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LIQUID ROCKET PLANT

Report No. (LRP 297, Volume I
SUMMARY

Sea Dragon

Prepared by
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Liquid Rocket Plant

0133009

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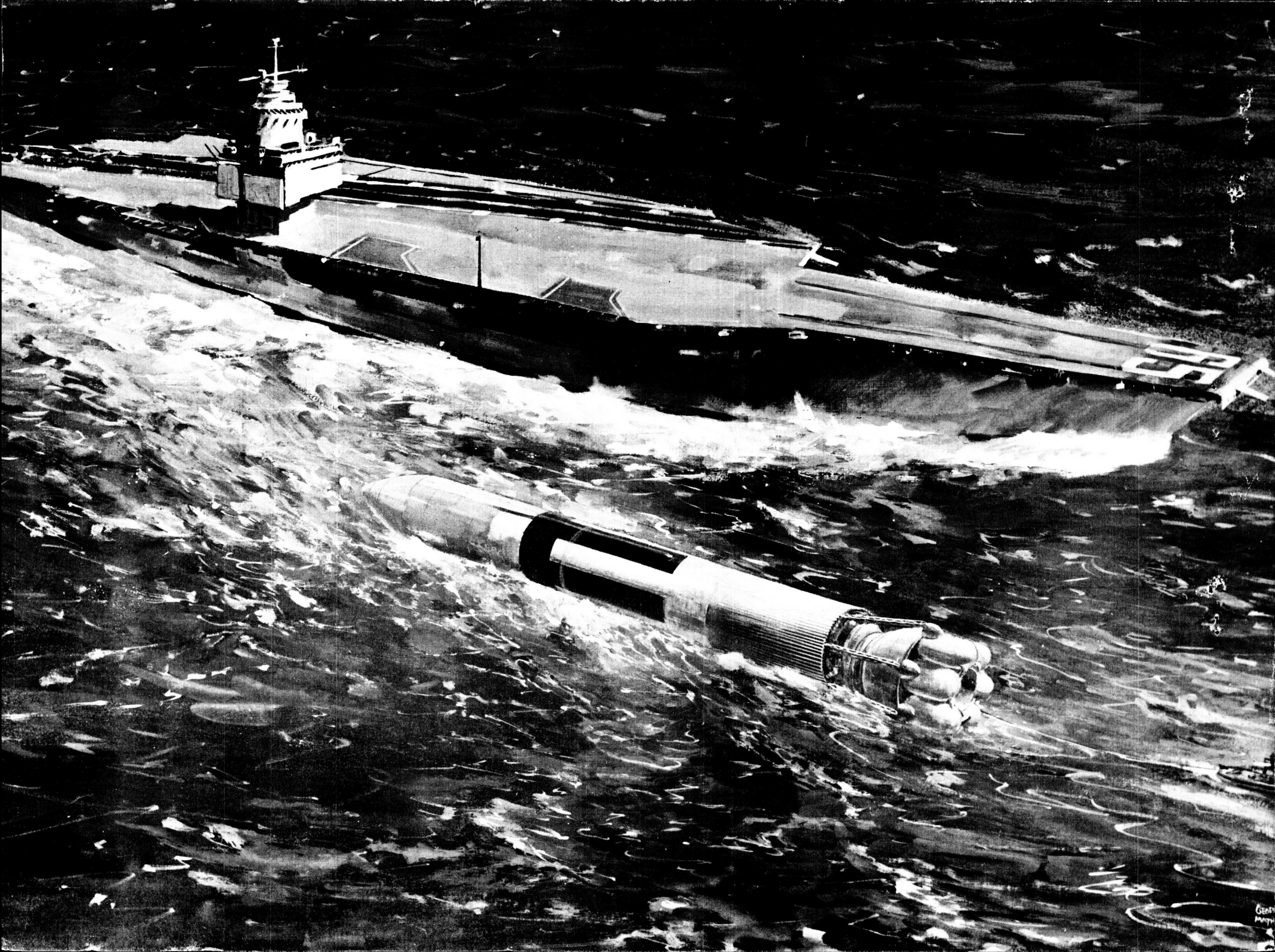

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I. INTRODUCTION

A. THE CONCEPT

The Sea Dragon concept has been developed assuming that space transportation economy will result if launch vehicles are used that are very large, simple, and reusable, even if payload-to-liftoff weight ratio is sacrificed in securing these characteristics. Prior studies led to the embodiment of this concept in a vehicle as large as a ship, which used a single pressure-fed engine per stage (Figure I-A-1), and which was assembled and transported using shipbuilding methods. The rocket was to be launched from a vertical floating attitude directly out of the water. After burnout, the stages were to be decelerated solely by normal atmospheric drag and water impact forces. The recovered stages were to be towed back to the launch site for reuse (Figure I-A-2). The seaborne operating concept was extended to include propulsion system development testing at sea using cruiser-weight, vehicle configuration tankage for full-scale work.

I, Introduction (cont.)

B. THE STUDY PURPOSE

The purpose of the present study was to examine the foregoing concept in sufficient detail to determine its technical feasibility and to make a reasonably accurate estimate of its cost effectiveness.

C. THE GROUND RULES

To give the analysis a specific character, the following mission was defined:

> Transport from the surface of the sea near Cape Canaveral, to a 306-nm orbit, unit payloads weighing at least one million lb at rates of one per month and two per month.

Minimum cost was to be of paramount consideration, although operation in the 1970 time period was desired. For cost purposes, a 10-yr useful life for the system was to be assumed. No arbitrary restrictions were to be placed on takeoff weight. Payloads were not defined except that versatility was desired.

I, Introduction (cont.)

D. THE GENERAL STUDY RESULTS

In general, the study has confirmed that large, simple, recoverable vehicles can be highly effective from a cost standpoint. A total system development cost of $2.836 billion is forecast. The direct flight related cost is $10 to $20 per lb of payload. Amortizing the research and development cost over 240 flights gives a total cost effectiveness of $20 to $30 per lb of payload. No elements of the original concept have been shown to be technically unfeasible; however, the technical feasibility of a completely passive recovery system has not been demonstrated.

At the end of the study period, it appeared that a configuration having a sufficiently high drag to impact at a velocity acceptable from a structural point of view would suffer an unacceptable payload penalty. To ensure a completely workable system, an inflatable "drag bag" has been incorporated in the configuration discussed here. Further tradeoff studies may permit a return to the completely passive approach.

I, D, The General Study Results (cont.)

The question remains as to whether the inertial effect of the water in the first-stage thrust chamber leads to unacceptably long start transients. Several solutions appear possible, however, if the problem is found to exist.

The several unusual features of the Sea Dragon concept have lead to major questions that will be discussed in summary here and in greater detail in the remainder of this volume and in Volumes II and III.

1. Size Effects

The Sea Dragon vehicle is more than 500 ft long and 75 ft in diameter. Its size has led to some questions of development, fabrication, and handling feasibility. The study has indicated that reasonable solutions to these problems can be obtained. Of primary concern were the problems of transporting and handling a vehicle of this size. The sea transport mode has solved most of these problems, but has been responsible for creating a few more. Numerous existing drydocks will accomodate a completely assembled vehicle, or two like stages. One shipyard, the Maritime Administration's Pidgeon Point yard, has five adequate drydocks with handling equipment and supporting shops. The entire yard can be leased for only a few hundred thousand dollars a year.

Opinions were solicitated from several shipyards regarding feasibility of fabricating and assembling the Sea Dragon tankage. Replies were uniformly affirmative regarding feasibility. The average tankage cost quoted was $6 per lb. A number of shipyards are beginning to gain experience in missile fabrication through participation in the large solid rocket program. The quoted costs from yards having familiarity with the material and tolerance requirements for large solid cases did not differ markedly from the cost estimates of the less experienced yards.

The large size of the first-stage thrust chamber (80-million-lb thrust) has raised questions regarding development cost and combustion stability.

I, D, The General Study Results (cont.)

The cost analysis has shown that even with very generous propellant allowances the propellant cost is only about 15% of the total research and development cost. The sea development testing approach keeps the facility costs actually below those required for smaller engines such as the F-1 and M-1.

The cost of test hardware increases with size, but not at a prohibitive rate. Thrust chambers, the primary casualty items, are expected to cost about $4.5 million each. Repair and modification of injectors, and replacement of burned out tubes is expected to be more feasible and have greater economic justification than in the case of smaller engines. These factors lead to a quite reasonable cost for test hardware, in spite of the size.

The labor cost for each test is less than that for smaller pump-fed engines. The reason is that the increase in personnel required to handle the larger hardware is more than offset by the decrease in the number of people required to collect, reduce, and interpret the lesser amount of test data required by the simpler engine.

With regard to combustion stability, an analysis on the basis of sensitive time lag theory (perhaps the best theory so far developed) indicates that the Sea Dragon thrust chamber will operate well outside the region of combustion instability. One of the primary advantages of sea based development testing is that it permits early experimental evaluation of combustion stability on a full scale basis without an exorbitant outlay for facilities.

Thus, the sea handling philosophy provides reasonable solutions to most of the problems generated by large vehicle and engine size. The problems it creates are discussed below.

2. Sea Effects

Immersion of the vehicle in sea water during a significant number of operating phases gives rise to several problems not previously encountered to the same degree in space vehicle development and operation. Sea water is corrosive to many materials and has high electrical and thermal conductivity. Water has a higher freezing point than air. Access to wetted portions is denied except to divers. External pressures are greater than atmospheric pressures and increase more rapidly with depth than does that of the atmosphere. Water has a higher density than air, and provides a less rigid support than soil.

Some of the obvious problems have equally obvious solutions.

The solution to the corrosion problem lies in excluding the water from compartments containing equipment that can be injured by it or by providing protection for the individual items. This is the procedure used in warships, which contain at least as much complex equipment as will be used in space launch vehicles. The primary corrodable materials that could be in contact with sea water will be stainless steel in the thrust chambers, aluminum tank skin, and high nickel steel interstage structure. The aluminum tanks are protected by their insulation covering. The nickel steel will be protected by painting, but the stainless steel has adequate corrosion resistance without protection.

I, D, The General Study Results (cont.)

Electrical equipment, in general, is located inside the waterproof skin. A few items such as gimbal actuator servos are individually waterproofed and have waterproof conduits for related wiring.

The icing problem is met by a few inches of insulation. In vehicles the size of the Sea Dragon, the weight penalty is not too significant (1% Stage I inerts, 5% Stage II inerts). Thermal barriers in the form of insulating gaskets and gas pockets prevent formation of ice at the propellant-water interface in the plumbing.

In the unfueled condition, access is denied by the water to only a small part of the skin. Internal access in this state is relatively unhampered by the water environment. In the fully serviced condition approximately half of the external skin is wetted. Erected, two-thirds of the vehicle is under water, but relatively few components are below the waterline.

I, D, The General Study Results (cont.)

The water density, and the external pressures resulting from this density, present potentially more serious problems. The external pressure of nearly 150 psi at the first-stage engine level could cause collapse of the De Laval nozzle. Separation effects under water are unknown. If early gas separation takes place, the nozzle may not be subjected to an excessive pressure differential. The solution adopted in this study, however, is to use a nozzle insert that partially restricts the nozzle exit and maintains internal pressure greater than external pressure. Other possibilities include use of separation inducers, nozzle ventilating slots, and plug nozzles.

The large inertia of the water contained in the nozzle leads to starting transients of three seconds. Whether this long transient is objectionable or favorable is not known at present. Further analysis and tests are needed.

I, D, The General Study Results (cont.)

The type of support given by the water leads to various kinds of loading depending on the conditions of wind and sea and on the loading condition of the vehicle. The analysis has shown that loads up to Sea State No. 5 do not require structural reinforcement of the vehicle except for removable booms to support the ballast unit.

The constant motion of the vehicle requires some modifications in guidance, primarily in the provision of self-erecting and gyrocompass azimuth alignment capability together with initial position and velocity inputs from shore based tracking stations.

Although it is proposed that most of the checkout and the fuel servicing be done in a lagoon at Cape Canaveral, certain vehicle and payload functions must be commanded and monitored continuously up to the instant of launch. The simplification of the vehicle reduces the number of these functions, and the increased

I, D, The General Study Results (cont.)

difficulty of such monitoring will tend to reduce the number to those absolutely essential. Those that remain must be monitored by the flight crew on the service vessel and from telemetry signals received at the launch control center. Further study of the countdown is required to identify each item to be monitored and the manner in which the information or command will be handled.

I, D, The General Study Results (cont.)

3. Simplicity Effects

The most usual restriction to simplicity is reduction in performance, usually resulting in an inferior payload to gross weight ratio. In the Sea Dragon, simplicity is gained through two prime features; pressure-fed engines and a single thrust chamber for each stage.

Pressure-fed propulsion generally leads to inferior propellant fractions because the tank pressure must always exceed the combustion pressure. The Sea Dragon achieves a propellant fraction of about .89 in each stage. The lower propellant density of the second stage is counterbalanced by a reduction in tank pressure. This lower pressure is made possible, without loss of specific impulse, by use of an expandable nozzle. The latter makes possible a high area ratio without having the nozzle exit diameter exceed the diameter of the first-stage tanks.

I, D, The General Study Results (cont.)

Pump-fed engines might be expected to give propellant fractions of .95 with dense (LO_2 - RP-1) propellants or .93 with LH_2 and LO_2. Caution is indicated here, however, because hydrostatic pressures, and the pressures required to counteract payload and upper stage loads tend to become large in vehicles the size of Sea Dragon and may lead to pump-fed stages that are only marginally superior in terms of propellant fraction.

In addition to an inferior mass fraction, pressure-fed engines tend to have lower specific impulse because of lower optimum chamber pressure. The Sea Dragon has a specific impulse at sea level of only 242 sec. It should be noted, however, that sea level specific impulse is weighted only one-tenth to one-third of the vacuum value, depending on the trajectory. The vacuum specific impulse depends almost entirely on area ratio and is nearly independent of chamber pressure.

The combined effect of the lower specific impulse and mass fraction is to reduce the payload to gross weight ratio of the Sea Dragon to about one-fortieth. The development cost, however, is estimated (based on experience with smaller engines) to be one-half to one-third that of a pump-fed engine of equal thrust and reliability. Furthermore, a great improvement in general operability and recoverability results. Viewed from another angle, because of its lower development and operating costs, a pressurized vehicle several times larger than the pump-fed variety can be developed and operated for the same cost. This larger vehicle will carry more payload than the smaller and more efficient one.

As a result of the pressure-fed propulsion system, the vehicle is extremely rugged. The loads generated by the feed pressure are large compared with both handling and flight loads. Because the feed pressures are well known, structural adequacy is more easily established. A reduction in vehicle cost results when compared with fragile tankage systems where relatively unknown flight and handling loads may well govern the design.

I, D, The General Study Results (cont.)

The pressure-fed system also lends itself well to recovery because it has sufficient strength to resist breakup on atmospheric and high speed water entry.

4. Recovery

The ability of the pressure-fed stage to survive intact water impact velocities between 300 and 600 ft/sec, combined with a seagoing design that will survive immersion without requiring extensive refurbishment, makes a simple drag type recovery system most attractive. Without auxiliary drag devices, the impact velocity of the Sea Dragon first stage is supersonic. It is fairly certain that the current design will not survive such an impact without damage. It is possible that a redesign, incorporating a different nose shape, a larger nozzle area ratio, structural strengthening in key spots, and some repressurizing of the forward tank, would result in a vehicle capable of withstanding its normal impact. Because definitive feasibility could not be shown

I, D, The General Study Results (cont.)

in the time available, it was decided to incorporate an inflatable drag skirt. This drag skirt reduces the impact velocity below 300 ft/sec, low enough to prevent damage to the structure as designed. The weight penalty of the drag skirt is less than 2% in payload.

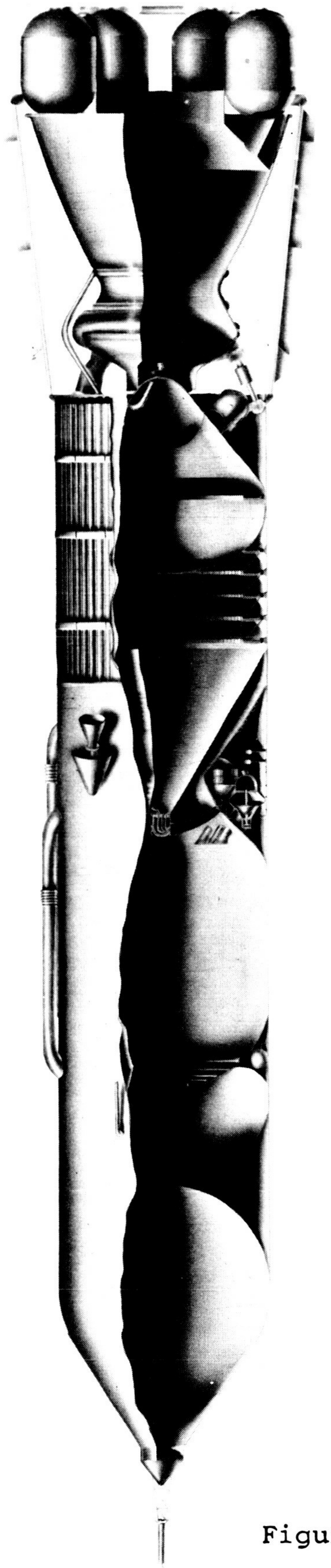
The 2% payload penalty, a negligible cost to tow the stage 170 mi back to base, and a 4% refurbishment cost are the only costs of recovering a stage that costs $24 million to duplicate.

In addition to the value of the recovered stage, such stages are expected to be more reliable on subsequent flights than new stages, corresponding to aircraft experience. Furthermore, recovery of stages in the development period will assist in design evaluation by permitting direct post-flight inspection.

Because of limitations on time and funds, recovery of the second stage was not investigated. Further considerable cost reduction should be possible by recovering these stages in a manner somewhat similiar to first-stage recovery.

I, D, The General Study Results (cont.)

Each of the principal features of the Sea Dragon contributes significantly to the overall cost effectiveness. None appears to introduce difficulties out of proportion to its contribution.



Cut-Away View of the Sea Dragon

Figure I-A-1

Phases of Sea Dragon Operation (Fabrication to Refurbishment)

Figure I-A-2

II. VEHICLE DESCRIPTION

A. GENERAL FEATURES AND FUNCTION

The Sea Dragon is a very large sea-launched two-stage liquid propellant rocket vehicle that will be used to launch very large payloads into earth orbit. As presently designed, the vehicle has a gross liftoff weight of 40-million lb and is capable of propelling a payload of 1,100,000 lb to a circular orbit of 306-nm altitude. The payload was assumed to be liquid hydrogen for this study, but it could be other material or equipment, or additional propulsion stages. A command module of the Apollo type provides the guidance and control and communication functions, and will be capable of separation, re-entry, and recovery as well as abort functions.

The vehicle is nominally 75 ft in diameter and 500 ft long. The general configuration is presented in Figures II-A-1 and II-A-2. Principle characteristics of the vehicle are given in Tables II-A-1, II-A-2, and II-A-3.

II, A, General Features and Function (cont.)

The major components of the vehicle, such as the first-stage, second-stage, and payload will be towed separately by sea to the assembly lagoon where they will be assembled in the horizontal position. Small components that might be better transported by land or air will be installed and checked out at the assembly site. The vehicle will be capable of being serviced and operated in moderately heavy seas in a free floating position. To achieve proper flotation and stability characteristics during towing and while in the vertical prelaunch attitude, the vehicle will be equipped with a ballast unit attached to the first-stage nozzle rim. During the launch sequence, the ballast unit is released and later taken in tow for reuse.

The first-stage of the vehicle is recoverable and reusable. After staging, the first-stage re-entry flight is passively controlled by an inflated drag skirt that limits its velocity at water impact so that the structure is not damaged. The stage can be recovered and reused with minimal refurbishment. Figure II-A-3 shows the details of the vehicle.

II, A, General Features and Function (cont.)

Each stage uses a simple pressure-fed propellant supply system. The propellant tank walls are correspondingly stronger than would be used in a pump-fed stage. These propellant tank walls form the primary stage structure. Interstage structure transfers the loading between stages and the transition structure provides the primary load path between the first-stage interstage structure and the second-stage tank. The main vehicle structure consists of the stage tank structure, the payload tank structure, the interstage, and the transition structure. The tanks, interstages, and transition sections are pressure vessels and can be pressurized to prevent the development of compressive instability during all modes of sea handling, propellant loading, erection, launch, and flight. Fill and vent lines provide for controlled pressure loading and venting of the propellant tanks in both horizontal and vertical vehicle attitudes.

II, A, General Features and Function (cont.)

The first-stage propulsion system is made up of the main propellant tanks, the feed lines, pressurization system, and a single gimballed thrust chamber regeneratively-cooled with a DeLaval nozzle, gimbal, actuators, and associated structure. It uses RP-1 fuel pressurized by methane (CH_4) using a unique pressurization technique called Secondary VaPak. The oxidizer is liquid oxygen pressurized by an autogenous system using a heat exchanger on the engine. The mixture ratio is controlled by control of the autogenous pressurizing gas flow. The first-stage engine gimbal actuators utilize RP-1 fuel at tank pressure. Roll control is provided during both stages of flight by four auxiliary engines on the second-stage. These engines also provide pitch and yaw control for the second-stage as well as assisting in orbital injection.

Flight reliability is enhanced using this system of auxiliary chambers because: (a) they are started before the main first-stage propulsion system and can be monitored for correct operation before flight and (b) they can be designed for "one chamber out" operation.

II, A, General Features and Function (cont.)

The second-stage propulsion system has a rigidly mounted thrust chamber and utilizes an expandable nozzle. The chamber plus a section of nozzle is nonregeneratively-cooled with hydrogen and the remainder of the nozzle is radiation cooled. The chamber utilizes liquid oxygen and liquid hydrogen as propellants. The oxygen uses acceleration head augmented by its own vapor pressure as feed pressure. No additional prepressurization is necessary. The hydrogen is prepressurized for first-stage operation and uses an autogenous pressurizing system during second-stage operation whereby acceleration head pressure drives hydrogen through a low pressure drop heat exchanger mounted on the thrust chamber external wall. The expandable nozzle on the second-stage provides a method of conforming to a simple configuration envelope while still producing a large expansion ratio when opened (compared to equivalent fixed nozzles).

II, A, General Features and Function (cont.)

A slightly modified, nearly conventional, all-inertial guidance system is incorporated in the vehicle's command module; it returns with the module for recovery. Self-checking and sequencing functions are included in the guidance system.

In the following sections the principle events and performance characteristics of the vehicle are described.

TABLE II-A-1

SUMMARY OF SEA DRAGON VEHICLE CHARACTERISTICS - CONFIGURATION No. 135

PROPULSION

Item	Main Stage Engines		TVC
	Stage I	Stage II	(4) Engines
Nominal Thrust (lb)	80 x 10^6(sea level)	14.12 x 10^6 (vac)	53,200 (ea)
Operating Time (sec)	81	260	1,340
Nominal Chamber Pressure (psia)	300	75	75
Nozzle Area Ratio	5.0:1	20:1 (exp. nozz)	20:1
Oxidizer	LO_2	LO_2	LO_2
Weight Oxidizer - Full Tank (lb)	17,617,568	8,005,045	583,000
Fuel	RP-1	LH_2	LH_2
Weight Fuel, Full Tank (lb)	7,659,812	1,601,009 (and line)	116,000 (total)
Mixture Ratio - Oxidizer/Fuel	2.3:1	5:1	4.0:1
Stage Propellant Mass Fraction	0.888	0.887	--

VEHICLE WEIGHT

Item		Vehicle Weight (lb)		
		Recoverable		Expendable
Payload (nominal)		1,100,000*		1,121,000
Stage I At Launch (full tanks)		28,217,195		27,961,397
Stage I Empty (dry)	(2,939,715		(2,684,017)	
Stage II At Launch (full tanks)		10,631,893		10,631,893
Stage II Empty (dry)	(1,025,839)		(1,025,839)	
Nominal Total Takeoff Weight		39,950,000		39,710,000

VEHICLE PERFORMANCE

	Stage I	Stage II
Velocity Increment (ft/sec)	5,800	17,630**
Maximum Acceleration (g)	4.21	5.2***
Altitude at Burnout (ft)	125,000	750,000 (150 nm)
Altitude at Injection		1,822,800 (299.8 nm)

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* This figure includes the beneficial effect of an eastward launch. It includes allowance for a payload decrement of 3.16% for underwater performance losses and 7.66% for a continuous burn versus restart trajectory (total penalty = 10.8%). It should be recognized that the preliminary staging ratio selection of 1.92 results in a payload 7% lower than the optimum value of 1.4. Use of a more optimum staging ratio would result in a payload of approximately 1,170,000 lb for the recoverable vehicle.

** The performance given is for the recoverable vehicle. The data for the expendable vehicle does not differ significantly.

*** At completion of the high thrust phase.

TABLE II-A-2

SEA DRAGON STAGE I RECOVERABLE CONFIGURATION No. 135 WEIGHT BREAKDOWN

Propellants	Weight (lb)	Expendable Version (lb)	Subtotal (lb)
LO_2	17,617,568		
RP-1	7,659,812		
			25,277,380
Tankage			
RP-1 Tank	420,496		
RP-1 Slosh Baffles	33,200		
LO_2 Tank (Includes Common Blkhd)	948,678	(874,280)*	
LO_2 Slosh Baffles	40,000		
LO_2 Tank Insulation	18,000		
Insulation, Common Bulkhead	9,479		
Encapsulation Skin	13,428		
Insulation (Methane RP-1)	1,760		
Encapsulation Skin	2,493		
		(1,413,136)	1,487,534
Skirts, Lines, and Structure			
Forward Skirt and Separation Equipment	29,200		
Aft Tank Support Skirt	39,000		
Structure between Gimbal and Injector	54,000		
Oxidizer Line from Tank to Injector	59,000		
Fuel Line from Tank to Chamber	40,900		
LO_2 Fill and Vent System	500		
RP-1 Fill and Vent System	500		
Oxidizer Pressurization Equipment	3,160		
		(212,060)	226,260
Engine System			
Gimbal	122,600		
Actuators	44,000		
Injector Assembly	88,500		
Thrust Chamber	180,000		
Ballast Mounting Structure	18,400		
LO_2 Valve	23,400		
RP-1 Valve	25,600		
Oxidizer Pressurant	236,000		
Heat Exchanger	8,200		
Fuel Pressurant	178,000		
Fuel Pressurization Equipment	700		
Fuel Trapped in Tubes	100,000		
			1,025,400
Miscellaneous			
Recovery Flare and Equipment	124,200	(0)	
Insulation on LO_2 Line	2,104		
Insulation on Pressurant Line	840		
Misc. Weight (5% Tankage)	73,477		200,621
Structural Strengthening not Required for Expendable Vehicle		(-43,000)	(33,421)
TOTAL SYSTEM WEIGHT			28,217,195 (27,961,397)
Total Propellant Weight	25,277,380		
Less Outage	252,774		
Total Usable Propellant	25,066,406		

Stage Mass Fraction $= \frac{25,066,406}{28,217,195} =$ 0.888 (0.896)

---

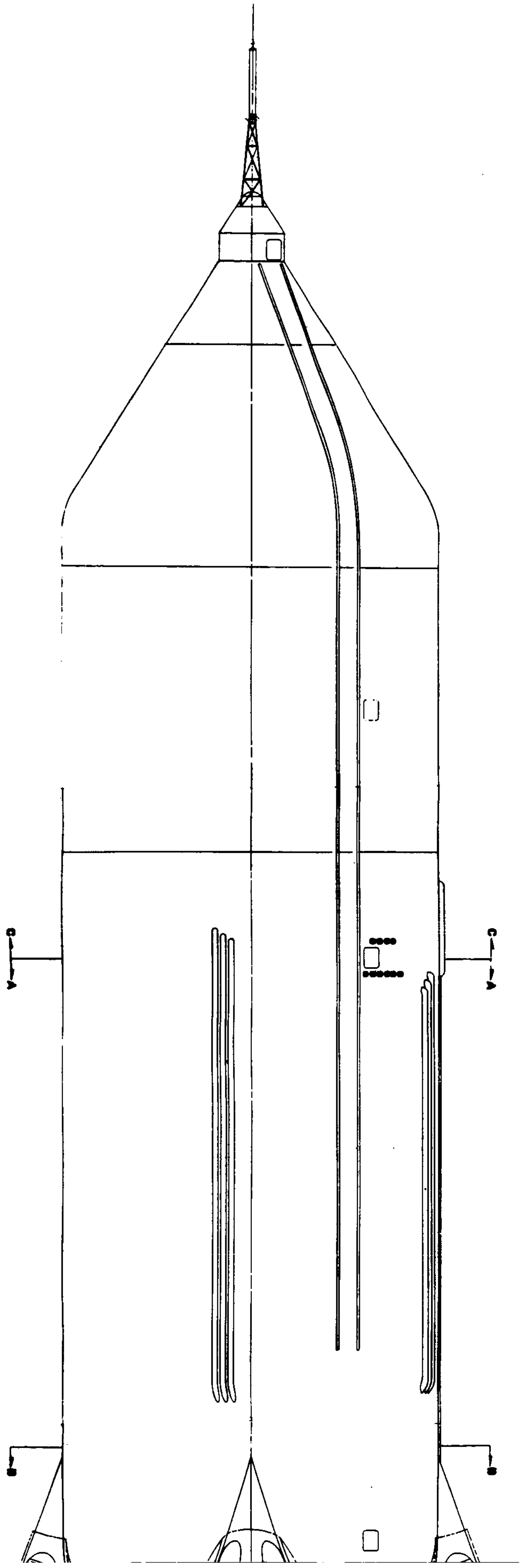
* The figures in parenthesis refer to weight changes for an expendable version of Configuration No. 135.

TABLE II-A-3

SEA DRAGON STAGE II
CONFIGURATION No. 135 WEIGHT BREAKDOWN

Propellants	Weight (lb)	Subtotal (lb)
LO_2		
in Tank	7,918,356	
in Line to Chamber	86,689	
		8,005,045
LH_2		
in Tank	1,601,009	
		1,601,009
	TOTAL	9,606,054
Tankage		
LO_2 Tank	123,310	
LH_2 Tank (includes bulkhead)	3.8,396	
Encapsulation skin	13,428	
Insulation on Bulkhead	9,479	464,613
Skirts, Lines, and Structure		
Aft Tank Skirt	211,984	
Skirt Between LO_2-LH_2 Tank	27,137	
LO_2 Line to Chamber	4,700	
LH_2 Line to Chamber	1,360	
Vortex Structure	2,700	
LO_2 and LH_2 Fill and Vent System	1,525	
Fuel Pressurizing Equipment	1,820	251,226
Engine System		
Injector Assembly	10,000	
Thrust Chamber	51,400	
Expandable Nozzle	71,500	
TVC System (Structure, Engine, Mounts)	5,300	
LO_2 Valve	3,640	
LH_2 Valve	4,480	
Heat Exchanger	13,400	
TVC Pressurization System	14,550	
Oxidizer Pressurization Gases	52,000	
Fuel Pressurization Gases	18,500	244,770
Miscellaneous		
Fuel Tank Insulation	36,000	
Oxidizer Tank Insulation	6,000	
Misc Weight (5% of Tankage)	23,230	65,230
TOTAL SYSTEM WEIGHT		10,631,893
Total Propellant Weighy	9,606,054	
Less Outage (1% of Total)	96,060	
Less LH_2 Cooling Requirements	40,560	
Less 1st Stage TVC Weight	42,000	
TOTAL USABLE PROPELLANTS	9,427,434	

$$\text{Mass Fraction} = \frac{9,427,434}{10,631,893} = 0.887$$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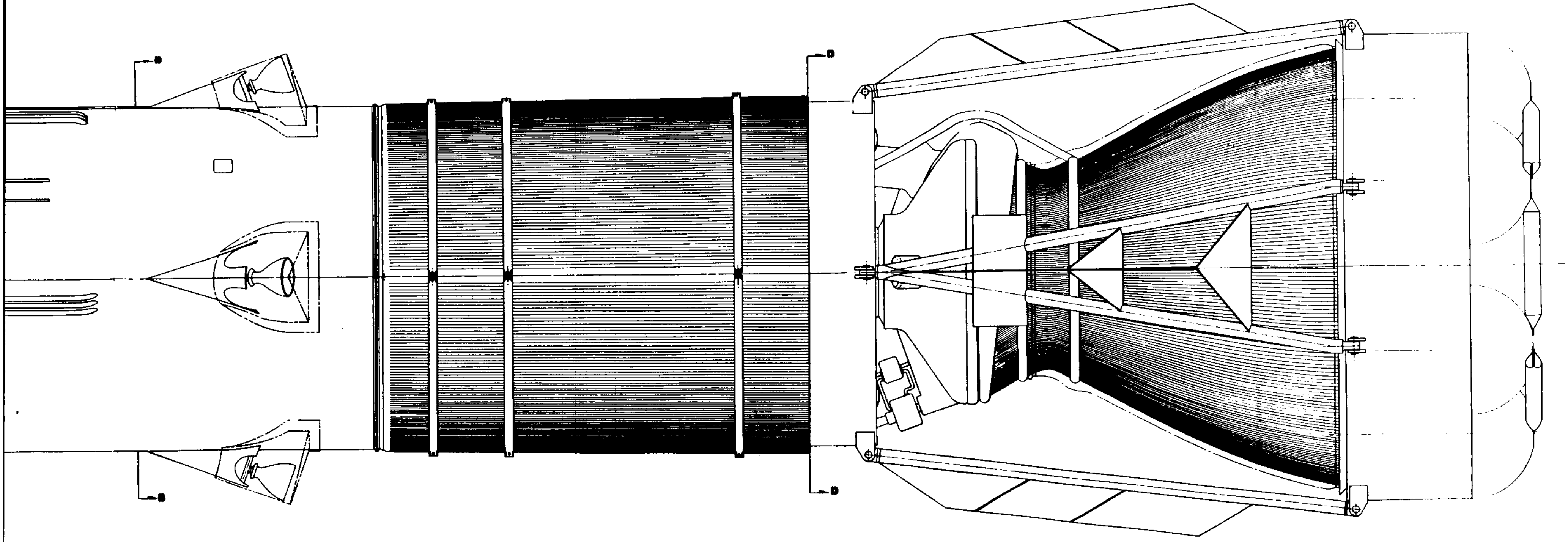
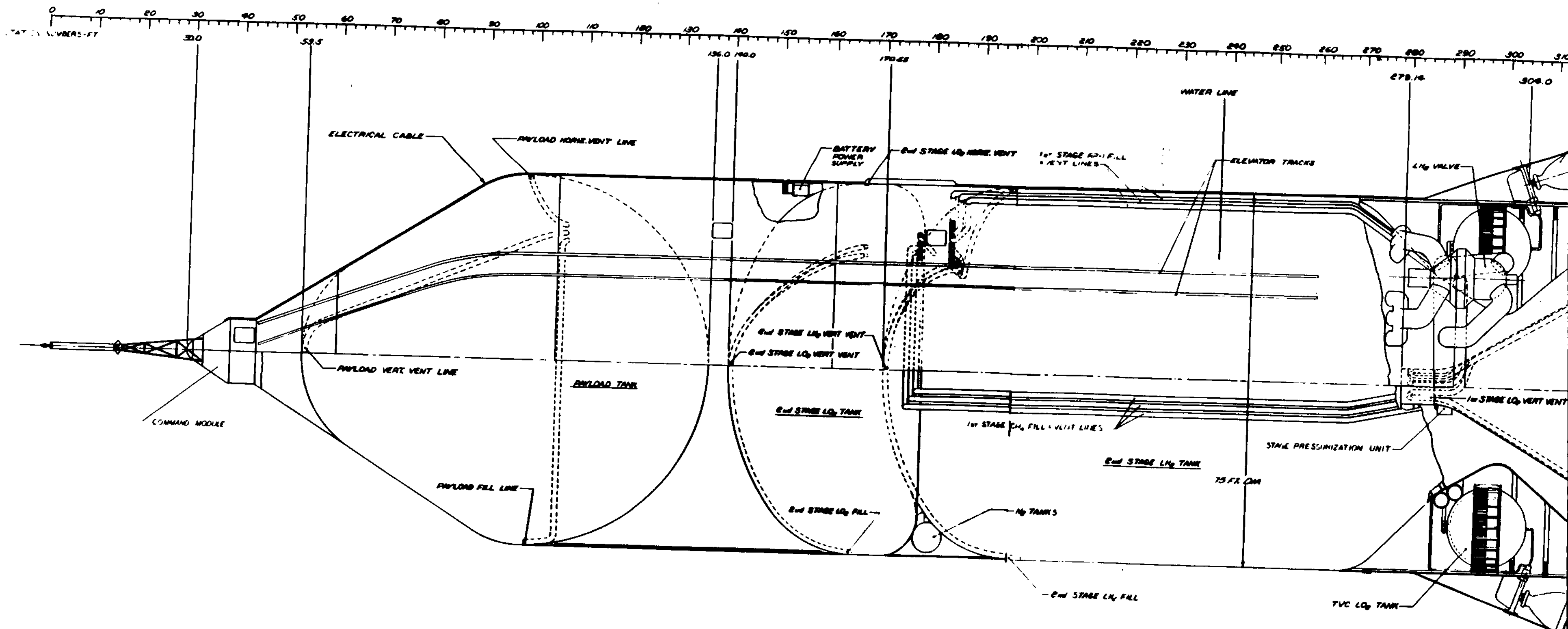


