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Sea Dragon.

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PART 1

INTRODUCTION

In order that the functions, activities, and requirements necessary for the Sea Dragon System from inception to completion be determined, a preliminary program plan has been prepared. This plan covers all aspects of the system support requirements; for convenience of analysis and clarity of presentation the program has been divided into three general areas (Figure 1-1):

I. DEVELOPMENT PLAN (PART 2)

All required major research and development activities from subscale feasibility testing through the tenth full-scale developmental flight will be included in this plan. The approach is concentrated on parallel development of operational facilities and support functions with the basic vehicle so that higher reliabilities and reduced costs can be achieved early in the program.

II. MANUFACTURING AND FABRICATION PLAN (PART 3)

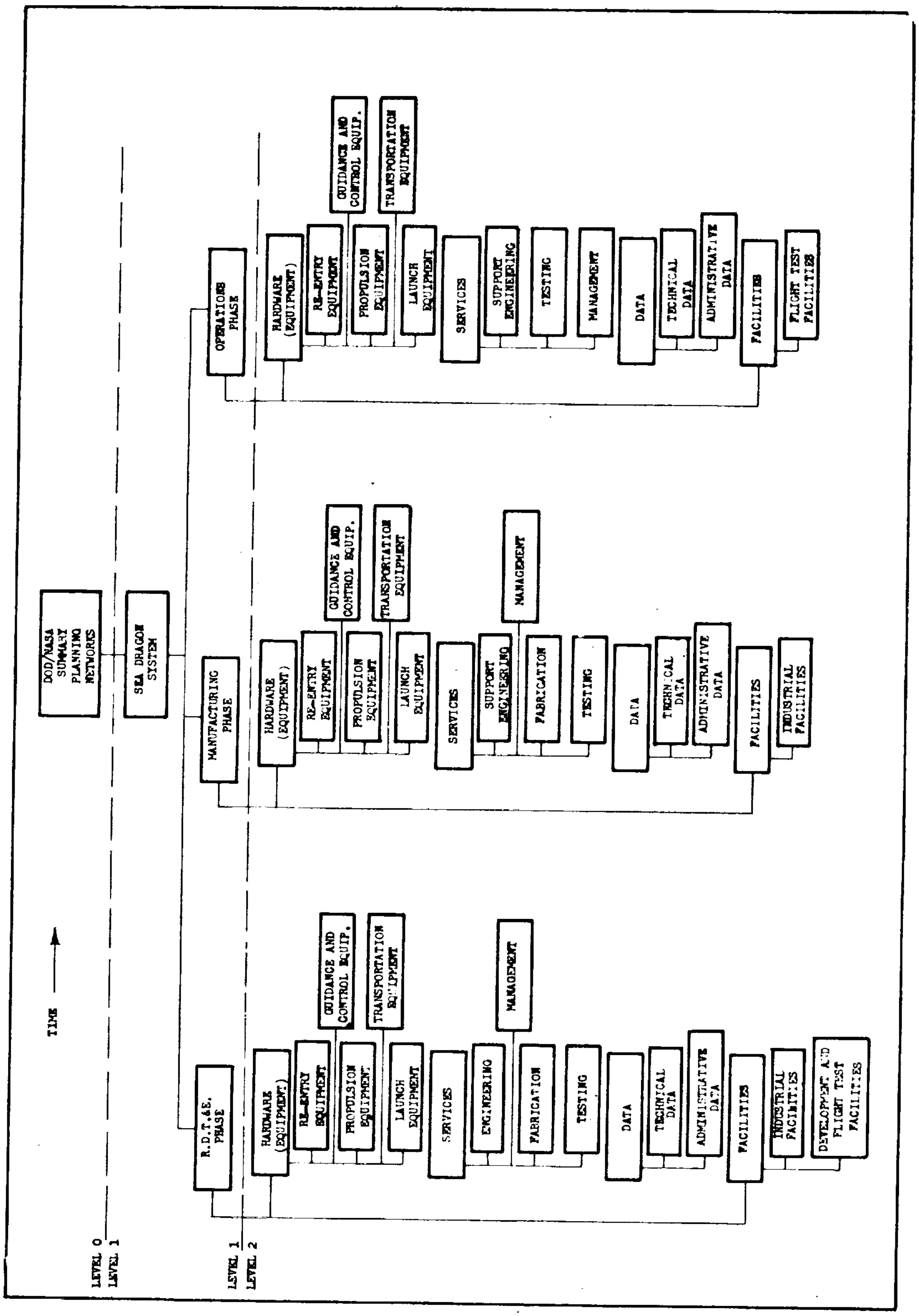
All manufacturing and fabrication operations for the vehicle and its support equipment are encompassed by this plan. The general approach has been to describe the complete manufacturing process in preliminary form and then to develop more detailed analyses for specific hardware such as the RP-1 tank or Stage I engine fabrication. The more severe problems can be studied in greater depth than would otherwise be possible.

III. OPERATIONAL PLAN (PART 4)

All operational activities from acceptance of the vehicle components at the manufacturing locations through launch are included in this plan. Transportation, vehicle assembly, propellant servicing, launch, and recovery operations are covered in detail.

III, Operational Plan (Part 4) (cont.)

The materials necessary to establish the feasibility of the concept and develop the resource requirements in facilities, equipment, material, and personnel necessary to implement the concept are presented in this plan. (Figure 1-1) The major effort of the study has been directed toward establishment of technical feasibility and definition of the system in sufficient detail to allow basic costs to be assigned. The results of the cost study are presented in Part 5.



Sea Dragon Work Breakdown Structure Showing Resource Requirements Necessary to Implement Concept

Figure 1-1

PART 2

SEA DRAGON SYSTEM DEVELOPMENT PLAN

I. OBJECTIVE

The objective of the Sea Dragon development program is to make available for operational flights at an early date a rocket launch vehicle capable of delivering million-pound payloads into low earth orbit at a specific transportation cost (dollars per pound of payload in orbit), which is less than any other system currently available or under development.

II. DESCRIPTION OF SYSTEM

The Sea Dragon system, for which a development plan is presented, consists of all the physical hardware, operating procedures, and personnel required to manufacture, assemble, check out, transport, launch, and track, (and for the recoverable version, to recover and refurbish the first stage of) a very large two-stage liquid rocket launch vehicle. The vehicle is designed to be fabricated in existing shipyards, towed by existing surface vessels through the water to its launch site, and launched from the water. In the recoverable version, the first stage is recovered in the water, refurbished, assembled with a new upper stage, launched again, and re-used many times.

III. DEVELOPMENTAL PHILOSOPHY

To exploit the unique virtues of the Sea Dragon concept and provide a development program that is both economical and effective, the following characteristics have been used to prepare the development plan:

All physical components of the system will be simple and rugged in design to give high reliability.

III, Developmental Philosophy (cont.)

Existing equipment, facilities, procedures, and personnel will be used to the fullest possible extent to save the cost and time required to provide new facilities. For example:

Fabrication of the vehicles and the necessary water handling devices, such as ballast units will be conducted at existing shipyards.

Existing sea-going tugs will transport the vehicles before launch and after re-entry.

Existing environmental test facilities and engine test stands will be used during the preflight test program.

Facilities and equipment will be leased, rather than purchased, where the need for such facilities and equipment is relatively short term in nature, or where lease terms are for other reasons more economical. For example, lease terms offered for shipyard facilities are very favorable as compared to purchase or replacement cost. One of the unique virtues of the Sea Dragon concept is this type of cost saving.

All transportation of major vehicle components will be on water in a free-floating condition; the high cost and size limitations of other methods are eliminated in this manner.

Many full-scale system tests and all later operational launches will be conducted in remote water areas to avoid the cost of providing large land areas for acoustic abatement, and explosion protection.

Full-scale, rather than small-scale, hardware will be used in developmental tests to avoid delay in grappling with the full-scale operational problems.

III, Developmental Philosophy (cont.)

Personnel, equipment, procedures, and facilities used during the development program will correspond as closely as possible to the final operators and operational designs. This will make it possible to prepare fully for the operational phase well ahead of the end of the development phase of the program.

Subsystem designs will be determined by the current state of the art, and relatively untried advanced concepts will be used only where their use is clearly advantageous from a system performance or cost standpoint, and where minimum deterioration of system reliability will be incurred.

Components of the two stages of the vehicle will be designed to be as similar as possible to avoid duplication in the support facilities, equipment, procedures, and training of personnel.

The development of operating procedures and operating personnel, as well as operational hardware, will be emphasized, in recognition of the critical importance of these elements to the reliable operation of a complete system.

It is assumed that, during a six-month period prior to the development contract initiation, a precontract study will be made that will result in system and subsystem specifications, a program management plan, and a final contract draft.

The development program will include thorough systems engineering and reliability programs.

IV. DETAILED DEVELOPMENT PLAN

For simplicity, the development plan described below refers in all respects to the Sea Dragon design that provides for first-stage recovery. The elements of the development plan which relate only to the recoverable version are, however, treated separately and can be ignored by the reader who wishes to learn only about the expendable version. It is assumed that the spacecraft planned for Sea Dragon will be developed simultaneously but independently of the Sea Dragon development, with close liaison and systems engineering coordination being maintained between the contractors.

The normal progression of development events is followed in this plan, with departures occurring only where necessary to exploit the virtues of the Sea Dragon system concept:

- Determination of mission operations and safety requirements and reliability objectives
- Selection of prototype design
- Selection and preliminary design of subsystems and components
- Fabrication of small models
- Testing of models in a simulated operating environment, with thorough analysis of results
- Design improvement based on model test and analytical results
- Fabrication of full-scale hardware
- Testing of full-scale hardware in a simulated operating environment with thorough mathematical analysis of results
- Design improvement based on full-scale simulation tests and analysis
- Fabrication of redesigned full-scale hardware
- Testing of full-scale hardware in actual operating environment and analysis of results
- Design improvement for operational system, based on test results and analysis

IV, Detailed Development Plan (cont.)

Fabrication of operational design

Proof-testing of operational design

Continued product improvement and test program, at a reduced level, during the operational flight phase.

Total development is estimated at 68 months, including ten developmental flight tests spaced at one-month intervals during the later phase of the developmental flight test program. In addition to the ten vehicles provided for research and development launches, there are provided:

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

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

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

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

A. FIRST-STAGE PROPULSION

The first-stage propulsion system is composed of a single, conventionally-shaped, De Laval thrust chamber moved on a single gimbal by hydraulic actuators. A thrust of 80-million lb is produced at liftoff, with liquid oxygen and RP-1 as the propellants. Triethylaluminum is used to provide a hypergolic start. Propellants are pressure fed. The first-stage engine is designed to start and operate at a water depth of 300 ft and to continue operating, during the boost phase, as the vehicle leaves the water and climbs to staging altitude.

IV, A, First-Stage Propulsion (cont.)

1. First-Stage Injector Tests

Early in the development program, a series of injector element tests will be conducted. An injector element will consist of one full-scale LOX-RP injection element and the associated triethylaluminum starting injector, constructed in accordance with the intended full-scale injector design. Several designs of injector elements must be fabricated and tested before a final choice can be made for the flight vehicle. It is estimated that five modifications of each of two basic injector types, or a total of ten designs, will be tested. Each will be assembled with a modified Titan I LOX-RP engine chamber and tested eight times in an existing LOX-RP test stand at the Aerojet-General Sacramento plant. Pressure feed will be used in all tests. It is estimated that five modified Titan I chambers will be required to support this series. The test chambers will be fitted with an operating scale model of the Sea Dragon gimbal system to obtain design data applicable to the full-scale gimbal. Thrust level of the test setup will be approximately 200,000 lb, or 1/400 of full-scale first-stage thrust. As a result of the 80 tests, (average duration 5 sec each), assigned to this series, it will be possible to select tentatively the best injector on the basis of ignition effectiveness, combustion efficiency, and injector flow stability. After tentative selection of an injector type, 20 additional test runs of 30 sec duration each will be made as a further check on the selection made. The Titan I engine, with the selected injector element, will then be installed at an underwater testing facility and 40 starts of only a few seconds duration each will be made to determine the applicability of the selected injector design to operational starts at sea.

IV, A, First-Stage Propulsion (cont.)

2. Wedge Chamber Tests

Six wedge chambers (five as primary test articles and one as a backup) will be constructed using the conventional tube-bundle thrust chamber wall design planned for the first-stage engine. These test engines will be composed of a 22.5° included angle, longitudinal pie-shaped section of the full-scale first-stage engine. Thrust level of this engine will be approximately 5-million lb, or 1/16 of full-scale thrust. The wedge engines will be manufactured at the shipyard vehicle fabrication site to extend early fabrication experience to those responsible for the manufacturing of vehicles and full-scale engines. The wedge engines will have prototype regeneratively-cooled circumferential sections and water-cooled flat side walls.

One-hundred tests of the wedge chamber will be conducted at NASA Mississippi Test Facility using the selected injector design. Average duration of these tests will be 30 sec each. This test series will serve to further improve the injector and the ignition system. Valuable heat transfer data on the tube-bundle segment that forms one wall of the wedge engine will also be provided. Heat transfer probes will be placed along the length of the cooling tubes and heat fluxes will be measured at all stations. The cooling capabilities and actual cooling requirements will be evaluated and used as a basis for design improvements in the flight engine. Of these 100 tests, ten will be of 100 sec duration to ensure that the selected tube design will successfully survive full duration of first-stage engine firing in flight.

IV, A, First-Stage Propulsion (cont.)

3. Full-Scale First-Stage Propulsion System Static Tests

The next series of tests will utilize the four complete first-stage vehicles previously described (three heavy-weight and one flight-weight) in testing statically at sea all elements of the first-stage propulsion system. The tanks of three of these vehicles will be full-scale but will be augmented with external longitudinal and circumferential stringers to provide the capability for withstanding rough use in multiple static runs and higher-than-flight pressures internally. This is necessary because in-flight gas pressures are normally supplemented by the hydrostatic head developed by vehicle acceleration in flight and must be simulated, in these static tests, by higher-than-normal internal gas pressures. Chambers and injectors will be flight weight. One of the heavy weight vehicles will be equipped with subcaliber propellant tanks, installed inside the operational tanks, to permit short duration runs of the engine system without filling the operational tanks. Tests with the flight-weight configuration will be limited to flight design loads.

The tests at sea will be accomplished with the first-stage test article freely floating with its nozzle exit submerged, stabilized in the vertical position by a special static test ballast-deflector unit. A sketch of the test setup is shown in Figure 2-1. The ballast-deflector unit will be cylindrical in cross-section, with hemispherical ends, and will be attached to the lower end of the first-stage vehicle by structural steel members. At its upper end is provided a flat thrust deflector which is cooled by sea water during engine operation. Radio links (or alternatively a floating hardline) provide for control of the tests from the control ship stationed a safe distance away. A superstructure, on top of the first stage, houses test instrumentation and recorders, and radio command equipment.

IV, A, First-Stage Propulsion (cont.)

The ballast-deflector unit provides for a large volume of sea water that may be admitted as necessary to adjust its buoyancy, and thus raise or lower the attached test article. In addition, it contains high pressure gas spheres of adequate volume to perform the necessary sea water pumping. Pressurization or flooding of the ballast cavity is controlled remotely by the control ship. The test rig also contains remotely controlled lighting equipment and closed-circuit television and motion picture cameras for observing the test operations.

Equipment required in the accompanying control ship will include:

a. Propellant and pressurized gas replenishment storage
b. Machine shop facilities for emergency work on the test rig while at sea
c. Test personnel housing and feeding facilities
d. Test control center
e. Fire-fighting equipment
f. Towing equipment for transporting the test rig to the test site

Prior to a test series, the test article and ballast-deflector unit are assembled at dockside in the horizontal position (ballast-deflector unit is not flooded). The test article is fueled, and the combination is towed by the test control ship in a horizontal position to the off-shore test site. Here it is filled with LO_2 by a LO_2 storage barge. On command from the control ship, the ballast-deflector unit is partially flooded, erecting the rig into vertical position for test.

IV, A, First-Stage Propulsion (cont.)

In the series of 200-tests, at least 50 tests will be of full-flight duration with tank pressures programmed to simulate the full range of variations in chamber pressure and mixture ratio expected in actual flight. All applicable parts of the flight system will be included in the test design to gain early experience with flight hardware. These tests will provide data on the following: heat transfer characteristics of the engine cooling system; effectiveness of tank insulation; heat transfer across the common tank bulkhead; propellant sloshing in tanks; the stability of full-scale engine combustion; structural integrity of the thrust chamber assembly and thrust carry-through structure; overall engine and nozzle thrust performance and specific impulse; start and shutdown characteristics of propellant valves and plumbing; operation of gimballing system; stabilizing performance of the hydraulic gimbal actuation system using inputs from the vehicle guidance system; practicality of launch abort techniques; effectiveness of methane secondary VāPak system of RP pressurization; and the autogenous heat exchanger system for LOX pressurization. The necessary fluctuations to stimulate gimbal actuation by the vehicle stabilizing sensors will be provided by the natural cyclic motion of the ballast unit floating on the ocean.

The remaining 150 tests of the 200-test series will be of limited duration, averaging 10 sec each. In each test, as propellants are used, the test rig will slowly rise because its weight is decreasing, thus providing data on engine operation at various underwater depths.

Insertion of the operational ballast unit for these tests will prevent exhaust gas flow separation and will establish the basic operational stability of the ballast unit.

IV, Detailed Development Plan (cont.)

B. SECOND-STAGE PROPULSION AND THRUST VECTOR CONTROL

The second-stage propulsion system consists of a single, conventionally shaped, De Laval thrust chamber fixed to the second-stage structure. It will produce 14 million pounds of thrust at altitude using liquid oxygen and liquid hydrogen as propellants. Triethylaluminum is used to provide hypergolic ignition. Propellants are pressure fed. The second stage is designed to start after staging at altitude. It is provided with an expandable nozzle that expands after engine ignition to a nozzle area ratio that provides favorable altitude engine performance at the low chamber pressure selected for this engine.

To provide thrust vector control for the second-stage engine, and roll control for the entire two-stage vehicle, four auxiliary swiveling, pressure-fed, hydrogen-oxygen engines are used. Each of these auxiliary engines provides a thrust of 53,000 pounds and is programed to operate during the entire period from launch to orbital injection of the spacecraft. For this reason, the auxiliary engines must be subjected to underwater tests, air tests at low altitude, and altitude tests to ensure satisfactory operational performance and to determine the interaction between their jets and second-stage structures.

1. Second Stage Thrust Vector Control

Development of the four 53,000 lb thrust auxiliary engines will be along conventional lines. Much of the design data required for this development can be derived from previous work on other hydrogen-oxygen engines as early as 1949. For example, heat transfer data, tube-bundle fabrication techniques, injector element design and performance data, nozzle thrust coefficients, and engine specific impulse versus mixture ratio and chamber

IV, B, Second-Stage Propulsion and Thrust Vector Control (cont.)

pressure are available from previous Aerojet-General work plus other projects, such as the RL 10-A3 engine (15,000-lb-thrust) and the J-2 engine (200,000-lb-thrust). These results can be easily interpolated to the 53,000-lb size required by Sea Dragon.

Two or three injector designs will first be tested in a water-cooled, boiler plate engine of the appropriate thrust level and cutoff at the throat. One-hundred injector tests of 10-sec average duration will be performed. After tentative selection of the injector design, 200 full-scale engine tests, with engine chambers fabricated in the operational tube-bundle design, will be conducted on an existing sea-level oxygen-hydrogen test stand capable of supporting the 53,000-lb thrust level. During these tests, the swivelling system to be used with the auxiliary engines in flight will be checked out, and the interaction of engine jets and adjacent structural materials will be observed. It is estimated that 20 developmental engines and their associated swivelling systems will be used during the development of these auxiliary engines. (Because the engines are pressure-fed, rather than pump fed, it is expected, based on Aerojet-General and Rocketdyne experience, that less than half as much time will be required for the development period than would be the case if it were necessary to unite a chamber and turbopump as in other engine development programs.)

In addition to the above tests, the selected engine will be installed at an underwater test facility and 50 runs of 5 sec duration each will be made to ensure that underwater starting of the auxiliary engines is reliable. Forty additional runs in an altitude chamber at Tullahoma will be made, varying in duration from a few seconds to full flight duration. Further tests of the auxiliaries will take place in connection with second-stage propulsion tests at sea described below.

IV, B, Second-Stage Propulsion and Thrust Vector Control (cont.)

2. Second Stage Main Propulsion and Expandable Nozzle

Development of the second-stage engine will follow generally the pattern of that for the first-stage engine, with some departures caused by the use of the expandable nozzle and the need for conducting preflight starting tests at altitude conditions.

First, a series of injector element tests will be conducted using five different injector element designs mounted in modified Titan I water-cooled engines of 20,000-lb (1/700 of full scale) thrust. Forty tests of 5 sec duration each will be run in an existing sea-level test stand at Aerojet-General's Sacramento facility. After selection of an injector, 20 additional runs of 30 sec duration each will be made as a further check on the selection made. These tests will establish ignition system effectiveness, combustion efficiency, and injector flow stability.

It is required that second-stage engine tests at simulated altitude conditions be conducted, prior to flight, to ensure satisfactory in-flight operation. Therefore, the best injector element (as determined by the sea-level tests) will be installed, using a water-cooled modified Titan I second-stage chamber in an altitude facility at the Arnold Engineering Development Center, Tullahoma, Tennessee, and will be used to conduct 40 starting tests of about 5 sec duration each.

Preliminary tests on the expandable nozzle are being conducted at Aerojet-General. A metal expandable nozzle will be tested on a modified Titan I second-stage engine of 10,000-lb thrust under simulated space conditions at Tullahoma. As a part of the Sea Dragon development program, it is proposed to fabricate a total of ten reduced-scale expandable nozzles and run them at

IV, B, Second-Stage Propulsion and Thrust Vector Control (cont.)

altitude in the Tullahoma facility on an M-1 engine (or equivalent). Ten such tests will provide information on the physical integrity and performance of the expandable nozzle at altitude. A single auxiliary engine will also be operated adjacent to the expandable nozzle during these runs to determine thermal and dynamic interactions between auxiliary jet and expandable nozzle wall.

It is expected that the new J-4 altitude test cell at Tullahoma can be used for these tests. The cell is 30 ft in diameter and 50 ft long and can support thrust levels up to 1.5-million-lb. It is expected to become operational by 1963. Test durations of the expandable nozzle to 30 sec are contemplated. The Tullahoma expandable nozzle test series will be the last hot tests conducted on the expandable nozzle prior to flight because it is considered uneconomical to provide a new facility for the Sea Dragon program capable of altitude simulation runs of the full-scale expandable nozzle.

At the NASA Mississippi Test Facility, the four complete second-stage vehicles, one with subcaliber run tanks internally installed (with engine cooling tubes foreshortened to permit sea level operation) will be utilized in static tests of all elements of the second-stage propulsion system (except the expandable nozzle). In case the Mississippi Facility is not available for these tests, a second floating ballast-deflector unit will be used, as in the first-stage engine development program. In this series of 200 tests, at least 20 tests will be of full-flight duration with tank pressures programed to vary mixture ratio and chamber pressure over the expected flight ranges. The objective of these tests is similar to that described for the first-stage propulsion system sea tests; however, in this case, the four auxiliary engines will be fired during at least 40 of the 200 test runs to demonstrate engine operability while swivelling. Also, 20 thrust vector control tests of full 1000-sec duration will be run without

IV, B, Second-Stage Propulsion and Thrust Vector Control (cont.)

main engine firing. The series will provide data on insulation effectiveness, heat transfer through the common tank bulkhead, operation of the LOX throttling valve, and effectiveness of the autogenous heat exchanger system for pressurizing the liquid hydrogen.

C. VEHICLE INSULATION DEVELOPMENT

The first and second stages of Sea Dragon must be provided with insulation for a number of purposes: to reduce or eliminate any requirement for propellant topping in a normal launch operation; to prevent high heat transfer between the oxidizer and fuel within the tanks; to prevent fast boiloff of propellants, including the cryogenic payload (when carried); to prevent structural damage due to aerodynamic heating while in flight.

Early insulation development tests will include water towing of heavily-instrumented insulated scaled-down (8 ft in diameter) first- and second-stage models filled with flight-type propellants. These tests will provide data on boiloff and heat transfer rates in a realistic rough water environment, and are expected to be sufficient to establish the required data for full-scale insulation design.

Further data on insulation effectiveness and structural integrity will be obtained during the first- and second-stage propulsion static tests described above, and during the full-scale system surface dynamic tests, and wind tunnel model tests described below.

IV, Detailed Development Plan (cont.)

D. GUIDANCE SYSTEM DEVELOPMENT

The proposed Sea Dragon guidance system is all inertial, using full self-alignment at sea in both azimuth and vertical directions through gyro-compass and stable-vertical search modes. Pre-launch initial position and velocity data will be obtained from shore installations, monitored continuously and mechanized in the vehicle guidance system.

The Sea Dragon guidance requirements for uncompensated gyro drift rate, initial platform misalignment, accelerometer errors, and initial position and velocity determination errors are within the state of the art, except for the initial alignment accuracy, in a self-aligning mode and at sea. This mode of operation will require a rather heavy gyro-compass and stable-vertical erection system.

The demand for a very high level of reliability may, in general, require over-design in some areas as well as a planned redundancy of the most critical subsystems and channels of operation.

It is believed that a guidance system for Sea Dragon can be provided at relatively low cost by adapting existing guidance units to Sea Dragon use. Development efforts associated with the guidance system, therefore, will be devoted primarily to providing an adequate interface between the guidance system and other systems of the vehicle. Use of existing guidance units can also be expected to reap considerable savings in surface support equipment because much of this equipment will have already been developed by others. The Litton P-3006 miniature inertial platform, for example, is considered capable of fulfilling Sea Dragon requirements.

IV, D, Guidance System Development (cont.)

It is planned to provide ten developmental guidance sets plus spare components for use in the surface-testing development phase. These will be fabricated, checked out, and subjected to many hours of running time in the laboratory, utilizing combined environmental testing in the later phases, with special emphasis being given to search for critical weaknesses and determination of MTBF for each component. During these surface tests, the guidance system will be subjected to simulated sea motions, and practice alignments will be made to investigate this critical operation and its effects on the guidance set.

Later, in conjunction with the first-stage engine static tests at sea, the guidance system will be needed to provide gimballing inputs to the first-stage gimbal actuators to test vehicle stabilization functions.

Electrical and mechanical interfaces between the guidance system and other vehicle subsystems will be an integral part of the pseudo-operational surface tests of the complete vehicle.

Finally, in the 10-vehicle flight test phase, guidance testing in the operational environment will be among the primary test objectives in all ten flights, with emphasis on first-stage attitude stabilization in the first three flights, and emphasis on second-stage guidance in the later flights.

E. COMBINED ENVIRONMENTAL TESTING

To the extent that Sea Dragon component sizes will permit, it is planned to test such components in one of several new combined environment testing facilities that are available now, or will be available when the Sea Dragon program requires their use.

IV, E, Combined Environmental Testing (cont.)

For example, it is desirable that the development program make provision for testing Sea Dragon components such as inertial platform, guidance computer, telemetry transmitters, electrical and hydraulic power supplies, valves, harness, and other relatively small-size items in a facility equivalent to the recently completed Combined Environmental Centrifuge at Edwards Air Force Base, California. Tests at EAFB would be run with component accelerations up to 32 g, combined with vibration frequencies of 5 to 3000 cps, temperature ranges from -300° to 500°F, 50-90% relative humidity, and sea level to 300,000 ft altitude, to provide as complete an environmental shakedown of components and subsystems prior to flight as possible.

F. SMALL-MODEL TESTS OF OVERALL SEA DRAGON SYSTEM

Early in the development program, a test series will be conducted using surplus rocket-propelled missiles of about 30-in. diameter, a number of which have been determined to be available at very low cost.

These vehicles will be run through the phases of the intended Sea Dragon operational sequence to help determine the relative emphasis to be given to these phases in the overall Sea Dragon development plan. These small missiles will be:

1. Launched into the water in the same manner as the Sea Dragon from the ways at its shipyard fabrication site
2. Towed free-floating through the water as the Sea Dragon will be towed from the fabrication site to the assembly lagoon
3. Fueled in the water like the Sea Dragon
4. Towed, fully-fueled, to a launching site at sea
5. Erected by a Sea Dragon-type ballast unit

IV, F, Small-Model Tests of Overall Sea Dragon System (cont.)

6. Launched by remote control
7. Recovered and refurbished, using a reduced-scale inflatable flare recovery system
8. Relaunched several times
9. Static tested underwater on a model water-borne ballast-deflector unit as the Sea Dragon will be static tested at sea prior to flight.

These tests will provide additional assurance regarding the feasibility of the Sea Dragon concept and will provide early experience with the sea launching of rocket vehicles to uncover and avoid later technical problems with the full-scale Sea Dragon. This program will be conducted where adequate shore-based engineering facilities and adjacent adequate open-water test areas are readily available. A number of such sites are known to exist.

G. FULL-SCALE SYSTEM SURFACE DYNAMIC TESTS

In this test series, the full-scale two-stage surface test article described earlier will be used. All components of the test vehicle will be flight weight.

1. Operational Sequence Tests

During this series, individual vehicle stages will be launched from their fabrication ways into the water, towed to the assembly lagoon at Cape Canaveral, Florida, assembled with the other stages and ballast unit into a complete vehicle, loaded with fuel, towed to Point Bravo, filled with liquid oxygen (LOX), towed to Point Able, erected, checked out, counted down, launched (simulated only), and recovered (simulated only). This pseudo-operational practice with the full-scale Sea Dragon system is intended to reduce

IV, G, Full-Scale System Surface Dynamic Tests (cont.)

development time and cost by uncovering as early as possible unforeseen technical problems and allowing time to solve them while still meeting a tight development schedule. The entire operational sequence will be performed at least five times during this series.

In these combined systems tests, all electrical, pneumatic, hydraulic, and mechanical interfaces will be studied for evidence of areas where corrective design must be applied to ensure systems integrity.

2. Vibration and Acoustic Tests

A logical location is provided by the assembly lagoon at Cape Canaveral for conducting artificially-simulated tests of structural vibration modes of the complete vehicle. Because the vehicle is free-floating in the water, its vibrational modes are not constrained as badly as in the case of dynamic tests on land where rigid physical supports must be provided.

To conduct these tests, the assembly lagoon will be equipped with the necessary electro-mechanical vibrators and acoustic sources. The initial tests will be performed on the full-scale vehicle described above.

3. Full-Scale Tests of Staging System

The full-scale surface test vehicle and facilities at the assembly lagoon will also be used in a free-floating relatively-frictionless mode to test the gas-pressurized staging system planned for use in flight. While the combined vehicle is floating in the assembly lagoon, the stage separation system will be activated a number of times, allowing the two stages to separate, and permitting observation of any design problems requiring correction.

IV, Detailed Development Plan (cont.)

H. RECOVERY DEVELOPMENT (FOR RECOVERABLE FIRST STAGE)

Studies of inflatable flare materials will begin early in the development program. Scale models and full-size models of the chosen design will be manufactured and inflation tests will be conducted at the factory. Resistance of the flare to aerodynamic heating will be determined in tests using a hot gas source.

The analytical uncertainties associated with the Sea Dragon recovery concept demand that actual water entry tests be conducted before final first-stage designs are established. For this reason, it is planned to fabricate scale models of the first-stage vehicle (30 in. dia) equipped with scale-model inflatable flares, and to fire them, by means of compressed gas, downward into a water tank that already exists at the Aerojet-General Plant, Azusa (Figure 2-2). As an alternative to the compressed gas system, current studies indicate that it may be more desirable to use steam, in the manner of the "steam rocket", upon which Aerojet-General has already completed extensive studies. High-speed movie cameras will be used to record the aerodynamic and hydrodynamic characteristics of the model's trajectory. The models will be heavily instrumented to measure water pressures, structural loads, and cavity growth (during water entry). These measurements will be recorded within the model and the data retrieved after the firing, or preferably, transmitted through unreeling wires to fixed recorders. Telemetry will be used only if the two more economical alternatives mentioned above prove unfeasible. For these tests, it is estimated that five models will be required, and that 50 firings will be conducted.

Various water entry velocities and incidence angles will be included in the tests, corresponding to the ranges of these parameters expected in the full-scale flight article.

IV, Detailed Development Plan (cont.)

I. WIND TUNNEL TESTS

The development program will include a series of thorough wind tunnel tests to obtain design data for flight components and ensure reliability of the full-scale article in flight.

Many test models and existing wind tunnel facilities will be used for these tests to obtain data regarding aerodynamic forces and aerodynamic heating effects on:

1. Fully assembled two-stage vehicle with insulation panels installed and expandable nozzle unexpanded
2. First and second stages during the staging process
3. First-stage vehicle after staging
4. First-stage vehicle on re-entering dense atmosphere
5. First-stage vehicle with model of inflatable flare recovery device installed, and both furled and unfurled
6. Second-stage vehicle after staging but before expansion of expandable nozzle
7. Second-stage vehicle with expanded nozzle

Separation within the wind tunnel of the first-stage and second-stage models will provide data on the effectiveness of the gas-pressure-energized staging system intended for Sea Dragon.

J. SELECTION OF MATERIALS

Although the current study has resulted in a tentative selection of Aluminum 2014 as the basic material of construction for the two stages of Sea Dragon, it is planned that further consideration must be given to this matter

IV, J, Selection of Materials (cont.)

prior to fabrication of any vehicles. Therefore, as a part of the development program, it is planned to conduct tests with a variety of materials, especially in the relatively thick sections required for the vehicle. Some of the metals that will be tested include stainless steel, 18% nickel maraging steel, and titanium; tests of strength, weldability, toughness, corrosion resistance, notch sensitivity, and compatibility with Sea Dragon propellants will be conducted. Tests of these materials will be carried out, when appropriate, both at room and cryogenic temperatures.

K. DEVELOPMENT OF MANUFACTURING SYSTEM

The current plan for fabricating Sea Dragon vehicles is detailed in another section of this report. Because the manufacturing method chosen for Sea Dragon is a significant departure from conventional space industry practice, especially in regard to the size of the article to be manufactured, it is expected that a research and development effort will be required for a number of elements in the manufacturing system if they are to be completely effective. Among these are:

1. Manufacturing process used to produce the thrust chamber cooling tubes (of varying cross-sectional area and shape) for both first-and second-stage engine chambers
2. The method of laying-up these tubes to produce the wedge chambers required by the research and development engine tests and the full-scale chambers
3. The special mandrel tentatively chosen as the form upon which chamber assembly will be achieved
4. The method of brazing the individual tubes into a finished chamber
5. Lifting fixtures for lifting tube-bundle segments from the preassembly area to the mandrel position

IV, K, Development of Manufacturing System (cont.)

6. The method of accurately aligning the cylindrical segments of the main tanks into a single cylinder
7. The method of cleaning the finished tanks so that they can accept the intended propellants without explosion hazard and without hazard to engine operation in flight
8. The method of conducting hydrostatic proof tests, leak tests, pressure cycling tests, and cryogenic tests of finished tanks
9. The method of horizontal movement of individual tank sections into position for welding, with accurate alignment
10. The method of welding cylindrical tank segments together
11. The method of fabricating the expandable nozzle

It is planned that all of these problems will be attacked early in the development program by small-scale experiments in each area. These results will be supplemented by skill gained at the fabrication site in the production of the R and D wedge chambers requiring full-scale tubes with the objective that the fabrication system will be well shaken-down in time for the larger production rates following R and D.

L. TRANSPORTATION SYSTEM DEVELOPMENT

It is expected that little difficulty will be experienced in ensuring that the assembled first-stage and assembled second-stage vehicles will float in a condition satisfactory for towing by conventional tow boats from the fabrication site to the assembly lagoon at Cape Canaveral. A specially-designed towing device will be required to transmit towing forces to the vehicle structure but its design is expected to be produced easily.

IV, L, Transportation System Development (cont.)

If it is decided that the expandable nozzle will be fabricated at a site remote from the vehicle stages, a different problem will arise. To water-transport the expandable nozzle, the program will rely on simple barge transportation of the nozzle in four sections. Handling of this bulky, but non-dense, member is expected to present no major problems.

The towing tests projected in the foregoing plan for small-scale and full-scale pseudo-operational tests will provide the basis for final design of the towing fixtures and equipment.

M. SEA OPERATIONS SYSTEM DEVELOPMENT

The process of assembling the complete vehicle at the assembly lagoon at Cape Canaveral will require some development effort in regard to the techniques and tools of assembly. These problems are described in detail and several alternative solutions are offered in the operational plan contained elsewhere in this report.

The test base for final selection of assembly technique will be formulated from the small-scale and full-scale pseudo-operational tests described earlier.

To conserve on development funds, it is planned to follow an assembly procedure that relies on water support of the parts to be assembled. It remains for further test programs to determine whether this technique will provide close enough control of interstage alignment tolerances and adequate accessibility for assembly personnel.

IV, M, Sea Operations System Development (cont.)

In support of this portion of the development requirements, assembly experiments will be performed with the small model vehicle previously described in the insulation development section.

Apart from the equipment required to join physically the individual stages in the assembly lagoon, it is expected that other facilities and equipment such as propellant fill and drain equipment will be conventional in character and will not require significant development effort.

N. LAUNCH SUPPORT EQUIPMENT DEVELOPMENT

Substantial development effort will be given to providing designs for functional and reliable launch support equipment for the Sea Dragon operation.

Types of equipment that must be provided for the sea launch, some of which are unique to this type of operation include:

1. The vehicle ballast unit, which provides buoyancy to the vehicle during horizontal water-transport and then provides the necessary ballast weight to erect the fully-loaded vehicle.

2. Propellant topping-off equipment (in case an extended hold is necessary).

3. Equipment for providing personnel access to the Sea Dragon in its erected position. This equipment may be required to give access to the below-water as well as above-water sections of the vehicle for adjustments to be made before launch.

IV, N, Launch Support Equipment Development (cont.)

4. Launch control equipment. This equipment will probably be very similar to the conventional consoles used in land launch complexes at Cape Canaveral. However, some modifications will be necessary to adapt it for use from a floating, rather than land-based control center, and to connect the control center to the erected Sea Dragon via radio link.

5. The barge for loxing the Sea Dragon at Pt. Bravo will probably be a standard barge with large liquid oxygen storage tanks of conventional construction, equipped with LOX transfer pumps and plumbing.

O. TRACKING AND RANGE SAFETY SYSTEM DEVELOPMENT

Other than providing a standard tracking beacon for the flight vehicle, it is estimated that no new tracking or data handling facilities will be required to support Sea Dragon launches in addition to those available or those to be supplied within the near future to the Atlantic Missile Range (AMR).

For example, it is understood that two Mobile Atlantic Range Stations (MARS) tracking ships will be delivered to the AMR in early 1963. These ships will complete the range's tracking coverage for the full 10,000 mile range. In addition, the new GLOTRAC global tracking network will soon give world-wide tracking coverage in all areas of interest for Sea Dragon flights.

The present Azusa range safety and destruct system is estimated to be adequate for Sea Dragon.

IV, Detailed Development Plan (cont.)

P. FLIGHT TEST PROGRAM

The Sea Dragon development program will culminate in a ten-vehicle flight test program (Table 2-1). 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 mid-term flights, and successful spacecraft delivery-into-orbit in the later flights (for final demonstration of operational readiness). Flight instrumentation channels will be allocated to individual vehicle elements in accordance with this general pattern.

Q. OTHER SUBSYSTEMS

Detailed development plans for many subsystems of Sea Dragon other than those described herein must eventually be devised, but time to do so during the current preliminary study effort was not available. It is planned to provide the additional details as well as refine what has been presented here (Figure 2-3) in later, more extensive studies prior to the contractual initiation of the hardware development program.

TABLE 2-1

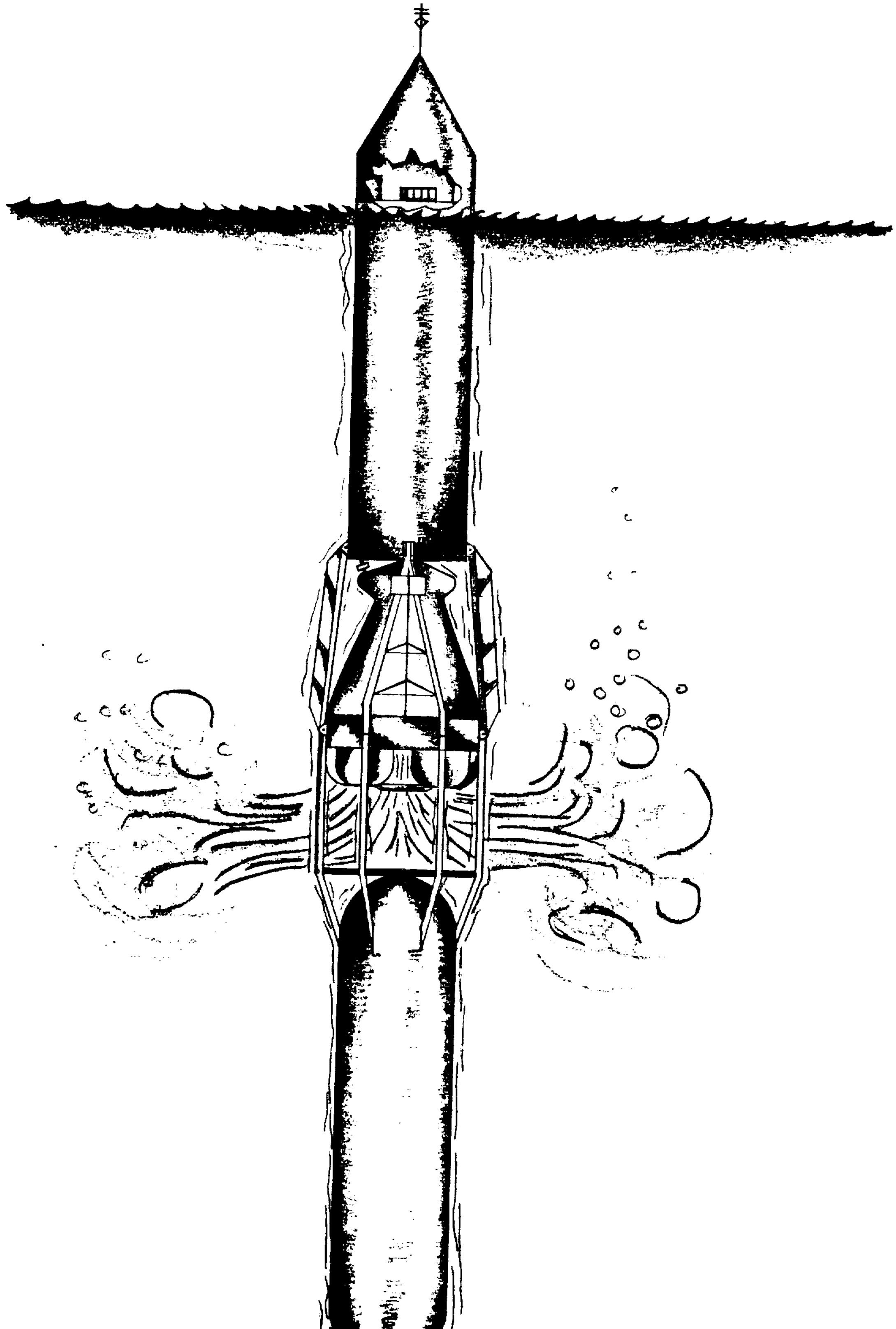
SEA DRAGON FLIGHT TEST PROGRAM (FOR RECOVERABLE FIRST STAGE)

(P = Primary Test Objective)
(S = Secondary Test Objective)

	Flight Number									
	1	2	3	4	5	6	7	8	9	10
Vehicle Configuration										
Active first stage	x	x	x	x	x	x	x	x	x	x
Dummy second stage	x									
Active second stage		x	x	x	x	x	x	x	x	x
Expandable nozzle installed		x	x	x	x	x	x	x	x	x
Dummy spacecraft	x	x	x							
Active spacecraft				x	x	x	x	x	x	x
Cryogenic payload							x	x	x	x
Test Objectives										
Water-tow individual stages	P	S	S	S	S	S	S	S	S	S
Lagoon assembly and checkout of vehicle	P	S	S	S	S	S	S	S	S	S
Lagoon fueling system	P	S	S	S	S	S	S	S	S	S
Water-tow fueled vehicle	P	S	S	S	S	S	S	S	S	S
Pt. Bravo loxing system	P	S	S	S	S	S	S	S	S	S
Water-tow fueled-and-loxed vehicle	P	S	S	S	S	S	S	S	S	S
Launching System	P	S	S	S	S	S	S	S	S	S
Launch-abort system	S	S	S	S	S	S	S	S	S	S
Ballast unit staging	P	P	S	S	S	S	S	S	S	S
First-stage propulsion	P	P	P	S	S	S	S	S	S	S
First-stage attitude control	P	P	P	S	S	S	S	S	S	S

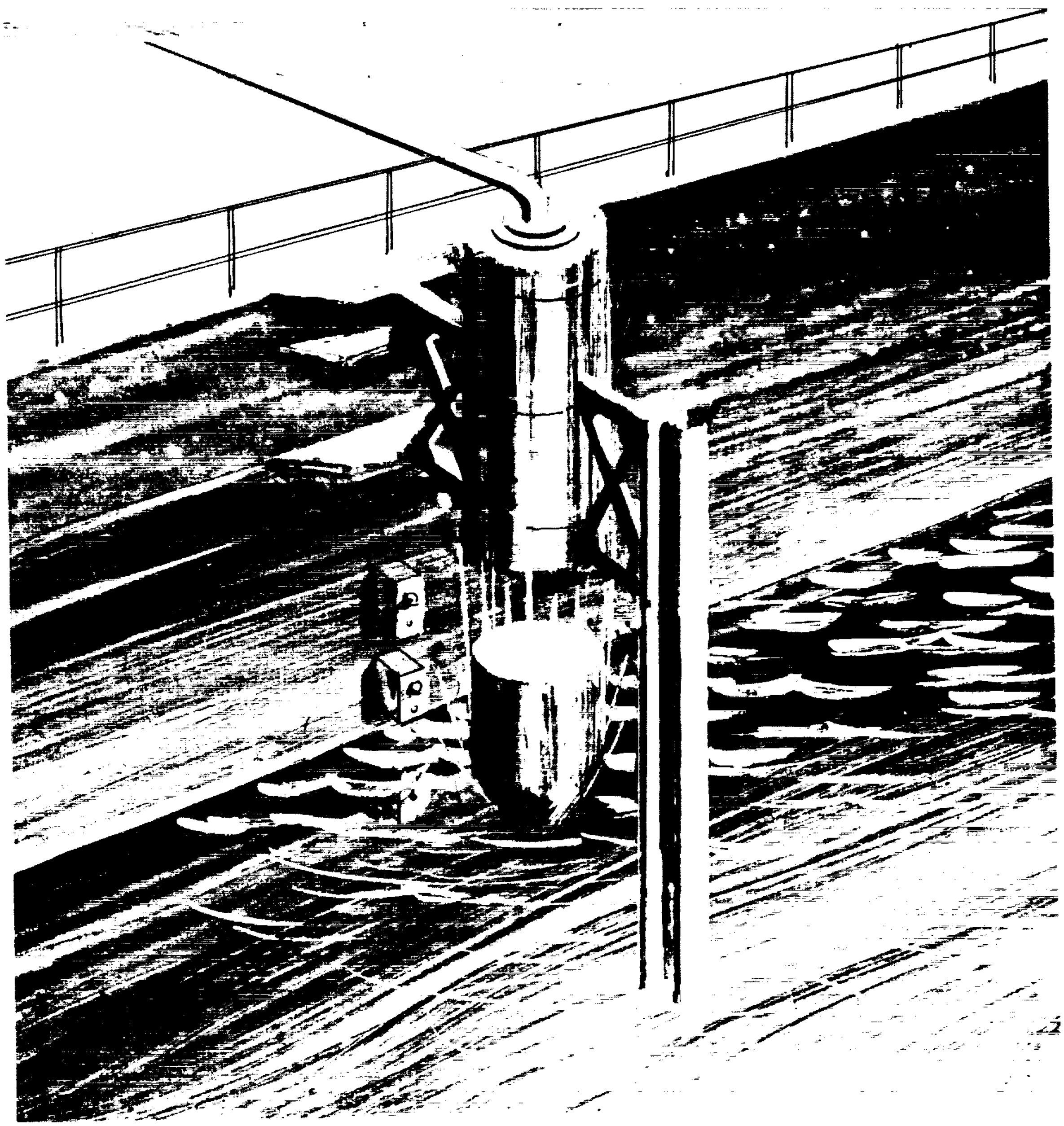
TABLE 2-1 (cont.)

	Flight Number									
	1	2	3	4	5	6	7	8	9	10
First-stage structure	P	P	P	S	S	S	S	S	S	S
First-stage destruct	S	S	S	S	S	S	S	S	S	S
First-stage insulation	P	P	P	S	S	S	S	S	S	S
Staging	P	P	P	P	P	P	S	S	S	S
First-stage atmospheric re-entry	S	S	S	P	P	P	S	S	S	S
First-stage water entry and recovery	S	S	S	P	P	P	S	S	S	S
First-stage refurbishment	S	S	S	P	P	P	S	S	S	S
Second-stage engine start and operation		P	P	P	P	P	P	P	S	S
Second-stage guidance and control		P	P	P	P	P	P	S	S	S
Second-stage structure	S	P	P	P	P	P	S	S	S	S
Second-stage destruct	S	S	S	S	S	S	S	S	S	S
Second-stage orbital injection		S	S	P	P	P	P	P	P	P
Spacecraft separation				S	S	S	P	P	P	P
Cryogenic payload survival							P	P	P	P



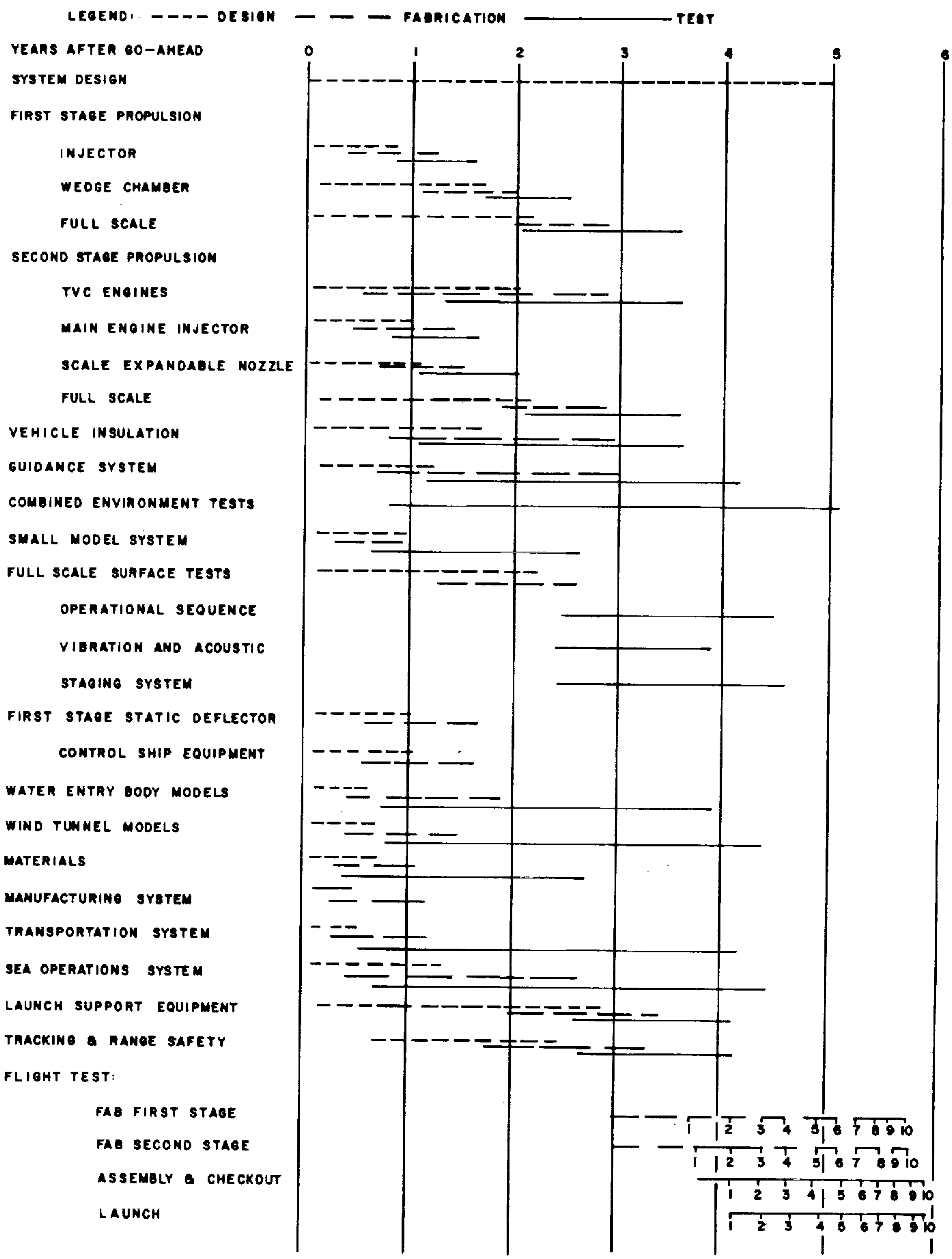
First-Stage Static Test at Sea

Figure 2-1



Water Entry Model Being Fired into Water Tank

Figure 2-2



Sea Dragon Development Schedule

Figure 2-3

PART 3

MANUFACTURING AND FABRICATION PLAN

I. SUMMARY

The Sea Dragon is a total system concept, and from the start of research and development to the firing of the last operational vehicle an elapsed time span of 15 to 20 years will result. A ten-year time span for manufacturing is included approximately in the middle of the projected program time.

The fabrication, assembly, and partial testing of the first-stage vehicle, the second-stage vehicle, the dummy payload and the ballast unit will take place in a shipyard in the San Francisco Bay area.

An alternative plan is proposed (providing schedule and firing requirements dictate) of having a shipyard assembly point on each coast and having the tanks for the various stages made in additional shipyards and floated to the assembly points. With this alternative, a master tooling concept would be initiated to ensure interchangeability of parts.

A brief discussion of the fabrication, assembly, and testing cycles to be used in the shipyard assembly point to produce the four major hardware items required for delivery to the operational personnel is included. To establish the feasibility of producing a Sea Dragon vehicle as suggested, two techniques were used. Four critical pieces of hardware, the first-stage thrust chamber assembly, the first-stage RP-1 tank, the second-stage fuel tank (LH_2), and the second-stage expandable nozzle were detailed according to the fabrication, assembly, and testing techniques to be used. Cost of these items were then extrapolated. The second technique used to establish Sea Dragon feasibility was to request manufacturing plans and Rough Order of Magnitude (ROM) costs from several shipyards across the country to produce Sea Dragon tankage.

I, Summary (cont.)

Preliminary facility, quality control and material considerations were documented.

The following conclusions were drawn from this study:

Additional time would be required to select an optimum system.

With one exception, the first-stage RP-1 tank, the Sea Dragon appears to be within the existing state of the art.

Current facilities, tooling, and knowledge are sufficient to allow construction of a Sea Dragon today.

Sea Dragon fabrication costs and tolerances are closer to shipbuilding rather than aerospace industry practices.

II. INTRODUCTION

The Liquid Rocket Plant's manufacturing plan for fabricating the Sea Dragon's first-stage vehicle, second-stage vehicle, dummy payload, and ballast unit is presented in this section. (For the identity of the above items and their relationship to the total vehicle, see Figure 3-1 attached.)

A. GENERAL

The Sea Dragon is a total system concept, and the feasibility plan must describe this "cradle to grave" operation that spans a time period of 15 to 20 years.

In order to fit the manufacturing plan into the proper time perspective, it was necessary to define the various phases of the Sea Dragon program. These evolutionary phases were identified as: the research, development, test, and evaluation phase; the manufacturing phase; and the operations phase.

It was recognized that these phases would have a considerable degree of overlap, but each would operate in a pure state at some instant of time. In order to more clearly identify the content of each phase, the "end item" requirements in terms of hardware, services, data and facilities were listed. (See Figure 1-1.)

The manufacturing phase would start approximately two to three years after the research development test and evaluation (RDTandE) phase had been initiated and end approximately three to four years before the operations phase ended and have a total life span of ten to 15 years.

The major interface between the manufacturing phase and the RDTandE phase will be the accomplishment of the tenth development flight. The interface between the manufacturing phase and the operations phase is defined as the delivery of the four major hardware items to the operations personnel.

II, A, General (cont.)

The assumptions used in developing the manufacturing plan are as follows:

The Sea Dragon is a two-stage vehicle to be launched from the sea with a primary purpose of placing a large payload into a medium orbit at a minimum cost.

The basic payload is presumed to be an Apollo Command Capsule, periphery gear, and a large tank of hydrogen.

A schedule of 12 or 24 launches per year is to be considered.

The first stage can be recovered, refurbished and reused for many flights or is expendable.

The second stage will go into orbit with the payload.

The various vehicles and "end items" to be manufactured under this plan will be assembled at Cape Canaveral in an assembly lagoon.

The fabrication techniques developed for the manufacturing phase will also be used for the RDTandE phase.

B. OBJECTIVES

The manufacturing plan was prepared on the basis of the following objectives:

II, B, Objectives (cont.)

When feasible, use systems that are currently within the state-of-the-art.

Use existing facilities, capabilities, and methods.

Similarity is to be maintained between R and D and manufacturing hardware and facility requirements.

Use existing skills and organizations.

Do not be overly optimistic; describe potential problems.

Describe a system sufficiently so that it may be costed and can serve as a basis for more definitized studies.

Achieve the minimum total cost without jeopardizing reliability.

C. MANUFACTURING CONSIDERATIONS

The following broad considerations were made pertaining to manufacturing sites, facilities, and transportation. The size of the Sea Dragon and the desire to use existing facilities whenever feasible, influenced the selection of shipyards as the potential manufacturing sites. 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 the existing shipyards as the manufacturing site simplified the facilities and transportation problems. An Aerojet-General Solid Rocket Plant study of the United States shipyard facilities indicates that existing shipyards are adequately equipped with the majority of the required facilities. Existing shipyards have access to the sea, which aids in resolution of the transportation problems. The shipyards have a complement of manpower that is trained in

II, C, Manufacturing Considerations (cont.)

handling, rigging, and building of large vehicles in excess of the Sea Dragon's requirements. Upgrading of shipyard practices, when necessary, by the addition of aerospace techniques and "knowledge" will form an efficient, capable organization.

D. ALTERNATIVE PLANS AND LIMITING FACTORS

During the preparation of this plan there was no attempt to select the optimum system. Many alternate materials and plans will be suggested in this report that should be investigated before final system selection.

In order to provide an adequate manufacturing and fabrication plan for the Sea Dragon manufacturing phase, it would be necessary to detail the following:

- Management plan
- Manufacturing plan
- Schedule plan and controls
- Facilities plan
- Quality control plan
- Support plan
- GFP, GFAE, GFE Requirements
- Customer Support Requirements
  (See Appendix 3-1 for detailed requirements)

Limiting factors pertaining to time and available manpower during the preparation of this feasibility plan required that specific items be selected for investigation on the basis that adequate extrapolation of these items would prove the feasibility of manufacturing the complete Sea Dragon system.

