\Delta = .0195 \text{ lb/ft}^3.$$

Volume required to support stage

$$V = \frac{120,000 \text{ lb}}{.0195 \text{ lb/ft}^3} = 6,150,000 \text{ ft}^3.$$

Weight of air to be heated

$$W = .0465 \text{ lb/ft}^3 \times 6,150,000 \text{ ft}^3 = 286,000 \text{ lb}.$$

Heat required to raise this weight of gas to 250°F

$$H = 50.50 \text{ BTU/lb} \times 286,000 \text{ lb} = 14,400,000 \text{ BTU}.$$

Propane required to generate this heat

$$W = \frac{14,400,000 \text{ BTU}}{21,700 \text{ BTU/lb}} = 664 \text{ lb}.$$

Balloon characteristics

Volume	6,150,000 ft3
Radius	113.5 ft
Surface Area	162,000 ft2
Thickness	.005
Weight	8,200 lb

Sustaining heat required, the following calculation is made

$$Q = .173 \; \epsilon A \left[\left(\frac{T_1}{100}\right)^4 - \left(\frac{T_2}{100}\right)^4 \right]$$

$$\epsilon = .7$$
$$A = 160,000 \text{ ft}^2$$
$$T_1 = 250°F = 700°R$$
$$T_2 = 40°F = 500°R$$

$$Q = 10,900 \text{ BTU/sec}$$

Weight of Propane required to sustain the stage is

$$W = \frac{10,900 \text{ BTU/sec} \times 3600 \text{ sec/hr}}{21,700 \text{ BTU/lb}}$$

$$W = 1,810 \text{ BTU/hr}$$

Sea Anchor

Although a great deal of effort is required in this area preliminary estimates indicate a weight of approximately 5000 pounds.

Materials

Preliminary thermoanalysis indicates a maximum temperature of 400 °F on leading surfaces. This preliminary analysis indicates small amounts of heat protection are required to be added to the aluminum structure. Siliconerubber or similar material will be adequate for this purpose.

Fabrics to be used in the deployable drag devices present a greater problem although preliminary investigation indicates DuPont's Nomex Nylon protected by a coating of silicone rubber could be used. This would be the subject of development testing to determine optimum material constituents to produce a fabric having the required properties of strength and flexibility.

Vehicle Redesign

The vehicle redesign falls into a number of categories for ease of description. First, the packaging of the recovery system must be considered. Secondly, the additional stress must be ascertained in an effort to evaluate any design changes. Next, the booster must be considered in terms of the high temperatures imposed by re-entry, and, lastly, the total effects of the system, stress, and thermoanalysis must be assessed in terms of added weight.

Packaging

There are two main areas which are being considered for storage of recovery gear, as shown in Figure 8. The first area is located between the [illegible] of the booster and has a useable volume of over 1,1[illegible]0 cubic feet. Any packaging within this area must be encapsuled by means of canisters (8 maximum) because of aerodynamic considerations.

The second area of potential use is in the interstage between the S-IB and S-IVB stages. There are 1,142 cubic feet available in this area which may or may not require enclosure depending on the sequence of events and the role the gear placed in this area will perform. There are smaller areas within the booster which are available for electronic devices but the two areas described are the only ones which are feasible for the actual recovery hardware.

Stress Analysis

Due to the recovery loading conditions, a stress analysis of the booster is mandatory. Reentry with the high q level, high temperature and high accelerations will definitely give rise to conditions which will require redesign. All surfaces which create stagnation pressures on reentry will be potential areas of over-heating and redesign.

Another design point will occur on deployment of any drag or buoyant devices in the atmosphere. In this case, shock loads will be induced during the deployment and necessary attachment points must be designed. This condition may prove critical to the booster because of high localized shock type accelerations and a dynamic analysis will be necessary.

Touchdown, where applicable, will be significant in the design of the booster, and will provide still another design condition. Obviously, to keep the refurbishment to a minimum, the structure must be strengthened where necessary to withstand any loads induced by the touchdown.

Weights

To make any meaningful trade-off between candidate systems, a detailed weight comparison must be made between them. The recovery paths, as shown in Figure 2, can be assembled into six basic configurations, these configurations are shown in the block diagram presented in Figure 3. Although it must be realized that any recovery weight calculation considered at this time is very preliminary, these weights should be satisfactory for the system selection. This weight comparison is shown in Figure 9.

Refurbishment

Final design of any recovery system would have to consider the amount of refurbishment required to be performed on the booster before reuse. Any system minimizing this operation could have a major cost advantage. Of major importance is maintaining structural integrity for the stage during recovery operations.

Limiting or precluding the immersion of the stage in salt water is an important consideration. Not only because of the basic aluminum structure, but also the many exposed electrical and tubing joints. The redesign required to protect these joints and the refurbishment required to maintain them could more than offset the development costs of a balloon system.

Design Considerations

While no definitive selection has been made, at this early date certain facts can be noted which reduce the problem in scope. Noting the weight comparison in Figure 10, it can be seen that a definite weight advantage lies with the parachute and retro-rocket combination and this system is most desirable if the salt water immersion can be tolerated. At a payload reduction of approximately 1,500-pounds, the system could be further simplified to using parachutes only. This would give higher system reliability in the process.

The hot air balloon offers a very attractive system, however, in that it offers a potential of eventually developing the recovery sequence, precluding salt water immersion. By eliminating the sea anchor and the development of fast refueling methods, the weight penalty for this system could be reduced to less than 600-pounds of payload over the parachute technique. Should additional work indicate that the larger balloon systems are required to stabilize the booster, this performance difference will be further reduced.

Delivery Schedule

Any recovery system developed for the S-IB should take advantage of the scheduled Research and Development flights, as shown in Figure 10. There should be a definite cost advantage in using these flights for initial flight testing of the system to prove its compatibility and absence of degradation to the boost reliability. Additional tests can be performed on operational flights as failure to recover will not degradate the prime mission of the flight, i.e., placing a payload in earth-orbit.

Conclusions

The recovery of the S-IB stage, while presenting many areas requiring development [illegible] the state-of-the-art; but, if recovery is to be effected for large first stages, work must begin now on the solution of the high altitude performance of a large, close-coupled drag device. Therefore, an integrated test program with analytical backup should be initiated, including the following steps:

1. Wind tunnel testing.
2. Sounding rocket tests of scale models.
3. Flight testing of "boilerplate" stabilization devices.