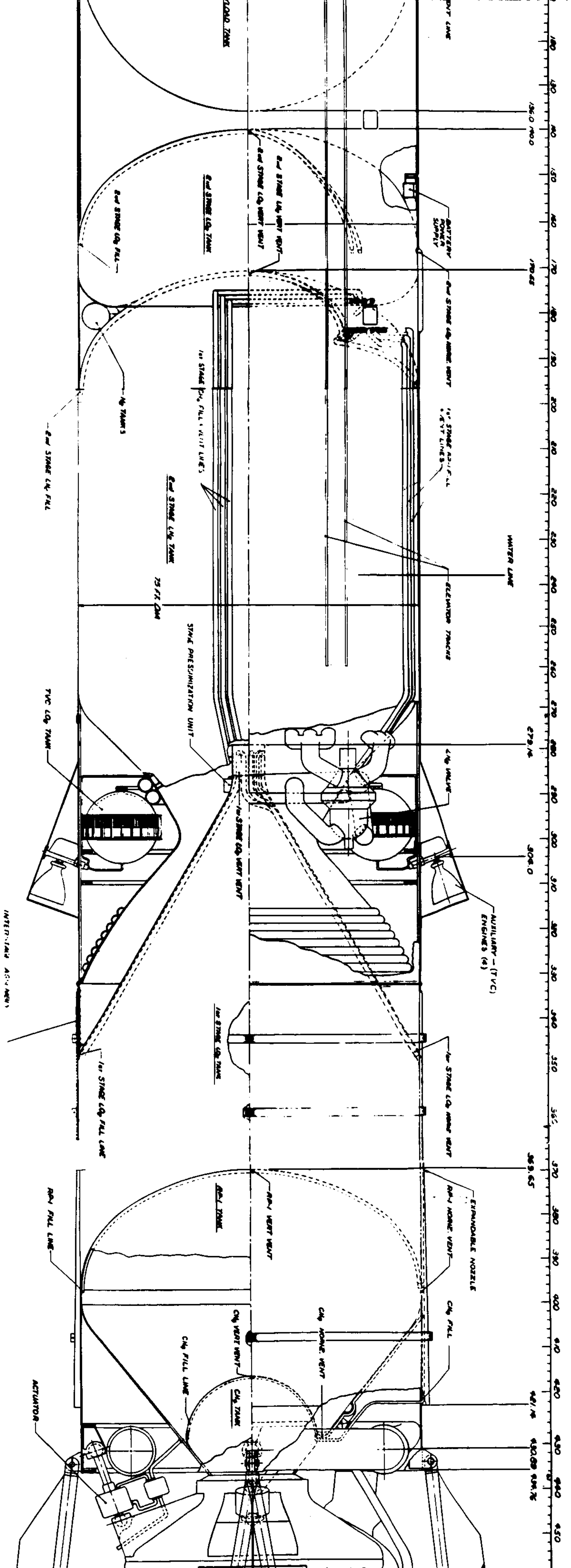
Sea Dragon Vehicle--External View

Figure II-A-1



Sea Dragon Vehicle--Internal View

Figure II-A-2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2nd STAGE LH2 FILL
2nd STAGE LH2 TANK
75 FT. DIA
1st STAGE RP-1 FILL & VENT LINES
WATER LINE
ELEVATOR TRACKS
STAGE PRESSURIZATION UNIT
TVC LO2 TANK
279.15
LH2 VALVE
1st STAGE LO2 VENT VENT
308.0
AUXILIARY – (TVC) ENGINES (4)
INTERSTAGE ASSEMBLY
1st STAGE LO2 TANK
1st STAGE LO2 FILL LINE
1st STAGE LO2 HOME VENT
369.65
RP-1 TANK
RP-1 FILL LINE
RP-1 VENT VENT
RP-1 HOME VENT
EXPANDABLE NOZZLE
CH4 FILL
CH4 HOME VENT
CH4 VENT VENT
CH4 FILL LINE
CH4 TANK
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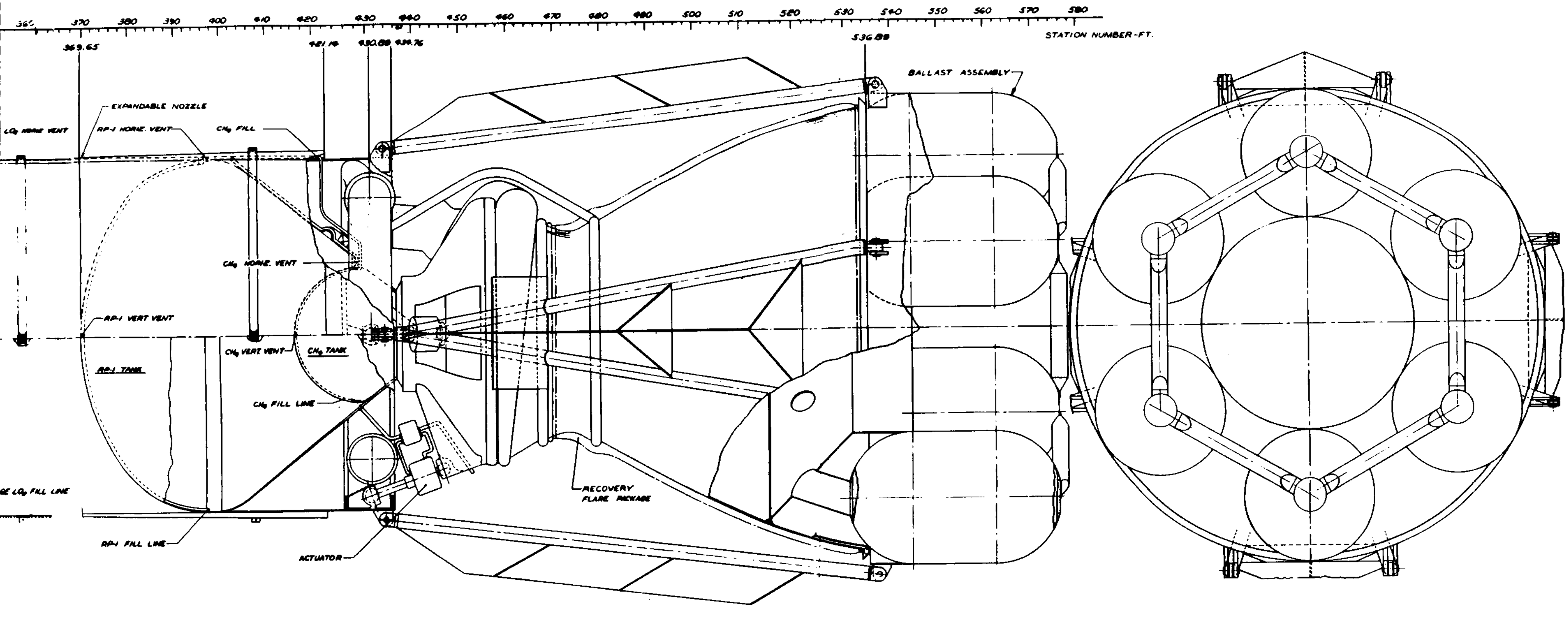
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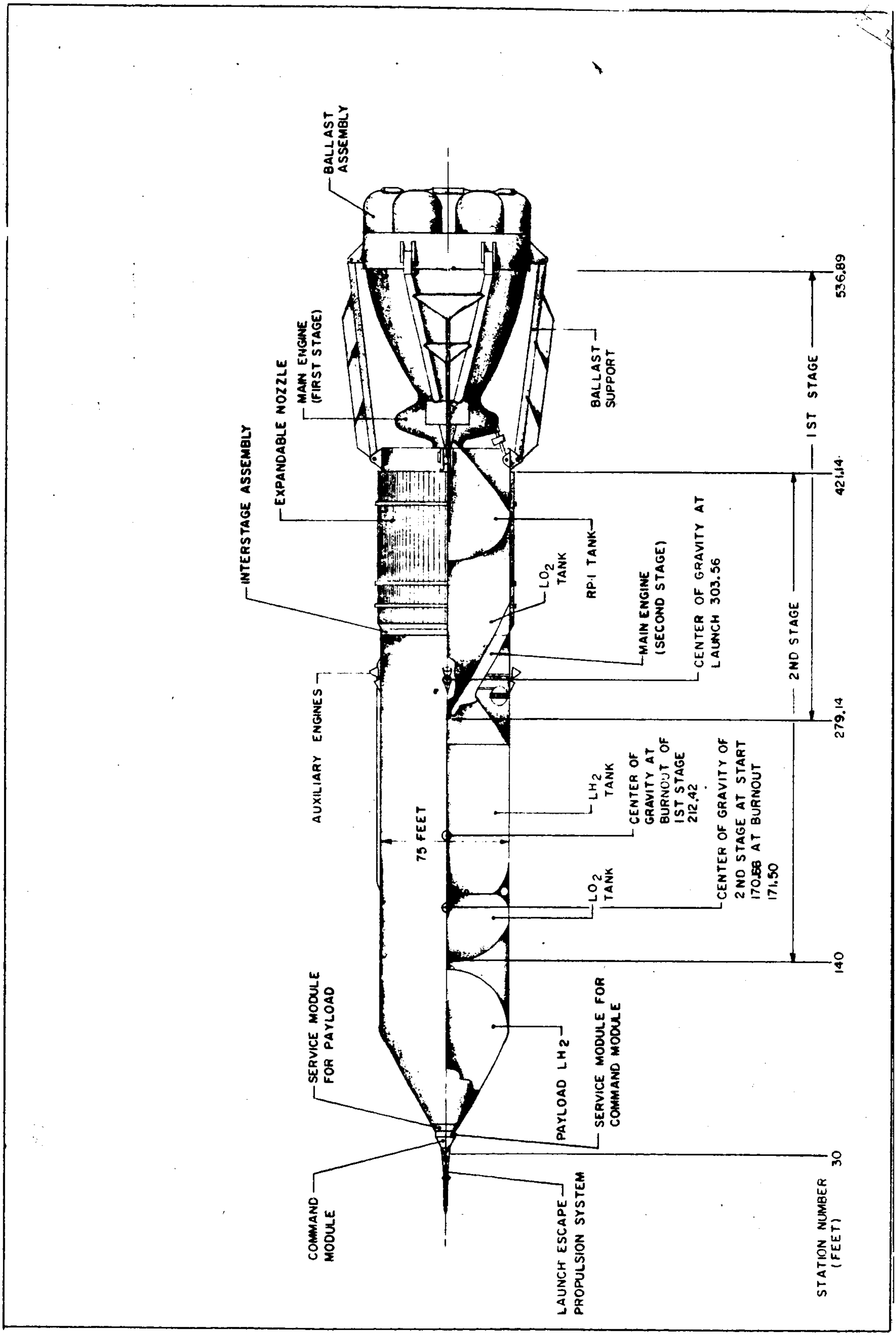
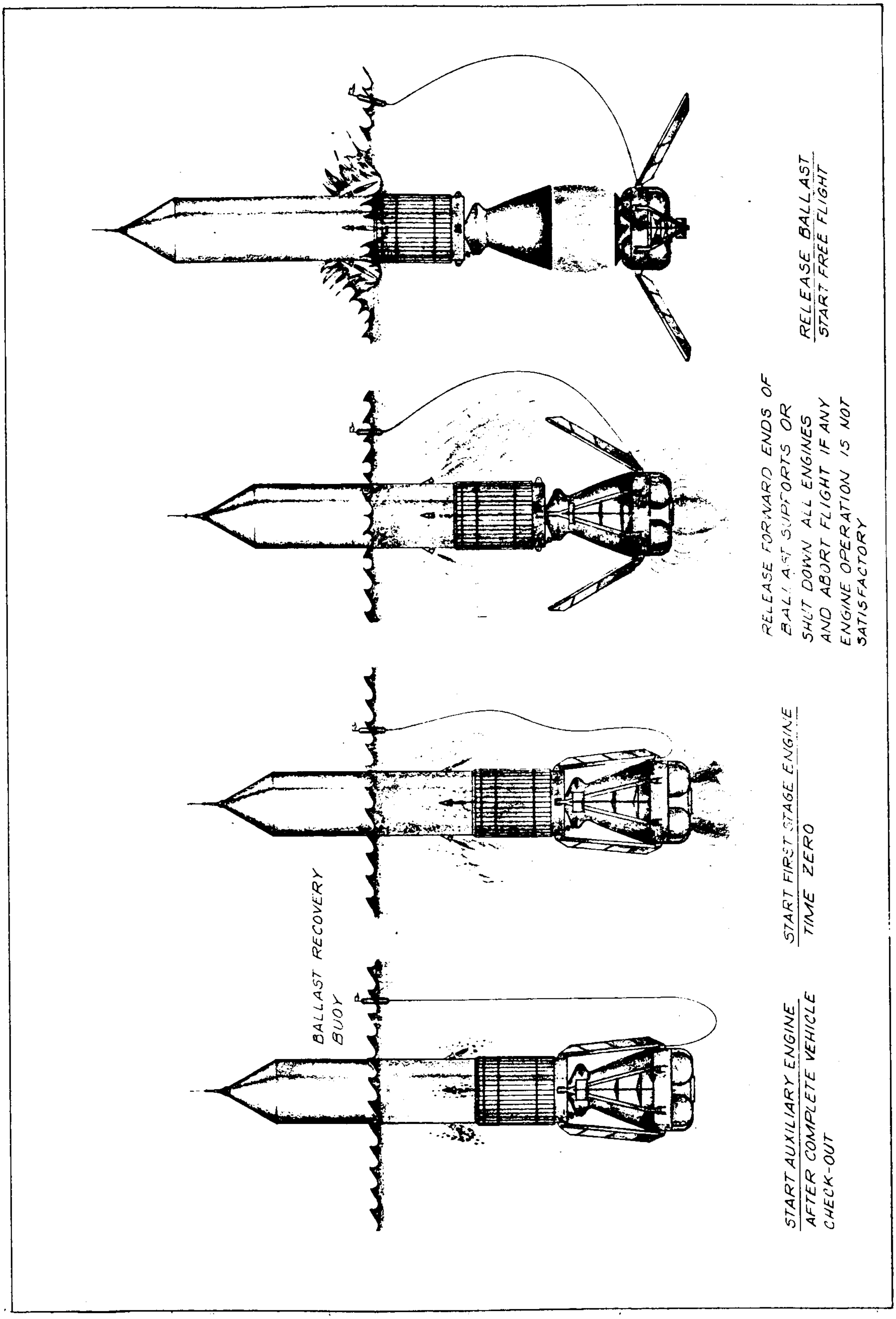
510
520
530
540
550
560
570
580
STATION NUMBER-FT.
369.65
421.14
430.88
434.76
536.88
EXPANDABLE NOZZLE
LO_2 HORIZ VENT
RP-1 HORIZ. VENT
CH_4 FILL
CH_4 HORIZ. VENT
RP-1 VERT VENT
CH_4 VERT VENT
CH_4 TANK
RP-1 TANK
CH_4 FILL LINE
E LO_2 FILL LINE
RP-1 FILL LINE
ACTUATOR
RECOVERY
FLARE PACKAGE
BALLAST ASSEMBLY



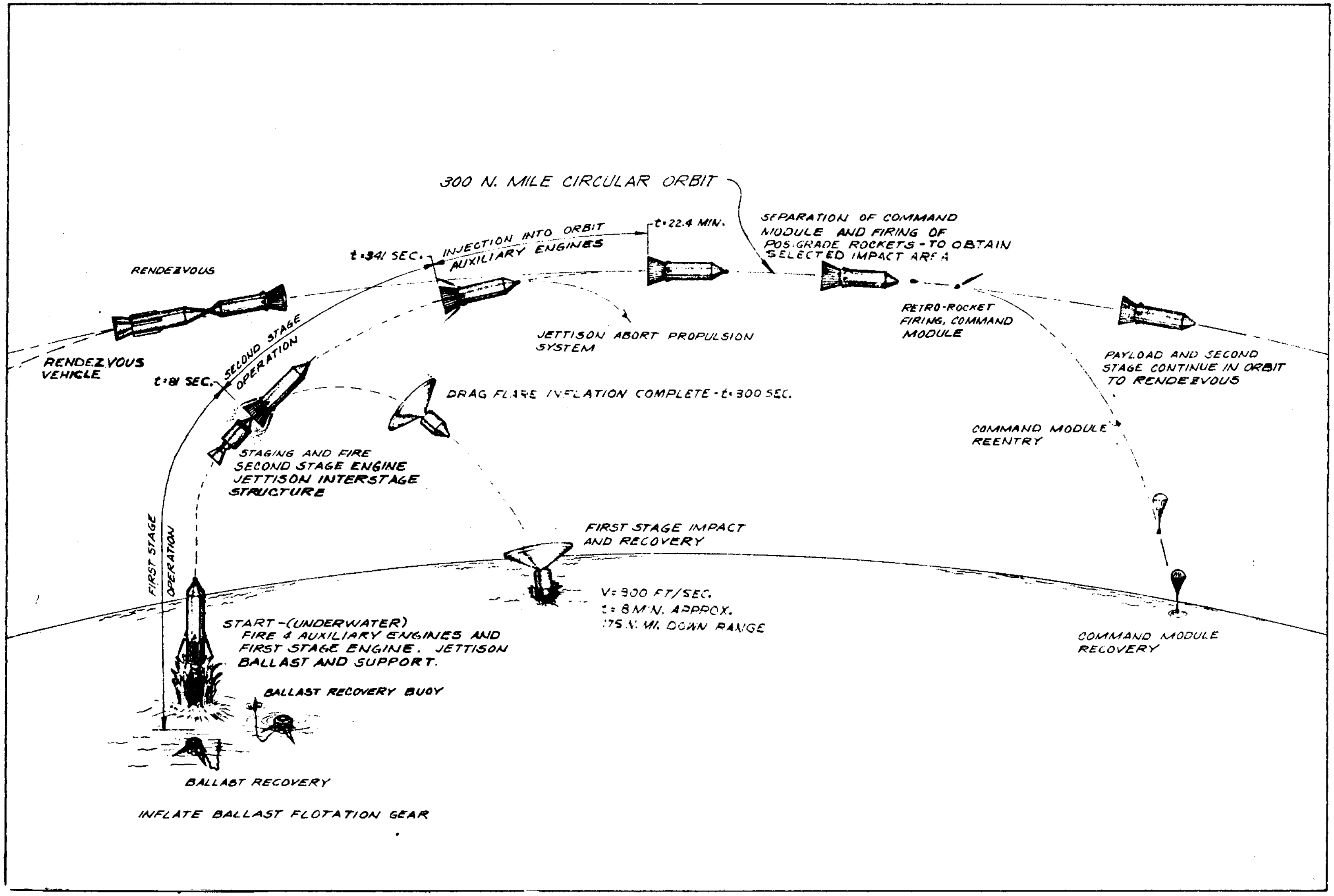
Vehicle Schematic

Figure II-A-3



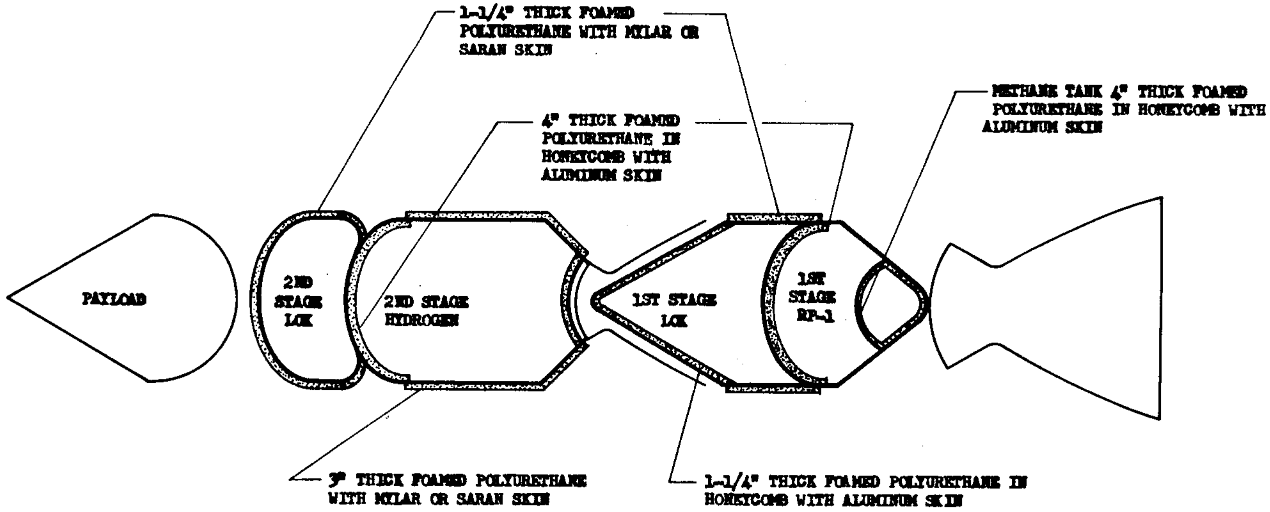
Sea Dragon Launch Sequence

Figure II-A-4



Sea Dragon Flight Sequence, Recoverable First Stage

Figure II-A-5



Vehicle Insulation

Figure II-A-6

II, Vehicle Description (cont.)

B. OPERATIONAL SEQUENCE

The operational sequence of the vehicle is considered to start after the vehicle has been assembled and checked out and is ready for fueling. After propellant servicing, the vehicle is towed to the launch site and erected. Operational readiness is verified and the launch sequence is started. The main events in the launch sequence are illustrated in Figure II-A-4 and the flight sequence in Figure II-A-5.

A list of the major vehicle operations is presented in Table II-B-1. More detailed plans and descriptions of the equipment for the entire Sea Dragon operation are presented in the Operational Procedures, Section III A of this volume. Detailed operational sequences or discussions of the operation of the major subsystems are included in corresponding portions of this report (i.e., Sections III A and B).

The recovery of the Apollo-type command module will be similar to that used in current earth orbital programs and is also illustrated in Figure II-A-5.

II, B, Operational Sequence (cont.)

The ballast unit will be recovered by inflating flotation bags on the unit after launch of the vehicle. Prior to launch, the unit will be attached to a buoy by means of a line, and an air hose to the flotation bag on the ballast unit is supported by the same line. After launch, the air hose will be connected to a service vessel for the ballast recovery operations. Retrieval of both the ballast and the first stage, after return from flight, is discussed in the section on the Operational Procedures.

TABLE II-B-1

SEQUENCE OF OPERATIONS

Item	Operation	Description
1.	Transportation	After satisfactory completion of vehicle checkout at the assembly point, it will be moved to the fuel service area.
2.	Childown and fuel servicing	At the fuel service area, all cryogenic tanks will be chilled down to their operating temperatures. The CH_4, LH_2, and RP-1 will be loaded onto the vehicle. The ballast unit, vehicle flotation, and compartment pressures will be adjusted as necessary.
3.	Transportation	The fueled vehicle will be towed to Point Bravo.
4.	Cxidizer servicing	The vehicle will be restrained close to the oxidizer servicing barge and oxidizer transferred.
5.	Transportation	The fully serviced vehicle will be transported to the vicinity of the launch site and adjusted for current effects.

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TABLE II-B-1 (cont.)

Item	Operation	Description
6.	Erection *	If all systems are in satisfactory condition upon arrival, the ballast unit will be flooded and the vehicle erected. In a normal operational sequence with no major holds, no horizontal propellant topping will normally be required.
7.	Final checkout	The final system checkout and pre-flight calibrations will be performed, the crew loaded, and the service vessels withdrawn.
8.	Start auxiliary engines	The four auxiliary engines are ignited.
9.	Startup of first-stage engine	The first-stage engine will be ignited.
10.	Drop ballast	The ballast will be released early in the underwater trajectory.
11.	Shutdown of first-stage engines	The first-stage engine will be shut down on decay of chamber pressure.

---

* Tank topping off will not be required unless long holds extend the time from LH_2 loading to launch to in excess of three days.

TABLE II-B-1 (cont.)

Item	Operation	Description
12.	Staging first and second stage	The first stage will be separated from the second stage by actuating the linear-shaped charge at the forward end of the interstage structure.
12a.	Recovery of first stage	The first stage will coast to apogee while the recovery flare is being inflated. It will return to the atmosphere, stabilize, and be recovered by direct impact into the ocean.
13.	Start of second-stage engine	The main engine of the second stage will be ignited, which will expand the expandable nozzle.
14.	Shutdown of second-stage engines	The second-stage engine will be shut down on command of the guidance system.
15.	Injection into orbit	The auxiliary engines will continue burning until injection into orbit.
16.	Shutdown of auxiliary engines	The auxiliary engines will be shut down upon command of the guidance system.
17.	Separation of the command module	A separation device will separate the command module and its service module from the vehicle.

C. SYSTEM PERFORMANCE

As presently conceived, the recoverable version of Sea Dragon will place into earth orbit a useful payload of 1,100,000 lb in addition to the spent second stage and attached command and service modules. An orbital altitude of 306 mm with a maximum eccentricity of .005 and an inclination of 28° will be achieved by launching along the Atlantic Missile Range (AMR) from a launch point 40 mi off Cape Canaveral. Orbit injection will occur 22.4 min after launch at a point 4,100 nm downrange.

After 81 sec of propulsion, the first-stage booster will separate at an altitude of 125,000 ft and a velocity of 5,800 ft/sec, having reached a peak acceleration of 4.2 g and after passing a peak q of 1600 lb/ft^2. The first-stage booster will coast to an altitude of 335,000 ft after staging; during this period, the conical flare will be inflated. Approximately 200 sec later, the flare will be fully inflated and atmospheric re-entry will begin, decelerating the first stage at a maximum of 6.5g to an impact velocity of 300 ft/sec at a location 170 nm downrange of the launch site. Water penetration of 45% of one body length occurs after impact and causes loading in the tankage, which is adequately balanced by the 100 psi minimum internal pressure. Because an inflatable flare and special structural reinforcement are not required for an expendable configuration, a higher stage propellant mass fraction is achievable and additional payload can be delivered to orbit. The payload capability of Sea Dragon with an expendable first stage will be 1,121,000 lb or an increase of 30,000 lb for equivalent launch and orbit conditions.

The second-stage booster propels the vehicle with its main engine for 260 sec, assisted by the low thrust auxiliary TVC engines that continue burning to orbit injection 1,344 sec after launch.

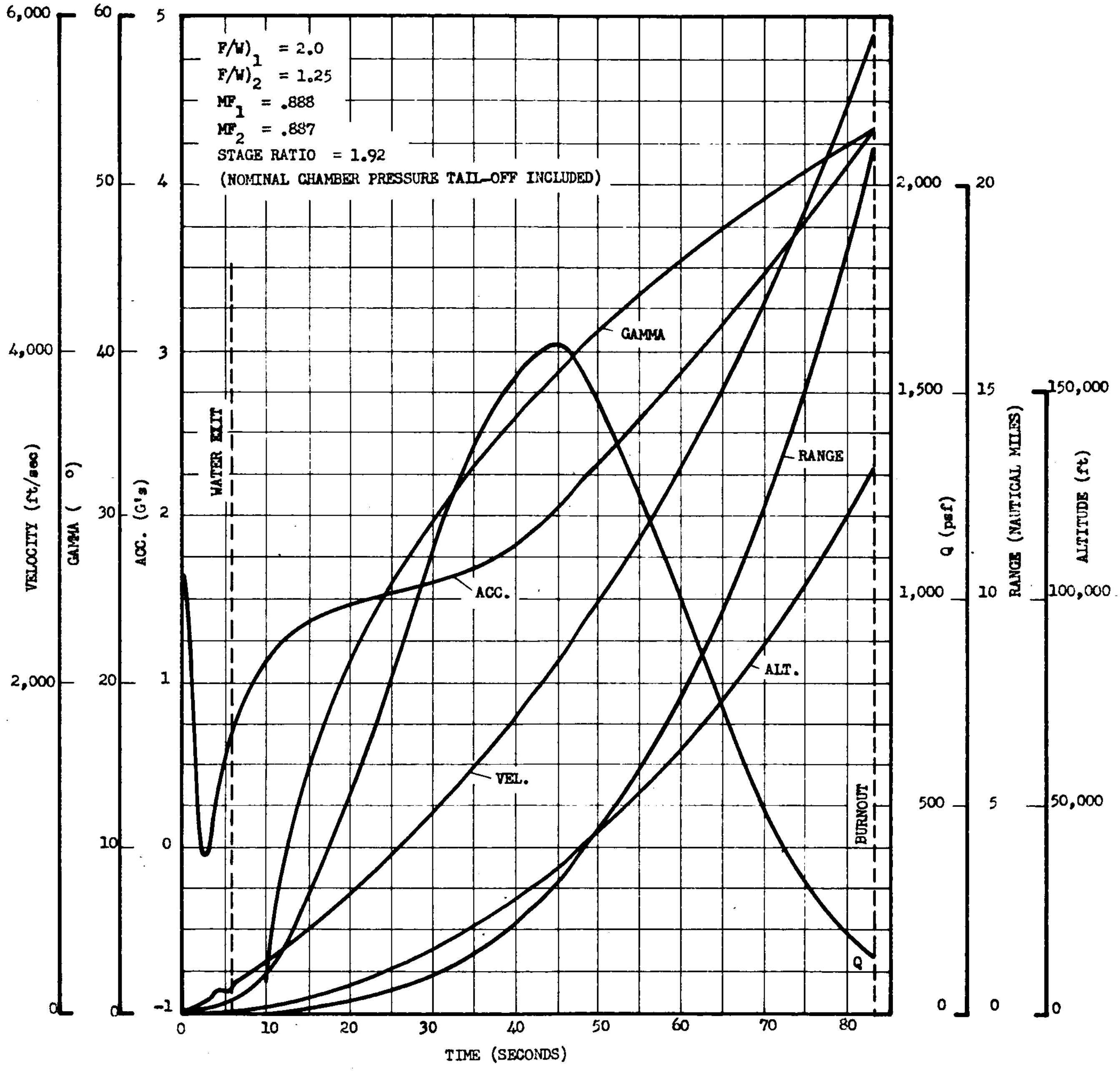
II, C, System Performance (cont.)

Table II-A-1 shows the nominal performance characteristics of the system. The trajectory characteristics are shown in Figures II-C-1 and II-C-2. Also in Section II, F, I are presented discussions of the performance analyses that have been conducted to evaluate the vehicle propulsion, loads, and dynamics in its modes of operation. It is shown therein that the main propulsion system has been optimized for a staging ratio of 1.92:1, a first-stage area ratio of 5.0:1, and a thrust-to-weight ratio of 2:1. Limited analyses have shown that the underwater launch causes a payload penalty of about 3.2% when compared to surface launch; however, an optimum launch mode has not been determined. The combined effects of sea state, wind, and thrust perturbations have been found to cause launch dispersion effects within the corrective capability of the first-stage control system. Subsequent flight maneuvers and wind influences, with longitudinal acceleration, give rise to a structural loading that exceeds those developed in the most severe water environment prior to flight. Whereas the fist-stage

II, C, System Performance (cont.)

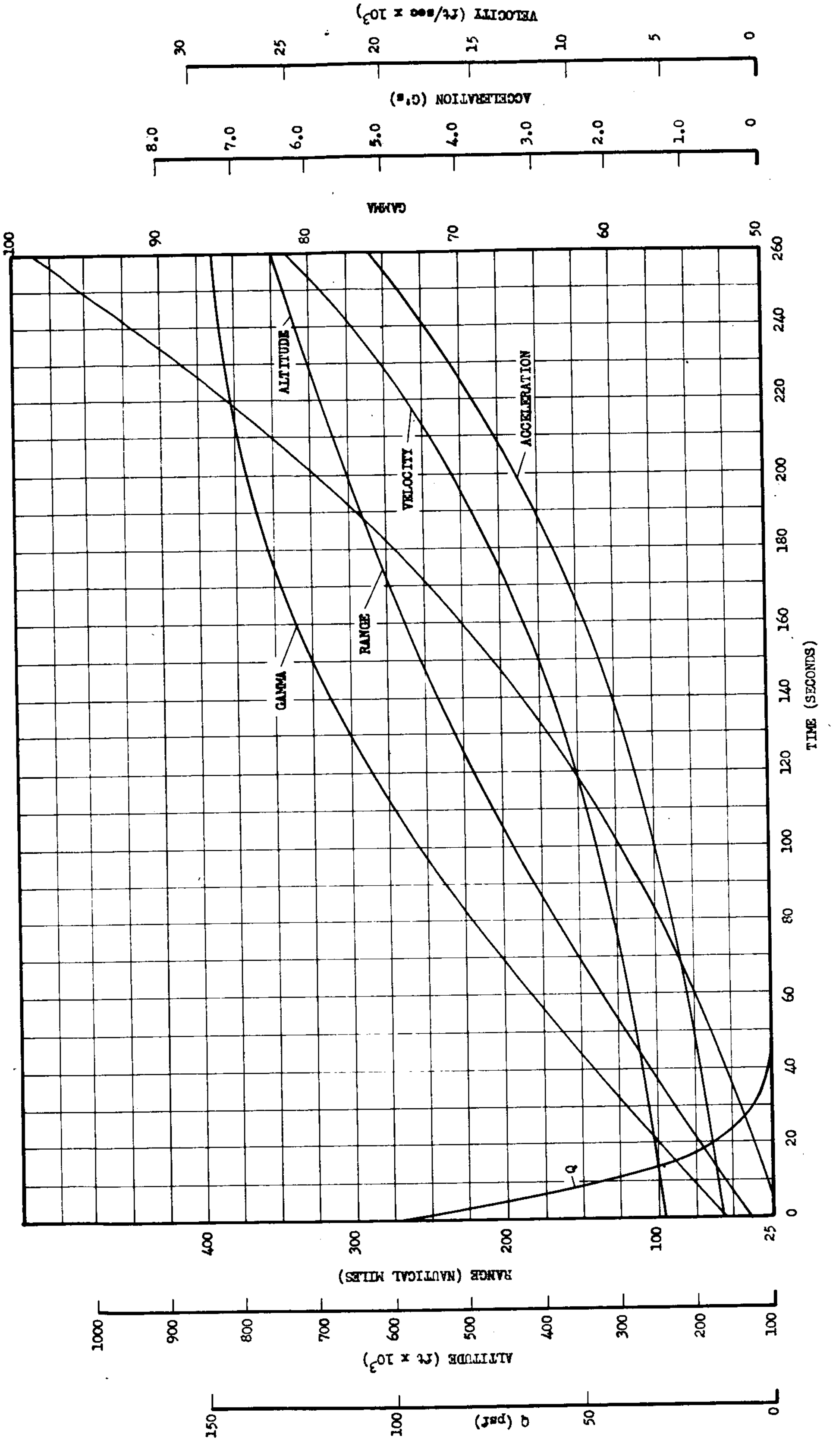
control system capability is found to be adequate, the auxiliary engines for the second stage, as presently sized, appear to be marginal. Improvement to an adequate level of TVC capability represents no basic problem.

The effect on payload capability of improvements in stage mass fractions by utilization of higher performance materials or more efficient design approaches is shown in Figure II-C-3 and II-D-5.



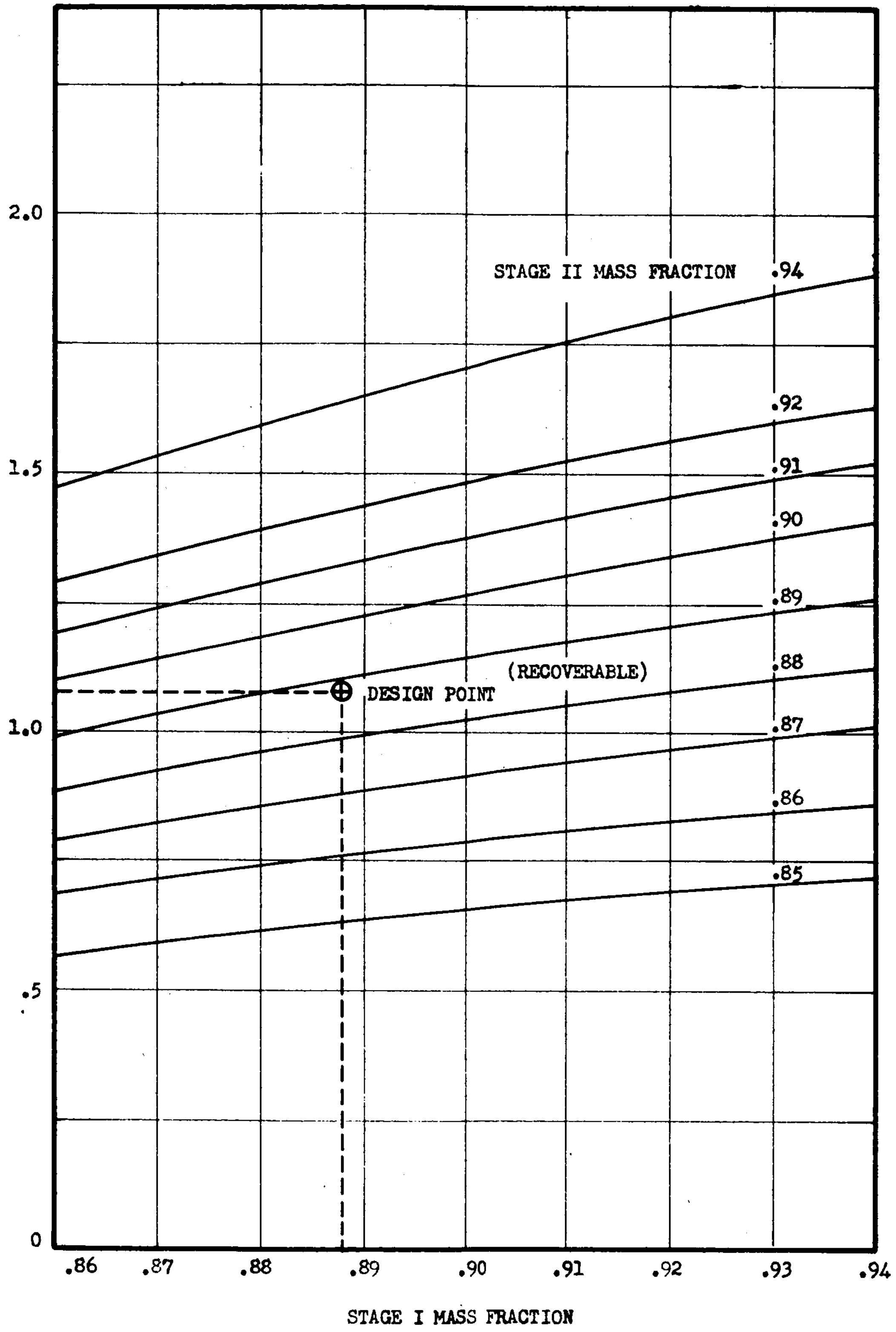
Stage I Trajectory Parameters

Figure II-C-1



Stage II Trajectory Parameters

Figure II-C-2



Payload versus Stage Mass Fraction

Figure II-C-3

II, Vehicle Description (cont.)

D. VEHICLE SUBSYSTEMS

1. Propulsion

a. Introduction

The propulsion systems for Stage I and Stage II on the Sea Dragon vehicle, Configuration No. 135, consist of all subsystems and components necessary for the propulsive operation of each stage as assembled with vehicle elements. The subsystems of the propulsion systems are defined as follows:

(1) Thrust Chamber Assembly

The thrust chamber assembly consists of the injector, chamber and expansion section, main propellant control valves, and connecting lines to the chamber gimbal mount, chamber attachment, and thrust structure. The general arrangement of these subsystems is shown in Figures II-D-1 and II-D-2.

II, D, Vehicle Subsystems (cont.)

(2) Tankage and Structure

The tankage and structure subsystem includes main propellant tankage, skirt sections, and mechanical joints that enable assembly of the propulsion stages to vehicle elements and to handling or servicing equipment.

(3) Propellant Pressurization and Feed

The propellant pressurization and feed subsystem consists of lines, pressurization tanks, valves, controls necessary for the pressurization of propellant tank ullage space, and delivery of propellant to the thrust chamber injector.

(4) TVC Subsystem

The thrust vector control subsystem, in the first-stage, consists of: gimbal, actuators, actuator controls, and associated structure. In the second-stage it consists of auxiliary thrust chamber assemblies, chamber gimbals, chamber actuators and controls, fuel feed lines, oxidizer supply including tankage, feed lines, pressurization system, and associated structure.

(5) Propellant Servicing

The propellant servicing subsystem includes all lines, connectors, and valves necessary for the filling, venting, and dumping of all pressurized and fluid filled compartments from external sources.

b. Design Philosophy

The propulsion system design approach fulfills the objective of simplicity by using a pressure-fed system with a minimum of moving components, by using single engines for each stage, and by using established designs such as the DeLaval nozzle and tubular wall construction. Use of sea handling for development and launching operations of the vehicle allows utilization of very large vehicles that are capable of lifting large unit payloads with attractive system economy.

For reliability, the advantages of the vehicle size have been exploited. Functional requirements on each component have been held to a minimum. The simple designs should involve low development and fabrication cost, and be rugged and reliable. Functional checkout is enhanced and adequate durability for sea handling and Stage I recovery is predicted. Examples of the execution of this design approach are the following:

The Stage II main LO_2 propellant feed system must provide start, shutdown, and throttling functions. While it is possible to perform these functions with a somewhat complex single valve, two simpler valves in tandem are used in this design. The start shutdown functions are provided by one large mechanically-controlled propellant line pressure-operated poppet valve. The throttling function is provided by a second valve located downstream of the shutoff valve.

Materials selected for the tankage and structure result in conservative stage mass fractions. All tankage is designed to withstand uniform pressure at proof testing of the highest pressure experienced by any single region of the tank. Thus advantage has not been taken of the pressure distributions that result from the hydrodynamic heads, which would permit reducing tank wall thicknesses in the forward tank portions.

Wherever possible, components that may require repair or replacement are located above the water line when the vehicle is in the launch attitude. In the horizontal position, all components can be placed above water by rotation of the vehicle.

II, D, Vehicle Subsystems (cont.)

Fill and vent piping system provide control of the contents and pressure levels of all Stage I and Stage II compartments by external services through umbilical lines connected above the water line for all sea handling modes. Functional checkout of line components is possible by similar means.

Propellant feed is provided by simple gas pressurization rather than by the more sophisticated (and complicated) turbopump units. The gas pressurization system utilizes a combination of vaporized propellants or fluids and hydrostatic pressure of the propellants themselves. Pressure-fed systems result in rugged tanks that can be used to advantage for first-stage recovery as well as for transportation and handling. This pressure-fed approach applied to the second stage also supplies simplicity in start and flight operation. Loss in second-stage mass fraction because of the pressure-fed system is compensated for by the improved engine performance resulting from the use of an expandable nozzle that permits the use of low tank and chamber pressure levels while still retaining a high nozzle gas expansion ratio and specific impulse.

II, D, Vehicle Subsystems (cont.)

In the first stage, a single large thrust chamber is used instead of the cluster of chambers suggested in most large vehicle designs. The simplicity of a single chamber and its vehicle installation provide reliability, economy, and rugged features for recovery and reuse. Large engine development testing and launching operations at sea, well removed from noise and explosion hazard problems, is another advantage of the sea operation concept.

c. Propellant Selection

The propellants selected for the first-stage engine were LO_2/RP-1 at a mixture ratio of 2.3:1. The primary basis for its selection is a low cost per pound with a reasonable performance and its high state-of-the-art status.

The propellants selected for second-stage engine was LO_2/LH_2 at a mixture ratio of 5:1. The primary basis for its selection is its high performance at a reasonable cost per pound.

II, D, Vehicle Subsystems (cont.)

The state of the art is advancing rapidly because of the current widespread interest in this combination. For both stages, the specific impulses used for vehicle performance predictions are conservative.

d. Stage I Propulsion System

(1) Description

The Stage I rocket propulsion system is a liquid bipropellant, pressure-fed stage. The general arrangement of the stage is shown in Figure II-D-1. Basic system characteristics are given in the following table:

Diameter	75 ft
Length	262 ft
Weight, total	28×10^6 lb (approx)
Usable propellants	25×10^6 lb (approx)
Propulsion system mass fraction	0.892

II, D, Vehicle Subsystems (cont.)

Propellants	LO_2/RP-1
Mixture ratio	2.3:1
Thrust chamber type	DeLaval regeneratively-cooled
Throat diameter	41.6 ft
Throat area	1360 ft^2
Expansion area ratio	5:1
Thrust nominal	80 x 10^6 lb
I_s, sea level (actual)	242 sec
Chamber pressure nominal	300 psia
Thrust vector control	Gimbal plus roll control by Stage II aux engines
Propellant tank ullage pressures, nominal LO_2	226 psia
RP-1	425 psia

Propellants are fed from integral tankage by a combination of ullage pressurization and dynamic heads. The tankage is shaped conventionally with exception of the forward closure on the forward LO_2 tank. This closure is a 60° cone as is required to enable water entry and recovery of the stage. LO_2 is fed to the thrust chamber through a multiple line that is routed outside of the aft RP-1 tank. During expulsion of the LO_2, the difference between required injector inlet and dynamic heads is provided by ullage pressure that is developed by heating a portion of the LO_2 flow and ducting it to the ullage space. This autogenous system is controlled by throttling the flow from the high pressure, LO_2 injector inlet manifold down stream of the main LO_2 valve to the heat exchanger, which is located on the thrust chamber assembly. Figure II-D-3 is a schematic of the pressurization systems.

The RP-1 fuel tank is located aft of and integral with the LO_2 tank; an insulated bulkhead separates the tank compartments. The RP-1 tank pressure is developed by methane (CH_4) that is stored in a separate tank at equilibrium with its vapor pressure at 500 psia. The vapor pressure is used as the driving force to inject methane vapor into the bottom of the RP-1 tank where it is heated as it bubbles through to the ullage space. This

II, D, Vehicle Subsystems (cont.)

secondary VaPak system maintains RP-1 feed line inlet pressure at equilibrium with the methane tank pressure. Ullage pressure is maintained at a level equal to the difference between methane tank pressure and the dynamic head. No regulating controls are therefore required.

The ignition system is hypergolic and uses the chamber injection of triethylaluminum. The TEA is pressurized by a blowdown gas system.

Main propellant valves are poppet types that are sealed in the closed position with a clamped diaphragm, which is sheared by the poppet movement. Valve actuation forces are provided by the propellant feed line pressures and valve position is controlled with mechanical detents.

The gimbal is a rubber pad device that allows chamber motion by shear deflection. This was selected for study because it has promise of simplicity without problems of lubrication

II, D, Vehicle Subsystems (cont.)

and bearing tolerances. This approach was considered as "frozen" for the study vehicle. However, a brief investigation of TVC by secondary injection was also made with promising results. A secondary injection installation is shown in Figure II-D-4. The gimbal actuators are low pressure hydraulic cylinders that utilize fuel at tank pressure as energy source.

Propellant tanks are designed by the propellant feed requirements. The aft skirt consists of stiffened skin and frames that counteract the gimbal actuator and ballast support loads. For purposes of the study, the tank materials were assumed to be 2014-T6 aluminum for conservatism and all weights are for this material. Figure II-D-5 illustrates changes in system mass fractions for various materials.

Fill, vent, and dump lines are provided that enable loading and off loading propellants and pressure charges from all Stage I compartments. Lines from Stage I are connected by means of internal umbilical to Stage II. From the internal umbilical on

II, D, Vehicle Subsystems (cont.)

Stage II, the lines are routed to the external umbilical at Station 180. Control of the contents and pressure levels of all Stage I compartments by ground equipment is possible through lines connected at the external umbilical; component functional checkout is possible by the same means.

e. Stage II Propulsion System

(1) Description

The Stage II rocket propulsion system is a bipropellant pressure-fed stage. The general arrangement is shown in Figure II-D-2. Basic Stage II propulsion system characteristics are given in the following tabulation:

Diameter	75 ft
Length to separation joint	188 ft
Overall length	275 ft
Weight, total	10.6×10^6 lb (approx)

II, D, Vehicle Subsystems (cont.)

Usable propellants	9.5×10^6 lb (approx)
Propulsion system mass fraction	0.8905
Propellants	LO_2/LH_2
Mixture ratio	5
Thrust Chamber Type	DeLaval-fixed
Throat diameter	30.6 ft
Throat area	736 ft^2
Expansion area ratio	20
Thrust nominal	14×10^6 lb
I_s vac (actual)	409 sec
Chamber pressure, nominal	75 psia
Thrust vector plus roll control	4 aux engines at 53,200 lb each
Propellant tank pressures, nominal	
LO_2	30 psia
LH_2	100 psia

II, D, Vehicle Subsystems (cont.)

The second-stage thrust chamber and a portion of the expansion section of the nozzle are cooled, using conventional tubular wall construction, with hydrogen from the main tank. The hydrogen flow is non-regenerative with the heated hydrogen gas being expelled at the open ended tubes into the main gas stream at an area ratio of 6.2:1. The remainder of the nozzle is constructed of thin stainless steel and is cooled by radiation alone. This cooling technique is possible because of the low chamber pressure and the resulting lowered heat flux. The thin sheet metal nozzle is folded about the first-stage tankage during first-stage operation and is expanded to a full conical shape when the second-stage engine fires. An example of a nozzle of this type is shown in Figure II-D-6.

Propellants are pressure fed from integral tankage. Injector inlet pressure is developed by a combination of ullage pressurization and dynamic head. The forward LO_2 tank is pressurized by the LO_2, which is loaded at a temperature equilibrium

II, D, Vehicle Subsystems (cont.)

with its vapor pressure at 25 psia. The required injector inlet pressure of 100 psia results from the additive dynamic head. The aft located LH_2 tank is separated from the LO_2 tank by an insulated bulkhead. Pressurization of the LH_2 tank is autogenous; liquid hydrogen is admitted to a heat exchanger on the cooled section of the thrust chamber where it is vaporized. Vapor is ducted to the propellant tank ullage in a low pressure drop line. Figure II-D-7 is a schematic of the Stage II pressurization systems.

Auxiliary thrust vector control engines use propellant from the main LH_2 tank; LO_2 is provided from separate spherical tanks which are pressurized from a regulated high pressure gas source as shown in the schematic of Figure II-D-8.

Main stage and auxiliary engines are ignited by flow down chamber injection of gas pressurized triethylaluminum.

II, D, Vehicle Subsystems (cont.)

The main propellant valves are poppet types normally sealed in the closed position with clamped diaphragms that fail with the initial poppet motion. The poppets are actuated by propellant-fed line pressure and their travel is controlled with mechanical detents.

Propellant tank structure is designed by the propellant feed pressure requirements and are stabilized by pressure for all handling and flight loads. Skirt structure, other than propellant tanks, consist of stiffened skins. As for the Stage I tanks, the material assumed for study purposes was 2014-T6 aluminum.

Fill, vent, and dump lines are provided for loading and unloading of propellants and pressure charges from all Stage II compartments. Lines from Stage II compartments are routed to an external umbilical at Station 180. Control of all the contents and pressure levels of all Stage II compartments is possible by ground equipment by external lines connected at this point; component functional checkout is possible by the same means.

II, D, Vehicle Subsystems (cont.)

2. Interstage Structure Assemblies

a. General

The interstage structure assemblies of the vehicle are the interconnecting structures that transmit the loads between the major sections of the vehicle. These structures are:

(1) The cylindrical structure supporting the command module and enclosing the service module

(2) The conical structure at the forward end of the payload which encloses the payload service module

(3) The cylindrical structure between the payload and second-stage

(4) The interstage and separation structure between the first and second stages.

II, D, Vehicle Subsystem (cont.)

(5) The transition structure which connects the second stage aft tank with the nozzle skirt and which carries the structural loads from the above Stage I and II interstage structure.

The interstage structure (Item 4) incorporates provisions for the separation or staging operation between Stage I and II as shown in Figures II-D-9 and II-D-10.

Except in the case discussed above, the interstage structures do not contain staging provisions since the entire vehicle forward of the first stage remains connected through orbit attainment. However, there are separation devices for the command module for abort and re-entry operations. All interstage structures are designed to provide access as required for assembly and maintenance operations. When these structures are pressurized, and emergency access is required, air-lock provisions will be used for manned entry.