III. DISCUSSION

The Sea Dragon Configuration #135 uses a recoverable first-stage; in configuration #136, both stages are expendable. The production schedule, facilities, and cost would deviate widely with the assumption of a recoverable first-stage vehicle. For this study, the most taxing situation from a production standpoint was assumed--that of a completely expendable vehicle.

A. SYSTEMS ANALYSIS

The broad analysis outlined in the introduction helped to isolate the requirements for the manufacturing phase concerning hardware, services, data, and facility "end items".

A further definition of the manufacturing phase was formulated by identifying the hardware "end item" requirements at the next lower level of indenture. (See Appendix 3-2.)

On the basis of the hardware "end item" breakdown, a preliminary basic parts list was prepared. (See Appendix 3-3.)

It was presumed at the time that the "end item" breakout was prepared, that it would serve as a basis for preparing PERT networks and summarizing PERT Cost requirements. Time did not permit this refinement.

The analyses of these appendices indicated that the portrayal of the fabrication and assembly techniques to be used on only some of the major components of the Sea Dragon would suffice to show the feasibility of manufacturing and assembling a Sea Dragon system at the level of this study.

III, A, Systems Analysis (cont.)

The three components initially selected for detailing, because of their complexity and cost, were the first-stage thrust chamber assembly, the second-stage fuel tank (LH_2), and the second-stage expandable nozzle. Because of the fabrication difficulties that could be encountered, the first-stage fuel tank (RP-1) was added at a later date.

B. FABRICATION AND ASSEMBLY PLAN

1. General Approach

The manufacturing investigation was restricted to the fabrication and assembly aspects to more competently portray the technical feasibility of the concept. Organizational alinement, responsibilities and experience or controls will be referred to in context only, as they may relate to a specific requirement.

The four major hardware items, consisting of a first-stage vehicle, a second-stage vehicle, a dummy payload and a ballast unit would be delivered to the operational personnel from the manufacturing assembly site. The manufacturing assembly area would be responsible for the fabrication of the first- and second-stage thrust chamber assemblies and tankage, the completion of the tank assemblies, the fabrication of the expandable nozzles, the mating of the thrust chamber assemblies to the tank assemblies, all required testing and decontamination and the delivery of the vehicles to the dock area. Figure 3-2 is an artist's concept of a potential assembly point with side launched ways. The first-stage TCA is partially completed. The injector plate is on the ways awaiting assembly. The first-stage tankage has just been completed and awaits assembly. Farther

III, B, Fabrication and Assembly Plan (cont.)

down the way the second-stage vehicle is shown in a partially completed state. To take advantage of existing facilities and to minimize shore requirements, it is possible that end-launched ways or dry docks will be utilized for assembly rather than the side-launched ways portrayed.

2. First-Stage Vehicle Assembly Technique

The first-stage vehicle assembly technique is as follows:

• The support structures that cradle the vehicle are lined up on a large way.

The major assemblies are lined up on platforms along the way. The act of placing them in correct sequence and the removal of the injector from its vertical fabrication position to a horizontal position, is accomplished as follows:

The tanks are moved along the track to the foremost position on the way.

The injector is hinged or pivoted from a vertical ground fabricating position onto a railroad operating platform, which holds the injector in a horizontal position. The injector is now moved to the way and is made ready to be attached to the combustion chamber.

The combustion chamber is made ready to install onto the injector by removing the upper end of the mandrel, swinging a portion of the chamber-holding platform away at its pivot point, and the injector and chamber are brought together and welded inside and outside completing the TCA which consists of the chamber and the injector.

III, B, Fabrication and Assembly Plan (cont.)

The injector holding platform is lowered hydraulically and moved to a side track.

The TCA is moved into position for welding the gimbal to the injector gimbal pad. The gimbal is swung into position by crane and welded.

The tankage is brought into position with the cone of the fuel tank contacting the gimbal sphere. Gimbal is welded to tankage inside and out. Lines, bellows, swivel joints, and valves are swung into position by crane. All components are supported in place by special holding tools or slings to allow alignment and welding.

The actuator mountings and arms are aligned, then the actuators are swung into position for bolting in place.

The platform holding the TCA is lowered hydraulically and pulled from beneath the pad and stored on a side track for later use.

The entire rocket engine now undergoes complete electrical installation and pressure sphere installation. The controls and lines are connected and checked out. Final inspection completes the assembly effort.

The rocket is moved to a position for back flushing and filling of tanks with water, for system checkout and flow characteristics.

III, B, Fabrication and Assembly Plan (cont.)

The rocket assembly is now moved to a position on the tracks where the tanks and TCA are drained of all water and then thoroughly cleaned (LOX clean) with trichlorethylene or other solvent until all surfaces are void of oil or other foreign matter.

The openings are immediately sealed.

Just prior to launching down the way, the electrical power supply is attached to the support structure.

The ballast unit would be attached to the first-stage vehicle prior to launching down the way as scheduling requirements necessitated.

The second-stage vehicle would be assembled in the same manner as the first-stage vehicle except that no ballast units would be attached but payloads would be delivered by sea to the assembly point and attached to the second-stage vehicle prior to delivery of this item to the operational personnel.

The dummy payloads required for the R and D flights and the ballast units are considered to be sufficiently similar to the tanks that the following description of the tank fabrication techniques will suffice.

a. Alternate Fabrication and Assembly

In the event that future scheduling requirements dictate expansion of the above concept, the following alternate has been considered.

III, B, Fabrication and Assembly Plan (cont.)

It is conceived that the four major hardware items, consisting of a first-stage vehicle, a second stage-vehicle, a dummy payload and a ballast unit, would be delivered to the operational personnel in equal quantities per year on the eastern seaboard and the western seaboard of the United States. Considering a quantity of twelve launches per year, and an expendable vehicle, this would presume a delivery of six vehicles per year for each coastal area. Preliminary scheduling considerations indicate that this rate could be maintained with one major assembly point on each coast. These manufacturing assembly points would be supplied with completely fabricated first- and second-stage tankage from shipyards along the coastal area. The manufacturing assembly areas would be responsible for the fabrication of the first- and second-stage thrust chamber assemblies, the receipt of the tankage, the completion of the tank assemblies, the mating of the thrust chamber assemblies to the tank assemblies, all required testing and decontamination and the delivery of the vehicles to the dock area.

The assembly techniques portrayed and discussed are all well within the existing capabilities of known shipyards on both the east and west coasts, but definite problems pertaining to vehicle misalignment can be foreseen. In order to minimize or eliminate this potential misalignment and still use the maximum number of vendors, a master tooling concept, using the Cartesian Coordinate System for dimensioning, is proposed and briefly outlined in Appendix 3-4.

III, B, Fabrication and Assembly Plan (cont.)

3. Fabrication and Assembly of the First-Stage Thrust Chamber Assembly

In the fabrication of the first-stage thrust chamber assembly, wall configurations varying from the older double-wall configuration, to the drilled aluminum type chamber, to the tube wall, used on the Titan, were considered. Tube wall type construction was chosen based on scaling studies made by Aerojet-General and others in the industry. The coolant tubes will consist of stainless steel, seamless .065 in. wall tubing approximately 3 in. in diameter. The tubes would be delivered to the assembly point by boxcar in a partially assembled state. The tube segment would be lifted from the boxcar with a crane and placed on a preformed concrete support. The final tube connection would then be made and the tube assembly would be leak and pressure tested. The tube assembly would then be lifted onto a rotating mandrel as originally portrayed in Figure 3-2. After tack welding the tubes in position, the mandrels would be removed and the tubes would be brazed with a quartz lamp process.

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

For details pertaining to the fabrication and assembly process, see Appendix 3-5.

The following areas appear to require additional investigation.

III, B, Fabrication and Assembly Plan (cont.)

A separation of more than .010 in. between the tubes during the brazing process will permit the braze material to run out.

The tubes must be cleaned prior to brazing by quartz lamp, but acid cleaning can not be used.

The injector fabrication process is new and untried.

This technique of fabrication is relatively unique in the ship building industry and a definite learning factor will be encountered. (Aerospace "know-how" will be required here.)

4. Fabrication of the Second-Stage Fuel Tank (LH_2)

During the preliminary stages of this study effort, initial investigations were conducted pertaining to the possible fabrication of the second-stage fuel tank (LH_2) for Configuration #132 from either titanium or 18% Ni steel (maraging). This was prior to the selection of 2014T6 aluminum as the candidate material. Since this information may be helpful in future Sea Dragon work and for costing considerations, the study work completed is documented herein.

Two studies are furnished for this tank, one using 18% Ni steel (maraging) and the other using 5Al-2.5sn titanium.

III, B, Fabrication and Assembly Plan (cont.)

The tank is broken down into three basic parts, the elliptical head, the cylindrical, and the conical section. The number of sheets, sheet size, linear weld length, number of passes, and gross area are furnished for all three sections on each study. Only the elliptical head sequence of operations with the appropriate setup and fabrication manhours were computed. The above information is available in Appendix 3-6.

5. Fabrication and Assembly of the First-Stage Fuel Tank (RP-1).

Two different modes of assembly have been considered in the fabrication of the first-stage fuel tank (RP-1). One mode uses a horizontal assembly technique similar to the shipyard fabrication of a submarine in a drydock or building way. The vertical assembly technique uses a drydock or basin that could be flooded. Figure 3-3 portrays the vertical assembly technique. Although the investigation of this technique was limited, preliminary studies indicate that if mismatch or excessive membrane stresses become a serious problem, this alternate plan of assembly can help to correct the situation. Preliminary estimates indicate that the vertical method of tank assembly is three to four times as costly as the horizontal method. This information is based on preliminary cost estimates received from shipyards that are considering both modes of fabrication. As a substantiation of preliminary studies conducted at Aerojet-General pertaining to the horizontal method of assembly of the Sea Dragon tankage, preliminary proposals were solicited from the major shipyards in the country for fabricating this tankage.

III, B, Fabrication and Assembly Plan (cont.)

The following preliminary manufacturing plan is submitted for building the first-stage RP-1 tank from Aluminum 2014T6. More detailed information is presented for this assembly because it is felt that it represents one of the most severe manufacturing problems associated with Sea Dragon.

a. Technical Discussion

(1) Material

The major considerations in selecting the material are weldability, strength, and difficulty to post-weld heat treat.

The primary problem of fabricating the RP-1 tank of Aluminum 2014 is the thickness of the shell (4 in.) with the necessity for doubling the thickness (8 in.) in the weakened weld areas. Aluminum was selected as the tank material early in the study. Later information obtained by continuing materials selection studies indicate that 18% Ni (maraging) steel may be a better selection for the RP-1 tank. Because this data was obtained late in the course of the study, it is not possible to change the approach used in the manufacturing plan; thus the study was completed using the Aluminum 2014 originally selected. The information developed for Aluminum 2014 is presented below to show the results of the study based on this material and as an aid to final material selection. This is not necessarily the material or technique recommended.

(2) Welding and Heat Treatment of Aluminum 2014-T6

It is proposed to fabricate the Aluminum 2014 for the RP-1 tank by welding the 4.17 in. thick plate to an 8 in. x 12 in. bar for welding to adjacent sections.

III, B, Fabrication and Assembly Plan (cont.)

The plate edges will be prepared by use of the Plasma-Arc cutting process and by mechanical means. The joint design for the plate to bar will be of the groove-T design and the joint preparation for plate edge welding will be double U groove type. Immediately before welding, all joint surfaces and surfaces on which welds will be deposited will be cleaned with a suitable degreasing solvent and the oxide removed by power brushing with a stainless steel brush.

The metal inert gas (automatic and semiautomatic) process is proposed for welding the aluminum alloy tanks. The filler metal will be Aluminum 4043. The shielding gas will be argon (for down hand position) and a mixture of 75% argon and 25% helium (for vertical and overhead positions). All joints welded by automatic machine will be positioned for down hand welding. Joints welded by semiautomatic will also, insofar as practicable, be positioned for down hand welding.

Tack welds will be made with the same grade of electrode as the finished weld, will be of the same quality, and in general, will be deposited in such a manner as to facilitate incorporation in the final weld. Cracked or broken tack welds, and those of doubtful or poor quality will be chipped out; and all others thoroughly cleaned and inspected prior to being incorporated with the actual weld.

Welding technique, such as electrode size, mean voltage, current, wire feed, travel speed, shielding gas flow, etc., will be substantially as established and qualified in the development of the welding procedure. The welding current and manner of depositing the weld metal will be such that there will be no undercutting of the adjoining base material.

III, B, Fabrication and Assembly Plan (cont.)

Any cracks, blowholes, or defective welding will be removed by chipping material recleaned prior to repair welding. Defects will be rewelded by use of the semi-automatic MIG process or TIG process. The TIG process will be advantageous and desirable in making minor repairs.

It will be necessary to heat treat the plate and bar assembly to provide T6 temper both in the base material and weld. Present furnace capacity is limited to 12 ft in width and 24 ft in length. To heat treat sections such to 40 ft in length, it will be necessary to build a furnace of sufficient size to accommodate the larger slabs. Heat treatment of Aluminum 2014 to produce a T6 temper will require heating to 950°F. for approximately one hour at temperature followed by quenching. Because of the unusual section thickness and cross section, it may be necessary to provide quenching fixtures to decrease distortion resulting from the quenching. The feasibility of water spray quenching will be investigated to determine if this type of quenching would be suitable and result in less distortion than quenching by submergence. Following the quench, the aluminum would receive a precipitation treatment for such time as required to develop the necessary physical properties.

It will be necessary to construct handling facilities for movement of the hot slab from the furnace to the quenching facility. No additional heat treatment is anticipated for the 8 in. thick butt weld joint.

It is not expected that heat treatment will be needed for butt welds in the other tanks.

III, B, Fabrication and Assembly Plan (cont.)

(3) Design Responsibilities

The selection of the material and the design of the tankage is to be furnished by Aerojet-General. There would be a close liaison between Aerojet-General and the shipyard on the development of the design details in order that manufacturing procedures would remain within the capabilities of the shipyard and the concept of Sea Dragon; namely, construction based on exploiting standard shipyard techniques for large diameter vessels and not airframe fabrication.

The design plans and specifications to be furnished by Aerojet-General will be in reproducible form.

The shipyard will prepare shop drawings showing welding details, plating seams and butts and design of all jigs and fixtures.

The shipyard will prepare and submit a quality control procedure from guidelines furnished by Aerojet-General and the Quality Control and Inspection Department would maintain close liaison with Aerojet-General representatives, to carry out all phases of inspection, testing, metallurgical laboratory services and maintaining inspection and test records.

The shipyard would be responsible for all calculations for launching, floating stability of the tankage, construction of scale models or mock-ups as necessary and collaboration with Aerojet-General on arrangements for towing the stages away from the shipyard.

III, B, Fabrication and Assembly Plan (cont.)

b. Manufacturing Discussion

The manufacturing concept is the same for both Stage I and Stage 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 extremely large diameter vessels in this project. The tankage would be finally erected on regular shipbuilding ways and joined in the same manner as submarines or other large cylinders. The tankage would then be floated by conventional ship launching methods.

In the preliminary design of the Sea Dragon tankage, there is no internal framework such as would be found in ships or submarines other than the free surface baffling and it is necessary to provide support or internal shoring during the building, launching and shipping phase. These supports to be of interchangeable structural members arranged to allow dismantling and removal for reuse.

The jigs and fixtures used for subassemblies, maximum assemblies and final erection would be the same for either the 18% Ni steel or the Aluminum 2014-T6, with some adjustments to allow for variance in plate thicknesses. There would be machine shop special tooling required for the weld preparation of the aluminum plates and bars.

(1) Facilities

Existing yard areas and ship launching ways would be used for this program.

III, B, Fabrication and Assembly Plan (cont.)

Portable covers - semi-cylindrical - as now used over the submarine building ways would be required for launch ways. Other portable covers would be required on the platens.

A special heat treat facility, including quenching and handling equipment, will be required.

(2) Manufacturing Sequence

(a) Fabrication

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

(b) 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 weld prepped by compound portable edge milling machines mounted on a gibbed carriage traveling laterally on a machined track.

III, B, Fabrication and Assembly Plan (cont.)

The tapered plates for the RP-1 tanks leading to the gimbal support would also have to be machined in the shop by a compounded vertical mill, cross fed and laterally adjusted before forming.

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

(c) Maximum Assembly

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

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

(d) Final Assembly

Final joining of all of the units making up the first stage fuel tank will now take place. 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 be next performed. Final cleaning, addition of protective coatings, and instalation of insulation will then be accomplished.

III, B, Fabrication and Assembly Plan (cont.)

(e) Launching

The tank will be blocked on the sliding ways and ground ways prepared for launching. After launching, the tank will be towed to the outfitting docks for removal of sliding ways and final preparation for towing. The vehicles will be delivered to the towing contractor for the voyage to the assembly point.

To help clarify the sequence of operations, a proposed schedule for building the first- and second-stage vehicle tankage out of Aluminum 2014-T6 is enclosed. (See Figure 3-4.) The schedule could be compressed considerably by paralleling of first- and second-stage construction if required.

(3) Manufacturing Problems

Some of the following difficulties are foreseen with the horizontal method of assembly.

The ratio of thickness to diameter primarily in the second-stage tankage is such that sag could seriously affect the configuration if adequate support by fixtures is not provided.

Consideration of the permissible geometry variations is mandatory before the fabricating method for the case can be established.

III, B, Fabrication and Assembly Plan (cont.)

Since most rocket pressure vessels have a margin of proof test to yield strength of about 20%, a mismatch of 10% of the wall thickness for the longitudinal welds would cause stresses that would exceed the yield strength in the weldment.

6. Fabrication of the Second-Stage Expandable Nozzle

The second-stage expandable nozzle is presumed to be fabricated from stainless steel, type 310 or 321. The sheet will range in thickness from 0.165 in. at the upper end to 0.20 in. at the nozzle exit. In the finished condition ready for delivery to the operational personnel, the nozzle segment is 1/4 of a 75 ft diameter circle, approximately 118 ft long and covered with a layer of styro-foam on the inside.

Material of the proper varying thickness will come from the mill preformed and in rolls, or delivered as sheets, formed, welded, and coiled on rolls at the fabrication site. The rolls are then mounted to permit the material to feed out through a series of rubber rolls to a mechanical welder which will weld all the material together before it goes through the explosive forming tool. The operating speed of the welders is controlled by the pilot control device mounted in or on the rubber feed rollers.

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 proposed cooling tubes in this report would be sufficient for the expandable nozzle application.

III, B, Fabrication and Assembly Plan (cont.)

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 previous operation. The solvent used is compatible with the foam; therefore, rinsing is not necessary. Foam is then sprayed into each convolution. (See Figure 3-5.)

7. Assembly of the Interstage Structure (First- and Second-Stage)

The interstage assembly is shown in Figure III-C-1, Volume II. The main interstage structure is cylindrical and is bolted to the stub skirt at the forward end of the first-stage. This structure will be fabricated at the manufacturing plant and attached to the first stage before it is towed to the vehicle assembly site, where the expandable nozzle will be attached. The flange of the stub skirt will be machined so that the interstage structure, or first-stage forward skirt, is manufactured independently and assembled later to the first stage.

The bolt holes on all flanges will be located linearly considering the circumference of the bolt circle rather than the diameter. That is, a circumference or "pi tape" approach will be used so the length of the bolt circle will be the critical dimension rather than the diameter. It is realized that this approach will require some type of special measurement system to locate and measure the circumference since the bolt circle will not be round. Thus, the circumference of the specified bolt circle will be located on the flange so that it is equal to the specified circumferential length.

III, B, Fabrication and Assembly Plan (cont.)

A drill jig will be used to locate the holes on the scribed bolt circle. This drill jig will cover a portion of the length of the bolt circle center line and will be clamped to the flange with orientation such that the vehicle will have a top center locating hole. The holes along the length of the drill jig will then be located and drilled accurately.

When this series of holes is completed, the drill jig will be moved over one length minus the last hole which will be matched with the drill jig. This process will be continued until the entire bolt circle within a maximum mismatch between the last and beginning holes of less than approximately 1/4 in. All bolt circles on flanges will be dimensioned and fabricated essentially in the manner outlined above to provide independent and accurate drilling of the bolt holes on matching flanges.

The matching flange on the aft end of the second stage would be drilled in a like manner and it would be desirable to have a reversible drill jig so that any unequal distances will be reproduced in the same pattern on mating flanges. Thus, a closely matching flange hole pattern is obtainable.

An alternate method would be to match drill the hole pattern on the aft end of the second-stage after drilling all the holes on the forward flange of the first-stage. However, unless these assemblies are made in the same manufacturing plant and unless adequate equipment for moving and matching the flanges is available, the holes on matching flanges must be drilled independently as indicated above.

III, B, Fabrication and Assembly Plan (cont.)

8. Shipyard Tank Fabrication Plans

Preliminary manufacturing plans for the fabrication of the Sea Dragon first- and second-stage tankage were solicited from major shipyards across the country. These plans were predicated on the delivery of one each Stage I and Stage II tanks per month for ten (10) years. Stage I tank delivery to start 24 months after "go ahead" - Stage II tank delivery to start 40 months after "go ahead". These were the bare tanks for the Sea Dragon Configuration. Both 18% Ni and Aluminum 2014-T6 were to be considered. Tolerances were limited to one quarter of commercial shipyard practice with 1 in. control on the girth. (See Appendix 3-8 for three specific cases of data submitted by selected shipyards.)

III, Discussion (cont.)

C. FACILITIES PLAN

1. Existing Facilities

The facilities plan for the Sea Dragon program will be on the basis of use of existing government owned or leased facilities. Production operations will use existing state-of-the-art methods and materials. Facilities scale-up will be required due to the very large size requirements of the vehicle and its components. Total facility requirements for the program will be determined by development and production schedules and rates; and new facility requirements will be dependent on the availability and utility of existing facilities.

Because of the scope of the program, government assistance will be required in acquisition of new facilities, and in obtaining authorization for use of appropriate existing facilities.

The preliminary nature of the program definition as to exact methods of fabrication and assembly, machine tool requirements, and production cycle times, in addition to time limitation in establishing firm facility requirements preclude preparation of an estimate of the cost of facilities for the program at this time. As program definition is more firmly established, facility requirements will be reviewed to provide preliminary cost estimates.

2. Additional Facilities Required

Total facility requirements for the program will include the following general categories:

III, C, Facilities Plan (cont.)

a. Production Facilities

(1) Personnel Facilities

Engineering and administrative offices and cafeteria facilities will be required; and depending on the location of the plant site, personnel living quarters may or may not be needed. Existing facilities could possibly satisfy these requirements.

(2) Receiving Inspection and Warehousing

Warehousing facilities with very high capacity material handling equipment will be needed. This requirement may also be satisfied by existing facilities with the possible exception of the material handling capability. Receiving inspection facilities will include equipment of the type currently in use with major emphasis on optical equipment to inspect large parts and components.

(3) Component Fabrication, Assembly and Test

A major portion of the engine components will be fabricated at the manufacturing assembly site because of handling and transportation problems. Some metal working operations will require modification of machine tools to provide portability to the extent that the tools will be moved to the operation, with the parts being produced remaining in a relatively fixed position. The facilities required for the integrated fabrication-assembly operation will be similar to shipyard ways to reduce handling requirements and allow "launching" of the completed engine and tankage. Special facilities for component testing will also be required. The number of assembly positions, or ways required will depend on assembly cycle times and production rates and schedules.

III, C, Facilities Plan (cont.)

(4) Inspection

Inspection during fabrication, assembly, and upon completion of the finished product for tolerance, alignment, and deflection will be accomplished by optical methods as currently used in ship building and large air frame industries. Large portable X-ray equipment will be needed to inspect welds, and large volume, high capacity pressurization and leak test equipment will be required to inspect propellant piping, etc. Standard and scaled-up measurement devices, and gages, will also be required.

b. Support Facilities

Maintenance and repair facilities will be required at the manufacturing assembly plant, and floating maintenance and repair facilities may also be needed.

D. QUALITY CONTROL PLANS

1. Quality Control Considerations

The standard techniques of quality control in the fields of inspection, material control, process control, gaging and nondestructive testing can be applied to this project. Experience from the large aircraft and ship building industries is also applicable. In many cases, quality control problems will actually be less because of the greater 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

III, D, Quality Control Plans (cont.)

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 will be required and probably radioactive isotopes will be necessary to secure the required portability.

In associated techniques, such as magnetic particle inspection, the dry powder method commonly used in the ship building industry will be much more extensively applied than it is now on the smaller components. The wet method will continue to be used on the small components. Spray type dye penetrant will be used rather than immersion type. Ultrasonic testing will be particularly suitable because of the numerous parallel surfaces and can be used also for wall thickness determination.

Much of the dimensional work will be done with optical equipment. Techniques from aircraft work will be used and refinements of these techniques will no doubt be required. Optical gaging points will be a necessary part of all fabrication and tooling, both for tooling checkout and for inprocess 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 which are hazardous will require reassessment, since 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 expected

III, D, Quality Control Plans (cont.)

to be encountered in association with the brazing of the thrust chamber assembly tubes. Portable brazing techniques will require ingenious approaches for the maintenance of atmospheric control, dewpoint controls, and brazing component controls. Although this engine 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.

2. Quality Control Facilities

	Item and Description	Cost
a.	Optical Inspection Equipment	$ 50,000
	Standard optical measuring equipment such as transits, collimators, squares, optical micrometers, stands, targets, and scales	
b.	Nondestructive Inspection Equipment	
	X-Ray	$1,000,000
	150 KV, 300 KV, and 1 MEV isotope units, portable boom type Film processing and interpretation requirements to be met by Van type facilities capable of movement about the assembly areas	
	Dye Penn, Magnaflux, and Zyglo Inspection Equipment	$ 30,000

III, D, Quality Control Plans (cont.)

Item and Description		Cost
c.	Decontamination Control	$ 50,000
	A self-sufficient decontamination monitoring laboratory will be housed in a trailer, capable of relocation	

E. MATERIAL CONSIDERATIONS AND PLAN

1.. Capacity

The needs of the proposed program will have no noticeable effect on aluminum supply. Present production is well over two-million tons per year, with additional capacity to meet new requirements. Plate is presently available in thicknesses up to 3 in. with the limitations on size from each of the three vendors listed.

SIZE LIMITATIONS OF ALUMINUM PLATE

Limits	Vendors		
	Alcoa	Reynolds	Kaiser
Plate width, unstretched	144 in.	132 in.	120 in.
Plate width, stretched	140 in.	132 in.	———
Max. heat treatable length	720 in.	540 in.	490 in.

III, E, Material Considerations and Plan (cont.)

Limits	Vendors Alcoa	Reynolds	Kaiser
Max. cross-sectional area, stretched			
2014-T6	400 sq in.	300 sq in.	
6061-T6	800 sq in.	400 sq in.	
Max. Thickness, stretcher leveled 6 in.			
Max. ingot size	10,000 lbs	____	12,000 lbs

2. Cost - $/#

Alloy	1962	1967	1972
Aluminum 2014-T6	0.60	0.60	0.60
2219-T6	0.765	0.765	0.765
6061-T6	0.50	0.50	0.50
5456-H321	0.60	0.60	0.60

3. Weldability

Considerable concern has been expressed pertaining to the feasibility of welding aluminum in thicknesses up to and including 4.17 in. Figure 3-6 presents industry experience in heavy aluminum plate welding. As can be seen the 4.17 in. is not within present experience.

In Appendix 3-8 a study is presented pertaining to the welding of thick plate Aluminum 2014. There is nothing to indicate that the welding of aluminum in these thicknesses is an every day occurrence; however, there is a definite theoretical implication on the basis of the study cited that aluminum may be welded in thicknesses in excess of those required by the Sea Dragon

III, E, Material Considerations and Plan (cont.)

tankage and the properties of the weldment can be assured. Additional investigations will have to be carried on to prove the practicality of this theory.

Previous statements made about possible alternative approaches to material selection are reiterated here for emphasis. The 4.17 in. of required aluminum is equivalent to 1.18 in. of 18% Ni steel and 2.7 in. of titanium 5 Al-2.5 Sn. These latter two thicknesses may be more easily attainable with acceptable properties even though aluminum technology appears more mature at this point. See Appendix A of Volume II for further discussion of this point.

F. VEHICLE PRODUCTION COSTS

1. The ROM costs presented in this report are the estimated costs required to fabricate and assemble the first- and second-stage Sea Dragon Configuration No. 134, (27 November 1962). (See Figures 3-7, 8, 9, and 10.)

2. All costs include direct labor, material, O.P., and applicable overhead charges required to fabricate and assemble.

3. Costs for facilities, GSE, tooling, testing, fees, implementation of Quality Control Specification 200-2 and -3 requirements, and delivery of vehicles to operation site have not been included. Hardware items not included in the cost estimate are main and auxiliary electrical power supplies and electrical harness. Fabrication provisioning spares have also been excluded.

III, F, Vehicle Production Costs (cont.)

4. The estimated costs presented in this enclosure are based on the tenth unit and use a 90% learning curve.

5. The dollar per pound figures used to obtain tank costs were derived by examining costs submitted by several vendors together with data from previous Aerojet-General studies (cosmos). Facility costs range from .5% to 3% and tooling cost ranges from .2% to 8% of the total tank program cost. The low facilities and tooling cost is explained by the fact that the vendors that bid on the tanks are experienced in the required method to fabricate, and already have most of the required facilities and tooling.

6. The dollar per pound figures related to engine costs were obtained from cost estimates acquired through the efforts of personnel experienced in fabricating and costing missiles and ships. The tooling cost is estimated at 10% of total engine program cost. A higher tooling cost is required to fabricate the engine than the tank because the method of fabrication used on the engine is not common to the ship building or the present missile building industry; therefore, special tooling and facilities would be required.

7. A large differential exists between the Sea Dragon dollar per pound figure for fabrication and the figure for the smaller conventional rocket engines such as the M-1 and Titan. This difference is because of the level of precision required in all the Titan controls and mating components and the cost phenomenon of increasing weight of a vehicle resulting in a decreasing cost per pound. This trend has been substantiated by extensive M-1 production costing studies which show a significant decrease. It is assumed the Sea Dragon will not require a high level of precision hardware items during fabrication and assembly because such items as the turbopumps, gas generator and their controls have been omitted from the Sea Dragon.

III. Discussion (cont.)

G. ALTERNATIVE APPROACHES

1. Introduction

Assuming the Sea Dragon tankage and other structure will be fabricated of Aluminum 2014-T6 several alternative fabrication approaches appear attractive. Mechanical fastening will be applicable to transition structure other than tankage. All tank structural joints will be welded and used in the welded condition. To minimize the incremental weight effect of the reduced mechanical properties of the weld joint, the plates will be prepared with a builtup edge to form a weld joint reinforcement. The resulting weld joint thickness in some areas of the Sea Dragon tankage is considered to be excessive, probably requiring considerable weld process development. Also, the thicker plates will be relatively small as a result of current mill capacity in regard to billet size and stretch leveling press size. Accepting the current mill limitations, the following alternative approaches appear to offer advantages:

2. Weld Joint Thickness Reduction

The propellant tank elements where the wall thickness is in excess of 2 in. could be constructed of two separate sheets of 1/2 total thickness. The weld joint reinforcement will be applied to one side only of each sheet of the two sheets; the weld joints will be made back-to-back, the outer sheet will be ported to eliminate the chance that leakage of the inner wall would permit pressurization and failure of the outer sheet. The potential advantages of this approach is that the weld joint thickness will be reduced to 50% of the homogenous wall weld joint thickness and the total inches of weld will be reduced as a result of the increased sheet size available.

III, G, Alternative Approaches (cont.)

3. Reduction of High Stress Weld Joints

Elimination of all unheat-treated longitudinal (hoop stress reacting) welds in the cylindrical sections is possible with the development of mill capability to roll, or roll and weld, heat treat, and stretch level circumferentially continuous strips at 75 ft in diameter. The hoops so prepared and with minor edge thickening for weld reinforcement for the circumferential weld would be transported to the weld assembly site nested within inself at manageable diameters.

4. Mechanical Joining

Elimination of all welding appears to be possible if the tankage is constructed of multiple 1/4 in. thick laminates, mechanically joined and sealed with a soft metallic liner. Mechanical joint efficiencies of over 94% are possible. The use of sheet materials under 1/4 in. thickness from guaranteed properties aspects, and the direct process control techniques applicable to mechanical joining methods offer distinct and immediate advantages in the construction of very large pressure vessels. These advantages are pronounced where fabrication is to be attempted in shops which do not have a history of aircraft quality manufacturing experience.

5. Clustered Tanks

Although clustered tankage appears to offer only vehicle performance penalties, application of the approach offers some advantages. Material thickness is reduced which enhances confidence in the fabrication processes and reduces the structural or fabrication development span time. The greater number of units produced makes application of learning curves realistic. Transportation to stage assembly areas is facilitated.

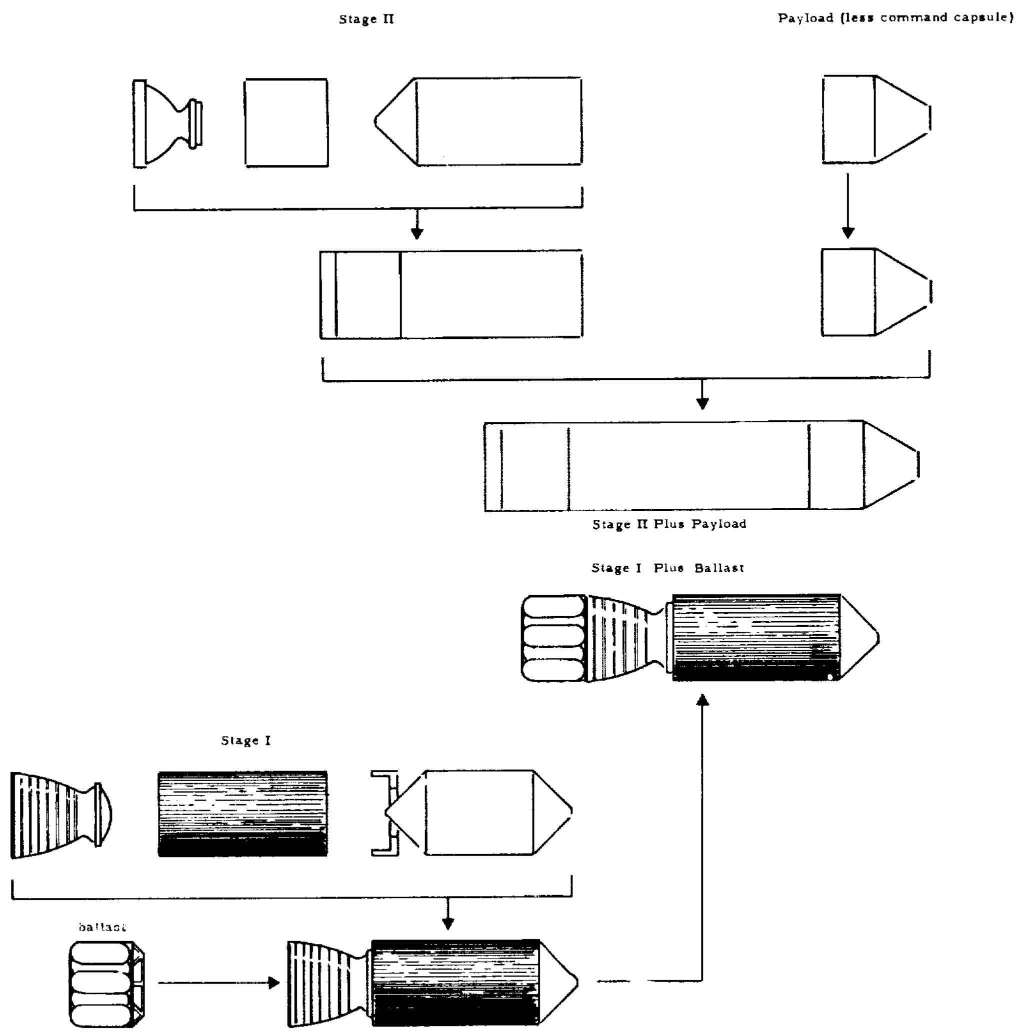
IV. CONCLUSIONS

A. Additional time would be required to select an optimum system and perform the necessary material evaluations required.

B. With the exception of the fabrication techniques required for the thick sections of aluminum in the RP-1 tank, the Sea Dragon is within the existing state of the art.

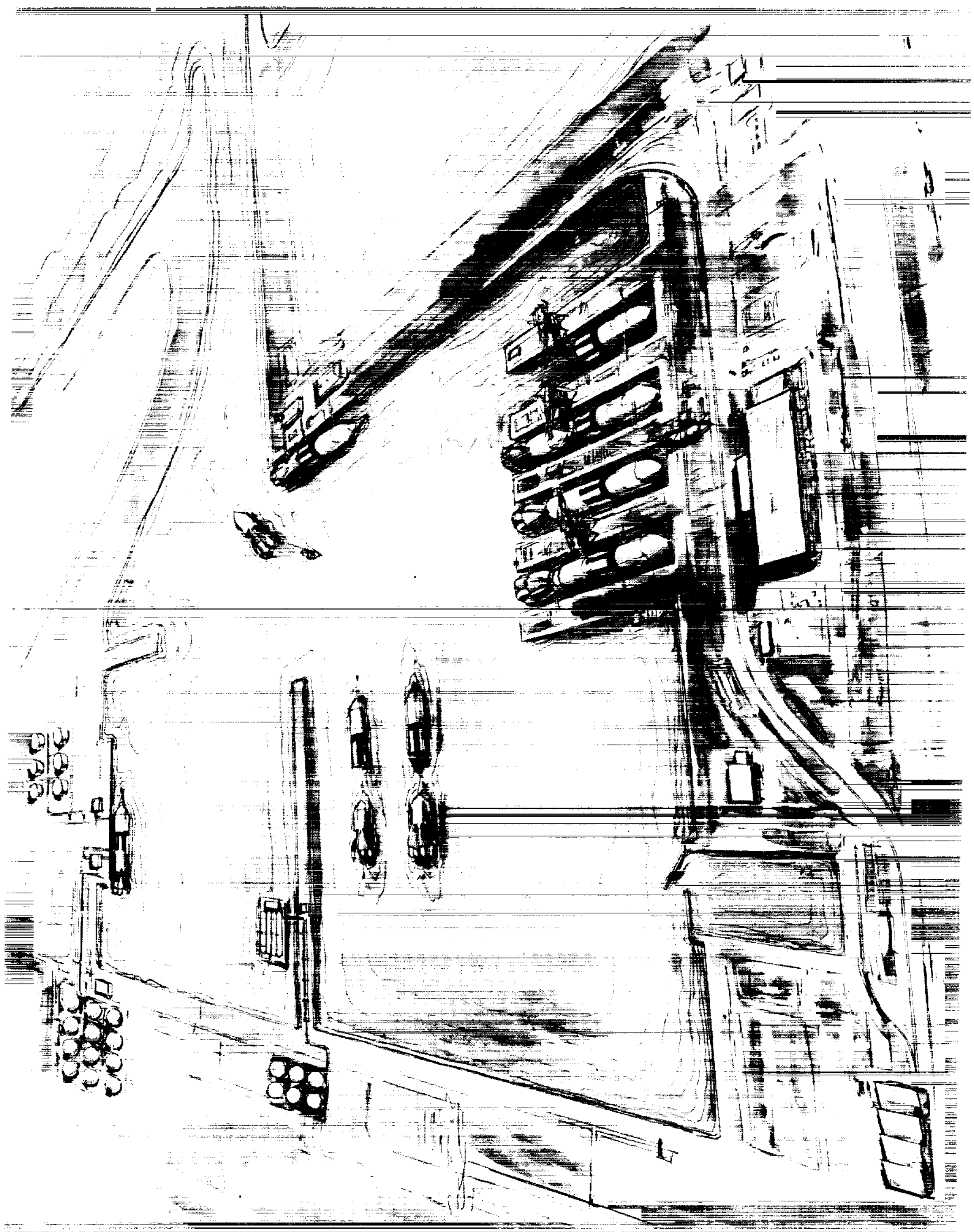
C. Current shipyard facilities, tooling, and "know-how" exist that would enable a Sea Dragon to be built today.

D. Sea Dragon fabrication costs and tolerances should be conceived to lie somewhere between the aerospace and the shipbuilding industry, but probably closer to the latter.



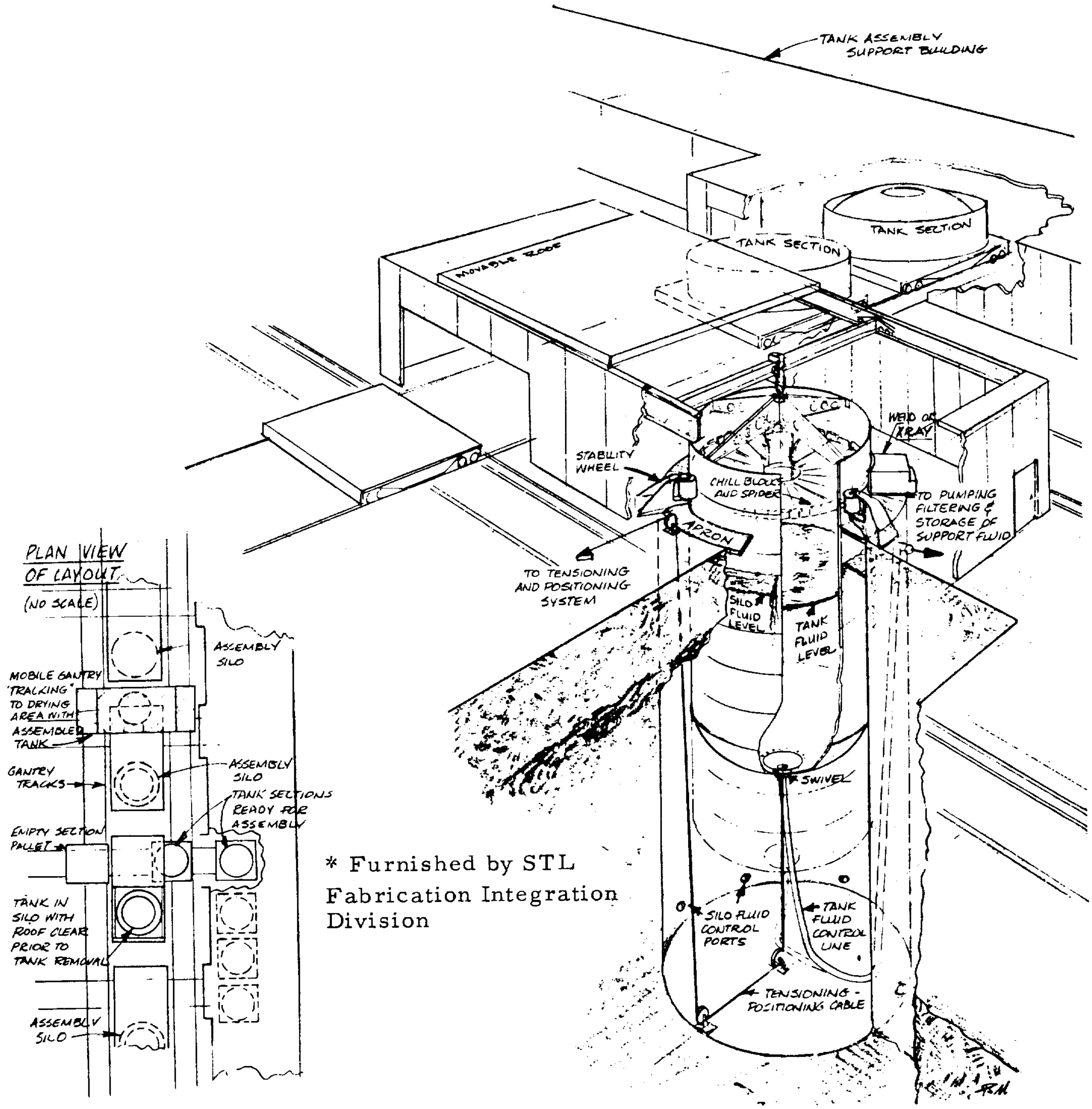
Manufacturing Assembly Flow Diagram

Figure 3-1



Manufacturing Operations

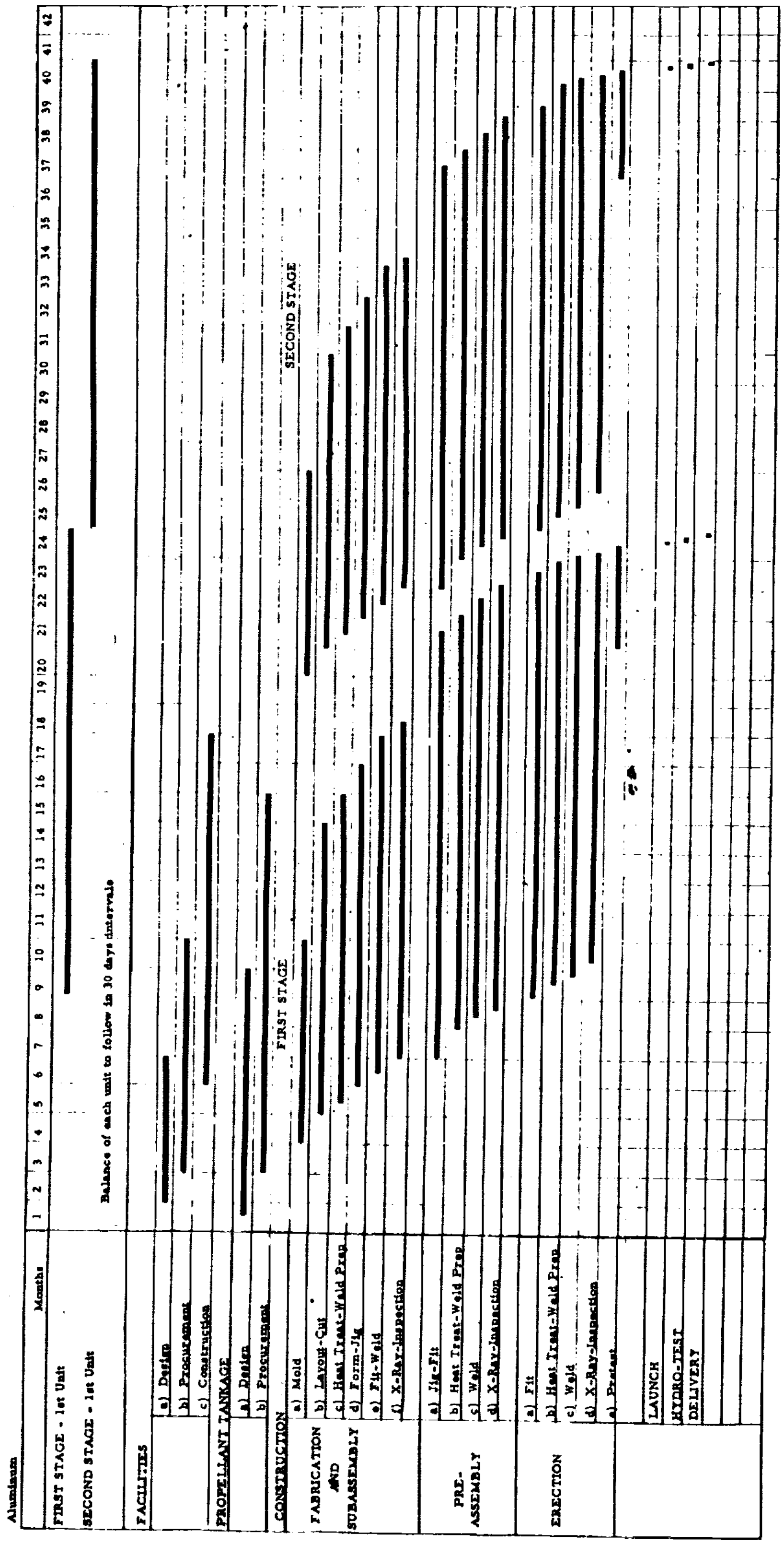
Figure 3-2



* Furnished by STL Fabrication Integration Division

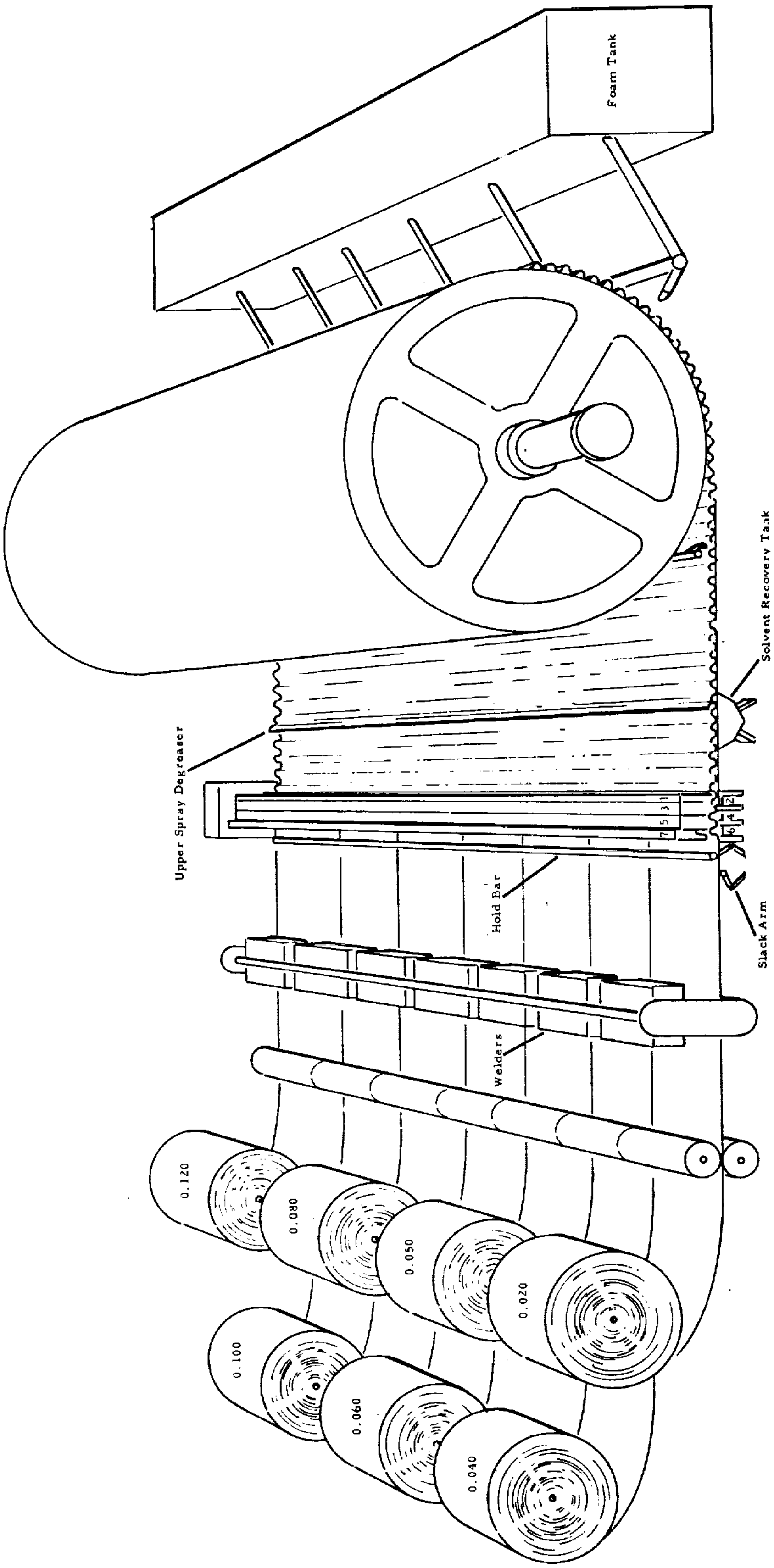
Vertical Tank Assembly

Figure 3-3



Tankage Fabrication Schedule

Figure 3-4



Expandable Nozzle Fabrication Technique

Figure 3-5

Source	Alloy	Filler Wire	Wire Dia.	Plate Thickness	Procedure	No. of Passes	Amperes	Volts	Weld Speed IPM	Wire Speed IPM	Shielding Gas	Remarks
GAM-77 Missile	2014-T6 Forging to 2014-T3 Plate	4043	1/16 in.	0.190 to 0.250	Auto-TIG	1	250	25	12	115	18 Argon-18 He cfh	Square Butt.
Nat'l Steel and Shipbldg.	6061		3/32 in. 1/8 in.	1 in.	Auto-MIG	2	500	25-26	10-12	240 135	Argon-100 cfh	Square Butt.
	6061		9/6 in.	1 1/2 in.	Auto-MIG	2	590	26	8	130	Argon-100 cfh	Square Butt.
Westing-house	1100			22 in.	Multipass							Modified "U" Joint
Boeing	2219			3 in.	MIG	1						
Food Machinery	5083-H321	5346	1/16 in.	1 1/4 in.	Auto-MIG	2	360-380				Argon-cfh	5/16 in. Groove each side.
Reynolds	7002-T6	5356	3/32 in.	1 1/4 in.	Auto-MIG	2	360-380	27	17		Argon-100 cfh	90° Double "V" 1/4 in. Land

Heavy Plate Welding

Figure 3-6

SEA DRAGON STAGE I ENGINE ROM COST ESTIMATE
ACCUMULATIVE AVERAGE OF UNIT COST FOR THE 10th UNIT
BASED ON A 90% LEARNING CURVE

	Cost	Weight	$/lb
Gimbal	1, 280, 000	182, 600	10.4
Structure between gimbal and injector	59, 000	54, 000	1.1
Injector	1, 192, 000	88, 500	13.4
Combustion chamber	2, 180, 000	280, 000	7.8
Ballast mount structure	39, 000	18, 400	2.1
Heat exchanger	162, 000	8, 200	19.6
Actuators	2, 032, 000	44, 000	46.2
LO_2 valve	440, 000	23, 400	18.8
RP_1 valve	480, 000	25, 600	18.8
Total engine cost	8, 254, 000	664, 700	12.4

Figure 3-7

SEA DRAGON STAGE II ENGINE, CONF No. 134 ROM COST ESTIMATE
ACCUMULATIVE AVERAGE OF UNIT COST FOR THE 10th UNIT
BASED ON A 90% LEARNING CURVE

	Cost	Weight	$/lb
Injector	134,000	10,000	13.4
Combustion chamber	400,000	51,400	7.8
Heat exchanger	262,000	13,400	19.6
Expandable nozzle	360,000	71,500	5.1
Thrust vector control system	413,000	5,300	78.1
LO_2 valve	68,000	3,640	18.8
LH_2 valve	84,000	4,480	18.8
Total engine cost	2,111,000	159,720	13.2

Figure 3-8

SEA DRAGON STAGE-I VEHICLE No. 134 ROM COST ESTIMATE ACCUMULATIVE AVERAGE OF UNIT COST FOR THE 10th UNIT BASED ON A 90% LEARNING CURVE

	Cost	Weight	$/lb
Tankage	12,629,000	1,416,765	8.9
Pressurization system	48,000	8,162	6.0
Ballast tank	6,000,000	3,000,000	2.0
Inter-stage skirt	169,000	29,200	6.0
Engine Stage I	8,254,000	664,700	12.4
Miscellaneous hardware	1,545,000	249,302	6.2
Total vehicle without ballast	23,035,000	2,368,129	9.7
Total vehicle cost	29,035,000	5,368,129	5.4

Cost on a 90% Learning Curve, Unit Cost in Accumulative Average Millions $

	1st Unit	10th Unit	100th Unit	120th Unit	240th Unit
Tankage	15.9	12.6	9.2	9.0	8.1
Engine	9.3	7.4	5.4	5.3	4.7
Vehicle-less ballast	2[illegible]1	23.0	16.9	16.4	14.9
Vehicle-with ballast	36.7	29.0	21.3	20.7	18.7

Figure 3-9

SEA DRAGON STAGE II VEHICLE, CONF No. 134 ROM COST ESTIMATE ACCUMULATIVE AVERAGE OF UNIT COST FOR THE 10th UNIT BASED ON A 90% LEARNING CURVE

	Cost	Weight	$/lb
Tankage	3, 589, 000	420, 437	8. 5
Pressurant system	491, 000	16, 370	30. 0
Payload	151, 000	16, 852	9. 0
Engine Stage II	2, 111, 000	159, 720	13. 2
Miscellaneous hardware	1, 649, 000	288, 141	5. 7
Vehicle cost without payload	8, 230, 000	884, 468	9. 3
Total vehicle cost	8, 381, 000	901, 520	9. 3

Cost on a 90% Learning Curve, Unit Cost in Accumulative Average Millions $

	1st Unit	10th Unit	100th Unit	120th Unit	240th Unit
Tankage	4. 5	3. 5	2. 6	2. 5	2. 3
Engine	2. 6	2. 1	1. 5	1. 47	1. 3
Vehicle less payload	10. 4	8. 23	6. 0	5. 9	5. 4

Figure 3-10

APPENDIX 3-1

DETAILED OUTLINE OF THE SEA DRAGON MANUFACTURING AND FABRICATION PLAN REQUIREMENTS

I. MANUFACTURING AND FABRICATION PLANS

A. MANAGEMENT PLAN

1. Management objectives. policies, participation and reliability concepts.

2. Capabilities and related experience of management personnel.

3. Organization chart including names and responsibilities of management personnel to be assigned to the program indicate:

   a. Relationship to overall corporate structure.

   b. Stability of the organizations.

   c. Support organizations.

4. Management controls

   a. Type, frequency and effectiveness.

   b. Method for corrective action.

5. Manpower plan consisting of a total plan and individual plans for Engineering, Manufacturing and Quality Control.

   a. Build-up charts including skilled manpower requirements.

   b. Acquisition plan.

   c. Charts showing programs relationship to current and future business.

   d. Labor affiliations, dates of contract expiration and recent labor history.

6. Make or buy plan including documentation.

I, Manufacturing and Fabrication Plans (cont.)

B. MANUFACTURING PLAN

1. Manufacturing organization and experience
2. Manufacturing responsibilities
3. Tool Policy and Plan
4. Fabrication and Assembly Plan
5. Manufacturing Quality Assurance
6. Manufacturing Configuration Control
7. Manufacturing Controls

C. SCHEDULE PLAN AND CONTROLS

1. Schedule planning approach
2. Operational controls
3. Systems and procedures

D. FACILITIES PLAN (provide layouts, lists, dollar value and square footage)

1. Existing physical resources, government owned or leased
2. Existing physical resources, government owned or leased, to be utilized on Sea Dragon.
3. Additional physical resources required and acquisition plan

I, Manufacturing and Fabrication Plans (cont.)