These steps will furnish the data required to make an optimum selection of a total recovery system while developing the stabilization device and thereby resulting in a minimum cost program.

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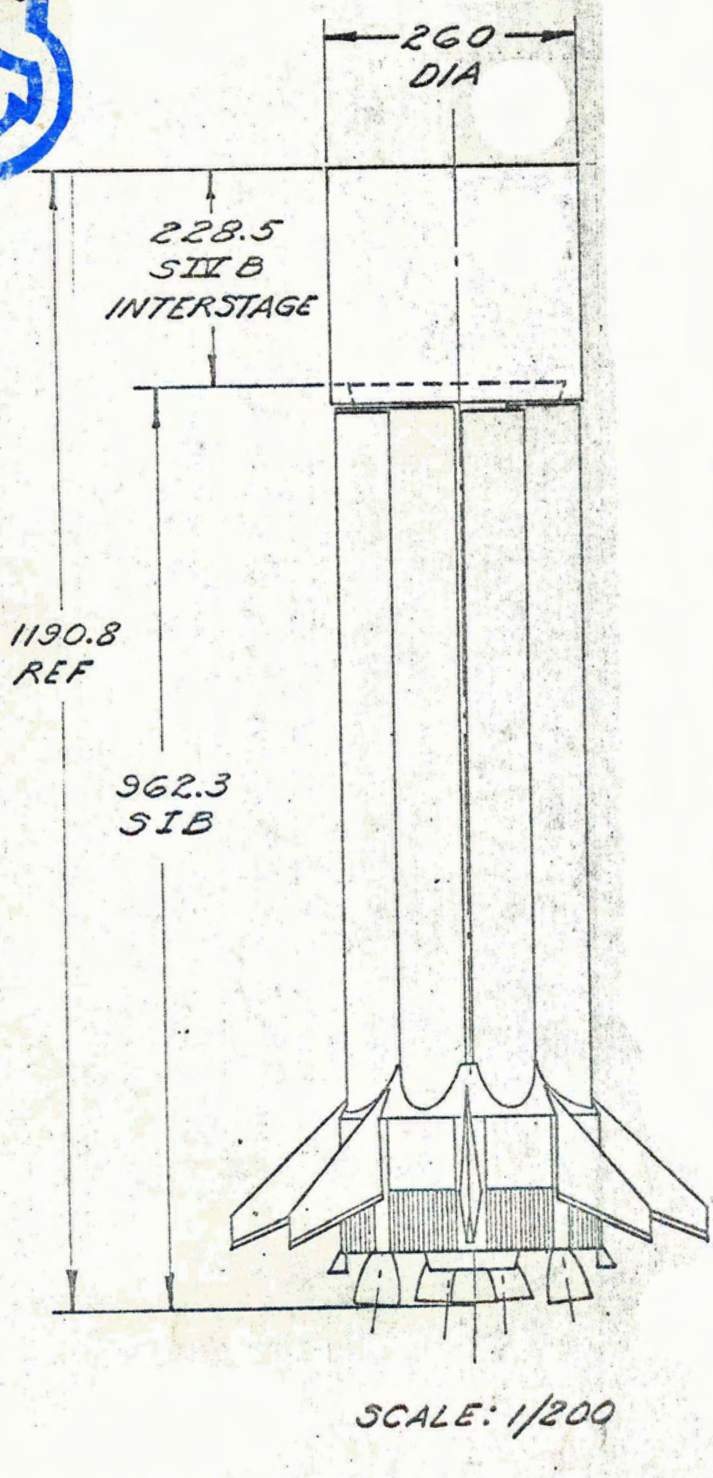


Interstage	4,000#
Residuals	11,000#
Dry Stage Weights	91,000#
Recovery Weight Allowance	20,000#
	127,000#