II, D, Vehicle Subsystems (cont.)

b. Interstage Assembly, Stage I to II

A sketch of a typical assembly is shown in Figure II-D-9. Its basic function is to connect the two stages and provide for the staging function. In addition, the expandable nozzle is attached to the forward end of this structure at the transition-interstage connection. The basic structure is a high strength steel cylinder bolted to the stages at each end. It will be pressurized to 50 psig for two reasons: (a) to prevent collapse caused by the sea hydrostatic pressure while in the erect launch position, and (b) to provide a positive separation force during staging. A linear shaped charge assembly is located slightly aft of the second-stage joint to effect separation of the structure. Additional shaped charge assemblies will be used to jettison the remaining structure after complete separation to leave a nose configuration suitable for recovery. The sequence of staging operations is shown on Figure II-D-10.

II, D, Vehicle Subsystems (cont.)

c. Transition Structure

The transition structure will be primarily constructed of aluminum reinforced with stiffeners designed also to take longitudinal loadings. At the aft end, however, there will be a material change to steel to provide for second stage operating conditions where the metal temperatures in the vicinity of the nozzle skirt will be high. The entire outside surface will be coated to resist sea water corrosion.

This section is designed by flight conditions as an unpressurized structure. It will, however, be made pressure tight for reasons associated with water handling. An internal pressure of 40 to 45 psig will be used to counteract external hydrostatic pressures when the vehicle is in an erect position. No pressure is required for structural reasons but will be present during the fully loaded erection maneuver. Just before the vehicle is launched, the compartment pressure will be allowed to start bleeding down to a low pressure. This low pressure will be attained before the flight Stage I and II staging operation. This prevents crushing of the second stage chamber when its internal pressure decreases rapidly during staging.

3. Payload

The basic payload is assumed to be a tank containing more than one million pounds of liquid hydrogen with a service module attached to provide those functions that must be performed by the payload after orbit has been achieved and the command module has separated to return to earth. Because the second stage and command module are attached to this payload, the entire payload that is placed in circular orbit includes the entire vehicle forward of the second stage as shown in the flight sequence illustration, Figure II-A-5.

The payload could be varied for other missions to provide additional propulsion stages or variations in configuration density and function.

The command module is a manned Apollo type space craft module that will provide the basic guidance, control, and communications functions during flight. The module will return to earth using its service module to provide separation and recovery functions. An abort propulsion system is also provided. If the only function of the command module is to ensure attainment of orbit by the LH_2 payload, a considerably smaller and simpler module similiar to Mercury or Gemini could be utilized.

The payload fuel tank will be constructed of alumimum, and provisions are made for fueling and venting in the same manner as the liquid hydrogen tank in the second stage. The tank will be insulated as necessary to limit heat transfer during transportation, flight, and the orbital environment.

After orbit has been attained and the command module has separated and returned to earth, the remaining payload will continue to orbit until rendezvous with a spacecraft. The service module of the payload will provide communications and attitude control functions to assist in location, identification, and docking. Fuel transfer functions will also be provided.

II, D, Vehicle Subsystems (cont.)

4. Control System

In the present design, all of Sea Dragon attitude control is achieved by jet forces; neither moveable nor fixed fins are employed. Directional control moments for the vehicle during first-stage operation are developed by rotation of the entire first-stage engine, which is gimbaled. Movement of the system is obtained by means of piston-type actuators and an open-loop hydraulic system fed by the main fuel tank at 400 psi. An estimated 40,000 lb of RP-1 is dumped after use by the control system. Second-stage directional control is accomplished by four auxiliary LOX-hydrogen engines, each pivoted about a single inclined axis and electrically actuated to provide a maximum side thrust component of ± 53,200 lb or an equivalent deflection of the main engine thrust equal to 0.43°. These engines provide roll control throughout all stages of flight in addition to directional control after completion of first-stage operation.

II, D, Vehicle Subsystems (cont.)

Analyses of the control system have consisted of evaluating performance capabilities of the preliminary design, which was on the basis of estimates, while also defining a more complete set of requirements for the final design. In this process, consideration was given to the effects of imperfections in the vehicle itself and of perturbations caused by its environment and program. Wind and sea conditions, thrust and aerodynamic misalignments, maneuver programs, propellant sloshing, and body bending were analyzed. Excepting the two latter effects, it was found that the original estimated ± 3° rotation of the first-stage main engine provides more than adequate control capability. Propellant sloshing and body bending influence mainly the control loop stability, which was not completely analyzed. Preliminary results indicated that sloshing will not be troublesome but that body bending coupling possibilities will require careful selection of loop gain, instrument location, and actuation system lag. For this evaluation, a simplified autopilot design was selected on the basis of a single plane rigid body analysis of first-stage attitude control.

II, D, Vehicle Subsystems (cont.)

The second-stage system requirement is determined primarily by the effects of thrust misalignment, although staging effects, propellant sloshing, wind and maneuver program conditions were also examined. It was found that the combined effects of thrust misalignment and wind forces require a directional trimming moment corresponding to .37° main thrust deflection. To obtain sufficient performance margin above the .43° present design capability, the auxiliary engine size will be increased; however, a more complete analysis of the system requirements will be made first. In particular, the effect and likelihood of control system saturation caused by propellant sloshing must be considered when specifying the required performance margin. The auxiliary engines provide the vehicle roll correction capability that is difficult to achieve with the single first-stage gimbaled engine. For both stages, alternate TVC concepts have been studied and will be reviewed in follow-on vehicle design phases.

II, D, Vehicle Subsystems (cont.)

5. Guidance System

a. System Performance and General Characteristics

The fully inertial guidance system proposed for the Sea Dragon launch and orbital injection vehicle has been specially adapted for vehicles launched at a sea site sufficiently close to shore Loran installations. The system is characterized by

(1) Capability for full self alignment at sea, both in azimuth and vertical directions, through gyrocompass and stable-vertical search modes, under the conditions of existing roll and pitch while afloat.

(2) Necessity for a prelaunch insertion of initial position and velocity conditions obtained from shore installations, monitored continuously and mechanized in the vehicle guidance system.

II, D, Vehicle Subsystems (cont.)

(3) A fully self-contained inertial performance during the flight mode of the vehicle from launch to injection into orbit.

The nominal trajectory injects into a 306 nm altitude circular orbit approximately 4,100 nm downrange from the launch site, 22.4 min after first-stage ignition. The injection tolerances caused by guidance system accuracies are:

(a) Orbit altitudes and velocity 300 ± 4.27 nm and 24,888 ± 15 ft/sec

(b) An eccentricity of established orbit of 0 + 0.005, with a probability of 0.99

(c) A difference between apogee and perigee altitudes of 37.5 nm, with another probability of 0.99, for an overall probability for not exceeding the mission orbital specifications of 0.98.

II, D, Vehicle Subsystems (cont.)

The error budget drawn up by the performance analysis has assigned the following component and parameter tolerances, which are on the basis of meeting the foregoing injection requirements.

Uncompensated gyro drift rate = 0.022°/hr

Initial platform misalignment = 1/3 min of arc

Accelerometer error = 10^{-4}g

Initial position determination error = 2,000 ft = 0.33 n

Initial velocity determination error = 3.16 knots

These values are within the state of the art, except for the initial alignment accuracy, in a self-aligning mode and at sea. Consequently, this mode of operation will require a rather heavy gyro-compass and stable-vertical erection system, more of a naval-ordnance type than of an avionics type.

II, D, Vehicle Subsystems (cont.)

Systems growth capability will include the addition of radio-command guidance, and possibly, stellar monitoring as a further improvement in system accuracy and reliability and for mission growth. Further, in the orbital mode, the addition of a horizontal scanner and other auxiliary equipment is anticipated as a necessity for adequate attitude control.

A significant factor influencing the study of guidance concepts is that there may be a human crew aboard. Accordingly, the system reliability must be man-rated, and provisions made for the crew to become an important link in the orbital mode of operation.

While an entirely automatic operation is envisioned, the crew must be able to provide certain overrides, insert radioed guidance information, and take action in possible mission abort situations.

II, D, Vehicle Subsystems (cont.)

b. Physical Characteristics

The guidance system selected for the Sea Dragon consists of two main assemblies, one containing the miniaturized guidance computer and associated electronics, and the other, a relatively heavy stable platform. This equipment will be located in the command modules of the vehicle.

The computer, which uses transistor components and solid wiring, weighs 100 lb, occupies 1.0 ft^3, consumes 100 w of electric power, and has a storage capacity of about 8,000 words. This may be compared to an existing prototype digital computer using printed circuitry weighing 35 lb, occupying 0.3 ft^3 and consuming 30 w of electric power. The actual choice will be determined primarily by reliability considerations. The entire computer and electronics package is thermally and shock-insulated, and its estimated physical characteristics are as follows: weight, 200 lb and volume 7 ft^3. The estimated power requirements are: 300 w at 26 v, 400 cps. The design of the package will allow operation in the space environment.

II, D, Vehicle Subsystems (cont.)

The accuracy requirements for self-alignment of the stable platform call for gyros with very high angular momentum, and therefore high moments of inertia. This requirement will lead to a considerably increased size and weight of stable platform by comparison with existing units for avionics applications. Anticipated physical characteristics for a stable platform unit located within the pressurized capsule are: weight, 400 lb, volume 6 ft^3, and 1 kw peak power demand. By comparison, a typical fully developed miniature platform for avionics applications weighs $33\frac{1}{2}$ lb, occupies 0.65 ft^3 of space, and consumes 230 w peak power.

In addition, a certain allowance for radio equipment and for a telesextant to be used by the astronauts may be included. A horizon scanner, probably mounted on a secondary stable platform slaved to the master unit, will be used in the orbital mode to establish the local vertical.

c. Special Features

The rather special conditions existing at the launch of the vehicle floating at sea in the vertical position impose the requirements of an accurate self-alignment of the stable platform in the required aximuth and vertical directions. Such an alignment cannot be performed in the conventional manner of using an optical alignment system located outside the vehicle. Instead, the highly accurate gyro-pendulum self-erecting system of the vehicle stable platform will operate during this mode as a self-contained North and vertical seeking element. A simplified block diagram of the self-alignment mode is shown in Figure II-D-11.

During the flight-navigation mode of the inertial guidance system after launch, which is diagrammed in Figure II-D-12, the use of the all-inertial system will obviate the necessity for a

II, D, Vehicle Subsystems (cont.)

network of ground stations along the ephemeris of the inertial 4100 nm downrange flight of the vehicle till its injection into orbit. Moreover, the guidance system of the type proposed here will provide complete freedom of selection of orbital planes of the vehicle and of the injection trajectory. In fact, it is expected to be sufficiently flexible to accommodate future growth or expansion to the required modes of operation, mission and maneuverability requirements, orbital navigation with full attitude control, and a re-entry with or without active participation of the crew.

The location of the stable platform, the associated electronics and digital computer packages, and the horizon scanner and radio transponders in the command module of the Sea Dragon vehicle will ensure complete recoverability of this expensive precision equipment because the command module will be designed with full capability for controlled re-entry.

An essential simplification of the overall system is expected to be achieved through a judicious application of the multi-function principle to various system elements, networks, and subsystems so that they could be switched sequentially into different modes of operation, as required. However, the demand for a very high level of reliability may, in general, require an emphasis on overdesign in some areas as well as a planned redundancy of the most critical subsystems and channels of operation.

For example, marked simplification of the guidance and control equipment is achieved by using the vehicle-borne equipment to perform in sequential modes of operation the various prelaunch checkout and alignment functions as well as the airborne guidance. Test and checkout equipment is simplified by using the airborne digital computer to check itself functionally and to monitor the performance of the guidance system during all modes of operation.

6. Recovery

A recovery system for the Sea Dragon first-stage vehicle has been selected on the basis of operational simplicity and reliability. In choosing the recovery method, advantage was taken of the increased strength of the pressurized booster in overcoming adverse scale effects that tend to make very large vehicles less adaptable to conventional recovery methods; consideration of this size scale effect showed, for vehicles that are aerodynamically decelerated to a given landing velocity, that the ratio of required "drag diameter" (size of accessory drag device) to vehicle diameter increases as vehicle size increases. Deceleration of the Sea Dragon vehicle to normal letdown velocities of 20-25 fps would require a drag device, for example, a parachute, of 3,000 ft dia.To overcome this problem,use was made of the inherent structural strength of the Sea Dragon (a result of using a pressure-fed propellant feed system).

II, D, Vehicle Subsystems (cont.)

The booster tanks in a pressurized condition (with ullage pressurant) can counteract landing loads most efficiently in an axial direction. Therefore, the final attitude of the vehicle at water impact, regardless of the method used to reach terminal velocity, was restricted to a nose down vertical position. Because final deceleration of the vehicle will be caused by water impact forces, analyses of the hydrodynamic pressures and decelerations were carried out so that limiting impact velocities could be established. Pressure distributions over the conical nose of the vehicle were quantitatively predicted and compared with experimental results. Deceleration-time histories were developed; for an impact velocity of 600 ft/sec a maximum deceleration of 90 g is encountered, and for 300 ft/sec the maximum is 22 g, (see Figure II-D-13) assuming a cone half angle (B) = 30°. Analysis of the structural response to impact loads at various velocities showed that for velocities less than 600 ft/sec no dynamic load amplification will occur. Using these facts, an allowable impact velocity-tank pressure criterion was established, relating water entry velocity to tank pressure required for acceptable axial load reactions, i.e., for a LO_2 tank pressure of 400 psi an impact velocity of 600 ft/sec can be accepted. For 100 psi (the first-stage LO_2 tank pressure achieved at burnout), the allowable impact velocity is slightly less than 300 ft/sec (Figure II-D-14).

The basic recovery sequence consists of two main phases: An atmospheric entry phase and a terminal or impact phase. At first-stage burnout, the propellant valves in the booster are closed and the pressurant gases are trapped in the tank (approx. 100 psi in the LO_2 tank and approx. 290 psi in the RP-1 tank). After staging occurs, the first stage coasts upward along its ballistic trajectory and then re-enters the atmosphere. During atmospheric flight, drag and stabilization forces are produced so that vertical impact at the proper terminal velocity is achieved.

Three different aerodynamic deceleration methods were considered: Parachutes, large first-stage nozzle skirt, and inflatable aerodynamic decelerator. Parachutes were excluded because of potential deployment and attachment problems. The large nozzle skirt concept, which made use of a very large area ratio first-stage engine, had the highest estimated reliability because of its passive operation as a decelerator. However, because of relatively high drag losses during ascent flight, possible nozzle vibration caused by the high degree of overexpansion and separation at low altitude, and adverse reaction to sea operation towing loads, this concept was discarded for the present time.

The inflatable flare decelerator was selected for the Sea Dragon because it provides a high degree of reliability and ease of operation with minimum ascent drag penalty. This device is attached, in deflated package form, to the first-stage thrust chamber. When inflated, it takes the form of a large conical flare 300 ft dia with a half angle of 55^{o}.

II, D, Vehicle Subsystems (cont.)

The flare is made up of a large, 30 ft dia torus rigidized with a smaller inflatable tube 10 ft dia and covered with a surface generating outer skin. The torus and supporting tubes are constructed of rubberized nylon-dacron reinforced fabric and are protected from thermal environment by the outer skin. The outer skin is an ablating rubberized asbestos fabric and is sacrificial; that is, it is replaced for each flight. The outer skin is kept in tension and carries the aerodynamic external pressure of 5 psia max by the reaction of the tubes on the torus structure.

The flare structure is inflated to a maximum of 30 psia with pressurant gas (CH_4) from the first-stage fuel tank. Thus, the need for a separate gas supply to inflate the flare is avoided. After inflation of the flare, there remains sufficient pressure in the fuel tank to counteract the impact loads.

II, D, Vehicle Subsystems (cont.)

The maximum temperature point on the flare skin during re-entry reaches approximately 1000°F; however, the asbestos cloth with its ablative covering can withstand this temperature pulse.

The flare device represents a weight penalty of 3.8% of recovered weight, which corresponds to a payload penalty of approximately 1.7%.

7. Vehicle Secondary Subsystems

a. Power Supplies

The main power supplies for the vehicle during flight will be the batteries and associated equipment located in the compartment between the forward end of the second stage and the aft end of the payload. In this compartment, power converters will be used to convert the direct current battery power into alternating current as required for the various subsystems of the vehicle. Separate power supplies will be provided in the command module and its service module for their operation after separation from the vehicle. A separate power supply will be provided on the first stage for recovery operations.

During the towing of each individual stage, electrical power will be supplied externally from the towing ship. After assembly into the complete vehicle, power will continue to be supplied by an external power supply at the launch point and during the erection operations and subsequent operations up to final prelaunch checkout.

Before final prelaunch checkout, the vehicle power supply batteries will be activated and the external power supply disconnected. This final checkout will be performed using vehicle power only and the external power for vehicle functions will not be reconnected except in case of an extended delay in flight operations.

II, D, Vehicle Subsystems (cont.)

The first-stage power supply for recovery purposes will be a battery pack on the first stage that will be checked out prior to launch, but will not be used until after separation of the first stage from the vehicle. This power supply will provide power for a sequencing system that will control all functions of the onboard recovery system and will provide power for the operation of these systems.

The main functions that will be controlled by the sequencing equipment are: jettisoning of the forward interstage structure by means of explosive charges; inflation of the recovery flare bag; telemetry throughout the recovery phase including impact; and signaling of the location of the first stage after impact through an active beacon and lights.

The onboard equipment for the first stage will be rugged enough to withstand the landing impact. The battery pack will be comprised of dry cells potted in plastic, and the sequencing equipment will be especially designed for the purpose and will be shock-mounted.

All major external electrical wiring will be contained in conduits that are pressurized with dry nitrogen gas, and a replenishment system will maintain the pressure. The replenishment rate will be monitored to assure there are no leaks in the system. The electrical connection including the umbilical cord connection will be adaptations of currently available hardware at the time period of the development program.

b. Ordnance System

There are vehicle and propulsion system functions that will be accomplished by means of various types of ordnance items. A partial list of these is:

(1) Command module abort propulsion system

(2) Posigrade and retrograde propulsion systems in the service module for the command module

(3) Command module abort separation system

II, D, Vehicle Subsystems (cont.)

(4) Command module re-entry separation system

(5) Interstage (Stage I/II) separation system

(6) Propulsion system valve operating devices

(7) Ballast staging devices

(8) Frist-stage recovery operation devices

There will be an integrated ordnance system that includes provisions for checkout of all items and for operations as commanded by the guidance computer and sequencing equipment.

Positive mechanical safe and arm provisions will be made for all ordnance items to prevent inadvertent firing. These safe and arm mechanisms will be operated remotely by electrical signals and will be monitored as to position. These mechanisms will be reversible to provide for operational checkout and for safety after checkout.

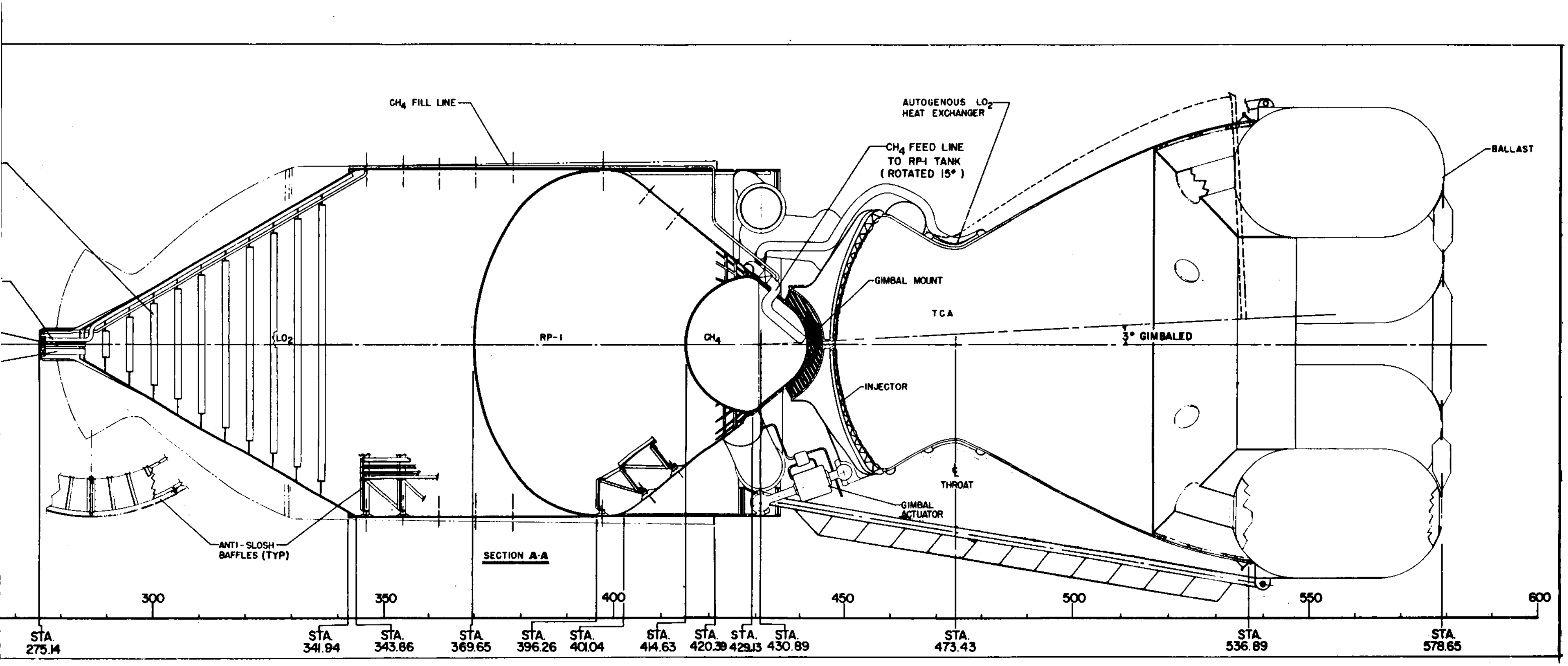
II, D, Vehicle Subsystems (cont.)

The first-stage recovery operation devices will operate after separation from the vehicle, and therefore will operate separately with its own sequencing system and power supply. However, the checkout procedures and equipment will be integrated with those of the vehicle.

8. Ballast

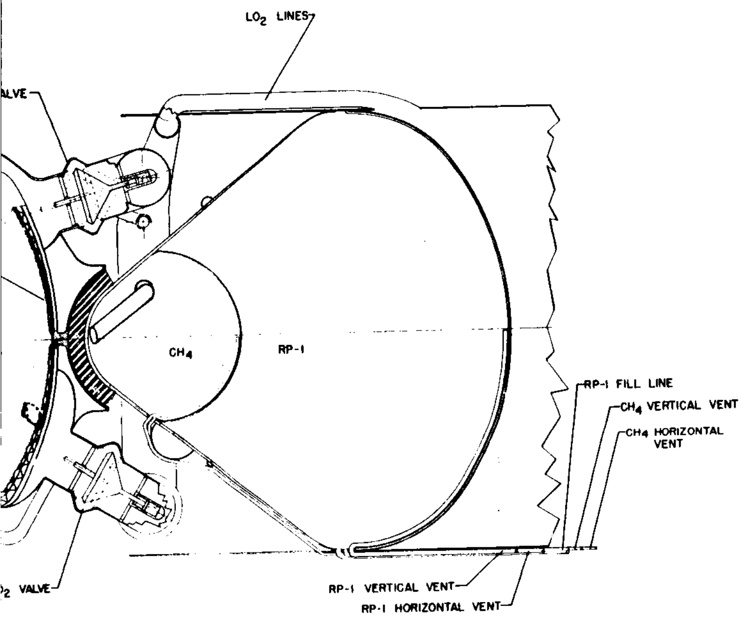
The ballast unit provides aft end flotation for sea handling and a balancing mass for erection and stabilizing of the vehicle in the launch altitude. The unit is shown in interface with Stage I in Figure II-D-1.

The ballast unit consists of a structural assembly of six cylindrical tanks and support struts. The forward structural element is an orifice that provides a control of thrust chamber environment for underwater operation. The ballast unit as attached to Stage I thrust chamber assembly, and with struts to the aft skirt, provides aft end flotation for sea handling of the vehicle. The ballast tankage, when filled with a heavy fluid, SG = 2, such as drilling mud, provides balancing mass that erects and stabilizes the vehicle in the vertical launch attitude. Provisions exist for staging the ballast during the ignition sequence.

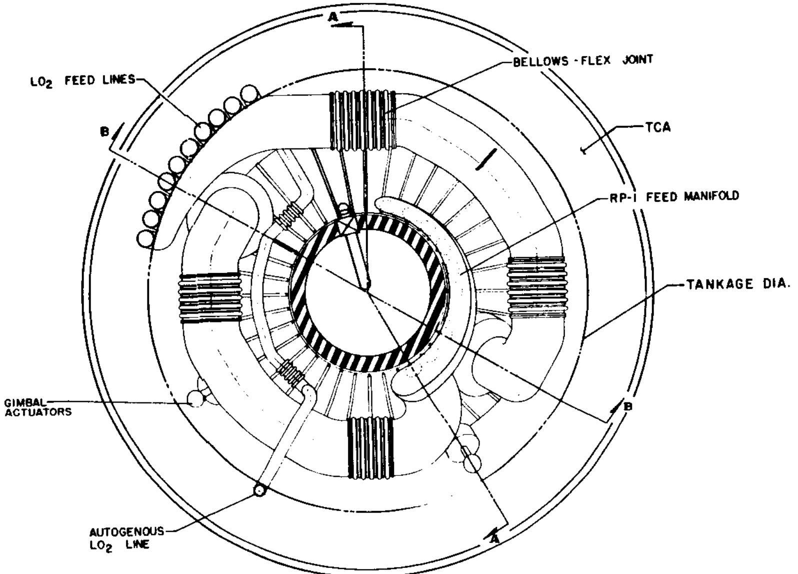


Stage I Propulsion System Layout Drawing

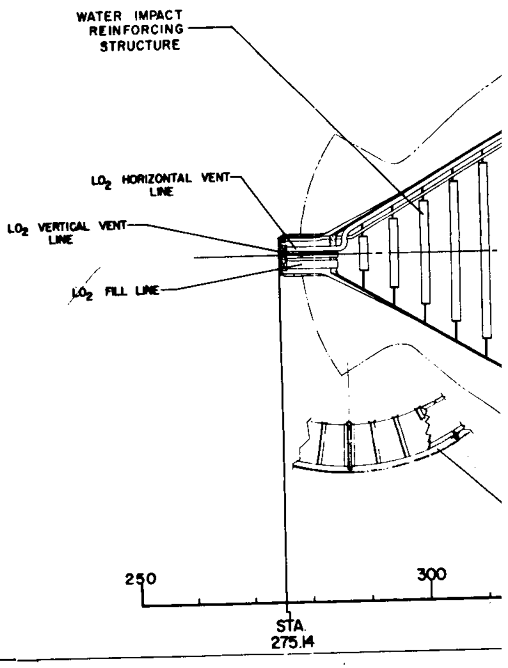
Figure II-D-1

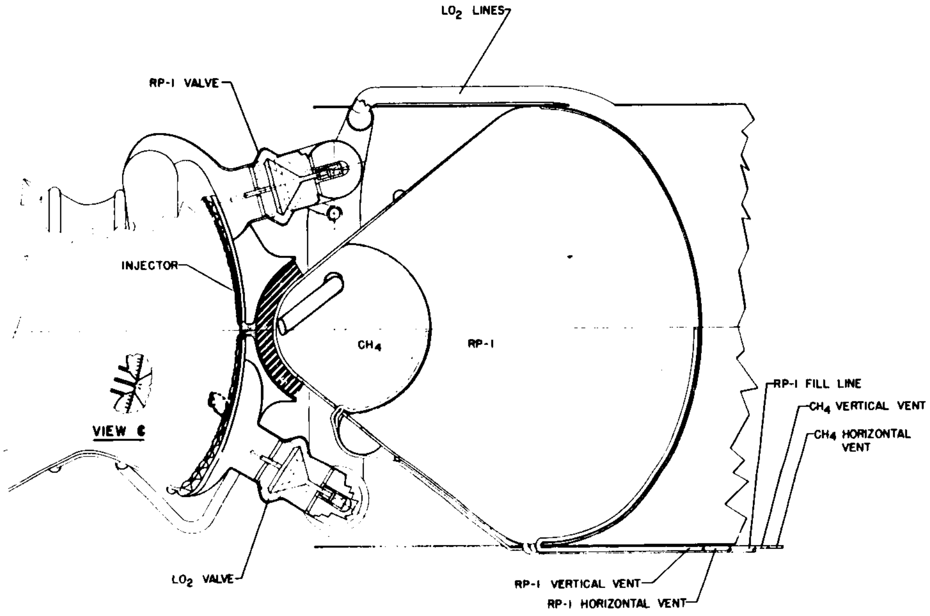


SECTION B-B
ROTATED 60°



VIEW LOOKING AFT WITH
TANKAGE REMOVED FOR
PURPOSES OF CLARITY





SECTION B-B
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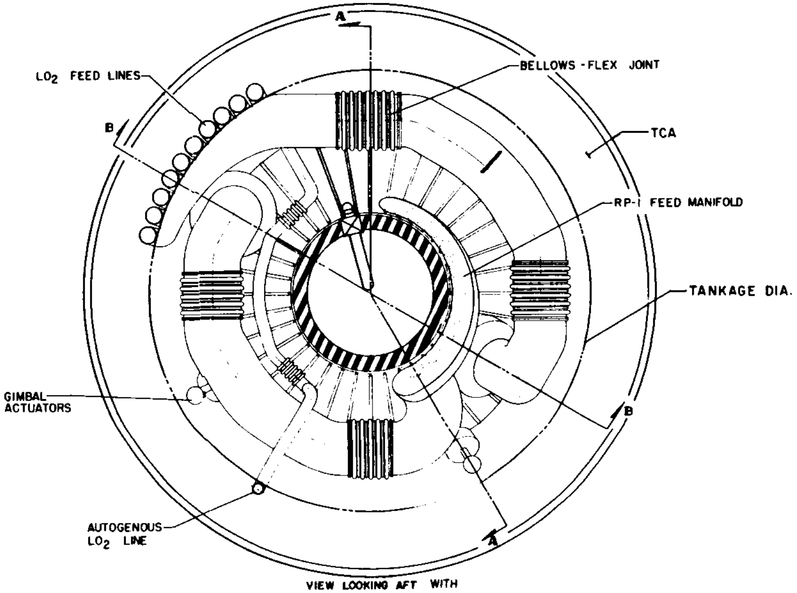
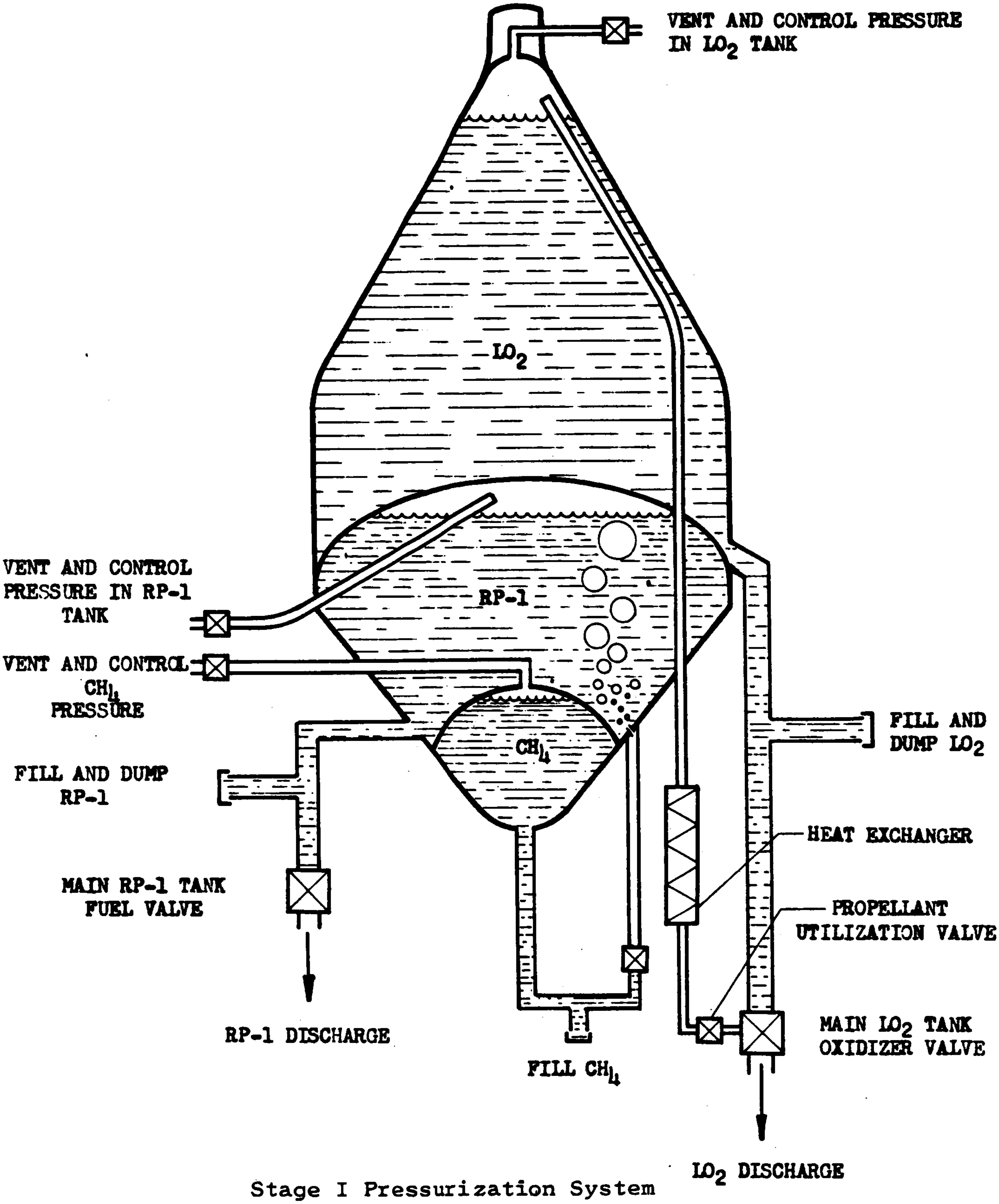
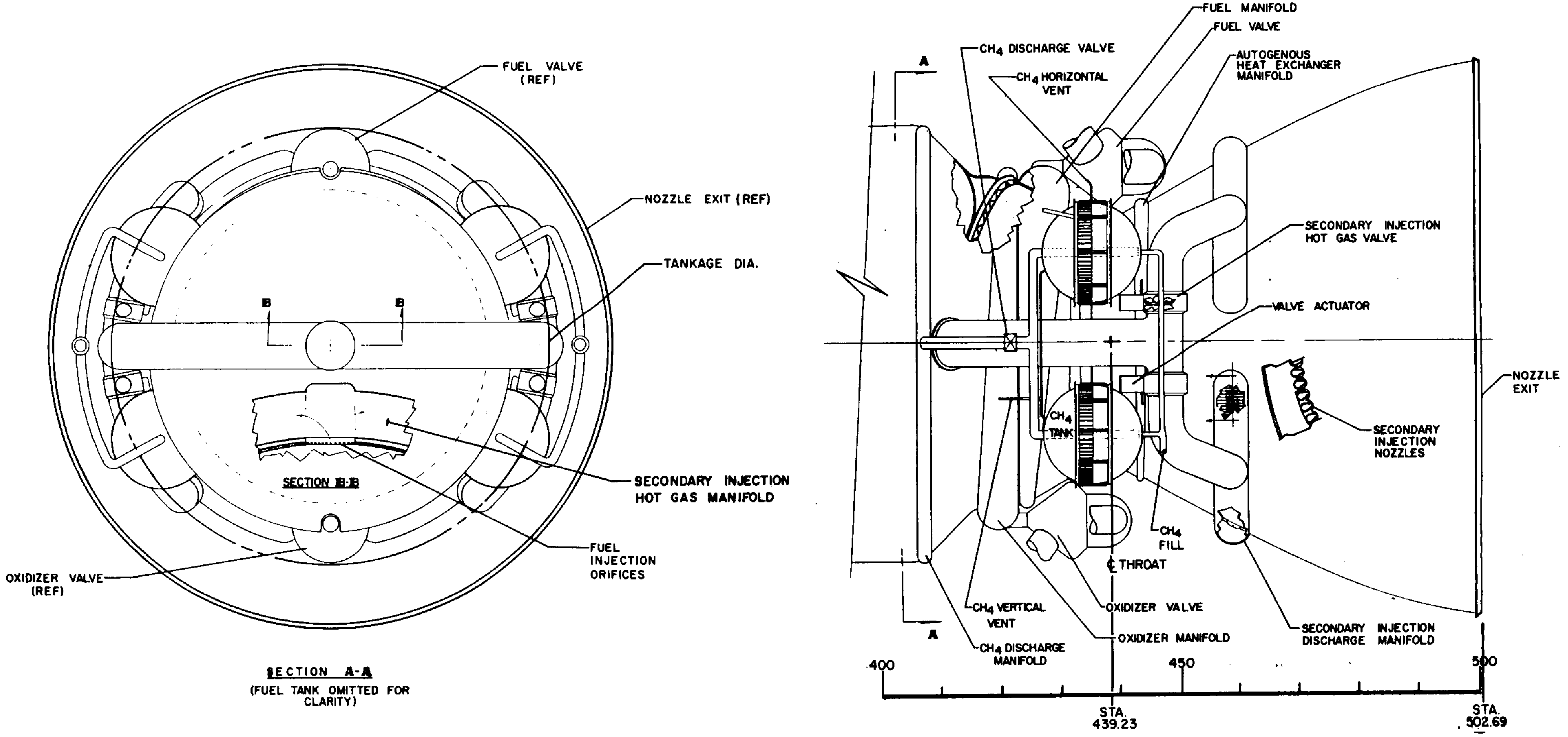


VIEW LOOKING AFT WITH
TANKAGE REMOVED FOR
PURPOSES OF CLARITY



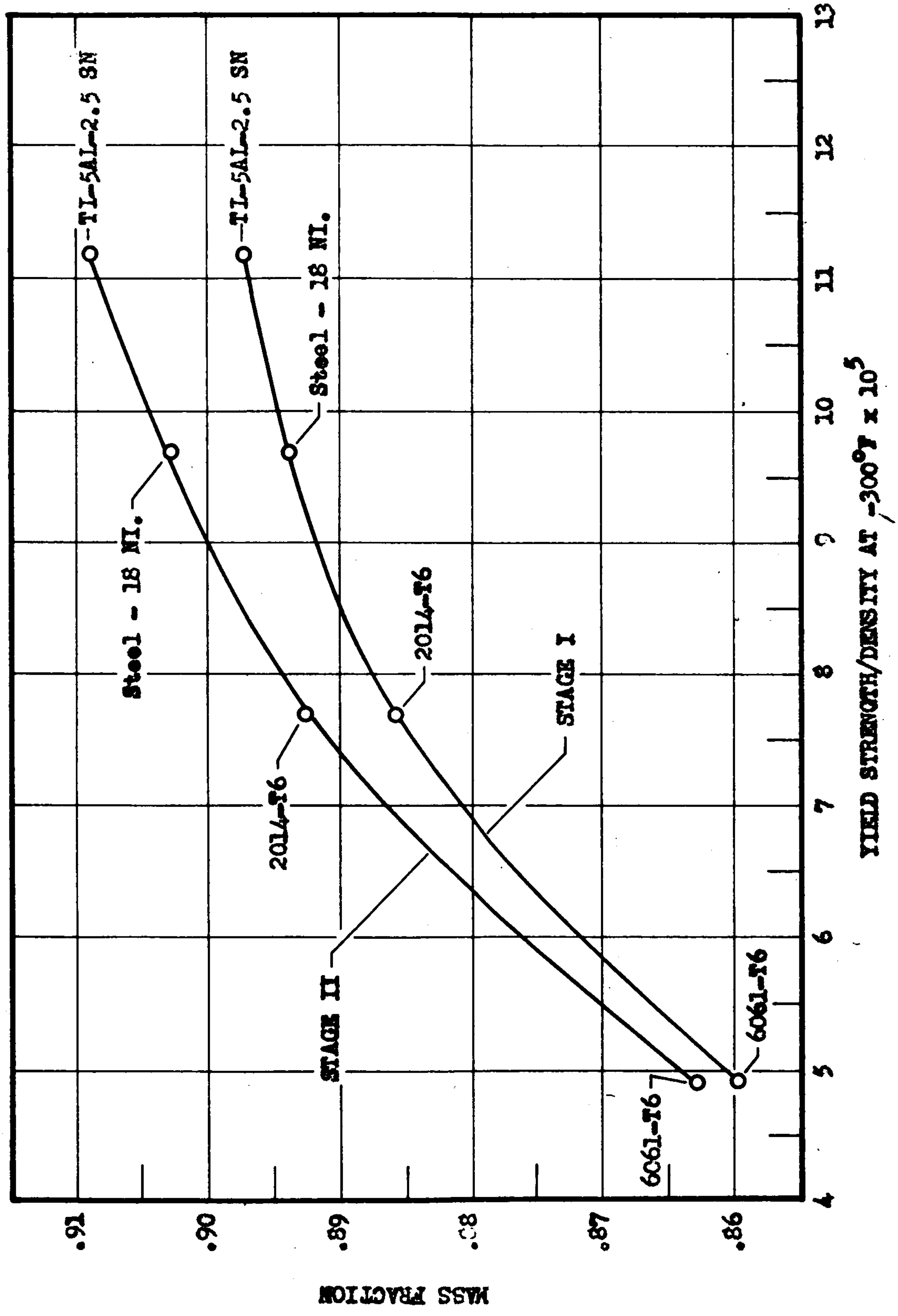
Stage I Pressurization System

Figure II-D-3



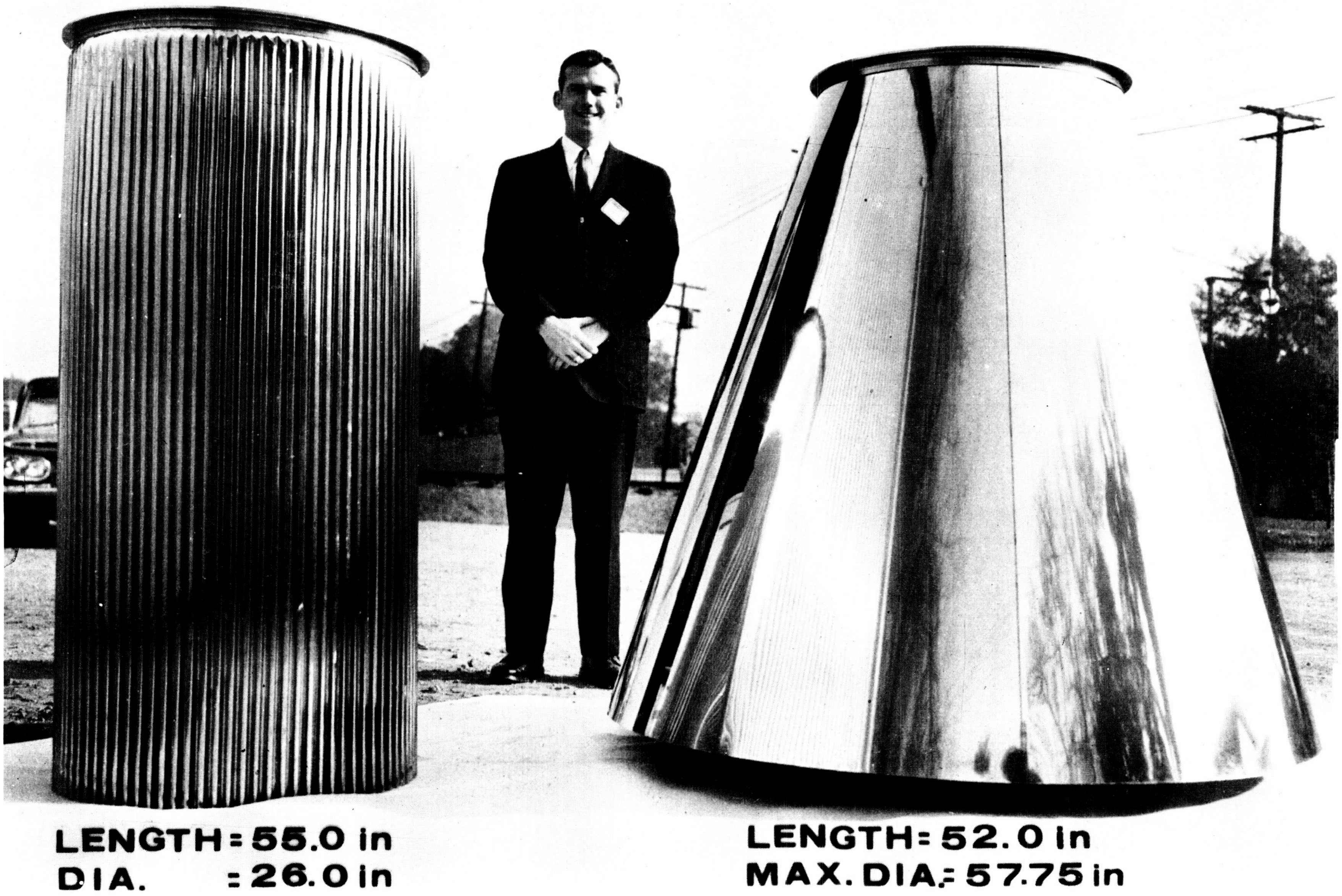
Secondary Injection Thrust Vector Control Engine