E. QUALITY CONTROL PLAN

1. Quality control organization
2. Quality control policies
3. Technical capabilities
4. Quality control facilities
5. Quality control operational system
6. Reliability program
7. Records system

F. SUPPORT PLAN

1. Maintenance
2. Spares plan for hardware and special test equipment
3. Technical manuals
4. Training

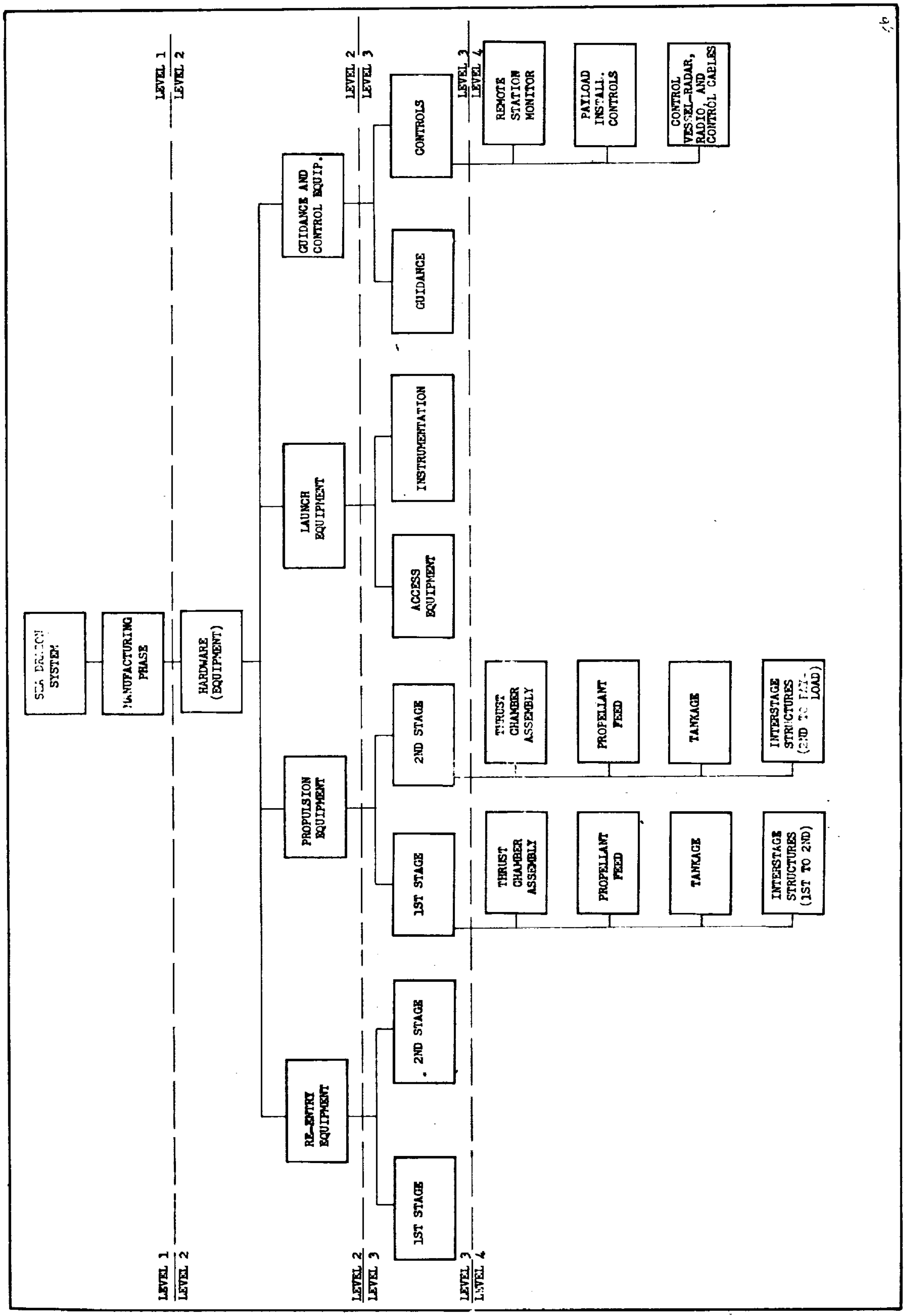
G. GFP, GFAE, GFE REQUIREMENTS

H. CUSTOMER SUPPORT REQUIRED

APPENDIX 3-2

SEA DRAGON
MANUFACTURING PHASE
HARDWARE AND EQUIPMENT
"END ITEM" REQUIREMENTS

FIGURE LIST



Manufacturing Phase Hardware and Equipment "Christmas Tree"

Figure 1

APPENDIX 3-3

SEA DRAGON
MANUFACTURING PHASE
TENTATIVE BASIC PARTS LIST

SEA DRAGON CONFIGURATION NO. 135

TENTATIVE BASIC PARTS LIST

Item No.	Part Name
A.	Sea Dragon No. 135 - 1st Stage Propulsion
1.	1st Stage Propulsion Unit
1.1	Thrust Chamber Assembly
1.1.1	Injector Assembly
1.1.1.1	Injector
1.1.1.2	LOX Torus, Manifold Assembly
1.1.2	Combustion Chamber Assembly
1.2	Tankage
1.2.1	Oxidizer (LO_2)
1.2.2	Fuel (RP1)
1.3	Pressurization System
1.3.1	RP1 Pressurization System
1.3.1.1	Liquid Methane Tank
1.3.1.2	Tubes
1.3.1.3	Valves
1.3.2	LO_2 System
1.3.2.1	Tubes
1.3.2.2	Heat Exchanger
1.4	Propellant Feed System
1.5	Gimbal
1.5.1	Actuator
1.6	Electric Harness
1.7	Interstage Assembly
2.	2nd Stage Propulsion Unit
2.1	Thrust Chamber Assembly
2.1.1	Injector Assembly

TENTATIVE BASIC PARTS LIST (cont.)

Item No.	Part Name
2.1.1.1	Injector
2.1.1.2	LOX Torus, Manifold Assembly
2.1.2	Combustion Chamber Assembly
2.1.3	Valve Assemblies
2.1.4	Pressure Sequencing Valve Components
2.1.5	Frame
2.1.6	Expandable Nozzle
2.2	Tankage
2.2.1	Oxidizer (LO_2)
2.2.2	Fuel (LH_2)
2.3	Pressurization System
2.3.1	LH_2 Pressurization System
2.3.1.1	Tubes
2.3.1.2	Valves
2.3.1.3	Heat Exchanger
2.3.2	LO_2 Pressurization System
2.3.2.1	Tubes
2.3.2.2	Opening and Closing Valve
2.4	Propellant Feed System
2.5	Electric Harness
2.6	Thrust Vector Control (TVC)
3.	Payload
3.1	Command Capsule
3.2	Tankage
4	Ballast

APPENDIX 3-4

MASTER TOOLING

I. MASTER TOOLING

It is the intent of this section to show the objective, the necessity, and the use of master tooling.

A. OBJECTIVE

The master tooling will control the fabrication and assembly of the entire vehicle package, subassembly or detail part in the following areas.

1. It will control the geometric centerline of thrust.

2. It will control the height.

3. It will control the rotation and outboard position of assemblies and detail parts in respect to the geometric centerline and the pitch and yaw actuators.

B. This type of tooling program is necessary to the Manufacturing Phase for the following reasons:

1. To deliver a geometrically consistent package to the purchaser.

a. Consistency will make it possible to establish a level of reliability that will be acceptable for a man rated craft.

b. This will become possible by knowing the geometric configuration of each tested assembly within as close a tolerance as deemed necessary. This knowledge will give the capability to make fast and accurate changes for improvement.

2. To establish basic ground rules that will govern the fabrication, assembly and quality control of critical hardware and will not deviate from the designer concept.

I, Master Tooling (cont.)

C. THE USE OF MASTER TOOLING WILL:

1. Establish the master layout by the use of the digital computer. The tool design in turn will be coordinated to the master layout.

a. Reduce the design and fabrication cost of production tooling and hardware.

b. All critical tooling dimensions will be established on the master tooling designs. This will make it necessary when designing production tooling to only reference those dimensions to the master tool. This will reduce repeating lengthy calculating and checking of control dimensions for a family of tools.

2. When fabricating the production tools that are coordinated to a master, all of the details are fabricated, those details are then coordinated to masters (Match Plates) as necessary. This will eliminate costly jig bore time. A match plate simulates two mating interfaces and their hole patterns. Then when the tool is assembled it will be coordinated to the facility master, bolted in position and dowled. A facility master simulates a part, controlling interface height, rotation and tool hole.

a. This same procedure will be followed when fabricating quality control gages.

b. All inspection of production tooling and quality control gages will be to quality control master. Quality control masters will be controlled and used by quality control personnel only.

3. By establishing a basic physical control of all critical dimensions on production tooling and in quality control gages it follows that a very high degree of uniformity in production hardware will be achieved.

I, C, The Use of Master Tooling Will (cont.)

a. In this one area alone, a great saving will be shown. Not only will everyone involved with the fabrication and quality of this assembly be working to the same basic control but the uniformity of the part will reduce the assembly time by making all details and assemblies, controlled by the masters, interchangeable.

II. MASTER DIMENSIONING CONCEPT USING THE CARTESIAN COORDINATE SYSTEM

A. The procedure would be to first establish that the top assembly print would control all planes, centerlines and points not only for assembly but also for subassembly and detail part print dimensions.

B. Using the Cartesian coordinate system, a method of establishing centerlines, planes and points from which the parameters of a part or an assembly of parts can be dimensioned will be established.

1. These planes, centerlines and points are established relative to two (2) common planes 90 degrees to one another. Reference "X" and "Y" Planes as in a conventional Cartesian system. The "X" plane is horizontal, and "Y" plane is perpendicular to the "X" plane. ("X" dimensions to the right, "Y" dimensions up from the datum point are positive.)

2. At the intersection of the "X" and "Y" planes, an axis is created, the "Z" axis.

a. A datum point is established by the designer on the "Z" axis that will best serve as a starting point.

b. In the "Z" axis all dimensions from the datum point in the direction of the viewer will be plus and all dimensions away from the datum point be minus.

II, Master Dimensioning Concept using the Cartesian Coordinate System (cont.)

3. From that point established as datum or origin, any plane, centerline or point may be established relative to it in space.

a. A plane passing through the datum point, perpendicular to the "Z" axis will be named the datum plane.

C. It is of equal importance that the subassembly prints will establish their working dimensions in reference to those planes, centerlines and points already established on the top assembly print.

1. That is, that those coordinates on a top assembly print, which a subassembly falls within, will be shown and identified with their coordinate symbols, on the subassembly print. From these references all working dimensions will be established on the subassembly print.

D. The detail prints will establish their working dimensions from either the top assembly or subassembly prints, whichever is more practical, following the same method of coordination.

E. Critical dimensions such as fit surfaces and tooling holes will be established in relation to the coordinate system. Noncritical dimensions, such as cast surfaces which only encounter space at assembly, will not be coordinated to this system.

F. The designer using this method of controlling the geometric location of planes, centerlines and points will simplify the manufacturing engineer's task of coordinating the details, subassemblies and top assemblies of the entire deliverable package.

II, Master Dimensioning Concept using the Cartesian Coordinate System (cont.)

1. It will make it possible to make a tolerance chart for each critical part in an assembly that will be related directly to the top assembly. This will eliminate cross referencing several design formats which must eventually be corrolated to the top assembly print.

2. This method of dimensioning is also compatible to the system employed by the automatic programing techniques. It will make it possible for the design and manufacturing engineers to take advantage of the versatility and capability of the modern general purpose digital computers for automatic processing of design data with much less effort than is necessary with the general design techniques in use at present.

3. This will help provide an effective and reliable means for achieving the ultimate benefits from the numerically controlled manufacturing facilities that are now available at the Sacramento complex.

G. With the Cartesian based system of design it follows that all production tooling that will be used will be controlled from the same basic planes, centerlines and points.

H. This system will also set the master tooling philosophy, the master tools being those tools which will control the fabrication of all production tooling and quality control gages that in turn are used in the fabrication of critical production hardware.

1. Critical hardware would be that hardware that has in its parameters any physical bearing on the geometric centerline of thrust, the length of the overall top assembly or a rotational value in respect to the pitch and yaw actuation of the top assembly.

II, Master Dimensioning Concept using the Cartesian Coordinate System (cont.)

2. The master tools will control, by the use of tooling, holes and surfaces. These holes and surfaces will be established by the designer using the Cartesian coordinate system.

3. The master tools will consist of quality control gages, facility gages (simulated parts) and match plates.

a. The quality control gages will be duplicates of the facility gages and match plates in some cases.

b. The facility gages will simulate the actual piece part of assembly in respect to interfaces, tooling holes and tooling surfaces.

c. The match plates will simulate only the interfaces of two (2) mating parts and their hole patterns. At such time as master tooling is available, it will be possible to subcontract any item controlled by the masters, to as many different vendors as desired and maintain uniformity to a desired level.

APPENDIX 3-5

SEA DRAGON
MANUFACTURING PHASE
DETAILED THRUST CHAMBER ASSEMBLY FABRICATION PLAN

FIGURE LIST

DETAILED THRUST CHAMBER ASSEMBLY FABRICATION PLAN CONFIGURATION NO. 134

Enclosure:
(1) Sketch of Production Fabrication of Tubes and Tube Assembly Prior to Assembly on the Combustion Chamber Mandrel

(2) Combustion Chamber Fabrication Sketches

(3) Injector Fabrication

(4) Combustion Chamber Tube Loading Tack Welding, Cleaning, Drying and Oven Brazing Sequence

I. COMBUSTION CHAMBER ASSEMBLY

A. COMPONENTS

1. Coolant Tubes
2. Upper Flange
3. Fuel Torus and Inlet Flange
4. Crossover Manifold
5. Reinforcement Bands
6. Final Assembly, Epoxy and Wire Wrap
7. LO_2 Heat Exchanger
8. Acceptance Test, Proof, Leak and Flow for kw

B. FABRICATION METHODS

1. Coolant Tubes

Coolant tubes shall consist of stainless steel, seamless tubing with a total tube assembly length of 82 ft. The tube assembly will be built up on a mandrel and consist of 4 split tube sections.

I, B, Fabrication Methods (cont.)

The split tube construction is a common state-of-the-art method, having proved successful on engines as large as the M-1 wedge and Titan first-stage engines. Detail blueprints will determine the exact size and shape of each tube within a tube assembly--precut, formed and shaped to fit on a mandrel and welded to the next set or adjoining lengths of tubes.

Fabrication of the tubes will be performed either on plant at Aerojet-General Liquid Rocket Plant or acceptable vendor and delivered to the way or shipyard for final welding into a tube assembly on a segment of a mandrel, proof and leak tested prior to assembly onto the chamber mandrel. At this point the tubes have been welded together on the joining ends to make them water tight lengthwise, but only tack welded together side by side to afford just sufficient strength for handling and retention of dimensions. The brazing of the tubes together, forming a leakproof chamber between the tubes is discussed in the final assembly portion of this memorandum.

Because of the length of each tube assembly, the upper tube will be welded to the tube assembly at the shipyard. The length of three sections welded together equals 60 ft, which approaches the maximum allowable shipping length by rail (flat car). The total length after the upper tube or fourth section is welded in place equals about 82 ft.

The tube assemblies shall be identical except for the following: 50% of the tube assemblies shall be slotted at a point part way down the chamber and above the throat area to allow inlet of fuel for tube cooling. This tube shall be capped at the top (a plug welded into the elongated shape of the tube).

The other 50% of the tube assemblies shall be open at the top and have no slots.

I, B, Fabrication Methods (cont.)

These tube assemblies will be stacked on the chamber mandrel by alternating each set making every other set an inlet and the adjoining every other set outlets flowing into the injector fuel manifold.

2. Upper Flange

The upper flange shall consist of a stainless steel inner and outer plate, approximately 12 in. thick, premachined to the contour of both the critical ID and OD and the shape of surrounding coolant tubes. The diameter of the flange will be about 45 ft. and capable of supporting the loads and stresses of the chamber, the weight of the injector to chamber and the forces required to gimbal the entire thrust chamber assembly. The inner and outer upper flange will be placed on the chamber mandrel prior to stacking assemblies onto the mandrel. The tube assemblies will be inserted into the machined elongated openings of the upper flange.

3. Fuel Torus and Inlet Flange

The torus shall consist of approximately 1/2 in. stainless steel plate preformed to fit over a steel and cement form. The torus will be made in five subassemblies consisting of four segments to allow ease of final assembly onto the chamber and the inlet flange. One segment of the torus shall have the inlet hole torch cut, following the subassembly welding. The inlet flange and elbow assembly will be prefabricated and installed on one segment of the torus prior to weldment of torus onto the chamber.

I, B, Fabrication Methods (cont.)

4. Crossover Manifold

This is fabricated identically to the fuel inlet torus, except additional machining of scalloped surface is required to mate with coolant tubes at bottom of chamber.

5. Reinforcement Bands

A strong light band used successfully on large rocket engines are those of v-type construction. A rolling process shall be used to form the V-shaped stainless steel heavy gage sheet stock, precut and welded into lengths of approximately 20 ft and finally welded into one circular band and tacked onto the chamber at points around the outer surface of the chamber after oven brazing of the coolant tubes. This tack weld will have no ill effect on oven brazed areas.

6. Final Assembly, Epoxy and Wire Wrap

Final assembly of combustion chamber consists of:

a. Mandrel preparation of tube self-centering devices and availability of all essential material and tools.

b. Installing upper machined flange onto mandrel.

c. Install tube holding band at throat of mandrel (self-locking type).

I, B, Fabrication Methods (cont.)

d. Laying up the tube assemblies onto the mandrel (upper and entering the machined flange and the lower end held with a self-centering spring-loaded tool).

e. Tack weld tube assemblies together as mandrel slowly rotates at assembly speed.

f. As assembly progresses the tacked tubes reach the cleaning booth which automatically cleans the tubes.

g. The next automatic operation under the mandrel dries the tubes with hot dry air.

h. As the tube assemblies appear above the opposite mandrel platform, men begin applying the brazing solution.

i. Brazing powder and solution is applied over the powder between all tubes, one set at a time.

j. Each section, prior to brazing is preheated by a portable heater which is swung into position by a crane.

k. A portable quartz brazing lamp is lowered by crane into position during chamber rotation and brazes one section at a time.

I, B, Fabrication Methods (cont.)

l. The mandrel is prepared for a proof and leak testing function of the high pressure chamber area with an air and soap bubble solution. All leaks between tubes are brazed from the inside of the chamber by partially removing the mandrel.

m. After the entire chamber has been brazed, wire-wrap machines are swung into position (one on each side) wrapping the combustion chamber high pressure area simultaneously with prestressed heavy stainless steel wire. Epon is applied with nozzles protruding from the wire-wrap machines and control flow based on wire-wrapping speeds.

n. The V-bands are welded to the chamber surface and the chamber is slowly baked under heat lamps for one day to speed up curing of the epoxy at the wire-wrap area.

7. Heat Exchanger

The heat exchanger consists of two crossover manifolds going around the exterior of the chamber, one just above and below the throat area, and a series of tubing approximately 12 in. diameter and 13 ft long connecting the two manifolds. The manifold and connecting tubes lay against the chamber coolant tubes. The manifold in preformed segments, is welded to the outer-most surface of the coolant tube--the heat exchanger tubes are then welded to the upper and lower manifolds.

II. INJECTOR AND MANIFOLD ASSEMBLY

A. MAJOR COMPONENTS

1. Injector Face Plate
2. Fuel Channel Structures
3. Oxidizer Plate
4. Fuel and Oxidizer Face Tubes
5. Oxidizer Channel Structures (web)
6. Injector Side Structure Plate
7. Injector Top Structure Plate
8. Oxidizer torus and inlet flange
9. Gimbal Pad
10. Gimbal Actuator Arm

B. FABRICATION METHODS

1. The injector face plate consists of orange peel sections cut from 10 ft square sheets of 1/4 in. thick stainless steel and welded together on a large 45 ft diameter concaved, elliptical form made of reinforced cement.

A superstructure is designed to move in a circular direction over the surface of the injector face, with capabilities of lifting and laying the plates into position to be welded. Pneumatic movable hold down pads are provided to hold the plates in the correct form while welding. Automatic welding machines swing down from the structure to seam weld. After sufficient cooling time has elapsed, a portable X-ray and weld analyzing machine rolls over all welded seams and reports penetration, cracks, holes, and porosity.

II, B, Fabrication Methods (cont.)

2. Fuel Channel Structures

The superstructure is raised like an elevator to the next assembly level affording installation of the fuel channel structures. Bulk heads having large lightening holes to provide equalization of fuel flow from the manifold to the injector face tubes and to reduce weight, are then assembled and welded.

3. Oxidizer Plate

With the superstructure still in the same position as operation (2) above, the oxidizer plate, consisting of flat sheets of 1/4 in. stainless steel, is welded together across the flat vertical surfaces of the fuel channel structures forming a separation for the fuel and oxidizer circuits. The same methods of welding and X-ray are used as mentioned in paragraph (2) above.

4. Fuel and Oxidizer Face Tubes

Through the use of segmented templates, holes are drilled into the injector face and the oxidizer plate to install precut stainless steel, thin wall tubes. The fuel tubes are welded flush with the injector face at the correct angle, per pattern blueprint. The oxidizer tubes extend from the injector face, on the correct impinging angle, to the upper surface of the oxidizer plate and are welded at each end to prevent premixture of fuel with oxidizer.

5. Oxidizer Channel

The superstructure is raised to the third level, allowing the crane to pick up large plates of stainless steel and erect them vertically onto the oxidizer face and extending up to interface with the gimbal pad.

II, B, Fabrication Methods (cont.)

6. Injector Side Structure Plate

These are preformed plates of 1/4 in. or heavier stainless steel welded to the sides of the fuel circuit ribs and edge of the oxidizer plate that serve as a means of holding fuel circuit pressures as well as vertical transmission of thrust and other forces.

7. Injector Top Structure Plate

Preformed oxidizer side plates are welded to the rib structure that extends up from the oxidizer face circumference; this forms the injector dome with a spherical well for mounting the gimbal cradle socket. Welding must be accomplished inside as well as outside. This surface serves to contain the oxidizer fluid as well as hold the oxidizer torus which is later installed around the outer surface of this conical area.

8. Oxidizer Torus and Inlet Flange

This torus is prefabricated on the ground near the injector and lifted by cranes in sections to the injector top structure plate and welded in place both inside and outside. Fabrication of the torus segments are similar to methods discussed for fabrication of the fuel inlet torus, including the inlet flange subassembly.

II, B, Fabrication Methods (cont.)

9. Gimbal Pad

The superstructure is now moved to the next higher level to provide accessability and working facilities for installation of the heavy gimbal plate. Large segments of the gimbal pad, approximately 1 ft thick and 10 ft in diameter, are swung into place and welded to the surrounding ribs and injector top plate or cone.

Machining operations continue until all gimbal holes and surface alignments are completed.

10. Gimbal Actuation Arm

This is a large "A" frame cantilever type steel constructed arm consisting of heavy wall, tapered tubes and structural web plates, welded together to form a rigid arm about 20 ft long and capable of transferring tension and compression from an electrical powered screw type gimbal actuator. These arms are fabricated on a level cement slab and lifted into position for welding one end onto the injector and two ends at the heavy throat band of the chamber. The "A" frame construction provides both horizontal and vertical strength.

This completes fabrication of the injector and it is ready for final machining which is performed from machines attached to the superstructure performing all drill lathe and mill work operations.

III. THRUST CHAMBER VALVES

A. MAJOR COMPONENTS

1. Fuel and Oxidizer Valve and Actuation

B. FABRICATION METHOD

The valves are designed to operate normally open and the flow characteristics shall be of low P or pressure drop. The valves will close upon electrical signal to a sheer pin that releases the poppet into the fluid pressure flow stream assisting the valve to close with no alternative and 100% efficiency expected. The valve will be cast out of aluminum due to size and weight.

A special sealer will be applied to all surfaces exposed to salt water and other elements.

Proof and leak tests will be conducted to provide assurance of safe performance.

Flow tests to determine K values shall not be performed because of the size and flow capacity--research and development tests will have qualified this requirement.

IV. DIAPHRAGMS

A. MAJOR COMPONENTS

1. Diaphragm
2. Diaphragm Housing

IV, Diaphragms (cont.)

B. FABRICATION METHOD

1. Prediaphragm burst tests are conducted on random samples of 20% of the accepted diaphragms to further increase the expected reliability of performance.

2. The diaphragm housing is made of stainless steel pipe, about 1 ft in diameter. Double flanged and hinged at top and bottom to allow the housing to swing out and remove burst diaphragms and provide access to the interior of the tanks and valves. The diaphragm housings are installed during final tank and TCA assembly.

V. LINES AND FLEX JOINTS

A. MAJOR COMPONENTS

1. Line Fuel
2. Line Oxidizer
3. Flex Joints

B. FABRICATION METHODS

1. The lines will be constructed of heavy wall, 5 ft and 11 ft diameter pipe. The lines will be welded inside and outside of the tank. Flex bellows shall be prefabricated and welded to the lines prior to assembly onto the tanks. Each line will have two bellows to provide both alignment during assembly and gimbal action and vibration absorption during gimbaling and firing. The bellows are made of multilayers of thin stainless steel having the ability to flex and twist. One end of each line is welded to a flange that mates with a flange on the thrust chamber valves. Lines, flanges and bellows will be finally assembled at the way.

VI. THRUST CHAMBER ASSEMBLY

A. MAJOR COMPONENTS

1. Combustion Chamber Assembly
2. Injector Assembly
3. Gimbal Assembly
4. Fuel and Oxidizer Valves
5. Burst Diaphragm Housing
6. Gimbal Actuators

B. ASSEMBLY METHOD

1. The support structures that cradle the vehicle are lined up on a large way. The frame slides side ways down into the water, thus launching the completely assembled stage, which is supported with inflated flotation gear at the non-buoyant end of the vehicle.

2. The major assemblies are lined up on platforms along the way. The act of placing them in correct sequence and the removal of the injector from its vertical fabrication position to a horizontal position, is accomplished as follows:

a. The tanks are moved along the track to the foremost position on the way.

b. The injector is hinged or pivoted from a vertical ground fabricating position onto a railroad operating platform, which holds the injector in a horizontal position. The injector is now moved to the way and is made ready to be attached to the combustion chamber.

VI, B, Assembly Method (cont.)

c. The combustion chamber is made ready to install onto the injector by removing the upper end of the mandrel, swinging a portion of the chamber holding platform away at its pivot point, and the injector and chamber are brought together and welded inside and outside completing the TCA which consists of the chamber and the injector.

d. The injector holding platform is lowered hydraulically and moved to a side track.

e. The TCA is moved into position for welding the gimbal to the injector gimbal pad. The gimbal is swung into position by crane and welded.

f. The tankage is brought into position with cone of fuel tank contacting gimbal sphere. Gimbal is welded to tankage inside and out. Lines, bellows, swivel joints and valves are swung into position by crane. All components are supported in place by special holding tools or slings to allow alignment and welding.

g. The actuator mountings and arms are aligned, then the actuators are swung into position for bolting in place.

h. The platform holding the TCA is lowered hydraulically and pulled from beneath the pad and stored on a side track for later use.

i. The entire rocket engine now undergoes complete electrical installation and pressure sphere installation. The controls and lines are connected and checked out. Final inspection completes the assembly effort.

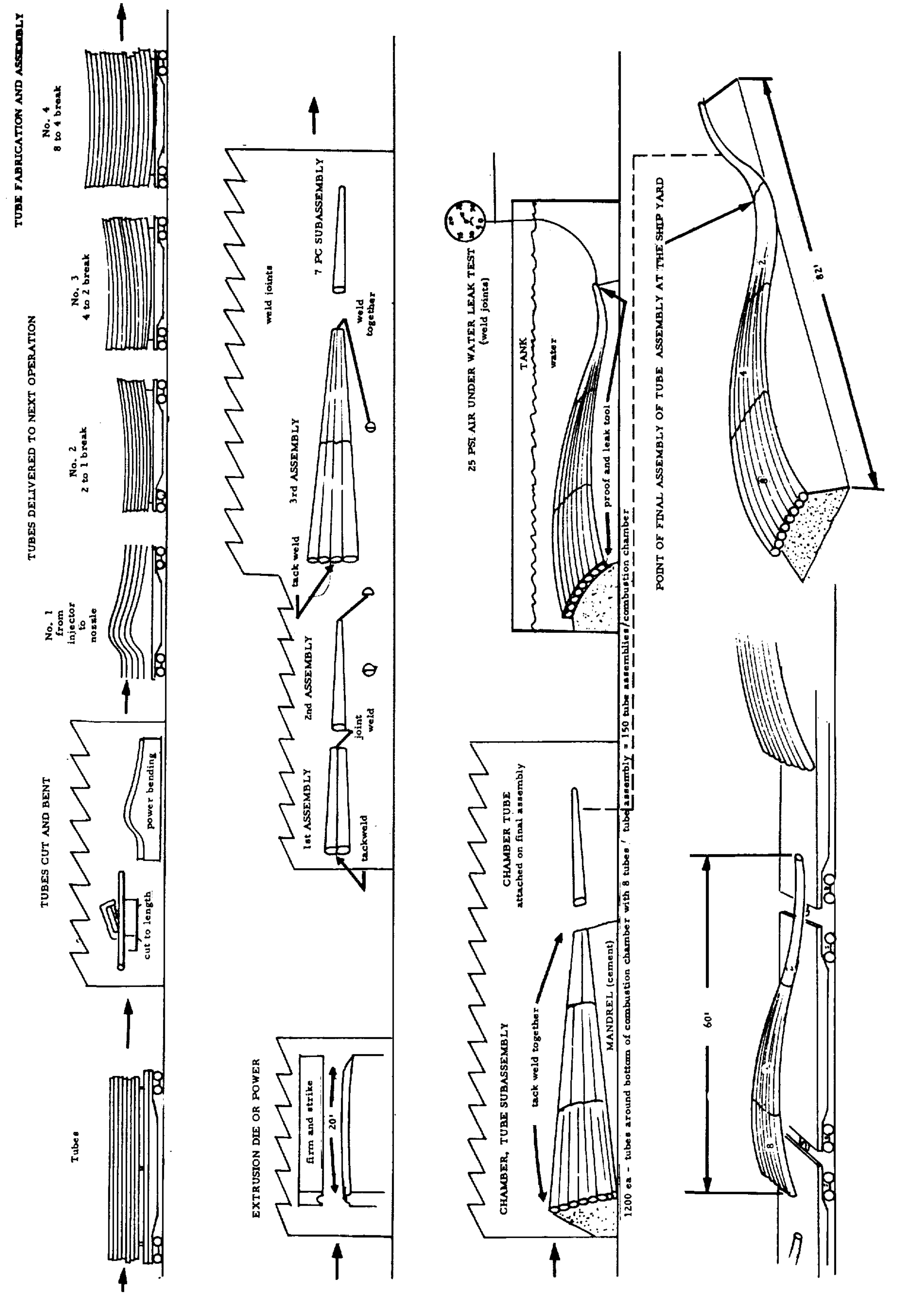
VI, B, Assembly Method (cont.)

j. The rocket is moved to a position for back flushing and filling of tanks with water, for system checkout and flow characteristics.

k. The rocket assembly is now moved to a position on the tracks where the tanks and TCA are drained of all water and then thoroughly cleaned (LOX clean) with trichlorethylene or other solvent until all minor surfaces are void of oil or other foreign matter.

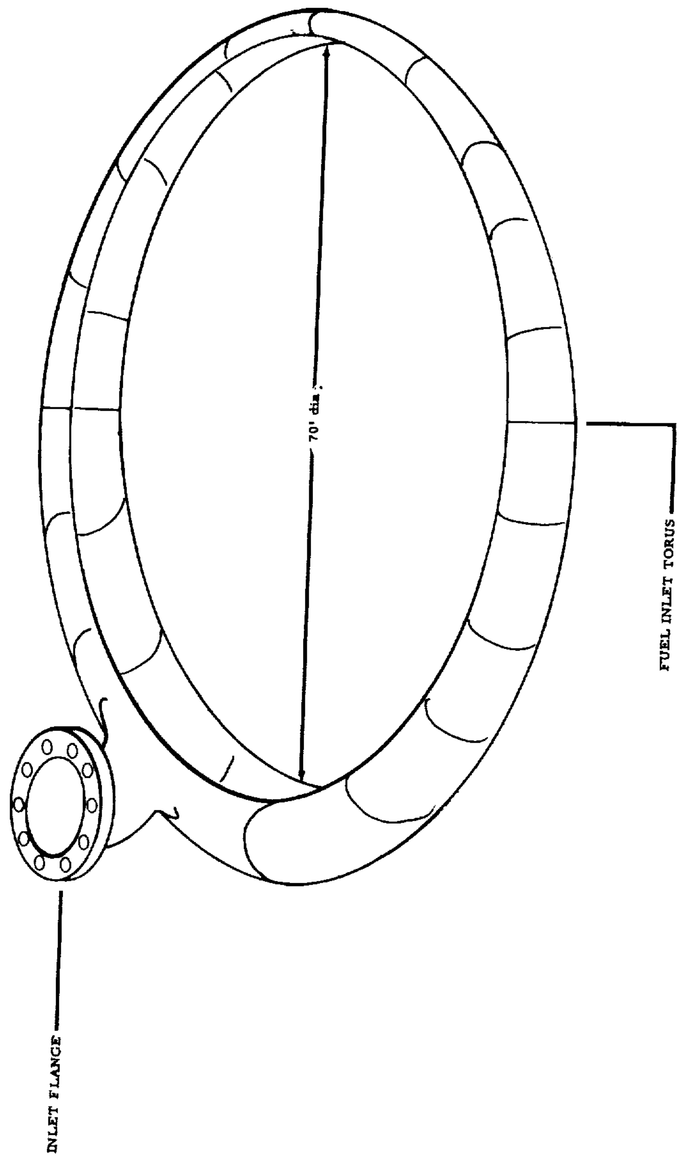
l. Dehydration is followed by purging the system with clean dry hot air or nitrogen.

m. The openings are immediately sealed upon removal from the dehydrator.



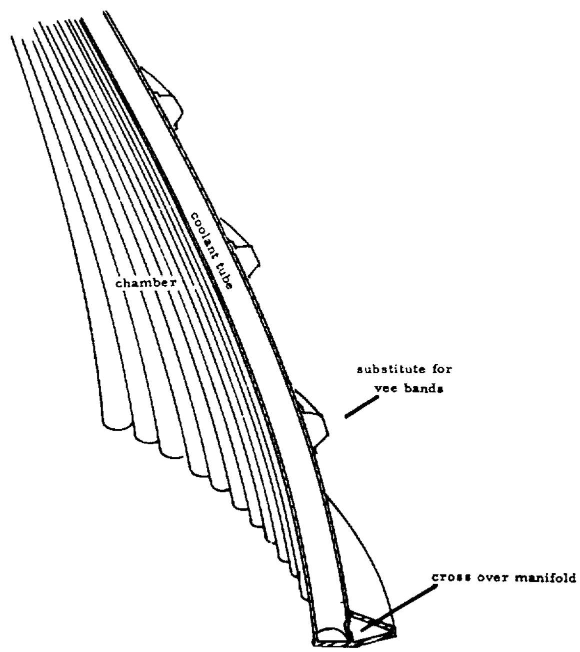
Tube Fabrication and Assembly

Figure 1



Combustion Chamber Fabrication (Torus)

Figure 2



Combustion Chamber Fabrication (Tubes)

Figure 3

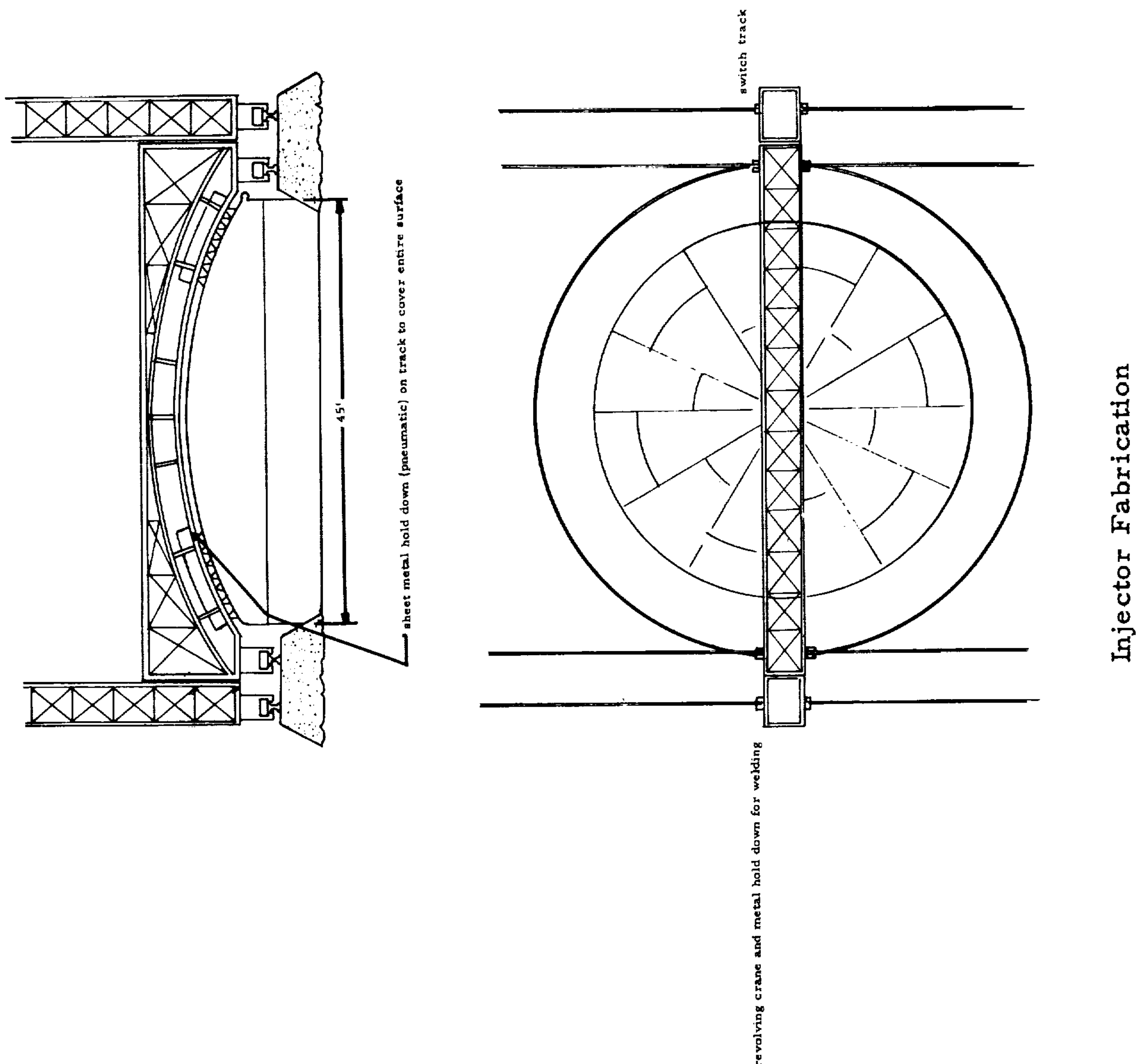
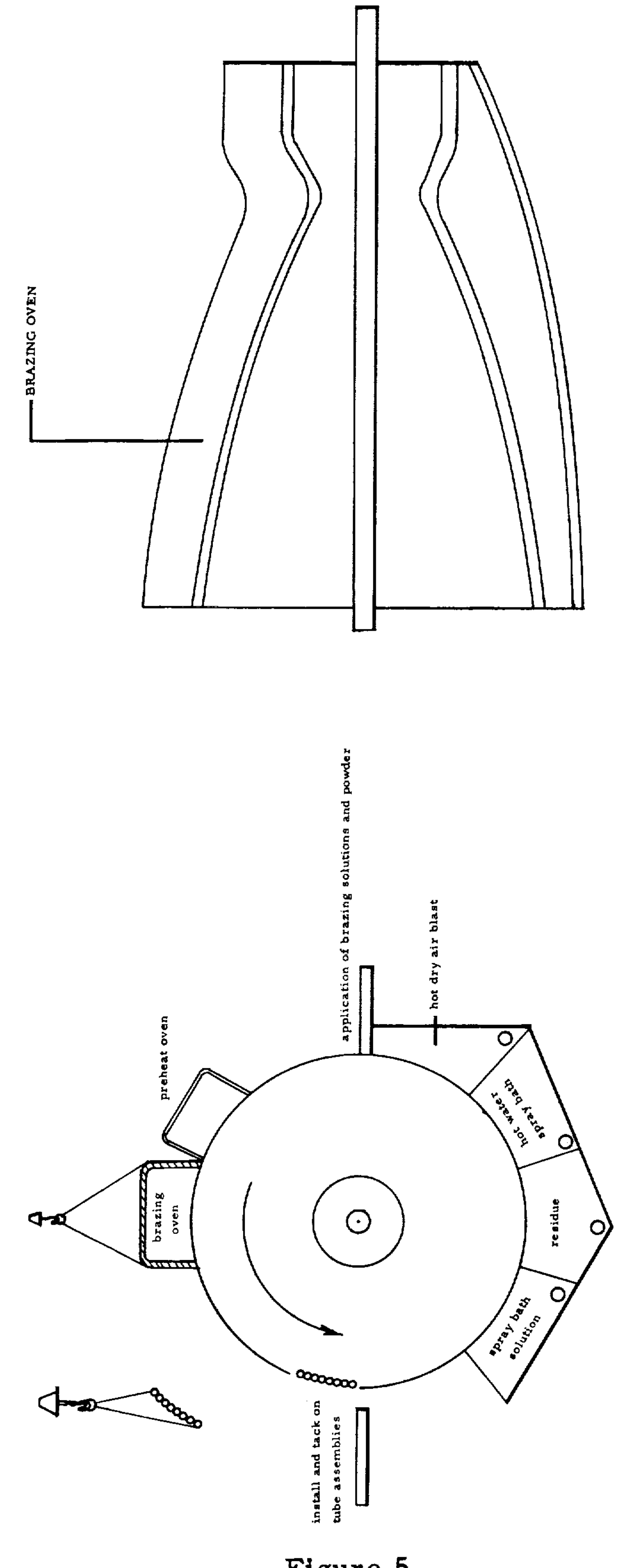

Injector Fabrication
switch track
sheet metal hold down (pneumatic) on track to cover entire surface
45'
revolving crane and metal hold down for welding

Figure 4



Combustion Chamber Fabrication (Brazing)

Figure 5

APPENDIX 3-6

SECOND-STAGE FUEL TANK STUDIES

S_2 FUEL TANK (LH_2)

18% Ni STEEL (MARAGING)

ELLIPTICAL 2:1 HEAD

No. of Sheets	Sheet Size	Linear Weld Length	No. of Passes	Gross Area
27	12 ft x 35 ft	1020 ft	1	11, 340 sq/ft

BARREL

No. of Sheets	Sheet Size	Linear Weld Length	No. of Passes	Gross Area
48	11 ft x 30 ft	2152 ft	3	15, 840 sq/ft

CONICAL SECTION

No. of Sheets	Sheet Size	Linear Weld Length	No. of Passes	Gross Area
32	11 ft x 30 ft	1170 ft	3	10, 560 sq/ft

LH$_2$ Tank Fabrication

Maraging Steel

Elliptical Head

Operation	Description	Set-Up Hr	Fab Man Hrs	Tooling
10	Degrease and inspect outer section	0 0	8.0 8.0	
20	Stretch press from	32.0	36.0	Stretch Die #1
30	Scarf rout for welding	8.0	24.0	Template
40	Assemble and tack weld	4.0	16.0	Form Block
50	Inspect	0	8.0	Template
60	Scarf rout girth for second tier	6.0	14.0	Template
70	Repeat operation #10 for second tier	0	8.0	
80	Stretch press form	24.0	32.0	Stretch Die #2
90	Scarf rout for welding	6.0	8.0	Template
100	Assemble and tack weld	4.0	12.0	Form Block
110	Inspect	0	8.0	
120	Scarf rout girth (2) places	5.0	25.0	Template
130	Assemble to first tier and tack weld	8.0	12.0	Form Block
140	Inspect	0	16.0	
150	Repeat operation No. 10 for third tier	0	8.0	
160	Stretch press form	20.0	24.0	Stretch Die
170	Scarf rout for welding	4.0	5.0	Template
180	Assemble and tack weld	4.0	10.0	Form Block
190	Inspect	0	6.0	
200	Scarf rout girth (2) places	4.0	15.0	Template
210	Assemble to second tier and tack weld	8.0	10.0	Form Block
220	Inspect	0	12.0	Template
230	Repeat Operation #10 for fourth tier	0	8.0	
240	Stretch press form	16.0	16.0	Stretch Die
250	Scarf rout for welding	4.0	4.0	Template

Operation	Description	Set-Up Hr	Fab Man Hrs	Tooling
260	Assemble and tack weld	3.0	8.0	Form Block
270	Inspect	0	4.0	
280	Scarf rout girth (2) places	3.0	8.0	Template
290	Assemble to third tier and tack weld	6.0	8.0	Form Block
300	Inspect - Contour joint preparation	0	24.0	Template
310	Weld	0	250.0	
320	Sand weld joints flush	0	250.0	
330	Radiographic inspection	0	150.0	
340	Repair weld joints as required	0	50.0	
350	Reinspect	0	24.0	
360	Final inspection (test coupons)	0	100.0	

S_2 FUEL TANK (LH_2)

Ti - .5 AL - 2.5 SN

ELLIPTICAL 2:1 HEAD

No. of Sheets	Sheet Size	Linear Weld Length	No. of Passes	Gross Area
50	10 ft x 20 ft	1280 ft	3	10, 000 sq/ft

BARREL

No. of Sheets	Sheet Size	Linear Weld Length	No. of Passes	Gross Area
56	9.5 ft x 30 ft	2420 ft	5	15, 960 sq/ft

CONICAL SECTION

No. of Sheets	Sheet Size	Linear Weld Length	No. of Passes	Gross Area
56	10 ft x 19 ft	1470 ft	5	10, 640 sq/ft

LH$_2$ Tank Fabrication

Titanium

Elliptical Head 2:1

Operation	Description	Set-Up Hr	Fab Man Hrs	Tooling
10	Degrease and inspect outer section	0	13.0	
20	Stretch press form-first tier hot	32.0	60.0	Stretch Die #1 (Heated)
30	Scarf rout forweld	13.0	77.0	Template
40	Assemble and tack weld	4.0	27.0	Form Block
50	Inspect	0	13.0	Template
60	Scarf rout upper girth for second tier	6.0	42.0	Template
70	Repeat operation #10 for second tier (12 pcs)	0	12.0	
80	Stretch press form hot	24.0	48.0	Stretch Die #1 (Heated)
90	Scarf rout for weld	6.0	30.0	Template
100	Assemble and tack weld	4.0	18.0	Form Block
110	Inspect	0	12.0	
120	Scarf rout girth (2 places)	5.0	75.0	Template
130	Assemble to first tier and tack weld	8.0	18.0	Template
140	Inspect	0	24.0	
150	Repeat operation #10 for third tier	0	9.0	
160	Stretch press form third tier hot	20.0	40.0	Stretch Die #1 (Heated)
170	Scarf rout for weld	4.0	25.0	Template
180	Assemble and tack weld	4.0	17.0	Form Block
190	Inspect	0	10.0	
200	Scarf rout girth (2) places	4.0	45.0	Template
210	Assemble to second tier and tack weld	8.0	15.0	Form Block
220	Inspect	0	20.0	Template
230	Repeat operation #10 for fourth tier (8 pcs)	0	10.0	
240	Stretch press form (8 pcs)	16.0	32.0	Stretch Die #1

Operation	Description	Set-up Hr	Fab Man Hrs	Tooling
250	Scarf rout for welding	4.0	16.0	Template
260	Assemble and tack weld	3.0	14.0	Form Block
270	Inspect	0	12.0	
280	Scarf rout girth (2 pcs)	3.0	24.0	Template
290	Assemble to third tier and tack weld	6.0	12.0	Form Block
300	Repeat operation #10 for fifth tier (7 pcs)	0	8.0	
310	Stretch press form fifth tier	12.0	28.0	Stretch Die #1
320	Scarf rout for weld	4.0	14.0	Template
330	Assemble and tack weld	3.0	12.0	Form Block
340	Inspect	0	10.0	
350	Scarf rout girth (2 pcs)	3.0	14.0	Template
360	Assemble to fourth tier and tack weld	5.0	10.0	Form Block
370	Repeat operation #10 for sixth tier (4 pcs)	0	5.0	
380	Stretch press for sixth tier	8.0	16.0	Stretch Die #6
390	Scarf rout for weld	3.0	8.0	Template
400	Assemble and tack weld	3.0	8.0	Form Block
410	Inspect	0	8.0	
420	Scarf rout girth (2 pcs)	3.0	9.0	
430	Assemble to fifth tier and tack weld	4.0	6.0	
440	Inspect-contour-joint preparation	0	30.0	
450	Weld	0	768.0	
460	Sand weld joints flush	0	255.0	
470	Radiographic inspection	0	155.0	
480	Weld repairs as required	0	100.0	
490	Reinspect	0	32.0	
500	Final inspection	0	150.0	

APPENDIX 3-7

SEA DRAGON
SHIPYARD TANK FABRICATION PLANS

CASE I

PRELIMINARY PROPOSAL FOR THE MANUFACTURE OF 75-FT DIAMETER LIQUID ROCKET TANKAGE

I. INTRODUCTION

This proposal is made to present a reliable system for the production and test of 75 ft-0 in. dia. rocket vehicle tanks using available techniques and facilities without resort to extensive experimentation or the acquisition of large machine tools on long term orders. As will be shown, it is intended that certain special tools will be designed and constructed to handle the unusual sizes and weights involved. The plan covers methods and tooling for production of one unit. Meeting the schedule outlined would require at least three parallel facilities of equal capacity.

The proposed encompasses the production of both first and second stage tankage from steel of the maraging type. The Shipyard Division facility provides the background for this manufacturing plan, but fabrication and testing can be accomplished at whichever of our eight divisions is most efficient for the program as finally developed. In addition to wide geographic coverage, these eight plants encompass all the final erection and launching means -- end launch shipways, side launch shipways, graving dock and single section floating steel dry docks. Prime consideration is given here to the single section steel dry dock because of its ready availability, mobility and versatility.

II. PRELIMINARY FABRICATION PROCEDURE

A. FIRST STAGE

Forward Section of First Stage - The LO_2 tank is comprised of a forward cone-shaped segment, a cylinder and a dished head. Flat plates rolled into cylinders and cones and shaped to form the head are required for construction of this section. Each of the plates will be purchased in the annealed and aged condition, cleaned and coated with corrosion preventive at mill. The plates for the shell courses are to be beveled on all edges and plasma-torch cut to a nominal finished size. The exact length of the closing plate on each course will be established by patterning. This will insure maintaining necessary diametral tolerances.

After the plates are beveled and cut accurately to length and width they will be welded together with portable automatic welding machines where possible and manually where not using the metal inert gas process (MIG).

The RP-1 tank requires a cylindrical shell, two formed heads and a conical transition. All will be fabricated by forming flat plates as in the forward section. However, the elliptical head knuckle and the spherical head must be formed hot because of the tremendous strength of the plate.

B. SECOND STAGE

The first section of the second stage being constructed of two elliptical heads will be constructed similar to the second section of the first stage; that is, the heads will be made of gores. The material will be purchased in the same condition as for the "first" stage and a portable automatic welding

II, B, Second Stage (cont.)

machine will be used. As these plates are only .174 in. thick no difficulty in shaping will be encountered. However, extensive temporary internal stiffening will be necessary.

The second section of the second stage is similar to the second section of the first stage. However, the thickness of the material is only .244 in. and will present less of a problem in construction, but will involve extensive temporary stiffening.

The diameter of both stages is such that flat plates can be used in the construction of all dished head gores.

For all places and methods of construction, whether building ways, graving docks or float dry docks, a semicircular cradle 75 ft. in diameter will be guilt. This cradle will be fitted with rubber-covered steel rollers so that all welding can be done in a downhand position.

A form of wood and steel to the exact shape of elliptical welds will be used for manufacturing the heads. These heads will then be lifted in one piece and fitted and welded to the cylindrical section. These heads will be smaller by the thickness of the shell material so that they can be welded into the shell thereby eliminating complicated skirt rings.

III. AGING

Because the steel will be purchased in an annealed and aged condition the welded seams and the immediate vicinity will need to be aged. This will be accomplished by controlled induction heating in way of welds only.

IV. TOLERANCES

It is contemplated that the tolerances for welding and machining the various elements of the project can be maintained within the levels indicated below:

A. 1. Concentricity level for fabrication of 75 ft-0 in. diameters is to be .500 maximum.

2. Ovality level for 75 ft. diameter is to be within .750 in.

B. 1. Welding mismatch for both long seam and round seam is to be .025 in. maximum.

2. Permissible crown is to be $\frac{.05}{.00}$ inside and outside.

C. Maximum tolerance level for machined joints

1. .032 in. variation for major diameter.
2. .010 in. variation for straightness of line.
3. .050 in. variation for flatness of line.
4. .012 in. variation for perpendicularity of face to diameter.
5. .030 in. variation for parallelism of faces.

All dimensions and tolerances are to be in jig position when measured for acceptance and are to be adjusted to 80°F ± 5°F.

V. TESTING

Quality of welds will be determined by the 100% X-ray inspection.

The second section of the first stage will be leak tested with air in a dry dock in the submerged condition.

V, Testing (cont.)

The thin plate sections will be tested with air, and by coating welded seams with a soap and water solution. A final hydrostatic proof test will be performed on all tanks with the dry dock partially submerged. The buoyancy thus developed will uniformly support the rocket even when full of water.

VI. CLEANING AND PAINTING

On completion of all fabrication, the interior surfaces will be sandblasted and coated to prevent corrosion with material compatible with the eventual contents. The outsides which will be exposed to the sea will be coated with an anti-corrosive and anti-fouling paints.

CASE II

I. MANUFACTURING PLAN

A. ORGANIZATION

The project would be headed by able and experienced administration staff, consisting in part of project engineer and staff, whose first tasks would be development of facilities, organization of material flow, personnel training and the like.

This staff could be organized from existing company personnel, and here, our company occupies a unique position in that it has experienced personnel in all phases of the project from the basic steelmaking to heavy fabrication and machining. Our company is one of the producers of maraging steels.

I, Manufacturing Plan (cont.)

B. FACILITIES AND TOOLING

Analysis of the project indicates that to make required deliveries, six stages must be in the production line at all times.

This requirement makes it necessary to consider substantial addition to present facilities as follows:

3 stage-I graving docks for erection, 100 ft x 200 ft

3 stage-II graving docks for erection, 100 ft x 200 ft

2 test basins, 100 ft x 200 ft x 100 ft depth

2 subassembly buildings, 150 ft x 500 ft

All the above to be suitably equipped with cranes, heavy transport, and auxiliaries peculiar to their individual needs (such as pumping facilities for graving docks).

Tooling, such as welding positioners, plate rolls, hot forming equipment, and heat treating equipment would be especially designed for optimization of quality and efficiency.

It is our belief that existing facilities in the area of large machining and the smaller subassembly work would be adequate for the needs of the project.

I, Manufacturing Plan (cont.)

C. MANUFACTURING TECHNIQUE

Raw materials, chiefly plate, would flow first to subassembly buildings, where forming of cylindrical elements and heads would be accomplished. Cylindrical elements would be finished out as "cans" in optimum length, and transported to graving docks for final assembly.

Heads would be built up by "orange peel" or other method, as development would indicate, and be transported to docks as complete units. Forming dies and assembly fixtures would be required.

Both cylindrical elements and heads would be equipped with stiffening rings, which would remain with the piece during final fit-up and closure, and would serve as roll path for final welding, on welding positioners stationed in the graving docks.

Radiography of all welds would be completed in the graving docks, and minimize the need for preliminary pressure testing.

After completion of assembly, heat treatment of weld zones would be accomplished; using modifications of either the travelling ring-burner technique or internal firing.

On completion of heat treatment, docks would be flooded and the tankage floated. Outside supporting rings would be removed, leaving temporary internal support. The tanks would then be moved to a testing basin where they would be equipped with pontoon buoyancy chambers and filled with water for

I, C, Manufacturing Technique (cont.)

hydrotest. Buoyancy supplied would be sufficient to expose about one fourth of the surfaces and rotated between successive quandrants by means of winches ashore, or other suitable device.

This method cannot expose all of the shell for examination however, unless more than half of the tank were lifted. Since this presents practical problems in support, we contemplate the simpler method of upending the tank and exposing the ends.

Also, this would serve as the most practical and safe means of testing the internal heads.

Any leakage or defective seam discovered would have to be repaired in the testing basin and heat treated by localized methods.

Following satisfactory completion of hydrostatic test, the tanks would be removed to an outfitting wharf and prepared for tow by being pressurized slightly, and internal supports removed.

Suitable towing bridles and other outfit would be installed, and delivery made.

The above presents only the major aspects of the procedure. Naturally, many detailed procedures would be developed as a part of the preliminary engineering and planning.

Quality control a nd process inspection would be applied to the utmost degree to all phases of the project, to assure highest quality as an end result.

CASE III

I. SCOPE OF WORK TO BE PERFORMED

A. DESIGN

Design would require as thorough optimization as possible within limits of time and money available. It would probably include construction and testing of large scale models under cryogenic conditions. It is assumed that this will be done by Aerojet-General and detailed working drawings will also be furnished by Aerojet-General.

B. DEGREE OF COMPLETENESS

This study is on the basis of furnishing tanks without piping or insulation. Tanks would be cleaned and preservative coatings would be applied.

C. TESTING

All welding would be X-rayed to prove quality standards commensurate with strength requirements. Dye penetrant or magnetic particle inspection would be employed to supplement X-ray inspection.

A tightness test of 10 psi of air would be performed to demonstrate tightness integrity prior to shipment. It is understood that Aerojet-General desires the tanks to be proof tested before delivery. However, to accomplish a meaningful proof test, it is considered that all piping and connections should be installed. Further, the proof test should be performed in a submerged condition to equalize the weight of the testing water, preferably in a dry dock to permit control of the unit, examination during test, and recovery in the event of a failure. Since the units are to be assembled with the balance of the vehicle in a

I, C, Testing (cont.)

dry dock by Aerojet-General, it is recommended in the interests of economy that the proof testing be accomplished at that time. Proof testing, therefore, is not included under this proposal.

II. DELIVERY

Tanks would be delivered afloat, with internal stiffening spiders and with special apparatus for towing attached.

It is assumed that the temporary stiffening, temporary closures, and towing apparatus would be returned to the shipyard for reuse within three months of delivery of each unit.

Units would be delivered at a rate of one each of tanks for Stage I and Stage II each month for ten years. The first delivery of Stage I to be 24 months after release for manufacture, and 28 months for Stage II.

III. FABRICATION PROCEDURE

A. GENERAL

It is planned to use normal shipyard procedures as much as practicable consistent with the characteristics and requirements of the units to be produced. The major differences from normal ship construction are the inability of the structure to stand without support, requiring a system of temporary supports, special measures necessary in preparation of structure to withstand cryogenic conditions, and the large quantity of duplicate units to be produced permitting extensive tooling and automation to a greater extent than is now found in shipbuilding.

III, Fabrication Procedure (cont.)

B. FABRICATION

Raw material fabrication will take place at the fabrication plant, where adequate land is available for the establishment of an automated plate processing area. Plates of a standard size, say 10 x 30 ft, will be unloaded from railway cars into flat stacks by thickness. Plates will be moved as needed to conveyors that will position them on tape-controlled plasma-arc burning machines for automated profile cutting and weld joint edge preparation. Conveyors will then transport the plates to existing plate shaping facilities, where presses and plate rolls will be utilized for the more simple forming operations. Plates requiring complex curvatures may be formed either hot or cold in matched dies, in presses, on mocks, or by explosive forming techniques. Fully fabricated plates will then be transported to the subassembly area.

C. SUBASSEMBLY

Progress of fabricated material from the time of receipt from the fabrication plant until completion of the tank will be generally in a straight line towards the river from a receiving area at the head of the main erection ways.