FIGURE I. S-IB STAGE

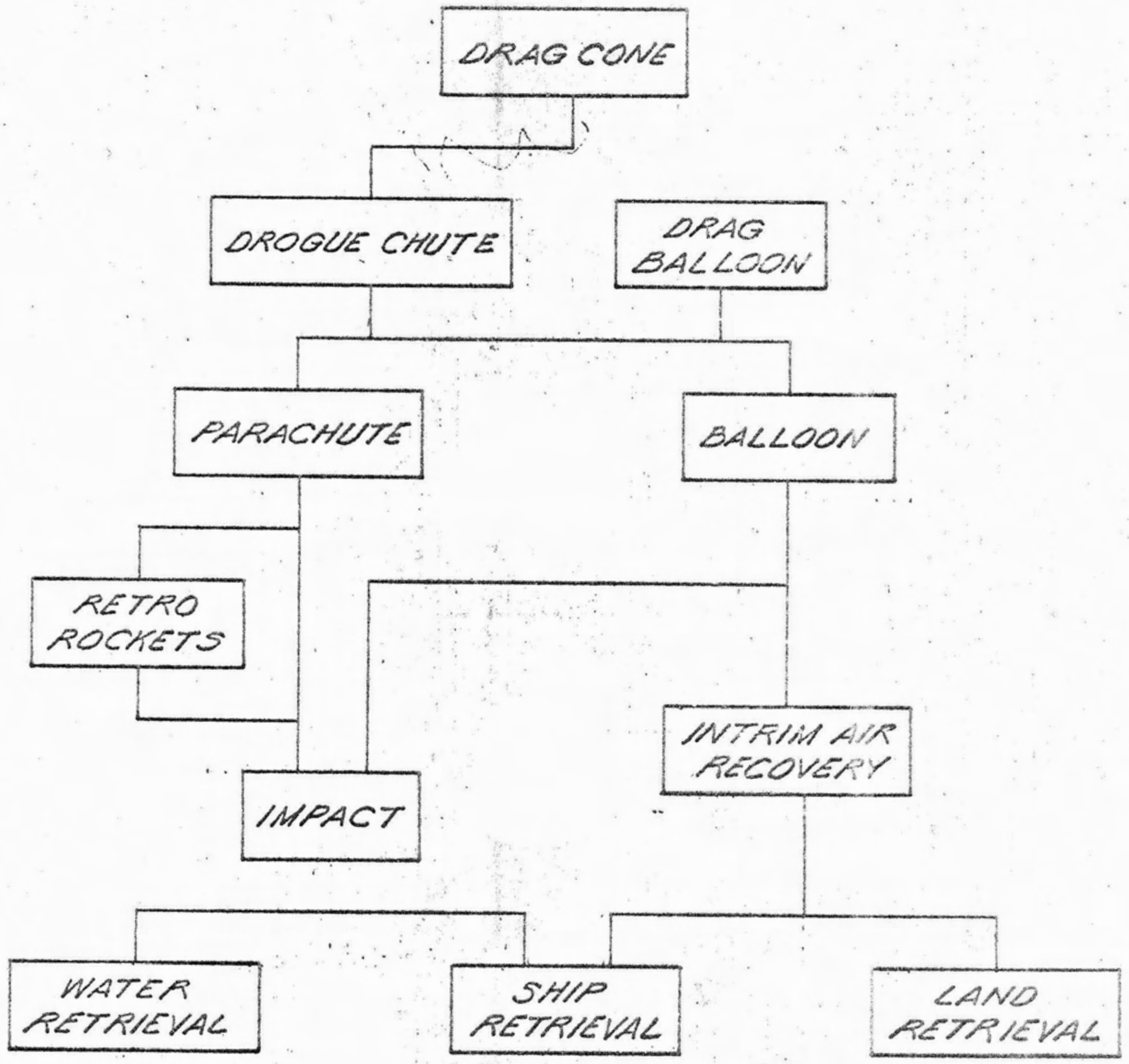


FIGURE 2 RECOVERY PATHS

RECOVER SYSTEMS
BLOCK DIAGRAM