Figure II-D-4



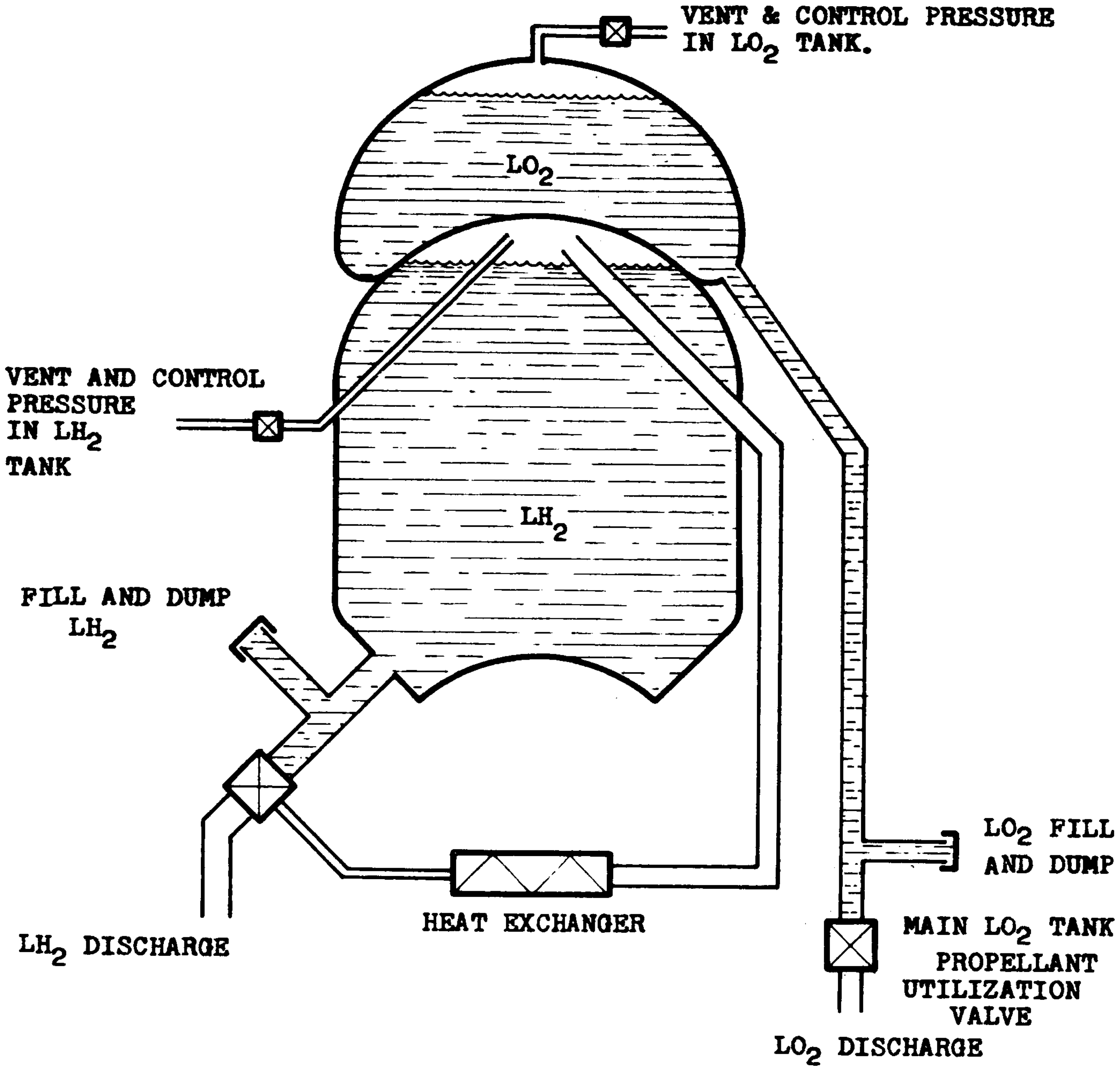
Mass Fraction versus Tank Material

Figure II-D-5



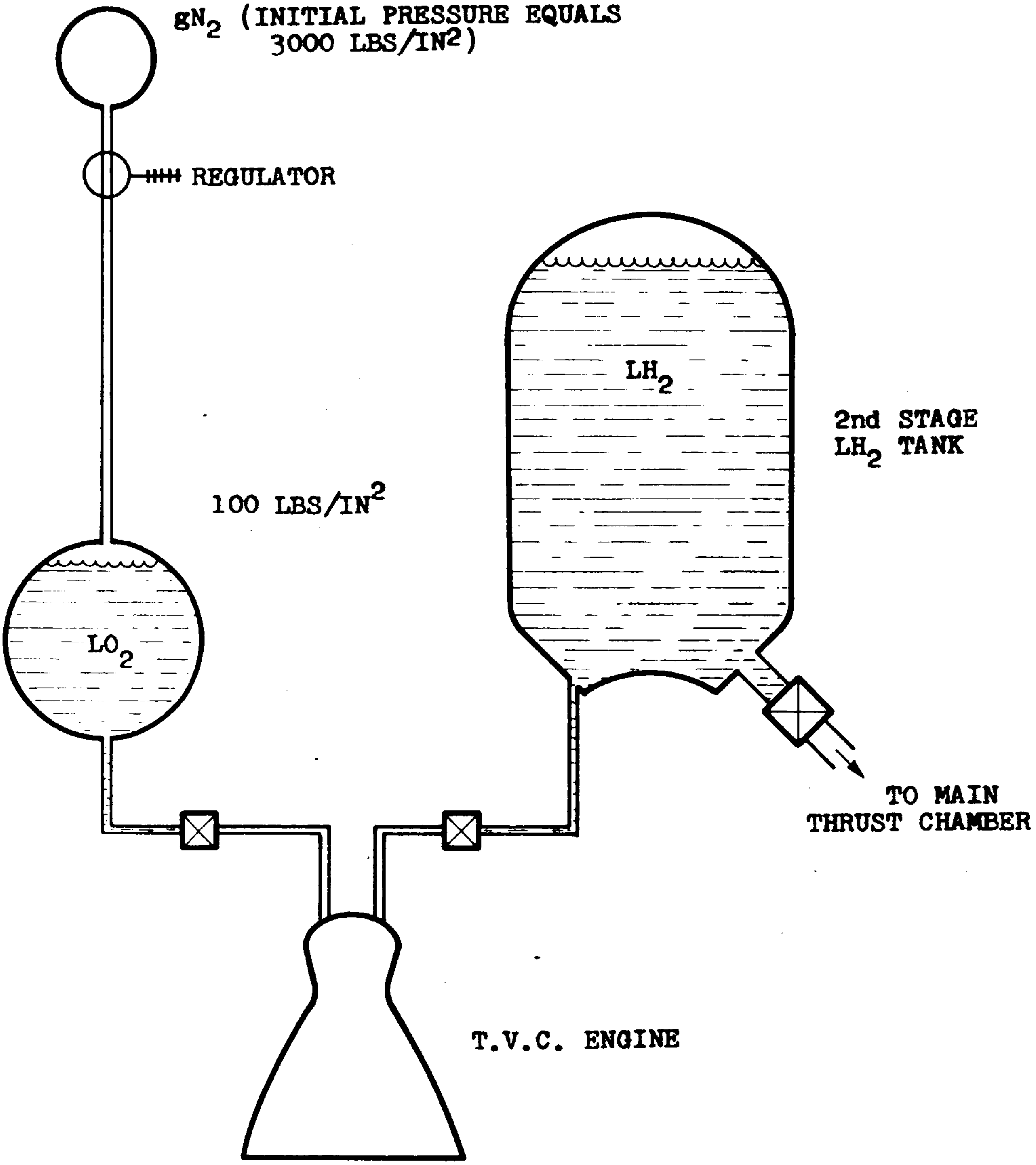
Large Expandable Nozzles Currently Undergoing Altitude Tests

Figure II-D-6



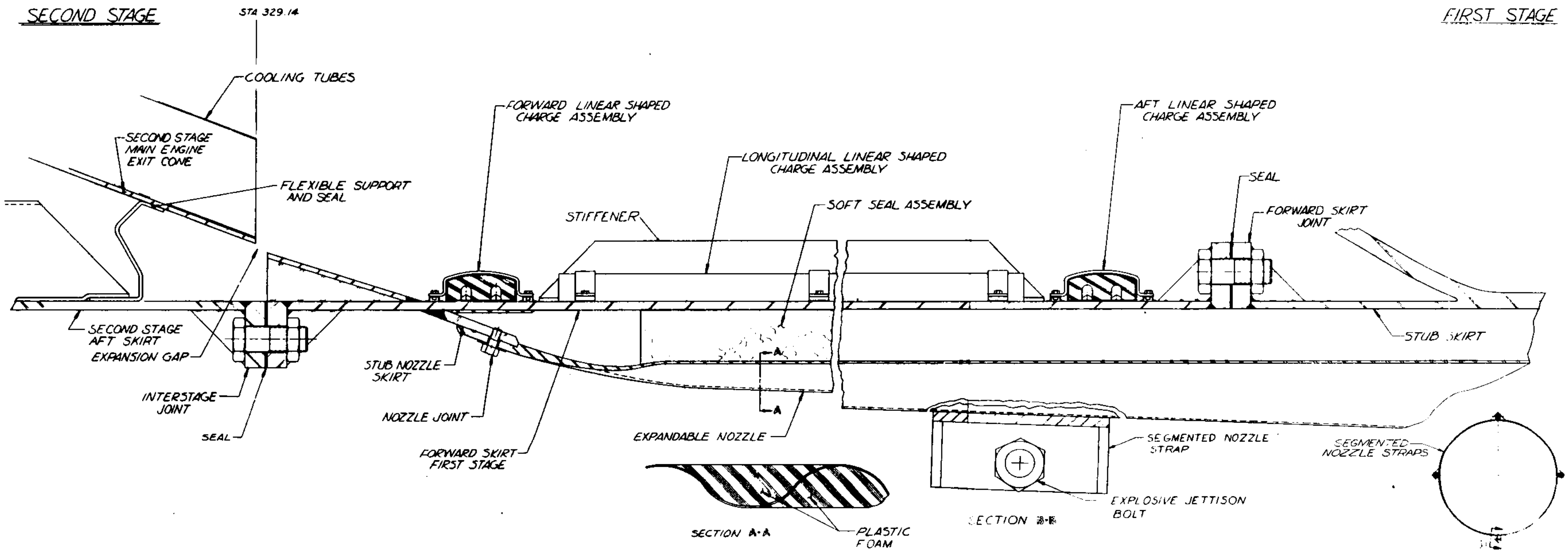
Stage II Pressurization System

Figure II-D-7



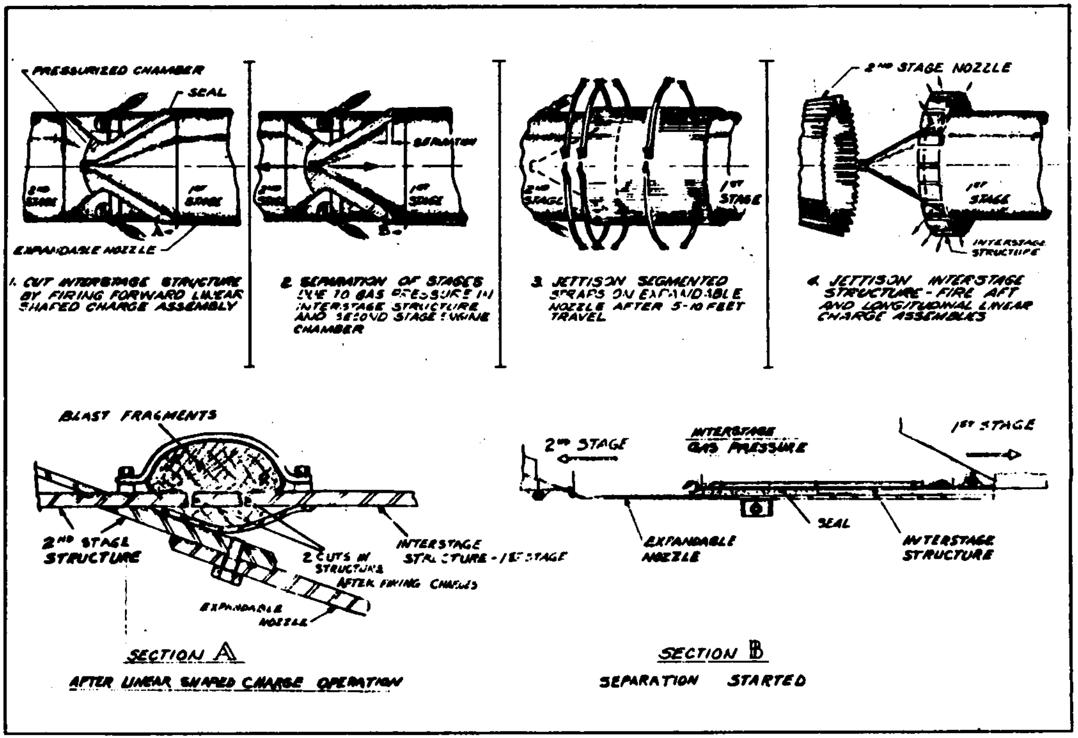
TVC Engine Pressurization System

Figure II-D-8



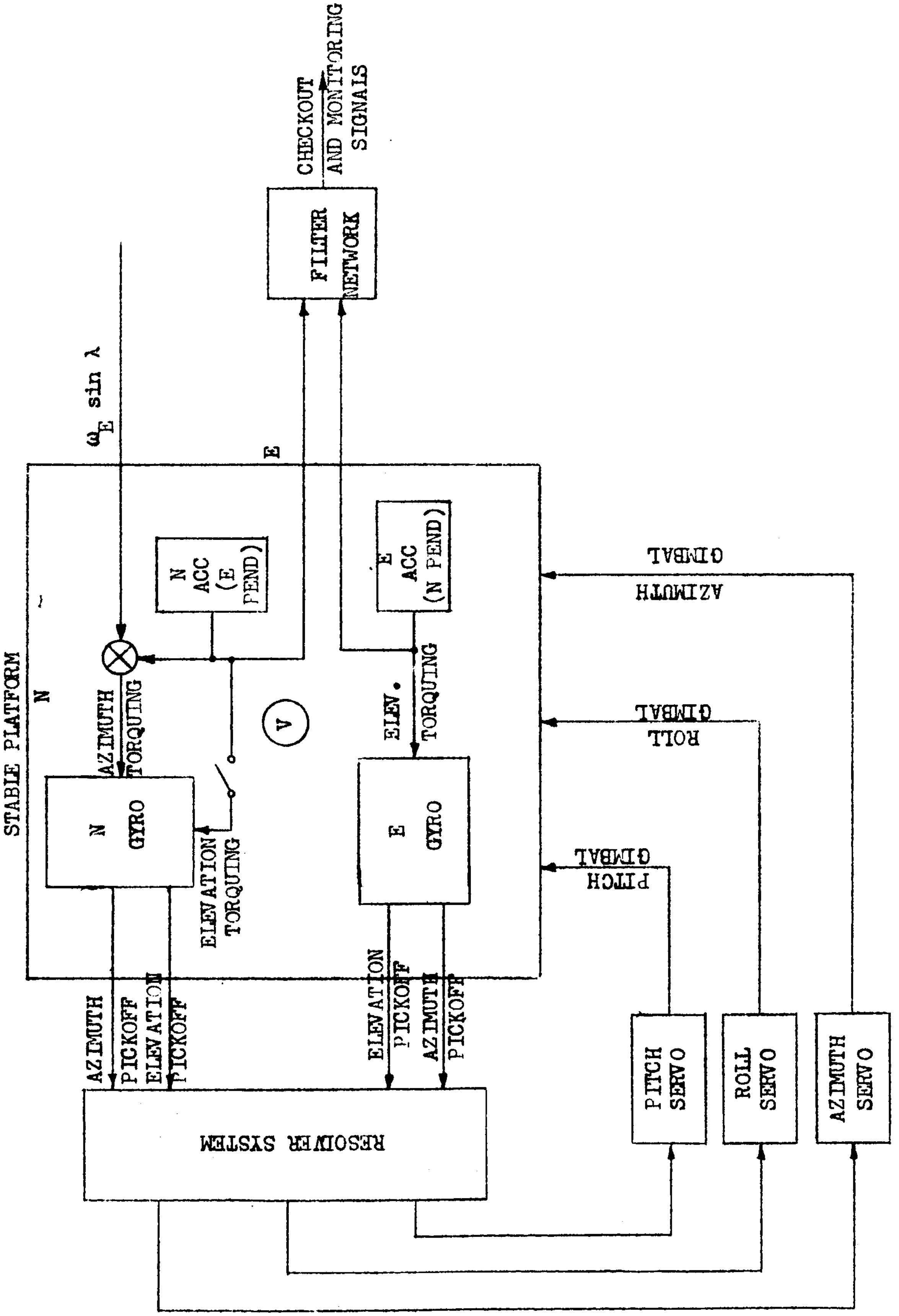
Interstage Assembly Schematic

Figure II-D-9



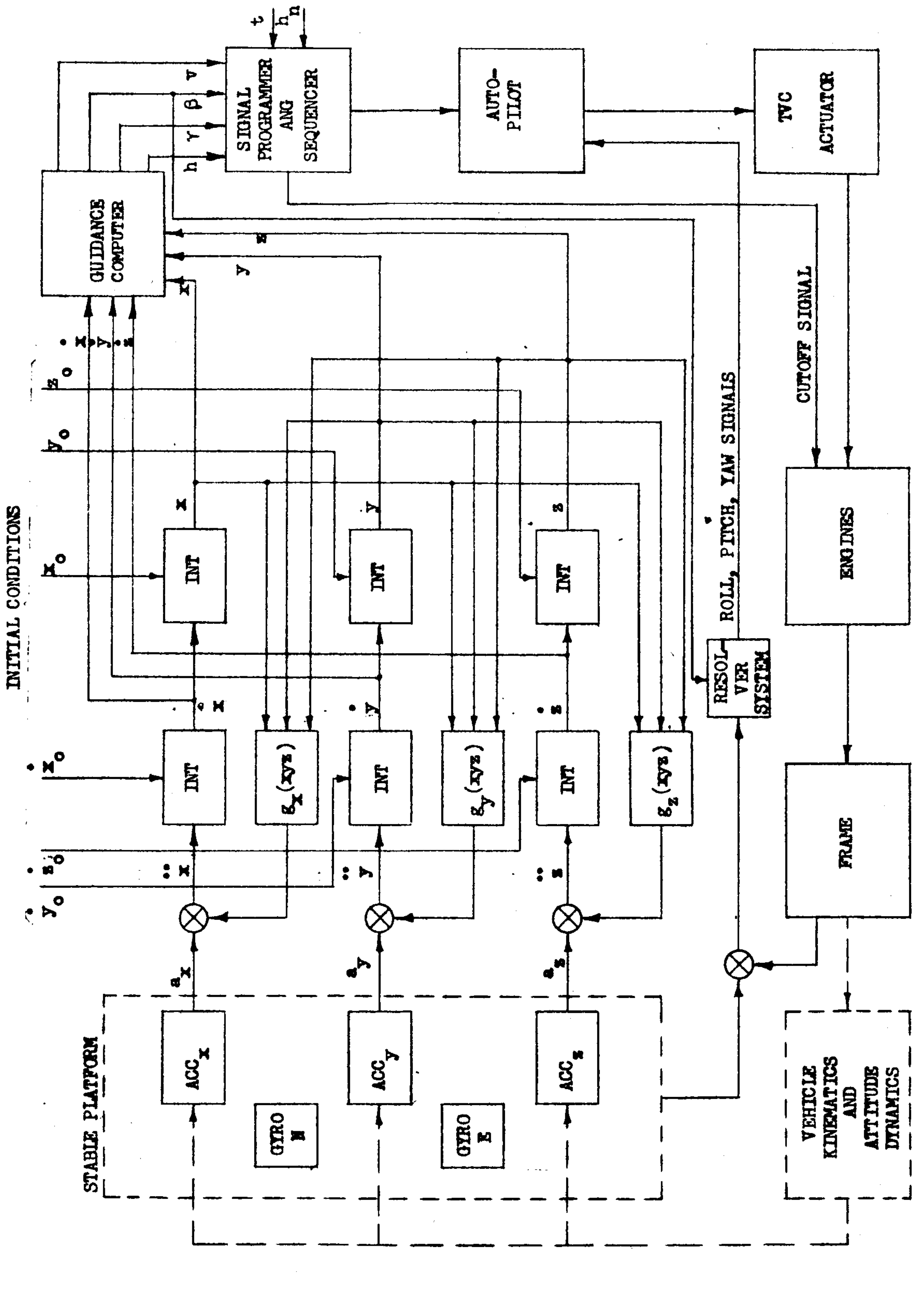
Staging Sequence Schematic

Figure II-D-10



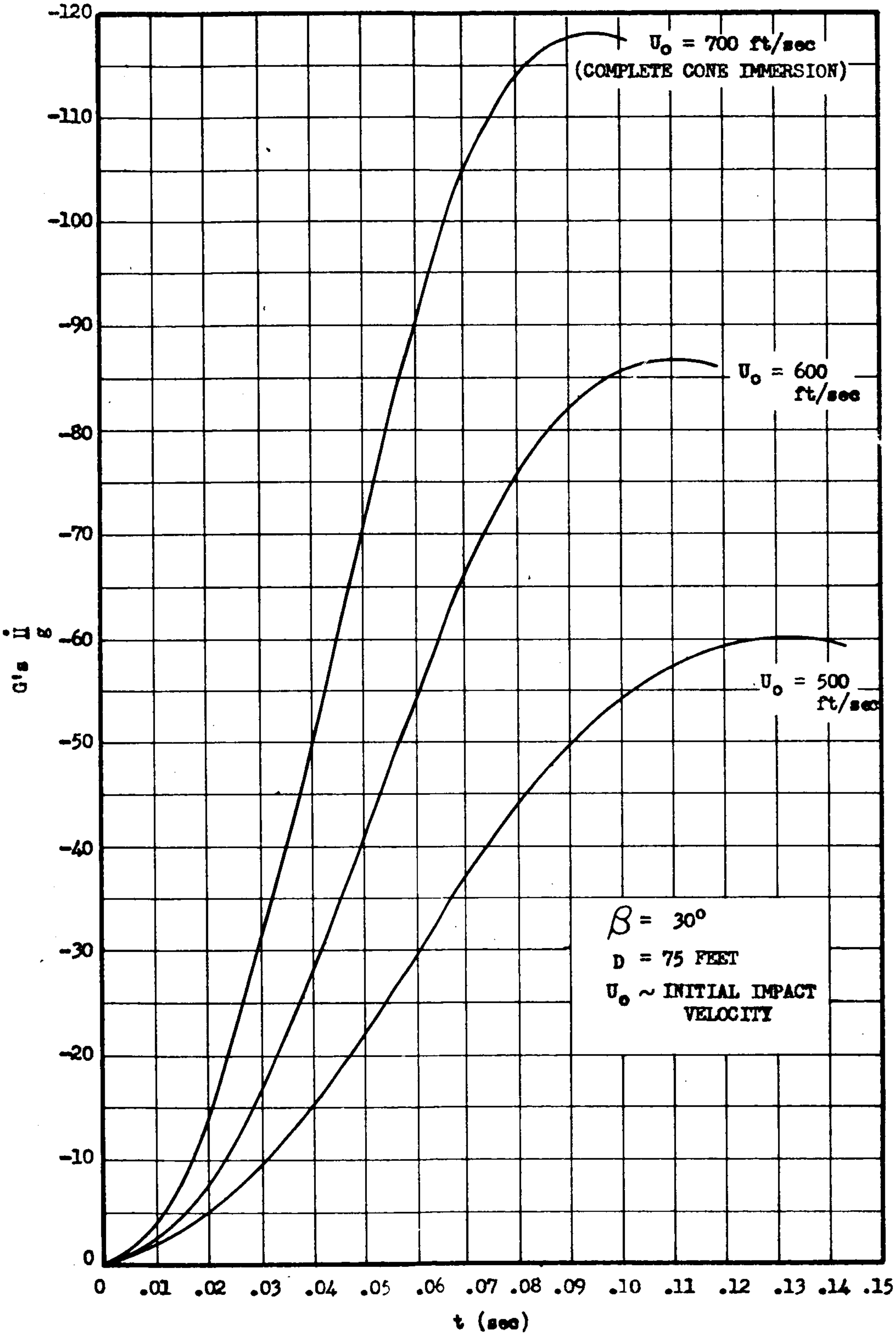
Guidance System Block Diagram of Self-Alignment Mode

Figure II-D-11



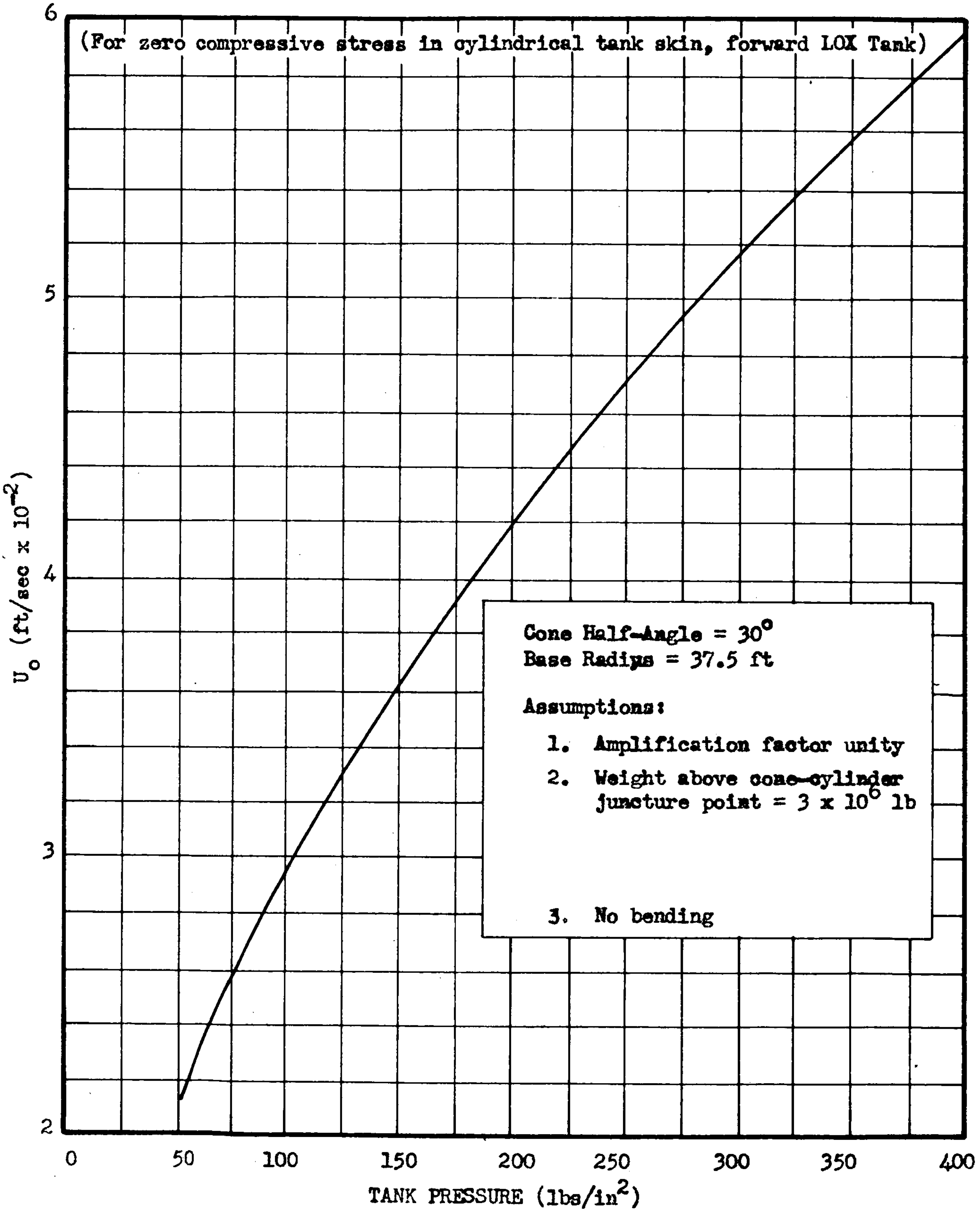
Flight Navigation Mode

Figure II-D-12



Deceleration versus Time

Figure II-D-13



Tank Pressure at Burnout versus Critical Impact Velocity

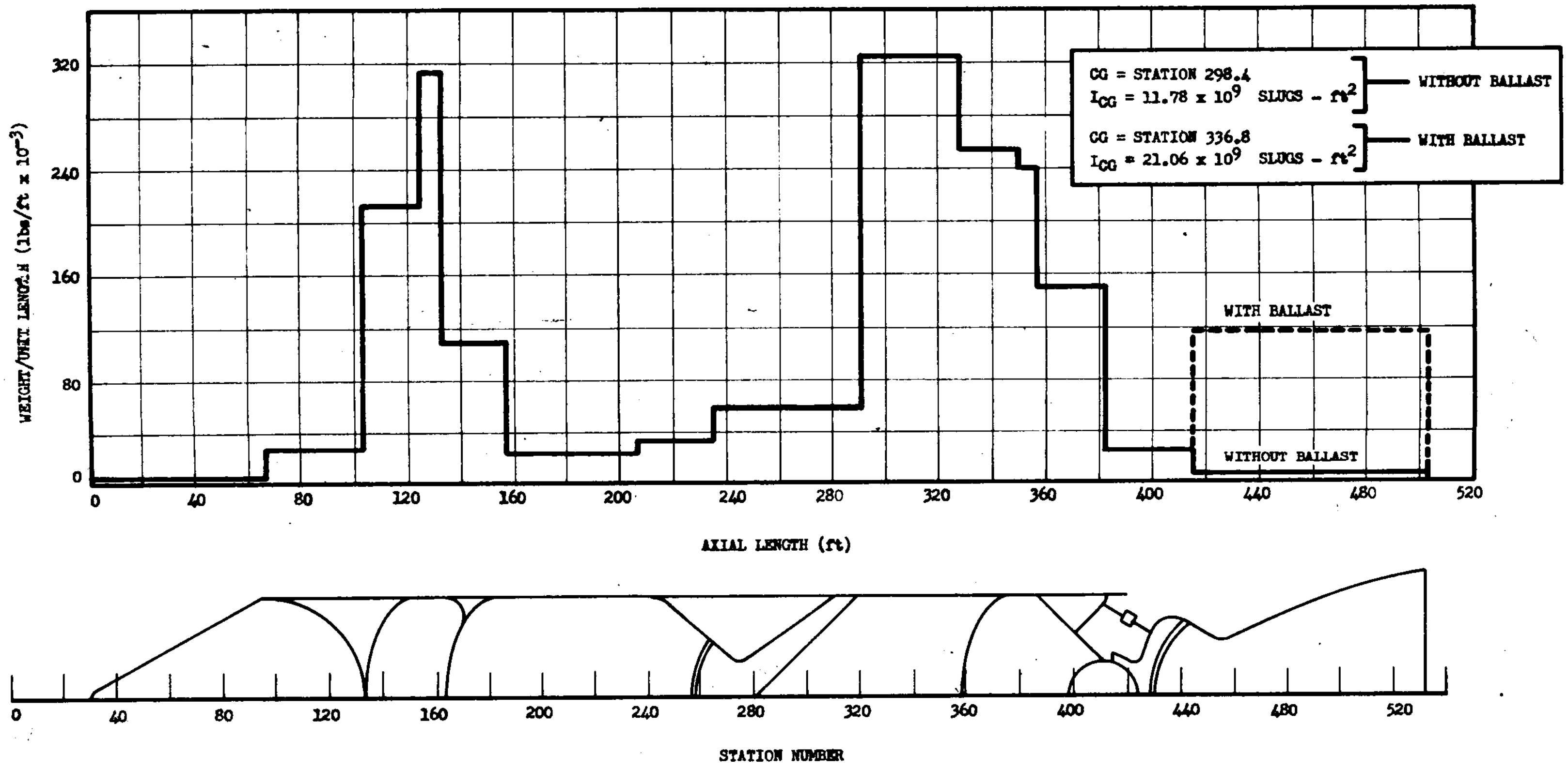
Figure II-D-14

II, Vehicle Description (cont.)

E. VEHICLE STRUCTURAL CHARACTERISTICS

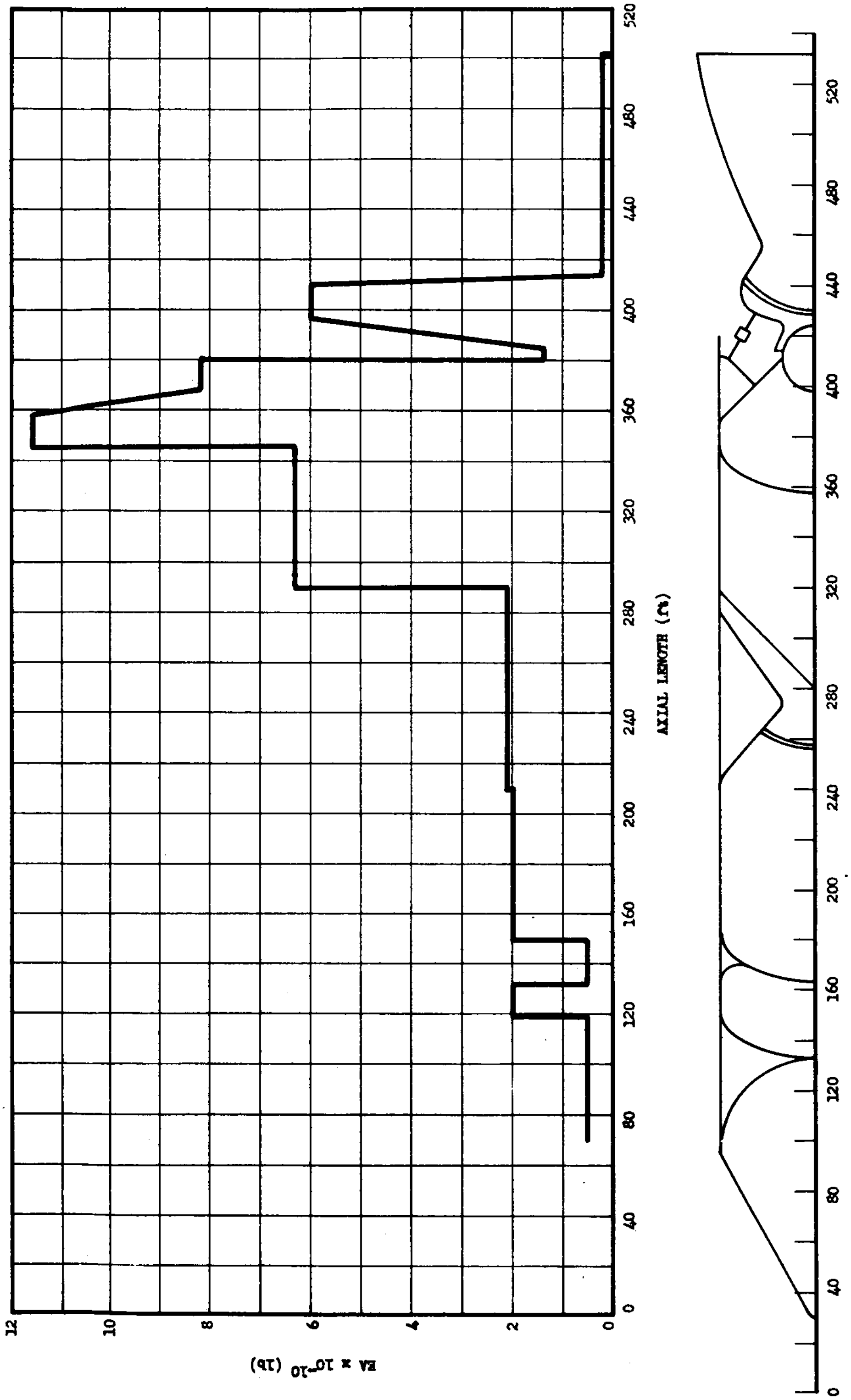
For use in the investigation of vehicle dynamics, primarily, the airframe stiffness and mode shapes were computed. This was done for the many different vehicle conditions of interest, such as towing, fueling, launch, flight, and impact. Characteristic results of the weight and stiffness distribution calculations are given in Figures II-E-1, -2 and -3.

From these results, modal analyses were made using a modified Myklestad technique, mechanized for digital computation. The mode shapes and frequencies for two vehicle conditions were thus determined; these are shown in Figures II-E-4 and II-E-5. Although used primarily for launch and towing dynamics analyses, these modal data were also used in considering the autopilot-control-body loops and instrument locations.



Weight Distribution at Liftoff

Figure II-E-1



EA versus Length

Figure II-E-2

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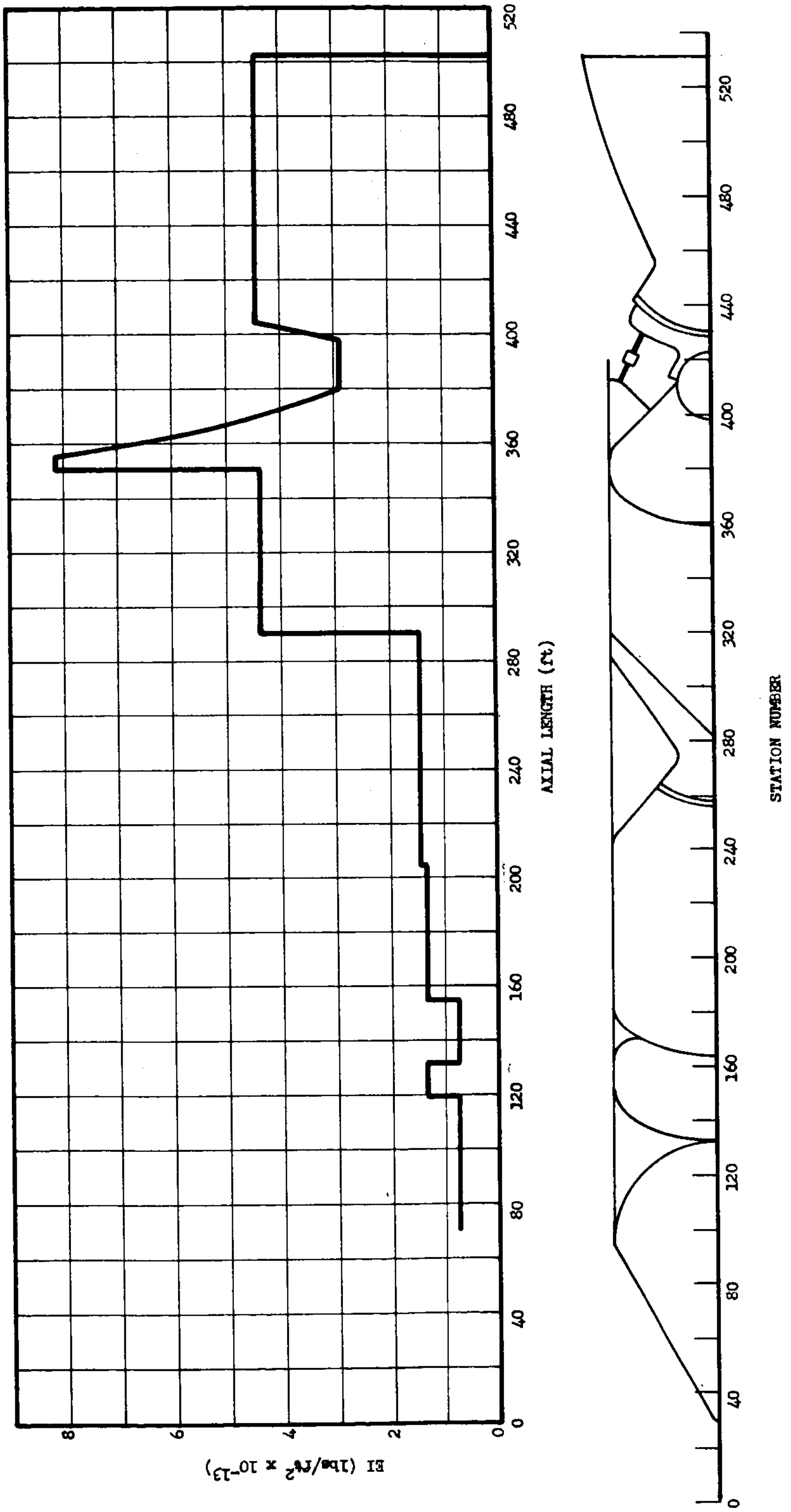
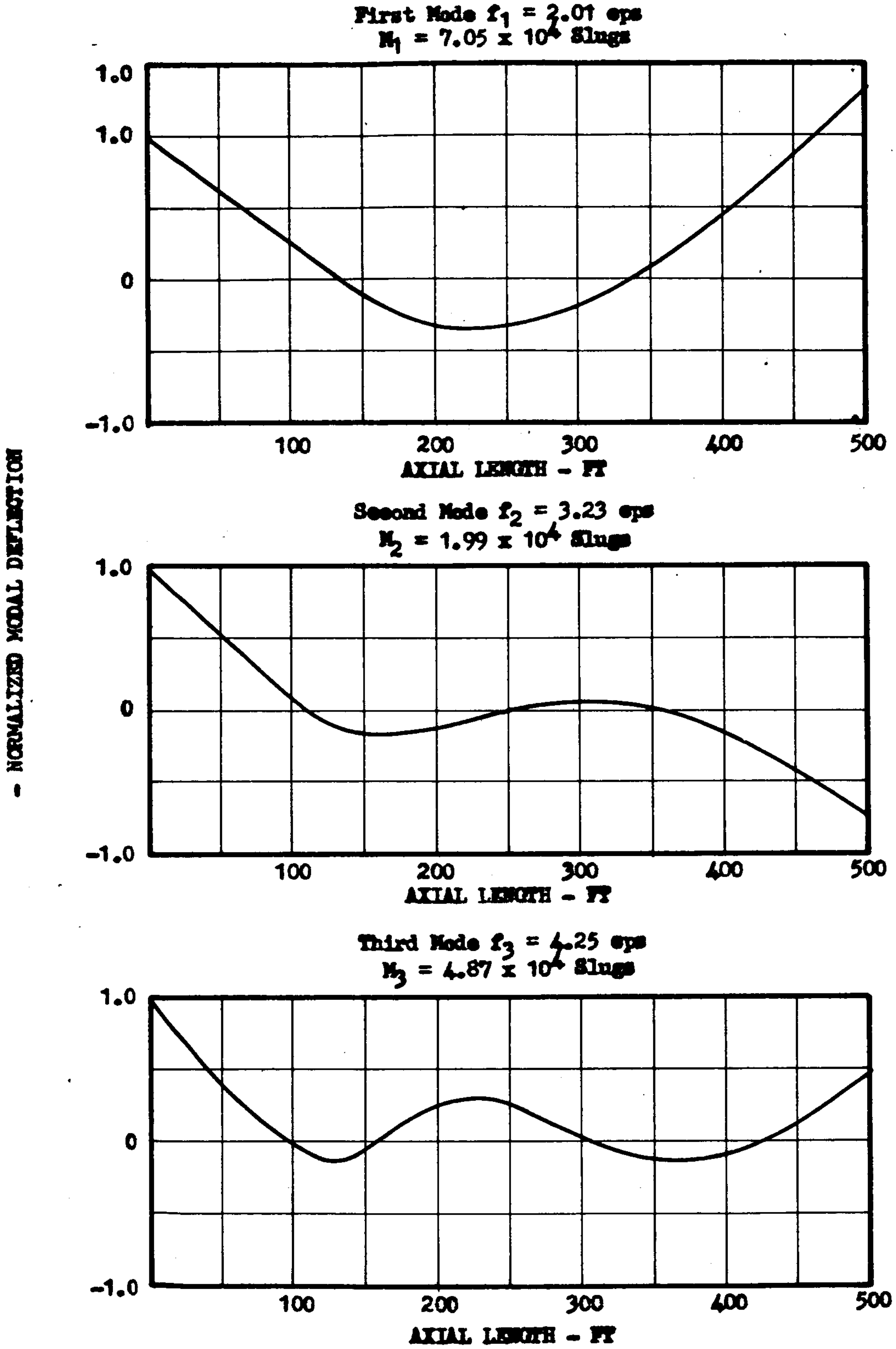


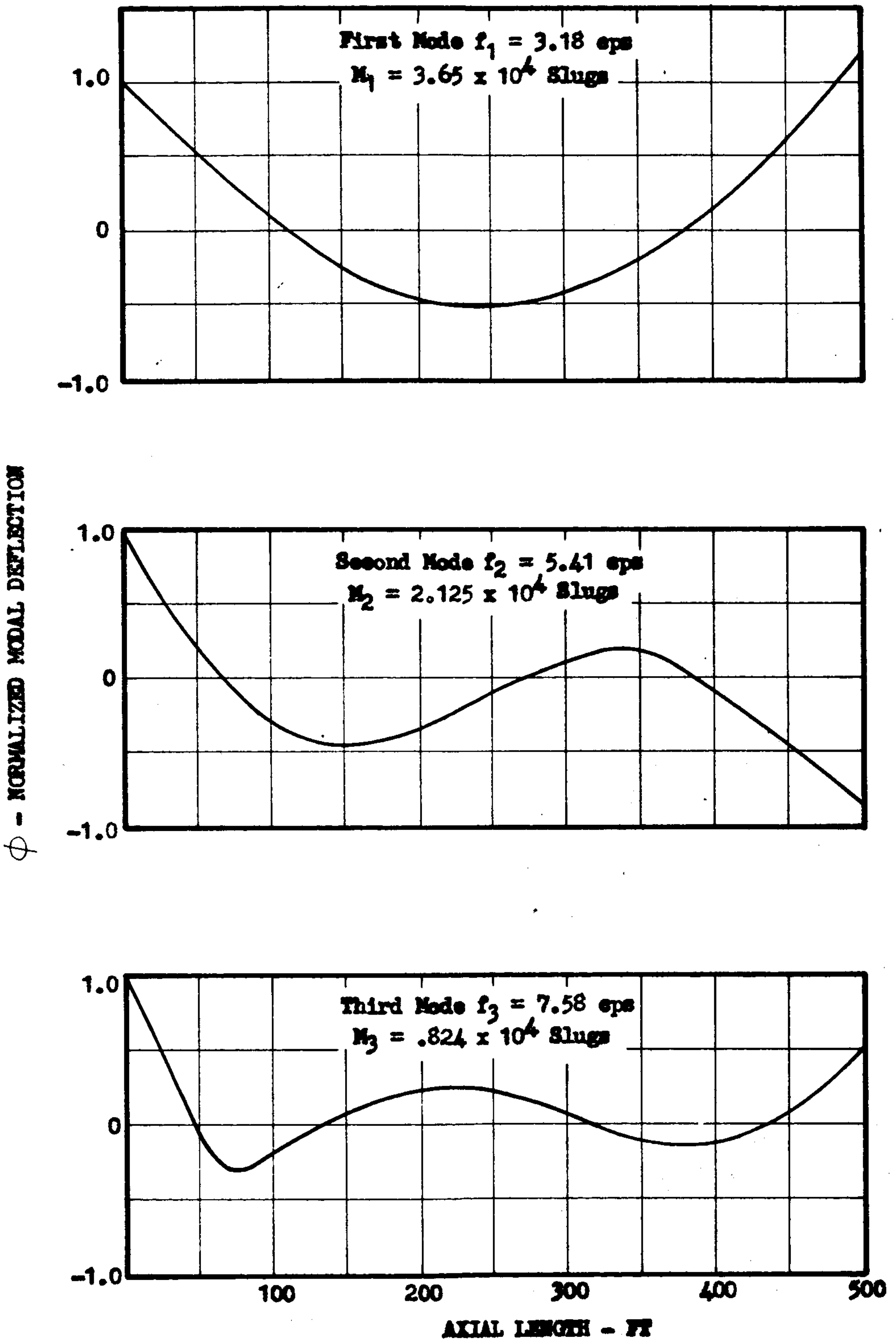
EI versus Length

Figure II-E-3



Bending Modes, Launch Condition

Figure II-E-4



Bending Modes, Empty Condition

Figure II-E-5

II, Vehicle Description (cont.)