Subassemblies of approximately 50 tons and approximate dimensions of 30 x 60 ft will be assembled on mockups, welded, and X-rayed completely in the first area. In the event that 18% nickel maraging steel is selected, heat treatment of welds at 900°F, is required; consequently, the subassemblies will be heat treated in a large, specially constructed furnace featuring a pass-through design which will serve as a conveyor for moving the assemblies to the next area.

III, C, Subassembly (cont.)

Unit assemblies of major elements of the tanks, such as elliptical heads, conical sections, and spherical units will be completed prior to erection on the ways. Again, welding and X-ray inspection and quality control clearance would be complete before release of a unit for erection.

D. ERECTION

Erection will be on two specially designed shipways, one for each stage, with two basic construction positions on each shipway to permit erection of two units concurrently. The shipways will feature positioning rolls with axes horizontal and parallel to the shoreline. The subassemblies or unit assemblies for the parallel-sided area will be placed on the rolls. The temporary internal support spiders will be set up as the units are added. After all are erected, the tank will be rolled to permit downhand work on the connections between assemblies. Welding, X-ray and final inspection will progress concurrently with erection. Major units such as the heads will then be erected and welded.

Heat treatment will be performed on the erection welds by means of local heating in long narrow specially constructed heat treating enclosures. It is feasible but significantly more costly to heat treat a complete tank using special furnaces for heat supply and heavy blanket insulation over the complete unit.

III, Fabrication Procedure (cont.)

E. WELDING

All welding is to be done wherever possible by automatic means using inert-gas shielded arc welding equipment on self-propelled carriages. Mechanization of this sort will result in the welding being done under more controlled conditions with uniform heat input and higher weld quality. Manually-controlled inert-gas shielded arc welding will be used in areas where automatic means are not adaptable.

F. AIR TEST

Tightness integrity of the completed structure will be demonstrated by the application of a ten-pound air test.

G. FINISHING

The tanks will be finished by cleaning the surfaces and applying preservatives where required, and installing temporary apparatus for towing and delivery.

It will be noted that temporary support structure will remain within the tanks for support until final assembly at destination.

The tanks must be pressurized slightly at all times after the temporary supports are removed in order to hold their shape.

It is anticipated that temporary external structure will be used at the final assembly point to support the tank while piping and insulation are installed and other outfitting is performed after the internal spiders have been

III, G, Finishing (cont.)

removed. Tank internals such as anti-slosh baffles will be separately assembled in units which will fit through piping cuts and may be shipped by barge or rail to the final assembly point.

H. LAUNCHING

Launching will be accomplished by lowering the positioning rolls and rolling the unit down the ways under the control of cables and winches until the unit is waterborne and towed away.

IV. EQUIPMENT, FACILITIES, SPECIAL TOOLING

The section on construction procedure has described the equipment, facilities and special tooling proposed for use in the construction of "Sea Dragon" tankage. The following is a summary of the required additions to existing facilities for this work:

A. FABRICATION PLANT

Conveyor system for automatic plate transfer

High-speed tape controlled burning machine to accommodate plasma-arc equipment

Shed to cover burning equipment

Explosive forming tank

High-speed crane for automated plateyard

IV, Equipment, Facilities, Special Tooling (cont.)

B. NEW SHIPWAY AREA

Two special shipways 140 ft along river

Four sets of positioning rolls

Four 50-ton cranes with transfer rails

Portable heat treatment facilities (steel tanks only)

C. SUBASSEMBLY AREA

Heat treatment furnace 30 x 60 ft (for steel tanks only) 20,000 sq ft covered assembly flats

Four 25-ton cranes

D. INSPECTION FACILITIES

Four portable high-powered X-ray units

Ultrasonic testing equipment

E. WELDING FACILITIES

Automatic inert-gas shielded arc welding equipment

F. SPECIAL TOOLING

Explosive forming dies

Temporary support spiders

Towing apparatus

V. MANAGEMENT ATTENTION

Although in many respects the operations involved in construction of these tanks parallel those of normal shipyard construction, the scope of the work is such that separate facilities would be set aside for efficient accomplishment of the bulk of the work. Therefore, a separate division of the corporation would be set up under a manager, with a production control staff, a Quality Control staff, and a small technical staff. The line functions in the division would include material control, fabrication, assembly and erection departments. Existing departments of the parent shipyard would handle purchasing, cost accounting, record keeping, personnel, material handling, and maintenance of facilities.

VI. PROGRESS INFORMATION

Because of the necessity of close coordination of the delivery of the tanks with the vehicle assembly activity, progress information would be complete and timely. Daily reports would be made of material fabricated, assembled, welded, erected, and X-rayed for each unit. These reports would be used to develop weekly reports of percentage completion of each operation on each unit. Tabulated against the actual percentage completion would be the target percentage completion for the date. The weekly report would also include percentages of material received for units not yet in fabrication, and promised delivery dates for material not yet received. The weekly reports for each week would be completed and mailed to Aerojet-General on each Monday of the following week.

Progress data would be collected, processed and tabulated on electronic equipment. The tabulations would be monitored under adequate control techniques.

Photographic supplements to the above reports would be utilized during the prototype development stages of the work.

CASE IV

I. GENERAL STATEMENT

Aerojet-General is proposing a sea-launch vehicle that will reduce the cost per pound of payload for the very large boosters that will be needed in the future for manned space flights to the moon and beyond. This vehicle has been named "Sea Dragon".

The size of the vehicle is such that its stages must be built alongside a deep water channel with access to the sea so that they can be readily launched by conventional ship launching methods and towed to an assembly point.

The fabrication of the propellant tanks for the first and second stages is best done in a shipyard, especially one that has the experience in the large diameter structures of the nuclear submarines being built today. Basically, - proven techniques will have to be scaled up, new tooling developed and present capabilities extended.

The shipbuilding company meets all of the above conditions and could fabricate and launch these tanks with its present launching facilities.

There is presented herewith a preliminary outline, with brief discussion of the major elements of a proposed method of manufacturing the propellant tankage of the first-and second-stages of "Sea Dragon". This will include procedures for both candidate materials elected by Aerojet-General, all 18% nickel and all Aluminum 2014-T6, and a flow chart showing fabricating time. This preliminary outline is to be followed shortly by a more detailed manufacturing plan.

I, General Statement (cont.)

A. PRELIMINARY MANUFACTURING PLAN

1. Technical Plan

a. Aerojet-General to furnish the basic engineering. This is to consist of design of tanks; size, material thicknesses, material specifications, tolerances and testing requirements. This information, both plans and specifications, shall be furnished in reproducible form.

b. The shipbuilding company will be responsible for the following:

(1) Preparation of shop plans to show welding details, locations of plating seams and butts, internal circularity and other jigs, launching calculations and arrangement.

(2) Construction of any scale models or mock-ups necessary to permit the determination of ordered plate sizes.

(3) Preparation of bills of material for plates and shapes.

(4) Test memoranda.

(5) Collabration with Aerojet-General and the towing company regarding arrangements for towing rocket engines away from the shipyard.

I, A, Preliminary Manufacturing Plan (cont.)

2. Manufacturing Considerations

a. 18% Ni Steel - Largest plate size available is 96 in. x 480 in.

b. Aluminum 2014-T6 - largest plate size available 144 in. x 720 in., Alcoa - 132 in. x 540 in., Reynolds

c. Platen lifting capacity - 70 tons

d. Building way lifting capacity - 70 tons

e. Quality Control

(1) Radiographic inspection

(2) Magnafluxing and/or dye penetrant

(3) Pressure testing

(4) Tolerance - 1 in. out of round on diameter

f. Delivery - One each Stage I and Stage II per month for ten years. Stage I delivery to start 24 months after "go ahead" - Stage II delivery to start 40 months after "go ahead".

3. Jigs and Tooling Concept

To implement the fabrication, inspection, preassembly, erection, launching, and delivery of the "Sea Dragon" tankage components, our plan is based on the concept of interior supports and structures composed of typical and interchangeable structural members so fashioned and arranged to

I, A, Preliminary Manufacturing Plan (cont.)

provide the necessary support during manufacturing, launching and shipping. These supports can be easily dismantled and removed. The following jigs and fixtures will be required:

a. Six or seven shell jigs for shipping

b. One conical section jig - semi-permanent

c One conical section spherical head jig - semi-permanent

d. One shell section assembly jig - semi-permanent

e. One elliptical head assembly jig - semi-permanent

f. One internal elliptical head assembly jig - semi-permanent

g. A complement of preassembly jigs

4. <u>Manufacturing Sequence</u>

a. Fab Shop

(1) Mold Loft - Develop plate size, templates, roll sets and jig sets

(2) Plates to be cut to size and formed to correct shapes in rolls and press

b. Platen Area

(1) Subassembly jigs to be located here

(2) Shell plating and bulkhead plating after sizing and forming will be welded together into subassembly units of three to five plates

I, A, Preliminary Manufacturing Plan (cont.)

(3) Plates so welded to be heat treated after inspection (radiographic), as follows:

18% Ni - This steel will be purchased in the solution treated and maraged condition so only the butt welds will be heat treated. Strip heaters will be used at butt welds to marage the weld and adjacent metal heat affected zone.

Aluminum 2014-T6 - On the thick aluminum plating for the RP-1 tanks only, it will be necessary to weld an 8 in. x 15 in. bar to the adjacent plate section to form the butt for welding the adjacent sections together. The weld of the bar to the plate will require heat treatment in a specially built furnace of sufficient size to accommodate slabs up to 40 ft in length. Special quenching facilities will also have to be provided. No heat treatment required for the other tanks made of aluminum or for the final assembly welds at the 8 in. thick butts.

c. Assembly Area at Head of Shipways

(1) Semi-permanent jigs to be located here

(2) Subassembly units brought to this point and assembled into maximum weight units

(3) These units to be held in proper shape by removing part of the jig fixture with the unit when unit is hoisted to the building way

d. Building and Launching Ways

(1) Final joining to take place here. Strip heaters required for all joints of the 18% Ni tanks not maraged on the platens or assembly areas.

I, A, Preliminary Manufacturing Plan (cont.)

(2) The shell jig fixtures and those parts of the assembly jig will remain in the completed first and second stages during launching and towing to final assembly point.

(3) The jigs to be dismantled and returned to the shipyard, after delivery, for reuse.

II. NEW FACILITIES

Most of the work can be done with the existing facilities; however, there will be required portable protective covering on the building ways and in the assembly area adjacent to the building ways. There will also be required permanent foundations for the large semi-permanent jigs and in the case of the RP-1 tanks, if constructed of aluminum, there will be required a special heat treat facility consisting of furnace, quenching and handling equipment.

APPENDIX 3-8

SEA DRAGON
THE WELDING OF THICKPLATE ALUMINUM ALLOY 2014

The use of Aluminum 2014 T-6 for the proposed Sea Dragon application is tied directly to the ability of the fabricator to consistently produce sound welds in this material.

Variations in the procedures used in welding the high-strength heat-treatable alloys will affect the properties of the resulting welds. As a rule, properties are lowered by procedures that introduce defects, such as notches, oxide films, and excessive porosity or increase the width of the weld or the heat-affected zone.

Of the automatic welding procedures, DC straight-polarity tungsten-arc welding has generally proven to be superior to consumable electrode or AC tungsten-arc welding. For thicknesses required for the Sea Dragon application however, see Table I, DCSP tungsten-arc welding is considered impractical because of the large number of passes required to fill a typical joint. Furthermore, overall heat input may be very high and could result in appreciable strength decreases across the weld joint and greater deterioration of metallurgical properties as compared to the competing MIG process.

TABLE I

PLATE THICKNESS REQUIREMENTS FOR SEA DRAGON APPLICATION

Alloy 2014 T-6

	Stage	Thickness
First		
	RP-1	4.15 in.
	LOX	2.11 in.
Second		
	LOX	.72 in.
	LH	.72 in.

The MIG welding technique has demonstrated great flexibility and is capable of producing reliable welds in thick plate when welding conditions are varied over wide limits.

The welding of heavy aluminum plate using the inert gas consumable electrode process normally required the use of a beveled joint. Welding is carried out from one side after back chipping, from the other side. Several weld passes are made from each side to complete the joint. Current for this operation is normally limited to values below 400 amperes so as not to produce an unstable arc with resultant porosity and oxide folds.

Work done at the Linde Company has shown that heavy plate could be welded with fewer passes if higher current, above 400 amperes were used. It was found that the use of higher current levels during welding made it possible to greatly simplify the preparation of plate edges such that a square butt or slightly modified square butt joint could be used. The welding operation was often carried out in one pass from each side and at a much higher speed per pass than previously possible. Back-chipping was rarely required and because of the single pass used, overall heat input was greatly reduced. This reduction in heat input reduced distortion, and in the case of heat treatable alloys, produced better as-welded properties.

In considering square butt welding several factors must be considered, First, the torch, whether manual or mechanized, must be able to pass large volumes of gas (80-100cfh) without excessive turbulence. Next, the welding wire must be free of foreign material. The edges of the sheared plate must be cleaned by the removal of surface metal such that all oil or grease embedded in the metal from the shearing operation is removed. The selection of an appropriate power supply was another factor which proved to be important in high current welding. Recently developed constant potential power supplies which incorporated slope control proved to be beneficial in achieving the necessary current ranges although good results were also obtained with conventional power supplies.

For heavy plate in the thickness range considered for the Sea Dragon, Linde used a modified square butt joint with both sides slightly V-shaped to reduce the amount of weld reinforcement and produce a more balanced weld contour. It was found that the amount of V-shaping required with this technique was considered by less than was the case with a conventional double V-joint. . The nose can be quite thick and in some cases may be as much as 1/2 (one-half) the thickness of the plate. Joint preparation is not critical and therefore the bevel does not have to be machined to the same degree of accuracy as a conventional double V-joint.

Welding conditions used by Linde were such that a spray type transfer is achieved. Using this technique Linde found that costs were significantly reduced over conventional multipass deposition techniques. Typical welding parameters and properties obtained are shown in Table II.

In contrast to the work done at Linde, Kaiser found that the answer to lower costs was in increasing weld deposition rates. The weld metal deposition rate was in turn a function of the welding current used. It was found that for a given size filler wire, there was a maximum practical current level which could be used, therefore the efficiency with which metal can be deposited was limited by the diameter filler wire that was available.

For its studies, Kaiser obtained special supplies of 5/32, 3/16, and 7/32 in. diameter filler wire, considerably larger than the standard 1/8 in. diameter wire commercially available. Use of these larger diameter aluminum filler materials required the use of heavy wire feeders and power supplies with high current capacities.

The significant difference between the Linde and Kaiser work was the lower current density used at Kaiser and the resultant change in metal transfer characteristics across the arc. (12,000-30,000 amps/in^2 for Kaiser as compared to 50,000-100,000 amps/in^2 for Linde). Because of the lower current densities used, the metal transfer across the arc was globular as opposed to a fine spray typical of the transfer characteristics of small diameter wire used in combinations with high current densities.

The initial welding procedures used at Kaiser to make butt welds with large diameter filler wires were carried out using a spray type transfer similar to that used at Linde in their work with the high current density-square butt technique. Results of these early treats were unsatisfactory, and it was found that these welds were characterized by a lack of fusion to the side walls. In analyzing this work, it was found that long arcs, although having deeper penetration at the roots, missed 100% fusion to the side walls. The shorter arcs decreased penetration at the root, but increased fusion at the side walls. The decreased root penetration using the short arc made it necessary to decrease the thickness of the welding lands and improve the fit-up of the joint in order to insure 100% penetration.

Kaiser found that the addition of helium (higher ionization potential as compared to argon) to the inert gas shielding resulted in a higher arc voltage for a given arc length with resultant increase in the heat input from the short arc. Using various helium-argon combinations, it was found that satisfactory welds could be made in thick plate even where severe misalignment was present. Typical properties of welds produced by the Kaiser process are shown in Table III, together with the welding parameters used for the various thickness plate joined in this investigation. Although the avowed purpose of the Kaiser work was to decrease welding costs, in effect, their investigation has demonstrated that sound welds can be made under conditions which significantly vary from those recommended by the Linde Company.

The conventional approach to joining heavy aluminum plate is used, by Chicago Bridge and Iron. This company has been a leading fabricator of aluminum tankage for cryogenic applications. Their approach, as used in field applications has been to use a conventional double-V bevel and weld from both sides using a multipass technique. Small diameter filler wires are used and current densities are in the range to produce a globular type transfer. Typical data obtained from this company as related to the welding of heavy aluminum plate is shown in Table IV.

If typical weld data from these companies are plotted in graphical form, curves are produced. These curves illustrate the latitude that exists in selection of welding parameters that would satisfy requirements for producing sound welds in aluminum plate in thicknesses common to the Sea Dragon application.

It should be recognized that weld soundness, by itself, is not a criterion for weld acceptability. Work at both the Linde and Kaiser Companies was directed towards reducing costs by decreasing the number of weld passes required to make the weld joints. The welding procedures used for the Sea Dragon are dependent upon the fact that a single pass weld is inherently weak from a metallurgical standpoint due to the freezing characteristics of the weld which produces a plane of low strength at the approximate center line of the weld. This plane of weakness can be minimized by multipass welding, which results in many weld beads and therefore no preferentially oriented low strength plane. However, the use of heat treatable aluminum alloys such as Al 2014 adds additional complex factors to the welding process which must be considered, since now the metallurgical effect of the precipitating phase must be considered. The Aluminum 2014 is classified as an aluminum-copper-magnesium-silicon system employing copper aluminide ($CuAl_2$) as the primary precipitation hardening agent. A secondary precipitate, $CuMg_5S._4Al_4$ greatly increases the strengths obtainable through artificial aging and is also responsible for the natural aging characteristics of this alloy. Manganese is added to prevent formation of the undesirable Al-Cu-Fe-S. constituent (present as AlFeMuS.) and acts to some extent as a grain refining agent. Titanium is present in limited quantities for its action as a grain refiner. Iron, chromium and zinc are usually present as undesirable impurities.

The secondary Aluminum 2014 alloying elements, magnesium and silicon, result in low melting point ternary and quaternary eutectics which limit the solution treatment temperatures to 925° and 945°F. The eutectics formed, their melting points, and the resulting solution treatment temperature of this alloy are shown in Table V. Complete resolution of the $CuAl_2$ can not occur at the low solution treatment temperature used for this alloy, consequently some residual $CuAl_2$ is always present in the microstructure. The distribution of this residual $CuAl_2$, as determined by the fabrication and heat treat history, greatly affects the ductility and toughness of the end product. During welding the material in the heat affected zone is heated rapidly to high temperatures for very short periods of time and is then cooled slowly to room temperature. The material may not remain at the high heat sufficiently long to result in incipient melting of the ternary and quarternary eutectics but, during the cooling process large amounts of $CuAl_2$ are precipitated in a more or less continuous network at the grain boundaries. The quantity of $CuAl_2$ precipitated at any given point is a function of the grain boundary surface area available for precipitation, i.e., the net effect becomes worse in a region of large grain with small total boundary area as opposed to a region of small grains with large total boundary area. If ductility and toughness are required in the welded structure, this continuous $CuAl_2$ network must be agglomerated and broken up by resolution treatments. The permissible solution treatment temperature of the 2014 alloy is lowered by the presence of the secondary alloying elements and therefore neither adequate resolution or agglomerization can take place. The resolutioning of this undesirable constituent can take place upon exposure to higher than normal solution treatment temperatures but only at the expense of incipient melting of lower melting eutectics and the formation of internal porosity. Work done at the Boeing Company has shown that the effect of the brittle, continuous grain boundary network was largely a function of matrix hardness. The presence of this constituent ($CuAl_2$) has little or no effect on the properties of as-welded or solution-treated weldments, but drastically reduce the ductility and toughness of solution treated and artificially aged weldments. The Boeing Company concluded that the soft and ductile matrix of the as-welded or solution treated material was more capable of redistributing stresses than the matrix of the artificially aged material. Data reflecting the effect of matrix hardness are shown in Table VI.

It can readily be seen that the tensile elongation, bend, and bulge properties of the welded 2014 alloy post weld heat treated to the T-4 condition are far superior to similar properties for the T-6 condition.

A further clue to the behavior pattern of the 2014 alloy can be obtained from an analysis of data relating to the effect of short time exposure to elevated temperatures on the hardness of this material. These data presented in Table VII cover a range of temperatures from 500-1000°F and exposure times ranging from two sec to 120 sec. Hardnesses are taken immediately after quenching and over an interval of six weeks. The effects of overaging and resolution of the aging constituents are readily evident. Specimens heated to 700°F or below exhibit a loss in hardness indicative of overaging. Specimens heated at 800°F and above show an initial drop in hardness with recovery in hardness as a function of time. The higher the exposure temperature the more rapid the recovery. The specimens treated at 800°F show a progressive drop in hardness with increasing exposure time, dropping to a minimum of $73R_F$. The gradual recovery of properties over the six weeks interval of time indicates that some resolution of the aging constituent has occurred. The failure of these specimens to reach peak hardness levels after six weeks indicates that the original exposure to 800°F for the periods of time indicated resulted in some overaging.

The specimens heated to 900°F and above lose hardness to a minimum of about $80R_F$. This is the approximate hardness of the alloy immediately after quenching from a normal solution treatment temperature. These specimens age at a rate depending on the testing temperature and time, but all ultimately recover to a hardness level of about $95R_F$.

The metallurgical changes that result from short time exposure to elevated temperatures simulate in a crude fashion, the behavior of base metal in the heat affected zone as influenced by the passage of a welding torch.

If the assumption is made that normal welding speeds for the MIG process would range between 8 and 32 in./min depending on the amount of filler metal deposited per pass, then, at the higher speeds metal adjacent to the torch must be exposed to extremely high heats for periods approaching 2 sec. Conversely, at low speeds, exposure time would increase to approximately 7.5 sec per in. of metal traversed. The temperature gradients for any single pass between the high heat adjacent to the weld head and ambient conditions in the metal must then be a function of weld metal temperature, exposure time and rate of heat abstraction. These are controllable factors. The detrimental effects resulting from the precipitating phase have been shown to be related to available grain boundary area; therefore, welding conditions that favor maintenance of a small grain adjacent to the weld head area tend to minimize the deleterious effects of the grain boundary precipitation.

The problem becomes exceedingly complex when multipass welding is considered since each succeeding pass tends to age, overage or resolution the aging constituents in the heat affected zone until predictable behavior becomes impossible to estimate.

It can be seen, therefore, that a delicate balance exists between metallurgical weld quality and welding procedure for the heat treatable aluminum alloys. Although the quench effect present in connection with the single pass welding of heavy plate is a definite factor in abstracting heat from the weld heat affected zone and thus minimizing grain growth, the effects of multipass welding on metallurgical changes in the weld heat affected zone are largely unknown.

It has been shown that sound single pass welds can be produced in the 1-1/4 - 2-1/8 in. thickness range. The predictable behavior of a single pass weld makes it possible to vary welding parameters to accomodate the metallurgical characteristics of the Aluminum 2014 metal alloy. For thicker plate (4 in.), multipass welding is a requirement regardless of the techniques used. For these heavier plates, definite weld and heat affected zone property deterioration should be expected. The less optimum metallurgical characteristics of these multipass welds can be minimized somewhat by providing weld reinforcement at the joints and imposing a high temperature aging treatment on the alloy such that a more ductile matrix would be provided in the heat affected zone.

A final area of concern relates to repairs imposed on the completed weldment. Data related to repeated repair welds of heat treatable alloys in thick plate are extremely limited. Reference is made to recent work of F. G. Nelson of Alcoa Research Laboratories relating to repair welding of the 6061-T6 alloy. In this work, repairs were made in welded 3/4 in. plate using a manually held MIG torch. The 6061-T6 test panels were prepared with a 60° single-V bevel using a 1/8 in. land. The panels were joined using 5356 filler wire using two passes to complete the "V" and a single pass to complete the weld after back chipping. The welded panels were allowed to cool to room temperature with no post weld heat treatment. To simulate a weld repair, the face weld was chipped out to a depth of 1/2 the plate thickness. The groove was filled in one pass with no subsequent thermal treatment. Subsequent test panels repeated this procedure up to a total of six repairs on a single panel. Results shown in Figures 2 through 5 indicated that the tensile properties, or widths of the heat affected zone are not significantly affected by the number of times the panels are rewelded. The effect of the heat of welding did not extend more than 1-1/2 in. from the weld centerline regardless of the number of rewelds. It is apparent from these data that sound repair welds can be made without significantly extending the width of the heat affected zone but little can be deducted from this data relative to the effect of such repairs on the metallurgical characteristics of the higher strength heat treatable alloys. These effects would be similar in nature to those encountered in multipass welding.

TABLE II

HEAVY PLATE WELDING PRACTICE AT LINDE

Alloy	Filler Wire	Wire Dia.	Plate Thick-ness	Procedure	No. of Passes	Amperes	Volts	Weld Speed IPM	Wire Speed IMP	Shield-ing Gas	Remarks
5356	5356	1/8 in. or 3/32 in.	1/2 in.	Auto MIG	1	450	25	14-15	125 210	Argon - 100 cfh	Sq. butt joint-Tungsten are cut or sheared with edges filed.
		1/8 in. or 3/32 in.	1 in.	Auto MIG	2	500	25-26	10-12	135	Argon - 100 cfh	Sq. butt joint-Tungsten are cut or sheared with edges filed.
		1/8 in.	1 1/4 in.	Auto MIG	2	550	26	8-10	145	Argon - 100 cfh	Sq. butt joint-Tungsten are cut or sheared with edges filed.
		9/64 in.	1 1/2 in.	Auto MIG	2	590	26	8	130	Argon - 100 cfh	Sq. butt joint-Tungsten are cut or sheared with edges filed.
6061	4043	3/32 in.	1 1/4 in.	Auto MIG	2	400	27	6-8	--	Argon - 100 cfh	3/8 in. chamber on butted edges - 6 in. run-off pads.

TABLE III

HEAVY PLATE WELDING PRACTICE AT KAISER

Alloy	Filler Wire	Wire Dia.	Plate Thick-ness	Procedure	No. of Passes	Amperes	Volts	Weld Speed IPM	Wire Speed IPM	Shield-ing Gas	Remarks
5083	5183	5/32 in.	1 in.	Auto MIG	1st Side 2nd Side	450 500	28 28	10 10	78 88	Argon - 100 cfh	Double "V" 70°, Land 3/16 in.
5083	5183	3/16 in.	1 in.	Auto MIG	1st Side 2nd Side	500	26.5 26.5	12 12	63 63	Argon - 100 cfh	Double "V" 70°, Land 1/8 in.
5083	5183	7/32 in.	1 1/2 in	Auto MIG	1st Side 2nd Side	650 675	27 27.5	8 8	75 80	Argon - 100 cfh	Double "V" 70°, Land 3/16 in.
5083	5183	7/32 in.	2 in.	Auto MIG	2 passes each side	600 600 600 600	26 28 30 30	10 10 10 10	65 65 65 65	Argon - 100 cfh	Double "V" 70°, Land 1/8 in.
5083	5183	3/16 in.	2 in.	Auto MIG	2 passes each side	550 550 550 550	31 33 32 33	10 10 10 10	80 80 80 80	75% He-25% Argon Total of 120 cfh	Double "V" 70°, Land 3/16 in.
5083	5183	3/16 in.	3 in.	Auto MIG	1 and 2 3 and 4 5 and 6 7 to 12 (Total 12)	600 500 625 600	25 23 26 27	9 11 9 9	94 63 101 94	25% He-75% Argon Total of 100 cfh	Double "V" 70°, Land 1/4 in.
5083	5183	7/32 in.	3 in.	Auto MIG	1 and 2 3 to 6 (Total 6)	650 650	29 31	10 10	75 75	75% He-25% Argon Total of 120 cfh	Modified "U", 1/4 in radius on bottom, 30° included angle, 1/2 in. Land Welding Procedure applicable to 5456 plate with 5556 filler and EC plate with 1100 filler.

Table III

TABLE IV

HEAVY PLATE WELDING PRACTICE AT CHICAGO BRIDGE AND IRON

Alloy	Filler Wire	Wire Dia.	Plate Thick-ness	Procedure	No. of Passes	Amperes	Volts	Weld Speed IPM	Wire Speed IPM	Shield-ing Gas	Remarks
5083	5556	1/8 in.	1 in.	Auto MIG	1 pass each side	400-450	25-27	10	70-90	Argon - 100 cfh	60 to 70° inc. angle, "V", 1/4 in. Land
		5/32 in.	2 in.	Auto MIG	3 passes each side	450-480	25-27	10	70-90	Argon - 100 cfh	60 to 70° inc. angle, "V", 1/4 in. Land
		5/32 in.	3 in.	Auto MIG	4 passes each side	450-500	25-27	9-10	70-90	Argon - 100 cfh	60 to 70° inc. angle, "V", 1/4 in. Land (experimental)
											Also welded 5456 2" plate with 5556 filler wire.

TABLE V

IMPORTANT ALUMINUM EUTECTICS ASSOCIATED WITH 2014 ALLOY

Eutectics	Temperature
AL-$CuAl_2$-Mg_2 Si	965°
AL-$CuAl_2$-$CuMg_2$ Si_4Al_4	970°
AL-$CuAl_2$-Si	977°
AL-$CuAl_2$	1018°
Solution Treatment Range	925° - 945°

TABLE VI

EFFECT OF MATRIX HARDNESS ON THE DUCTILITY OF WELDED 2014 ALUMINUM ALLOY (1)

Samples Tested	Alloy	Filler Wire	Post Weld	UTS	Ultimate Strength	Elongation, % Max.	Elongation, % Min.	Elongation, % Aver.
12	2014-T6	2319	None	43.6	27.7	6.0	3.0	5.0
10	2014-0	2014	T-4	62.1	37.5	15.0	8.0	12.0
32	2014-0	2014	T-6	58.9	61.8	11.0	1.0	5.5
10	2014-0	2319	T-6	69.7	62.5	9.0	2.0	2.5
9	2014-0	4043	T-6	65.8	60.0	3.0	2.0	2.5
15	2014-T6 (Base Metal Properties)			67.5	46.5	19.0	14.0	16.0

Bend Properties

Samples Tested	Alloy	Filler Wire	Post Weld	Bend Radius	Bend Angle-Degrees Max.	Bend Angle-Degrees Min.	Bend Angle-Degrees Aver.
12	2014-T6	2319	None	ST	41	16	23
9	2014-0	2014	T-4	ST	60	60	60
36	2014-0	2014	T-6	ST	60	3	13
20	2014-0	2319	T-6	ST	42	3	14
12	2014-0	4043	T-6	ST	49	9	18

Bulge Properties

Samples Tested	Alloy	Filler Wire	Post Weld	Test Pressure Max.	Test Pressure Min.	Test Pressure Aver.	Bulge Height, Inches Max.	Bulge Height, Inches Min.	Bulge Height, Inches Aver.
6	2014-T6	2319	None	2250	1456	2030	.56	.38	.50
3	2014-0	2014	T-4	4000	3200	3750	.62	.62	.62
12	2014-0	2014	T-6	3150	750	1390	.50	.12	.31
12	2014-0	2319	T-6	3850	1250	2530	.56	.31	.50
2	2014-0	4043	T-6	2800	2700	2750	.56	.38	.50

(1) Boeing Data

TABLE VII

EFFECT OF SHORT TIMES AT ELEVATED TEMPERATURE ON SOME PROPERTIES OF 2014ST6 ALUMINUM ALLOY

Time (Secs)	Temperature °F 500	600	700	800	900	940	1000
	Hardness R_F Immediately After Quenching						
2	103	103	102	98	96	95	92
4	103	103	98	89	85	80	80
8	103	98	91	81	79	79	79.5
10	103						
15				77	78	79	80
16	102.5	94.5	85				
30		94	78	76	78	80	80
32	101.5	93	78				
60	100	91.5	75	76	79	80	81
120	100	87	73	73	78	80	80
	Six Weeks After Quenching						
2	103	103	102	100	97	97	97
4	103	103	98	93	93	94	94
8	103	98	91	91	94	94	97
10	103						
15				90	95	95	97
16	102.5	94.5	85				
30		94	78	90	95	96	97
32	101.5	93	78				
60	100	91.5	75	89	96	96	98
120	100	87	73	88	96	98	98.5

Typical Properties

14ST6 940°F H_2O Quench + 8-12 Hrs at 340°F

UTS	Y.S.	Elong	Hardness BTU	Hardness RF
60-70	53-60	7-13	135	103

PART 4

OPERATIONAL PLAN

I. SUMMARY - OPERATIONAL PROCEDURES

The operational procedures for the Sea Dragon system are divided into four major categories: transportation, assembly and checkout, propellant servicing, and launch site operations. An operational flow chart defining these functions sequentially is shown in Figure 4-0. The assembly, servicing, and launch operations will be in the vicinity of Cape Canaveral as shown in Figure 4-1. The major operational categories are discussed below:

A. TRANSPORTATION

The Sea Dragon vehicle system components will use conventional transport practice. Smaller parts such as the vernier engines will be shipped by land or air transport; larger parts, such as expandable nozzle sections, by barge, and the major items, such as the stages or the assembled vehicle, by tug tow of the free floating item. The free floating and barge tow techniques are present day practice in the transport of tanker sections of Sea Dragon size. For example, two 4200 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.

B. ASSEMBLY AND CHECKOUT

Final vehicle assembly and checkout operations will take place in a specially dredged lagoon in the Cape Canaveral area (Figure 4-2). Stage 1, the stage 2 and payload section, and the ballast unit will be assembled here using a floating assembly technique (Figure 4-5, 6, 7). The various components will be kept under tight control with mooring cables and brought together in the assembly lagoon. Two major joints - ballast to stage 1 and stage 1 to stage 2 - will be made after joining.

I, B, Assembly and Checkout (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; this plus proper design should ensure accessibility of transducers, line runs, valves, and other similar items. If necessary, the vehicle 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 (TM) monitoring will be initiated. This monitoring will function continuously through the launch operations.

C. PROPELLANT SERVICING

After proper system operation has been verified, the vehicle will be towed to the fueling point (See Figure 4-2). It was decided to fuel the vehicle (LH_2 and RP-1) first because of tankage design and because it was felt that the handling of the LH_2 would be easier under more controlled conditions. There are arguments such as reduced LH_2 boiloff and better towing characteristics that could be made for LOXing first, a final decision should be closely related to vehicle design. After chilldown and fueling operations are completed, the vehicle will be towed to Point Bravo (Figure 4-1) where the LOXing vessel is moored. The vehicle will be kept under close translational control by mooring lines during the LOXing operations. After LOX tanking is completed, the vehicle will be towed to Point Able.

I, Summary - Operational Procedures (cont.)

D. LAUNCH SITE OPERATIONS

After arrival at the launch site, final systems checks are made. By use of relatively small amounts of insulation (1% of S_I inerts, 5% of S_{II} inerts) it is possible to eliminate the need for any propellant topping operations for three days after LH_2 tanking. This is possible because the tanks are loaded with LH_2 that has been stored at atmospheric pressure. Since all propellant tanks are maintained at higher than atmospheric pressure, the propellant is no longer in saturated equilibrium and it requires roughly three days for the LH_2 to gain sufficient heat so that it is in equilibrium at the higher pressure. This period can of course be extended by use of additional insulation.

After all systems are verified, the ballast unit is gradually filled with 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 pounds.

Historical data shows that the vehicle should be able to function efficiently in sea conditions up to state 5 (wind velocity 20-25 knots, wave height 8-12 ft) to ensure a 95% operational capability. Under these conditions, the vehicle is very stable-maximum pitch amplitude 0.17 degrees, maximum heave amplitude 3 ft.

Access to the vehicle is accomplished from the service craft (Figure 4-3). The small access car rides on rails permanently affixed to the side of the vehicle. It can carry men and equipment to any of the above water portions of the vehicle including the command module. Any final checkout requirements and crew loading or debarking is accomplished with this device.

I, D, Launch Site Operations (cont.)

After the crew has boarded the vehicle and all systems are "Go," the service craft will withdraw to a safe distance. The larger launch control vessel has previously withdrawn to its launch station; this vessel monitors all systems to ensure flight readiness and maintain overall control of the launch operation. When the service craft reaches its station, the final countdown is completed and the vehicle launched.

E. POST-FIRE RECOVERY OPERATIONS

The ballast unit will be staged from the vehicle during the underwater trajectory. It will sink to the bottom; from there it will be recovered by inflating attached flotation bags.

The stage-one vehicle will impact downrange approximately 170 miles. It will be picked up by a tug in the vicinity and returned to the assembly lagoon for refurbishment.

II. OPERATIONAL SUPPORT SYSTEM AND GENERAL SUPPORT SYSTEM PHILOSOPHY

To establish the most feasible and economical combination of equipment, facilities, and manpower essential for the support of the Sea Dragon Vehicle, a study was made of all vehicle operational requirements and solutions evolved to satisfy them. The hardware and techniques configured, although not entirely common to the aircraft/missile industry, were found to be within the state of the art or requiring minimum development.

II, Operational Support System and General Support Sytem Philosophy (cont.)

In keeping with the vehicle system objectives, emphasis was placed on economies in cost and manpower, and high reliability through relatively simple techniques and low performance requirements.

The sequence of events or functions required of the support system from the factory through launch and refurbishment of the Sea Dragon are depicted in Appendix 4-1. The requirements for equipment, facilities, and manpower are also included. Appendix 4-2 relates the essential equipment and manpower to these functions or events.

In that the ocean is not considered a foreign environment to the vehicle, and its size and weight make land transportation and handling impractical, the towing of floating stages or the complete vehicle for transportation and assembly was pursued.

To preclude the necessity of having stage/vehicle control, monitoring and checkout equipment at every area where activities are performed, a service craft or vessel incorporating these features will be employed in both the assembly and launch areas. The craft will be mated to the vehicle during the assembly of the vehicle and will then remain tied to the vehicle via hardline until well into the countdown. For calibration purposes, the craft will also provide a secondary data link to the launch control vessel. The unique feature of this test, monitor and control system is that it will provide a continual surveillance of vehicle systems status during both ground and flight operations using the same onboard computers. Additional systems for monitor and control will be provided at the facilities but this will be only for a safety requirement and will be held to a minimum.

III. OPERATION AND MAINTENANCE PLAN

A. TRANSPORTATION AND HANDLING

For purposes of coping with the most severe condition of transportation, it was assumed that the vehicle stages and payload were fabricated on the west coast and required transportation to the Cape Canaveral assembly area. Noteworthy is the fact that the recovery and refurbishing of the Stage I and ballast units lessens the number of Stage I units to be delivered to the assembly area, and so dictates the transportation of the individual stages rather than the complete vehicle.

The manufacture of the separate stages and payload is expected to include final quality control and acceptance testing. The installation of all gear that will be required to protect the vehicle from salt water damage during the trip from the manufacturing area to the assembly area will be installed prior to floating the stages. This gear will consist of plastic closures or covers sealed to the injectors and any access ports and, in the case of the Stage I without the ballast unit, the nozzle support equipment will be installed.

1. Stage I

The stage will be ballasted with distilled demineralized water and towed in the free floating condition nose first. Several other methods were considered for providing ballast such as use of a detachable keel, but the water method appeared the most attractive. A liquid can be transferred easily and rapidly and the cheapest liquid is water. Additional study of coupling and sloshing effects is mandatory before a final selection is made.

III, A, Transportation and Handling (cont.)

Since the LOX tanks have been cleaned prior to acceptance, hydrocarbons must not be admitted into the tankage or the tanks will require a complete cleaning process. Because of this requirement, distilled demineralized water will be used. The distillation test plants in operation have proven the feasibility of obtaining distilled water from sea water at a relative low cost. Provisions to transfer the water ballast between tanks, (RP-1 and LOX) and ballast unit, and to vary the total quantity will enable the towing attitude, stage sail effect and pitch stabilization to be varied with sea conditions. Towing will be accomplished from the interstage structure to take advantage of the bow effect of the stage dome. Tank pressurization will also be provided to increase the structural rigidity and to prevent sea water from entering the vehicle. The monitoring and control of the pressurization and water ballast will be accomplished from the tow craft.

The stage will be fitted with either a deliverable launch ballast unit or a nozzle support assembly to provide support and protection to the thrust chamber during transit and especially while negotiating the Panama Canal locks. Because of the extreme aft center of gravity, flotation bags will be employed in conjunction with either unit to minimize the quantity of water ballast needed for proper towing attitude and the towing draught.

To orient the cylindrical stage in roll and to provide an acceptable degree of positive roll stability during towing, sponsons will be attached within the tangents of the cylinder diameter. The sponsons will be attached to the stage handling belts by cables and shall be physically held away from the stage by a 6 in. layer of foam. Using half cylinders of a 6 ft radius will place the metacenter approximately 48 ft above the center of buoyancy. The sponsons will be approximately as long as the stage tankage and will act as a protection device on the stage.

III, A, Transportation and Handling (cont.)

These sponsons will be attached when the stage is first placed in the water and then adjusted for proper positioning by the tie cables. The sponsons will contain the pumping unit required to transfer ballast in the stage. Electrical power and control will be either self contained or provided by the towing vessel. (See Figure 4-4)

Another method mentioned earlier would utilize an attached keel to provide roll control. This method was finally rejected because of the costs involved, underwater handling problems and canal transportation because of depth limitations in the locks. Additionally, the sponsons will provide stage protection while the keel would not.

In keeping with maritime law, the towed stage will be fitted with navigation and safety devices controlled from the tow craft. Provisions will also be made for an onboard stage pilot through the Panama Canal.

On the basis of large tow experience, where two (2) 4200 metric ton tanker bodies, 366 ft long, 80 ft in beam and 44 ft overall height with a 7 ft draft, were towed from Japan to the United States at 4-1/4 knots average speed using a 3500 hp tug, the transportation of the stage from San Francisco to Port Canaveral (4700 miles) may require 50 days. Tow costs for such an operation average $1500 per day, thus transportation of the stage would cost approximately $75,000 plus Panama Canal fees. Additional minor cost would be incurred for harbor tug aid in entering and departing the canal area and for aid in entering the Cape Canaveral Assembly Area.

III, A, Transportation and Handling (cont.)

2. Stage II and payload

The basic stage II and payload tank will be joined and then transported in essentially the same manner as Stage I. The stage II vernier engines will, however, be removed, packaged in containers and transported by highway or rail. The four (4) section expandable nozzle will be loaded aboard a standard sea going hopper barge and transported as a part of the Stage II/ payload tow train. The payload service module equipment that may be readily susceptible to deterioration or damage from the sea transportation environment will be packaged and shipped by land rather than being installed. A closure will be installed over the forward end of the payload to protect the payload service module plumbing and wiring from the elements during transit.

3. Command Module

Considering that a command module similar to "Apollo" is anticipated, the same transportation method would be appropriate for the Sea Dragon as is required for the Saturn C-5.

4. Assembled Vehicle

The complete vehicle with its launch erection ballast unit will be towed aft end first by the ballast unit in a free floating condition to the propellant loading areas and to the launch site.

To obtain an acceptable vehicle trim or towing attitude following propellant loading, control will be provided by the flotation characteristics of the ballast unit and associated flotation bags. No internal ballasting will be used because of the cleanliness requirements of the tanks prior to propellant loading.

III, A, Transportation and Handling (cont.)

Roll stabilization of the entire vehicle will be provided by the stage-II sponsons only. Positioning of the sponsons with the various vehicle depths and attitudes associated with propellant loading will be accomplished to aid in obtaining an acceptable aft towing attitude.

No marine navigation or safety devices need be carried aboard the complete vehicle in that all transportation will be accomplished within the AMR danger area.

Vehicle systems monitoring and control will be maintained by the accompanying service craft that was mated to the vehicle instrumentation and control systems during final assembly and checkout.

B. ASSEMBLY

The vehicle assembly problem is basically one of aligning and mating the first and second stage and the rotation of the stages or complete vehicle for exterior component installation. To help lower costs, a floating assembly technique employing stage transportation ballasting features and a network of drilled-in anchors, mooring cables and winches appears to be the most feasible. (Figure 4-5, 6, 7)

Another method that was considered was the use of a floating dry dock. The stages would be towed into the dry dock that has been fully submerged, positioned over rail-mounted cradles, and then the drydock drained. The stages would then be drained of ballast water and checked. After a complete checkout, the cradles would be moved together and the stages mated. Final assembly of the vehicle would be completed and the drydock reflooded. While this method is quite feasible, it appeared to be more expensive, and therefore not studied in detail.

III, B, Assembly (cont.)

The assembly will take place with the stages floating in protected waters of a lagoon adjacent to a wharf and will consist of slowly drawing the stages together for joining. Employing a portion of the same winching arrangement, the vehicle will be rotated in a controlled state for installation of the exterior components such as the expandable nozzle segments and vernier engines. A wharf crane will be used to lower the components into place and for positioning of the command module. Figures 4-5, 6, 7 depict this assembly operation.

There is a possibility that during the last three or four inches of the engagement of these large components it may be prudent to use auxiliary devices for very accurate final adjustment. For example, hydraulic cylinders or turnbuckles may prove useful.

Alignment of the stages presents a problem because of the cross-sectional area of the stages. It is assumed that the stages will be "out-of-round" and thus will require alignment tools to aid in the mating operation. A method that is used satisfactorily on other vehicles is provisioning of taper pins for alignment. This method is feasible since the mating flanges have external bolt flanges around the complete circumference of the vehicle. The stage-I-stage-II joint will have a slight taper ring that will also aid in alignment. Using both the taper joint and taper ring will allow the usage of small hydraulic cylinders to make the final alignment and mating operation. (Figure 4-8)

The final bolting of this joint may occur immediately after engagement or may be deferred until the missile is positioned for controlled rolling.

III, B, Assembly (cont.)

Following the joining operation, the expandable nozzle segments will be lowered in place and attached using the stage-I tanks as the assembly mandrel.

Because of the size and configuration of the nozzle segments, a problem exists in the type of handling to be used. A method of attaching holding rings or hooks must be employed that does not affect the shape of the convolutes or foam support. A possible means would be to fasten large hook pads on the segments by bonding these pads to the foam during the manufacturing operation. An alternative approach would be to use lifting eyes that are fitted into holes drilled into the skirt. Since the external foam covering will not be bonded, the only method now feasible is the use of bolted lifting eyes.

Each section is brazed to a previously installed section after it is placed on the vehicle. Because of the amount of brazing required, a portable automatic brazing unit will be employed (Figure 4-14). The brazing operation will be followed by installing the nozzle support bands, thereby completing the nozzle assembly. The braze will be a sine-wave pattern.

C. TEST AND CHECK

Following vehicle assembly, a complete checkout of the missile system will be performed using both hardline and T.M. verification. Access to the complete vehicle is possible through access ports. If access is required into any pressurized area, a temporary air-lock may be required, depending on the design philosophy followed. Because all control systems are redundant and all indications are both hardline and T.M., system verification can be easily and reliably accomplished.

III, C, Test and Check (cont.)

Because of the modular concept employed and the simplicity of design, components can be readily replaced in case of a malfunction. The complete checkout is to be performed by the service vessel, which minimizes the requirement for extensive land-based facilities. Safety functions will be provided by the facility for any emergency conditon. By accomplishing the complete checkout at this time, little time will be lost if any component malfunction arises. In addition, the equipment on the service craft will help isolate the faulty system, thus speeding the operation. All systems will be functionally actuated except the "one-shot" systems that will be simulated.

The following major systems will be monitored:

1. <u>Stage I</u>

   a. LOX tank temperature and pressure
   b. Fuel tank temperature and pressure
   c. Methane tank temperature and pressure
   d. Valve positions on all tanks
   e. Gimbal actuator pressure and position
   f. Autogenous system pressure and temperature
   g. Thrust Chamber pressure
   h. Voltage and current measurements
   i. Stiff leg-position
   j. Ordnance - safe and arm positions

III, C, Test and Check (cont.)

2. Stage II

a. LH_2 tank temperature and pressure
b. Main LOX tank temperature and pressure
c. TVC LOX tank temperatures and pressures
d. N_2 tank pressure
e. Valve positions on all tanks
f. Valve positions on TVC engines
g. Directional position on TVC engines
h. Thrust chamber pressures - Main and TVC
i. Voltage and current
j. Interstage (transition section) pressures and temperatures
k. Ordnance - safe and arm positions
l. Autogenous temperatures
m. Regulators

3. Payload

a. LH_2 tank temperature and pressure
b. Electrical voltage and current
c. All valves
d. Vehicle attitude

4. Command Module

Because of the complexity of the command module that will contain personnel, the same requirements will exist that exist for the "Apollo" module.

III, C, Test and Check (cont.)

The checkout will be performed by the service craft that was mated to the vehicle during assembly and will remain with it well into the countdown. In that the craft will continually monitor and control the vehicle through the entire operation up to launch, further refinements of calibration and alignment will be readily accomplished; for example, during propellant loading and pressurization.

During the testing, all systems will be completely integrated by a sequencer located on the vehicle, but will provide only a systems "go" or "no-go" indication to the service craft. Under a "no-go" situation, a fault locator aboard the service craft will program the onboard sequencer to transfer to another system or transmit all systems parameters to the fault locator for isolation and manual control.

To facilitate the leak checking of all fluid systems, the facilities at the assembly area will provide the pressurizing gases that will be controlled by the service craft. This direct reading of pressures through a wide range will further aid in the calibration of vehicle instrumentation.

During the checkout the monitoring of pressures, structural loads, temperatures, valve positions, liquid levels, attitudes, electrical power characteristics, and signal strength will be accomplished. Control of valves, vents, ordnance devices, and pressures will also be provided. The calibration and alignment of guidance and telemetry will be performed concurrently with all control and monitoring operations.

III, Operation and Maintenance Plan (cont.)

D. PROPELLANT HANDLING

Because of the explosive hazards presented by liquid oxygen and liquid hydrogen, the loading of these propellants near inhabited areas is not allowable. Neither propellant by itself presents a major problem, but a completely loaded vehicle if accidently detonated could produce an explosion equal to a force greater than 20 kilo tons of TNT. For this reason two separate loading areas are required with the seond area being sufficiently removed from shore installations as to afford an acceptable degree of safety. Because of the greater quantities of fuel required, fuel servicing will be accomplished from shore facilities with the oxidizer being transported by barge and loaded aboard at a remote sea location.

A consideration was made on which propellant would be loaded first. If LOX was to be loaded first, the fuel tanks would require greater pressure to preclude any danger of overpressurizing the tank domes. This would then increase the fuel loading time. Although the actual weight of LOX is greater than the LH_2, the volume of LH_2 required is approximately twice that of LOX. Therefore, to save time and loss of propellant, it was decided to load the fuel first.

1. Fueling Loading

Following complete checkout of the vehicle systems the vehicle with its service craft will be moved to the fueling area near the assembly area. Control of the fuel and pressurant loading equipment will be provided from the service craft to enable vehicle monitoring and control and the fuel loading control to be accomplished at a central control point.

III, D, Propellant Handling (cont.)

Additional controls required for a safety backup will be provided by the fuel loading faciltiy.

During the cooldown and loading operation, the vehicle telemetering instrumentation and computer systems will be tested, calibrated, and aligned against the service craft hardline monitoring systems for various pressures and quantities. The cooldown of the fuel tanks will be a part of the loading operation and will be accomplished by the propellant being used to eliminate any danger of propellant contamination. Because of the great amount of liquid required to chill the tanks, no prechill will be used prior to the actual propellant loading. Adjustments to the vehicle ballast, flotation, and sponson units will be made to maintain an acceptable vehicle trim attitude with the corresponding change of center of gravity.

To reclaim the large volume of gas being released during the cooldown period and to safely vent the gases from the immediate fueling area, the vehicle vents will be attached to the facilities vent system. Upon completion of loading, the facilities vents will be removed and the venting function switched to the vehicle system.

The fueling operation will consist of loading liquid methane and RP-1 fuel into the first stage, liquid hydrogen and gaseous nitrogen into Stage II, and liquid hydrogen into the payload tank. Large quantities of methane, liquid hydrogen and gaseous nitrogen will be required for cooldown and must be included in the storage capacity of the various propellant servicing areas. (See Appendix 4-3 for initial data obtained assuming LN_2 would be used as the chilling agent).

III, D, Propellant Handling (cont.)

2. Oxidizer Servicing

The vehicle in the fueled condition, with its tanks pressurized for structural rigidity, will be towed to the remote oxidizer servicing facility. This facility will consist of a network of drilled-in anchors and mooring cables to which both the oxidizer service barge and vehicle will be attached. Winching the cables from the barge will enable the vehicle to maintain its position relative to the barge, without making contact during oxidizer loading. The service craft will control the oxidizer loading in much the same manner as fueling and will accomplish additional test and calibration of the vehicle telemetering instrumentation and computer system.

The servicing operation will consist of loading liquid oxygen into both the first-and second-stage main oxidizer tanks and the four second-stage vernier engine oxidizer spheres. Additional oxidizer will be required for cooldown during loading since the cooldown is performed as the propellant is loaded. (Figure 4-9)

3. Propellant Tank Topping

Propellant tank topping will not be necessary during normal operation. The reasons for this are given in Appendix O-I. To cope with propellant boil-off from extended "hold" periods of three or more days or losses because of launch site maintenance, vertical or horizontal topping of the tanks will be accomplished by the service craft. For this operation, the service craft will control its own propellant valves while monitoring vehicle tank status by both T.M. and hardline instrumentation. The source of pressurized propellant will be from a barge away from the service craft and feed by means of relatively small, flexible propellant lines. The design could result in a vessel similar to the "Methane Pioneer" which is in service transporting liquid methane at -256°F between Louisiana and England.

III, D, Propellant Handling (cont.)

Depending on the amount of time between loading the propellants and launch, topping of the cryogenic tanks may or may not be required. The LH_2 will undergo a volumetric change and then will have a "boil-off" rate of approximately 5.0%/24 hrs. The tankage has been sized for this change so LH_2 topping will not be required for approximately three days. The LOX tanks are also insulated and the approximate "boil-off" rates are 1.0%/24 hour period. This lower rate on LOX "boil-off" will allow a longer hold time on LOX propellants than on LH_2.

E. PRELAUNCH AND COUNTDOWN

After propellant servicing is completed, the vehicle will be towed to a launch point approximately 40 miles offshore that will be readily located by Loran for exact positioning of the vehicle.

Upon arrival at the launch point, the ballast recovery cables and buoys will be removed from their vehicle storage position and disbursed.

If an extended delay was experienced from the propellant loading area, the cryogenic tanks will be "topped off" from the accompanying propellant storage vessel controlled by the service craft.

Just prior to erection, the "belly bands" securing the roll stabilization sponsons will be removed and moved away. The ballast unit is then flooded on command from a barge liquid source controlled by the service craft and the vehicle slowly erects to the vertical position. During the transition, tank venting is switched from the horizontal to the vertical system to enable tank pressure to be controlled from the service craft.

III, E, Prelaunch and Countdown (cont.)

Following erection of the vehicle, the service craft is positioned adjacent to the vehicle and the protective air bag is inflated between the vehicle and the service craft. This bag is flat and has a non-skid rigid, central surface. It serves two functions:

1. Keeps the service craft from colliding with the vehicle
2. Provides an access platform to the service elevator

The vertical service car is then attached to the elevator rail system. The service car is provided with electrical power from the service craft by a vehicle umbilical cable; (back up power is available on access platforms) and the car is elevated for the removal of the horizontal tank vent lines if they were required.

There are several methods that appear feasible for attachment of the service car. One approach involves the use of a monorail running vertically up the vehicle; two rails may be more attractive, or a guide cable system could be used. The dual rail system has been selected as it appears to offer the best structural, access, and weight approach.

The inflated "fender", used to prevent the vehicle from colliding with the service vessel, will serve as an access area to move between the vessel and the vehicle. The floating fender will be needed because the vessel and vehicle may heave at different rates under some sea conditions.

After lowering the vent lines to the deck of the service craft, the command module crew will be loaded aboard the car and elevated to the capsule portal. With the crew aboard the capsule and external power applied by

III, E, Prelaunch and Countdown (cont.)

the service craft, a combined airborne systems verification will be performed with the service craft calibrating and aligning its T.M. against hardline data. Through a secondary data link system this same calibration and alignment will be performed for the launch control facility or vessel.

With all systems verified, the vertical servicing car will be removed, the propellant tanks commanded to pressurize to flight pressure, which is provided by the service vessel, and the airborne electrical power system activated.

A complete airborne systems check is again performed using its own airborne power supply and vehicle monitoring and control transferred to telemetering.

With the countdown "go" to this point, all service hardlines are disconnected and the service craft is moved a minimum of five (5) miles from the launch point.

Upon command from the crew or from the launch control center, in the case of the unmanned vehicle, guidance and control is switched to flight mode and the ordnance devices are armed. With a launch enabling signal available from the monitor computer, energizing the fire switch will ignite the vernier engines. Ignition of the first-stage engine will follow. When the vehicle is committed to flight, the ballast stiff legs will be moved away from the vehicle skirt just prior to ballast jettison.

In the event a "hold" occurs during countdown, the vertical servicing car can be reinstalled for removal of crew and vertical maintenance. If an "abort" occurs, that is after main-stage ignition, the crew will use the escape system on the capsule.

III, Operation and Maintenance Plan (cont.)

F. MAINTENANCE AND LOGISTIC PHILOSOPHY

To preclude duplicating the shipbuilding facilities and equipment or other elaborate repair and test equipment at the assembly or launch area, maintenance of the Sea Dragon vehicle will be limited to modular or component replacement. Where simplicity has been built into all systems and exercising of these systems has been held to minimums, the need for frequent components repair is not warranted as indicated by experience gained with the later generation ballistic missile systems. Because of the size and massiveness of the components, deterioration, contamination, or disassembly for verification of integrity impose little need for scheduled maintenance or spare parts.

Other than periodic checks of the vehicle to check for salt water corrosion, no schedule maintenance except the refurbishing of the first stage and ballast unit is anticipated. These activities will consist of the replacement of "one-shot" items that require complete overhaul after use or general restoration activities such as the replacement of insulation, wiring, plumbing, connecting structure, or paint.

Unscheduled maintenance as the result of the continuous monitoring or specifically programed testing will be performed both at the launch site and in the assembly lagoon. Launch site maintenance will consist of "black box" or plug in type component replacement above the water level in either the vertical or horizontal position. Assembly lagoon maintenance will include not only the replacement of major and minor components but will involve minor structural

III, F, Maintenance and Logistic Philosophy (cont.)

repairs by welding not involving stress relieving or heat treating. This structural repair would be similar to that performed in the minor repair of ships plates. No large machining operations, fabrication or repairs requiring jigs or fixtures would be attempted.

G. RECOVERY OPERATIONS

Following a successful launch of the Sea Dragon vehicle, both the launch erection ballast unit and the Stage-I assembly will be recovered for refurbishment and reuse.

The ballast unit after separation from the vehicle, will drop to the ocean floor, but will provide surface contact through recovery cables and air hoses routed through marker buoys.

The recovery operation will consist primarily of attaching a service craft air supply to the ballast hoses and inflating the ballast recovery flotation bags. As sufficient buoyancy develops to float the unit, the cables, hoses, and buoys are brought in aboard the service craft or tug and the stiff legs hobbled together in preparation for towing back to the assembly lagoon.

Recovery of the Stage-I assembly will be performed downrange by a tow craft waiting outside of the predicted impact area. Following the venting of the tanks to a safer structural stablilizing pressure that will vary depending on any vehicle damage, and the deflation of the recovery impact bags, a harness will be attached to the interstage structure for towing the stage back to the assembly lagoon. No attempt will be made to ballast the stage but a suitable tow attitude will be achieved through the deflation of the appropriate impact bags. These bags will also provide adequate roll stability through flotation.