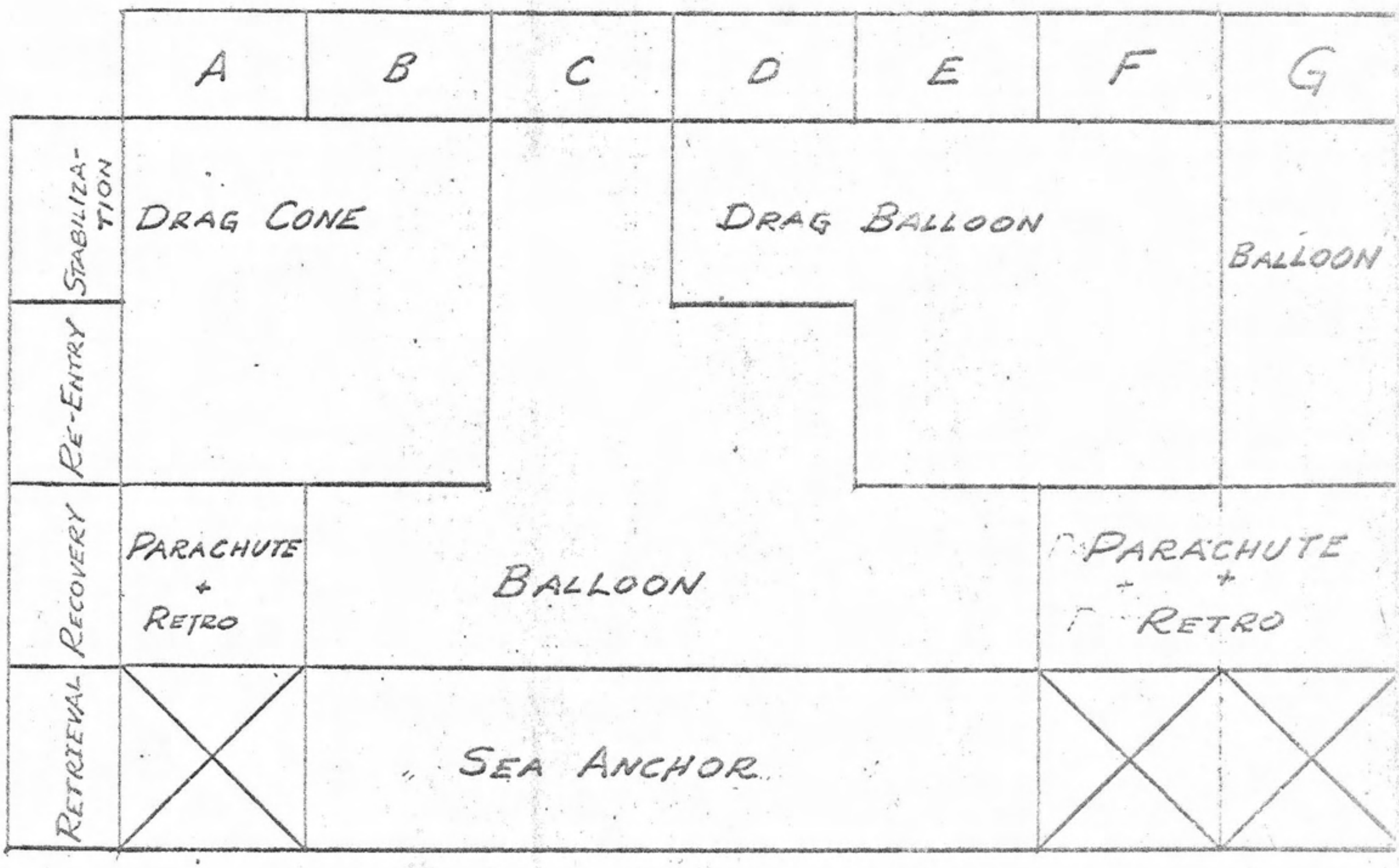


FIGURE 3 BLOCK DIAGRAM

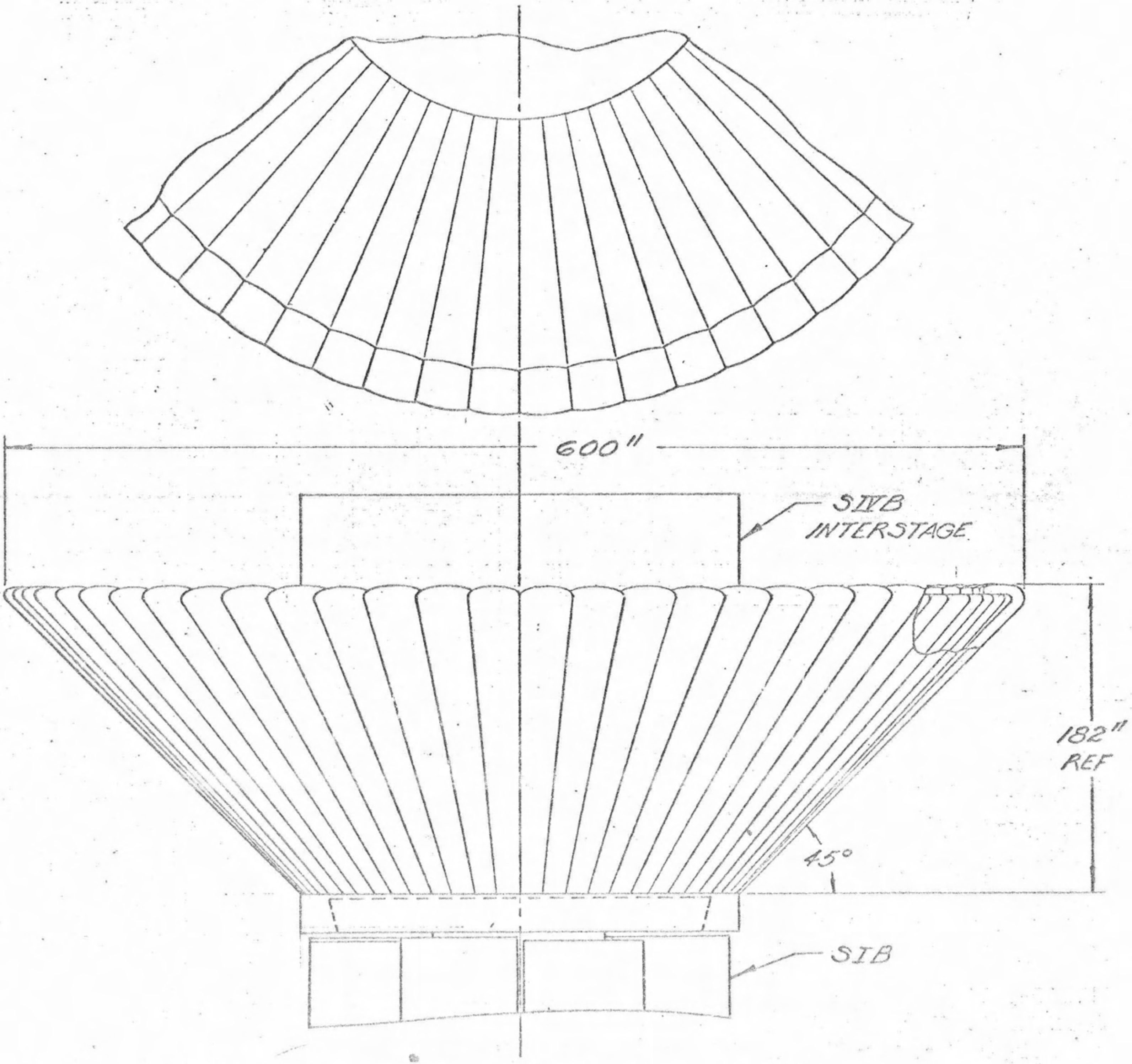


FIGURE 4 DRAG CONE
(INFLATED)