F. VEHICLE ANALYSIS

1. System Performance

The Sea Dragon recoverable vehicle Configuration No. 135 has a capability to deliver 1.10 million pounds of payload to a circular earth orbit of 300 nm altitude when launched from the sea off Cape Canaveral in an eastward direction. A preliminary optimization study established the following design parameters: first-stage nozzle area ratio of 5.0; thrust to weight ratio of first stage of 2.0, and staging ratio of 1.9 (mass ratio of the second stage/mass ratio of the first stage).

To accomplish a launch at sea, the first stage engine operates underwater for approximately 5 sec until total emergence of the vehicle from the sea. During this period, the variations in thrust, drag, buoyancy, and ballast weight combine to produce a momentary inflection in the acceleration characteristic. During underwater engine operation, the large ambient hydrostatic pressure is accomodated by a self-compensating plug-tupe ballast unit.

II, F, Vehicle Description (cont.)

When the vehicle has reached 280 ft/sec, it undergoes a pitch maneuver or kick downward of approximately 7° rotation. Thereafter it begins a gravity turn and continues to orbit. The first stage burns out at an altitude of 125,000 ft and at a velocity of 5,800 ft/sec. The first stage is immediately separated and the second stage is ignited with a minimum of coasting. At the end of the second stage burning 260 sec later, the altitude is 150 nm and the velocity 23,430 ft/sec. The auxiliary engines continue to burn for a total of about 22.4 min. During this low thrust period the altitude increases to 300 nm and the trajectory is shaped to reduce eccentricity. The entire trajectory is illustrated in Figure II-A-6 .

Many other trajectories were studied with variations in propellant utilization rate, kick angle, and payload. For comparison, some cases involving coast and restart were also examined. The best of these indicates that a payload gain (by restart) of 86,000 lb is possible; however, additional weight required to realize restart capability was not evaluated and would reduce the advantage.

II, F, Vehicle Description (cont.)

Analyses of staging dynamics show that the relative lateral motion between the first and second stages is sufficiently small to preclude damaging contact or severe perturbations to the flight path. Although the stages are aerodynamically unstable at the time of staging, the dynamic pressure and angle of attack are low enough to avoid appreciable rotation being developed before the longitudinal separation has proceeded past its critical point. This is made possible by the use of pressure-driven separation which results in a total staging time of approximately 3 sec.

The first stage unit is recoverable and reusable. The recovery operation starts after staging with the inflation of a drag device of flared shape that stabilizes the unit and reduces its velocity for sea impact. A parametric study of re-entry and impact conditions showed that an impact velocity of 300 ft/sec is required by structural considerations of the first-stage tankage at its final internal pressure of 100 psi. Analyses of various configurations for drag effectiveness showed that a conical flare of 300-ft diameter is required to achieve the impact velocity. An inflatable flare was chosen after a trade-off study and comparison with parachutes and fixed structures.

2. Vehicle Loads and Dynamics

a. Introduction

A wide variety of problems associated with static and dynamic loads, vehicle kinematics and dynamics, and the Sea Dragon environment have been investigated with differing degrees of completeness. In many instances the findings of this preliminary work have indicated that phenomena associated with the Sea Dragon concept (large size, water environment, etc.) do not give rise to insurmountable engineering problems with respect to present technology and conservative estimates of future advances. For example launch dispersion magnitudes and water re-entry loads can be readily handled. In other areas it has been recognized that the problems are not yet fully defined or that methods of solution are not readily available, e.g., the acoustic environment and resulting vehicle response. Another major result of this work, however, has been the identification and definition of problems in the area of vehicle loads and dynamics which will require more attention in the next design phase of the program.

II, F, Vehicle Analysis (cont.)

The more significant results of loads and dynamics studies conducted to date are summarized in the following paragraphs.

b. Sea and Wind Environments

Wave lengths, heights, and periods were defined as functions of sea state and wind velocity. The concept of "sea spectra" was used with particular attention being given to Sea State No. 4,5,6.

The upper atmosphere wind environment used in analytical and design studies presented in this report is taken from NASA TN 1274. A maximum wind velocity of approximately 320 ft/sec at 42,000 ft altitude is thereby specified in a 99% probability of occurrence profile.

c. Floating Loads

The most severe loading condition for the vehicle floating in still water is the case where the propellant tanks are full and there is no ballast attached. A maximum bending moment of 385 x 10^6 ft lb will exist in the interstage area under this condition; however, this load is substantially less severe than that experienced during vehicle erection and flight. Loads developed during other floating modes and sea conditions are discussed below.

d. Towing Dynamics and Loads

Maximum bending moments of 230 x 10^6 and 390 x 10^6 ft lb were calculated for the "sagging" and "hogging" conditions respectively. (Hogging refers to the condition in which the vehicle is supported near the center by an ocean swell. Sagging describes the condition in which each end of the vehicle is supported by a wave crest.) No dynamic amplification of these loads is anticipated because the vehicle bending modes are much higher in frequency than are the significant frequencies in the sea spectra.

II, F, Vehicle Analysis (cont.)

To avoid difficulties in controlling the towed vehicle with respect to yaw and roll in a cross-sea environment, anti-rolling devices will be studied in future work. The problem of dynamic interactions of the Sea Dragon vehicle, the towing cable, the towing vessel, and the sea environment was examined and a preliminary method of analysis was formulated. The solutions to these problems must combine analysis and model testing, much of which remains to be done.

Propellant sloshing frequencies for the vehicle in the towing mode were found to be in the range 0.208 to 0.722 cps for the first three modes (tanks 90% full). These sloshing frequencies could couple with wave forces when Sea State No. 5 conditions exist; however, the extent of the effects of this coupling on the complete towing configuration remains to be evaluated. It should be remembered that the tanks will be completely full (except for the RP-1 tank which has a 3% ullage) for most of the towing operations.

e. Vehicle Erection Loads

The process of erecting the vehicle gives rise to the largest bending moments experienced by the structure. A maximum bending moment of 1.0×10^9 ft lb is calculated for the case of a 5.0×10^6 lb effective ballast weight. An internal gas pressure of approximately 30 psi in the first-stage LO_2 tank and second-stage LH_2 tank is required to react the erection bending moment.

f. Prefire Loads and Motions

Dynamic loads due to wave action calculated for sea states up to and including Sea State No. 7 are found to be relatively small. Heaving motion, however, becomes quite violent for sea states above No. 5 because of strong coupling between sea spectra and the vehicle heaving mode. There also appears to be a strong possibility of encountering pitch-heave instability in Sea State No. 6. For this reason, it appears that launching will be restricted to Sea State No. 5 or less, for which a maximum pitch amplitude of 0.17°

II, F, Vehicle Analysis (cont.)

and maximum heave excursion of 3.0 ft are calculated. This area also requires additional study to determine if the same conditions exist for other configurations and to investigate ameliorating devices such as use of different ballast unit configuration to provide additional damping.

Preliminary analysis showed that forces due to wave induced vortex shedding will not be a problem for the Sea Dragon vehicle. Atmospheric vortex shedding, however, may result in significant responses of the erected vehicle because of coupling with the rigid body pitch mode. Calculations indicate an angular excursion in pitch of 1.75° for a 25 ft/sec wind velocity.

Propellant sloshing loads are not expected to be of importance during the prefire stage because of fullness of the propellant tanks and frequency separation between sloshing modes and other forcing and natural frequencies of the environment and vehicle.

II, F, Vehicle Analysis (cont.)

g. Launching Dynamics

"Launch dispersion" (motions of the vehicle as it leaves the water) were calculated for several disturbing forces. Wave forces in Sea States No. 5 and 6 result in maximum angular deflections and rates of 4.55° and 2.41°/sec respectively. A thrust misalignment angle of 0.25° was found to give rise to maximum dispersions of 1.56° displacement and 1.70°/sec rate. A 33-knot wind gives rise to 5.77° displacement angular dispersion and 1.17°/sec angular rate. The combined maximum dispersion displacement and rate for all cases considered were calculated to be 5.82° and 2.41°/sec respectively. It appears that the control system can handle these dispersions if activated at the time the vehicle leaves the water.

The possibility of large loads being generated by propellant sloshing response during launch seems remote, since only the higher sloshing modes (fifth and sixth) will couple with the fundamental vehicle bending mode.

The maximum bending moment experienced during the underwater phase of launch (with the control system inactive) is found to be 201.5 x 10^6 ft lb, which is less than the maximum erection load.

h. Flight Loads

The most significant flight bending load on the Sea Dragon vehicle occurs at maximum dynamic pressure conditions ($q = 1,600$ lb/ft^2, altitude = 34,600 ft). For this condition a wind-induced angle of attack of 4° is found to give rise to a bending moment of 120 x 10^6 ft lb in the interstage area. The most severe flight load occurs at first stage burnout, and first-stage tank pressures of 80 psi are required to react the 4.2g longitudinal acceleration, which occurs at that time. Although larger decelerations occur at re-entry, the resulting axial loads are smaller than those encountered for the burnout condition noted above because of the much smaller mass during atmospheric flight.

II, F, Vehicle Analysis (cont.)

i. Impact Dynamic Loads

The response of the first stage structure (including the fundamental longitudinal vibration mode) to impact loads was calculated for impact velocities of 300 ft/sec and 600 ft/sec. The relatively long rise time of force during the 300 ft/sec impact condition results in very little dynamic amplification. However, the rise time of the 600 ft/sec impact shock is sufficiently short to cause 93% dynamic overshoot in the acceleration felt at the nose. Figures II-F-1 and II-F-2 show impact accelerations and responses for various velocities and conditions.

Analysis of the effects of impact shock on the nose cone, cylindrical tanks, and the nozzle involves considerations of dynamic buckling. Considerable testing and analytical effort should be directed toward this area in future Sea Dragon studies. The response of specific subsystems to impact loads also remains to be investigated.

On the basis of results of impact studies to date, it appears that impact problems can be handled with presently available technology. A balanced combination of nose cone geometry and impact velocity (using the drag flare design) will result in a practical first-stage structure. The problem of isolating sensitive components is solvable with present packaging techniques.

j. Special Aeroelastic Effects

The problems of flutter of the first- and second-stage nozzles and the possibility of encountering oscillatory side loads during underwater operation were considered. Much further study in these areas will be required to evaluate the flutter possibilities. Oscillatory side loads arising out of flow separation in the nozzle underwater can be controlled or prevented in part by proper design and placement of the ballast plug and rings within the expansion cone.

II, F, Vehicle Analysis (cont.)

k. Propellant Sloshing

Propellant sloshing frequencies have been calculated for several first stage flight conditions. Fundamental mode frequencies ranging from 0.266 to 0.631 cps were found. Since only the higher modes will be excited by the launch transient, sloshing at this time does not appear to be a problem. Later in the flight, slosh frequencies combining with the control system frequencies is possible; however, a judicious selection of slosh suppression devices and control system damping and gain can be made to avoid the problem. Additional work in these areas, guided by analog simulation of the autopilot, is required.

l. Acoustics

A study of the Sea Dragon acoustic environment and its effect on the vehicle was conducted. The principal sources of acoustic environment were found to be: (1) generated by the first-stage engine (185 db); (2) caused by the aerodynamic boundary layer (150 db);

II, F, Vehicle Analysis (cont.)

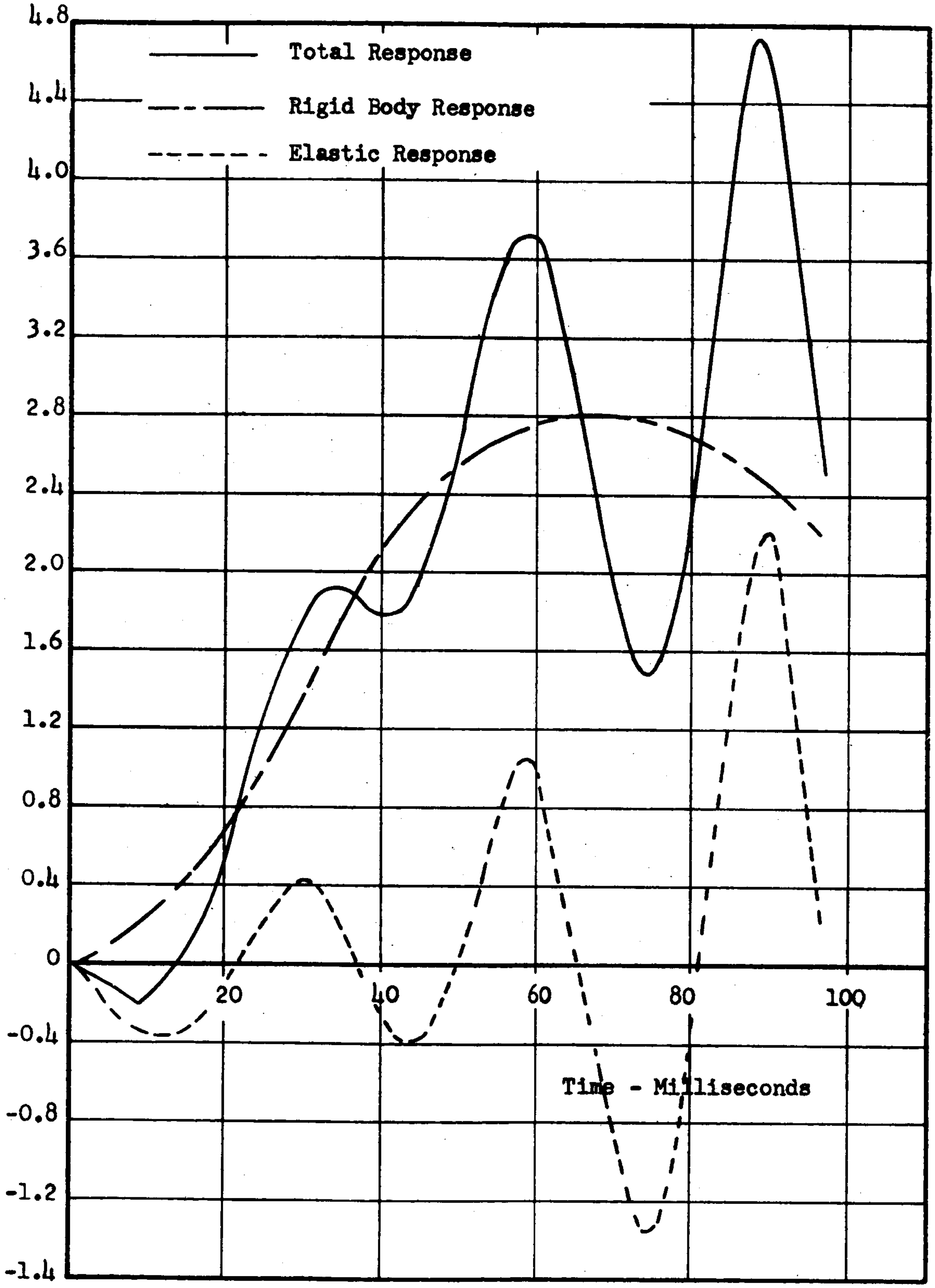
and (3) created by towing turbulence (155 db). The predominance of low frequencies in the rocket motor noise spectrum will result in levels of roughly 150 db at distances of 10 to 15 miles from the source for a duration of one minute A summary of acoustic environments is given in Table II-F-1 and Figure II-F-3.

Vibrational accelerations of 10 to 15g rms are anticipated for the airframe panel vibration modes. High-damped materials may be used to preclude intolerable panel responses.

TABLE II-F-1

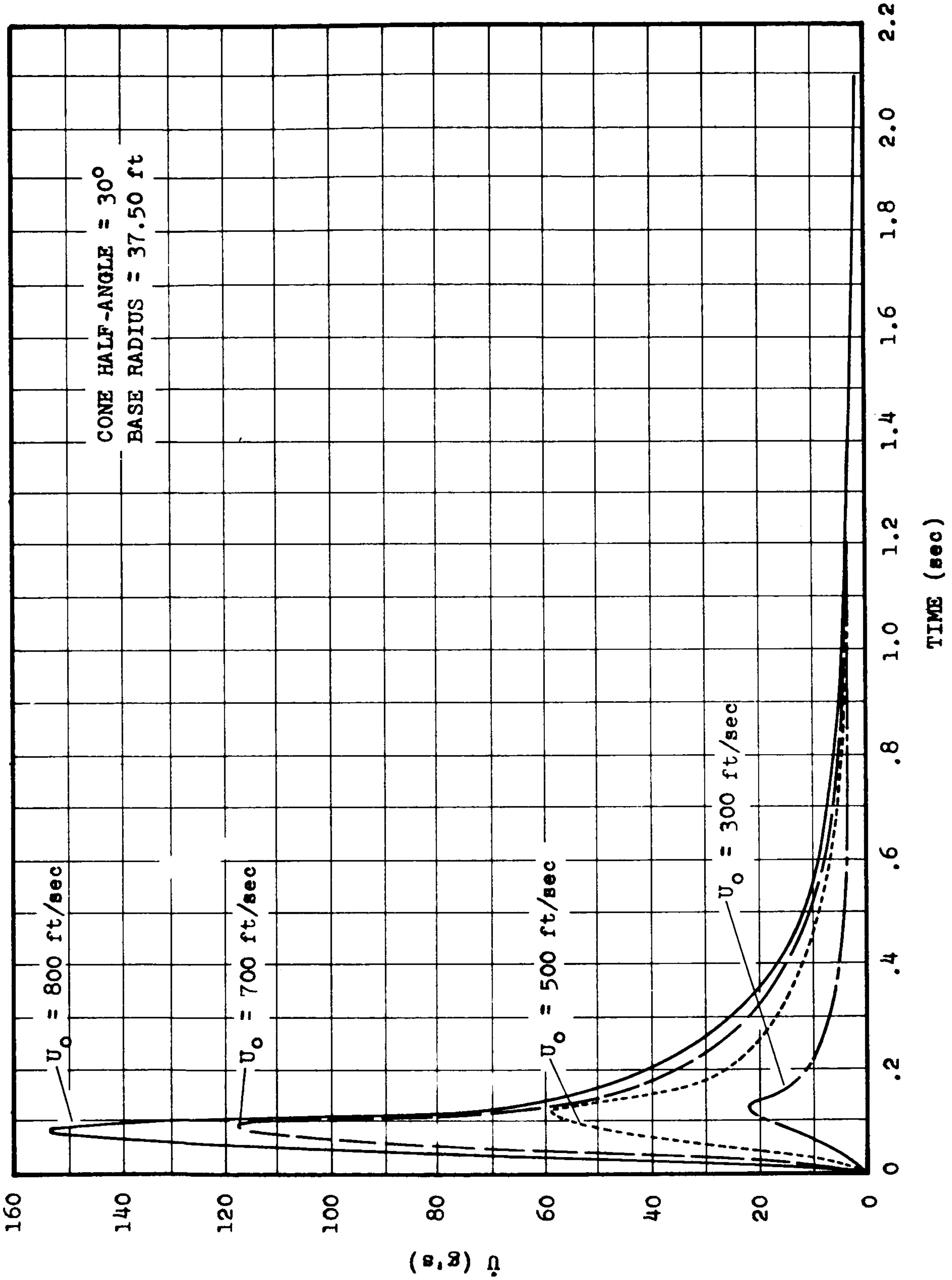
SUMMARY, SEA DRAGON ACOUSTIC ENVIRONMENT EXPERIENCED BY VEHICLE STRUCTURE

Source Description	Type of Spectrum	Frequency Range	Approximate Duration(sec)	Sound Pressure Level(db)	Confidence in Estimate of SPL
Rocket Exhaust Gas Interaction with:					
a. Water	Continuous with Random amplitude	4 cps to 10KC	4 to 5	184 to 190	+3 -10
b. Air	Continuous with Random amplitude	4 cps to 10KC	100	175 to 180	+6 -6
Rocket Engine Combustion Oscillation	Discrete	½ to 5 cps 10 to 1000 cps	60	10 to 20 db above chamber pressures	+12 -6
Surface to Bottom Reflection	Discrete	1 to 10 cps	4 to 5	20 db variations along structure	+6 -6
Towing Noise	Continuous Random Amplitude	50 cps to 5KC	5 hr	150 to 160	+10 -10
Aerodynamic Boundary Layer	Continuous Random Amplitude	50 to 10KC	30	146	+3 -3
Base Pressure Fluctuations	Continuous and Discrete	2 to 50 cps	Flight in Atmosphere	150 to 160	+10 -10



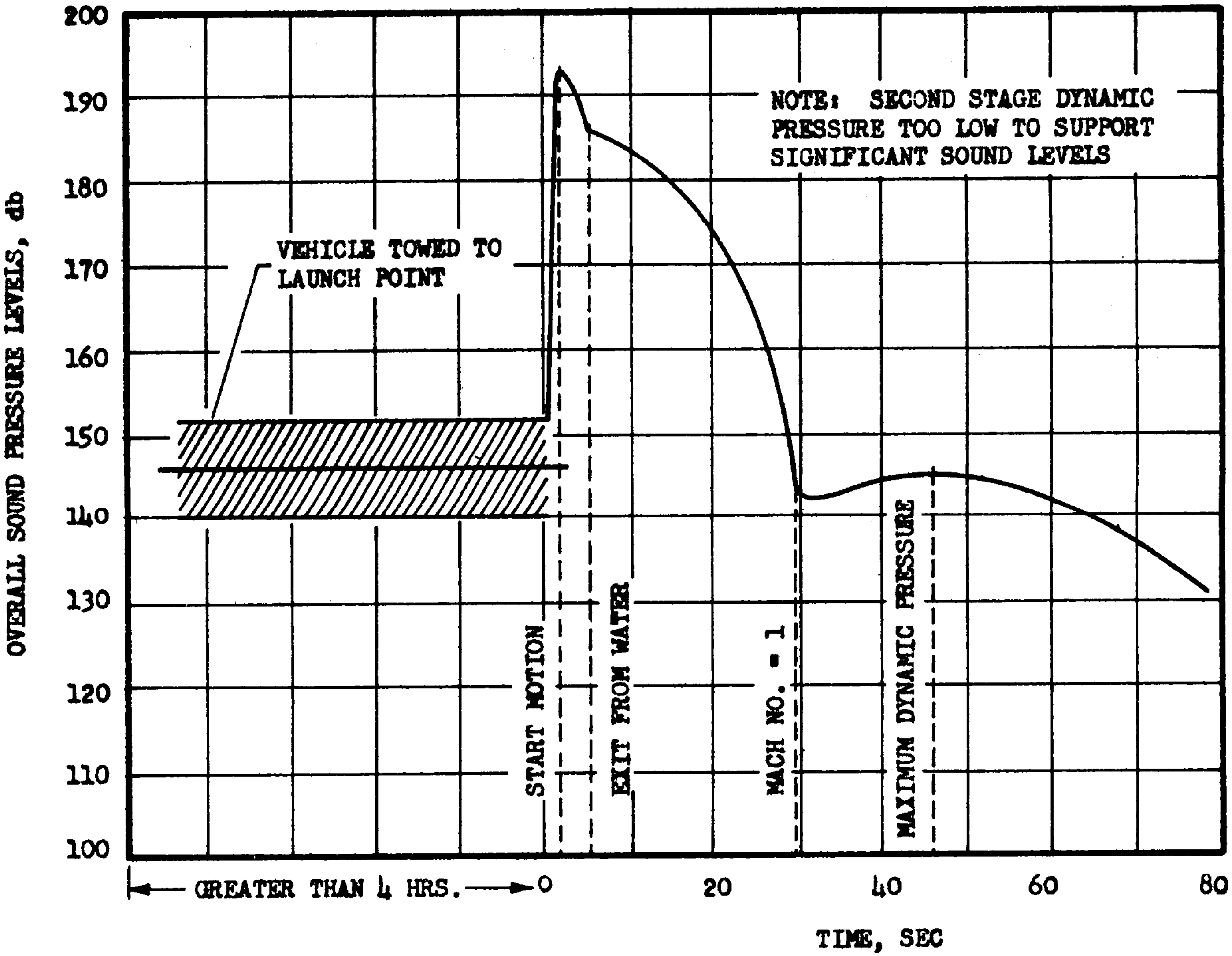
Sea Dragon Impact Acceleration

Figure II-F-1



Impact Acceleration versus Time

Figure II-F-2



Summary of Sea Dragon Noise Environment

Figure II-F-3

III SYSTEMS OPERATION

A. OPERATIONAL PROCEDURES

The operational life of the Sea Dragon covers four major periods--transportation from the fabrication site, assembly of the vehicle stages and checkout, propellant and vehicle servicing, and launch site operations. An operational flow chart defining these functions sequentially is shown in Figure III-A-1. The assembly, servicing and launch operations will be in the vicinity of Cape Canaveral as shown in Figure III-A-2 and III-A-3. The major operational categories are discussed below.

1. Transportation

The transportation of the Sea Dragon vehicle system components from the fabrication activity will be done with conventional ocean transport practice. Smaller parts, such as the vernier engines, will be shipped by land or air transport. Larger components, such as expandable nozzle sections will be shipped by barge and the major components, such as the stages or the assembled vehicle, by ocean-going tug towing the free-floating component. The free-floating barge tow technique is in practice currently in the transoceanic transport of tanker sections of the size of Sea Dragon and in barge operations along the coast. As an example, two 4,200 metric ton tanker bodies, 366 ft long, 80 ft in beam, 44 ft high with a 7-ft draft, were recently towed from Japan to the United States for use in T-2 Tankers.

2. Assembly and Checkout

Final vehicle assembly and checkout operations will take place in a specially dredged lagoon in the Cape Canaveral area (Figure III-A-3 and III-A-4). Stage I, the Stage II and payload section, and the ballast unit will be assembled here using a floating assembly technique (Figure III-A-5 and III-A-6). The various components will be kept under positive control with mooring cables and brought together in the quiet waters of the assembly lagoon. Two major joints--from ballast to Stage I and from Stage I to Stage II--will be made after joining. Figure III-A-5 shows the cable rigging of the stages as they are joined alongside the assembly dock.

III, A, Operational Procedures (cont.)

All continuity functional checkouts and calibrations will be performed in the assembly lagoon. Adequate access to the vehicle along its entire length is ensured by the wharf and crane facilities. The vehicle floats very high in the water at this time; rotation of the vehicle provides access to the complete vehicle. Proper attention to design will ensure access to transducers, lines, valves and other check and service items. If necessary, the vehicles can be rolled through a controlled number of degrees to allow access to normally submerged portions.

After all checkout operations have been satisfactorily completed and the proper functioning of all systems established, hard line and telemetry monitoring will be initiated. This monitoring will function continuously through the launch operations.

3. Propellant Servicing

After proper system operation has been verified, the vehicle will be towed to the fueling point (Figure III-A-3). Fueling the vehicle (LH_2 and RP-1) first in this tankage design would be easier under more controlled conditions, particularly for the LH_2 handling. Draft changes are nominal. Arguments, such as reduced LH_2 boiloff and better towing characteristics, might be made for loading LO_2 first; however, a final decision will depend upon the vehicle design eventually selected. After chilldown and fueling operations are completed, the vehicle will be towed to Point Bravo (Figure III-A-2) where the LO_2 loading barge is moored (Figure III-A-7). The vehicle will be kept under close translational control by mooring lines during the LO_2 operations. After LO_2 tanking is completed, the vehicle will be towed to Point Able, the launch point.

4. Launch Site Operations

Upon arrival at the launch site, final systems checks are made and propellant tanks topped as necessary. With relatively small amounts of insulation (1% of Stage I inert weight and 5% of Stage II inert weight) it is possible to obtain a three-day operational period between the time the LH_2 tank is filled and the time when propellant tank top off is required. This period is available because the propellants are at saturated equilibrium at atmospheric pressure before loading and are held under higher pressure in the vehicle tankage; therefore, some time elapses before the propellants absorb sufficient heat to begin boiling. There is a lower propellant density at the higher saturation pressures. This has been considered in tankage design. After the propellants reach saturation at the higher pressures, boiloff occurs at the rate of 1 to 2% per day for the LO_2 and 5% per day for the LH_2.

After propellant topping off is completed, the ballast unit is gradually filled with high density ballast fluid to destroy its buoyancy. This causes the vehicle to erect itself to the launch attitude. The ballast unit weight varies with the tankage and vehicle configuration chosen; for Configuration No. 134 it is in the order of 10 million lb.

Test data and theoretical dynamic calculations show that the vehicle should function efficiently in sea conditions up to State 5 (wind velocity 20 to 25 knots, wave height 8 to 12 ft) to ensure

III, A, Operational Procedures (cont.)

at least a 95% operational capability. Under these conditions, the vehicle is very stable-maximum pitch amplitude 0.17°, maximum heave amplitude 3 ft. Launching from close offshore from Cape Canaveral should allow dependable launch weather forecasting before the vehicle departs from the fueling point.

Access to the vehicle is accomplished from the service craft (Figure III-A-8) A small vertical service car, Figure III-A-9, transported by the craft, rides on rails permanently affixed to the side of the vehicle. Rails in each quadrant on the outside of the craft permit access to most of the skin. The car can carry men and equipment to any of the portions of the vehicle above water, including the command module (Figure III-A-10). All rails may be used simultaneously when four service crafts are employed (Figure III-A-11). Any final checkout requirements and crew loading or debarking is done with the service car.

After the crew has boarded the vehicle and all systems are ready, the service craft removes its trolley car from the rails and will withdraw to a safe distance. Then the final countdown to vehicle launch is begun.

III, A, Operational Procedures (cont.)

5. Launch Operations

The launch operations command ship that accompanied the tug when the vehicle was towed to the launch site provides support services to the service craft that are completing final launch activities. It provides communication links to the Cape and to the vehicle. When the Cape Control Center clears the launch, the command ship executes the launch of the Sea Dragon. The ship can provide radar services and helicoptor services for special access to the vehicle area and to assure that the general area is clear for launch.

6. Post Fire Recovery Operations

The ballast unit will be staged from the vehicle during the underwater trajectory. It will sink initially and then it will be recovered by inflating internal flotation bags.

The Stage I vehicle will land approximately 170 mi downrange. It will be taken in tow by a tug standing by in the vicinity and returned to the assembly lagoon for refurbishment.

	LOGISTICS				OPERATION	
SEQUENCE	FUNCTION	FROM	TO	TIME IN DAYS	DESCRIPTION	EQUIPMENT
1.	Transport Stage I	Component Fabrication Point (West Coast)	Lagoon at Cape Canaveral	40 days @ 5 Knots	Towing of Stage I via ocean from manufacture point to assembly area at Cape Canaveral	1 seagoing tug 2 sponson units & tow gear 4 vehicle belts
2.	Transport Stage II & payload	Component Fabrication Point (West Coast)	Lagoon at Cape Canaveral	40 days @ 5 Knots	Towing of Stage II and Payload via ocean from manufacture point to assembly area at Cape Canaveral. Transport TVC engines & Expandable Nozzle.	1 seagoing tug - 4 vehicle belts 2 sponson units 1 powered barge 4 engine containers service module container
3.	Transport Command Module	Component Fabrication Point	Lagoon at Cape Canaveral		Transportation of the Command Module and Service Module to assembly area.	Rail car or barge Handling crane
4.	Position Stage II and Payload	Lagoon Area		.5	Position Stage II and Payload in assembly slip.	4 winches 4 drilled in anchors
5.	Assy and Checkout-Stage II & Payload	Lagoon Area		3	Assy & c/o of Stage II and Payload. Install service module equipment. Install flight instrumentation. Remove flotation & navigation gear.	Stage II E/M checkout equipment Flight instrumentation hardware
6.	Position Stage I & Ballast Unit	Lagoon Area		.5	Position Stage I & Ballast Unit in assembly slip.	4 winches 4 drilled in anchors
7.	Assembly and checkout - Stage I & Ballast	Lagoon Area		2	Assembly & c/o of Stage I & Ballast Unit. Install flight instrumentation. Remove flotation & navigation gear.	Stage I E/M checkout equipment Flight instrumentation hardware
8.	Command Module Checkout	Lagoon Area		10	Assembly & c/o of Command Module	Command Module E/M checkout equipment. Command Module handling equipment.
9.	Final Vehicle Assembly	Lagoon Area		5	Final mating and assembly of the vehicle stages. Install expandable nozzle. Install command module. Install separation charges with S/A devices.	8 winches - 8 drilled-in anchors - 8 vehicle belts - 2 cranes - 2 nozzle slings - 1 automatic welder - 12 hydraulic alignment units - 2 ballast transfer units - command module handling equipment - 4 sponsons
10.	Vehicle Systems Test & Checkout	Lagoon Area		2	E/M systems tests, and checkout of the complete vehicle using service vessel and ground TM station or launch control vessel.	1 service vessel - Ground TM Station or Launch Control Vessel - 1 crane - 4 vehicle belts
11.	Load Ordnance	Lagoon Area		.05	Load TEA, Escape Rockets and Destruct Charges.	1 crane
12.	Transport to Fuel Service Area	Assembly Lagoon	Fuel Service Area	.1	Tow vehicle from the Assembly Slip to fueling area.	2 seagoing tugs - 1 service vessel - 2 sponsons - 4 vehicle belts
13.	Load Fuel	Fuel Area		.1	Secure vehicle to loading wharf. Attach Fuel Fill & vent lines. Attach facility controls to service vessel-load fuels	Fuel Facility - 4 drilled-in anchors & winches - 1 service vessel - 2 sponson units - 4 missile belts
14.	Transport to LOX Service Area	Fuel Area	Point Bravo	.2	Tow fueled vehicle from the fueling area to Point Bravo.	2 seagoing tugs - 1 service vessel - 2 sponson units - 4 vehicle belts

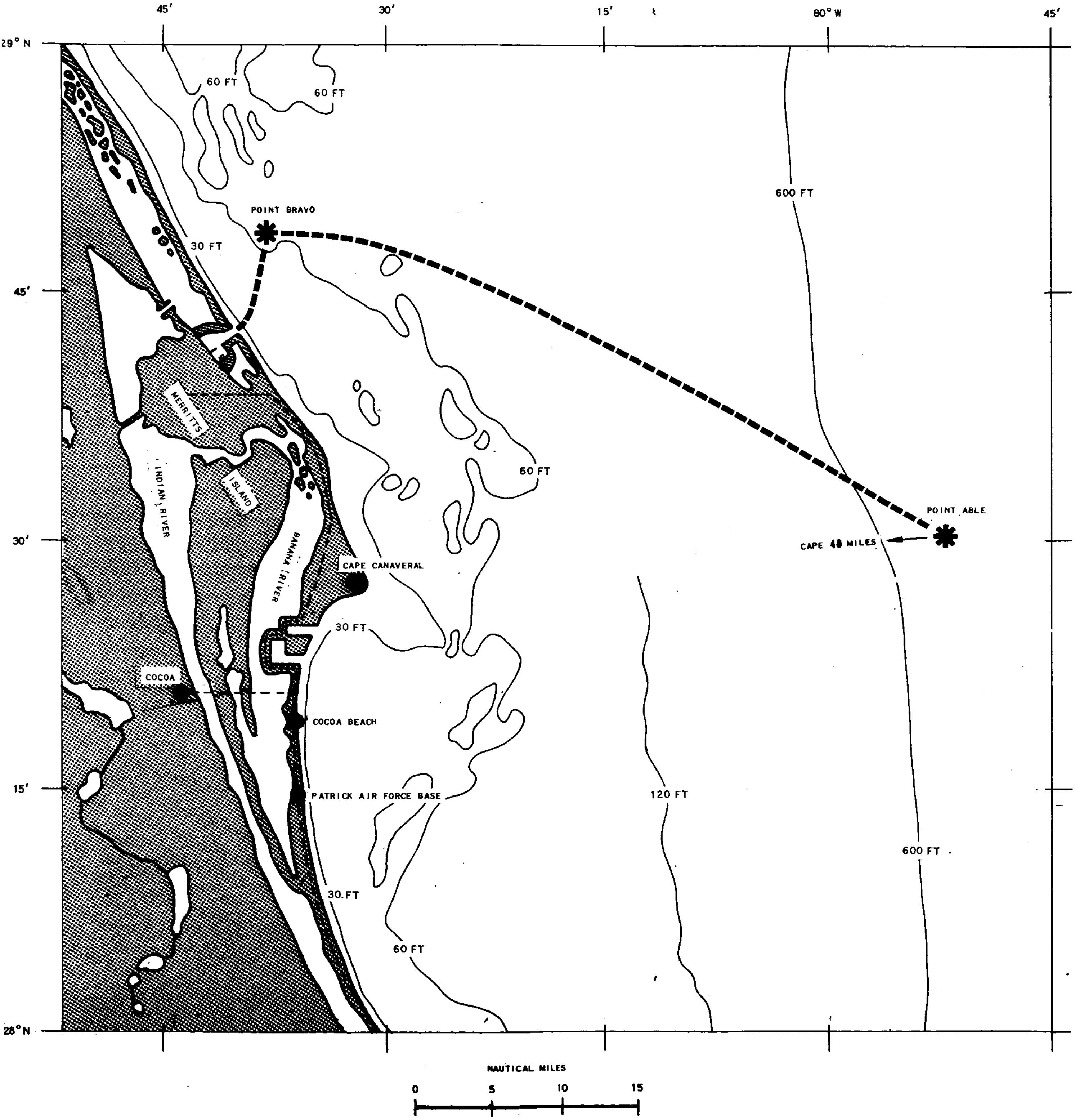
Operational Flow Chart

Figure III-A-1

15.	Load LOX	Point Bravo		.1	Secure vehicle to LOX barge. Attach LOX barge controls to service vessel. Attach LOX fill & vent lines.. Load LOX	LOX Barge - 6 drilled-in anchors & winches - 1 service vessel - 2 sponsons - 4 vehicle belts
16.	Transport to Launch Area	Point Bravo	Point Able	.4	Tow loaded vehicle to the launch site at Point Able.	2 seagoing tugs - 1 service vessel - 2 sponson units - 4 vehicle belts
17.	Checkout and erect vehicle	Point Able		.1	Perform final checkout of vehicle. Release sponson units. Disperse ballast recovery buoys. Erect vehicle. Attach positioning tug cable.	1 launch control vessel - 1 seagoing tug - 1 service vessel - 1 work boat - 1 ballast storage barge - 2 ballast recovery buoys
18.	Perform Final Servicing	Point Able		.2	Attach vertical service car. Load crew members. Perform final vehicle check	1 launch control vessel - 1 seagoing tug - 1 service vessel - 1 vertical service car
19.	Perform Launch Countdown	Point Able		.1	Remove vertical service equipment. Remove all ships from area. Perform launch	1 launch control vessel or relay ship and ground facility - 1 service vessel
20.	Recover Ballast	Point Able	Assembly Lagoon		Recover ballast unit buoys. Inflate recovery bags. Tow to assembly area.	1 seagoing tug - 1 work boat
21.	Recover Stage I		Assembly Lagoon		Recover Stage I. Attach tow cables. Tow to assembly area.	1 seagoing tug

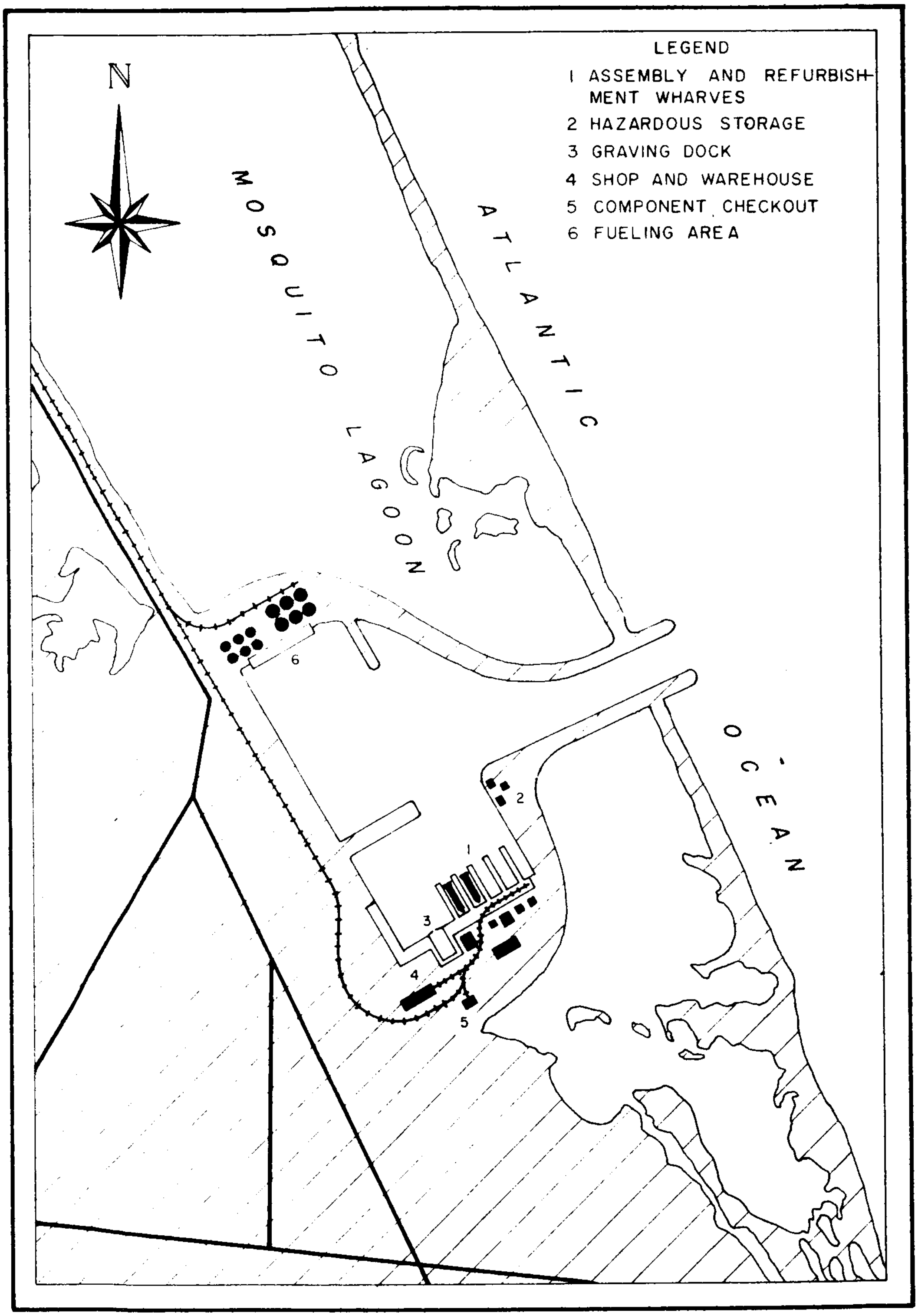
FIGURE III-A-1

Operational Flow Chart (cont.)