III, Operation and Maintenance Plan (cont.)

H. REFURBISHMENT REQUIREMENTS

1. Refurbishment of the ballast unit will consist of replacement of seals, cleaning of tanks, and retesting of the chambers. The flotation bags used for recovery will be tested and repackaged. Because of the awkwardness of the unit, the ballast unit may have to be beached using a ramp for this operation. The complete refurbishment, not requiring major repair, should be approximately $10,000. The only new material required will be for the seals. Distilled water will be used for cleaning the salt water from the flotation bags and tanks. In the event that any major damage has been received by the ballast unit, refurbishment costs will increase proportionally.

Refurbishment of the Stage-I assembly will not require tank supporting devices since 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 obtained through the use of portable air locks.

Because the Sea Dragon vehicle is built to be compatible with salt water, any damage caused by the 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.

III, H, Refurbishment Requirements (cont.)

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 at staging and thus require complete replacement. Sea water will be removed from the injector and other areas that have become contaminated and flotation bags checked and repacked. All refurbishment will be accomplished while the stage is in a floating condition; therefore, complicated and expensive fixtures will not be required. Again, the fact that the sea is not an unfamiliar environment to the vehicle is stressed because this will reduce the amount of maintenance that might otherwise be required.

IV. EQUIPMENT REQUIREMENTS

For this study, all major or vehicle peculiar items are included. All dimensions shown are approximate and may not be applicable to the final design. All equipment is of the present state-of-the-art concept although some modifications may be necessary because of the size of the vehicle.

A. SPONSON UNIT (Figure 4-4)

Sponsons will be used to provide roll control on the vehicle and separate stages during all transportation phases. These sponsons will be compartmented for structural integrity and safety. The sponsons will contain a pumping unit to transfer water ballast between the stage tanks for tow attitude during transportation.

IV, A, Sponson Unit (Figure 4-4) (cont.)

The sponsons are attached to the vehicle or stage by steel cables that are fastened to large belts circling the tankage. The belts are nylon and rubber containing steel cables. These belts and tie cables hold the sponsons firmly in place while allowing easy adjustment of the sponsons for various flotation depths. This adjustment will be made by self-contained winches in the sponsons. A large foam pad will be used between the sponsons and stage. Two sponsons will be used for each stage while the Stage II sponsons will be used for roll stability on the complete vehicle.

Sponson unit length:

Stage I--140 ft
Stage II--180 ft

B. HYDRAULIC MATING TOOL (Figure 4-8)

For the final joining operation between Stage I and Stage II, a means of precise positioning is required to align the mating bolt flanges. Small hydraulic cylinders will be used to pull the flanges together. A tapered guide pin will be used to align the bolt flanges. A number of units can be joined to a common hydraulic supply to allow equal pressure to be applied around the circumference. After the flanges are pulled together, the taper pins can be removed and the bolts installed.

Hydraulic mating tool:

length (expanded)--18 in. between jaws
total length --35 in.
cylinder diameter--3 in.
working pressure--3000 psi

IV, Equipment Requirement (cont.)

C. SERVICE VESSEL (Figure 4-10)

The "service vessel" will be used as a central control, checkout, and launch maintenance craft for the Sea Dragon vehicle. It will not contain a major portion of the checkout equipment of the launch control vessel. This service craft will perform a basic monitoring and service function that will not require extensive equipment. All electrical controls and checkout equipment will be located in a small control room and will provide a continuous, programed check of all conditions and systems of the vehicle from vehicle final assembly until the final launch sequence. The vessel will also provide control capability of the various propellant facilities during vehicle loading operation.

Because of precise positioning requirements of this vessel during vehicle transportation and servicing, the positioning method used in "Project Mohole" and by Shell Oil Co. water exploration vessels will be used. This method requires the use of three power units similar to outboard motors with a 360° rotational capability. Two of these units are mounted near the stern and one near the bow. These power units will allow the vessel to stay in a precise position near the vehicle; additional units may be used to increase reliability. A large, inflatable fender will be provided to prevent the vessel from colliding with the vehicle and also to be used as an access platform for the service car.

The service car will be carried on the service vessel. In the event that vehicle tanks require topping, the service vessel will accept lines from a topping vessel and will provide full control of propellant flow into the vehicle. It will also supply propellant tank pressurization.

IV, C, Service Vessel (Figure 4-10) (cont.)

During vehicle checkout, any error will be registered by the service vessel checkout equipment and will be isolated by a "fault locater" unit on the vessel. Any correction of the vehicle computer will be programmed from this unit.

All access to the vehicle at the launch area will be from this service vessel.

Service vessel:

length--75 ft
beam --30 ft

D. VERTICAL SERVICE CAR (Figure 4-11)

Access to the vehicle while in the vertical position is required. This service car will use a two rail system that is welded to the vehicle and will guide the car. Power will be provided by an electric motor drive, and this motor will be powered by the service vessel through an umbilical cable. The car will have four outrigger inflative bag wheels (4 psi) to provide stability and prevent tipping. Both local and remote control is provided. Failsafe locks will be provided on the drive gear.

Service car:

Length --7 ft
Width --5 ft
Height --7 ft
Capacity--4 persons and 1500 lb

IV, Equipment Requirements (cont.)

E. DRILLED IN ANCHOR (Figure 4-12)

To allow for positioning and joining of the stages during assembly, drilled in anchors will be placed in the assembly area. These anchors consist of a steel rod encased in concrete and buried in the ocean floor. A sheave is attached to the rod at the top and a winch cable is threaded through the sheave. Due to their location in the lagoon, a downward force can be applied to the stages during mating operations if required.

F. EXPANDABLE NOZZLE HANDLING SLING (Figure 4-13)

A special handling sling will be required to lift the expandable nozzle segments. Because of the size of the segments and the operations involved, two slings will be used for each operation. This will allow smaller slings to be used and enable more flexible positioning movements. Six supporting cableswill be attached to each sling for attachment to lifting eyes fastened to the nozzle segment.

Expandable nozzle handling sling:

length --35 ft
width --1 ft
capacity --20,000 lb
construction--truss

G. AUTOMATIC BRAZING UNIT (Figure 4-14)

A methodof brazing the expandable nozzle segments together is a requirement. The thickness of the metal will vary from 0.120 in. to 0.020 in. A welding device similar to the Aeroray brazing gun, although larger, is proposed.

IV, G, Automatic Brazing Unit (Figure 4-14) (cont.)

The unit would propel itself electrically along the seam guided by a knife blade wheel. A thickness-indicating device would be used to automatically control the temperature and depth of the weld. A cam-driven device will allow any weld pattern to be used as required. This cam device will control the brazing head in the horizontal plane.

Automatic brazing unit:

length--18 in.
width --18 in. (widest point)
height--12 in.

H. LAUNCH CONTROL VESSEL

During the actual countdown and launch of the Sea Dragon, all control and checkout will be provided by a telemetry link between the vehicle and a launch control vessel. This vessel will contain all the necessary controls and equipment that would be needed for a land-launched vehicle. An AV 1 - class sea plane tender appears to be an excellent vessel that can be modified to accomplish the necessary functions.

Another method would be to provide a telemetry link between the vehicle and a land-based complex. For this operation, a relay vessel would be required until the vehicle had attained adequate altitude for direct control.

The majority of equipment used for operations will consist of standard available items. Most equipment will be considered as "real property installed equipment." This will include all cranes, wharfs, winches, etc. that are a part of the various actual maintenance and operational facilities.

IV, H, Launch Control Vessel

A second group of equipment will be that equipment used for transportation such as tow tugs, barges, engine containers, etc. This equipment is still considered as standard available equipment and, therefore, is not detailed further.

V. FACILITIES REQUIREMENTS

The facilities requirements will be unique in that all operations take place while the vehicle or stages are floating. Because of this condition, all operations will not be standard to missiles but some will be of the type peculiar to ships. As far as possible, state-of-art methods and facilities are used in all procedures and concepts.

A. ASSEMBLY LAGOON

Because of the method of transportation and handling of the stages and vehicle, an assembly area will be required to allow all operations to be performed on the vehicle while in a floating condition. This area must be protected from major wave action and tide fluctuations to the greatest degree possible. Because of these requirements, a semi-secluded lagoon appears most attractive. Many operations would be performed in this area that would contain all facilities required to assemble, store, checkout, repair, and maintain the complete vehicle and service equipment.

The lagoon area will:

1. Be a minimum of 40 ft deep, 2500 ft long by 1500 ft wide
2. Contain a minimum of three assembly slips
3. Contain one repair dock for Stage I and Ballast refurbishment

V, A, Assembly Lagoon (cont.)

4. Have adequate acceptance, storage, administration, check-out and machine shop facilities
5. Have the necessary transportation system for transporting all required materials.
6. Have all necessary electrical, gas, and water supplies required.
7. Hazardous storage area
8. Fuel servicing area

B. FUEL SERVICE AREA

Because of the quantity of fuels required, the fuel servicing area will be a shore-based facility. LH_2, CH_4 and RP-1 will be loaded and unloaded at this point. Because of the required loading rates imposed, all propellants will be pressure fed during loading operations. Fueling will be accomplished from a wharf, and this area will be located adjacent to the assembly area.

The fuel servicing area will:

1. Be a minimum of 40 ft deep
2. Store a minimum of 1,200,000 gallons of LH_2, 1,500,000 gallons of RP-1, and 85,000 gallons of CH_4
3. Have power facilities capable of providing electrical power needed for loading pumps, vacuum pumps, valves, and winches
4. Provide pumps capable of transferring propellants at the required filling rates imposed by the vehicle.
5. Provide all necessary interconnecting hardware to be used between the facility and the vehicle.

V, B, Fuel Service Area (cont.)

6. Provide the necessary service wharf, winches and tie points to hold the vehicle in position during servicing.
7. Provide an LN_2 and GN_2 system for pressurizing and tank purging.

The LH_2 and CH_4 storage tanks will require insulation. The LH_2 lines used for transfer will require insulation to reduce losses. Because of the high cost of H_2 it is anticipated that the gases vented during the filling cycle will be collected and reprocessed.

C. LOX SERVICE FACILITY

Although the fuel is loaded from a shore facility, the LOX will be loaded at sea from a barge. This will ensure that, in case of any malfunctions, damage will be contained to a restricted area. The barge will be a standard sea-going barge with standard storage tanks mounted on it. These tanks must be capable of storing 2,500,000 gallons of LOX.

The barge will be towed to an offshore point and moored to a series of drill anchors. The vehicle is towed to a point adjacent to the barge and LOX is then transferred (Figure 4-15).

The LOX facility will:

1. Be a stable platform
2. Have an adequate storage capacity for a complete vehicle chilldown and loading
3. Provide the necessary electrical power required for pumps, and valves

V, C, LOX Service Facility (cont.)

4. Have an N_2 pressurization system for tank pressurization and purging

5. Have the required interconnection system for propellant transfer to the vehicle and for unloading the vehicle

The storage tanks will require insulation similar to the LH_2 storage tanks. The barge will be loaded from a shore facility and then towed to the vehicle loading area. Because any reclaiming facility would be more expensive than the LOX, it is not anticipated to attempt to save the gases.

VI. CONCLUSION

The operational support system described in this section is feasible with present day knowledge and capabilities. The facilities and equipment required to meet the support objectives of this plan do not require any significant new developments. The proper engineering application of known techniques should be sufficient to design and bring into being the support system defined.

	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 4-0
Page 1 of 2

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

Operational Flow Chart (cont.)

Figure 4-0
Page 2 of 2

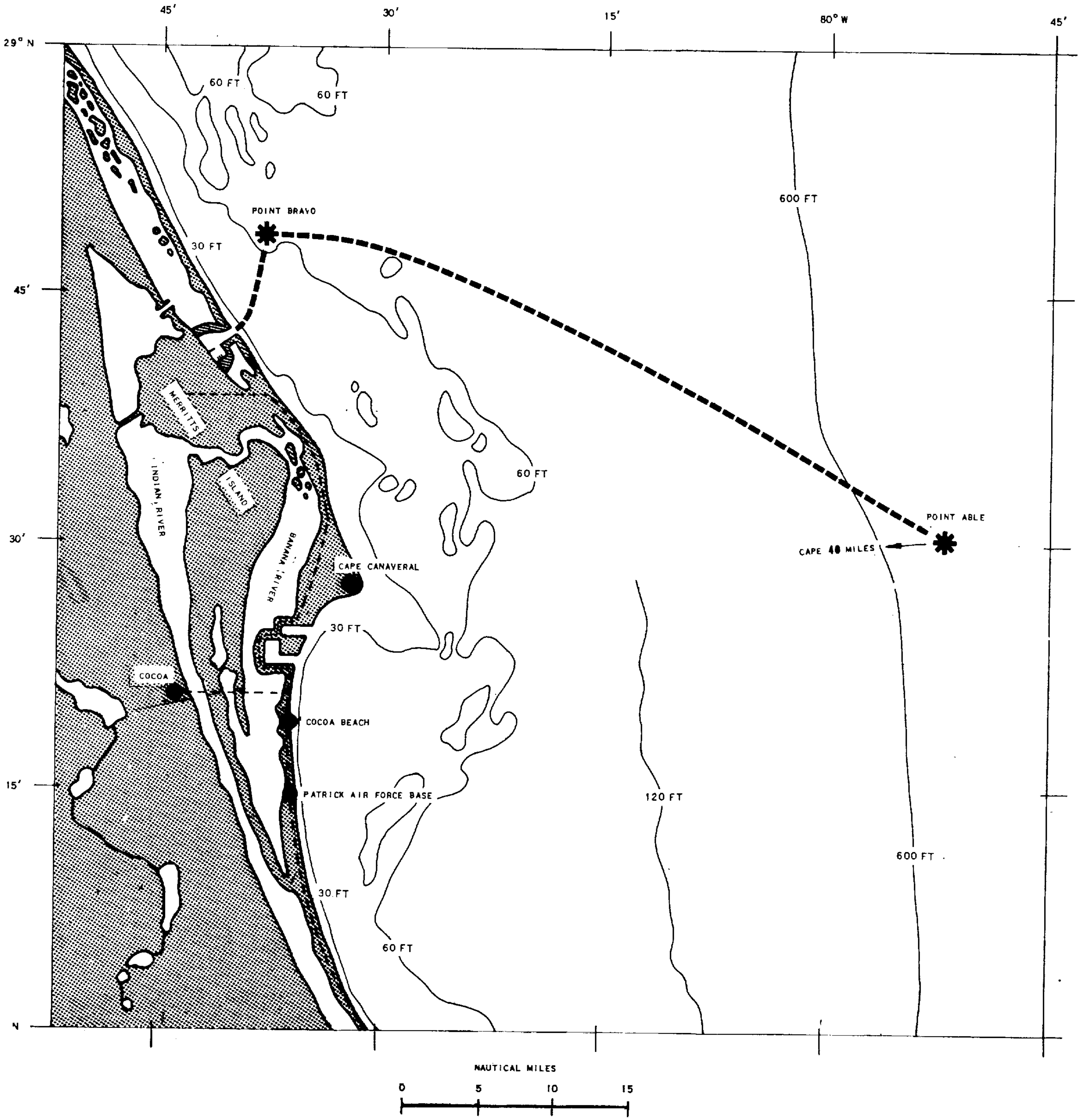
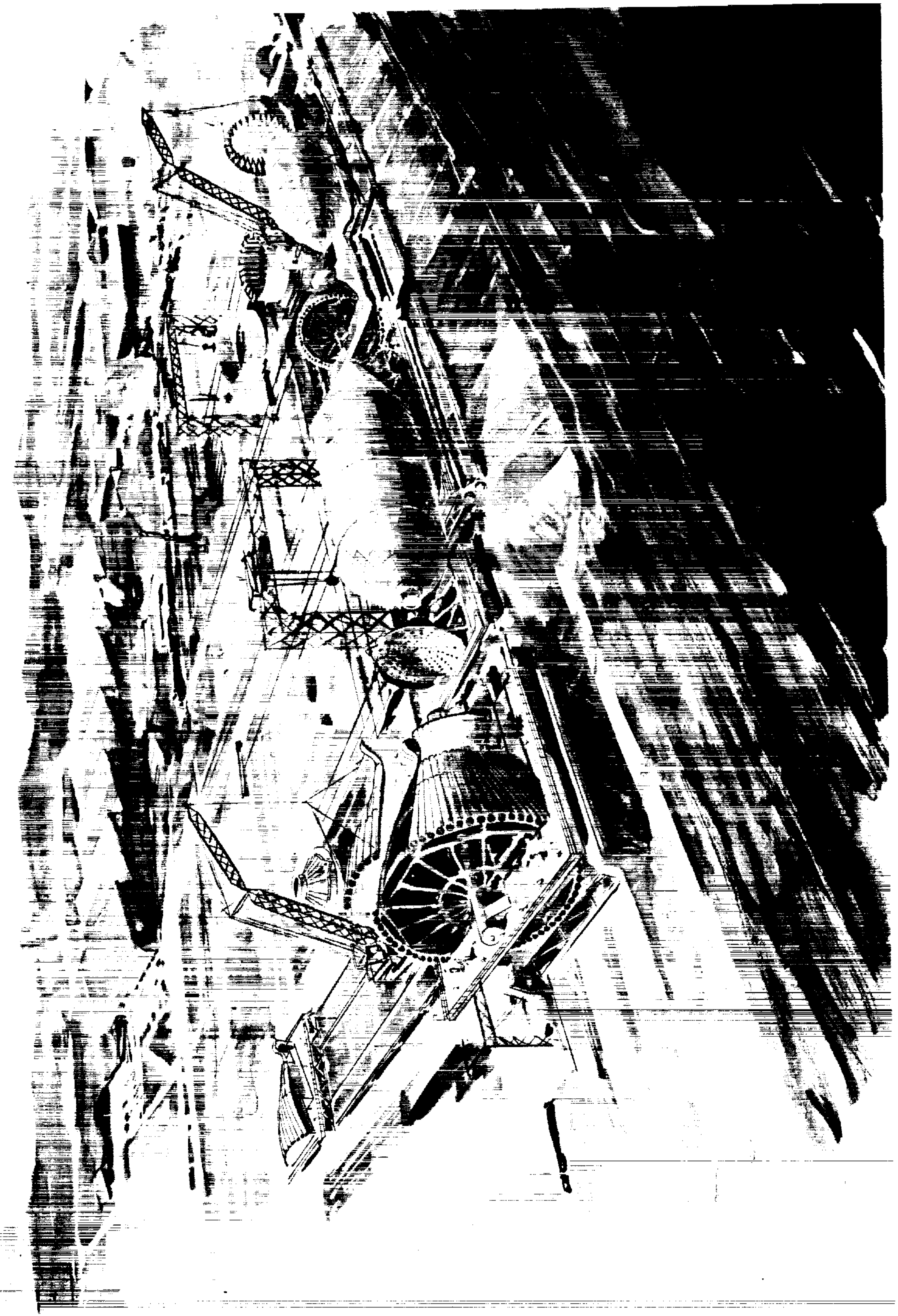


FIGURE 6-7

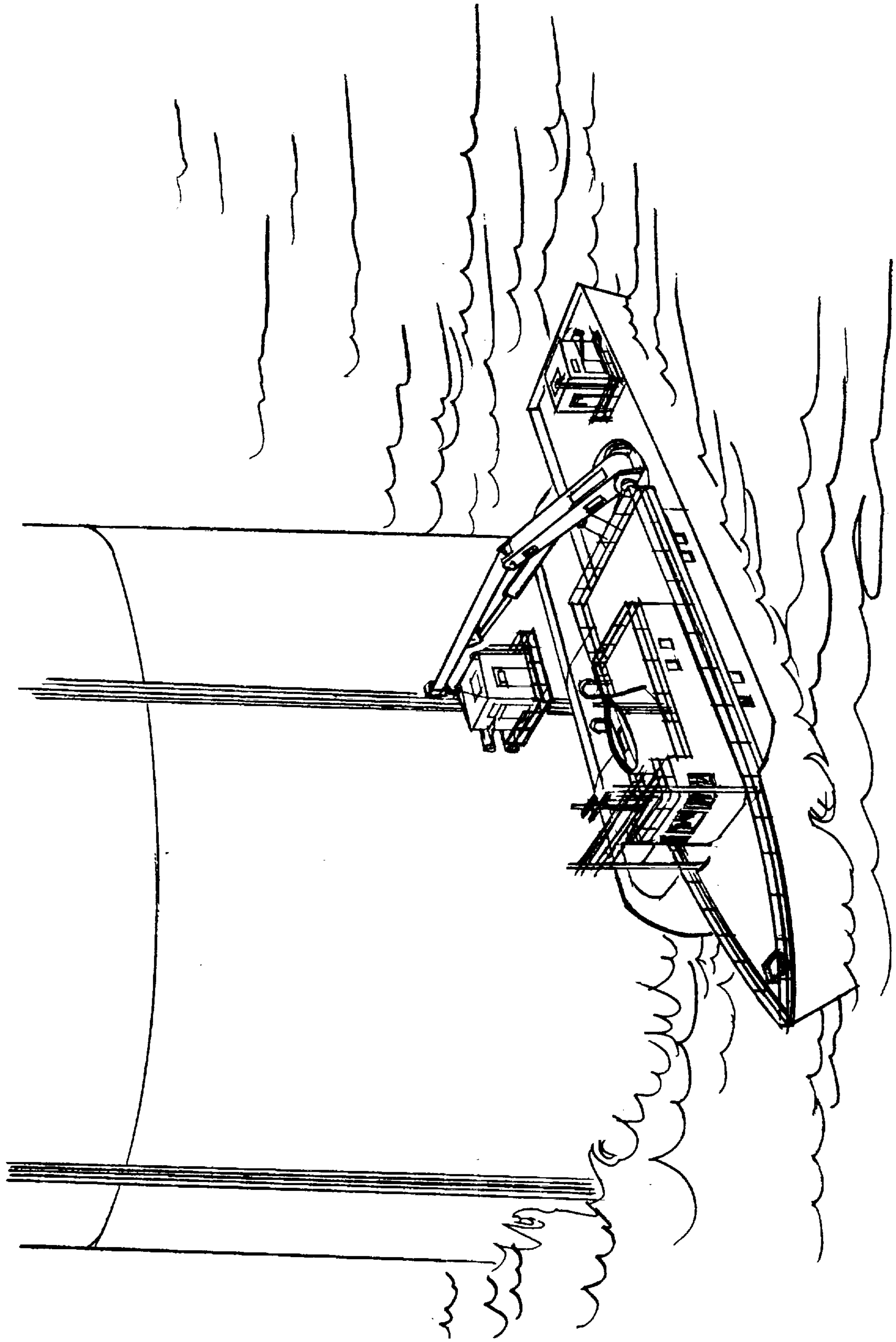
Sea Dragon Operations Area

Figure 4-1



Assembly Lagoon

Figure 4-2



Vertical Access Equipment

Figure 4-3

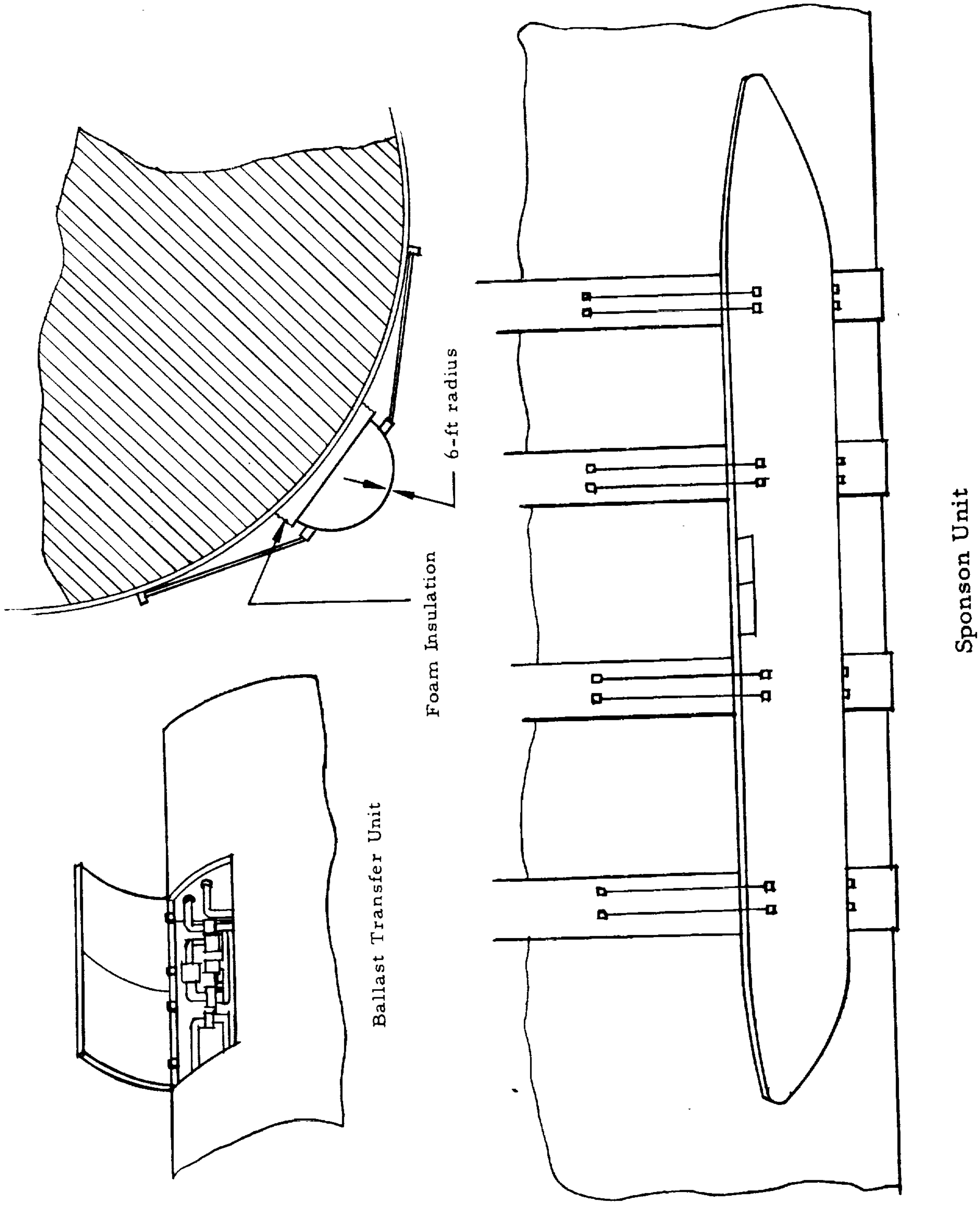
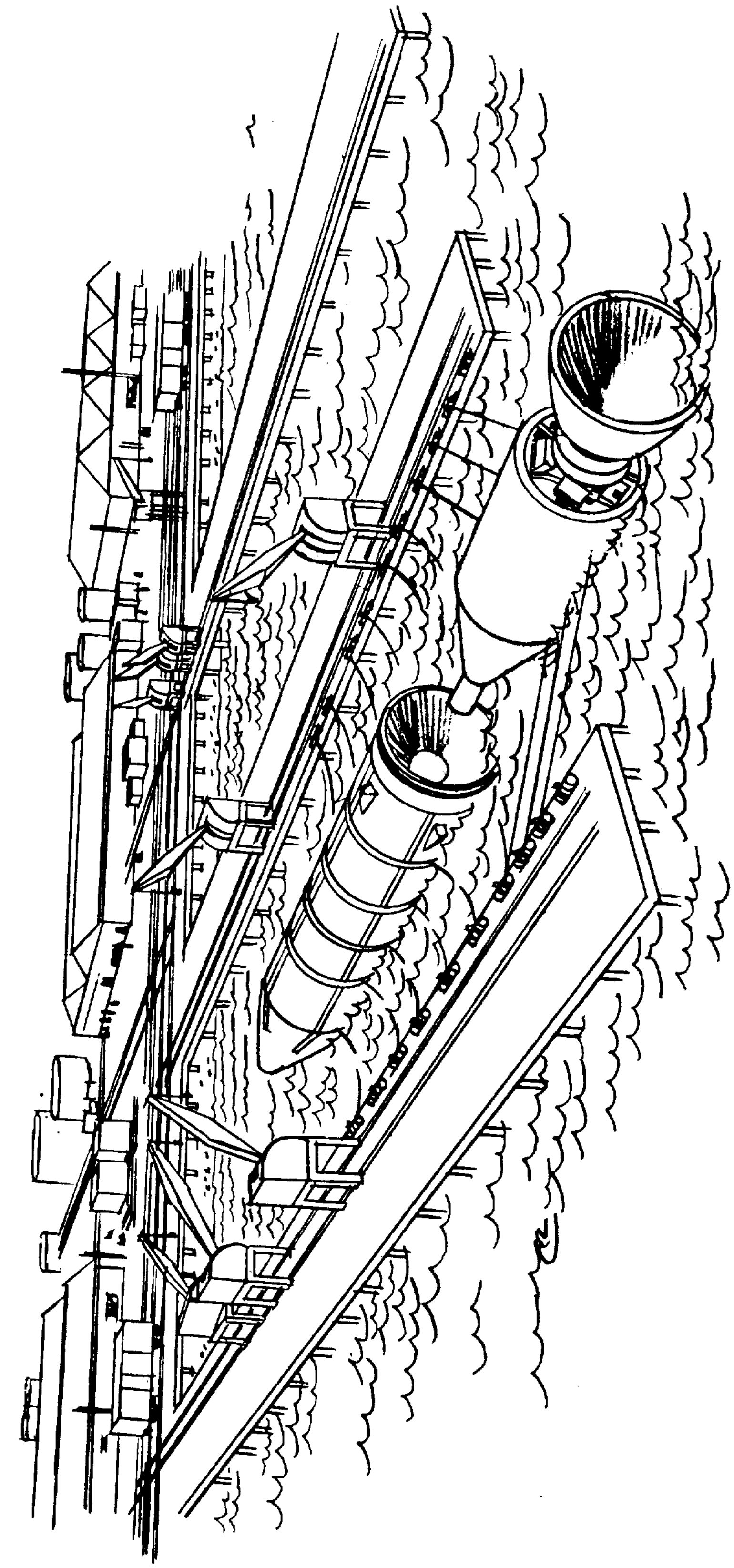
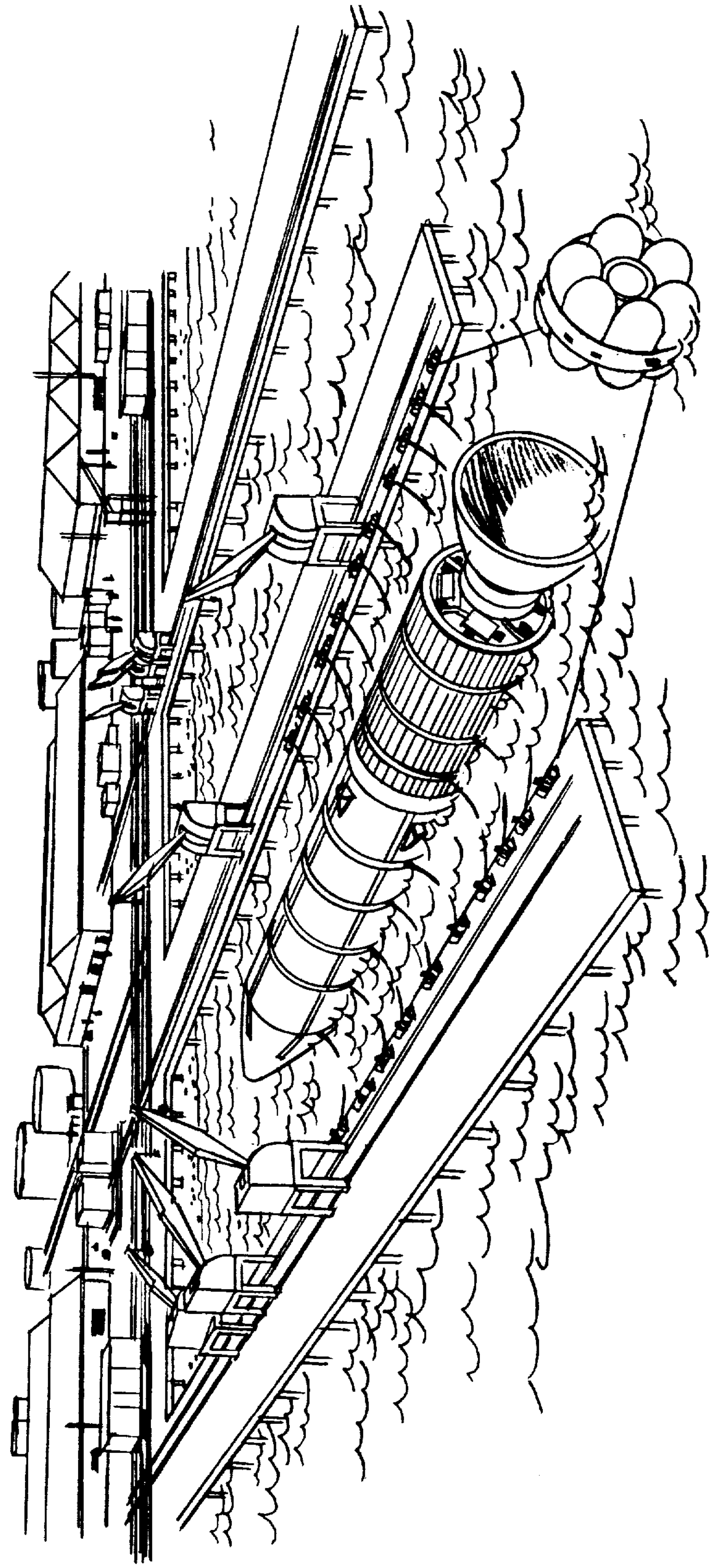

6-ft radius
Foam Insulation
Ballast Transfer Unit
Sponson Unit

Figure 4-4



Stage Assembly

Figure 4-5



Ballast Assembly

Figure 4-6

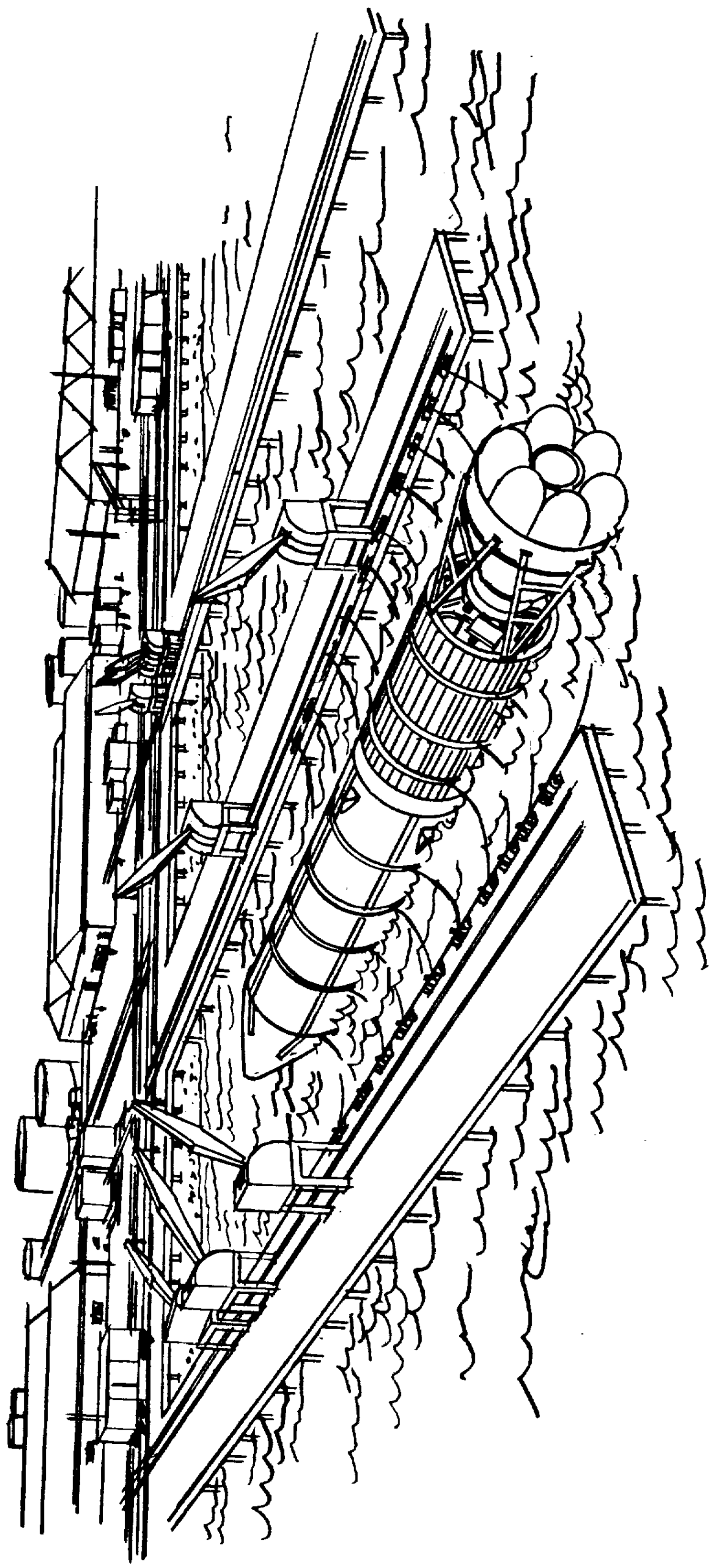
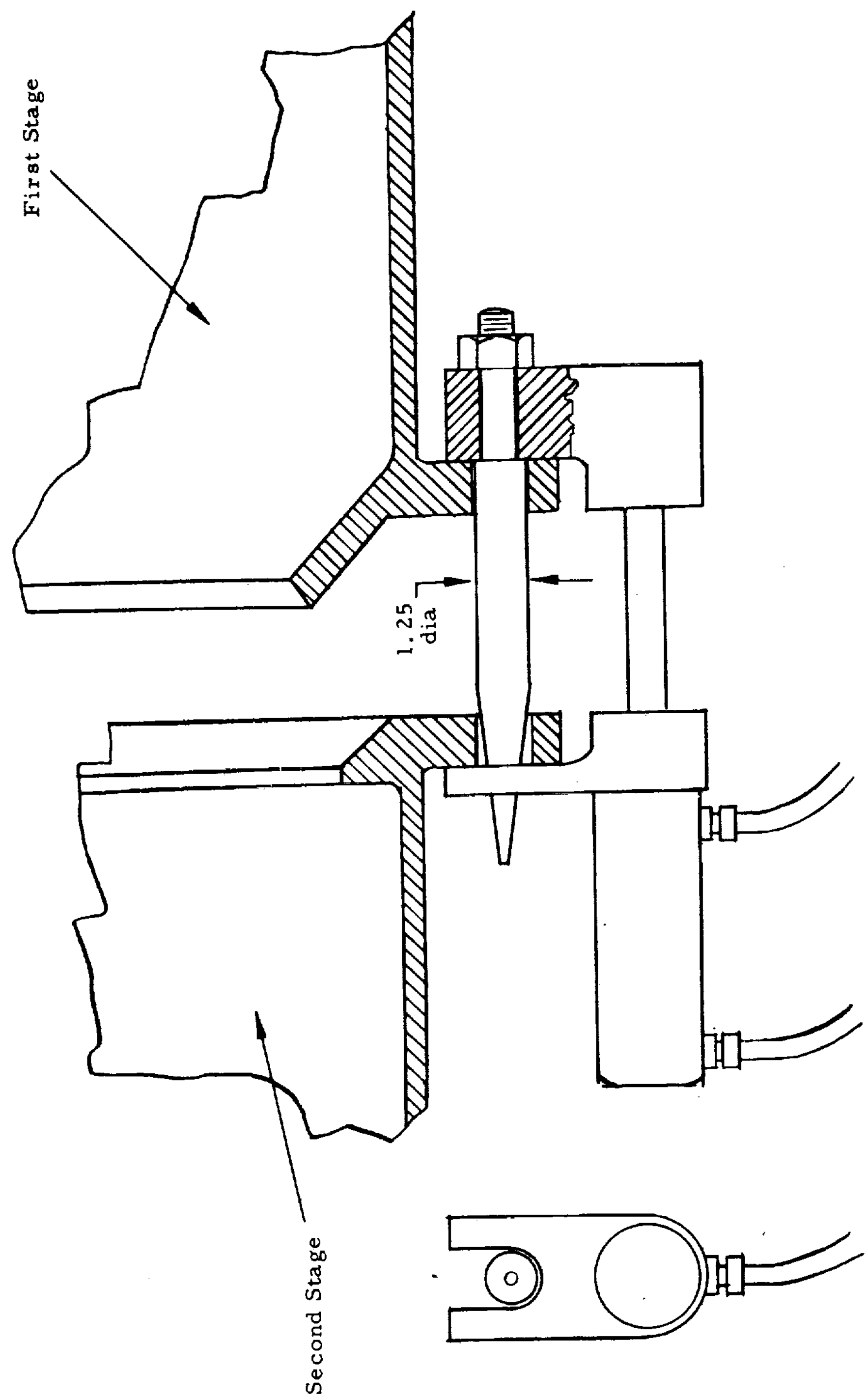


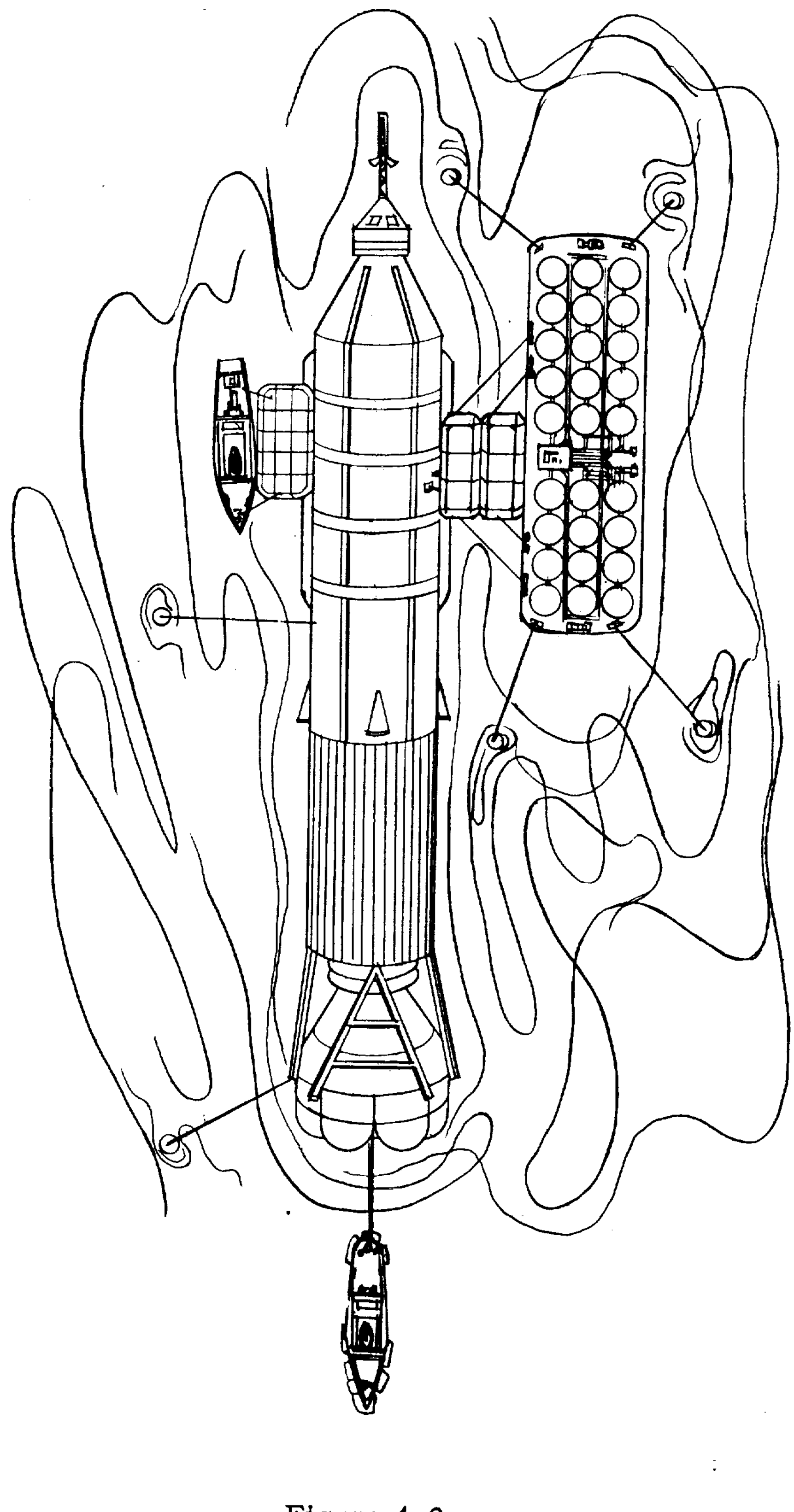
Figure 4-7

Ballast in Place



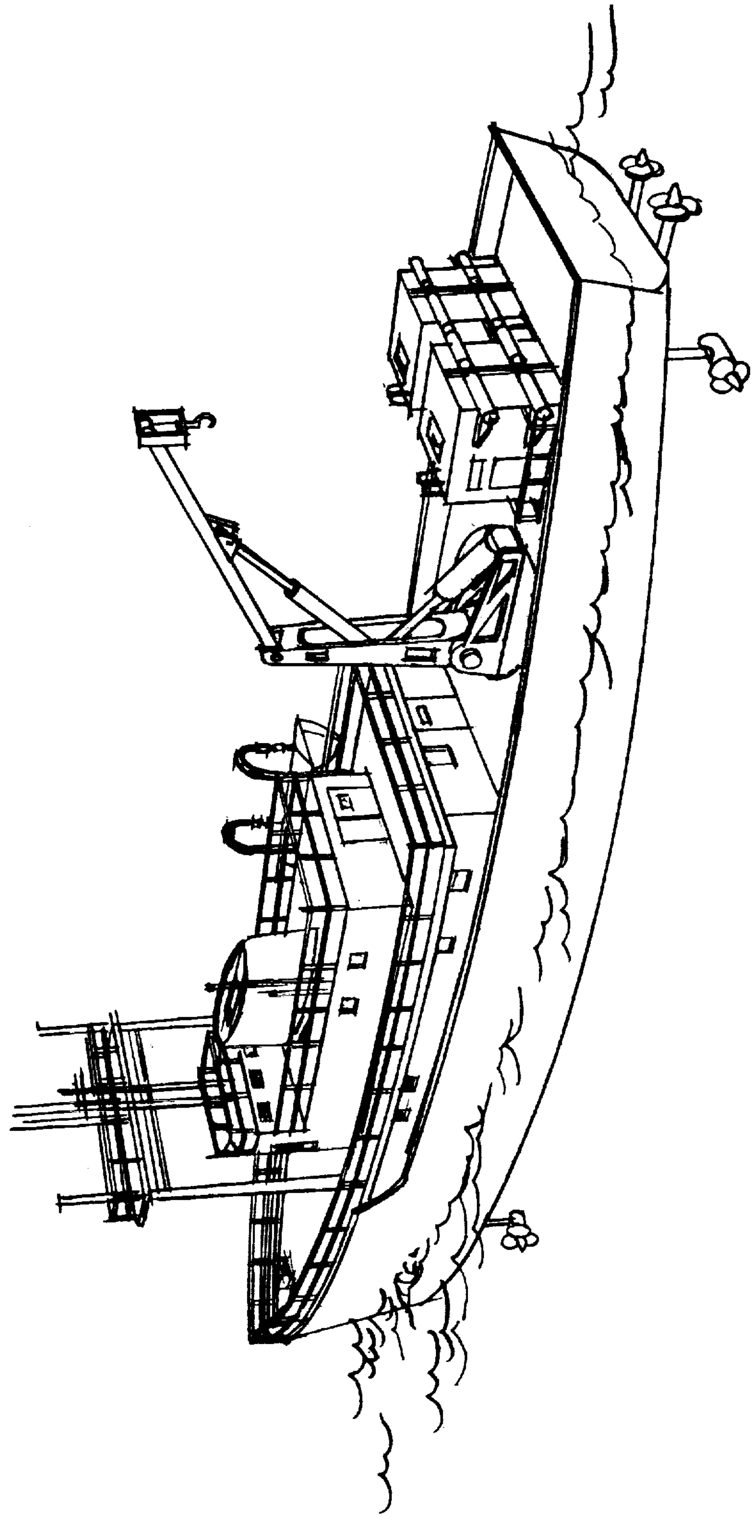
Hydraulic Mating Tool

Figure 4-8



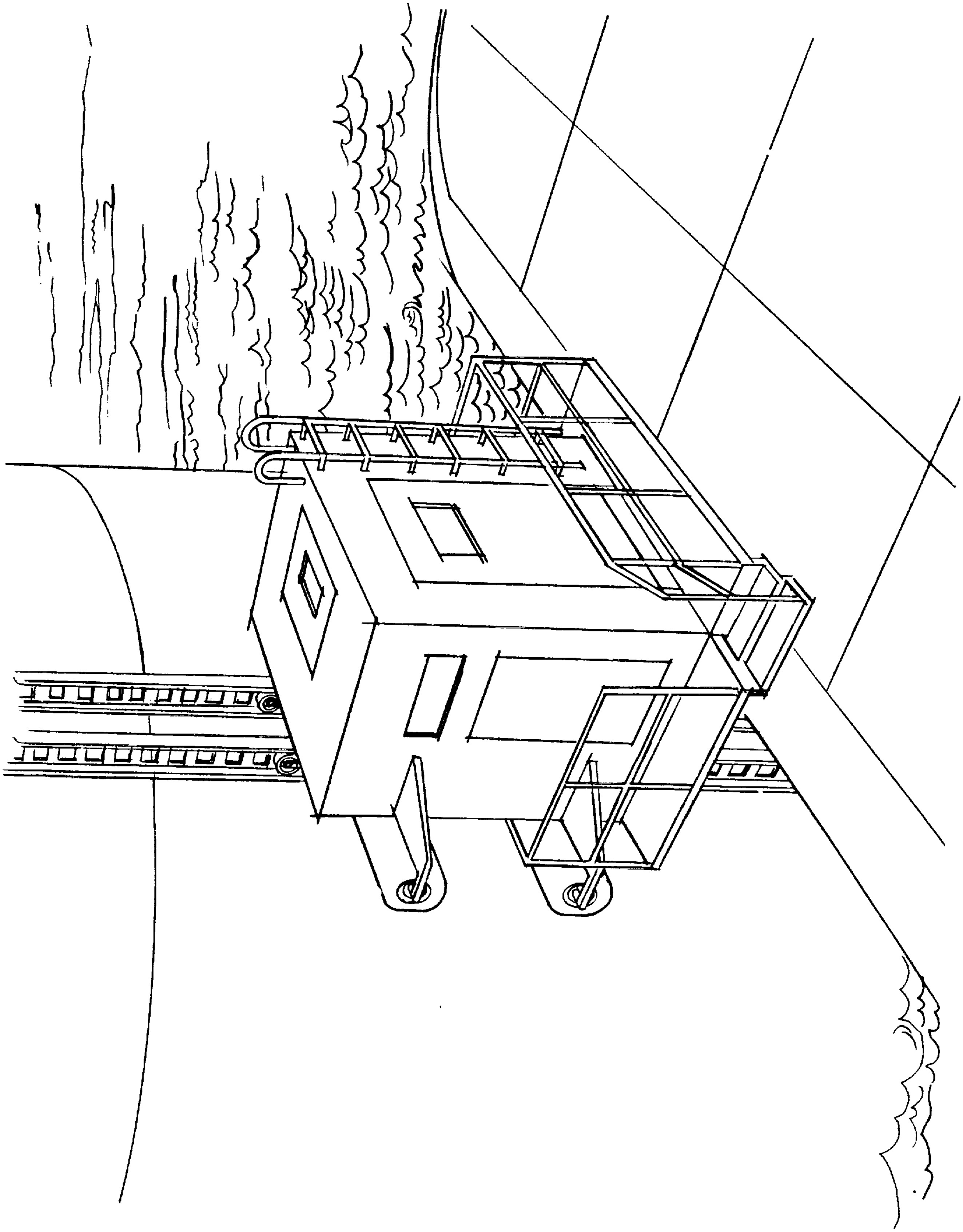
LOX Loading

Figure 4-9



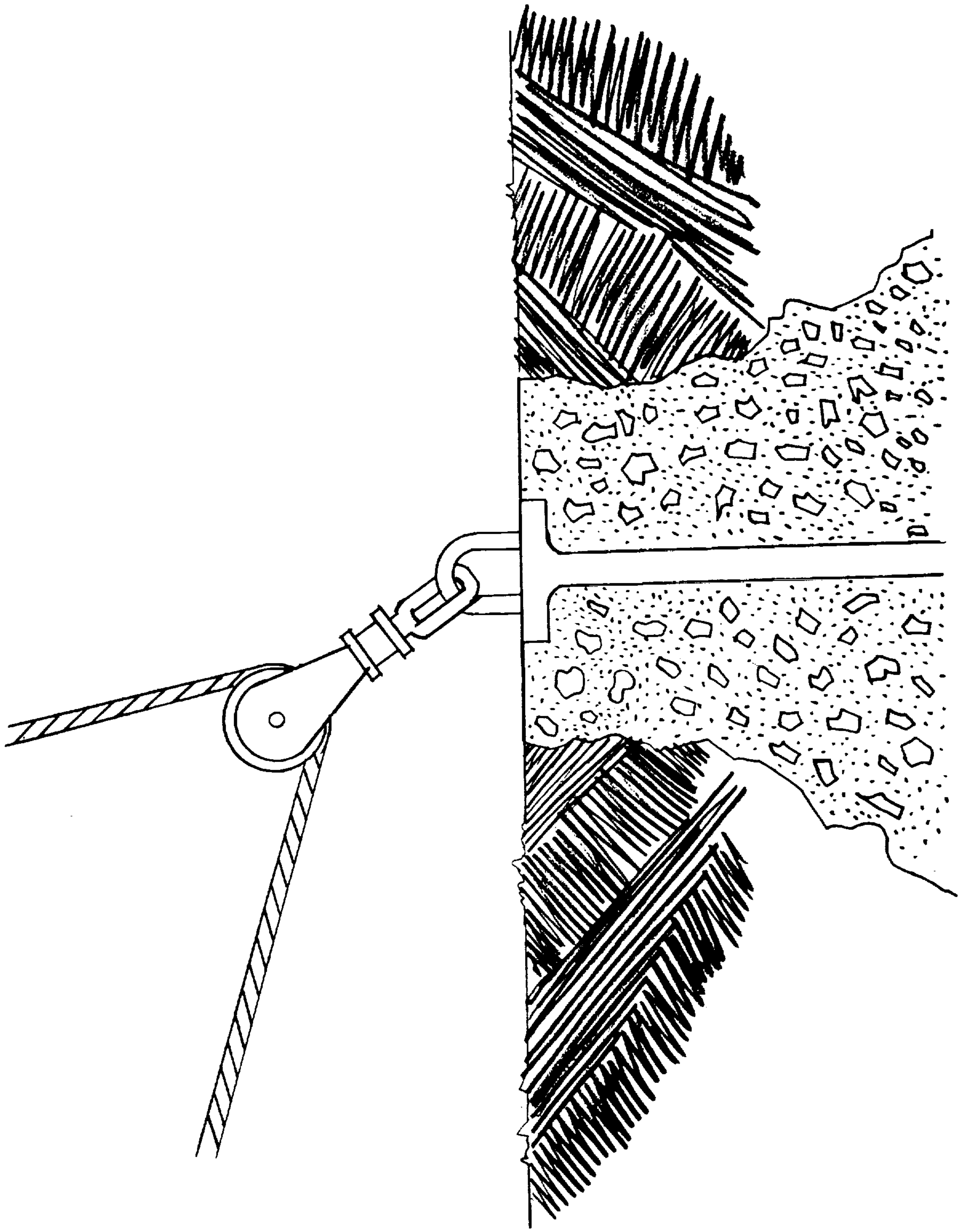
Service Vessel

Figure 4-10



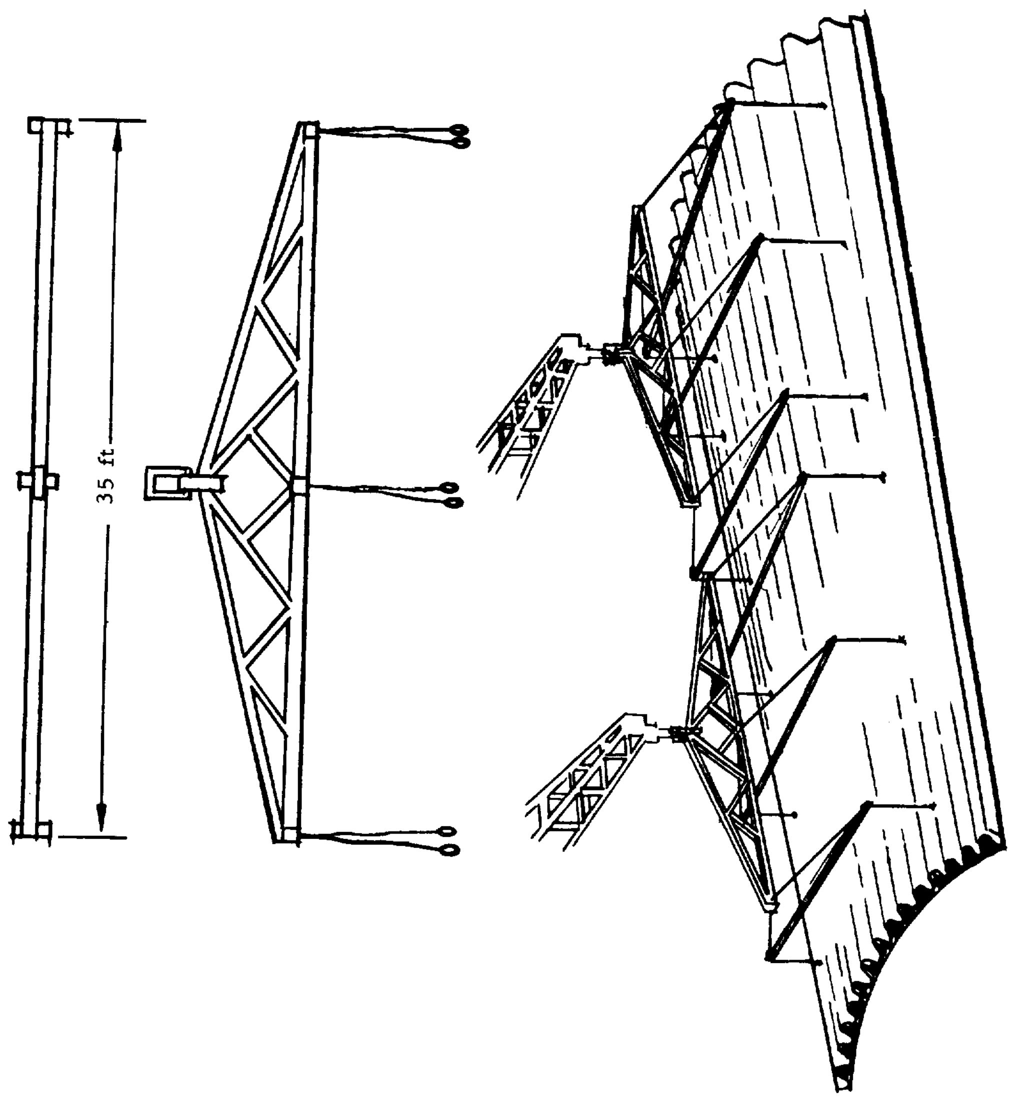
Vertical Service Car

Figure 4-11



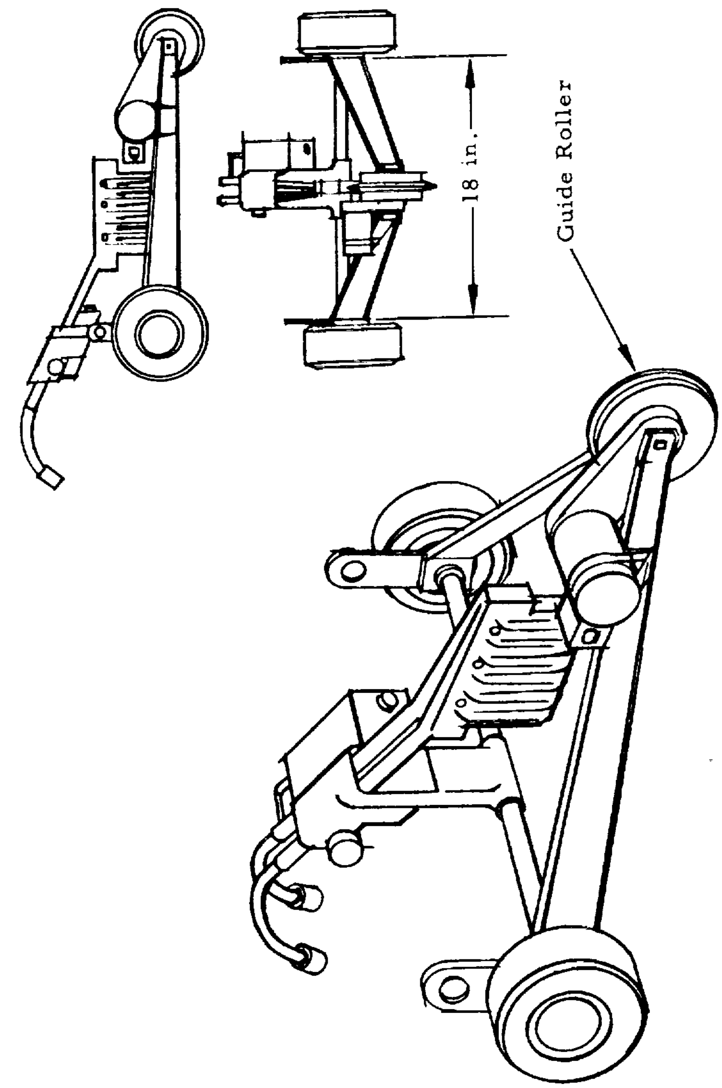
Drill Anchor

Figure 4-12



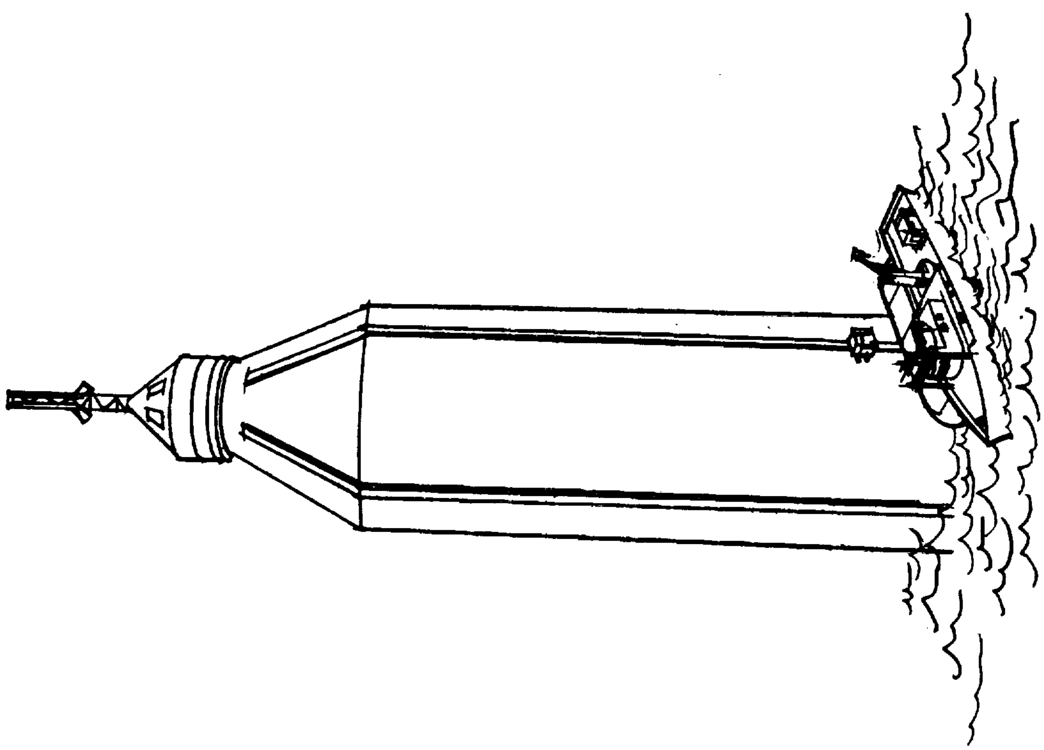
Expandable Nozzle Sling

Figure 4-13



Automatic Brazing Unit

Figure 4-14



Vertical Servicing

Figure 4-15

APPENDIX 4-1

SEA DRAGON SUPPORT SYSTEM FUNCTIONAL FLOW DIAGRAMS AND TECHNICAL REQUIREMENTS

TASK 1.0--TRANSPORT STAGE I TO ASSEMBLY AREA

TECHNICAL REQUIREMENTS, LIMITATIONS AND CONSTRAINTS

A requirement exists to transport Stage I of the vehicle from the west coast manufacturing area to the assembly area lagoon at Cape Canaveral, Florida. Vehicle limitations are imposed by the following:

1.	Length ----------------	261.75 ft (without ballast)
2.	Diameter (Body) --------	75 ft
3.	Diameter (Nozzle)	94.36 ft
4.	Weight ----------------	2,939,815 lb (includes recovery equipment)
5.	C. G. Sta. -------------	387.24

It is assumed that a flotation method of transportation will be used, towing the vehicle with sea-going tugs of the 3500 hp class a distance of approximately 5000 mi by way of the Panama Canal. Towing speeds will be approximately 5 knots The vehicle will be towed using its forward tank for bow effect and the interstage attach points for tow line attachment.