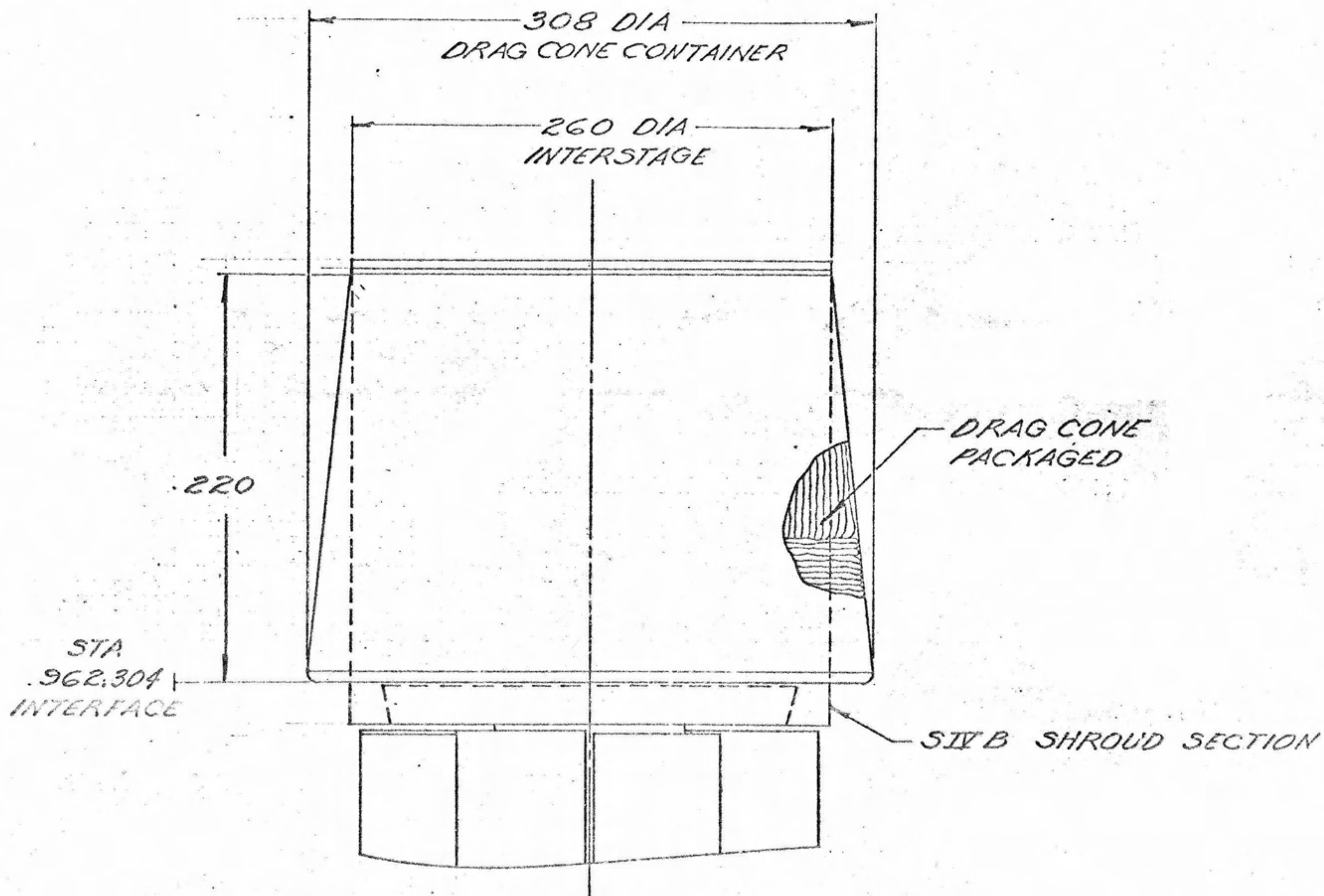


FIGURE 5 DRAG CONE
DEFLATED & PACKAGED
SCALE: 1/80

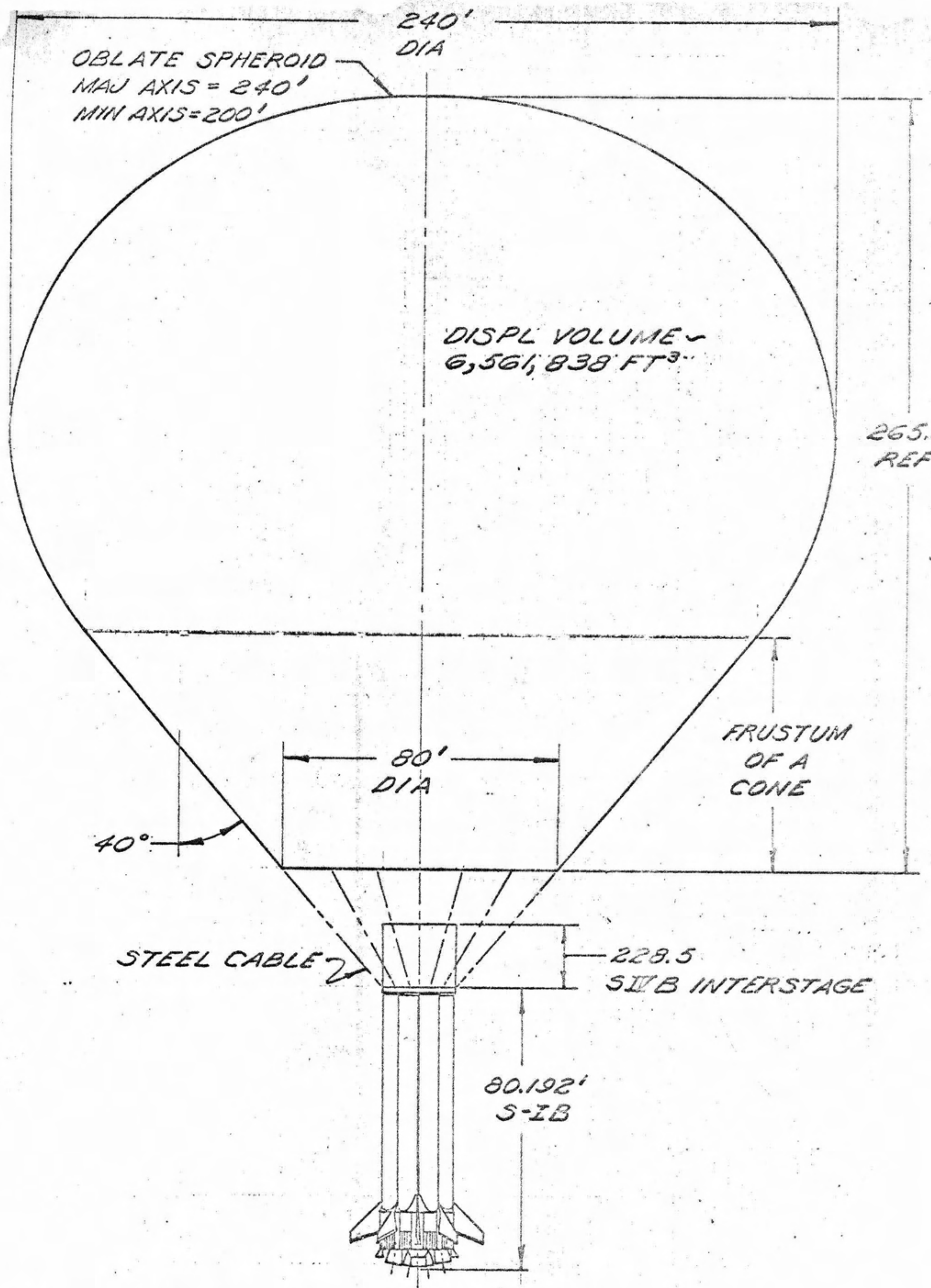


FIGURE 6 HOT AIR BALLOON

SCALE: 1"= 40'