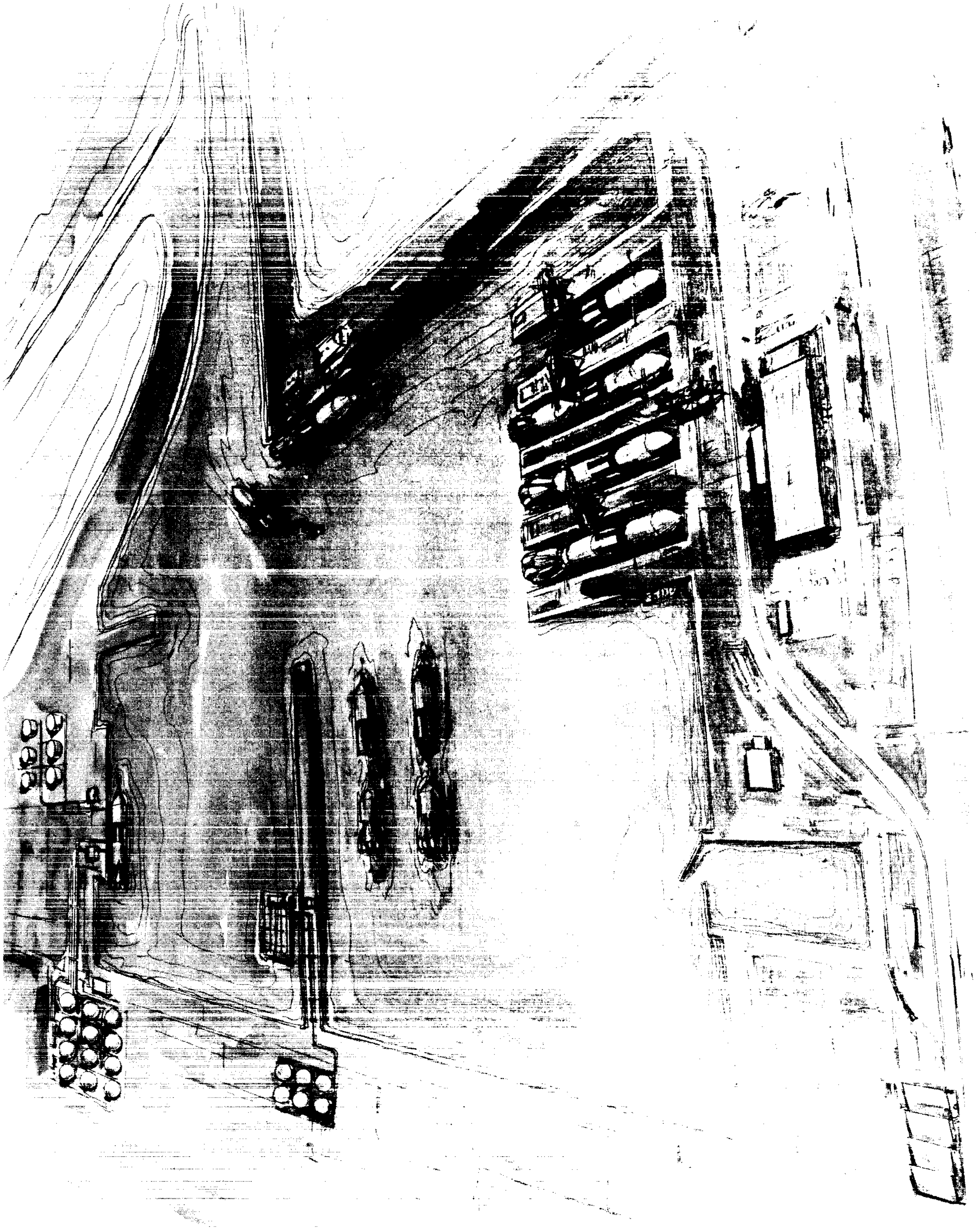
Servicing Area Map

Figure III-A-2



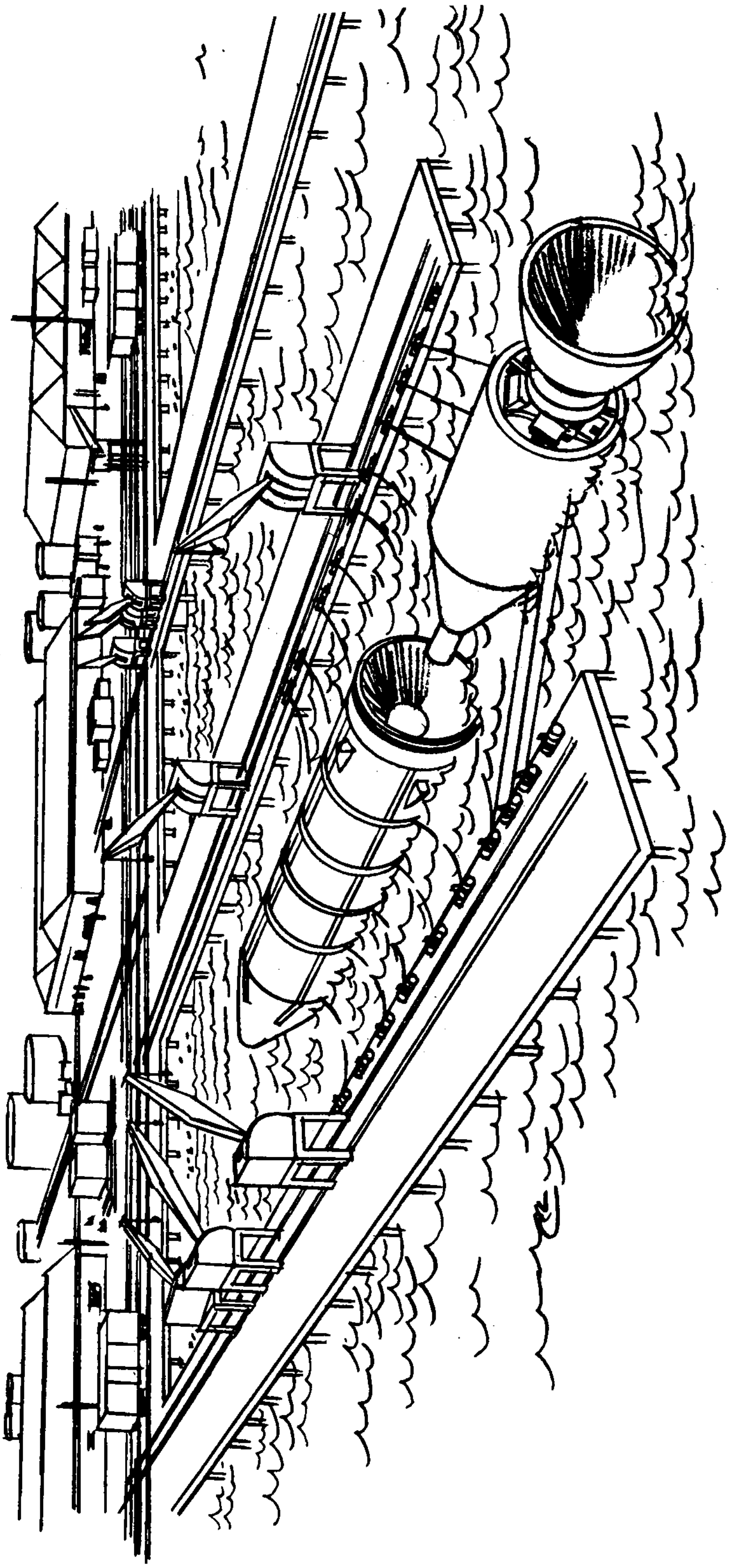
Assembly Lagoon--Plan View

Figure III-A-3



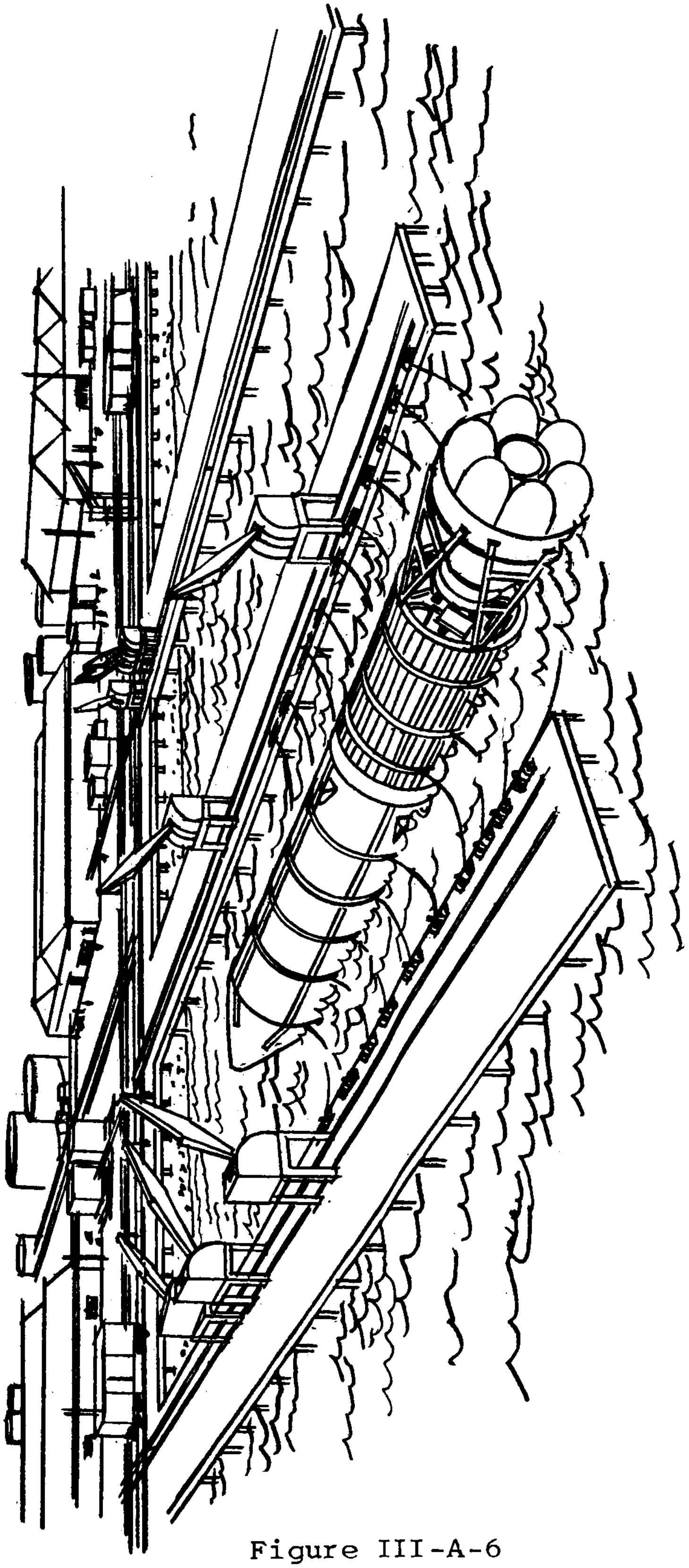
Assembly Lagoon--Artists Concept

FIGURE III-A-4



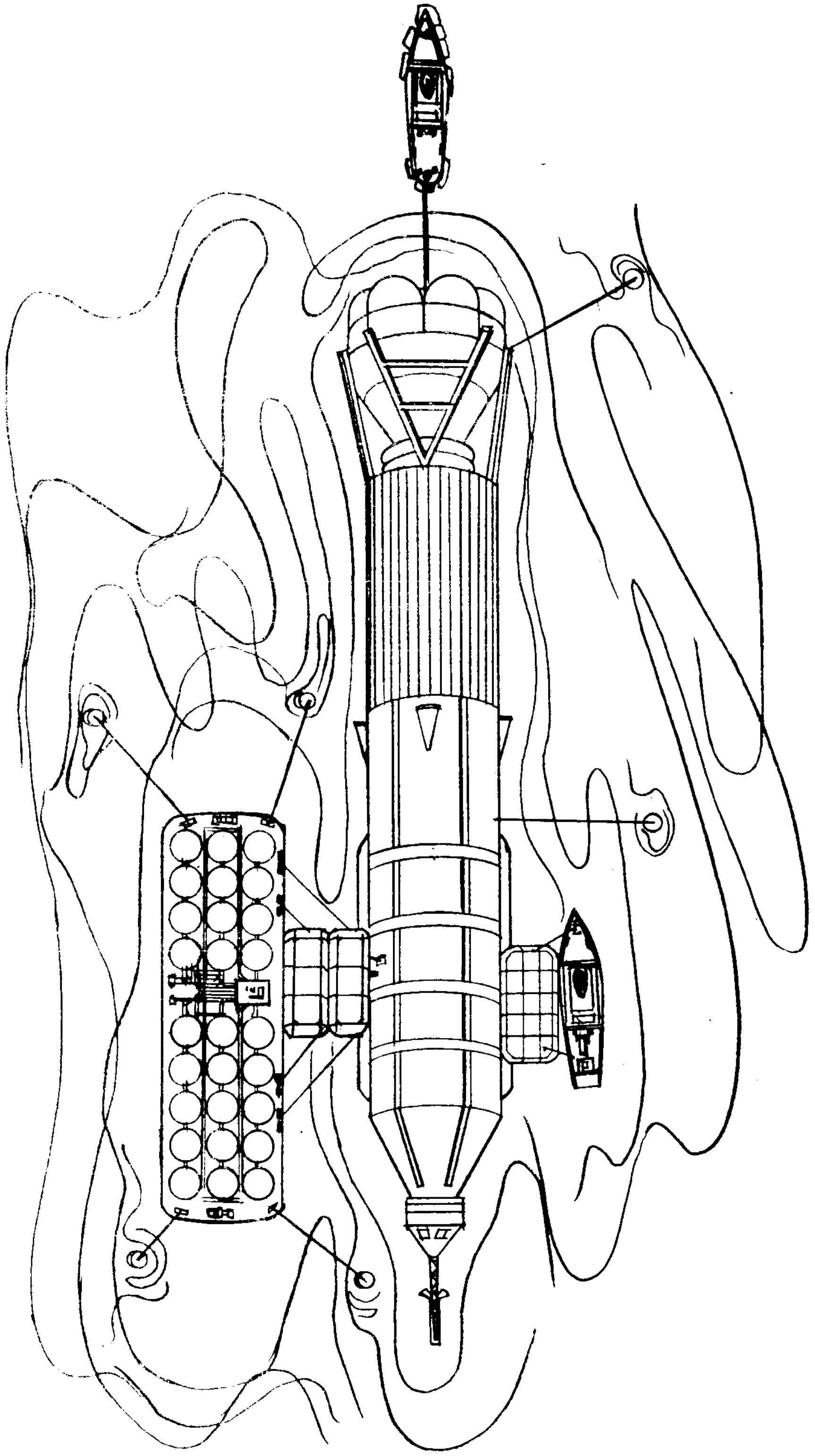
Stage Assembly Technique

Figure III-A-5



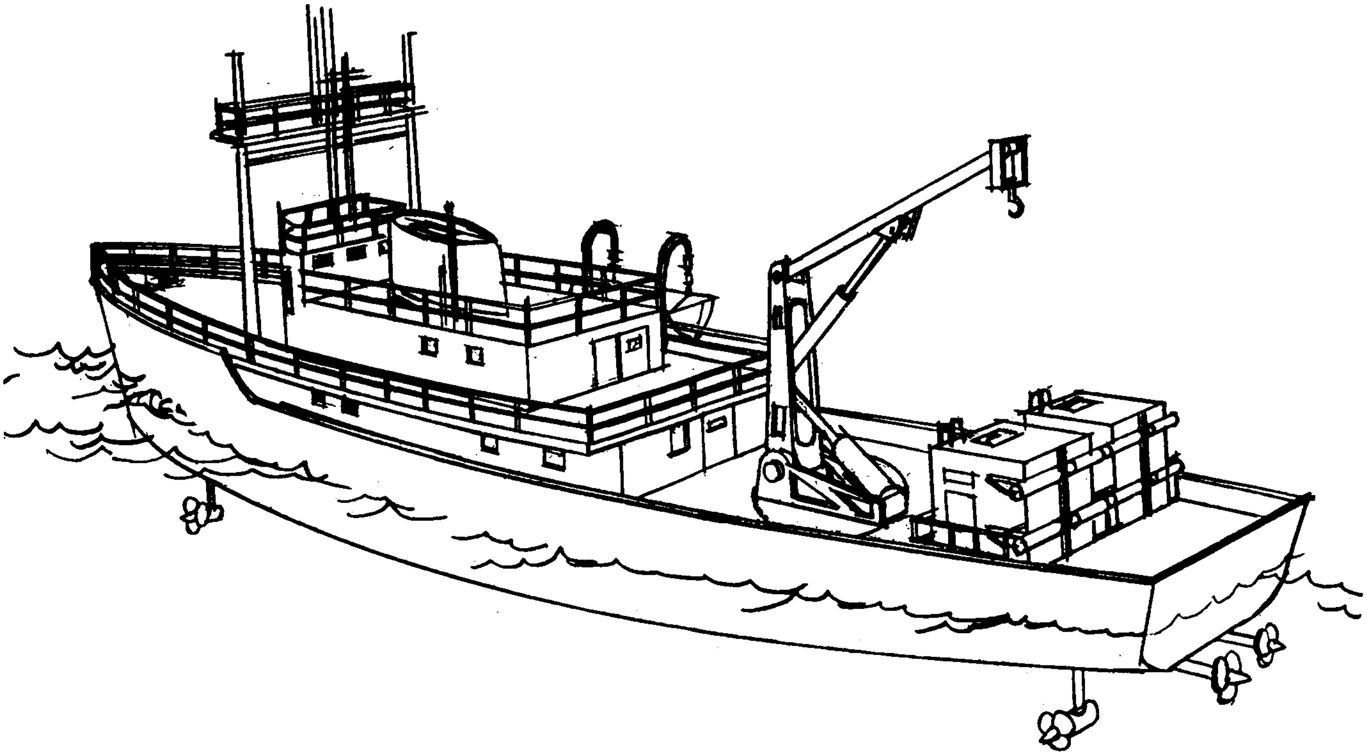
Ballast in Place

Figure III-A-6



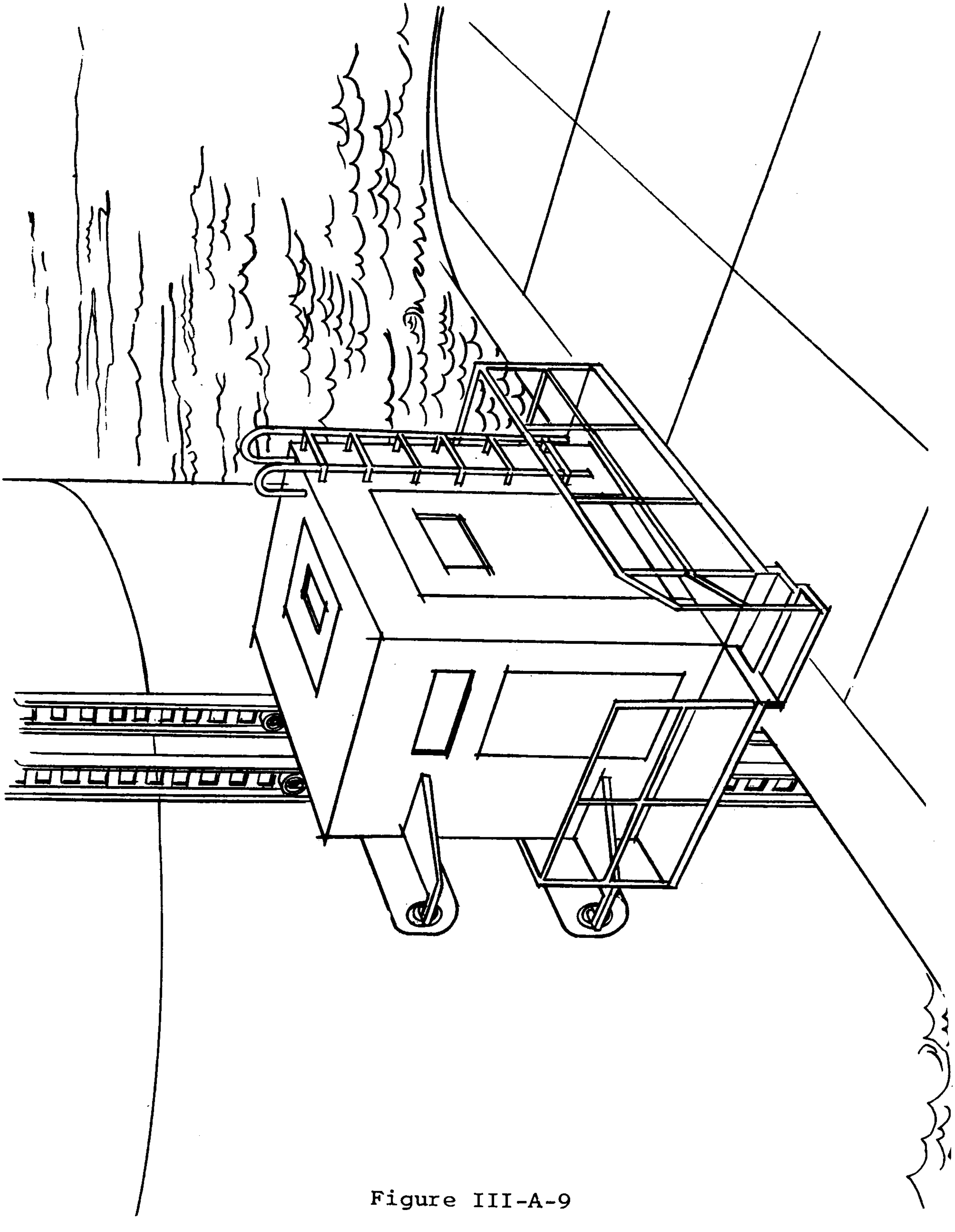
LO$_2$ Loading

Figure III-A-7



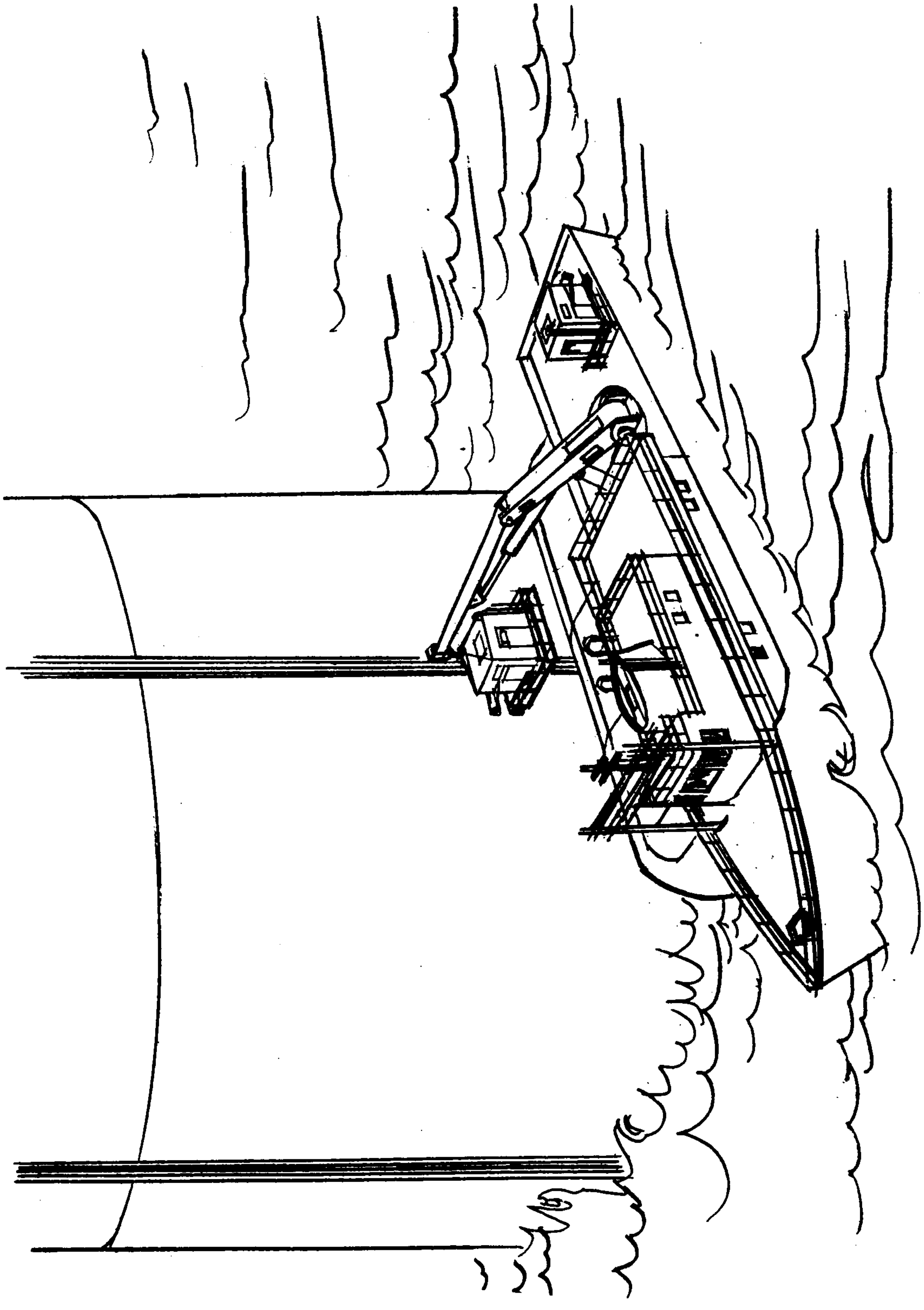
Service Craft

Figure III-A-8



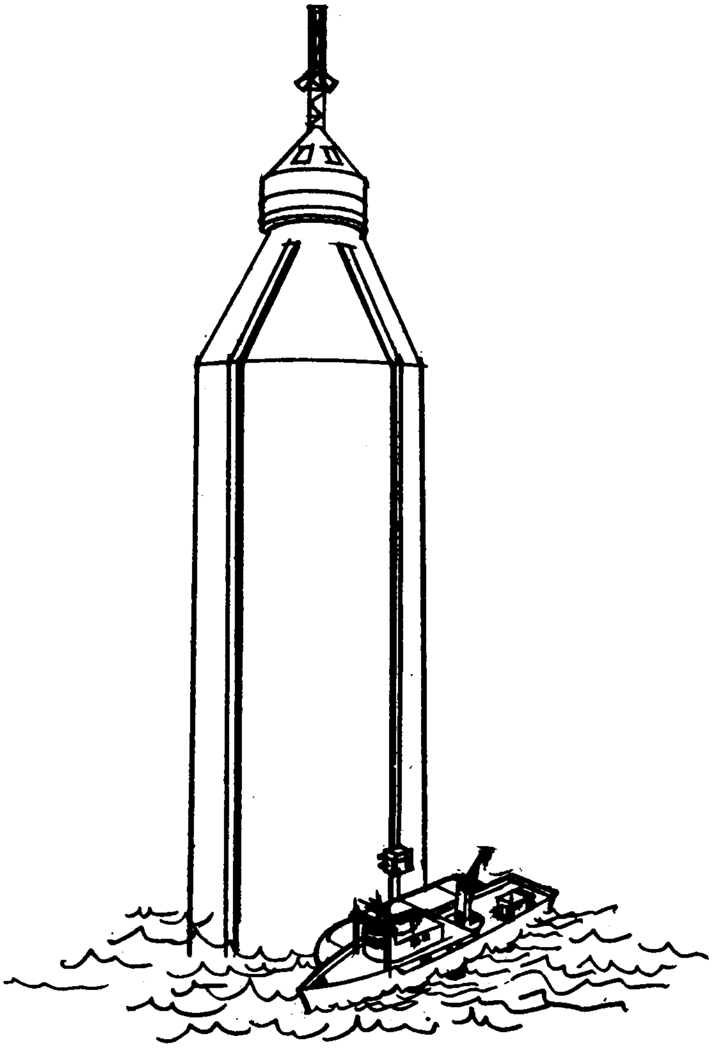
Vertical Service Craft

Figure III-A-9



Vertical Access Equipment

Figure III-A-10



Vertical Servicing

Figure III-A-11

III, System Operations (cont.)

B. SUPPORT EQUIPMENT AND FACILITIES

1. Facilities

a. Manufacturing

The major components of the vehicle, the propellant tanks, the main engine and the ballast unit are within the capacity of existing shipyard dry docks or building ways. Tooling, jigs and fixtures peculiar to the vehicle will be required; however machine tool needs will depend upon the facility selected. Smaller components such as the thrust vector control engines, the guidance system and the command capsule would use existing aerospace facilities. Upgrading of shipyard fabrication precision and inspection requirements will require corresponding equipment. This general facilities situation indicates that no problems are expected in obtaining suitable facilities and that the costs should be substantially less then in similar programs. The development techniques for jigs and fixtures for other large structural programs are directly applicable to Sea Dragon.

The provisioning of mill and rolling facilities for production of the thick basic tank plating is included in the suppliers plate price.

III, B, Support Equipment and Facilities (cont.)

b. Development

In the fabrication of both developmental and operational vehicle components, the same or similiar facilities will be used; no unusual problems peculiar to developmental components is evident. The developmental test equipment also would be fabricated in the same facilities as the operational equipment for open ocean testing. Special land based facilities will already exist under other NASA projects for those special land based tests. Supporting services for the test program at sea (e.g., tugs, barges, etc.) are available commercially or on a charter basis; and they could also be otained from government reserve equipment stocks.

c. Operational

New facilities will be required primarily to establish a suitable sea operating base at Cape Canaveral because none now exist. The basic facility is an assembly lagoon located to the north of the Cape well away from present launch installations (Figure II-A-3). A channel will be dredged from deep water, through the coastal land strip, and into the existing lagoon. The lagoon area will be deepened and the dredged material will be used to wall in the

III, B, Support Equipment and Facilities (cont.)

desired area. Supporting docks, supply and equipment buildings, cranes, and instrumentation installations will be constructed. A fuel storage and pumping facility will be established. Supporting utilities and access roads will be needed. Although the propellant production facilities are included in the price of the propellants, it may develop that the rate of propellant use is sufficient to warrant the supplier to construct production facilities nearby.

These total base facilities are very conventional for ship operations, and costs are readily predictable. No block houses, special fabrication facilities, special transport system or launch pads are required as for land launched vehicles.

Other operational facilities will be needed such as the oxidizer loading barge, the service vessel, and the vehicle associated small equipment (e.g., floats, camels, anchor gear, buoys, towing gear, and the trolley car). The vehicle ballast might also be placed in this catagory. The remainder of the servicing equipment needed would be conventional tugs, work boats, testing and checkout instrumentation, and land based materials handling equipment. Some high capacity fluid handling equipment will be needed for propellant

III, B, Support Equipment and Facilities (cont.)

servicing and ballast filling. The degree of special equipment required will depend upon the importance of high flow rate servicing.

2. Equipment

The support equipment requirements fall into two general catagories:

a. Standard Equipment Components

Existing available instrumentation for inspection, check out and services (e.g., pumping, communication, local auxiliary power, tools, etc.) would be required and normally would be placed in building installations, on trucks or trailers at the lagoon, or in conventional boats, barges or tugs participating in the operation. Cryogenic handling equipment would be conventional although the Sea Dragon size could necessitate multiple units. Checking and control panels would contain aggregates of common instruments, data handling units, and recording equipment.

III, B, Support Equipment and Facilities (cont.)

b. Special Equipment

The cryogenic tank capacities could be supplied by multiple existing tanks or larger custom units as the budget dictates. Specially formed bumpers, floats, and towing bridles would be needed as would special bridles and handling gear for the expandable nozzle installation. Considerable use of portable nondestructive testing and inspection equipment would be expected in the examining of recovered stages. Recovered stage disassembly is not planned thus precluding special handling equipment.

c. Special Equipment Complexes

The special equipment complexes could be considered as special ground support equipments; these are very limited in number.

The lagoon checkout complex is actually nothing more than a dockside adajacent to an equipment building. Cables and piping lead to the vehicle that is being checked out alongside the dock. The building equipment consists of the previously mentioned conventional checkout components.

III, B, Support Equipment and Facilities (cont.)

The service vessel is a moderate size ship with special installations. It is a very flexible, reliable vessel (80 to 100 ft long) and will accompany the rocket vehicle from the time it leaves the assembly lagoon until shortly before launch. It controls propellant servicing operations, acts to monitor all systems, and provides some checkout and trouble shooting functions. The special requirement which differentiates this from conventional vessels (other than the addition of rocket ground support equipment) is the necessity for maintaining close translational control between the servicing vessel and the rocket vehicle. The special access barge aids in this operation by limiting direct service vessel contact with the launch vehicle.

Should there be a desire to provide direct launch site control of the launch operation and secondary services, it is possible to adapt an existing available sea plane tender (AV-1) to a rocket tender configuration with the capacity for communications, limited tracking, command control (as provided in the land based block house), and hotel services for a work and servicing crew. Many other useful support functions at the launch site, such as small boat services, helicopter services and observation facilities for visiting dignitaries may be provided. Such a rocket·tender would provide a largely self-sufficient task force at the launch; however, the services are not included in the budget for the study.

C. STAGE RECOVERY AND REUSE

Booster recovery and reuse can play a very important role in realizing the low payload delivery costs required for the establishment of truly large scale space launch programs. Therefore, emphasis has been placed on developing a recovery concept for Sea Dragon that is simple and reliable in operation and represents a low weight penalty for the vehicle.

The size, weight, and, in part, the complexity of a vehicle recovery system are functions of the allowable touchdown or impact velocity. Conventional boosters require very soft landings because of their basic structural design. The Sea Dragon, by virtue of its pressurized tanks, has considerably more structural strength than other proposed vehicles. As a result it can, in general, withstand higher impact velocities and associated load environments. Thus, the complexity and weight of the Sea Dragon recovery system should be much lower than other comparable systems.

III, C, Stage Recovery and Reuse (cont.)

The ability of the Sea Dragon structure to withstand higher impact velocities is a fortunate one because there is a scale effect for very large boosters in general that places much higher requirements on the recovery system. This size-scale effect can be shown quite simply: for recovery methods, which depend on aerodynamic deceleration to final velocity, the ratio of accessory drag device diameter to the vehicle diameter can be expressed as follows:

$$\frac{D_a}{D_v} = \sqrt{\frac{8W}{C_{da}\,\rho\,V_i^2 D_v^2} - \frac{C_{dv}}{C_{da}}}$$

where ρ is the atmospheric density, V_i is the impact velocity, C_d is the drag coefficient, and the subscripts a and v refer to the accessory device and the booster vehicle, respectively. For geometrically similar bodies with comparable structural efficiencies, the diameter ratio can be written as:

$$\frac{D_a}{D_v} = \sqrt{K_1\,D_v = K_2}$$

III, C, Stage Recovery and Reuse (cont.)

thus, the drag diameter to body diameter ratio, for a fixed impact velocity, increases as vehicle size increases. If the Sea Dragon used conventional low pressure tanks with inherent lower structural strength limited to an impact velocity of 20 to 30 ft/sec, the necessary drag diameter (e.g., provided by a parachute) would be about 3,200 ft.

The Sea Dragon operation is based on the sea launch concept, hence final vehicle recovery and retrieval can take place at sea. Final deceleration of the expended booster can be caused by water impact forces. Because the Sea Dragon booster vehicle can take advantage of its increased strength in accepting higher impact velocities, it is important to know quantitatively, the water impact pressures and decelerations. An analysis of the water entry load environment and vehicle structural response was conducted. The following sections summarize this analysis.

III, C, Stage Recovery and Reuse (cont.)

1. Water Entry

a. Pressures and Deceleration During Water Entry

The pressure distribution over the conical nose as a function of immersion depth is shown in Figure III-C-1. This particular plot is based on an initial impact velocity of 600 ft/sec. The plot may be used for any initial impact velocity by using the nondimensional pressure $P' = \frac{P}{\frac{1}{2} \rho_w \nu_o^2}$ where P is the actual static pressure, ρ_w is the density of sea water and ν_o is the initial water entry velocity. Consequently, the pressure can be scaled according to the square of the initial impact velocity ratio. Thus, the maximum pressure for an initial velocity of 300 ft/sec is approximately 650 psia and occurs at the cone apex. Experimental pressure distributions obtained with scale booster models at the Aerojet-General water entry test facility indicates that this distribution is suitable for initial estimates. Figure III-C-2 shows, for the cone immersion portion of entry, the nondimensional depth of penetration, velocity, and deceleration versus nondimensional time. The immersion depth (I) shown in Figure III-C-1 can be correlated to the proper time of immersion (this is a critical factor in determining the structural response of the cone to the pressure loads). Figure II-D-13 illustrates the deceleration-time history, during flow establishment over the cone, for several initial entry velocities. Figure III-G-5 shows the complete deceleration history during the entire water entry phase, from initial penetration to maximum penetration.

b. Determination of Allowable Impact Velocities

(1) Propellant Tank Stresses

Using the deceleration-time data from Figure II-D-13, a criterion for determining allowable impact velocity was established: the structural response of the empty booster was found to have a first mode longitudinal natural frequency at 30 cps and a first mode bending frequency at 13 cps. Comparison of these frequencies with the impact frequency of the water entry loading

III, C, Stage Recovery and Reuse (cont.)

(Figure II-F-2 shows that no dynamic load amplification is probable for impact velocities less than 500 ft/sec. A general criterion using a dynamic load amplification factor of one can be established that relates impact velocity with the internal tank pressure required to react the associated water entry loads. This criterion is based on the conservative assumption that the cylindrical tank wall cannot accept any compressive stresses. Thus, the compressive stresses caused by the maximum deceleration inertia loads can be equated to the longitudinal tension stresses caused by internal pressure. Figure II-D-14 shows the results of this calculation. The proper impact velocity for the available internal pressure can be selected using this plot. For the pressurization system used in this design the LO_2 tank pressure at burnout is approximately 100 psia which corresponds to an impact velocity of 300 ft/sec in Figure II-D-14. The remaining vehicle structure (nose cone and components) were based on this velocity and the associated pressures and acceleration.

III, C, Stage Recovery and Reuse (cont.)

(2) Conical Nose

(a) Stresses

The dynamic stresses in the conical nose were analyzed using Figure III-C-1 and reducing the pressure for an impact velocity of 300 ft/sec. Preliminary results show that the stress levels in the tank wall during impact are below the material yield value, except in an area near the cone apex.* Stresses at this point may exceed the failure point and a reinforced apex may be required. However, the extent of the area over which this condition exists is small (approximately 10 ft) and the weight penalty is negligible.

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* It was also shown that membrane stresses, rather than bending stresses are predominant.

III, C, Stage Recovery and Reuse (cont.)

(b) Stability

Experimental results show that material failure is not the design criteria for nose cones such as used on Sea Dragon but rather that geometric or buckling instability is the mode of failure (as might be expected). While complete mathematical analysis of the buckling problem has not been completed, it has been shown by a simplified analysis that some stiffening will be required to stabilize the cone under the transient pressure loading. However, the weight penalty due to installing circumferential T-type stiffeners is very small, 4% of total cone shell weight and approximately 0.4% of the first stage inert weight. For stability purposes, it was found that approximately ten stiffener rings were required, spaced equally between a point approximately 6 $\frac{1}{2}$ ft from the apex and the cone base. The stiffeners were of thickness t, equal to the shell skin thickness, a depth of 10 t, and u flange width of 5 t.

III, C, Stage Recovery and Reuse (cont.)

(c) Vehicle Components

A major factor in the structural integrity of vehicle subassemblies is the amplification of the input acceleration pulse by vehicle resonances. For subassemblies whose mass is small relative to the vehicle, the input is more easily described as an acceleration pulse at the base of the attachment structure. This acceleration is a function of the amplification in the longitudinal mode and the location of the tie-down structure in the mode-shape. Components and subassemblies that are highly sensitive to these loads will be located as close to the nodal point of this mode as possible. Preliminary study of the subassembly attachments under a 22g deceleration pulse shows that stiffened and strengthened structure would be required which would impose a weight penalty of 2.0% of booster inert weight. Consideration of the thrust chamber dynamic interaction with gimbal joint and tankage indicates that structural stiffening of the gimbal joint would be required. The weight penalty because of the required increased structural strength is approximately 0.5% of booster inert weight.

III, C, Stage Recovery and Reuse (cont.)

2. Selection of the Aerodynamic Deceleration Device

Three basic recovery systems were selected for study: inflatable aerodynamic decelerator; large nozzle flare; and parachute. All of the systems studied, with the exception of the large nozzle flare, were required to yield impact velocities of 300 ft/sec, the allowable velocity based on available tank pressure for structural stability (Figure II-D-14). In each case the same basic recovery operation was followed: the first stage of the vehicle continues after burnout along its ballistic trajectory, re-enters the atmosphere and impacts the ocean surface at terminal velocity. Each recovery system examined was required to provide proper aerodynamic stabilization and drag for the given impact conditions. The aerodynamic decelerator was chosen as the most promising system on the basis of overall reliability, weight, and performance.

III, C, Stage Recovery and Reuse (cont.)

a. Parachutes

Recovery of the Sea Dragon first-stage booster with a single parachute requires a parachute diameter of 2,700 ft to attain the required impact velocity. Such a complete recovery system weight, including a 45-ft drogue parachute for main chute deployment would be approximately 0.7% of the total recovered weight. Supersonic deployment, at Mach No. 1.8 to 2.0 of the drogue chute deployment was assumed. Use of several smaller chutes was considered; however, the total weight of a clustered system was approximately the same as a single chute system. Deployment reliability of a clustered system appears to be lower than for a single chute.

Even though the parachute system appeared very favorable from a weight standpoint, some important disadvantages were found in initial atmospheric entry and deployment: the Sea Dragon booster, without accessory devices, has poor aerodynamic stability and at best is neutrally stable. Thus with a tumbling re-entry, as could be the case because of the staging tipoff torques, the problem of reliable parachute deployment is a serious one. The prediction of tumbling rates during re-entry is very difficult. Whether or not stable equilibrium at some angle of attack is reached before impact also poses an involved analysis program. Attitude and rate sensors must be utilized in the booster so that parachute ejection and deployment can be sequenced properly. If low-drag fin stabilization devices are used to provide sufficient stability for a stable flight path, the rapid descent of the booster allows insufficient time for parachute deployment, for with a stabilized (with fin) descent, a Mach No. of 1.8 is reached 105 sec after initial entry, and impact occurs at 113 seconds. Deployment at higher velocities to obtain a longer deployment interval presents severe problems in parachute stability and deployment (ref NASA TN D752). Therefore, based on overall ease of operation and reliability, the parachute was not considered practicable.