Requirements exist for the following:

A means of propelling the vehicle.

A series of external attach points on vehicle for auxiliary transportation equipment.

Ballast, flotation, and stabilizing the units to obtain proper C. G. and center of buoyancy relationship to restrain roll, pitch, and yaw during handling operations. (includes "bag" seal of whole chamber)

Task 1.0 (cont.)

A means of servicing the vehicle during transportation.

Transportation safety and marine navigational equipment will be installed and maintained during all transportation phases. Monitoring of the following parameters will occur during transportation:

1. Tank and Line Pressures
2. Leakage of sealed areas
3. Attitudes of vehicle
4. Strain encountered by vehicle

A constraint indicated as portions of the cabling required for the above must be installed during assembly, and continuity and functional checks must be performed prior to initiation of actual monitoring.

A requirement exists for an electrical power source on the dock side and tow craft that are interchangeable.

A requirement exists for dock side and tow craft monitors.

Transfer of vehicle control to dock facility at Cape Canaveral.

Clearance limitations exist at the Panama Canal which may require additional ballast and flotation aids to obtain proper vehicle attitude for reversed tow through the docks.

Task 1.0 (cont.)

Panama Canal limitations:

1. Lock Lengths -------------- 1000 ft
2. Lock Width --------------- 110 ft
3. Lock Depth ---------------- 37 ft (min at low tide)
4. Canal length ---- ---------- 52.1 mi (See Figure 1.0)

TASK 2.0--TRANSPORT STAGE II TO ASSEMBLY AREA

TECHNICAL REQUIREMENTS, LIMITATIONS AND CONSTRAINTS

A requirement exists to transport Stage II and the payload of the vehicle from the west coast manufacturing area to the assembly area at Cape Canaveral, Florida.

Vehicle limitations of the 2nd stage are imposed by the following:

1. Weight -------------------- 999,176
2. C.G. --------------------- Sta. 226.52
3. Length ------------------- 291.14
4. Diameter ----------------- 75 ft
5. Pressurization requirements during operations

TVC limitations are:

a. Weight ------------- 1350 pounds each
b. Height -------------- 8 ft
c. Diameter ----------- To be determined

Task 2.0 (cont.)

Expandable skirt limitations are:

1. Weight -------------------71,500 lb (17,875 pounds each segment)
2. Height ------------------ 30 ft
3. Length ------------------ 92.0 ft

It is assumed that:

1. A flotation method of transportation will be used.
2. The vehicle will be towed using the forward end of the vehicle for bow effect.
3. Interstage connection points will be used for tow line attachment.
4. Towing speeds will be 5 knots.
5. Skirt and vernier engines and equipment will be shipped with the stage, but may be shipped by land.

Transport requirements are:

1. A means of propelling the stage
2. A need for external attachment points
3. Ballast as necessary to obtain the proper relationship between center of buoyance and center of gravity with respect to stability.
4. Control and restraint of roll, pitch, and yaw during towing operations
5. Monitor stage attitude and functions are listed in Section 1.0 during towing operation

Task 2.0 (cont.)

6. That safety and marine navigation equipment be provided

7. Vehicle control from the tow craft be compatible with and transferred to the dock area upon arrival at the Cape lagoon

8. That vernier (TVC) engines (4) and expandable skirt segments (4) be packaged and shipped in conjunction with the stage

9. Packaging for the items in No. 8 shall provide environmental protection against all expected shipping hazards (See Figures 2.0)

TASK 3.0--TRANSPORT COMMAND MODULE TO ASSEMBLY AREA

TECHNICAL REQUIREMENTS, LIMITATIONS AND CONSTRAINTS

A requirement exists to transport the command module from its manufacturer's (location presently unknown) area to the assembly area at Cape Canaveral, Florida. Command module limitations are imposed by the following:

1.	Length	140 in.
2.	Diameter	160 in.
3.	Service module length	80 in.

It is assumed that:

1. The module may be manufactured at some location other than on the west coast.

2. The service module is considered as a part of the command module in this discussion.

Task 3.0 (cont.)

3. Weight and dimensions of the module are compatible with U. S. military cargo planes.

4. Means of transport may be land (rail or highway) or air.

5. Mating to the vehicle shall be accomplished by sling(s) and crane(s). (Module above water line at time of mating).

The following requirements exist:

1. Monitor of environmental transport, based on criticality of instruments contained in the module.

2. Protection against "g" loading for all conditions of shipment.

3. Handling points for mating or demating with vehicle.

For assembly and checkout of the module refer to Section 7.0 (See Figure 3.0)

TASK 4.0--POSITION STAGES (PAYLOAD AND BALLAST UNIT) AT ASSEMBLY AREA

TECHNICAL REQUIREMENTS, LIMITATIONS AND CONSTRAINTS

The stages with ballast unit and payload must, on arrival at the Cape Canaveral lagoon, be positioned for inspection and checkout prior to mating. Transfer of operations, required and performed during the transport phase, from tug boat to storage area facility shall be accomplished with a minimum loss in monitor and pressurization functions.

Task 4.0 (cont.)

It is assumed that:

1. Dock facility connections will be compatible with tug boat connectors.

2. Adequate space for each stage and its associated function will be provided in the assembly area.

3. Facility shall be capable of positioning the stages for inspection, checkout, and assembly as required.

4. Facility will provide the necessary facilities for refurbishing and mating the recoverable 1st stage and ballast units.

The following requirements exist:

1. Stages must be emplaced.

2. Control of hard lines, tow lines, and of monitor and pressurant operations must be transferred from tug boat to wharf facility.

3. Emplaced stages must be inspected.

4. Stages must be prepared for checkout prior to mating.

5. Facility must be provisioned for refurbishment of recoverable 1st stage (refer 38).

Task 4.0 (cont.)

6. Facility must be provisioned for refurbishment and mating of recoverable ballast units to 1st stage (refer 35). (See Figure 4.0).

TASK 5.0--ASSEMBLY AND C/O OF STAGE I

TECHNICAL REQUIREMENTS, LIMITATIONS AND CONSTRAINTS

After the 1st stage has been positioned (refer 4.0) and the various controls transferred dock side, it must be visually inspected for damages or deterious conditions created during transport, prior to being prepared for final checkout.

The following conditions will be established and verified prior to installation of electrical equipment:

1. Removal of marine navigation and safety devices

2. Removal of towing, floatation and nozzle support equipment not necessary for continued transport

3. Facility lines connected and all circuits verified

4. Tanks prepared for leak checks (drained, dried, and cleansed)

5. Stage leak checks performed.

Limitations and constraints on electrical equipment are as follows:

1. Stage and vehicle equipment will be functionally tested from equipment located on dock side; continuity check and functional sequence to be conducted in this manner

Task 5.0 (cont.)

2. All equipment mounted on missile to be of the type that requires the lowest drain from the power source and that where possible all logic, sequencing, and control circuits operate in the lowest level of power available; i.e., integrated circuits, transistors, and tunnel diode

3. All equipment be of modular construction, which shall be small and expendable.

Requirements:

1. Installation of equipment to perform the following test, checkout, and launch functions:

a. Pressure monitors
b. Valve operate
c. Position indicators for valve, regulators, and throttles
d. Liquid level sensors
e. Ord nance safe-arm devices
f. Topping (indication)
g. Temperature
h. Attitudes
i. Accelerometers
j. Power converters
k. Gimbal positions
l. Strain
m. T/M transmitters

Task 5.0 (cont.)

n. Abort controls

o. Antennas

p. Recovery system consisting of pressure monitor, beacon antenna, valve, and vent systems.

2. Installation of a fault locator with the compability of functioning various pieces of equipment within vehicle by manual operation ashore or aboard tow

3. Provide simulators for functional testing in areas where actual operation is impractical

4. Install and checkout monitoring equipment to be located on service vessel, which consists of:

a. T/M relay station for calibration of main T/M

b. Monitor equipment of all previous parameters

c. Power source equivalent to that of the vehicle with suitable safety factor

d. Command module control monitor and override system

e. Reentry control monitor and override

f. Guidance and control monitor and correction

g. Sequence and staging monitoring system

h. Monitors for pressure, valves, thrust, and power source

i. Abort control system

j. Monitor of sequence

k. Launch enabling system

l. Recovery system (See Figure 5.0).

TASK 6.0--ASSEMBLY AND CHECKOUT OF STAGE II AND PAYLOAD

TECHNICAL REQUIREMENTS, LIMITATIONS AND CONSTRAINTS

After the second stage has been positioned (Task 4.0) and the various controls transferred dock side it must be visually inspected for damages created during transport prior to being prepared for final checkout.

The following conditions shall be established and verified prior to installation of electrical equipment:

1. Removal of marine navigation and safety devices
2. Removal of towing, flotation and nozzle support equipment not necessary for continued transport
3. Facility line connected and circuits verified
4. Vernier engines shall be prepared for installation
5. Tanks prepared for leak checks
6. Vernier engines installed
7. Stage leak checks performed.

Limitations and constraints on electrical equipment are as follows:

1. Stage and vehicle equipment will be functionally tested from equipment located on dock side.

Task 6.0 (cont.)

2. All equipment mounted on vehicle will be of the type that requires the lowest drain from the power source and, where possible, all logic, sequencing, and control circuits operate at the lowest level of power available, i.e., integrated circuits, transistors, tunnel diode, etc.

3. All equipment will be of modular construction that shall be easily replaced. Where possible modules shall be small and expendable.

Requirements:

1. Installation of equipment to perform the following test, checkout, and launch functions:

a. Pressure monitors
b. Valve operate
c. Position indicators for valve, and regulators
d. Liquid level sensors
e. Ordnance safe-arm
f. Topping (indication)
g. Temperature
h. Attitudes
i. Accelerometer
j. Power converters
k. Gimbal positions
l. Strain
m. Sequencers for Stage II and payload
n. Life support systems
o. T/M transmitter
p. Abort controls
q. Antennas

Task 6.0 (cont.)

2. Installation of a fault locator with the capability of controlling various pieces of equipment within vehicle by manual operation ashore or aboard tow.

3. Simulators for functional testing in areas where actual operation is impractical will be provided. Installation and checkout monitoring equipment will be located on service vessel and will consist of:

a. T/M relay station for calibration of main T/M
b. Monitor equipment of all previous parameters
c. Power source equivalent to that of the vehicle with suitable safety factor.

4. Install the following at the launch facility:

a. T/M linkage
b. Computer complex
c. Personnel and life support
d. Command module control monitor and override system
e. Reentry control monitor and override
f. Guidance and control monitor and correction
g. Sequence and staging monitoring system
h. Monitor for pressure, valves, thrust, turbines, power source, etc.
i. Abort control system
j. Monitor of sequence
k. Launch enabling system

Task 6.0 (cont.)

5. Installation of guidance for second-stage payload with the capabilities to correct the following:

a. Attitude to earth
b. Orbit decay
c. Minor orbital changes. (See Figure 6.0)

TASK 7.0--ASSEMBLY AND CHECKOUT OF COMMAND MODULE

TECHNICAL REQUIREMENTS, LIMITATIONS AND CONSTRAINTS

1. Upon arrival at the Cape Canaveral assembly area, the command module shall be visually inspected for transport damages. Environmental controls shall be removed and the module prepared for checkout of:

a. Power supply systems
b. Life support systems
c. Module controls

2. Equipment to provide the following services shall be installed:

a. Life support
b. Command receiver
c. Attitude control
d. Reentry retropropulsion
e. Vehicle guidance
f. Power supply

Task 7.0 (cont.)

g. T/M linkage

h. Sequencing unit

i. Launch initiate

j. Abort safety system

k. Staging

3. Interface to Stage II payload unit and antenna systems for T/M and communications receiver shall be established. All systems will be checked out and the module will then be stored until needed or mated to the vehicle. (See Figure 7.0).

TASK 8.0--PERFORM FINAL MATING AND VEHICLE ASSEMBLY

TECHNICAL REQUIREMENTS, LIMITATIONS AND CONSTRAINTS

The stages and command module must be mated to produce the vehicle. This mating procedure is accomplished at and adjacent to the dock side assembly area. The stages will be mechanically attached through a circumferential interstage structure.

Vehicle limitations are imposed by the following conditions:

1.	Vehicle length:	506 ft (549 ft with ballast)
2.	Vehicle diameter:	75 ft
	First stage:	95 ft
3.	Vehicle weight (empty):	4,710,066 lb (8.3×10^6 with ballast)
4.	Vehicle c.g.:	Station 278.42

Task 8.0 (cont.)

5. Vehicle weight vertical lift-off condition: 40,000,000 lb

6. Vehicle c.g.: Station 298.4

7. Ballast tank unit length: (6 each) 45 ft

8. Ballast tank unit diameter: 28 ft

9. Ballast unit assembly weight: (empty) (includes stiff legs) 3,600,000 lb (6 tanks)

10. Ballast unit weight: (loaded) 10,000,000 lb

11. Flotation data

    a. Horizontal

        (1) empty-waterline 9 ft above horizontal bottom

        (2) loaded-waterline 9 ft below vehicle C_L

    b. Vertical (ballast unit flooded

    waterline at station 233).

Assumptions:

1. Stages will arrive in horizontal position.

2. The vehicle will be assembled in the horizontal position utilizing a flotation method.

Task 8.0 (cont.)

3. Cleanliness requirements necessitate precluding the entrance of sea water in the stages (tanks), payload, or command module.

4. Any means of vehicle support will preclude vehicle stage loads being transmitted through the nozzle skirt convolutions.

5. First- and second- stage mating shall be accomplished prior to installation of the expandable nozzle.

6. The four nozzle skirt segments shall be placed on dock side and prepared for installation. These quarter cylinders will be mated to the second stage, partially cover the first stage and be brazed together with 92.0 ft tapered stainless steel sheets 0.020 to 0.120 forming the segments. External convolutions taper from a depth of 0 to 9 in.

The command module will at all times be above the water line during assembly.

8. Block box changes in the command module can be made without de-erection of the vehicle.

9. Installation of vehicle instrumentation will be accomplished in each section prior to mating.

10 External mechanical support means between Stations 313.78 and 408.08 (Stage 1 baffles should be sufficient) shall be non-existant.

11. External hoops can be used for second stage stabilization when internal pressures are vented.

Task 8.0 (cont.)

Mating requirements include:

1. Precise positioning of assemblies for mechanical attachment operations

2. Capability of 90° vehicle rotation from normal attitude

3. Maintaining pressures of 20 to 100 psi in stages and payload during mating operations

4. Providing illumination within the injector dome recess and tunnel (or tubes) areas for connecting, maintaining and inspecting the electrical, hydraulic, and vent line connections from the interstage umbilical tower

5. A means of supporting and positioning the four nozzle segments (17,875 lb) or two half cylinders (35, 750 lb) with c.g. 32.3 ft from the attaching end. Forty-five convolutions of polyurethane are required for each segment

6. Protecting Stage 1 and the polyurethane against heat during expandable nozzle installation (brazing) and sea water during tow

7. Stabilization of the vehicle in roll and pitch during expandable nozzle positioning and attachment

8. Provisioning for complete radiographic inspection of all installation (brazed) joints

Task 8.0 (cont.)

9. Vehicle instrumentation and stage separation devices to be installed prior to attachment of the second-stage expandable nozzle.

10. Perform a continuity check of all intrastage wiring to assure proper mating.

11. Attachment of the command module as the final step in the mating operation

12. Tanks drained, dryed and cleaned

13. Perform tank leak check (See Figure 8.0)

TASK 9.0--PERFORM COMBINE SYSTEM CHECKOUT

TECHNICAL REQUIREMENTS, LIMITATIONS AND CONSTRAINTS

1. The completed vehicle will undergo an integrated system checkout prior to loading ordnance items or propellants. This checkout is required to verify the compatibility of all vehicle systems with the service vessel and dock side facilities. Propellant tankage and lines must be decontaminated, if required, and made ready for propellant acceptance. The vehicle propulsion systems, as well as pressurized compartments must be leak checked and flight readiness conditions initiated. Vehicles returning from hold or abort stations are subject to the same requirements.

Task 9.0 (cont.)

2. The service vessel/launch facility will initiate and perform the following:

a. Self check of telemetry and hardline systems control and monitor

b. Checkout of facility (dock side) telemetry and hardline systems

c. Vehicle checkout

(1) Electrical/electronic (continuity)

(2) Control systems

(3) Guidance

(4) Pressurization and propellant systems

(5) Electrical sequencing

(6) Gimbal actuator monitor

(7) Actuate TVC (See Figure 9.0)

TASK 10.0--LOAD ORDNANCE ITEMS

TECHNICAL REQUIREMENTS, LIMITATIONS AND CONSTRAINTS

1. A requirement exists to provide ordnance items or devices (including TEA) for the following purposes:

(a) Stage I thrust chamber ignition

(b) Stage II thrust chamber ignition

Task 10.0 (cont.)

(c) Vernier motors ignition

(d) Stage I and Stage II Staging (if required)

(e) Stage II and Payload Staging (if required)

(f) Vehicle Destruction

(g) Stage I and Ballast unit staging

2. Special handling is required in the loading of triethylaluminum in fuel systems of Stage I and Stage II thrust chambers. This chemical must be sealed against any possible inadvertant exposure to sea water.

3. A requirement exists to perform checkout of ordnance devices. (See Figure 10.0)

TASK 11.0--TRANSPORT TO FUEL SERVICE AREA

TECHNICAL REQUIREMENTS, LIMITATIONS AND CONSTRAINTS

1. A requirement exists to transport the fully assembled vehicle (Stage I, II, payload, and nose cone) from the assembly area to the fuel service area.

2. Water tow utilizing the aft nozzle stiff leg attach points is required for transporting the vehicle to the fuel servicing area.

3. A method of ballasting and restraining pitch, yaw, and roll of the vehicle is required.

4. External attach points, in addition to the stiff leg tow points, will be required for restraint.

Task 11.0 (cont.)

5. Monitoring of various pressures, attitudes, and temperatures is required during all operations.

6. Restriction and restraints are as follows:

Towing speed - 5 knots maximum

Length -- 506 ft (548.65 ft with ballast)

Weight -- 4,710,066 (subject to change if tanks are enlarged) (3.6×10^6 ballast) C. G. Station 278.42 (See Figure 11.0)

TASK 12.0--LOAD FUELS AND PRESSURANTS

TECHNICAL REQUIREMENTS, LIMITATIONS AND CONSTRAINTS

1. A requirement exists to load LH_2, RP-1, CH_4 and GN_2 into the vehicle.

2. Assuming that these operations can be performed simultaneously, a requirement exists for a facility with this capability.

3. A requirement exists to recover the propellant gases used during tankage "cool down" for reasons of economy. These gases can be reprocessed for future use.

4. A requirement exists to provide positive control of the facility valves and components by the service vessel through an electrical control cable.

5. A requirement exists of the facility to provide both "coarse" and "fine" filling capabilities to the vehicle.

Task 12.0 (cont.)

6. A requirement exists that the lines to be connected to the vehicle be of a flexible design to prevent adverse loads being applied to the vehicle during filling operations.

7. A requirement exists for the facility to provide any and all safety features which might be needed to prevent occurrence of any condition which would endanger or damage the vehicle.

8. A requirement exists to keep the fuel propellant vapors from mixing with the oxidizer vapors.

9. A requirement exists of the facility to be able to supply LH_2 at 470 lb/sec, RP-1 at 2130 lb/sec and CH_4 at 150 lb/sec.

10. A requirement exists to provide facilities for supplying pressurants GN_2 and GHe to the vehicle for propellant tank and vehicle compartment pressurization and purging.

TASK 13.0--TRANSPORT TO LO_2 AREA

TECHNICAL REQUIREMENTS, LIMITATIONS AND CONSTRAINTS

1. A requirement exists to transport the fully assembled fuel serviced vehicle from the fuel service area to the LO_2 service area.

2. Water tow utilizing the aft nozzle stiff leg attach points and additional flotation or ballast aids to maintain proper center of gravity to center of buoyance relationship will be required for transporting the vehicle to the LO_2 servicing area.

Task 13.0 (cont.)

3. A method of controlling pitch, yaw and roll of the vehicle is required.

4. Monitoring of various pressures, attitudes, and temperatures is required during all operations.

5. Restrictions and restraints are as follows:

Towing speed ------------	5 knots maximum
Length ------------------	548.65 ft
Weight ------------------	13,575.245

6. Support and restraint provisions for vents and servicing lines are required.

TASK 14.0--LOAD LO_2

TECHNICAL REQUIREMENTS, LIMITATIONS AND CONSTRAINTS

1. A requirement exists for the LO_2 Facility to be located at least five mi at sea.

2. A requirement exists to load LO_2 into the vehicle at maximum state of 5 seas.

3. Assuming the "cool down" gases can be used for pressurizing the facility, a requirement exists to recover this gas for reprocessing.

Task 14.0 (cont.)

4. A requirement exists to provide positive control of the facility valves and components by the service vessel through an electrical control cable.

5. A requirement exists of the facility to provide both "coarse" and "fine" filling capabilities to the vehicle.

6. A requirement exists that the lines to be connected to the vehicle be of a flexible design to prevent adverse loads being applied to the vehicle during filling operations.

7. A requirement exists for the facility to provide all safety features which might be needed to prevent occurence of any condition that would endanger or damage the vehicle.

9. A requirement exists to keep the oxidizer propellant vapors from mixing with the fuel propellant vapors during and after LO_2 loading.

10. A requirement exists for the facility to supply LO_2 at 7300 lb/sec. (See Figure 13.0)

TASK 15.0--<u>TRANSPORT TO LAUNCH AREA</u>

TECHNICAL REQUIREMENTS, LIMITATIONS AND CONSTRAINTS

1. A requirement exists to transport the fully loaded vehicle from the fueling area to the launch area.

2. A requirement exists to provide roll, pitch, and yaw restraints and navigational aids (Tasks 11.0 and 13.0).

Task 15.0 (cont.)

3. A requirement exists to start final calibration of T/M systems using tow relay as input to launch facility.

4. Restrictions imposed by the vehicle are as follows:

Length -------------	548.65 ft
Diameter (body) -----	75 ft
Diameter Stage I nozzle -------------	94.36 ft
Diameter ballast assy -	108 ft
Weight -------------	40,000,000 lb
Boil-off time to lose 5% H_2 - -	22 hr
Boil-off time to lose 1% O_2 --	15 hr
Tow distance from LO_2 area to launch area ----	35 mi
Tow speed (maximum) -----------------------	5 knots

Vehicle to be towed utilizing Stage I ballast attach points.

TASK 16.0--ERECT VEHICLE

TECHNICAL REQUIREMENTS, LIMITATIONS AND CONSTRAINTS

1. A requirement exists to erect the vehicle, loaded with propellants, to the vertical launch position from the horizontal towing position.

2. A requirement exists to limit vehicle bending forces.

3. A requirement exists to maintain tank structural and propellant stabilizing pressures in the tanks at all times.

4. A requirement exists to maintain electrical power on the G and C gyros and cryogenic propellant control valves heater blankets.

5. A requirement exists to provide roll stabilization equipment for the vehicle until launch.

6. A requirement exists to top off the cryogenic tanks in both the horizontal and vertical positions against tank structural and propellant stabilizing pressures.

7. A requirement exists to vent gaseous LOX and hydrogen at all times during erection.

8. A requirement exists to provide 14 million lb of high density fluid (specific gravity = 2) for vehicle erection.

Task 16.0 (cont.)

9. A requirement exists to transfer venting of the propellant tanks from the horizontal to the vertical position during vehicle erection.

10. A requirement exists to pressurize the propellant and pressure tanks to operating flight pressure.

11. A requirement exists to perform final airborne system checkout before disconnecting from the service vessel.

12. Launch vehicle stabilization requirements necessitate the retention of the ballast assembly until after vehicle first stage ignition.

13. Restrictions and Restraints:

a. Vehicle

(1) Weight 40,000,000 lb

(2) Length 548.65 ft

(3) Diameter 75 ft

(4) Center of buoyance (interstage sealed)

(a) Horizontal Approximately 3 ft below water line

W. L. 9 ft below

(b) Vertical Station 241.64

Task 16.0 (cont.)

b. Sea State 5:

(1) Wind 20 to 24 knots

(2) Waves 10 to 12 ft

(3) Swells 188 ft peak to peak

c. Buoyance:

(1) Vertical stability 0.13°

(2) Ballast medium $G_{sp} = 2$ (See Figure 14.0)

TASK 17.0--PERFORM LAUNCH COUNTDOWN

TECHNICAL REQUIREMENTS, LIMITATIONS AND CONSTRAINTS

1. After vehicle erection and final servicing, the countdown will be initiated to verify launch readiness. The following operations are performed leading to fire switch one:

a. Activate and verify airborne electrical power.

b. Verify all airborne systems in operation

c. Transfer vehicle monitor and control to TM

d. Disconnect all hard lines.

e. Move service craft from launch area.

Task 17.0 (cont.)

f. Transfer guidance and control to flight mode.

g. Arm ordnance items

h. Actuate ballast stiff legs to trail position (may follow S_I ignition)

i. Ignite vernier engines. (See Figure 15.0)

TASK 18.0--PERFORM VERTICAL VEHICLE MAINTENANCE

TECHNICAL REQUIREMENTS, LIMITATIONS AND CONSTRAINTS

1. A requirement exists to provide vertical vehicle maintenance capabilities.

2. A requirement exists to "safe" ordnance items.

3. A requirement exists to provide for a method to safety reduce propellant tank pressures.

4. A requirement exists to reestablish hardline connections with the vehicle, discontinue vehicle power, and initiate shipboard monitoring.

5. A requirement exists to reattach service equipment for vertical vehicle maintenance.

6. A requirement exists to provide a means for attaching propellant topping lines and pressurization lines.

Task 18.0 (cont.)

7. A requirement exists to initiate final checkout sequencing before disconnecting service craft. (See Figure 16.0)

TASK 19.0--DE-ERECT VEHICLE

TECHNICAL REQUIREMENTS, LIMITATIONS AND CONSTRAINTS

1. A requirement exists to de-erect the vehicle from the vertical position to the horizontal position.

2. Requirements in Task 18, Paragraphs 2 through 4 are applicable.

3. A requirement exists to pressurize the vehicle compartments and to assure that propellant tanks are pressurized for horizontal towing.

4. A requirement exists to provide a means to control the vehicle roll stabilization during de-erection.

5. A requirement exists to attach vehicle roll stabilization devices during vehicle de-erection.

6. A requirement exists to attach tow craft to the vehicle for stabilization during vehicle horizontal maintanance or vehicle towing to LO_2 service area. (See Figure 17.0)

TASK 20.0--VEHICLE HORIZONTAL MAINTENANCE

TECHNICAL REQUIREMENTS, LIMITATIONS AND CONSTRAINTS

1. A requirement exists to provide service equipment for maintenance on the vehicle in the horizontal position.

2. A requirement exists to checkout the repaired vehicle systems prior to vehicle erection. (See Figure 18.0)

TASK 21.0--TRANSPORT TO LO_2 AREA

TECHNICAL REQUIREMENTS, LIMITATIONS AND CONSTRAINTS

1. A requirement exists to transport an aborted (fully fueled) vehicle to the LO_2 area, approximately 35 miles, for LO_2 removal.

2. A requirement exists to provide roll, pitch and yaw restraints and navigational aids (Task 11.0 and 13.0).

3. A requirement exists to provide for additional auxiliary flotation or ballast aids in case an abort occurs after fire switch actuation.

4. Restrictions imposed by the vehicle are as stated in Task 15.0.

TASK 22.0--UNLOAD LO_2

TECHNICAL REQUIREMENTS, LIMITATIONS AND CONSTRAINTS

1. Assuming all possible propellant will be salvaged in case of an abort, a requirement exists to unload all LO_2 from the vehicle and store it at the LO_2 facility.

Task 22.0 (cont.)

2. Assuming that the same facility used to load the vehicle will be used to unload the vehicle, a requirement exists that the facility be capable of providing the necessary lines to unload the vehicle and transport the fluids to a storage area.

3. Assuming that LO_2 can be removed by pressurizing the vehicle tanks, a requirement exists for the facility to provide lines to flow pressurizing gases into the vehicle tanks.

4. A requirement exists that the facility controls and components be controlled by the service vessel through an electrical cable.

5. A requirement exists for the facility to provide any and all safety features which might be needed to prevent occurance of any condition which would endanger or damage the vehicle.

6. A requirement exists for the facility to be capable of accepting LO_2 and GN_2 as may be returned. (See Figure 19.0)

TASK 23.0--TRANSPORT TO FUEL SERVICING AREA

TECHNICAL REQUIREMENTS, LIMITATIONS AND CONSTRAINTS

1. A requirement exists to transport the vehicle, loaded with fuel, from the LO_2 area to the fuel servicing area for de-fueling.

2. Technical requirements, restrictions and restraints in Task 13.0 Paragraphs 2 through 6 are applicable.

TASK 24.0--UNLOAD FUELS AND PRESSURANTS

TECHNICAL REQUIREMENTS, LIMITATIONS AND CONSTRAINTS

1. Assuming all possible propellant will be salvaged in case of an abort, a requirement exists to unload all LH_2, RP-1 and CH_4 from the vehicle and store it at the fuel facility.

2. Assuming that the same facility used to load the vehicle will be used to unload the vehicle, a requirement exists that the facility be capable of providing the necessary lines to unload the vehicle and transport the liquids to a storage area.

3. Assuming that the LH_2, RP-1 and CH_4 can be removed by pressurizing the vehicle tanks, the requirement exists for the facility to provide lines to flow pressurizing gases to the vehicle tanks.

4. A requirement exists that the facility controls and components be controlled by the service vessel through an electrical cable.

5. A requirement exists for the facility to provide any and all safety features which might be needed to prevent occurrence of any condition which would endanger the vehicle.

6. A requirement exists that the facility be capable of accepting and storing all fluids originally delivered by the fueling area. (See Figure 20.0)

TASK 25.0--TRANSPORT TO ASSEMBLY AREA

TECHNICAL REQUIREMENTS, LIMITATIONS AND CONSTRAINTS

1. De-erected vehicles must be transported from the fuel service area to the assembly area to have maintenance operations performed.

2. Upon arrival at the assembly area these functions are required:

   a. Vehicle controls transferred from tow vessel to facility.
   b. Vehicle correctly positioned in the area.
   c. Functions of ordnance (Task 26.0) performed.
   d. Maintenance as required. (See Figure 21.0)

TASK 26--OFF-LOAD ORDNANCE ITEMS

TECHNICAL REQUIREMENTS, LIMITATIONS AND CONSTRAINTS

1. De-erected vehicles will, upon return to the assembly area, have the following functions performed:

   a. Ordnance items removed
      (1) Retro rockets
      (2) Staging rockets if required
         (a) Ballast
         (b) Stage I to Stage II (if installed)
         (c) Stage II to payload(if installed)
         (d) Payload to command module
      (3) Vernier engine initiators (if not used)
      (4) Vehicle destruct system
      (5) TEA Stage I (Trieythylaluminum)
      (6) TEA Stage II (See Figure 22.0)

TASK 27.0-- VEHICLE ASSEMBLY AREA MAINTENANCE

TECHNICAL REQUIREMENTS, LIMITATIONS AND CONSTRAINTS

Vehicle assembly area maintenance descriptions are intentionally omitted.

TASK 28.0--DEMATE STAGES, PAYLOAD AND COMMAND MODULE

TECHNICAL REQUIREMENTS, LIMITATIONS AND CONSTRAINTS

For requirements, see Task 8.0.

TASK 29.0--PERFORM STAGE MAINTENANCE

TECHNICAL REQUIREMENTS, LIMITATIONS AND CONSTRAINTS

For requirements, see Task 5.0.

TASK 30.0--PERFORM STAGE II MAINTENANCE

TECHNICAL REQUIREMENTS, LIMITATIONS AND CONSTRAINTS

For requirements, see Task 6.0.

TASK 31.0--PERFORM PAYLOAD MAINTENANCE

TECHNICAL REQUIREMENTS, LIMITATIONS AND CONSTRAINTS

For requirements, see Task 6.0.

TASK 32.0--PERFORM COMMAND MODULE MAINTENANCE

TECHNICAL REQUIREMENTS, LIMITATIONS AND CONSTRAINTS

For requirements, see Task 7.0.

TASK 33.0--RECOVER BALLAST UNIT

TECHNICAL REQUIREMENTS, LIMITATIONS AND CONSTRAINTS

1. A requirement exists to locate and recover the vehicle ballast unit assembly and attached stiff legs.

2. A requirement exists to tow the ballast unit assembly and stiff legs to the vehicle assembly area.

3. Restrictions and restraints:

   (a) Ballast unit assembly recovery depth--1,000 ft (approximately)

   (b) Total weight: (1) 10×10^6 lb (full)
   (2) 3.6×10^6 lb (empty)

   (c) Buoyancy factor (natural state) beneath surface. (See Figure 23.0)

TASK 34.0--TRANSPORT BALLAST UNIT TO ASSEMBLY AREA

TECHNICAL REQUIREMENTS, LIMITATIONS AND CONSTRAINTS

1. A requirement exists to transport the recovered ballast unit from the launch area to the assembly area.

2. A requirement exists to provide flotation aids to obtain proper ballast unit attitude and buoyancy for water towing.

3. It is assumed that marine navigational aids will be required.

Task 34.0 (cont.)

4. Restrictions and restraints:

Total Weight	3.6 million lb (empty) 10,000,000 (full)
Size 45 x 28 each tank	Assembly dia 108 ft
C.G.	to be determined

There may be a requirement for launch area repair of the ballast unit prior to transportation operations. (See Figure 24.0)

TASK 35.0--REFURBISH BALLAST UNIT

TECHNICAL REQUIREMENTS, LIMITATIONS AND CONSTRAINTS

1. A requirement exists to provide maintenance and checkout facilities for refurbishing the ballast unit assembly and stiff legs.

2. A requirement exists to provide a storage facility for storing the refurbished ballast units and stiff legs. (See Figure 25.0)

TASK 36.0--RECOVER STAGE I

Performance of a successful flight mission necessitates the separation of the vehicle Stage I. Recovery of the stage in a pre-determined impact area is required.

Task 36.0 (cont.)

It is assumed that:

1. The area of impact is 170 mi from the launch area.
2. Increased tank pressures will be maintained through impact.
3. Recovery equipment will not be severely damaged on impact.
4. Interstage connect points will be utilized for towing.

The following requirements exist:

1. The Stage I vehicle must be located.
2. Stage I must be remotely de-pressurized to towing pressures.
3. Attach area for towing must be accessible.
4. Navigational, flotation or ballast units must be installed and maintained during the return transport cycle.
5. Monitor and control of stage attitudes must be maintained.
6. Tow conditions as applied in Task 1.0 shall apply. (See Figure 26.0)

TASK 37.0--TRANSPORT STAGE I TO ASSEMBLY AREA

TECHNICAL REQUIREMENTS, LIMITATIONS AND CONSTRAINTS

1. A requirement exists to transport the recovered Stage I from impact area to the assembly area.

2. A requirement exists to provide a tow fixture which mates to the interstage field joints.

Task 37.0 (cont.)

3. Restrictions and restraints stated in Task 1.0 (except that auxiliary tow points on the vehicle at the field joint will be utilized) are applicable.

TASK 38.0--REFURBISH BALLAST UNIT

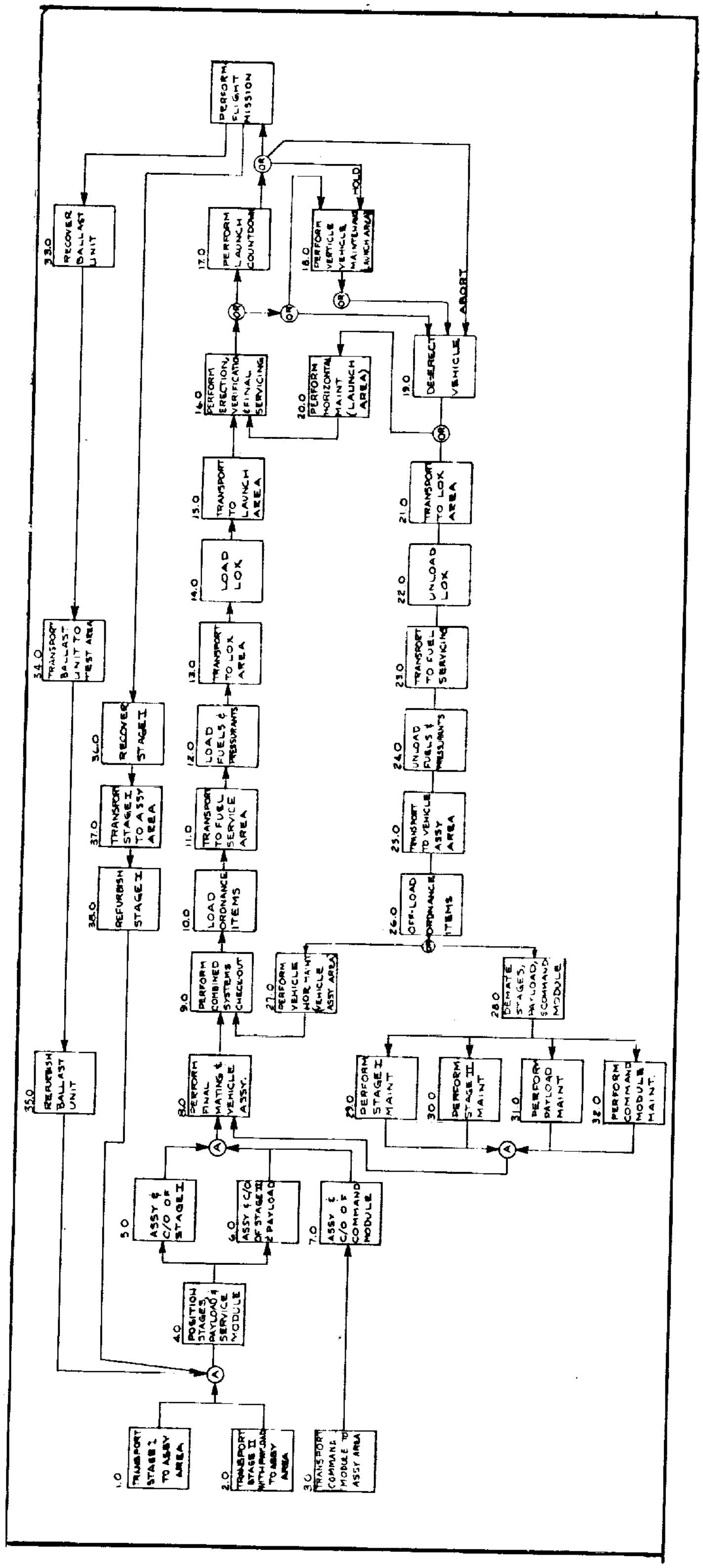
TECHNICAL REQUIREMENTS, LIMITATIONS AND CONSTRAINTS

1. A requirement exists to provide a maintenance facility for disassembling, inspecting, replacing, or repairing the Stage I assembly.

2. A requirement exists to provide a storage area for the refurbished Stage I assembly.

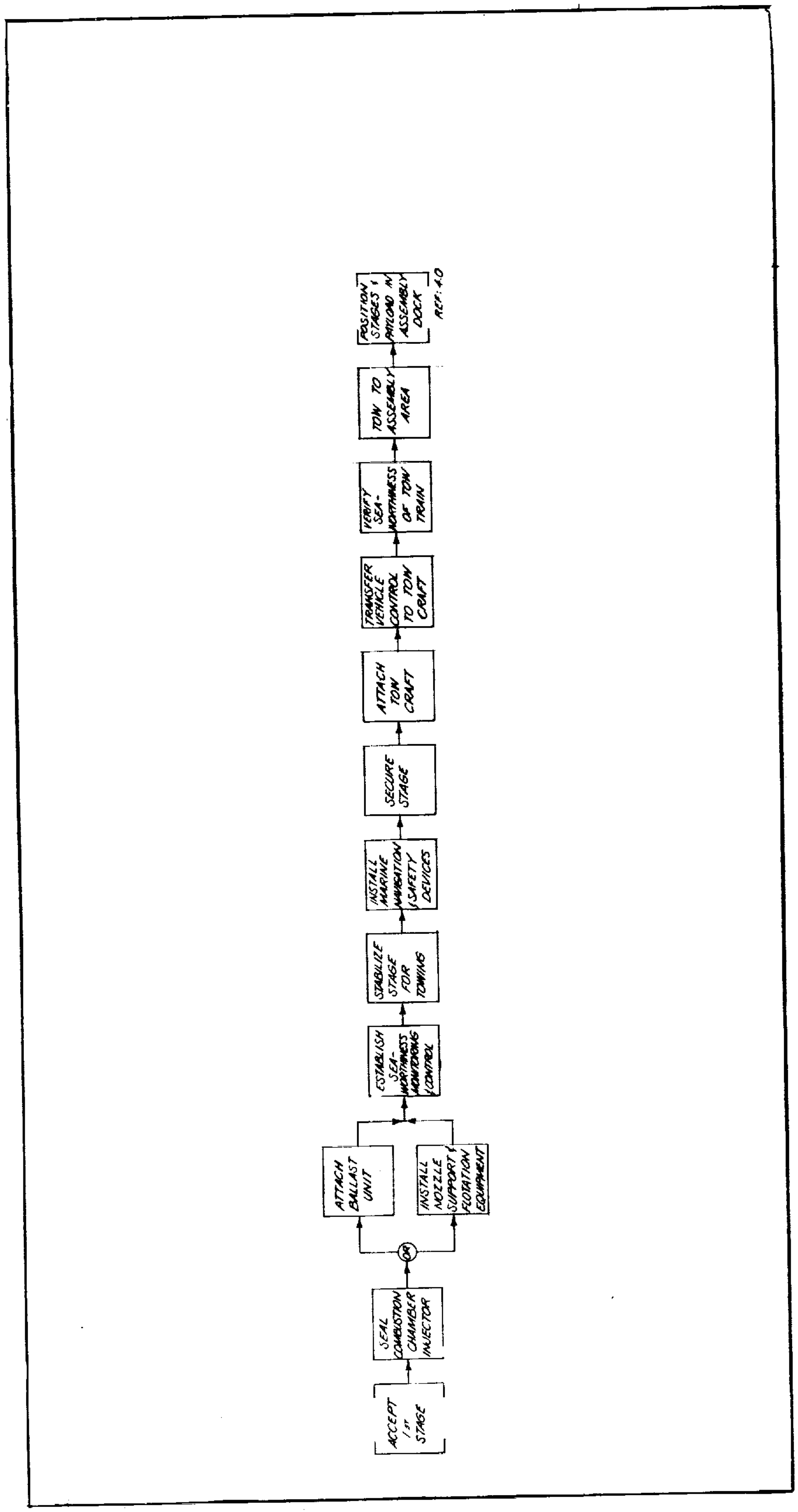
3. A requirement exists to provide a means to return the salvaged Stage I hardware to the manufacturing area.

4. Restrictions and restraints in Task 37.0 apply.
(See Figure 27.0)



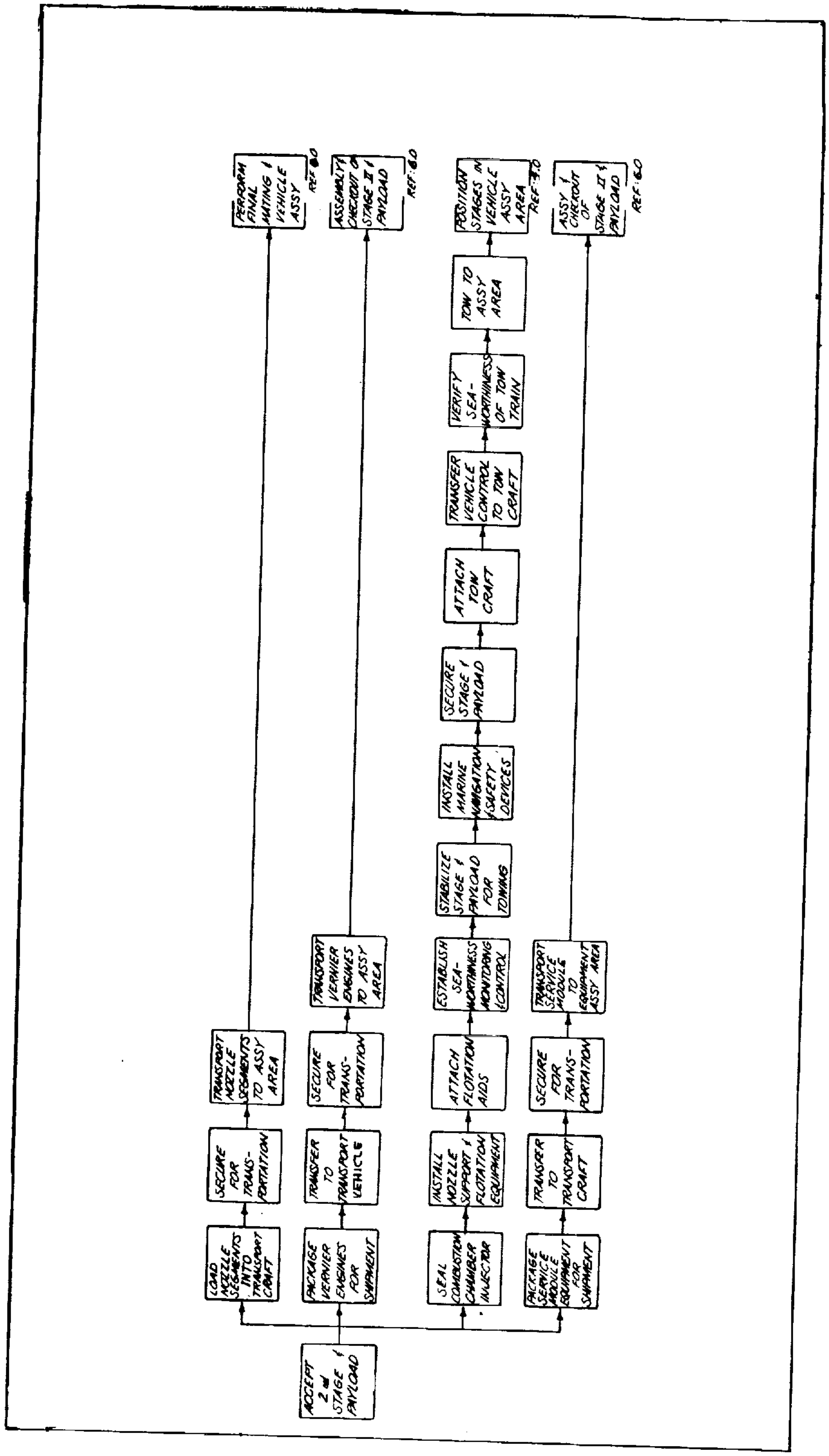
Master Flow Diagram

Figure I-1



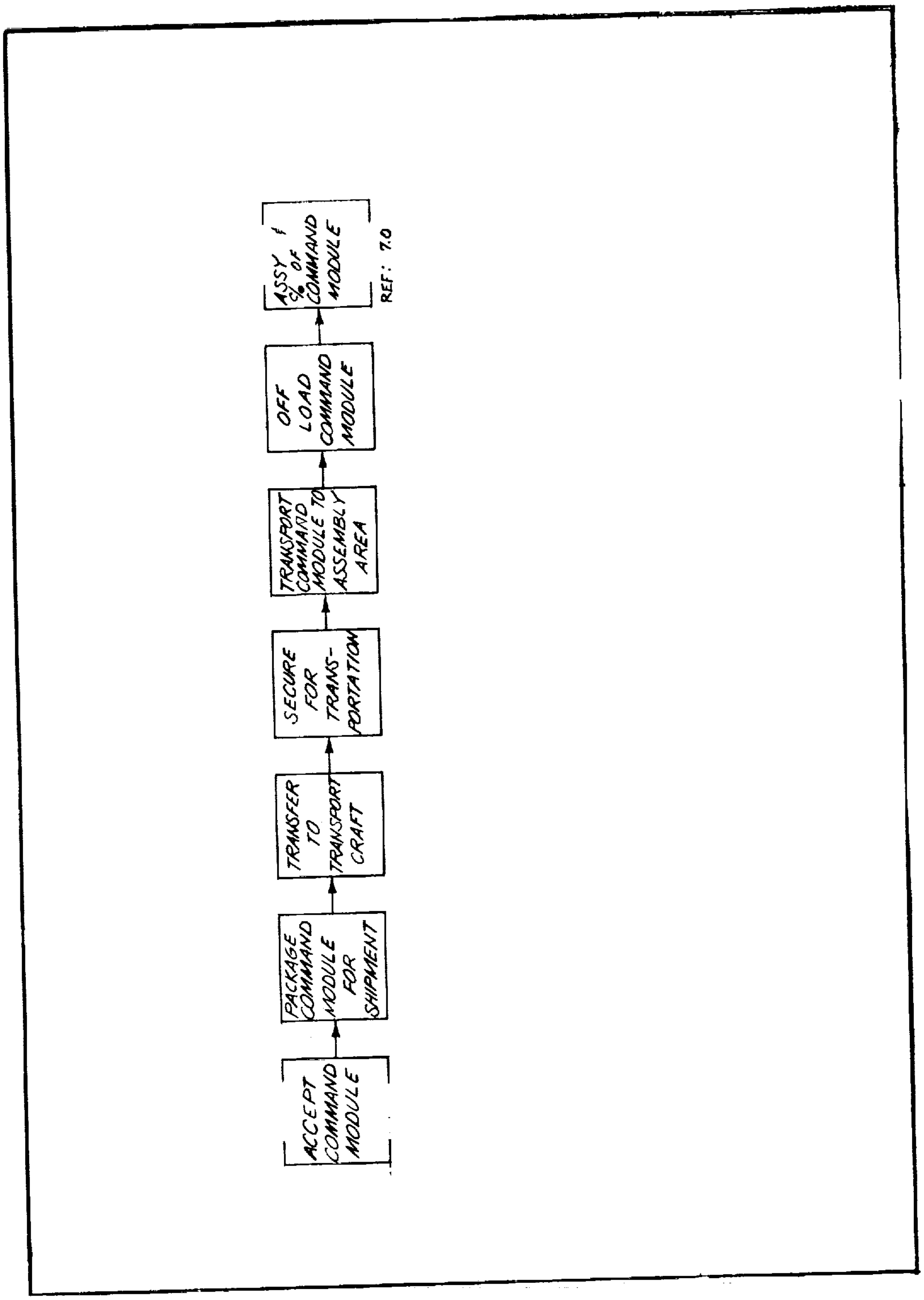
Transport Stage I to Assembly Area

Figure 1.0



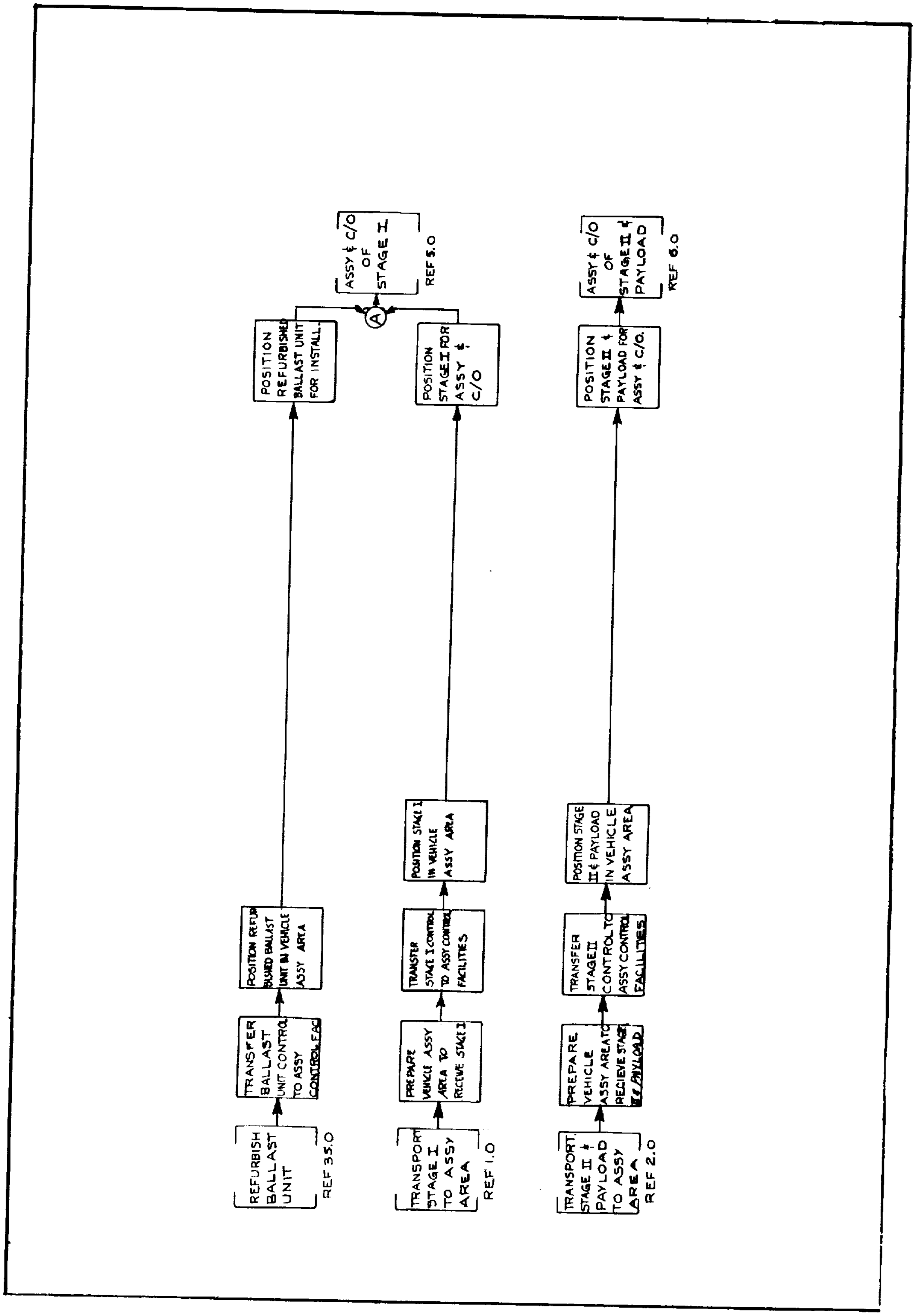
Transport Stage II with Payload to Assembly Area