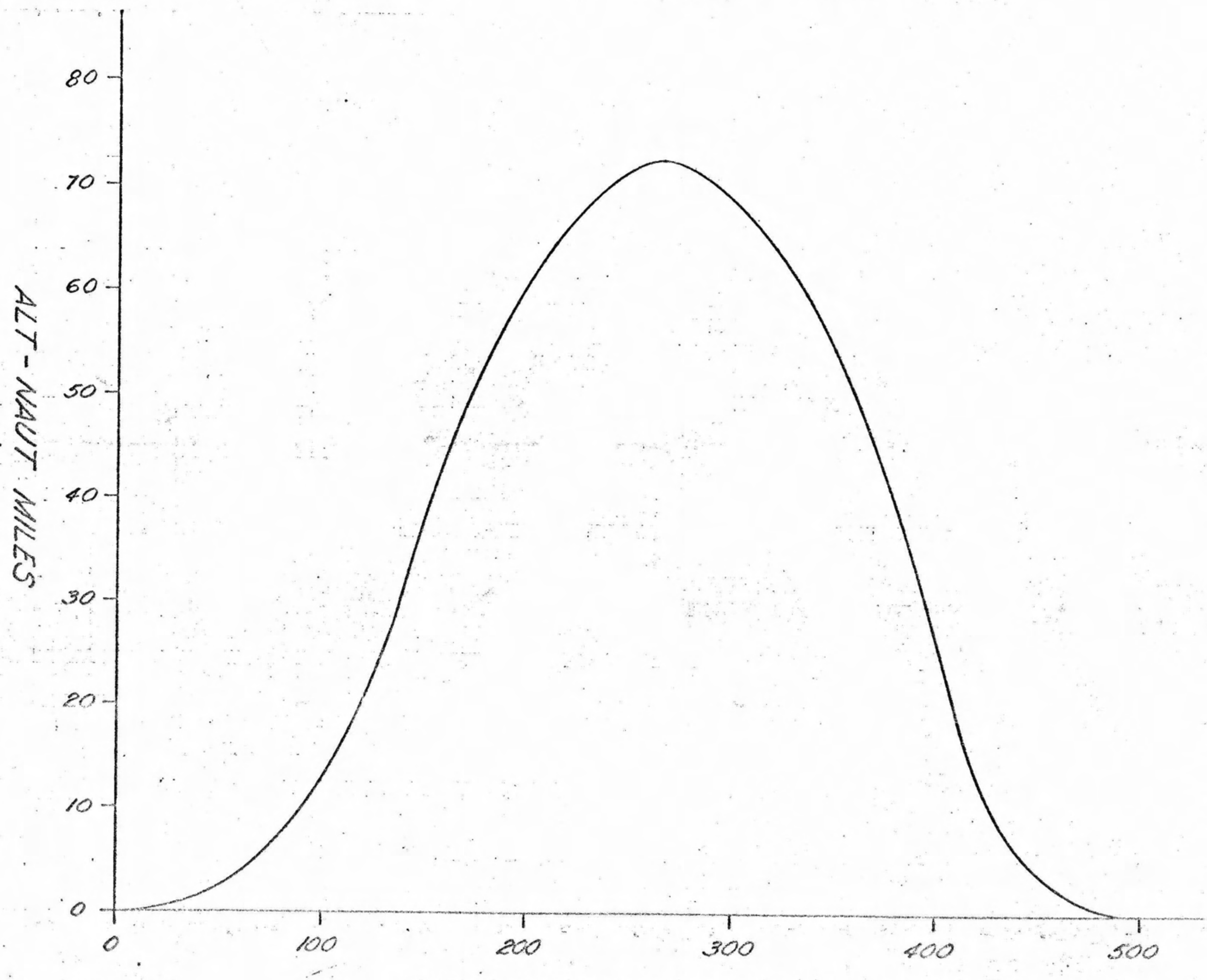
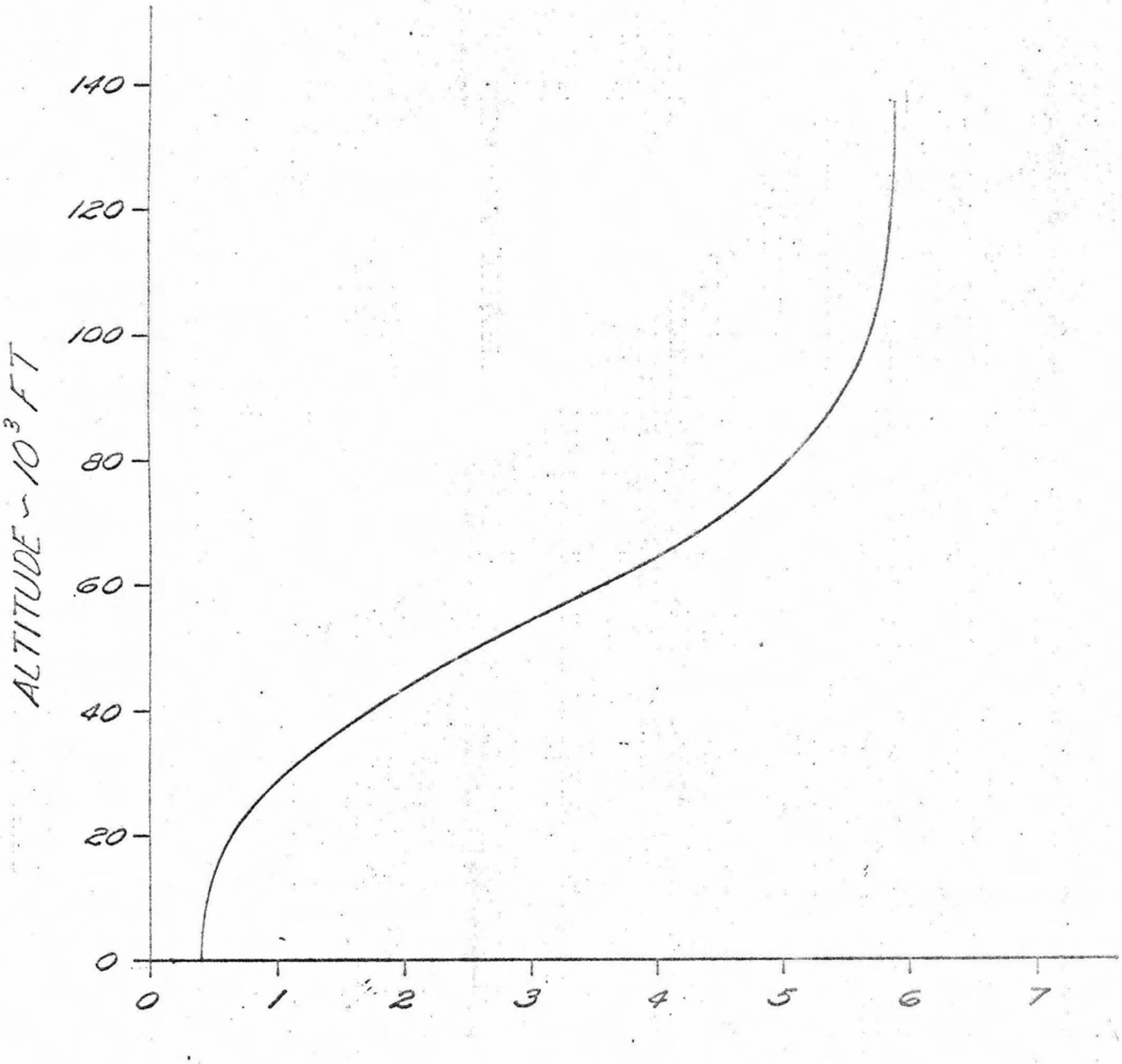