III, C, Stage Recovery and Reuse (cont.)

b. Large Nozzle Flare

A recovery system with the highest reliability possible, would be possible when almost complete passive operation is used. One configuration that provides this feature is the basic Sea Dragon first stage using a very large area ratio engine nozzle. The function of the large nozzle is to provide re-entry stabilization and drag forces that would give the proper velocity and attitude at impact. For this particular system, the exit diameter required for water entry velocity of 300 ft/sec was impractically large from a structural and thrust coefficient standpoint, so a modification of the pressurization system was made to provide a cone tank pressure of 400 psi. An impact velocity of 600 ft/sec corresponds to 400 psi in Figure II-D-14. A nozzle diameter of 175 feet is required (for a 20° half angle conical nozzle) to obtain 600 ft/sec impact velocity. The payload penalty associated with the additional drag losses during ascent, increased nozzle weight, additional structure in the components, specific impulse loss due to over-expansion, and increased outage gas weight was approximately 18%. This payload penalty and the additional fabrication and other associated problems over-shadow the high recovery reliability available with this system.

c. Inflatable Aerodynamic Deceleration

An inflatable aerodynamic decelerator that incorporates a high degree of reliability with reasonable weights and deployment simplicity and provides the necessary drag and stability during atmospheric entry could combine the best features of the systems discussed previously. Basically, it is an inflatable conical flare attached to the thrust chamber of the booster (Figure III-C-3). The base diameter of the flare required to provide an impact velocity of 300 ft/sec is 300 ft. The flare consists of a large, 30-ft diameter torus made rigid with smaller inflatable tubes (spokes) 10 ft in diameter. The torus and supporting tubes are constructed of rubberized nylon-dacron reinforced fabric and are protected from the thermal environment by the outer skin. The outer skin is an ablating rubberized

III, C, Stage Recovery and Reuse (cont.)

asbestos fabric that is replaced for each flight. The outer skin is kept in tension and reacts the air loads (design aerodynamic external pressure was 5 psia) by the reaction of the tubes on the torus structure.

The flare structure is inflated to a maximum of 30 psia with methane pressurant gas from the first-stage fuel tank. The volume of the torus and tubes is such that the fuel tank retains sufficient pressure to react the water impact loads.

The conical flare provides low terminal velocity and high aerodynamic stability, yet presents no drag penalty during ascent. The weight of the complete system is approximately 3.8% of the total recovered stage weight. The basic vehicle can withstand the impact loads without additional stiffening, however, some stiffening will be required in the component attachments and the gimbal joint, which is charged to the recovery system and is approximately 2.5% of the stage inert weight. The total recovery weight is approximately 6.3% of stage dry weight. This lower penalty compared favorably with other system weights (10% of inert weight and higher) because structural design of the Sea Dragon will accept higher impact velocites. This recovery system will have a payload penalty (for a 30-nm orbital mission) of 2.5%. The important advantage of using a vehicle with strength that allows higher impact velocites is readily apparent. The use of a pressure fed fuel system eliminates the need of carrying separate flare inflation gas where the tank pressurant gas required for the propulsion phase is available for flare inflation.

(1) Operational Sequence

(a) Flare Deployment

The staging sequence occurs upon attainment of first-stage burnout conditions, and the expended booster coasts upward along its ballistic trajectory. Immediately after staging the forward extended skirt of the interstage structure is detached and the outer fabric cover of the cone flare containing the deflated flare structure is ejected. When the dynamic pressure has decreased to a value of 10 lb/ft^2 (17 sec after staging), inflation of the flare structure begins. Methane gas from the fuel tank is passed through a pressure regulating valve into the flare. The flare structure is fully inflated, to a pressure of 1 psi, in approximately 100 sec. At this time, the vehicle has reached its apogee (335,000 ft). Pressurization of the flare continues, and at approximately 200 sec from inflation initiation, the flare is pressurized to its design value of 30 psia. At this time, the altitude is 182,000 ft, the trajectory flight path angle is 33^o below the local horizontal, the velocity is 5,450 ft/sec and the dynamic pressure is 15 lb/ft^2.

(b) Atmospheric Entry

Atmospheric entry of the Sea Dragon booster stage "effectively" occurs at an altitude of 200,000 ft at a velocity of 5,350 ft/sec, and a flight path angle of 30^o below the local horizontal. Tumbling of the vehicle, caused by the initial

III, C, Stage Recovery and Reuse (cont.)

tip-off forces at staging will begin to affect the vehicle trajectory at this point; however, due to the high aerodynamic stability and damping be the flare configuration, the tumbling motion will subside rapidly and the vehicle will attain a stable flight path at or approximately at a zero angle of attack. The flare structure is not fully pressurized to its design pressure of 30 psia until the vehicle reaches an altitude of 182,000 ft. The flare, however, is fully inflated at all times during entry, and the internal pressure at all times substantially exceeds the external flow field static pressures.

During the subsequent descent trajectory, the following maximum conditions are experienced by the vehicle. The maximum stagnation radiation equilibrium temperature (on the 7 ft diameter blunt nose cap) is 1,390°F. Temperatures on the flare structure, assuming no ablative materials, should not exceed 900°F. If an ablative outer skin is used, temperatures within the flare on the torus and tubes will be in the order of 250°F maximum. The maximum dynamic pressure is 300 lb/ft^2 and the maximum deceleration is 6.5g.

(c) Impact Conditions

An impact velocity of 300 ft/sec and a flight path angle of 89° from the horizontal are the terminal conditions for the atmospheric trajectory described above (Figure III-C-2). Oscillatory motions of the booster are damped out and, for a still air condition, the water entry angle of attack is zero at impact. The effect of surface winds in the splash area could produce an angle of attack of possibly 6° for a 30 ft/sec surface wind; however, slow response of booster to such drift effects, should result in an angle of attack no greater than 3°.

3. Second-Stage Recovery

Recovery and reuse of the second stage can offer economic advantages. The general method for recovery of the first stage could be applied to second-stage recovery. A conical nose would be incorporated in the second stage.

III, C, Stage Recovery and Reuse (cont.)

The second-stage auxiliary engines provide orbital injection thrust for the payload, and the second stage will go into orbit with the payload. During ascent into orbit and after the second-stage main engine has ceased firing, the expandable nozzle skirt will be separated and ejected from the stage. After attaining orbital condition, the payload and expended second stage will be separated. When the second stage has reached the desired position, small retro rockets in the nose will be fired to eject the vehicle out of orbit. A velocity impulse of 480 ft/sec will be required to give an initial re-entry angle of 2.5° from the local horizontal.

Aerodynamic stabilization and deceleration of the stage will be attained with an inflatable flare similar to the one used for first stage recovery. The size of the flare will be smaller than the flare used on first stage. The available tank pressure is lower, 50 psi, however, the recovered weight is also lower, 1.2×10^6 lb. This 50 psi tank pressure, available for axial load reactions, corresponds to a terminal velocity of 210 ft/sec for which a flare diameter of 240 ft is required.

III, C, Stage Recovery and Reuse (cont.)

Aerodynamic heating for second stage recovery will be more severe than for first stage. Use of flare material with higher thermal resistance, such as Rene 41 mesh and ablative coatings, will be necessary.

4. First-Stage Recovery

The first-stage vehicle will carry redundant radio beacons that will be activated prior to launch to facilitate in-flight tracking and post-flight recovery. As the stage re-enters the atmosphere, radar trackers at Cape Canaveral will predict the approximate water impact point (which will be about 170 mi downrange from the point of launch) and advise the recovery tugs by radio links.

Several seagoing tugs of the 3500 hp class equipped with radio-direction finders will be stationed in a circular array at a safe distance from the predicted point of water entry. As the stage approaches and then enters the water, the tugs will home on the stage's radio beacons, assisted by the radar tracking information.

III, C, Stage Recovery and Reuse (cont.)

After the stage impacts the water surface, it will slowly settle into a shallow-draft, near-horizontal attitude, with its tail buoyed up by the inflated flare.

Following venting of the stage tanks by the tug to a safe structural stabilizing pressure that will vary depending on any stage damage, and the partial deflation of the flare, a harness will be attached to the interstage structure for towing the stage back to the assembly lagoon. No attempt will be made to add ballast to the stage, but a suitable tow attitude will be achieved through controlled deflation of the flare.

Navigation lights and monitoring lines between tug and stage will be installed. During the towing period, the towing vessel and accompanying tugs will monitor and remotely control stage attitude, tank and line pressures, and structural strains. Tow will be performed at 5 k.

On entering the assembly lagoon, handling of the recovered stage will be similar to that for a new first stage being delivered from the factory. Stage controls will be transferred from tow vessel to the facility and the stage will be correctly positioned in the refurbishment area. For safety reasons, ordnance or other dangerous items will be the first to be inspected and, if necessary, deactivated prior to any refurbishment processing. Among these are the vehicle destruct system, the triethylaluminum ignition system, and residual propellants.

5. Expected Recovery Damage

It is expected that recovered first stage will not have experienced damage beyond those items of a sacrificial nature that must necessarily be replaced prior to re-use of the stage. The general simplicity and ruggedness of stage design and the low stress levels to which stage and recovery components will be subjected are believed to warrant this expectation. For example, internal pressurization of the propellant tanks enable the structure to withstand very severe water impact loads; the inflatable flare is subjected to only 5 psia pressures and 1,000°F temperatures during the atmospheric re-entry trajectory; because the stage is brought to a stop during water entry within 45% of its length, the inflatable flare will not be subjected to severe water forces; the flare torus will experience temperatures of only 250°F during re-entry.

III, C, Stage Recovery and Reuse (cont.)

6. Refurbishment

Refurbishment of the first-stage assembly will not require tank supporting devices because the tank structure will support itself in the unpressurized condition. In the event that tanks must remain pressurized to prevent sea water admission, access to pressurized compartments can be attained through the use of portable air locks.

Because the Sea Dragon vehicle is built to be compatible with salt water, any damage caused by sea water will be held to a minimum. The major repair requirements to refurbish the stage and ready it for further use will be:

a. Repairs or replacement of "one-shot" valves
b. Repair or replacement of paint, insulation, and ablative material
c. Replacement of the interstage structure

The disconnects on the service interconnection will need replacement because of the position of Stage I during the staging sequence. It is anticipated that plumbing and electrical units in the area of the Stage II thrust chamber exhaust will suffer extensive damage

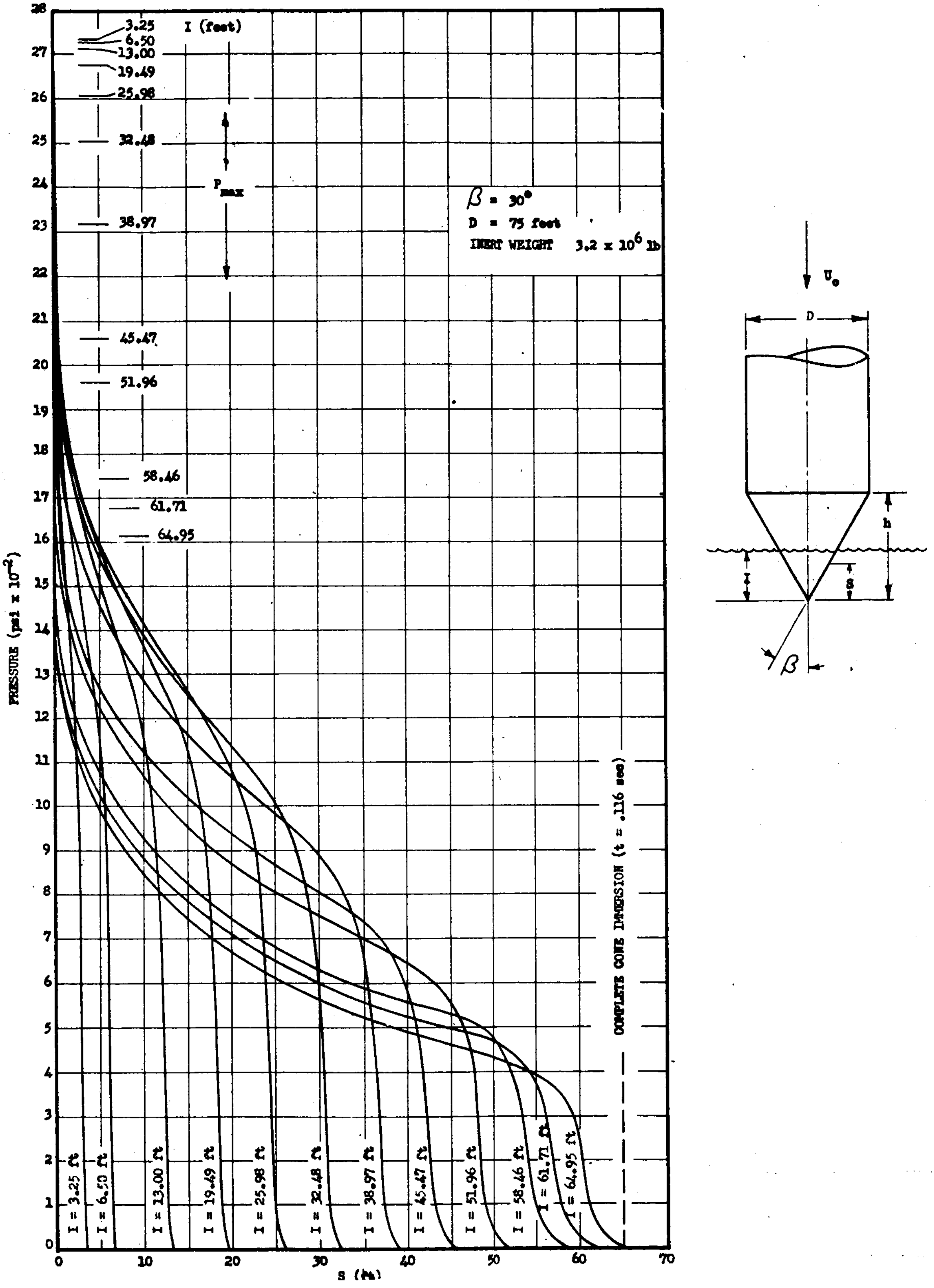
III, C, Stage Recovery and Reuse (cont.)

at staging and thus require complete replacement. Sea water will be removed from the injector and other areas that have become contaminated. A reconditioned inflatable flare will be exchanged for the ablated flare recovered with the vehicle, and the used flare will be returned to the factory for installation of a new ablating outer skin.

All refurbishment will be accomplished while the stage is in a floating condition; therefore, complicated and expensive fixtures will not be required.

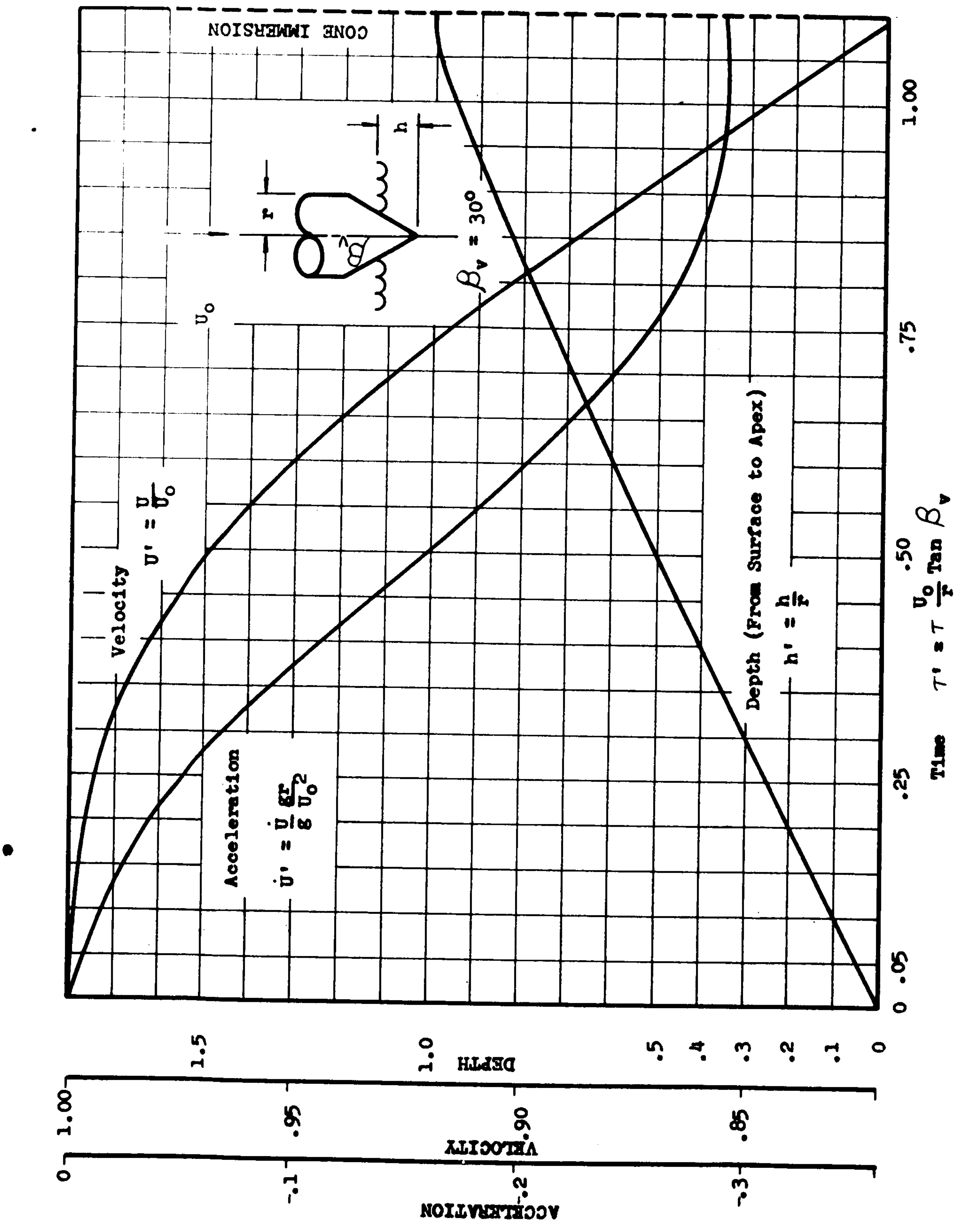
After complete inspection, replacement of expended or damaged components, and re-inspection, the recovered stage will re-enter the prelaunch assembly process and be mated with a new second stage and ballast unit preparatory to being launched.

Repetition of the cycle will depend upon the launch and recovery reliability achieved. Reliabilities presently attained by pressure-fed rockets indicate that a single Sea Dragon stage will operate for more than ten cycles and could approach 100 cycles.



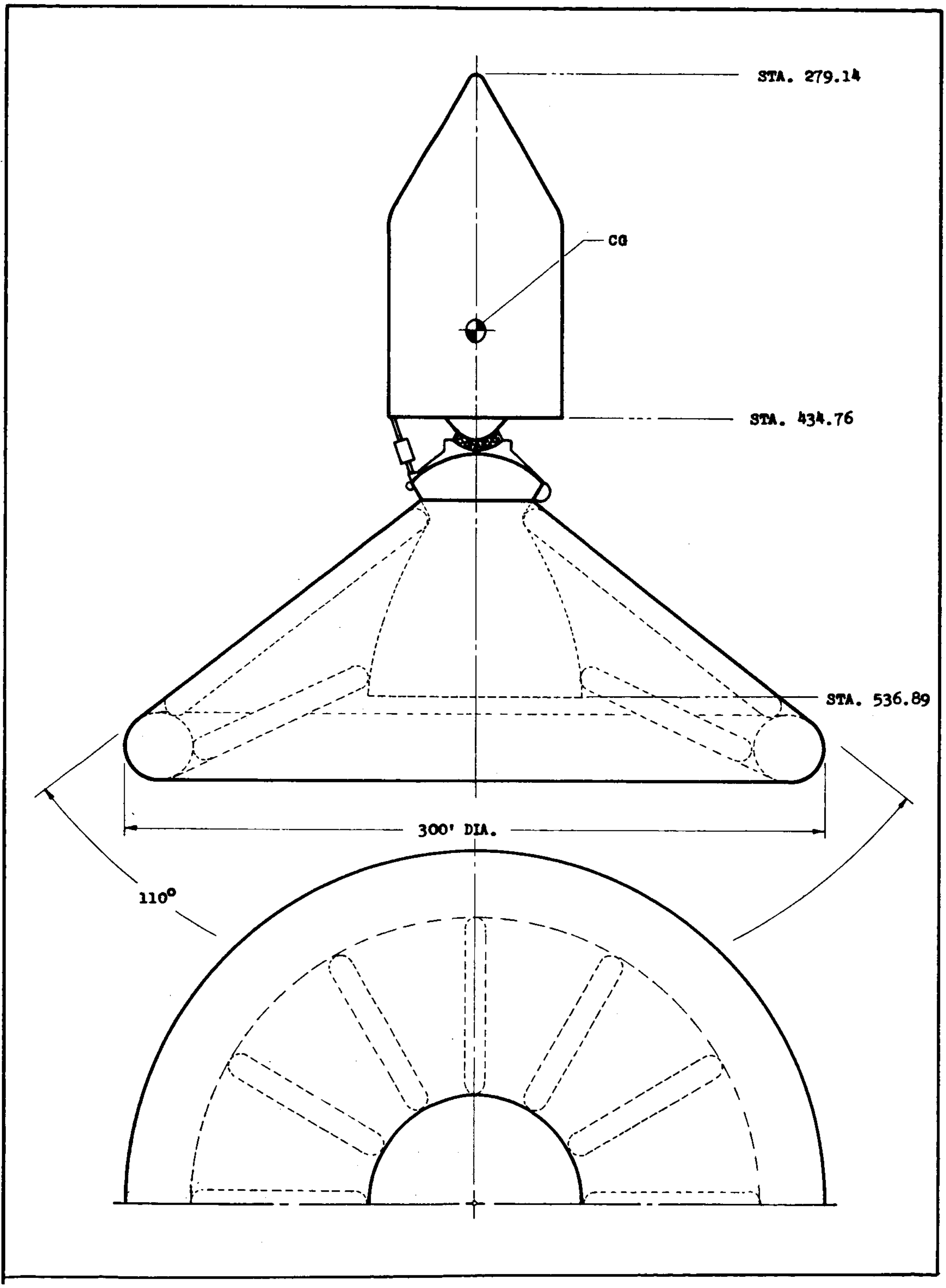
Pressure Distribution at Various Immersion Depths

Figure III-C-1



Water Entry Parameters versus Entry Time

Figure III-C-2



Re-entry Flare Design

Figure III-C-3

III, System Operations (cont.)

D. DEVELOPMENT PROGRAM

1. Introduction

The Sea Dragon development program is estimated to require 68 months and $2.8 billion for its completion. The development program includes extensive surface-based testing of all vehicle and supporting subsystems and will culminate in ten developmental flights of the complete flight article. Special emphasis is given to the development of personnel and procedures as well as hardware (in recognition of their importance to system integrity).

The development plan is designed to be both economical and effective by exploiting the unique characteristics of the Sea Dragon concept. The simplicity and ruggedness of Sea Dragon design, the proposed use of the sea as the primary transportation medium and testing site, and the use of existing shipyards for vehicle fabrication all combine to permit a development program of short duration and low cost, considering the very large size of the vehicle.

III, D, Development Program (cont.)

In addition to the ten flight articles intended for launch, the development plan provides for the following:

a. One complete flight-weight, two-stage vehicle to be used for dynamic tests on the surface.

b. Four complete first-stage vehicles (three cruiser-weight and one flight-weight) for system static tests at sea.

c. Four complete second-stage vehicles (three cruiser-weight and one flight-weight) for system static tests on land.

The test programs proposed for these and other major developmental test articles are summarized in the remainder of this section.

III, D, Development Program (cont.)

2. First-Stage Propulsion Development

Development of first-stage propulsion will begin with a series of tests of candidate injector elements (representing a portion of the full-scale injector) in modified Titan I engine chambers, with scale-model Sea Dragon gimbals. Tests will be conducted in air and underwater to simulate the operational environment.

Next, six wedge chambers, each a 22° longitudinal pie-shape section of the full-scale engine, will be tested at NASA's Mississippi test facility.

Finally, the four complete first-stage vehicles previously described will be used in full-scale system tests at sea, with a floating ballast-deflector unit provided for this purpose. (Figure III D-1). (Testing at sea is emphasized in the development program to permit the early discovery and solution of operational problems associated with the sea-launch concept and to simplify the test stand requirements as compared to conventional land based vehicles.) A total of some 10,000 sec of engine firing will be accomplished, and an estimated 105,000 man-months will be consumed in this phase of the development.

3. Second-Stage Thrust Vector Control and Main Propulsion Development

Development of the four 53,000-lb thrust auxiliary engines will be along conventional lines, depending heavily on the large body of experience already gained by Aerojet-General and others with hydrogen-oxygen engines of a similar size.

A boiler-plate engine chamber will be used for injector development tests.

Tube-bundle chambers, constructed with swivelling attachments in accordance with the proposed operational design will be tested first in air at sea-level, then under water, and at altitude

III, D, Development Program (cont.)

(in the Tullahoma facility or an equivalent facility). Approximately 13,000 sec of engine firing will be included, and 34,000 man-months of effort will be expended in this phase.

Generally, development of the second-stage main engine will follow the pattern of that for the first-stage engine, with some departures occasioned by the use of the expandable nozzle and the need for conducting preflight starting tests under altitude conditions.

Injector element tests in modified Titan engines, and full-scale second-stage vehicle static tests at NASA's Mississippi Test Facility are included.

As a follow-on to current Aerojet-General tests of expandable nozzles at Tullahoma using Titan chambers, the proposed Sea Dragon development plan provides for larger-scale expandable nozzles to be similarly tested in the Tullahoma altitude facility, using M-1 engine chambers. The capacity of the new J-4 test cell at Tullahoma will be adequate for these tests.

The second-stage main engine tests (including associated runs of the four auxiliary engines) will accumulate 93,000 sec of firing time, and will use 108,000 man-months of effort.

4. Development of Other Subsystems

It is proposed that a guidance system for Sea Dragon be provided by adapting an existing guidance system, such as that for Saturn, to Sea Dragon use.

A series of small 30-in diameter rocket vehicles will undergo the simulated Sea Dragon operational sequence, including launch and recovery, to help anticipate possible problems in later full-scale operations.

III, D, Development Program (cont.)

Other phases of the surface-testing program include tests of vehicle insulation, combined environment tests of vehicle subsystems, pseudo-operational surface tests with full-scale vehicle, vibration and acoustic tests, staging system tests, recovery system tests, wind tunnel tests, and tests of materials, transportation equipment, manufacturing techniques, assembly and fueling equipment, launch support equipment, and tracking and range safety equipment.

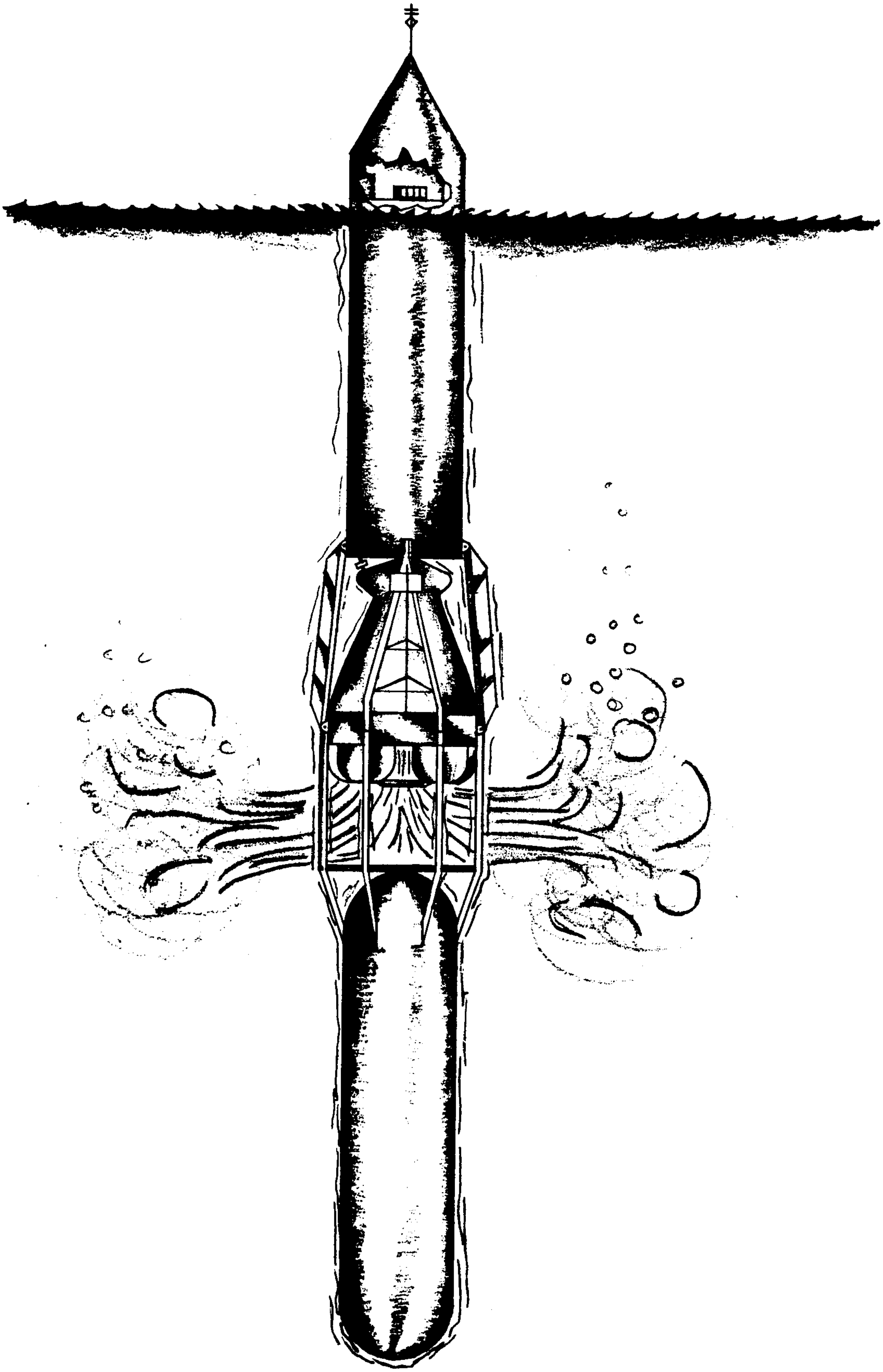
5. Flight Tests

The development program will culminate in 10 flights of the full-scale vehicle including recovery and refurbishment of the first stage (Figure III-D-2). The flight program is generally designed to emphasize surface operations and first-stage functions in early flights; second-stage functions and first-stage recovery in middle-term flights, and successful delivery of the spacecraft into orbit in the later flights.

III, D, Development Program (cont.)

6. Statistical Summary

The total estimated cost of development is $2.836 billion, including $0.3 billion for contingencies and spares. The program includes 116,000 sec of engine static firings (before flight) and the constant labor of an average of 13,800 personnel. The development will use $256 million in materials and $406 million in propellants. First-stage propulsion development (before flight) is estimated at $515 million including facilities.



First Stage Static Test at Sea

Figure III-D-1

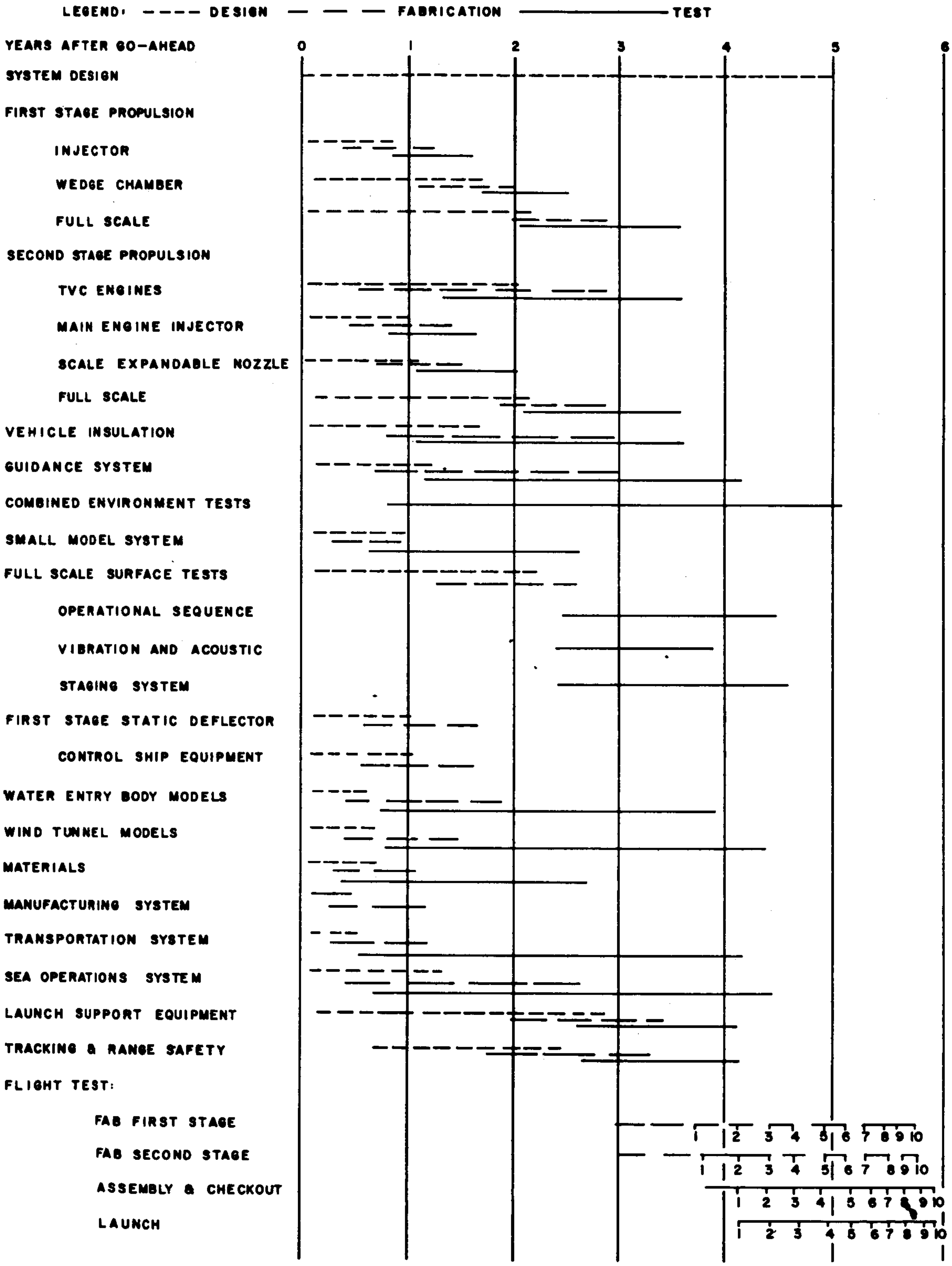


Figure III D-2

III, System Operations (cont.)

E. FABRICATION PROGRAM

1. Introduction

The size of the Sea Dragon, the waterborne environment, and the objective to use existing facilities whenever feasible, inherently lead to the strong consideration of shipyards as the potential manufacturing site. The United States shipyards are not extensively involved in the space effort, therefore there would be little competition existing between the Sea Dragon program and other space programs for the use of existing facilities. Selection of existing shipyards as the manufacturing site would simplify not only the facilities problem but the transportation problem as well. A study of the United States shipyard facilities indicated that existing shipyards are adequately equipped with the majority of the required facilities; they have access to the sea that would aid in resolving transportation problems; andthey have extensive experience in

III, E, Fabrication Program (cont.)

handling, rigging, and building large vehicles in excess of the Sea Dragon's requirements. It is thought that using these facilities and experience in combination with aerospace industry techniques and "know-how" will result in an organization quite capable of efficiently meeting the program objectives.

Fabrication, assembly, and production testing of the four major hardware end items comprising a complete Sea Dragon vehicle (first stage, second stage, payload, and the ballast unit) could utilize shipyard facilities in the San Francisco Bay area. After stage assembly, as shown in Figure III-E-1, each stage would be towed to the vehicle assembly point in the lagoon at Cape Canaveral.

To establish the feasibility of fabricating these four major hardware end items, a degree of engineering judgment was used. Critical components of hardware were selected for detailed study. It was thought that the extrapolation of these findings would establish Sea Dragon feasibility at the level possible in this study.

III, E, Fabrication Program (cont.)

Because the first-stage engine had a larger thrust requirement than the second-stage engine, the first-stage engine was selected. Past experience indicated that the thrust chamber assembly of liquid rocket engines was normally the pacing hardware item in fabrication. On this basis, the first-stage engine thrust chamber assembly fabrication technique was designated as critical. The extrapolation of this study would establish the feasibility of building the Sea Dragon first- and second-stage engines.

The apparent large percentage of fabrication cost represented by the Sea Dragon tankage indicated that the fabrication techniques necessary to build at least one of these tanks should be documented. Because the cryogenic property requirements were the most stringent in the second-stage hydrogen tank, this item was initially selected. The designation of 2014 T6 aluminum as the basic material consideration revised this selection. The thick wall sections in the

III, E, Fabrication Program (cont.)

first-stage fuel tank, which resulted from selection of this material, presented larger fabrication problems that those of the second-stage tankage. On this basis, the first-stage fuel tank (RP-1) was selected as a critical hardware item.

Attached to the second-stage thrust chamber is an expandable nozzle that presents a unique fabrication problem because of its size, thinness of material, and the requirement for tapered convolutions. Because of these unique characteristics, the expandable nozzle was also designated a critical hardware item.

Sufficiently detailed fabrication techniques were outlined for those critical items selected to permit an idea of costs, determination of facility, tooling, quality control, testing, lead time, and support requirements. This level of analysis also permitted the determination of whether the critical items of the Sea Dragon were exceeding the existing state of the art.

III, E, Fabrication Program (cont.)

2. Fabrication and Assembly Plan

Because the use of a completely expendable vehicle places a greater burden on the manufacturing operation, (more S_I vehicles must be built) this version was selected for detailed study.

In the consideration of fabrication and assembly techniques to be utilized in a shipyard, side or end launched ways and drydocks were considered for fabricating the stages in a horizontal position and drydocks or basins were considered for vertical fabrication.

A fabrication facility utilizing side launched ways is shown in Figure III-E-2. The first-stage thrust chamber assembly is partially completed. The injector plate is on the ways awaiting assembly. The first-stage tankage has just been completed and awaits assembly. Farther down the way the second stage is shown in a

III, E, Fabrication Program (cont.)

partially completed state. To take advantage of existing facilities and minimize shore requirements, drydocks would be utilized for assembly rather than the side launched ways protrayed. (See Figure III-E-3 for manufacturing operations in a drydock.)

The ballast unit shown in Figure III-E-1 is a recoverable item. Therefore, fewer of these units would be made than complete vehicles (for the expendable configuration). As scheduling requirements dictate, the ballast units would be fabricated in the San Francisco shipyard and attached to a first stage for towing to the main assembly lagoon at Cape Canaveral.

The payload minus the command capsule would be delivered by sea to the San Francisco shipyard assembly point and assembled to the second stage prior to towing to the assembly lagoon at the Cape.

III, E, Fabrication Program (cont.)

The second stage would be assembled in the same manner as the first stage with the exception of the ballast unit and the interstage structure.

The assembly techniques shown are all well withing the existing capabilities of known shipyards on both the east and west coasts. Potential problems in misalignment between the first and second stage and second stage to payload can be handled by an adequate master tooling program.

a. Fabrication and Assembly of the First- and Second-Stage Engines

The manufacturing procedure is similar for both the Stage I and Stage II Sea Dragon engines.

A tube-wall type thrust chamber was selected for the DeLaval nozzle. The tubes would be delivered to the assembly point by a boxcar in a partially assembled state. The tube segment would be lifted from the boxcar by a crane and placed on a preformed

III, E, Fabrication Program (cont.)

concrete support. The final tube connection would then be made and the tube assembly leak and pressure tested. The tube assembly would then be lifted onto a rotating mandrel as originally portrayed in Figure III-E-2. After tack welding the tubes in position, the mandrels would be removed and the tubes would be brazed by a quartz lamp process (see Figure III-E-4).

The injector would be assembled off-line in a vertical position similar to the fabrication of a ships bulkhead. Upon completion of the injector, it would be rotated into position with the combustion chamber and welded. This would be followed by assembly of the LO_2 and fuel lines to the manifold assembly, the gimbal support, mounting, and actuator.

b. Fabrication and Assembly of the First- and Second-Stage Tankage

The manufacturing concept is the same for both Stage I and II of the Sea Dragon tankage. The use of roll-and-weld or press-and weld technique is well understood and applicable to the requirements in the development of the large diameter vessels in this project.

III, E, Fabrication Program (cont.)

Two different modes of assembly have been considered in the fabrication of the tankage. The selected mode utilizes a horizontal assembly technique similar to the shipyard fabrication of a submarine in a drydock or on a building way.

The first-stage fuel tank (RP-1) would be fabricated of 2014 T6 aluminum in a shipyard in the following manner.

(1) Fabrication

The mold loft would develop plate sizes, using reduced scale optical lofting, and produce templates required for roll and jig sets. Optical layout of plates, cutting to size, and roll and press forming to correct shapes would be done in the fabrication shop.

III, E, Fabrication Program (cont.)

(2) Subassembly

The material would then move to the platen area and onto the subassembly jigs located there. Sized and formed plates would have their joining edges prepared for welding and then be welded into units of 3 to 5 plates. The RP-1 aluminum plates would have been prepared for welding by compound portable edge milling machines mounted in a gibbed carriage traveling laterally on a machined track.

Inspection of welds by quality control prescribed methods would then be made.

(3) Maximum Assembly

The subassemblies would be transported to the area at the head of the shipways and erected into maximum weight, head or cylindrical units on semipermanent jigs. When subassemblies have been welded together, the welds will be inspected by quality control prescribed method.

III, E, Fabrication Program (cont.)

When ready for removal to the shipways, the portable feature of the jig will de disconnected and the completed cylinder or head section will be lifted into its position on the ways with the shoring intact.

(4) Final Assembly

Final joining of all of the units making up the first-stage fuel tank will follow. Additional internal shoring will be added. Weld inspection will be done on the final welds as previously described. Testing of the tanks to the extent that will be developed by requirements of Aerojet-General and the shipyard's quality control will then be performed. Final cleaning, addition of protective coatings, and installation of internal insulation will be done.

The welding of 2014 aluminum in 8 in. thick plates exceeds the present state of the art. A preliminary material study was performed to determine the theoretical possibilities of

III, E, Fabrication Program (cont.)

performing this welding. A possible technique has been determined but it would require considerable developmental effort. Because of this and attendant recent advances in other materials, 18% Ni maraging steel was selected for the S_I RP-1 tank. The fabrication procedure outlined is applicable to either materials with one exception; the maraging steel welds would require heat treatment by strip heaters.

(5) Alternate Approach-Vertical Assembly

The alternate plan, a vertical assembly technique, utilizes a drydock or basin that can be flooded. Figure III-E-5 shows the vertical assembly technique. Preliminary estimates indicate that the vertical method of tank assembly costs three to four times more than the horizontal method of tank assembly. This information is on the basis of preliminary cost estimates received from shipyards that are considering both modes of fabrication.

III, E, Fabrication Program (cont.)

c. Fabrication of the Second-Stage Expandable Nozzle

The second-stage expandable nozzle is to be fabricated from stainless steel, type 310 or 321. The sheet will range in thickness from 0.120 in. at the upper end to 0.020 in. at the nozzle exit. In the finished condition ready for delivery to the operational personnel, the nozzle segment is $\frac{1}{4}$ of a 75 ft dia circle, approximately 118 ft long and covered with a protective layer of styrofoam.

Material of the proper varying thickness will come from the mill preformed in rolls, or delivered as sheet, formed, welded, and coiled on rolls at the fabrication site. The sheet metal rolls are mounted so that the material feeds out through a series of rubber rollers to a mechanical welder that welds the sheets together before they go through the explosive forming tool. The operating speed of the welders is controlled by a pilot control devise mounted in or on the rubber feed rollers.

III, E, Fabrication Program (cont.)

The explosive forming technique proposed is similar to the outline presented in the interim report on a cooled thrust chamber design using high-energy forming by William J. D. Escher for NASA (MTP-P and VE-P-62-7). One half of the cooling tube bundle discussed in this report would be sufficient for the expandable nozzle application.

An alternate method is as follows:

Each forming die operates individually in sequence, one through seven. The dies operating in this manner draw the material and fold it without stretching it. After all the dies have functioned, the dies retrack and the folded material passes through the degreaser. The degreaser sprays a solvent over the material to remove any oil film left by the previous operation. The solvent used is compatible with the foam; therefore, rinsing is not necessary. Foam is then sprayed into each convolution. (See Figure III-E-6.)

III, E, Fabrication Program (cont.)

3. Quality Control Plan

Quality control requirements for this vehicle are formulated somewhere between the aerospace and shipbuilding industry practices.