Figure 2.0



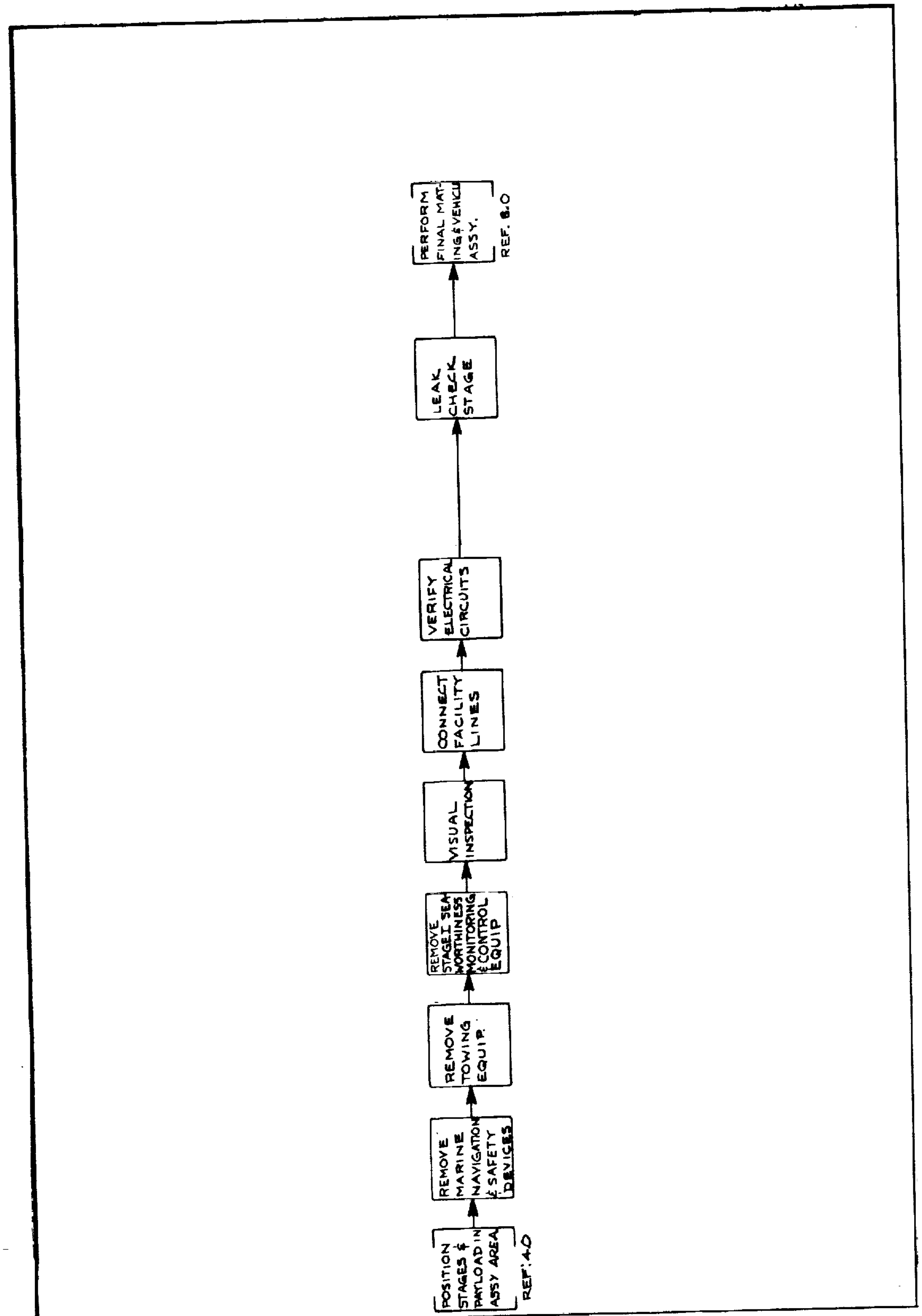
Transport Command Module to Assembly Area

Figure 3.0



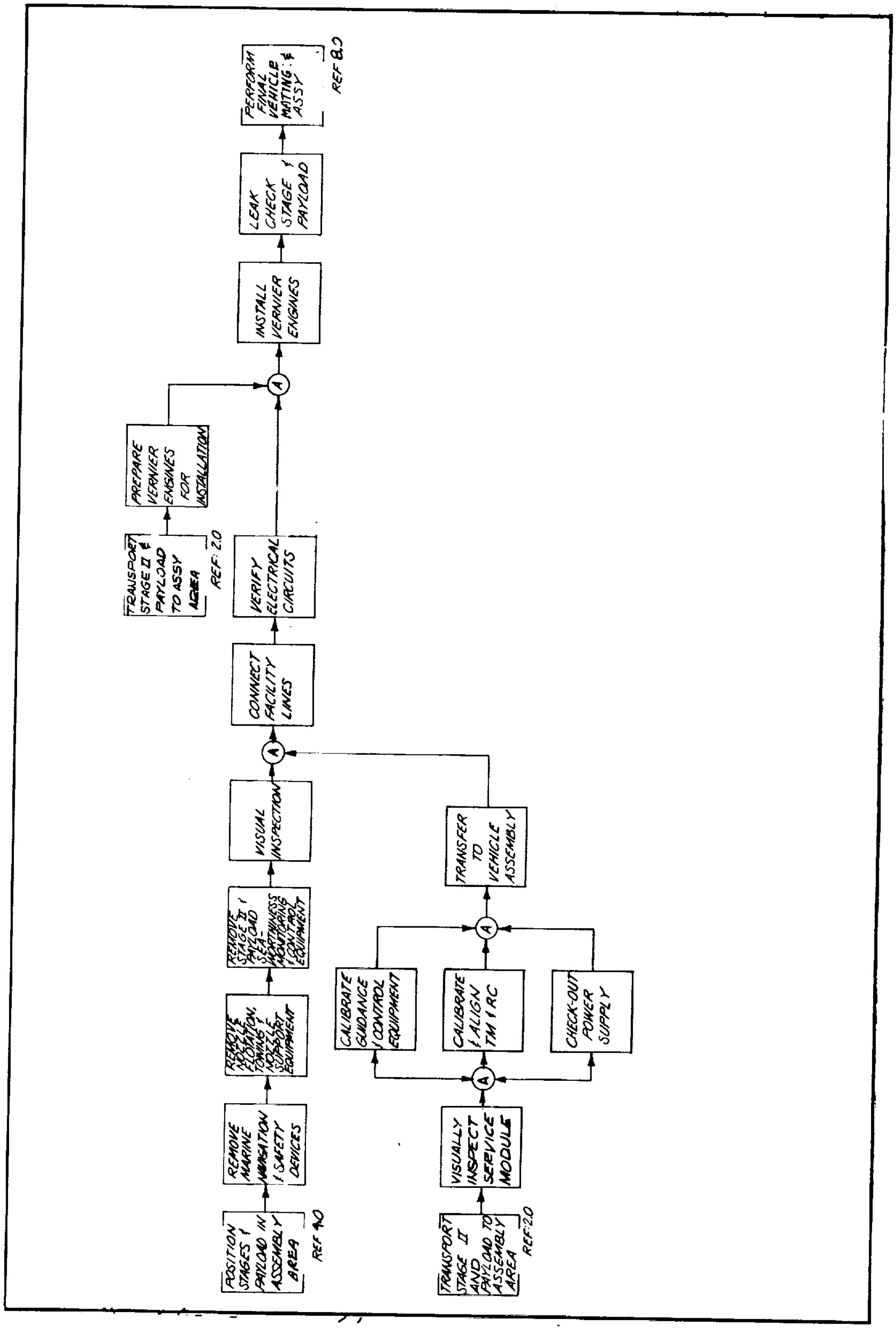
Position Stage and Payload in Assembly Area

Figure 4.0



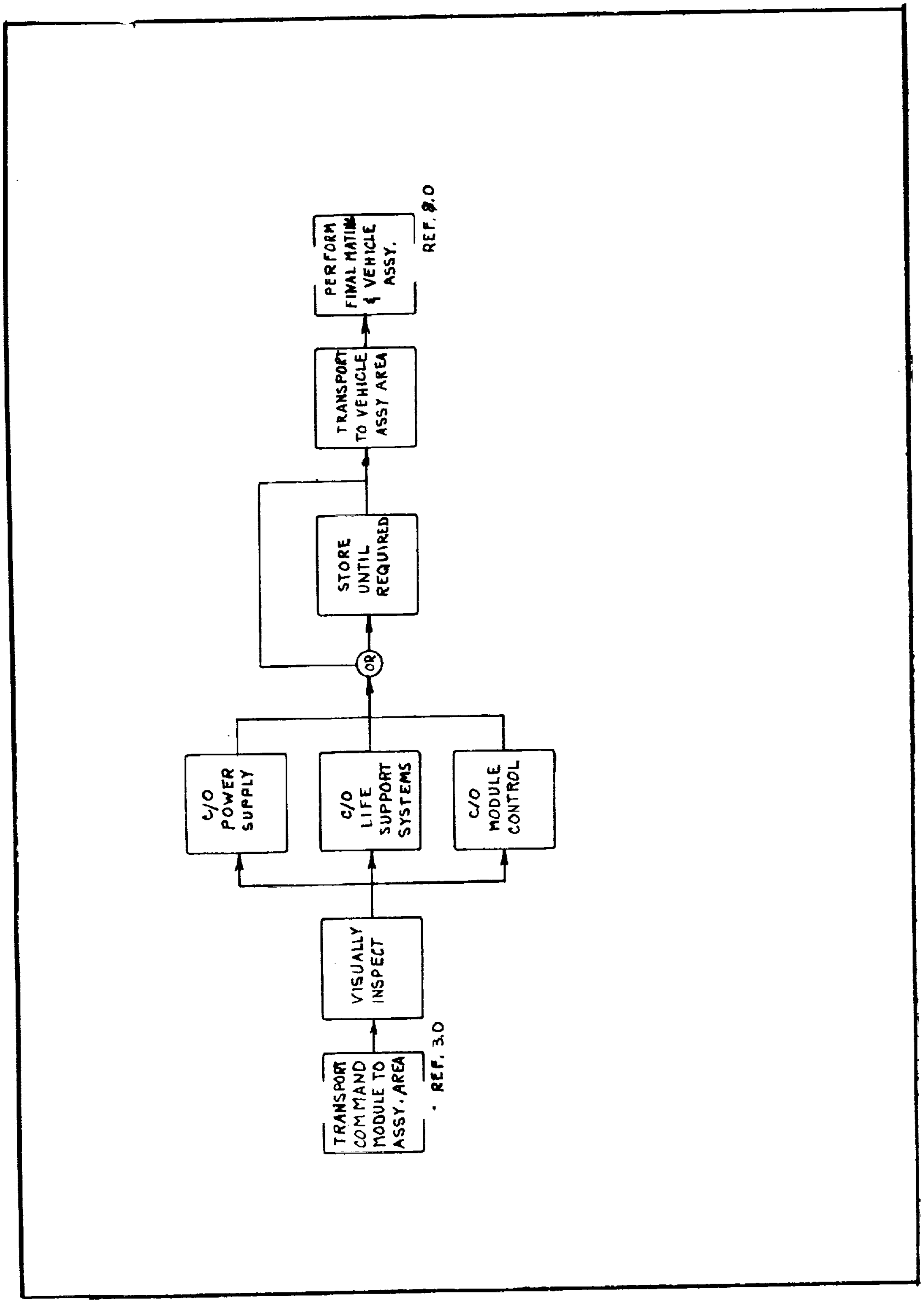
Assembly and c/o Stage I

Figure 5.0



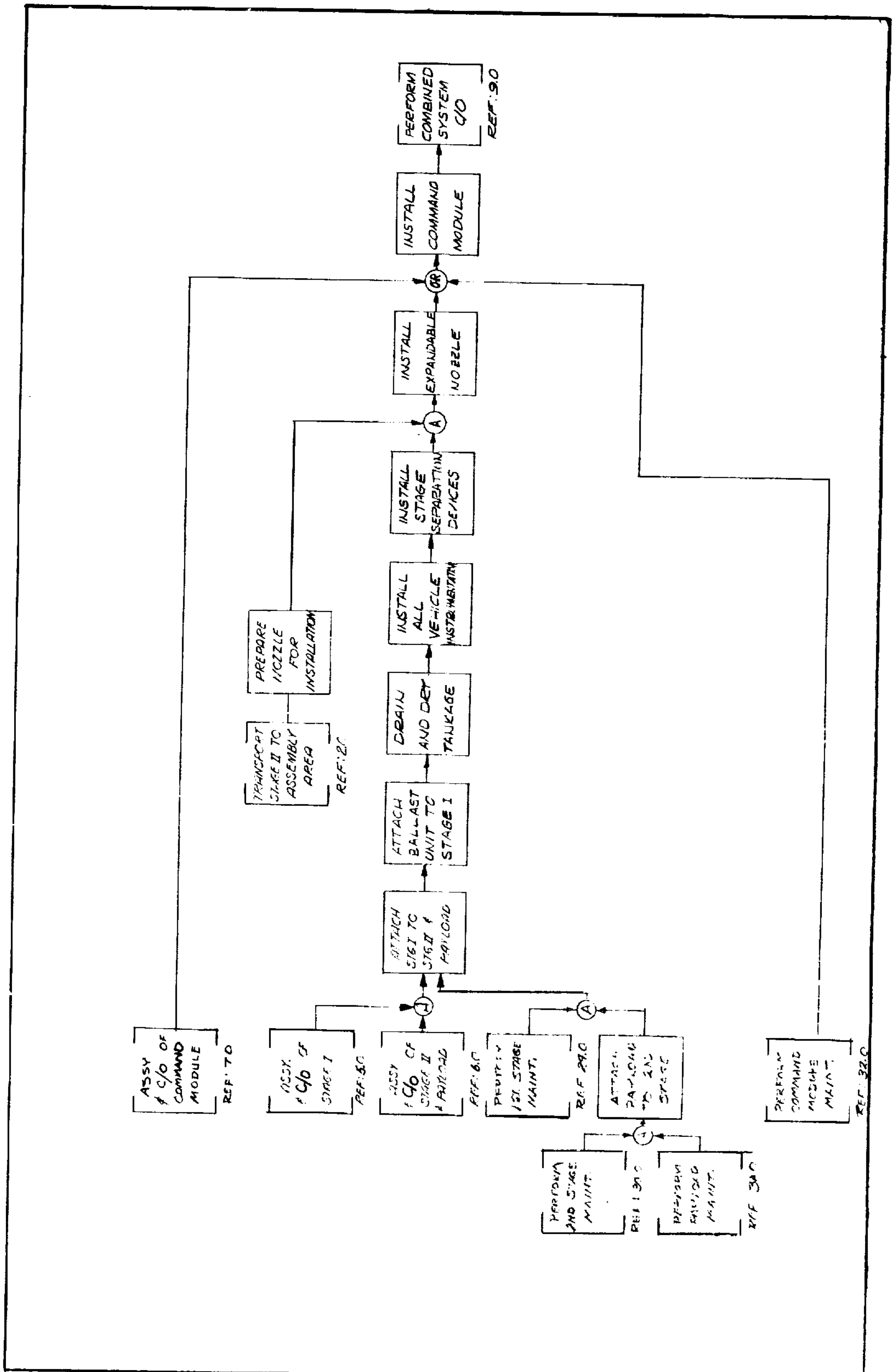
Assembly and c/o Stage II and Payload

Figure 6.0



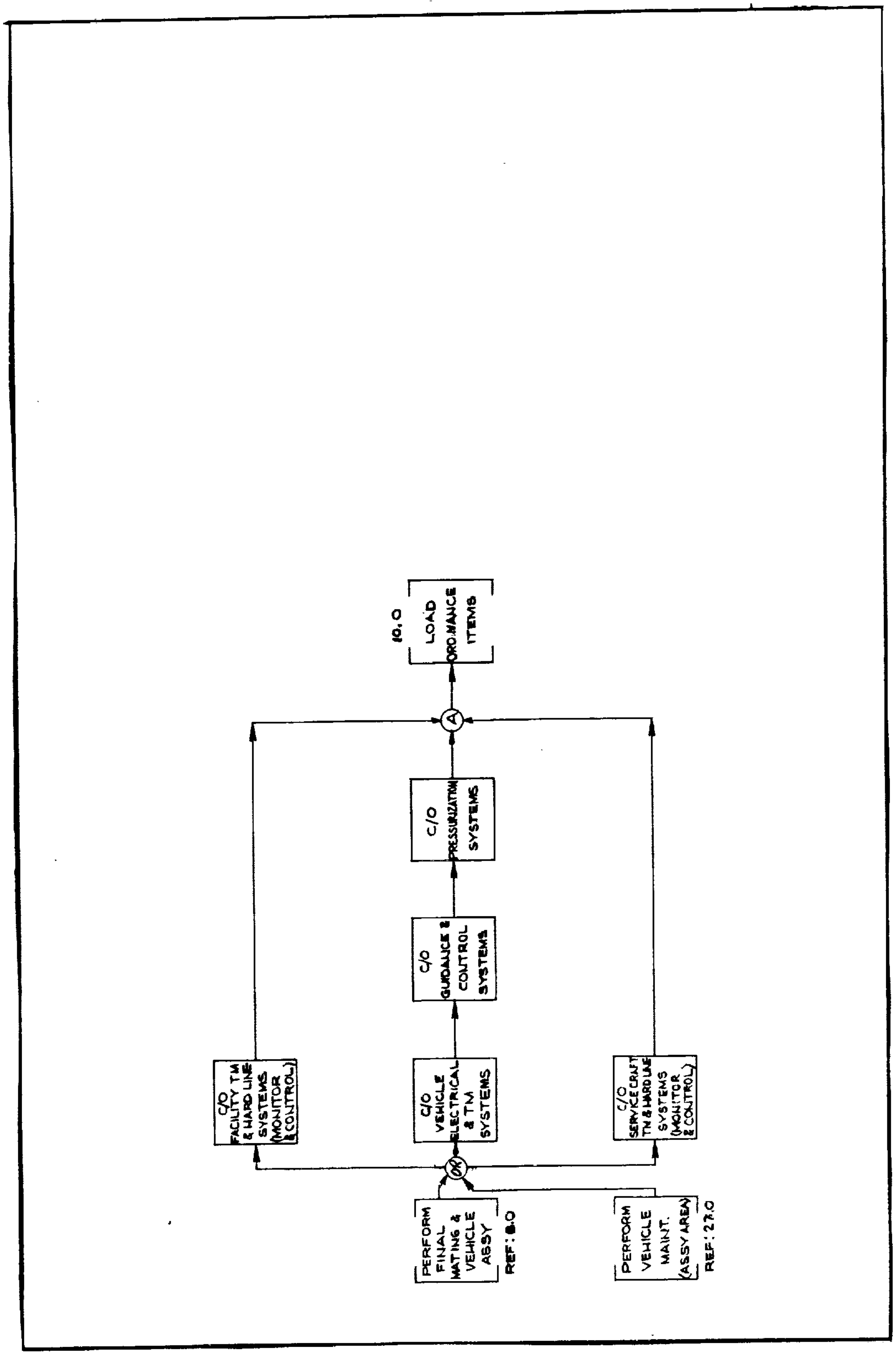
Assembly and Check Out of Command Module

Figure 7.0



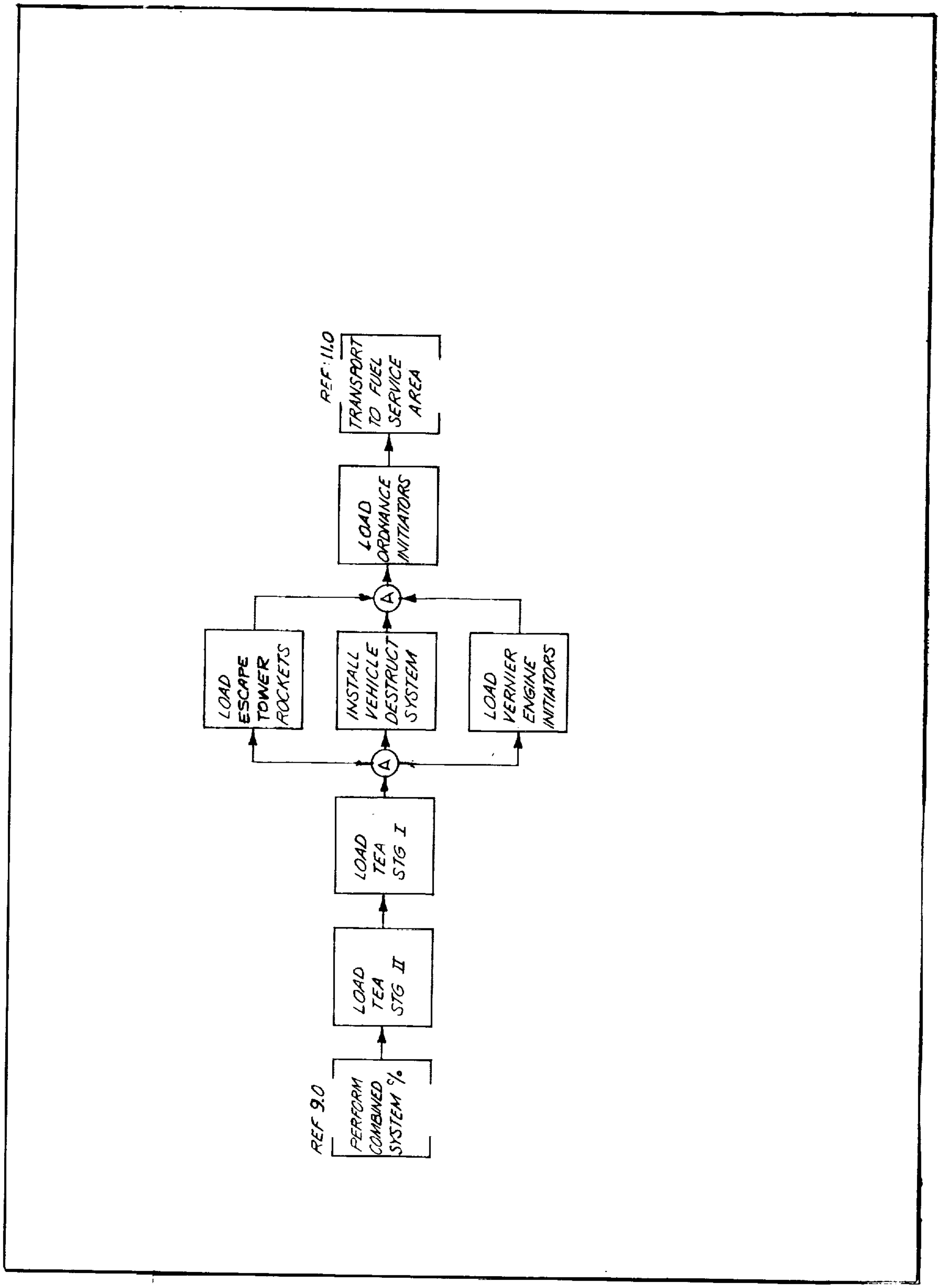
Perform Final Vehicle Mating and Assembly

Figure 8.0



Perform Combined Systems c/o

Figure 9.0



Load Ordnance Items

Figure 10.0

Transport to Fuel Service Area

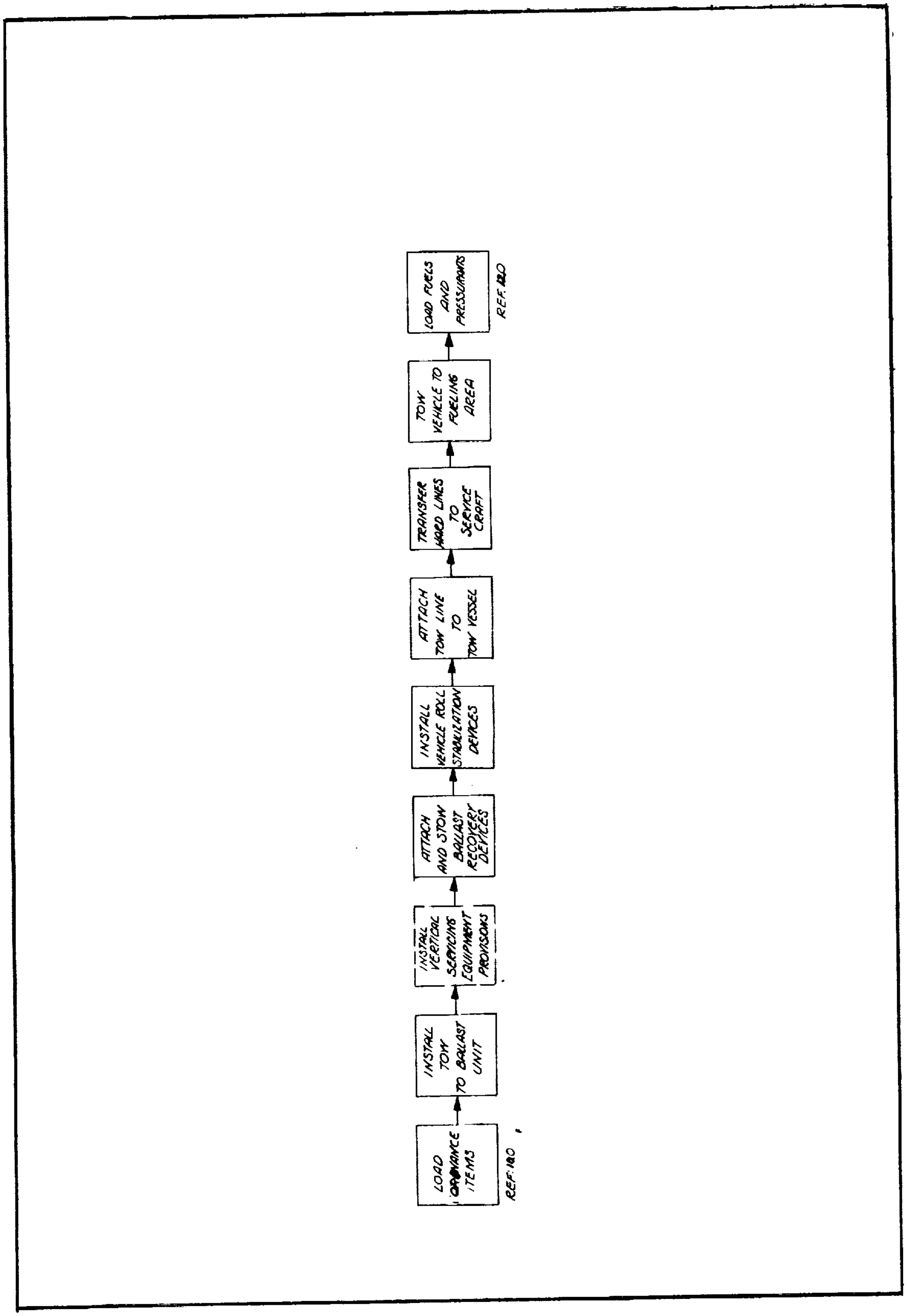
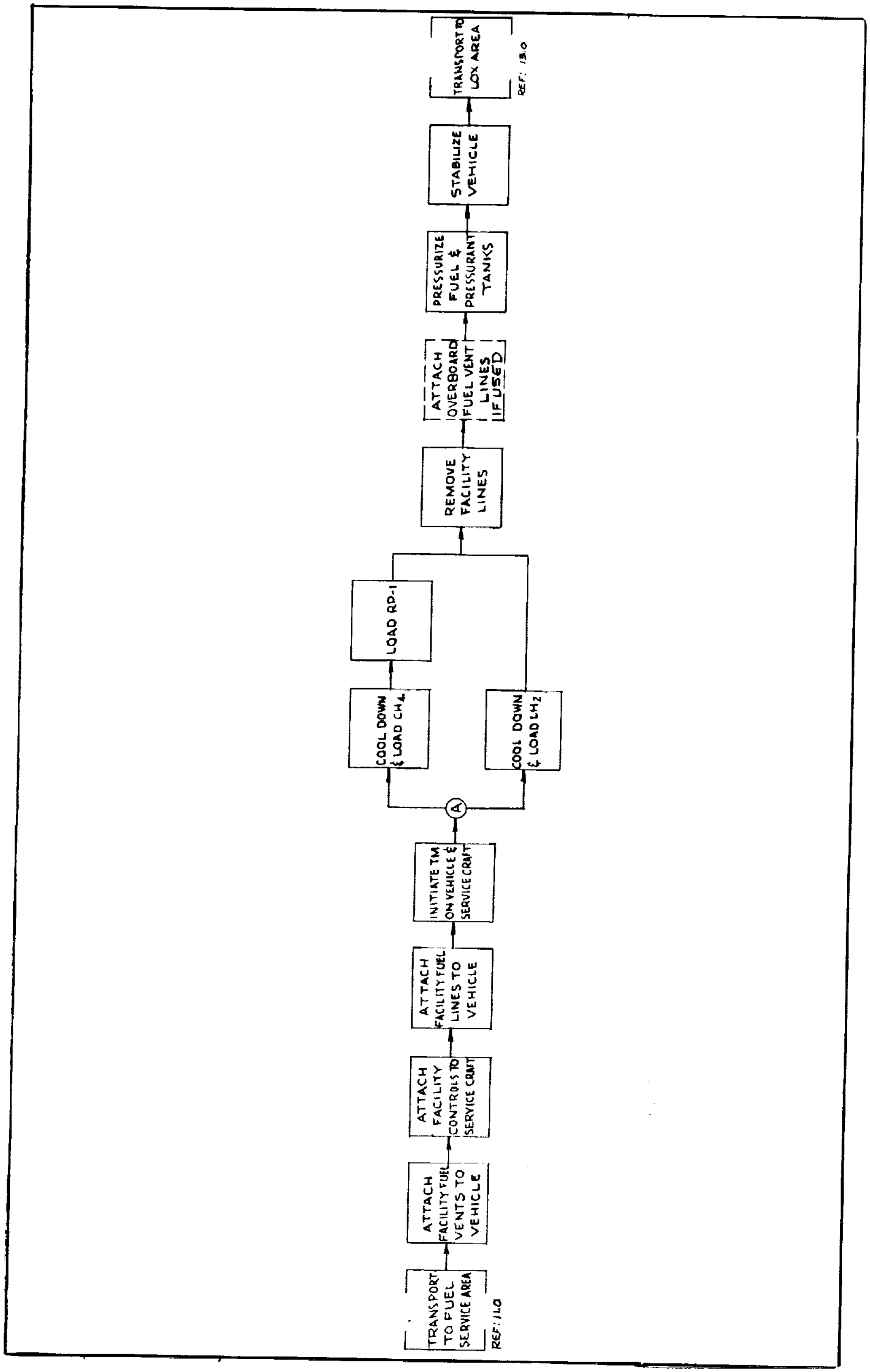


Figure 11.0



Load Fuels and Pressurants

Figure 12.0

LOX Load

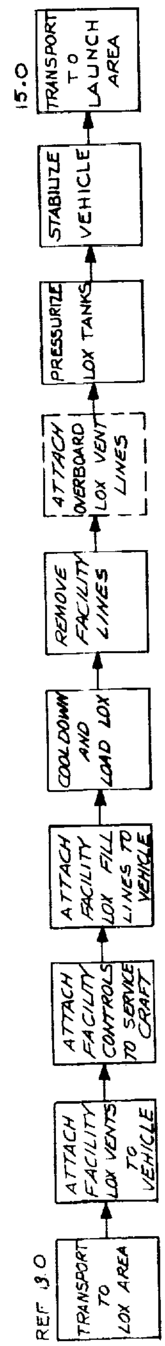
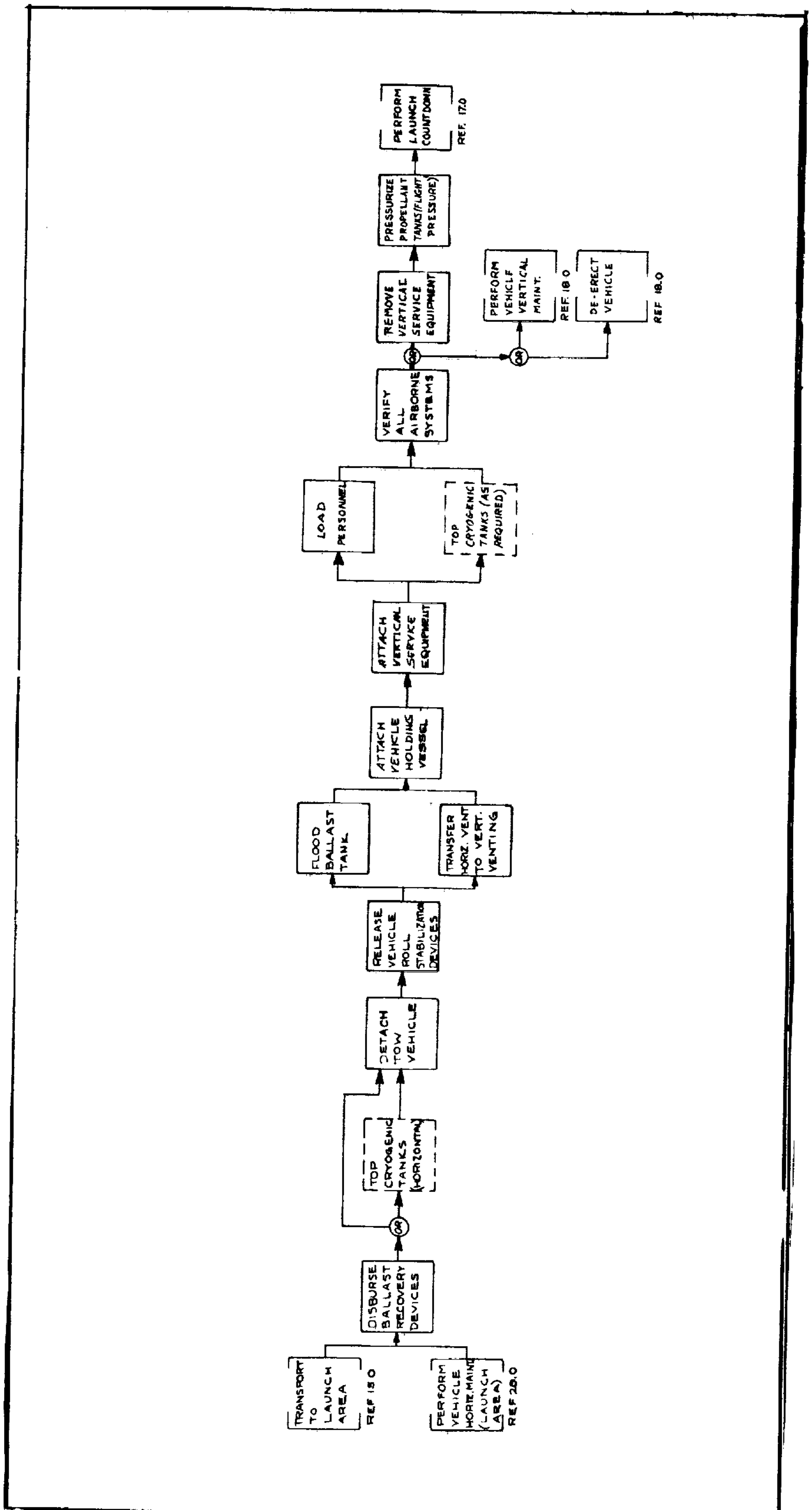
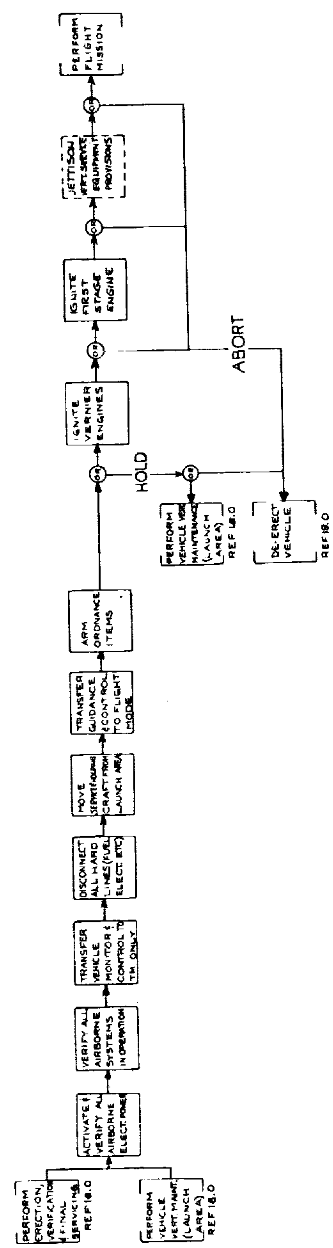


Figure 13.0



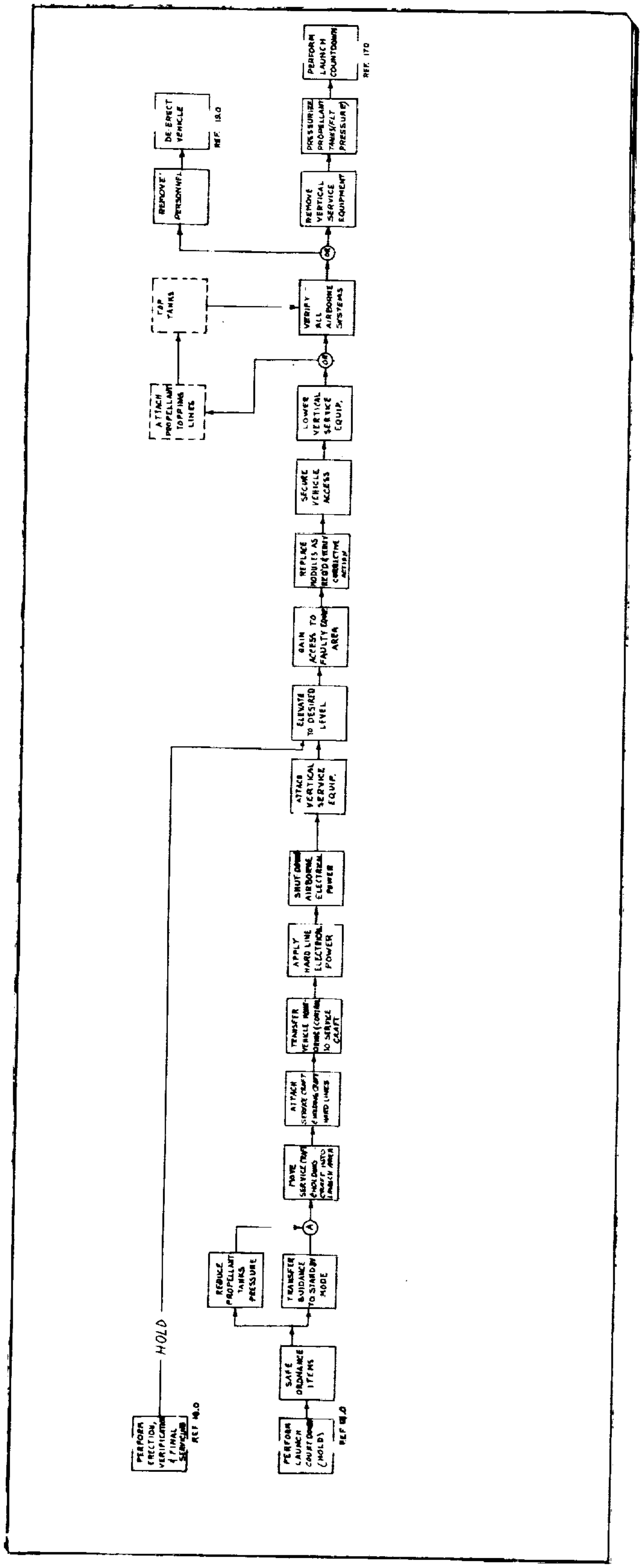
Perform Erection, Verification, and Final Servicing

Figure 14.0



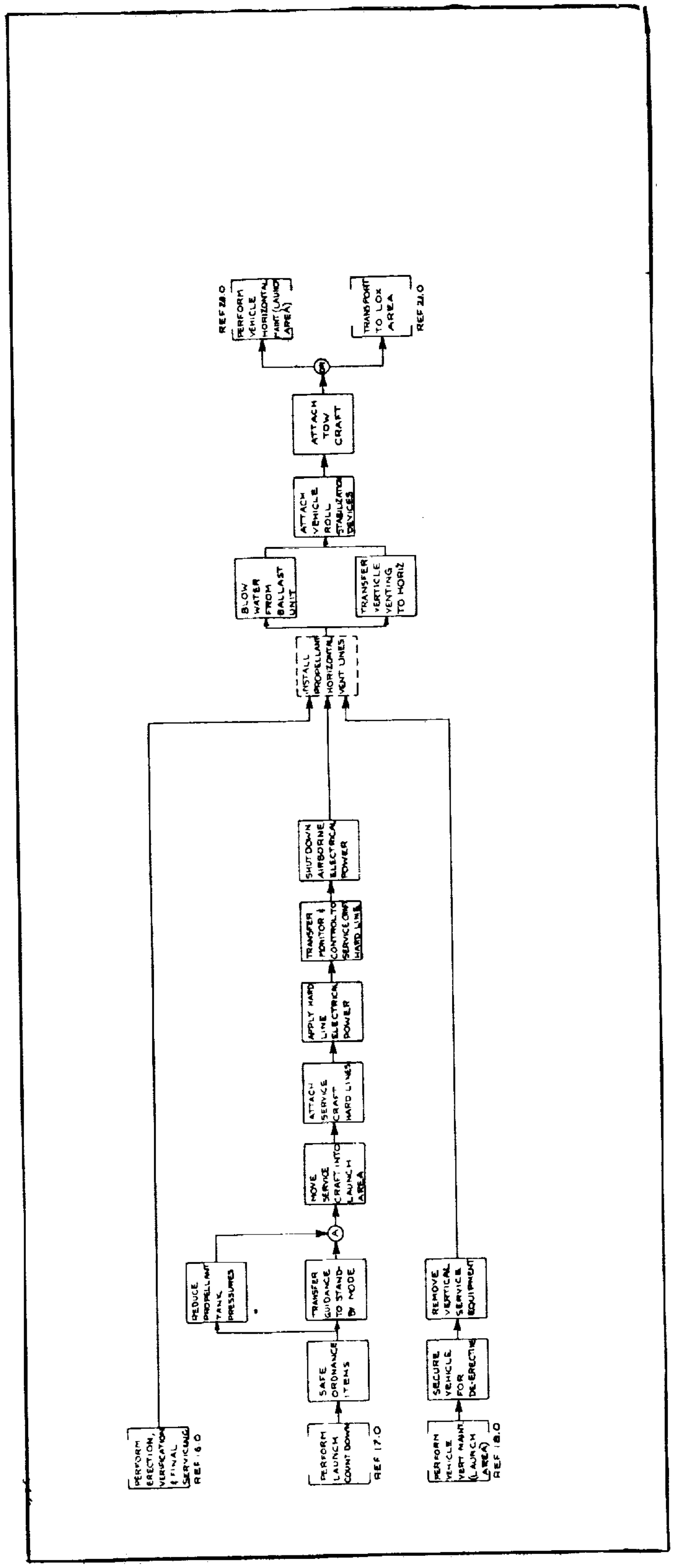
Perform Launch Countdown

Figure 15.0



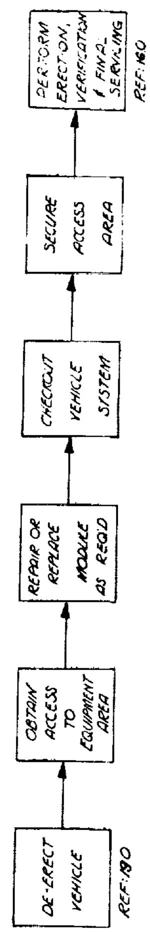
Perform Vehicle Vertical Maintenance

Figure 16.0



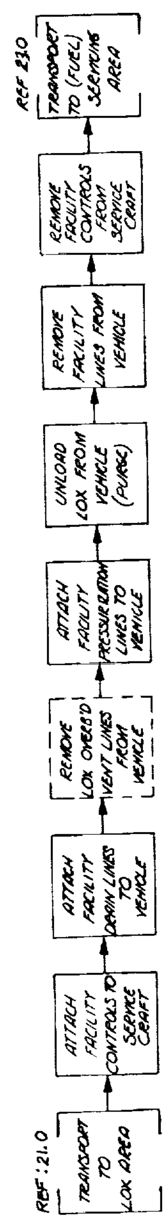
De-erect Vehicle

Figure 17.0



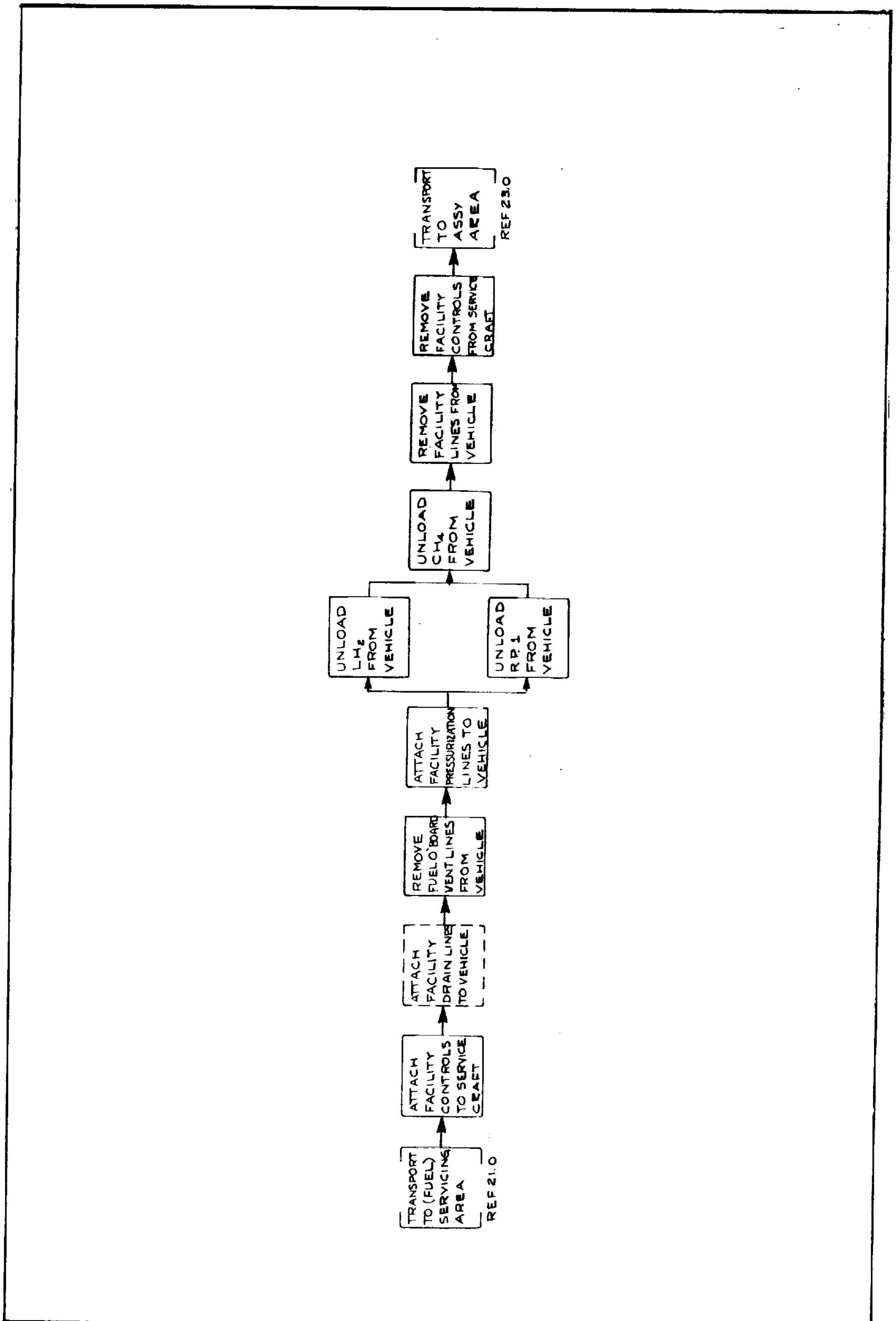
Perform Vehicle Horizontal Maintenance (Launch Area)

Figure 18.0



Unload LOX

Figure 19.0



Unload Fuels and Pressurants

Figure 20.0

Transport to Assembly Area

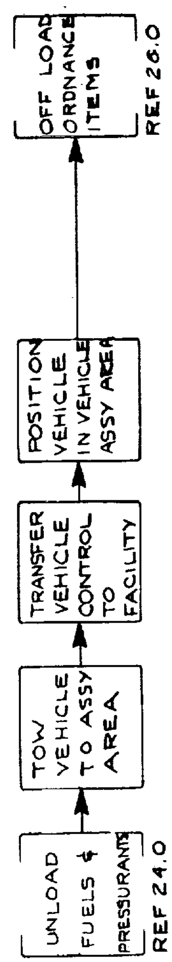
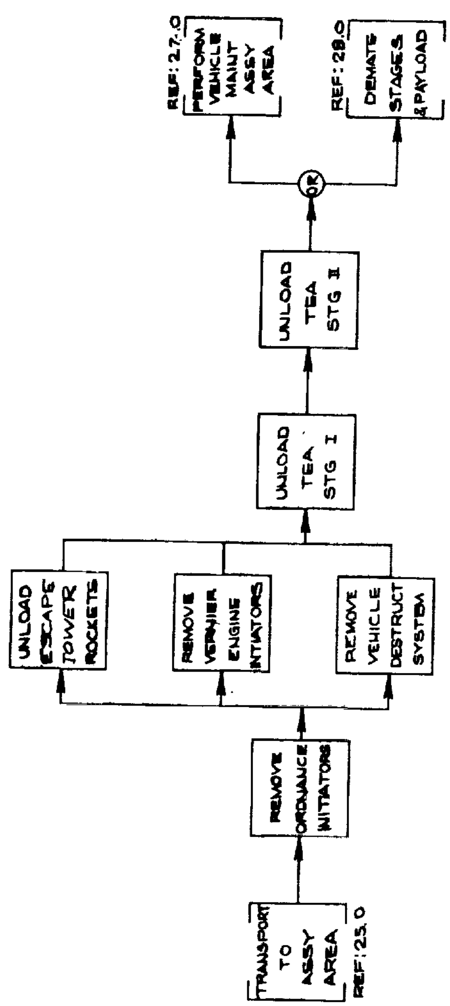


Figure 21.0



Off Load Ordnance Items

Figure 22.0

Recover Ballast Unit

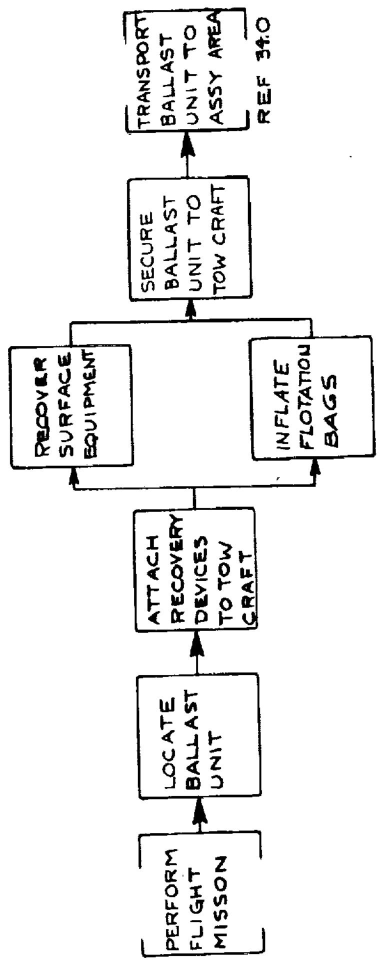


Figure 23.0

Transport Ballast Unit to Assembly Area

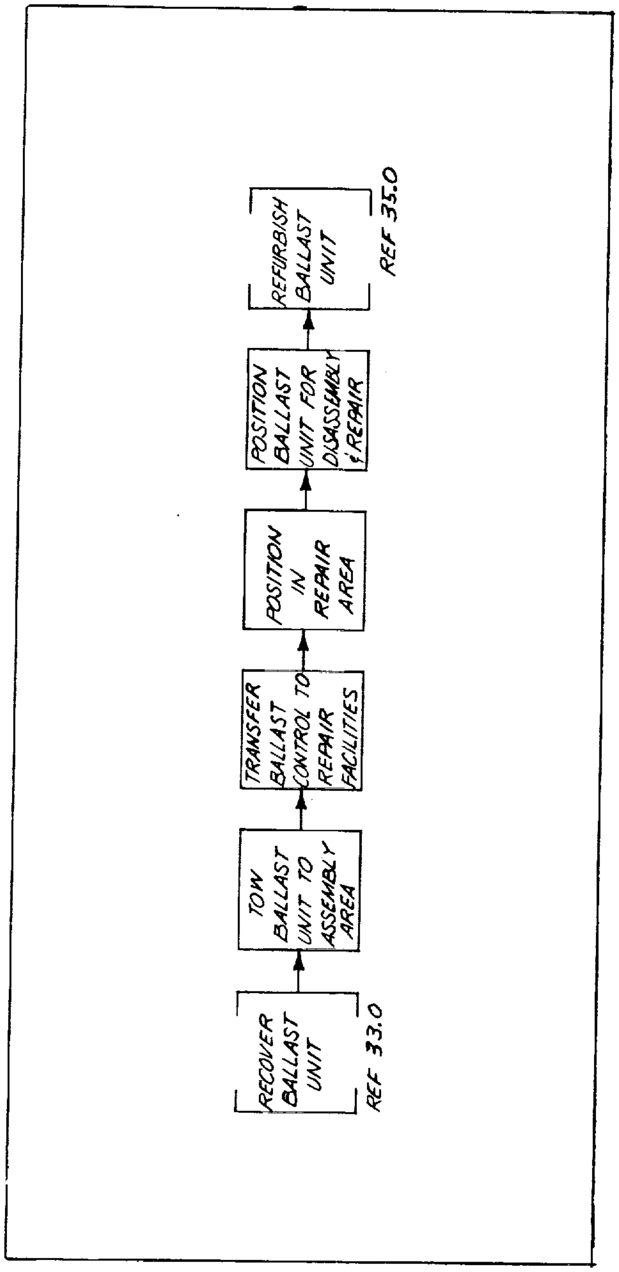
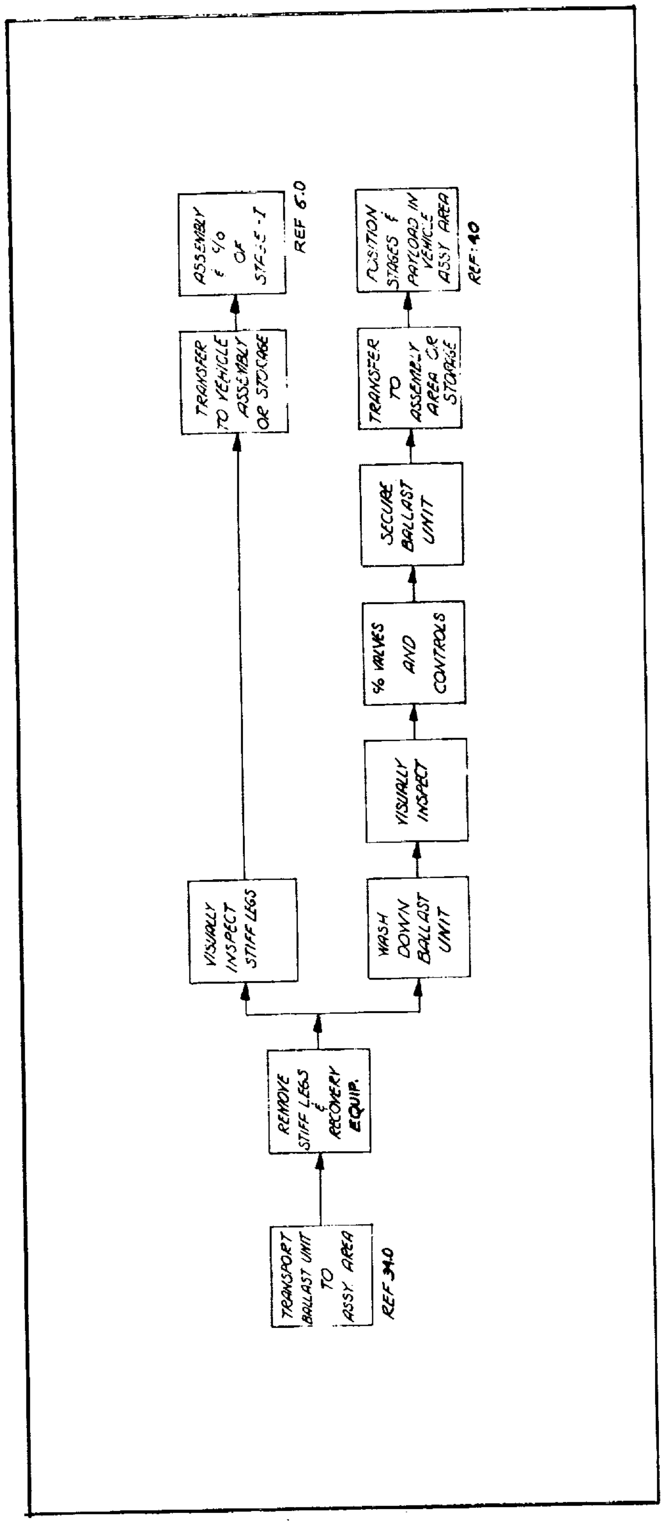


Figure 24.0



Refurbish Ballast Unit

Figure 25.0

Recover Stage I

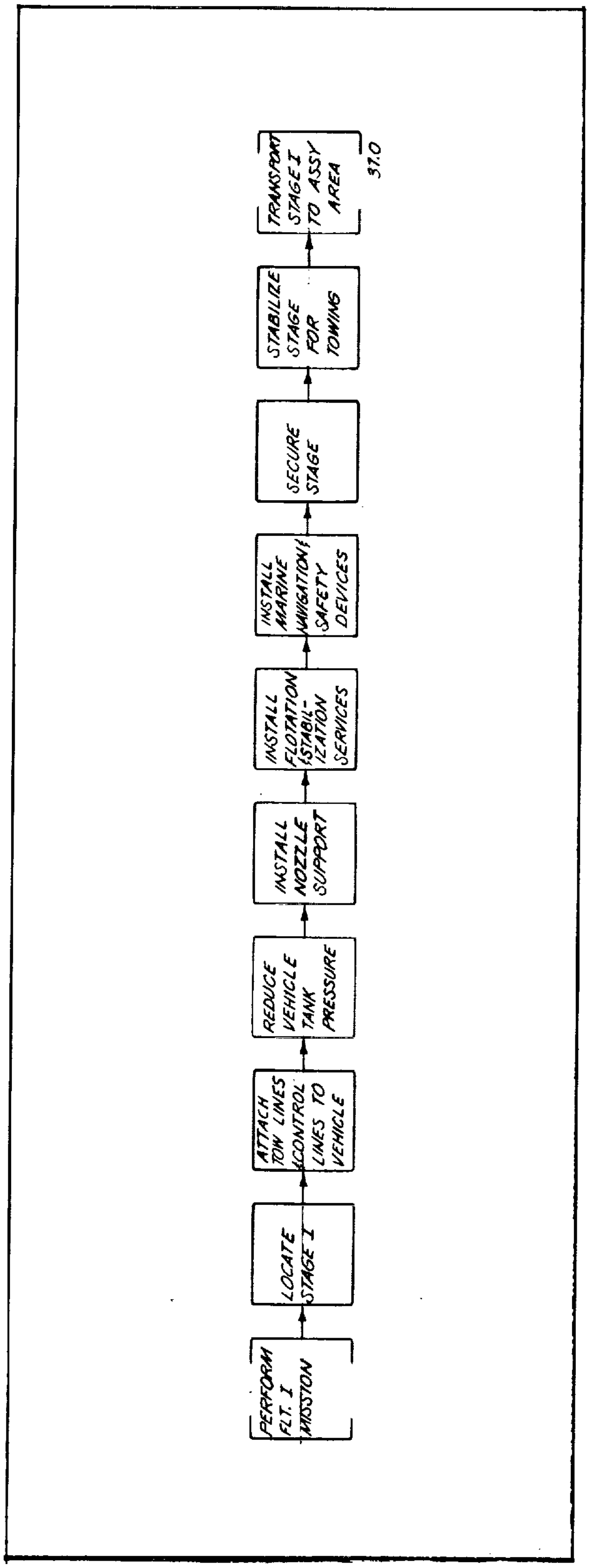


Figure 26.0

Refurbish Stage I

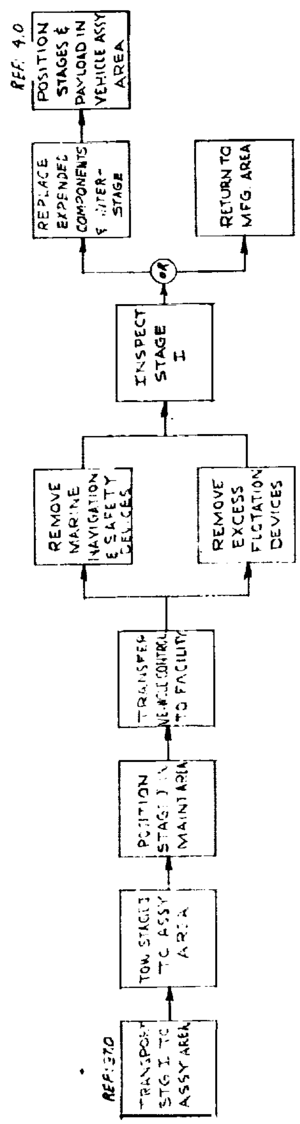


Figure 27.0

APPENDIX 4-2

EQUIPMENT AND MANPOWER LIST

I. INTRODUCTION

Detailed manpower requirements would necessitate more detailed study and analysis than has been possible in this study and therefore are not reflected in this report. The major equipment required to perform each total function is listed against each function or activity.