FIGURE 2A TRAJECTORY



Unassited Stage Zero
Angle of Attack

FIGURE 7B TRAJECTORY

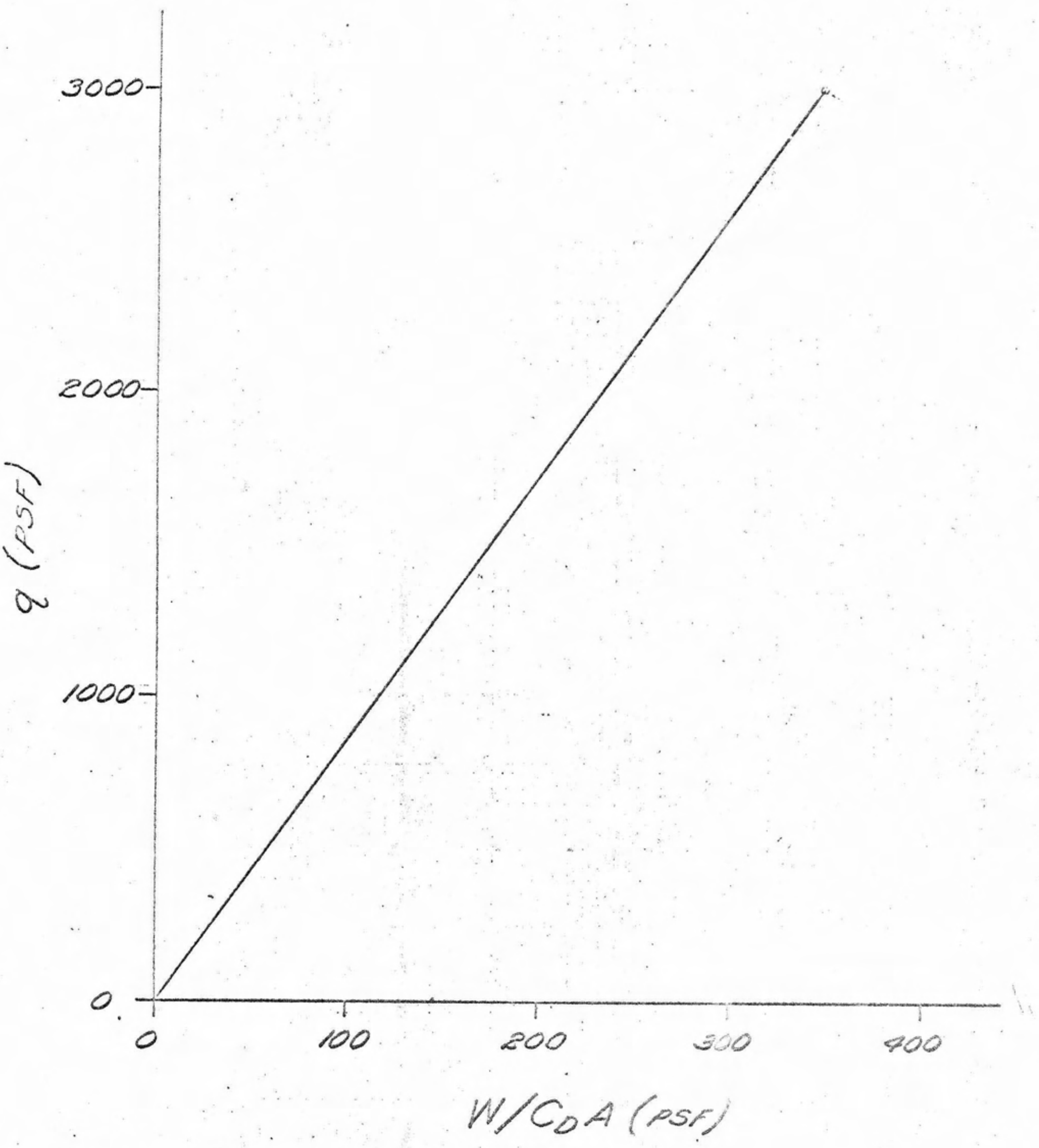


FIGURE 7C TRAJECTORY

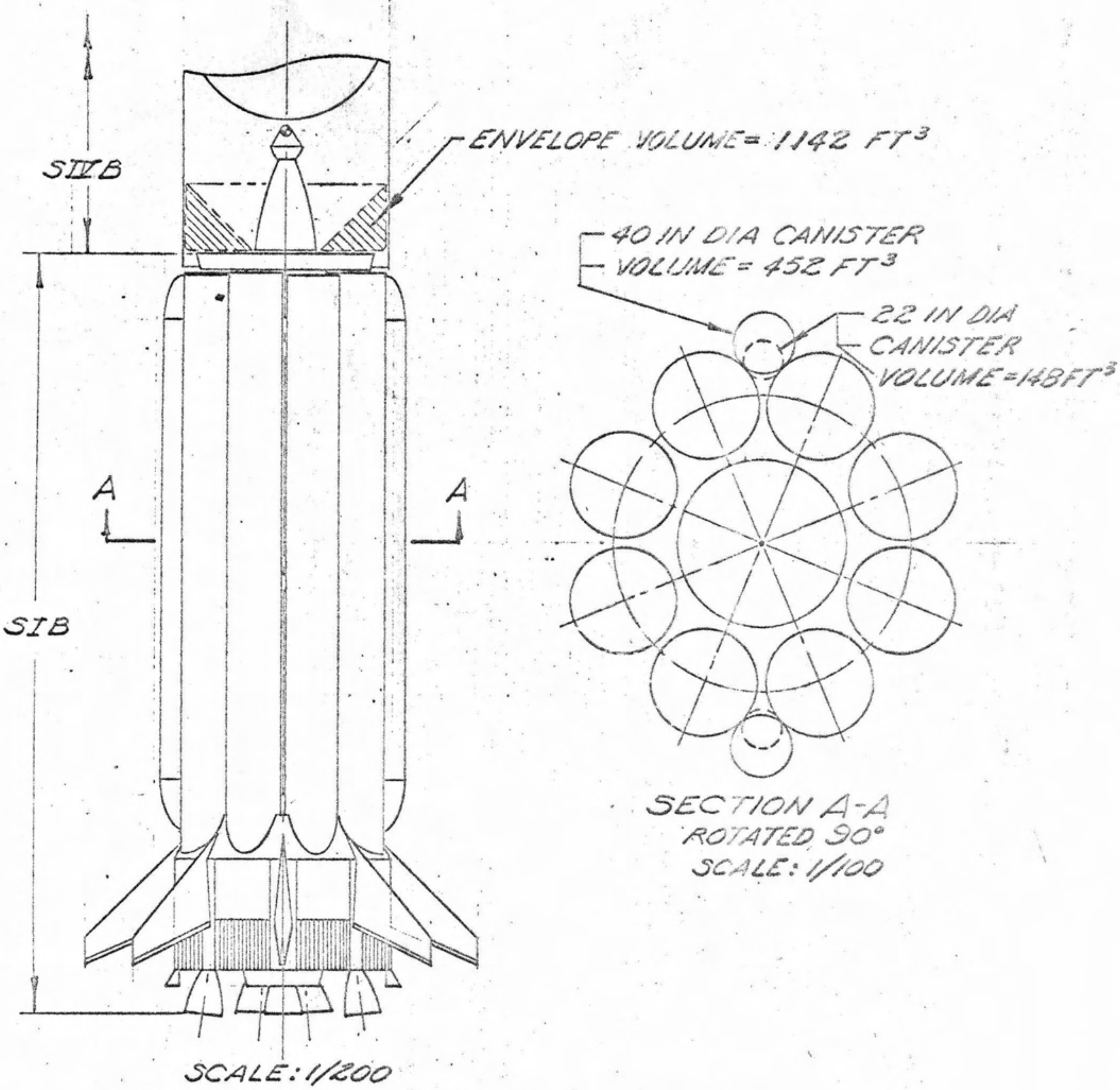


FIGURE 8 PACKAGING

RECOVERY SYSTEM WEIGHTS

CONFIGURATION	A	B	C	D & E	F	G
Basic Vehicle	106,000	106,000	106,000	106,000	106,000	106,000
Recovery Systems	(5,400)	(18,200)	(16,000)	(19,500)	(6,700)	(13,200)
Stabilization						