The standard techniques of quality control in the fields of inspection, material control, process control, gaging, and nondestructive testing will be applied. Experience from the aerospace and shipbuilding industries is applicable. In many cases, quality control problems will actually be less severe because of the simplicity, accessibility, and large size of the components with corresponding increases in tolerances and dimensioning. For instance, in the field of nondestructive testing, the increased size will permit better accessibility for radiographic work. It is estimated that over ninety-eight per cent of the welds on the project can be handled with single wall radiography. This will also simplify the inspection of castings for areas like the aluminum rib section. Portable X-ray equipment and radioactive isotopes will be required.

III, E, Fabrication Program(cont.)

Much of the dimensional work will be checked with optical equipment. Techniques from aerospace work will be utilized and refinements of these techniques will be required for this vehicle. Optical gaging points will be a necessary part of all fabrication and tooling, both for tooling checkout and for in-process inspection and acceptance of components. Contamination control, which has been a problem in present missile construction, will continue to be a problem with the larger components, and new techniques, both for control and inspection, will be required. The determination of those levels of contamination that are hazardous, will require re-assessment, because the size of the various propellant orifices will be considerably increased. This could well reduce the difficulties in this area, although special attention by quality control will always be required when liquid oxygen is being used and the hydrocarbon hazard is present. Another problem may be encountered in association with the brazing of the thrust chamber assembly tubes. Portable brazing techniques will require approaches for the maintenance of atmospheric control, dew-point controls, and brazing component controls. Although this vehicle

III, E, Fabrication Program (cont.)

system will create a family of new requirements for the quality control specialists, it does not pose any problems that are not well within the capabilities of the present aerospace industry to resolve.

4. Conclusions

The study indicates the following: A feasible but not necessarily an optimum manufacturing approach has been selected.

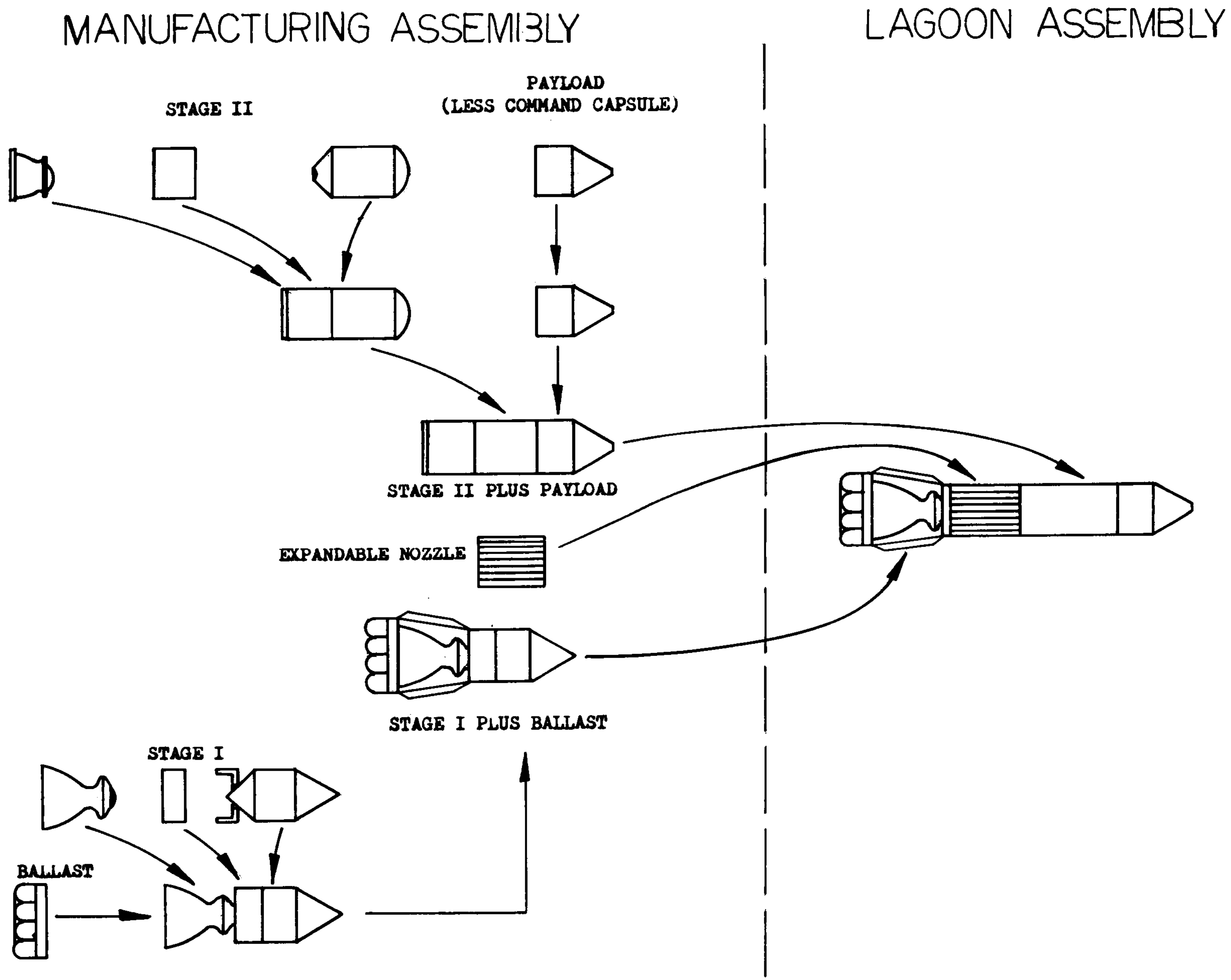
If it is assumed that the results obtained in the investigation of the critical items described can be extrapolated, the Sea Dragon is within the existing state of the art with the exception of the fabrication techniques required for the thick sections of aluminum in the first-stage fuel tank. The use of aluminum or of maraging steel as is now recommended, will require additional developmental effort before this tank could be built.

III, E, Fabrication Program (cont.)

Current shipyard facilities, tooling, and "know-how" exist that could build a Sea Dragon today, providing quality control and additional material evaluations are performed.

Fabrication tolerances that are required for the Sea Dragon are closer than normal shipbuilding practice but considerably less rigid than missile practices in the aerospace industry. This should result in much lower fabrication costs than would normally be realized in the aerospace industry.

(End Section III)



Manufacturing Assembly Flow Diagram

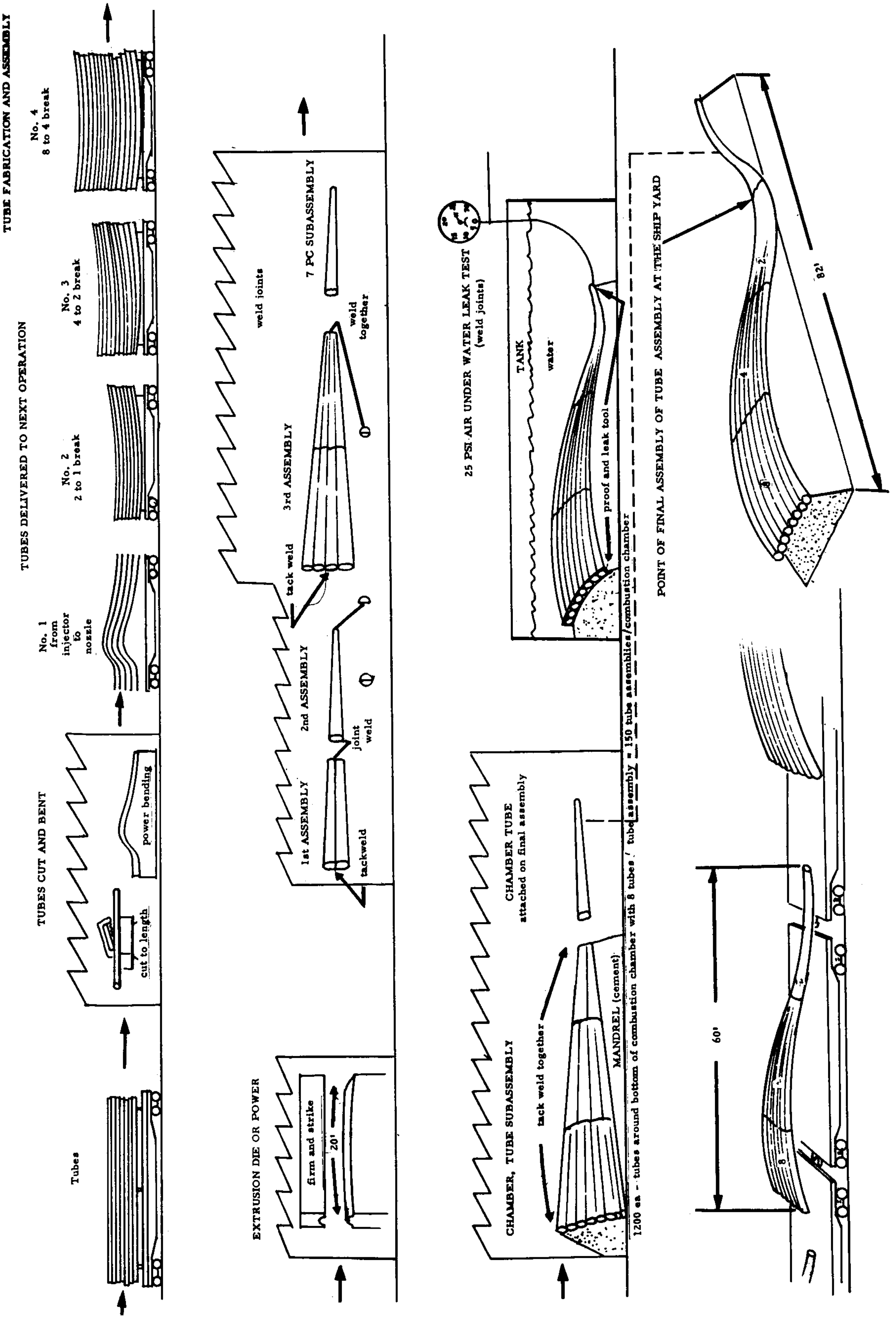
Figure III-E-1

Manufacturing Operations on Ships Ways

Figure III-E-2

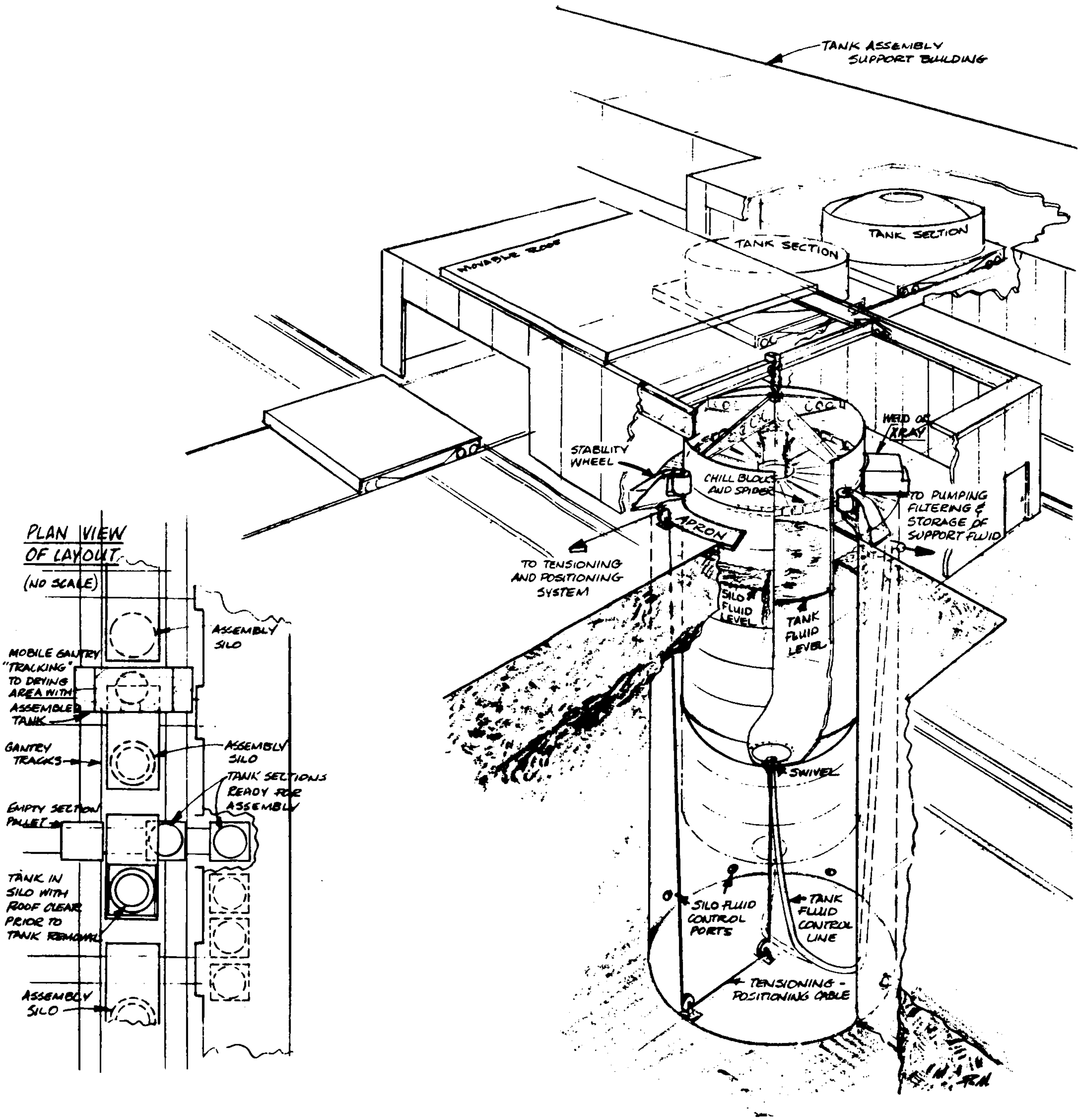
Manufacturing Operations in Dry Dock

Figure III-E-3



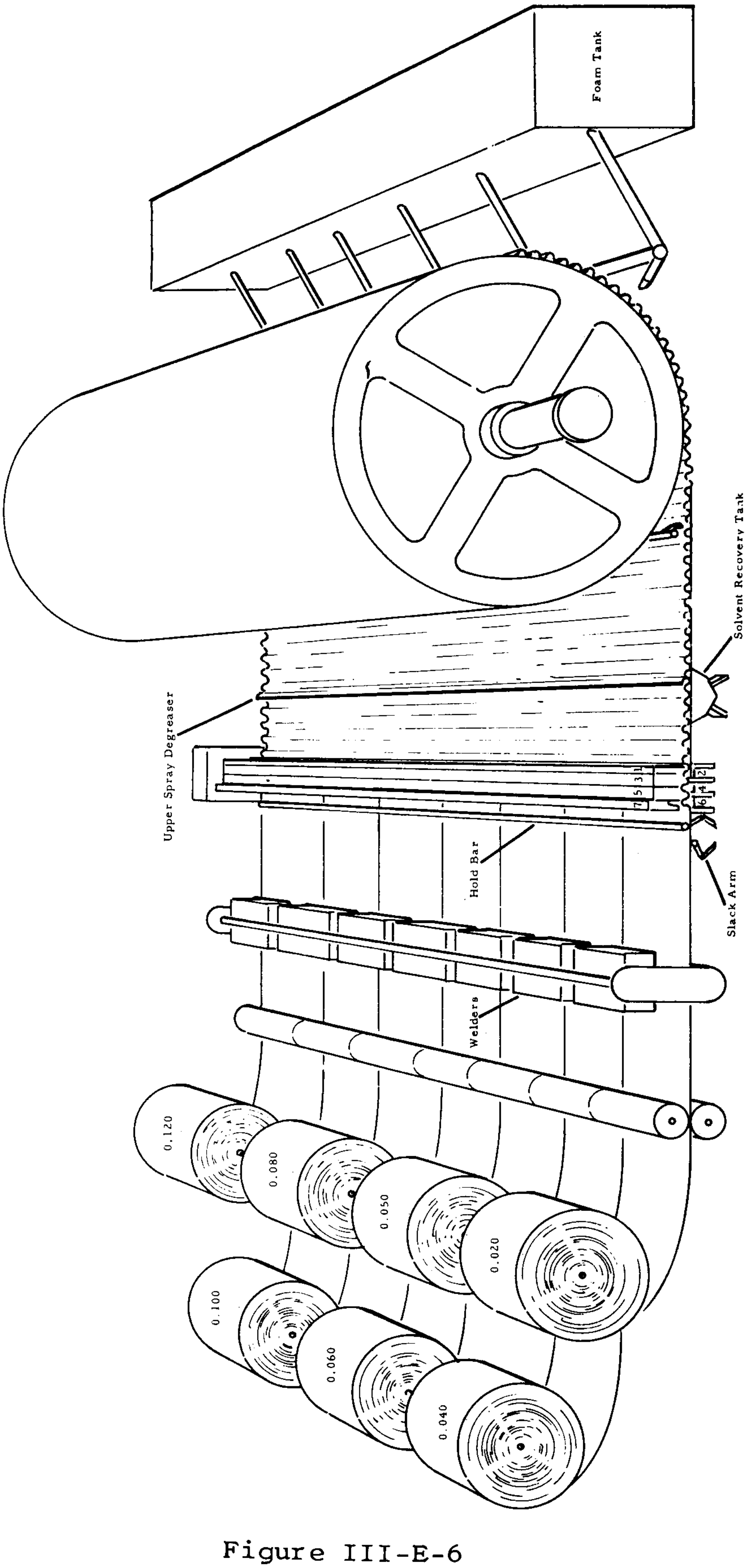
Tube Fabrication and Assembly

Figure III-E-4



Vertical Tank Assembly

Figure III-E-5



Expandable Nozzle Fabrication Technique

Figure III-E-6

IV. PROGRAM COSTS

Once it has been determined that a particular launch vehicle can transport a specified payload into a specified space location, the effectiveness of that launch vehicle as compared to other competitive vehicles is resolved into two basic comparisons: (1) the chronological availability of the vehicle; and (2) the total vehicle system cost effectiveness. However, for future national space transportation planning, cost effectiveness has received major emphasis.

The cost effectiveness of the Sea Dragon system described has been studied on an arbitrary operational life and launch rate. No optimization of life and launch rate for the Sea Dragon has been attempted. A ten year operational life is assumed; two different launch rates are used: (1) 120 launches and (2) 240 launches in the 10-year operational period.

The criterion of cost effectiveness adopted for the analysis is specific transportation cost, or cost per pound of payload successfully delivered into earth orbit (following Koelle's convention). The values of cost effectiveness are presented to indicate the variation of cost effectiveness with operational years, optimism of performance assumptions, launch rate, recovery or nonrecovery of the first stage, and the use of direct costs only or total costs (direct plus indirect) in the calculations

Direct operating costs are taken to include:

V (vehicle production cost)

P (propellant cost)

T (vehicle transportation cost)

L (vehicle launch cost), and

M (vehicle maintenance and repair cost, for recoverable configuration only)

Indirect operating costs include:

R (range cost and general overhead)

G (surface-support equipment cost)

F (launch facility cost), and

D (system development cost)

A 90% learning curve is utilized throughout the analysis.

IV, Program Costs, (cont.)

To illustrate the effects of optimism or pessimism on the determination of specific transportation cost for Sea Dragon, the primary values resulting from the cost analysis (which are considered to be realistic) are designated the "most probable" values. Cost parameter values which are considered to represent the limits of reasonable optimism and pessimism regarding the primary values are so labelled (Figure IV-5). It is highly unlikely that, in the final analysis, the cost effectiveness of Sea Dragon will be found to lie outside this range which is indicated by the cross-hatched area in the figures.

To cover the combinations of the above programing elements that are of interest, eight programing cases are considered:

Case	Description	10-yr. Average Delivery Cost ($/lb)
I	120 launches, pessimistic parameter values, recoverable	31.70
II	120 launches, optimistic parameter values, recoverable	10.20
III	120 launches, most probable parameter values, recoverable	18.30
IV	240 launches, pessimistic parameter values, recoverable	28.60

IV, Program Cost, (cont.)

Case	Description	10-yr. Average Delivery Cost ($/lb)
V	240 launches, optimistic parameter values, recoverable	8.90
VI	240 launches, most probable parameter values,recoverable	16.20
VII	120 launches, most probable parameter values, expendable	32.80
VIII	240 launches, most probable parameter values, expendable	27.90

Values of each of the elements of direct and indirect costs are derived and applied to each of the above programing cases. The results are shown in Table IV-1.

Figures IV-1 through IV-4 show the plots of the results of the cost analysis, broken down by operational years. The 10-yr average values of E and O/W from the preceding table appear as circles on the curves in each case.

Summary

The cost analysis indicates that specific payload transportation costs (based on direct costs) of $10 to $20 per lb can be attained using the Sea Dragon system. If total costs (direct and indirect) are charged, the specific transportation costs correspondingly increase to $20 to $30 per lb. From these results, it appears that Sea Dragon clearly offers substantial economy, in the transport of heavy space payloads.

Program changes that result in cost changes from those elements of cost used to establish the tables and curves of the previous figures can be evaluated by using Figure IV-5. In this figure, the parametric values of Case VI are used as a basis. The individual curves show the effect, on $/lb of payload, of independently varying the values of each cost parameter from 20% to 200% of its basic value (100%), while maintaining the other parameters at their 100% values. For example, if the cost of development (D) is raised to 200% of its basic value, the specific transportation cost for the Sea Dragon system is raised 40% to a new value of $40.50/lb.

TABLE IV-1

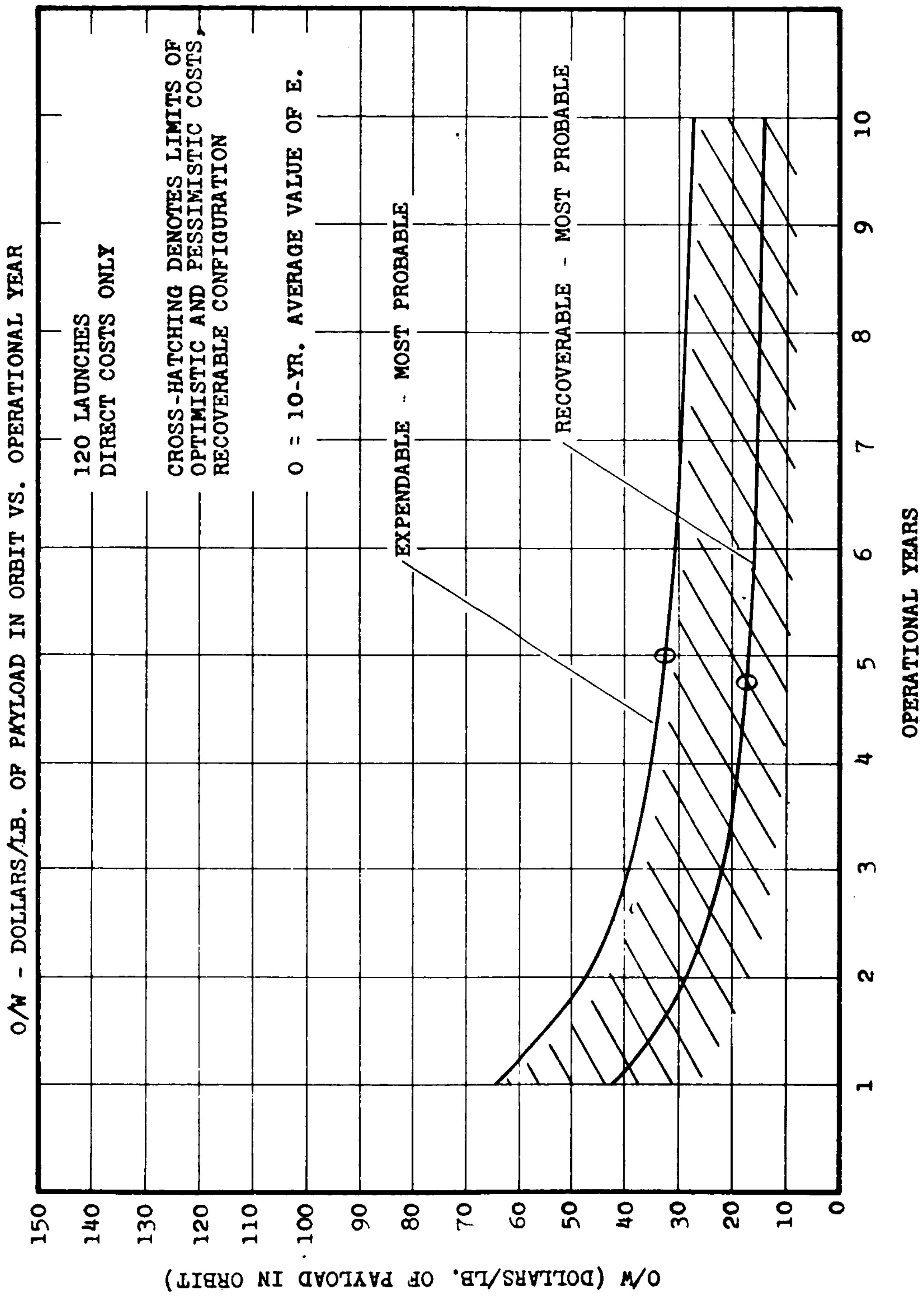
BASIC COST DATA
(MILLIONS of DOLLARS--10yr)

Case	I	II	III	IV	V	VI	VII	VIII	%of Total (Case VI Only)
Cost Parameter									
V, Production	2232	1090.8	1635.8	3984	1896	2856	3456	6192	40.5
P, Propellants	437.2	207	295.8	749.5	390	591.5	295.8	591.5	8.4
T, Transportation	12.36	2.4	5.8	7.5	0.62	11.0	13.2	26.4	.2
L, Launch Services	300	72	144	600	144	288	144	288	4.1
M, Maintenance	187.2	65.5	100.8	379.2	138.2	206.4	0	0	2.9
R, Range	26.4	26.4	26.4	50.2	50.2	50.2	26.4	50.2	.7
G, Surface Equipment	70	40	55	140	80	110	58	118	1.6
F, Launch Facilities	54	40	47	98	70	84	42	77	1.2
D, Development	4000	2000	2836	4000	2000	2836	2807	2807	40.4
O, Total Cost (direct only)	3168.8	1437.7	2182.3	5720.3	2568.8	3952.9	3909	7097.9	56.2
C, Total Cost (direct & indirect)	7319.2	3544.1	5146.7	10,008.5	4769	7037.1	6842.4	10,150.1	100.0

TABLE IV-1 (cont.)

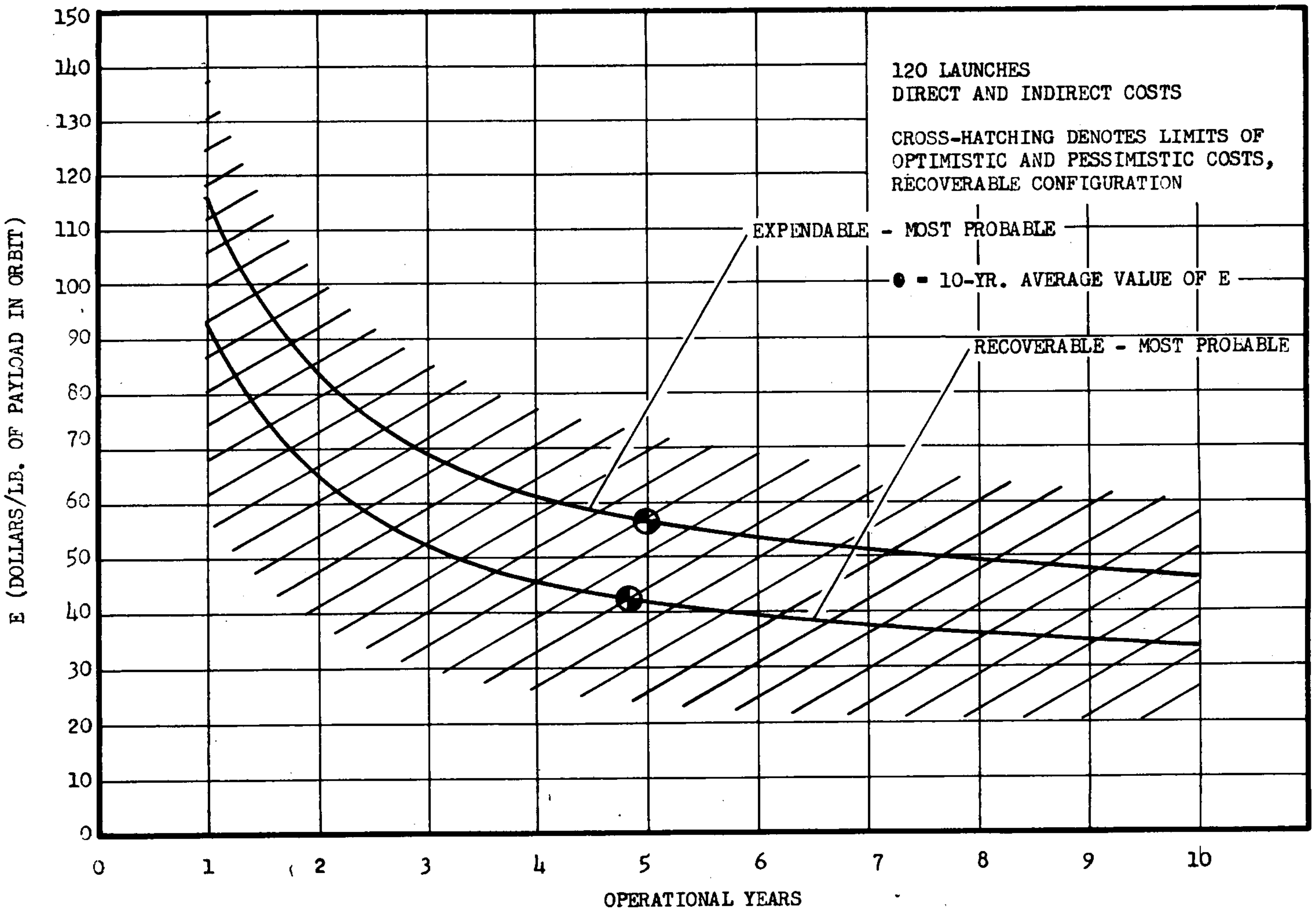
BASIC COST DATA
(MILLIONS of DOLLARS--10yr)

Case	I	II	III	IV	V	VI	VII	VIII
W, Payload in orbit, (millions of lb)	99.91	140.8	119.2	199.8	287.5	243.8	119.2	254.5
O/W, Direct Costs/lb of payload	$ 31.70	10.20	18.30	28.60	8.90	16.20	32.80	27.90
E, Total Costs/lb of payload	$ 73.30	25.20	43.20	50.10	16.60	28.90	57.40	39.90



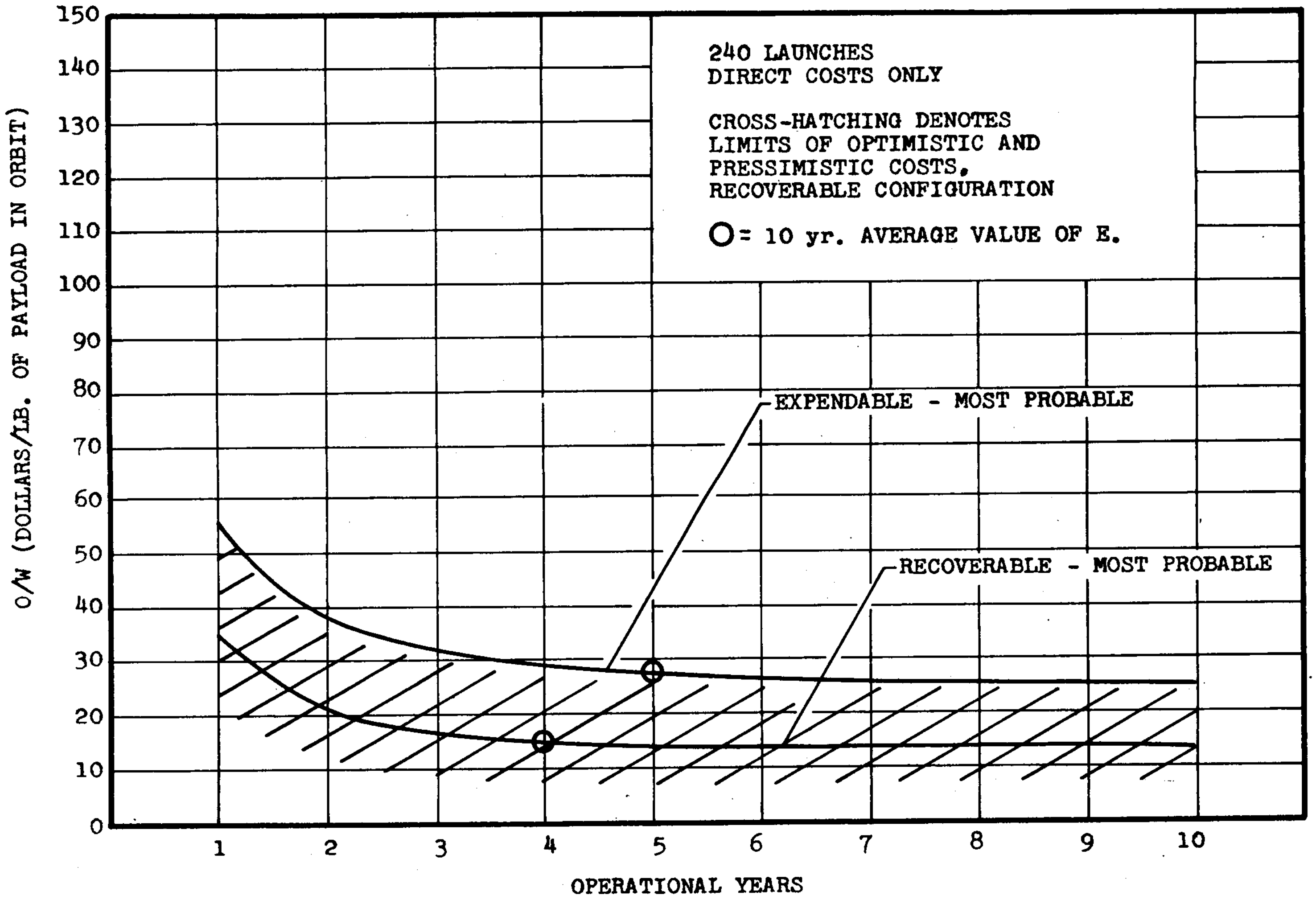
Payload Delivery Costs, 120 Launches, Direct Costs Only

Figure IV-1



Payload Delivery Costs, 120 Launches, Direct and Indirect Costs

Figure IV-2



Payload Delivery Costs, 240 Launches, Direct Costs Only

Figure IV-3

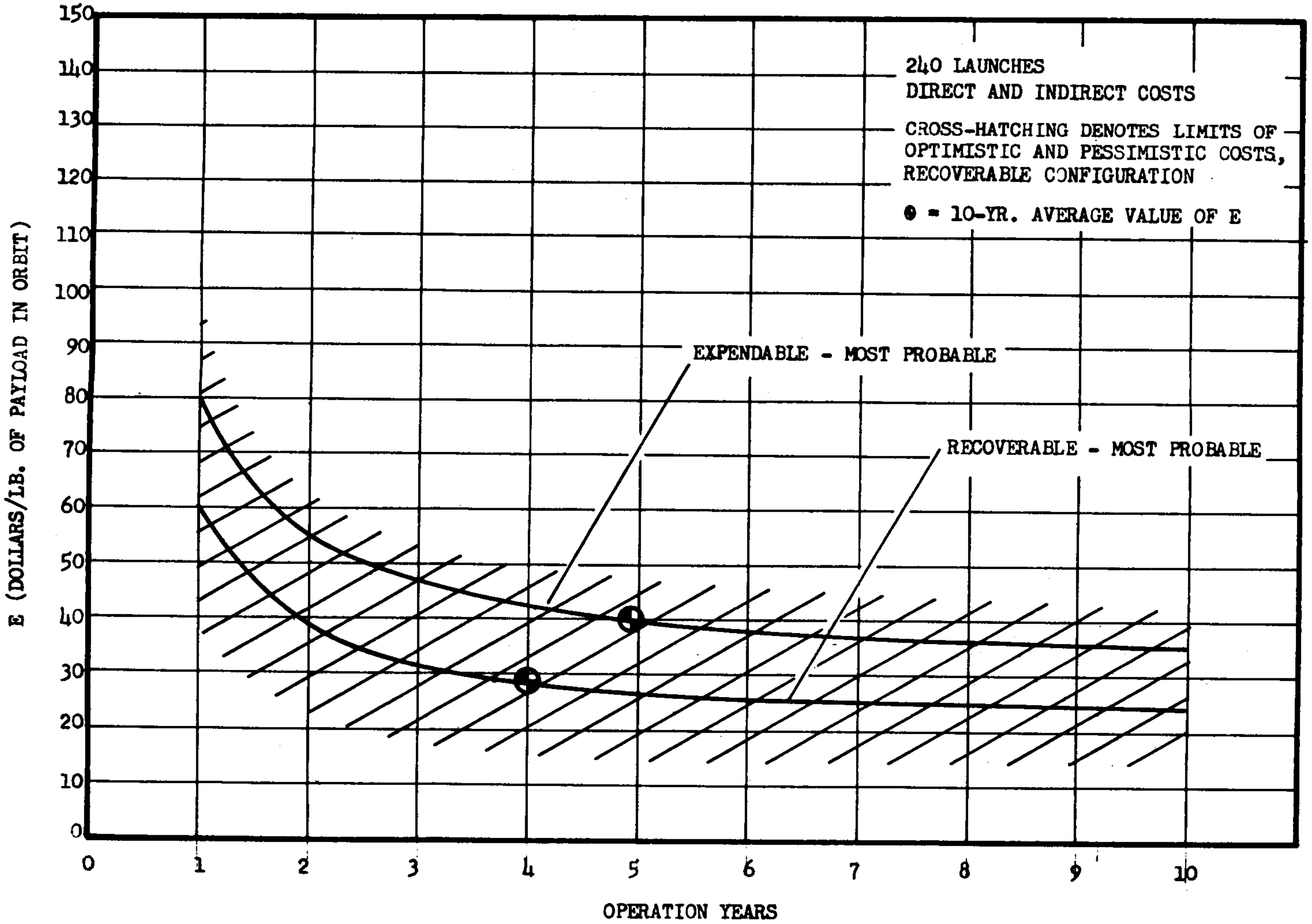
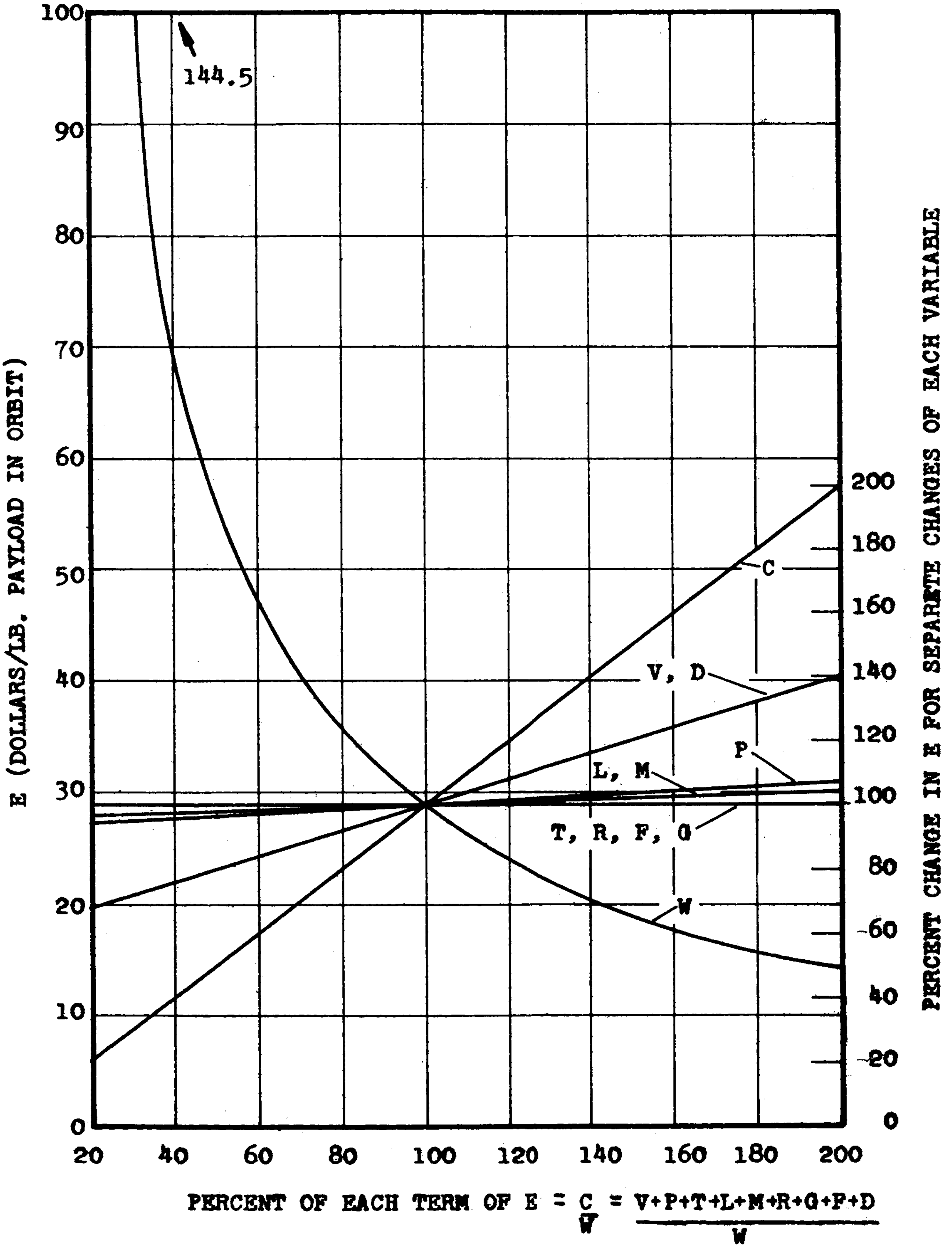


Figure IV-4

Payload Delivery Costs, 240 Launches Direct and Indirect Costs



Effects of Varying Cost Parameters

Figure IV-5

V. FUTURE INVESTIGATIVE PROGRAMS

While the study conducted has been sufficiently complete to indicate technical feasibility and the strong possibility of high cost effectiveness for the Sea Dragon concept, there are a number of areas where further exploratory work is needed before any definitive decision on the future of the concept can be made. These are as follows:

A. STUDY AND ANALYSIS

1. One of the initial tasks of the study and analysis phase will be to remove minor discrepancies that exist in the present report.

2. Study of Alternate Configurations to Explore Possible More Optimum Features

Two or three alternate configurations should be studied and preliminary designs developed sufficient to determine technical feasibility and comparisons. These alternate designs should include the best combinations of the following features:

V, A, Study and Analysis (cont.)

a. Second stage recovery and reuse

b. Nonregenerative H_2 engine cooling

c. Flexible intertank bulkheads and GH_2 pressurization systems

d. LH_2 and LO_2 first stage

e. Other engine designs such as plug nozzle, forced deflection nozzle and ventilated DeLaval nozzles

f. Other thrust vector controls for the first stage such as fluid injection, separate control motors, and differential throttling.

3. Expanded Cost Analysis

The cost data obtained to date are most encouraging. Data obtained from outside sources have been tempered with rather large safety factors. Refinement of costing should improve the confidence in the results.

V, A, Study and Analysis (cont.)

3. Develop Preliminary PERT Program Networks

Reduction of the development and the operational program to the details of a PERT network will materially assist in determining the critical elements and provide the framework for later PERT-cost analysis and definite program planning.

4. Develop the Supporting Equipment Requirements Details

a. Establish an instrumentation detailed plan and data acquisition plan for checkout, launch, and flight operations

b. Study alternate techniques for transportation of stages, assembly of the vehicle, loading and launching, and recovery and refurbishment

c. Study support requirements for launch operations in other ocean areas remote from the Atlantic Missile Range

d. Expand the recovery, refurbishment and reuse details.

V, Future Investigative Programs (cont.)

B. ANALYTICAL AND EXPERIMENTAL WORK

1. Examine the range of conditions to be encountered in underwater starting to assure that starting transients present no unsolvable difficulties

2. Determine what limitations might be expected in engine free-floating developmental test rigs such as agitation of the water or other unforeseen effects

3. Examine and test materials, fabricating and testing techniques for very large high strength tanks to identify and solve associated problems

4. Identify and solve currently unforeseen problems associated with the water operational mode

V, B, Analytical and Experimental Work (cont.)

5. Determine the optimum recovery configuration, striking the best balance between aerodynamic and water drag.

C. FULL SCALE TESTS

If after the above investigations, no essential changes in the results of this study are indicated, fabrication and test of a full scale propulsion system with supporting subscale testing should be initiated.

(End V)