Re-Entry	2,200	2,200		3,500	3,500	10,000
Recovery	3,200	11,000*	11,000*	11,000*	3,200	3,200
Retrieval		5,000	5,000	5,000		
TOTAL	111,000	124,000	122,000	126,000	113,000	119,200

*Hot air balloon including one-hour fuel supply. This fuel could be reduced for early flights where water impact is planned.

FIGURE 9 WEIGHTS

RECOVERY SYSTEM DEVELOPMENT SCHEDULE

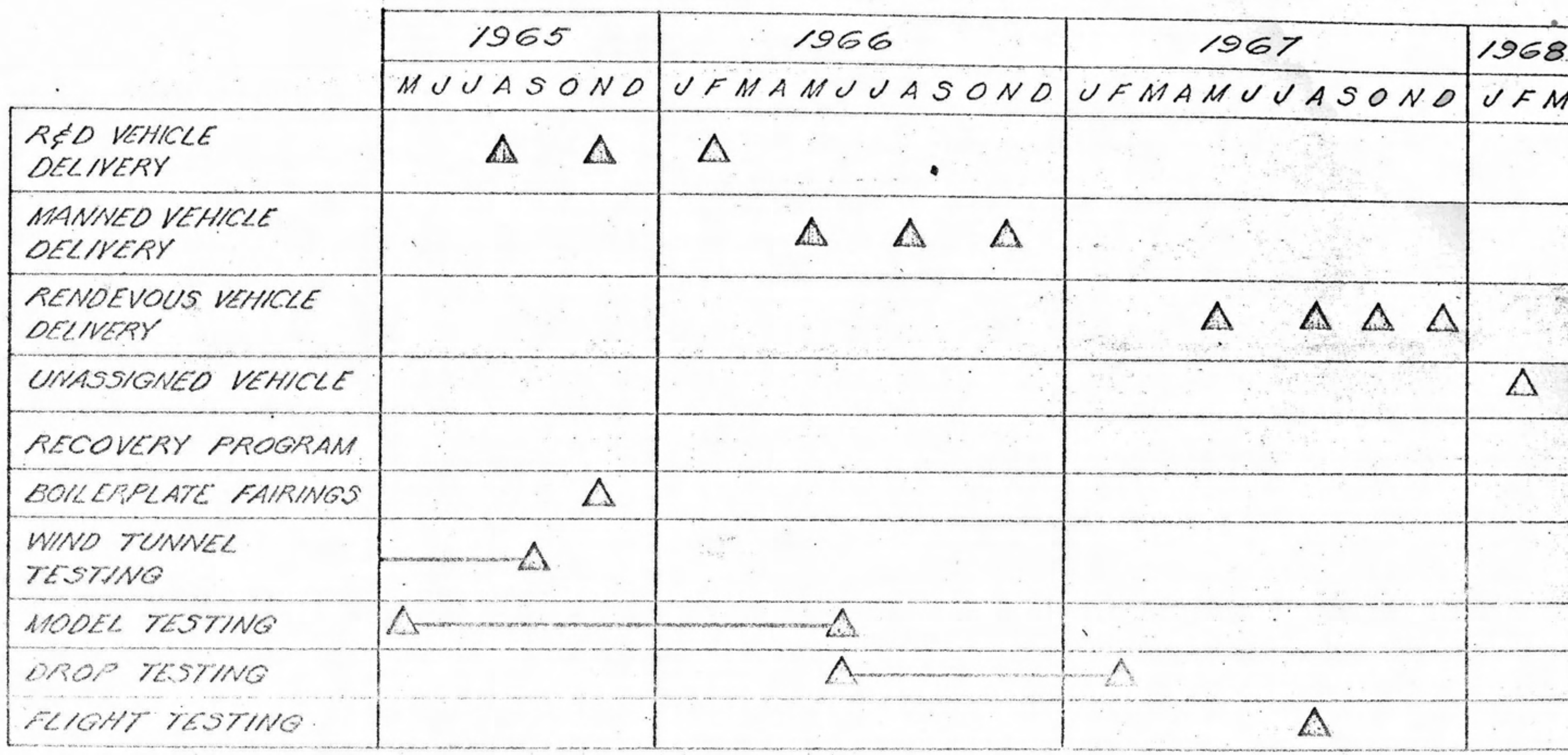


FIGURE 10 SCHEDULE