II. EQUIPMENT AND MANPOWER LIST

Function	Equipment	Manpower
1. Transport Stage I to assembly area	Ballast float bag or nozzle support unit	
	4 belts	
	Ballast transfer unit	
	2 sponsons	
	2 marine navigator lights	
	2 landing net ladders	
	1 sea-going tug boat	
2. Transport Stage II to assembly area	4 belts	
	Ballast transfer unit	
	2 sponsons	
	2 marine navigator lights	
	1 sea-going barge	
	4 vernier engine transtainers	
	2 landing net ladders	
	2 handling slings, expandable nozzle	
	1 sea-going tug boat	
3. Transport command module to assembly area	undetermined	
4. Position stages, payload, and service module	8 drilled in anchors	
	8 electric wrenches	
	2 work boats	
5. Assembly and C/O of Stage I	ballast float bags	
	1 service craft	
6. Assembly and C/O of Stage II	1 mobile crane	
	1 service craft	

II, Equipment and Manpower List (cont.)

Function		Equipment	Manpower
7.	Assembly and C/O of command module	Undetermined	
8.	Perform final mating and vehicle assembly	8 belts	
		2 ballast transfer units	
		4 sponsons	
		8 drilled in anchors	
		8 electic wrenches	
		2 mobile cranes	
		2 slings, expandable nozzle segment	
		1 portable brazing machine	
		2 work boats	
9.	Perform combined system check-out	1 service craft	
		1 launch control vessel or shore control facility	
10.	Load ordnance items	1 mobile crane	
		1 work boat	
11.	Transport to fuel area	Ballast Float Bags	
		4 belts.	
		2 ballast transfer unit	
		2 sponsons	
		2 landing net ladders	
		1 work boat	
		1 service craft	
		1 sea-going tugboat	
12.	Load fuels and pressurants	2 landing net ladders	
		4 drilled in anchors	

II, Equipment and Manpower List (cont.)

Function		Equipment	Manpower
		4 electric winches	
		1 service craft	
13.	Transport to LO_2 area	Same as 11.	
14.	Load LO_2	2 landing net ladders	
		6 drilled in anchors	
		6 electric winches	
		1 service craft	
		1 sea going tugboat	
15.	Transport to launch area	Same as 11.	
16.	Perform erection verification and final service	1 work boat	
		1 service craft	
		2 vertical service cars	
		6 ballast recovery buoys	
		1 launch control vessel	
17.	Perform launch count-down	1 service craft	
		1 launch control vessel or shore control facility	
18.	Perform vehicle vertical maintenance	1 service craft	
		2 service cars	
19.	De-erect vehicle	Ballast float bags	
		4 belts	
		2 ballast transfer units	
		2 sponsons	
		1 work boat	
		1 service craft	

II, Equipment and Manpower List (cont.)

Function	Equipment	Manpower
	1 sea-going tug boat	
20. Perform Horizontal maintenance	Undetermined	
21. to 26.	Same as 10 to 15	
27. Perform vehicle maintenance	Undetermined	
28. to 32.	Undtermined	
33. Recover ballast unit	1 work boat	
	1 service craft	
	6 ballast recovery buoys	
	1 sea-going tug boat	
34. and 35.	Undetermined	
36. Recover Stage I	2 landing net ladders	
	1 work boat	
	1 sea-going tugboat	
37. and 38.	Undetermined	

APPENDIX 4-3

THERMODYNAMIC CONSIDERATIONS IN PROPELLANT SERVICING

I. CHILL-DOWN OPERATIONS

Preliminary calculations were performed to determine the Sea Dragon chill-down requirements. It was assumed the chilling would be done with liquid nitrogen. Because the figures are approximate the results are conservative. The values were obtained by assuming that all of the heat extracted from the walls during chill-down goes into latent heat of vaporization of liquid N_2, and further that all of the heat leaking in also goes towards vaporizing N_2. The results are as follows:

	First-Stage LO_2	Second-Stage LO_2	Second-Stage H_2
N_2 required to initially chill tank	7.5×10^5 lb	1.1×10^5 lb	2.4×10^5 lb
N_2 required to keep tank cool (lb/hr)	7,800	3,600	5,900
Rate of temp. rise when cooling stops (°F/hr)	4.0	14.4	9.5

The approximation that tends to make the above results conservative is the ignoring of the vapor phase heat transfer. As the nitrogen boils, it gives off vapor at -320°F. This vapor will contact the walls and contribute significantly to chilling the tank, particularly in the first part of the chill-down process.

One problem would be in implementing the chill-down. If the required amount of nitrogen was simply poured into the tank, only that portion of the tank directly in contact with the liquid would be cooled. The remainder of the tank never would get chilled.

There are several solutions to this problem. The first would be to slowly rotate the vehicle so that the liquid N_2 would contact most of the tank surface. This would have to be continued until shortly before loading the propellants, as the wall temperatures would rise at a rapid rate once this rotating ceased.

I, Chill-Down Operations (cont.)

Another method would be to have a spray system inside the tanks to spray the liquid nitrogen against the walls. This should probably be a recirculating system to prevent the accumulation of large quantities of liquid nitrogen in the bottom of the tanks.

II. TRANSIENT EFFECTS IN LOADING AND STORING

A. SUMMARY

Following loading or pressurization of cryogenic propellants there may be a period during which the heat leaking into the tank raises the propellant temperature with no boil off occurring. It is shown that this transient period may extend over many hours, sharply reducing or eliminating topping off requirements. However, it is also shown that volumetric changes during this transient period can completely overshadow any beneficial effects for very long pre-launch holds.

B. INTRODUCTION

Because of the difficulties of storing cryogenic propellants under pressure, it is highly probable that immediately before loading the propellants will be at atmospheric pressure. Furthermore, as it is necessary to pressurize the propellant tanks to maintain structural integrity, it can be assumed that once the propellants are loaded they will be subjected to pressures substantially above atmospheric pressure. From this it is apparent that immediately following loading of the tanks the propellants will be subjected to pressures which are greater than the existing vapor pressure of the liquid causing all general boil off to cease immediately after loading and to resume when the propellant temperature has been increased to the point where its vapor pressure equals the existing tank pressure. This report describes what takes place during this no-boil-off period and how rapidly it occurs.

C. DISCUSSION

It will be assumed that the tanks have been pre-chilled and that very little cooling of the tanks is done by the propellants. It will also be assumed that the propellant in the tank is at a uniform temperature (low effective Biot modulus).

II, C, Discussion (cont.)

The strict validity of this assumption is questionable. Most likely there may be local hot spots at which boiling never ceases, so that there will always be a very slight amount of boil off. However, the coefficients of thermal expansion for both LO_2 and LH_2 are relatively high and will promote good convective mixing in the tanks. The discussion will cover only subjects of immediate interest to Sea Dragon.

1. First-Stage LO_2

The first stage LO_2 tank was sized to take propellant at -297°F. It is assumed that the tank is insulated enough to hold the boil off at 1% a day when loaded with LO_2 under atmospheric pressure, that loading takes place in a reasonably short time (several hours), and that the LO_2 is at -297°F when it enters the tank.

After the LO_2 tank is loaded and pressurized the LO_2 bulk temperature will begin to rise at about 0.092°F/hr. Because of this rising temperature the volume of the LO_2 will increase at a rate of 0.028%/hr. This will continue for about 4.5 days until the ullage space is filled with liquid. At the end of this period the bulk temperature would be -287°F and the LO_2 vapor pressure would be 26 psia.

Further heating of the LO_2 would result in losses being incurred because of LO_2 flowing out the vent line. These losses would amount to about 0.66% a day and are essentially independent of the tank pressure so long as it is greater than the LO_2 vapor pressure.

Losses due to volumetric expansion will continue at the above rate until the LO_2 vapor pressure equals the total pressure in the tank. Then boil

II, C, Discussion (cont.)

off will begin. However, at elevated LO_2 temperatures the boil off rates will be higher than the 1% a day figure as the latent heat of vaporization is lower at higher temperatures. Thus insulation which allows 1% boil off a day at -297°F allows 1.2% at -275°F, 1.7% at -250°F, and 2.65% at -225°F.

The losses incurred due to thermal expansion cannot be replaced by simply topping off, as the tank would already be filled to the top with LO_2. The only method by which these losses can be replaced is by chilling down the LO_2 in the tank. One possible method of performing this would be to vent the tank to atmospheric pressure and allow it to cool itself. This of course will result in further LO_2 losses. The magnitude of these losses can be computed from results given in another report. Unfortunately, depressurizing the tank may be impossible for structural reasons.

There exists other alternatives to the problems associated with long (over 4.5 day) hold periods. One is to simply increase the insulation and thereby increase the length of the no-loss period. Another method is to increase the tank volume to enable it to hold the lower density LO_2. This method was adopted for the configuration presented in this study. A third method is to pre-chill the LO_2. Chilling the LO_2 to about N_2 temperatures would give either approximately 15 days of no-loss hold time or else would allow the tanks to be made smaller.

2. Second-Stage LO_2

The problems associated with the second-stage LO_2 tanks are quite unlike those of the first-stage LO_2. The second-stage LO_2 tank is to be VāPaked and thus requires storage at elevated temperatures and pressures.

II, C, Discussion (cont.)

As the LO_2 most likely will be loaded at operating temperatures and pressures there will be no transient period. Hence boil off will begin immediately after loading.

Perhaps the only significant observation to be made concerning the second-stage LO_2 is that it should not be stored with the first-stage LO_2. If they are stored together the second-stage LO_2 should be heated to operating temperature during the loading operation to avoid a long mandatory pre-launch hold.

Similarly any topping off of the second stage should be done with LO_2 that is at the operating temperature. Any topping which is done with hotter or colder LO_2 could upset the VāPak system.

Because the tank is sized to take the heated LO_2, no difficulties will be encountered from volumetric expansion.

3. Second-Stage Hydrogen

In discussing the hydrogen system it will be assumed that the insulation of the hydrogen tank is sufficient to maintain boil off at 5%/day when the H_2 is under atmospheric pressure. Further it will be assumed that the hydrogen is loaded at about -423°F and is pressurized to 55 psia after loading. This is the pressure required to maintain structural integrity once the vehicle is loaded. The pressure will be assumed fixed at this level until it is elevated to operating level immediately before light off.

Once the hydrogen is loaded it will begin to heat up at a rate of about 0.15°F/hr. This will continue until the hydrogen bulk temperature attains

II, C, Discussion (cont.)

a value of about -413°F. The length of time required for this to take place will be from 40 to 66 hr, depending on the amount of pre-chilling. During this period of no boil off the hydrogen experiences about a 10% volumetric change. Because the tank is sized for the less dense state, during the no-boil off period only a reduction in excess capacity occurs.

If the tank is filled to the top with propellants when initially loaded, it will have about 10% more propellant in it than is required. During the pre-launch hold this excess propellant will gradually be lost as it runs out the vent line in the liquid state. Should the vehicle be launched while it has an excess of hydrogen the hydrogen can be utilized by changing the propellant mixture ratio.

The boil off rate at -413°F will be about 20% greater than that at -423°F. As noted earlier for the LO_2 this is primarily a result of a lower latent heat of vaporization at the elevated temperature.

Topping off the hydrogen presents no problem. Topping with hydrogen at -423°F will temporarily stop boil off and increase the tank capacity by chilling the hydrogen already in the tank.

PART 5

SEA DRAGON COST ANALYSIS

I. SUMMARY

The cost analysis indicates that specific payload transportation costs (based on direct costs) of \$10-\$20/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-\$30/lb. From these results, it appears that Sea Dragon clearly offers substantial economies in the transport of heavy space payloads.

II. INTRODUCTION

Sea Dragon is a large, two-stage liquid propellant launch vehicle designed to carry approximately one million pounds of payload per successful launch into a 300 n.m. earth orbit. The first stage may be expendable or recoverable. The second stage is expendable. It is desired to determine the cost effectiveness of this system to permit a comparison with other existing and proposed launch vehicle systems on two operational bases: 120 launches in a 10 yr operational period, and 240 launches in a 10 yr operational period. Characteristics of the vehicle, tentatively established by the Sea Dragon conceptual studies currently underway at Aerojet-General are as follows:

A. VEHICLE DATA	1st Stage	2nd Stage
Thrust (lb)	80×10^6 (SL)	14.12×10^6 (vac)
Mixture ratio, O/F	2.3 to 1	5 to 1
Fuel	RP-1	LH_2
Fuel tank volume	156,851 (cu ft)	374,017 (cu ft)
Oxidizer	LOX	LOX
Oxidizer tank volume, (cu ft)	254,471	112,410

B. WEIGHT (LB)			Totals
Propellants:			
LOX	17,853,568	8,057,045	25,910,613
RP-1	7,759,812		7,759,812
LH_2		1,619,509	1,619,509

II, B, Weight (lb) (cont.)

Propellants	1st Stage	2nd Stage	Totals
Methane	178,000	-	178,000
Tankage	1,416,765	420,437	1,837,202
Other Structure	243,746	235,784	479,530
Engine System (Dry)	611,400	102,770	714,170
Expandable Nozzle	--	71,500	71,500
Miscellaneous	87,168	54,177	141,345
Sub-Total	28,150,459	10,561,222	

TOTAL LAUNCH VEHICLE	38,711,681
PAYLOAD	1,205,000*
GRAND TOTAL	39,916,681

III. COST EFFECTIVENESS EQUATION

The criterion of cost effectiveness assumed for this analysis is:

$$E = \frac{C}{W} \qquad (1)$$

where

E = program cost effectiveness, average dollars/lb. of payload successfully delivered into orbit

C = total cost, dollars

W = total pounds of payload successfully delivered into orbit

For highest program cost effectiveness, E must be minimized.

* This payload value was used rather than the payload for configuration No. 135 as it is presently defined (1,030,000 lb) in order to present a clearer picture of the actual cost effectiveness of the system. Changes in the vehicle design to use more optimum staging and materials alone will result in a payload of 1.2 million lb. Other conservative design improvements presently under study will result in further performance increases. The effect of changes in payload delivery capabilities upon specific transportation costs can be determined by using Figure 5-8.

IV. PAYLOAD CONSIDERATIONS

The total payload successfully delivered into orbit,

$$W = wNR_1R_2 \tag{2}$$

where:

W = payload carrying capability of one vehicle, (lb)

N = total number of launches

R_1 = average reliability of first stage, launch through stage separation

R_2 = average reliability of second stage, from stage separation to orbital injection.

V. ELEMENTAL COST EQUATIONS

The total cost, C, may be considered to consist of the sum of direct operating cost and indirect operating cost, or

$$C = O + I$$

Direct operating cost, O, may be subdivided into:

V = vehicle production cost, including manufacturing facilities and equipment

P = propellant cost

T= vehicle transportation cost from factory to launch site (not including recovery transportation)

L = vehicle launch cost (personnel services required to assemble, checkout fuel, and launch the vehicle)

M = vehicle maintenance and repair services (only for recoverable stages), including recovery of vehicle, transport to refurbishment site, and refurbishment

V, Elemental Cost Equations (cont.)

Indirect operating cost, I, may be subdivided into:

- R = range and general overhead cost
- G = surface-based support equipment cost
- F = launch facility cost, including facilities for assembly and checkout of vehicle at assembly lagoon (and including refurbishment facilities for recoverable version only)
- D = system development cost

A number of these cost elements can be represented as functions of vehicle operating parameters. In the following paragraphs, these will be considered individually. A 90% learning curve is assumed for the entire program, a value considered representative of aerospace industry experience.

A. V, VEHICLE PRODUCTION COST

Because the second stage is not recoverable, the number of second stages to be produced is equal to the number of launches, N. The production cost of second stages is:

$$V_2 = Nv_2$$

where:
- V_2 = total production cost of second stage vehicles
- N = number of launches
- v_2 = average unit manufacturing cost of second stage

Because the first stage may be recoverable, the number of first stages produced will vary with the reliability of the launch and recovery operations. Thus, noting that the number of first stages produced must equal the number

V, A, V, Vehicle Production Cost (cont.)

of first stages lost due to unreliability, we obtain the following expression for first-stage production cost:

$$V_1 = Nv_1 \ (1-R_1R_R)$$

where V_1 = total production cost of first stage

v_1 = average unit manufacturing cost of first stage

R_R = average reliability of first-stage recovery, from separation to splash

Thus, total production cost is

$$V = V_1 + V_2$$

or

$$V = Nv_1 \ (1-R_1R_R) + Nv_2 \qquad (3)$$

Obviously, where recovery is never attempted, or where recovery always fails, then R_R becomes zero and the above equation reduces to

$$V = Nv_1 + Nv_2 = N(v_1 + v_2)$$

However, we will employ the more general equation (3) in this analysis to provide for the case of successful recovery.

B. P, PROPELLANT COST

Total propellant cost is determined by number of launches, and propellant cost per launch, as modified by a propellant utilization factor to

V, B, P, Propellant Cost (cont.)

account for losses of propellants due to boil-off prior to launch.

$$P = N(u_1p_1 + u_2p_2)$$

where
u_1 = average utilization factor for first-stage propellants
p_1 = average cost of one load of first-stage propellants
u_2 = average utilization factor for second stage propellants
p_2 = average cost of one load of second-stage propellants

C. T, TRANSPORTATION COST

Total transportation cost is determined by the number of stages transported and the cost of transporting a stage. The number of second stages transported from factory to assembly lagoon is equal to the number of launches. The number of first stages transported from factory to assembly lagoon is equal to the number of first stages manufactured. The number of complete vehicles transported from assembly lagoon to launch site is equal to the number of launches. Thus,

$$T = Nt_2 + N(1-R_1R_R)\,t_1 + Nt_{1,2}$$

where:
t_2 = average cost of transporting one second stage from factory to assembly lagoon
t_1 = average cost of transporting one first stage from factory to assembly lagoon
$t_{1,2}$ = average cost of transporting one complete vehicle from assembly lagoon to launch site

V, Elemental Cost Equations (cont.)

D. L, VEHICLE LAUNCH COST

Total launch cost is equal to number of launches times cost per launch, or

$$L = Nl$$

where l = average cost of launching one vehicle

E. M, VEHICLE MAINTENANCE AND REPAIR

Total vehicle maintenance and repair cost is determined by the number of vehicles recovered and refurbished and the unit cost of recovery and refurbishment, or

$$M = NR_1R_Rm_1$$

where m_1 = average unit cost of first-stage recovery, transportation to assembly lagoon and refurbishment.

VI. COMBINED COST EFFECTIVENESS EQUATION

Rewriting equation (1) now, with the new values generated for C and W, we obtain

$$\begin{aligned} E = \Big[& Nv_1 (1-R_1R_R) + Nv_2 + N(u_1p_1 + u_2p_2) + Nt_2 \\ & + N(1-R_1R_R)t_1 + Nt_{1,2} + Nl + NR_1R_Rm_1 \\ & + R + G + F + D \Big] \left[wNR_1R_2 \right]^{-1} \end{aligned} \tag{4}$$

VII. DETERMINATION OF COSTING FACTORS

To generate useful cost effectiveness values for the Sea Dragon program, it is necessary to derive the values of the parameters of equation (4). This will be done in the following sections. In each case, three values of the parameter are provided: "most probable," "optimistic," and "pessimistic," to indicate the effects of optimism on the specific transportation costs of the Sea Dragon system.

In calculating the values of cost factors that are dependent on the number of vehicles to be launched, it is useful to consider the rate of launchings necessary to fulfill the stated program requirements of 120 and 240 launches in a 10 yr operational period. The following table shows the number of launches that must be accomplished in each program year to meet these objectives, assuming that the 90% learning curve (accepted as a premise of this analysis) applies to the launching of vehicles, as well as to other appropriate program elements.

Operational Year	No. of Launches Each Year: For 120 Launch Schedule	No. of Launches Each Year: For 240 Launch Schedule
1	8	16
2	10	20
3	11	22
4	12	24
5	12	25
6	13	25
7	13	26
8	13	27
9	14	27
10	14	28
TOTAL LAUNCHES	120	240

VII, Determination of Costing Factors (cont.)

The above table shows that eight launches must be accomplished in the first year to meet the 120 launch objective, and 16 must be accomplished to meet the 240 launch objective. Similarly, it can be assumed that if we provide manufacturing, assembly, check-out, fueling and towing facilities and equipment adequate for these first-year rates, those facilities need not be increased for the indicated higher launch rates later in the operational period. The following discussion is based upon this premise.

As an additional general consideration, it is useful to note that, as the size of a rocket vehicle increases, many of the elements of cost associated with development and production either do not increase at all, or increase at a slower rate than does size. For example, in Sea Dragon one can expect that, although the vehicle is very large compared to current vehicles, there should be no significant increase in costs (as compared to smaller vehicles) associated with engineering, design, engineering overhead, guidance system, telemetry, launch control crew services, tracking, data reduction, supporting research, wind tunnel model tests, recovery model tests, materials testing and selection, launch control equipment, range safety instrumentation, program management, reports and documents, and field technical liaison.

Also, as has been pointed out by Koelle and others, manufacturing labor costs do not increase linearly with vehicle gross weight. This is partially because manufacturing labor is more closely proportional to the surface area of materials processed, than to the volume (or the weight) of materials processed. For example, where Sea Dragon weighs (at liftoff) about 130 times as much as Atlas,

VII, Determination of Costing Factors (cont.)

its surface area is only about 40 times that of Atlas. Taking account, further, of the relative simplicity of Sea Dragon design, and the benefits of using shipyard fabrication techniques, it is not unreasonable to discover that Sea Dragon unit manufacturing costs are about 30 times the unit cost of Atlas (as this analysis shows).

A major reason for the relative simplicity and low cost of Sea Dragon is the use of a pressurized propellant feed system rather than a pump-fed system. Aerojet-General's experience (and this is generally borne out by Rocketdyne experience as well) indicates that (1) the manufacture of a pressure-fed system can be expected to cost only about 42% as much as a pump-fed system, (2) R and D test operations cost only about 57% of pump-fed, and (3) test hardware and propulsion engineering cost only 50% of pump-fed systems.

A. PRODUCTION COST PARAMETERS

In the course of the current Sea Dragon study, Aerojet-General obtained rough-order-of-magnitude quotations from five shipyards for the manufacture of 120 units of first-and second-stage tankage over a 10 yr delivery period. The average cumulative unit manufacturing cost from these quotations was $6.05/lb., including manufacturing facilities and tooling. A major contributor to this relatively low cost was the proposed use of existing shipyard facilities rather than new facilities. Applying the 90% learning curve of Figure 5-1, Sea Dragon tank costs of $12.60/lb were obtained and used as the basis for pricing first-unit tankage.

VII, A, Production Cost Parameters (cont.)

In-house cost studies yielded the following first unit costs for other vehicle elements:

1.	"Other structure" (including skirts and propellant lines)	\$18.80/lb
2.	"Engine system" (including gimbal, actuators, injector, thrust chamber, propellant valves, and heat exchanger)	\$24.42/lb
3.	Expandable nozzle	\$6.92/lb
4.	"Miscellaneous" (including insulation, guidance, electrical, hydraulic, pneumatic, etc.)	\$40.00/lb
5.	Ballast Unit	\$2.00/lb

Applying these cost factors to the weights of Sea Dragon yields the following table:

VII, A, Production Cost Parameters (cont.)

CALCULATION OF FIRST UNIT PRODUCTION COSTS

First Stage, Dry	wt., lbs.		1st Unit Cost
Tankage	1,416,765	at $12.60/lb	$17.85M
Other Structure	243,746	at $18.80/lb	$4.58
Engine System	611,400	at $24.42/lb	$14.92
Miscellaneous	87,168	at 40/lb	$3.48
	2,359,079		$40.83M or $17.30/lb
Second Stage, Dry			
Tankage	420,437	at $12.60/lb	$5.30M
Other Structure	235,784	at $18.80/lb	$4.42
Engine System	102,770	at $24.42/lb	$2.50
Expandable Nozzle	71,500	at $ 6.92/lb	$ .49
Miscellaneous	54,177	at 40/lb	$2.16
	884,668		$14.87M or $16.80/lb
Ballast Unit, dry	**wt., lbs.**		**1st Unit Cost**
Ballast Unit, dry	3,000,000	at $ 2.00/lb	6.00M
Total Second Stage and Ballast Unit			($20.87M)
Total Vehicle (first unit) w/ballast			$61.7M

VII, A, Production Cost Parameters (cont.)

Summary	Optimistic	Pessimistic	Most Probable
1st Stage (v_1)	\$30 M	\$50 M	\$40 M
2nd Stage plus ballast (v_2)	\$15 M	\$25 M	\$20 M

The first and second stages (neglecting for a moment the ballast unit, which is not a flyable unit) average out at \$17.20/lb. This figure appears reasonable when compared with other shipyard-built equipment as follows:

	Mfg. \$/lb
Sea Dragon Launch Booster	17.20
USS Nautilus (Nuclear submarine, experimental)	14.10
USS Scamp (Nuclear submarine, attack)	8.85
USS George Washington (Nuclear submarine, Polaris)	9.81
USS Andrew Jackson (Nuclear submarine, Polaris)	7.83
USS Long Beach (Nuclear guided missile cruiser)	11.40
USS Enterprise (Nuclear attack aircraft carrier)	2.60
Oil Tanker	.50

B. PROPELLANT COST PARAMETERS

Propellant usage has been costed using the values generated in the following table. "Optimistic", "Pessimistic" and "most probable" values of propellant costs and of utilization factors are shown in the Summary of Cost Parameter Values provided at the end of this report. (Tables 5-6 through 5-13.)

Propellant costs for engine testing shown in the section on Development Cost Parameters were taken, for conservatism, at three times the values generated in this table:

BASIS FOR COSTING PROPELLANT USAGE

ACTIVITY	PROPELLANT	PROPELLANT WT. LB.	$/LB.	COST OF PROPELLANT USED PER ACTIVITY	UTILIZATION FACTOR u	COST OF PROPELLANT REQ'D. PER ACTIVITY
1. Fill first stage (81 seconds firing duration)	LOX	17,853,568	0.015	$268,000	2.5	$ 670,000
	RP-1	7,759,812	0.015	116,000	1.2	140,000
	Methane	178,000	0.10	17,800	1.5	26,700
Sub-Total		25,791,380		$401,800	2.08	$ 836,700
2. Fill second stage (260 seconds firing duration)	LOX	8,057,045	0.015	121,000	2.5	302,000
	LH_2	1,619,509	0.25	405,000	3.3	1,335,000
Sub-Total		9,676,554		526,000	3.1	1,637,000
TOTAL (1) and (2)		35,467,934		$927,800	2.56	$2,473,700
3. Operate first stage engine for one second (80 m. lbs. thrust)	$\left[\frac{1}{81} \times \text{activity (1)}\right]$					$ 10,300
4. Operate Titan I first state injector test for one second (200K lbs. thrust)	$\left[\frac{200,000}{80,000,000} \times \text{activity (3)}\right]$					$ 25
5. Operate first stage wedge chamber for one second (5 m. lbs. thrust)	$\left[\frac{5}{80} \times \text{activity (3)}\right]$					$ 645

ACTIVITY	PROPELLANT	PROPELLANT WT. LB.	$/LB.	COST OF PROPELLANT USED PER ACTIVITY	UTILIZATION FACTOR u	COST OF PROPELLANT REQ'D. PER ACTIVITY
6. Operate second stage main engine for one second (14 m. lbs. thrust)		$\left[\frac{1}{260} \times \text{activity (2)}\right]$				$ 6,300
7. Operate Titan I second stage injector test for one second (20K lbs. thrust)		$\left[\frac{20,000}{14,000,000} \times \text{activity (6)}\right]$				$ 9
8. Operate M-1 Engine for one second (120K lbs. thrust)		$\left[\frac{120,000}{14,000,000} \times \text{activity (6)}\right]$				$ 54
9. Operate 4 TVC engines for one second (250K lbs. thrust)		$\left[\frac{250,000}{14,000,000} \times \text{activity (6)}\right]$				$ 112
10. Operate one TVC engine for one second (53K lbs. thrust)		$\left[\frac{1}{4} \times \text{activity (9)}\right]$				$ 28
11. Fill insulation test article (8 ft diam)		$\left[\frac{8^3}{75^3} \times \text{sum of activities (1) and (2)}\right]$				$ 3,000

VII, Determination of Costing Factors (cont.)

C. TRANSPORTATION COST PARAMETERS

Sea transport costs between 0.5 and 1.0 cents per ton-mile have been estimated, Reference (a). Using this value and assuming:

1. Distance from factory to assembly lagoon is 5,000 mi.
2. Distance from assembly lagoon to launch site is 50 mi.
3. Distance from recovery site to assembly lagoon is 200 mi.
4. Weight of first stage (empty) is 1,500 tons.
5. Weight of second stage (empty) is 500 tons, and
6. Weight of complete vehicle (full) is 20,000 tons, we obtain the following values for the transportation parameters:

Cost of transporting empty first stage from factory to assembly lagoon:

$$t_1 = 5,000 \times 1,500 \times \$0.01 = \$75,000$$

Cost of transporting empty second stage from factory to assembly lagoon:

$$t_2 = 5,000 \times 500 \times \$0.01 = \$25,000$$

Cost of transporting complete vehicle from assembly lagoon to launch site:

$$t_{1,2} = 50 \times 20,000 \times \$0.01 = \$10,000$$

Cost of transporting empty first stage from recovery site to assembly lagoon:

t_R = $200 \times 1,500 \times \$0.01 = \$3,000$ (see Maintenance and Repair section)

VII, C, Transportation Cost Parameters (cont.)

In the Summary of Cost Parameter values at the end of this report,

"Most Probable" values are based on $0.01/ton mile

"Pessimistic" values are based on 0.02/ton mile

"Optimistic" values are based on 0.005/ton mile

D. LAUNCH COST PARAMETERS

Sea Dragon launch costs were estimated by assigning costs to individual functional elements of the launching process as shown in Table 5-1. To provide for the event of launch abort, the abort process is charged to each launch at 20% of its full figure, assuming that one out of five launches may have to be aborted. The table also shows the cost of reperforming the launch countdown at a probability of 100%, to indicate (conservatively) that every launch may have an average of two countdowns, because of holds.

E. MAINTENANCE AND REPAIR COST PARAMETERS

Sea Dragon maintenance and repair (recovery and refurbishment) costs were estimated by assigning costs to individual functional elements of the maintenance process as shown in Table 5-2.

VII, Determination of Costing Factors (cont.)

F. RANGE AND GENERAL OVERHEAD COST PARAMETERS

Sea Dragon range and general overhead costs were estimated using the equation from Reference (b):

$$R = N \left(0.2 + \frac{2.4}{N}\right) 10^6 \quad \text{dollars/year,}$$

where N = number of flights in the year under consideration.

The values obtained for R are considered conservative because the sea-based operation planned for Sea Dragon is not likely to demand as much service from the range as would a conventional land-based operation. Specifically, range services normally supplied to a land-based launch complex, such as utilities, security services, fire protection, sewage disposal, building maintenance, motor vehicle maintenance, communications, and transportation will not be required by the Sea Dragon program.

G. SURFACE SUPPORT EQUIPMENT COST PARAMETERS

Estimated costs of Sea Dragon surface support equipment are detailed in Table 5-3.

H. LAUNCH FACILITY COST PARAMETERS

Estimated Sea Dragon launch facility costs are detailed in Table 5-4.

VII, Determination of Costing Factors (cont.)

I. DEVELOPMENT COST PARAMETERS

The development program constitutes a major element of total program cost, yet is perhaps the most elusive to the cost analyst. The unprecedented size of Sea Dragon prohibits the direct use of convenient rules-of-thumb derived from the more conventional vehicle programs. As an experiment, one of these conventional rules was used to estimate Sea Dragon development costs in the course of the current cost analysis. By extrapolating (off the paper) to the Sea Dragon size, a development cost of $25 billion was obtained. Because this figure appeared to be high, it was decided that a more realistic figure could be obtained by detailing the elements of the development program and assigning estimated costs to each (Table 5-5).

The proposed development program, including ten development flights, is expected to consume 68 months (from contract go-ahead) and $2.836 billion. It includes 116,000 sec of engine static firings and the constant labor of an average of 13,800 personnel. The development will use $256 million in materials and $406 million in propellants. A unique feature of the program is the proposed use of a floating ballast-deflector unit for first stage propulsion static tests at sea. Two such units, one as backup to the other (each with an accompanying control ship) are provided at an estimated total cost of $163 million. To cover developmental spares and contingencies, a factor of $300 million, is added.

It is believed that the assigned 116,000 sec of static firing (for the three engines required by Sea Dragon) is reasonable when compared with the 19,000 sec of such firings used in the Titan I engine development.

VII, I, Development Cost Parameters (cont.)

First-stage propulsion development cost is estimated at $515 million (including facilities). Applying the pump-fed versus pressure-fed factors discussed earlier, the cost of developing a pump-fed first-stage propulsion system would be approximately $980 million. Thus, a simplified propulsion system design offers developmental savings of about $465 million.

In the current cost analysis, ten vehicles (at $74 million each) were conservatively estimated to be needed to support the ten developmental flights. On the premise that a recoverable Sea Dragon is to be developed, it is reasonable to expect that at least some of the first stage vehicles will be successfully recovered and reflown during the development program although high recovery reliability during this early phase of the program should not be expected. If four of the developmental first stages are successfully recovered, a saving of the manufacturing cost of four first stages, or approximately $160 million, would accrue.

VII, Determination of Costing Factors (cont.)

J. RELIABILITY PARAMETERS

In the time available for the current Sea Dragon study program, it has not been possible to analyze thoroughly the expected reliability factors for Sea Dragon. Values for R_1 (first stage to separation), R_2 (second stage to orbit) and R_R (first stage from separation to splash) for the current cost analysis were estimated from the curves shown in Figures 5-2 and 5-3. The lower curve on each figure was taken from Space Technology Laboratory (STL) Phase II Summary Report (Recovery) prepared as a part of its Launch Vehicle Size and Cost Analysis, dated 17 November 1961. STL's recovery reliability analysis was on the basis of actual experience recorded for the Snark, Navaho, Regulus I and Regulus II programs. Since the relative simplicity of the Sea Dragon system should provide a higher level of reliability than would otherwise be expected, it was decided to use STL's numbers as the "pessimistic" values for Sea Dragon. Slightly higher values were estimated for the "most probable" and "optimistic" cases, and were applied in this cost analysis. It is expected that follow-on Sea Dragon studies will provide a more precise estimate of these values.

VIII. SUMMARY AND CONCLUSIONS

The following figures (Figures 5-4 through 5-7), present the tables (Tables 5-6 through 5-13) of cost calculations and plots for 8 programing cases:

Case	Description	10-yr Average Delivery Cost ($/lb)
I	120 launches, pessimistic values, recoverable	31.7
II	120 launches, optimistic values, recoverable	10.2
III	120 launches, most probable values, recoverable	18.3
IV	240 launches, pessimistic values, recoverable	28.6
V	240 launches, optimistic values, recoverable	8.9
VI	240 launches, most probable values, recoverable	16.2
VII	120 launches, most probable values, expendable	32.8
VIII	240 launches, most probable values, expendable	27.9

The current cost analysis indicates that specific transportation costs (total cost per pound of payload successfully delivered into 300 nm earth orbit) of $20-$30/lb are possible using the Sea Dragon system. If only "direct" operating costs are charged (following Koelle's convention), the specific transportation cost decreases to $10-$20/lb. Further refinement of the numbers is necessary, however, and it is anticipated that follow-on studies of Sea Dragon will provide time for such refinement. It is believed that the current study at least demonstrates that the Sea Dragon system presents an interesting potential for great economies in space flight.

Figure 5-8, entitle "Effects of varying cost parameters", (based upon Table 5-14) provides for the reader a method of injecting his own optimism or pessimism into the cost analysis. In this figure, the parametric values associated with the "240 launches, most probable values, recoverable" program are used as a basis. The individual curves show the effect, on $/lb of payload, of

VIII, Summary and Conclusions (cont.)

independently varying the values of each cost parameter from 20% to 200% of its "most probable" value (100%), while maintaining the other parameters at their 100% values, in each case. For example, if the cost of development D is doubled to a new value of \$5.6 billion, while maintaining all other cost elements at their 100% values, the specific transportation cost for the Sea Dragon system is raised 40% to a new value of \$40.50/lb.

Cost Equations Summary:

$$V = Nv_1 (1-R_1R_R) + Nv_2 = N \left[v_1 (1-R_1R_R) + v_2 \right]$$

$$P = N \ (u_1p_1 + u_2p_2)$$

$$T = Nt_2 + N (1-R_1R_R) \ t_1 + Nt_{1,2} = N \left[t_2 + (1-R_1R_R) \ T_1 + t_{1,2} \right]$$

$$L = Nl$$

$$M = NR_1R_Rm_1$$

$$C = V + P + T + L + M + R + G + F + D$$

$$W = wNR_1R_2$$

$$E = \frac{C}{W}$$

$$O = V + P + T + L + M$$

$$R = N (0.2 + \frac{2.4}{N})$$

IX. REFERENCES

A. Handbook of Astronautical Engineering, H.H. Koelle, Ed. McGraw-Hill, 1961. page 1-53.

B. Ibid, page 1-68.

C. Ibid, page 1-72.

TABLE 5-1

LAUNCH COSTS (INCLUDING OVERHEAD)

Event (per launch)	Man-Days Per Event	Probability of Occurrence, Percent	Man-Days Per Launch	Cost at $100/man-day
1. Position stages in assembly area	250	100%	250	$ 25,000
2. Assemble and checkout Stage I	2200	100	2200	220,000
3. Assemble and checkout Stage II	2700	100	2700	270,000
4. Perform final mating and vehicle assembly	1100	100	1100	110,000
5. Perform combined systems checkout	600	100	600	60,000
6. Load ordnance items	30	100	30	3,000
7. Load fuels and pressurants	40	100	40	4,000
8. Load LOX	30	100	30	3,000
9. Perfrom erection, verification and final servicing	800	100	800	80,000
10. Perform launch countdown	1800	100	1800	180,000
11. Re-perform launch countdown	1800	100	1800	180,000
12. Perform vehicle vertical maintenance (in case of abort)	300	20	60	6,000
13. De-erect vehicle	200	20	40	4,000
14. Perform vehicle horizontal maintenance (launch area)	200	20	40	4,000
15. Unload LOX	30	20	6	600
16. Unload fuels and pressurants	40	20	8	800

TABLE 5-1 (cont.)

LAUNCH COSTS (INCLUDING OVERHEAD)

Event (per launch)	Man-Days Per Event	Probability of Occurrance, Percent	Man-Days Per Launch	Cost at $100/man-day
17. Transport to assembly area	20	20	4	400
18. Off-load ordnance items	30	20	6	600
19. De-mate stages	200	20	40	4,000
20. Perform stage maintenance	2,000	20	400	40,000
TOTAL			11,954	$1,195,400
Most Probable				$1.2 M
Optimistic				0.6 M
Pessimistic				2.5 M

TABLE 5-2

MAINTENANCE AND REPAIR COST (INCLUDING OVERHEAD)

	Man-Days Per Event	Labor Cost at $100/man-day	Materials	Total
1. Locate Stage I in water	100	10,000		10,000
2. Attach tow lines and control lines	2	200		200
3. Reduce vehicle tank pressure	2	200		200
4. Install nozzle support	30	3,000		3,000
5. Install flotation and stabilization services	30	3,000		3,000
6. Install marine navigation and safety devices	20	2,000		2,000
7. Secure stage	40	4,000		4,000
8. Stabilize stage for towing	10	1,000		1,000
9. Transport stage to assembly lagoon	30	3,000		3,000
10. Position stage in maintenance area	100	10,000		10,000
11. Transfer vehicle control to facility	2	200		200
12. Remove navigation, safety, and excess flotation devices	50	5,000		5,000
13. Inspect stage	800	80,000		80,000
14. Replace expended components	4,000	400,000	400,000	800,000
15. Inspect stage	800	80,000		80,000
TOTAL				$1,001,600
Most Probable m_1				$1.0 M
Optimistic m_1				0.6 M
Pessimistic m_1				2.0 M

Table 5-2

TABLE 5-3

SURFACE SUPPORT EQUIPMENT COSTS (MILLIONS OF DOLLARS)

Configuration		Recoverable				Expendable			
Launch Schedule		120 Launches		240 Launches		120 Launches		240 Launches	
No. of First Stages Produced First Year		3		5		8		16	
No. of Second Stages Produced First Year		8		16		8		16	
Equipment Item	Unit Cost	No. Req'd	Total Cost	No. Req'd	Total Cost	No. Req'd	Total Cost	No. Req'd	Total Cost
1. Ballast support units	0.2	2	0.4	2	0.4	4	0.8	8	1.6
2. Nozzle support gear	0.1	2	0.2	2	0.2	4	0.4	8	0.8
3. Belts	0.01	12	0.12	24	0.24	30	0.3	40	0.4
4. Ballast transfer units	0.05	3	0.15	6	0.3	4	0.2	16	0.8
5. Sponsons	0.1	4	0.4	10	1.0	8	0.8	32	3.2
6. Navigation lights	0.05	4	0.2	10	0.5	8	0.4	32	1.6
7. Nozzle barges	2.0	1	2.0	2	4.0	1	2.0	2	4.0
8. Engine transtainers	0.02	16	3.2	32	6.4	16	3.2	32	6.4
9. Electric winches	0.01	20	0.2	40	0.4	20	0.4	40	0.4
10. Mobile cranes	1.0	4	4.0	8	8.0	4	4.0	8	8.0
11. Automatic brazing machines	0.2	3	0.6	6	1.2	3	0.6	6	1.2
12. Work boats	0.05	2	0.1	4	0.2	2	0.1	4	0.2
13. Vehicle support rings	0.02	30	0.6	60	1.2	30	0.6	60	1.2
14. Service vessels	10.0	2	20.0	4	40.0	2	20.0	4	40.0
15. Master control consoles	5.0	2	10.0	4	20.0	2	10.0	4	20.0
16. LOX transport barges	10.0	1	10.0	2	20.0	1	10.0	2	20.0
17. Service elevators	0.2	3	0.6	6	1.2	3	0.6	6	1.2
18. Launch control vessels*		1		2		1		2	
19. Tug boat equipment**	0.5	2	1.0	6	3.0	5	2.5	10	5.0
20. Miscellaneous, including ladders, anchors, slings and buoys			1.0		2.0		1.0		2.0
TOTALS			54.77		110.24		57.9		118.0
Most Probable			$55M		110		58		118
Optimistic			40		80		43		85
Pessimistic			70		140		75		150

* Cost of these vessels is included in development cost category

** Cost of towing is included under transportation cost category

TABLE 5-4

ESTIMATED LAUNCH FACILITY COSTS

	Millions of Dollars			
	Recoverable		Expendable	
Assembly Lagoon	120 Launches	240 Launches	120 Launches	240 Launches
1. Dredge assembly lagoon and channel	12.0	24.0	12.0	24.0
2. Assembly wharves	10.0	20.0	8.0	18.0
3. Pressurized gas storage	1.0	0.5	1.0	0.5
4. Water storage and pumping facilities	0.3	0.5	0.2	0.4
5. Maintenance buildings	3.0	6.0	1.5	3.0
6. Warehouses	1.0	2.0	0.5	1.0
7. Data processing facilities	10.0	12.0	10.0	12.0
8. Engineering and administration buildings	1.0	2.0	1.0	2.0
9. Utilities facilities	0.1	0.2	0.1	0.2
10. Cafeteria	0.1	0.2	0.1	0.2
11. Transportation buildings	0.1	0.2	0.1	0.2
12. Service fleet support facilities	2.0	4.0	1.5	3.0
13. Roads and rails	0.3	0.6	0.3	0.6
14. Security provisions	0.1	0.2	0.1	0.2
Fuel Service Area				
1. Hydrogen storage	3.0	6.0	3.0	6.0
2. RP-1 storage	1.0	2.0	1.0	2.0
3. Methane storage	0.2	0.4	0.2	0.4
4. Propellant handling equipment	1.0	2.0	1.0	2.0
5. Nitrogen storage	0.2	0.4	0.2	0.4
6. Nitrogen pressurization and purging equip.	0.1	0.2	0.1	0.2

TABLE 5-4 (cont.)

	Millions of Dollars			
	Recoverable		Expendable	
	120 Launches	240 Launches	120 Launches	240 Launches
7. Vehicle positioning équipment	0.2	0.4	0.2	0.4
8. Utility buildings	0.1	0.2	0.1	0.2
LOX Service Area				
(LOX barge provided under development cost category)				
TOTALS	$46.8 M	84.0	42.2	76.9
Most Probable	47	84	42	77
Optimistic	40	70	35	63
Pessimistic	54	98	49	91

TABLE 5-5

DEVELOPMENT COST BREAKDOWN (THOUSANDS OF DOLLARS)

	Seconds of Firing (Static)	Man-Months	COST: Labor* (Incl OH)	Materials and Equipment	Propellants	Total
First-Stage Propulsion						
First-Stage Injector Tests	(1,120)	(2,050)	(4,100)	(2,118)	(69)	(6,287)
Design and fabricate 10 injector types		400	800	20	--	820
Modify 5 Titan I engines (200,000 lb thrust)		200	400	2,000	--	2,400
Design and fabricate 5 gimbals		230	460	8	--	468
Assemble test articles		20	40	--	--	40
Prepare test stand		200	400	40	--	440
80 test runs (5 sec each)	400	300	600	--	15	615
20 proof runs (30 sec each)	600	150	300	--	45	345
Prepare underwater test stand		200	400	40	--	440
Install Titan engine underwater		50	100	10	--	110
40 starts underwater (3 sec each)	120	300	600	--	9	609
Wedge Chamber Tests	(3,000)	(17,700)	(35,400)	(2,620)	(4,842)	(42,862)
Design wedge chamber		350	700	--	--	700
Fabricate six wedge chambers (5M lb thrust)		7,200	14,400	2,000	--	16,400
Prepare test setup at Mississippi Facility		900	1,800	200	--	2,000
Transport wedge chambers		250	500	--	--	500
100 tests (30 sec each)	3,000	9,000	18,000	420	4,842	23,262

TABLE 5-5 (cont.)

	Seconds of Firing (Static)	Man-Months	COST: Labor* (Incl OH)	Materials and Equipment	Propellants	Total
Full-Scale First-Stage Propulsion Static Tests	(5,550)	(85,550)	(171,100)	(18,200)	(113,660)	(302,960)
Design full-scale cruiser article		1,200	2,400	--	--	2,400
Fabricate 4 full-scale cruiser articles (80M lb thrust)		70,700	141,400	12,000	--	153,400
Prepare test setup on deflector unit		1,200	2,400	160	--	2,560
Transport sea test rig		250	500	--	--	500
Design and fabricate ballast unit		600	1,200	6,000	--	7,200
Prepare test setup		600	1,200	40	--	1,240
50 tests (81 sec each)	4,050	8,000	16,000	--	83,600	99,600
150 tests (10 sec each)	1,500	3,000	6,000	--	30,060	36,060
Second-Stage Propulsion and TVC	(13,250)	(33,640)	(67,280)	(8,140)	(1,113)	(76,533)
Design and fab. 3 injector types		120	240	10	--	250
Design and fab. boiler plate engine (53K thrust)		150	300	10	--	310
Assemble test articles		20	40	--	--	40
Prepare test stand		100	200	20	--	220
100 tests (10 sec each)	1,000	200	400	--	84	484
Design operational TVC engine (53K)		200	400	--	--	400
Design swivelling system		150	300	--	--	300
Fabricate 20 TVC engines with swivels		30,000	60,000	8,000	--	68,000

TABLE 5-5 (cont.)

	Seconds of Firing (Static)	Man-Months	COST: Labor* (Incl OH)	COST: Materials and Equipment	COST: Propellants	COST: Total
Assemble test articles		300	600	--	--	600
Prepare test stand		100	200	40	--	240
200 tests in air (50 sec each)	10,000	1,200	2,400	--	840	3,240
Prepare underwater test setup		100	200	20	--	220
50 starts (5 sec each)	250	200	400	--	21	421
Prepare test setup at Tullahoma		400	800	40	--	840
40 runs (50 sec each)	2,000	400	800	--	168	968
Second-Stage Main Propulsion and Expandable Nozzle	(93,600)	(108,440)	(216,880)	(18,104)	(78,969)	(313,953)
Design 5 injector types		150	300	--	--	300
Modify 2 Titan I engines (20K)		150	300	1,000	--	1,300
Assemble test articles		40	80	4	--	84
Prepare test stand		100	200	20	--	220
40 tests in air (5 sec each)	200	200	400	--	6	406
20 tests in air (30 sec each)	600	100	200	--	15	215
Prepare test setup at Tullahoma		400	800	40	--	840
40 starts (5 sec each)	200	300	600	--	6	606
Design small expandable nozzle		100	200	--	--	200
Fabricate 10 small expandable nozzles		900	1,800	40	--	1,840
Fabricate 2 M-1 chambers (120K)		600	1,200	4,000	--	5,200

TABLE 5-5 (cont.)

	Seconds of Firing (Static)	Man-Months	COST: Labor* (Incl OH)	COST: Materials and Equipment	COST: Propellants	COST: Total
Assemble test articles		200	400	--	--	400
Prepare test setup at Tullahoma		400	800	200	--	1,000
10 tests (30 sec each)with 1 TVC engine	600	400	800	--	48	848
Design full scale cruiser articles (14M)		1,200	2,400	--	--	2,400
Fabricate 4 full-scale cruiser articles with TVC engines		87,750	175,500	12,700	--	188,200
Prepare test setup at Mississippi Facility		1,200	2,400	100	--	2,500
Transport test articles		250	500	--	--	500
20 tests (260 sec each)	5,200	4,000	8,000	--	9,840	17,840
180 tests (20 sec each)	3,600	6,000	12,000	--	60,600	72,600
20 TVC tests (1,000 sec each)	80,000	2,000	4,000	--	6,720	10,720
40 TVC tests (20 sec each)	3,200	2,000	4,000	--	1,734	5,734
Insulation Development		(920)	(1,840)	(100)	(72)	(2,012)
Design 8 ft dia test article		40	80	--	--	80
Fabricate test article		300	600	40	--	640
Design insulation for test article		40	80	--	--	80
Fabricate insulation		60	120	20	--	140
Assemble test article w/instrumentation		80	160	40	--	200
Towing tests in water (8 fills)		400	800	--	72	872

TABLE 5-5 (cont.)

	Seconds of Firing (Static)	Man-Months	COST Labor* (Incl OH)	Materials and Equipment	Propellants	Total
Guidance System Development		(3,700)	(7,400)	(3,720)		(11,120)
Design guidance system		500	1,000	--	--	1,000
Fabricate 10 test sets		1,200	2,400	3,520	--	5,920
Laboratory tests		2,000	4,000	200	--	4,200
Combined Environmental Testing		(10,000)	(20,000)	(400)	(36)	(20,436)
Small-Model Tests of Sea Dragon System		(6,920)	(13,840)	(836)	(120)	(14,796)
Procure 24 small rockets		20	40	96	--	136
Prepare rockets for test		300	600	400	--	1,000
Towing tests		100	200	40	3	243
Fueling tests		100	200	40	9	249
Erection tests		200	400	20	3	423
30 launches		3,000	6,000	--	45	6,045
15 recoveries (recoverable program only)		100	200	--	--	200
15 refurbishments (recoverable program only)		600	1,200	80	--	1,280
Design and fab water test rig		1,800	3,600	80	--	3,680
Prepare air test setup		100	200	40	--	240
20 tests in air		200	400	--	30	430
Prepare underwater test setup		100	200	40	--	240
20 tests underwater		300	600	--	30	630

TABLE 5-5 (cont.)

	Seconds of Firing (Static)	Man-Months	COST Labor* (Incl OH)	COST Materials and Equipment	COST Propellants	COST Total
Full-Scale System Surface Dynamic Tests		(48,000)	(96,000)	(9,400)	(45,000)	(150,400)
Design full-scale vehicle		10,000	20,000	--	--	20,000
Fabricate 1 full-scale vehicle		30,000	60,000	8,000	--	68,000
Operational sequence tests (4 fills)		4,000	8,000	200	30,000	38,200
Vibration and acoustic tests (2 fills)		2,000	4,000	1,000	15,000	20,000
Staging tests in water		2,000	4,000	200	--	4,200
First-Stage Static Test Deflector Unit		(27,200)	(54,400)	(30,000)	(4,800)	(89,200)
Design rig		1,200	2,400	--	--	2,400
Fabricate rig		10,000	20,000	26,000	--	46,000
Equipment (control ship)		12,000	24,000	4,000	--	28,000
Assemble and checkout overall system		4,000	8,000	--	4,800	12,800
Backup Static Test Deflector Unit		(22,000)	(44,000)	(26,000)	(4,000)	(74,000)
Fabricate rig		7,000	14,000	22,000	--	36,000
Equipment (control ship)		12,000	24,000	4,000	--	28,000
Assemble and checkout overall system		3,000	6,000	--	4,000	10,000
Water Entry Body Development (Recoverable Program Only)		(1,080)	(2,160)	(80)	(0)	(2,240)
Design test rig		80	160	--	--	160
Fabricate test rig		600	1,200	40	--	1,240

TABLE 5-5 (cont.)

	Seconds of Firing (Static)	Man-Months	COST Labor* (Incl OH)	Materials and Equipment	Propellants	Total
Design and fabricate 5 test models		100	200	40	--	240
50 tests at Azusa		300	600	--	--	600
Wind Tunnel Tests		(600)	(1,200)	(20)	(6)	(1,226)
Design and fabricate 6 wind tunnel models		400	800	20	--	820
30 wind tunnel test runs		200	400	--	6	406
Selection of Materials		(1,600)	(3,200)	(90)	(6)	(3,296)
Fabricate materials test models		600	1,200	90	--	(1,290)
Materials tests		1,000	2,000	--	6	2,006
Development of Manufacturing System		(19,000)	(38,000)	(2,660)	(13,000)	(53,660)
Tube forming tests		1,000	2,000	200	--	2,200
Tube lay-up tests		800	1,600	100	--	1,700
Mandrel tests		1,600	3,200	200	--	3,400
Brazing tests		600	1,200	200	--	1,400
Lifting fixture tests		400	800	160	--	960
Alignment tests		1,500	3,000	200	--	3,200
Decontamination tests		600	1,200	120	--	1,320
Hydrostatic and cryo tests		3,000	6,000	80	13,000	19,080
Tank handling tests		1,500	3,000	200	--	3,200
Tank welding tests		6,000	12,000	400	--	12,400
Expandable nozzle fab tests		2,000	4,000	800	--	4,800
Transportation System Development		(1,100)	(2,200)	(80)	(0)	(2,280)
Design stage towing devices		300	600	--	--	600

TABLE 5-5 (cont.)

	Seconds of Firing (Static)	Man-Months	COST: Labor* (Incl OH)	Materials and Equipment	Propellants	Total
Towing tests		800	1,600	80	--	1,680
Sea Operations System Development		(19,000)	(38,000)	(2,000)	(1,500)	(41,500)
Design assembly and fueling equipment for test		3,000	6,000	--	--	6,000
Fabricate assembly and fueling equipment		10,000	20,000	2,000	--	22,000
Test assembly and fueling equipment at assembly lagoon		6,000	12,000	--	1,500	13,500
Launch Support Equipment Development		(26,200)	(52,400)	(4,600)	(0)	(57,000)
Design and fabricate propellant topping equipment		2,000	4,000	400	--	4,400
Design and fab prelaunch access equipment		1,200	2,400	200	--	2,600
Design and fab launch control equipment		20,000	40,000	2,000	--	42,000
Equip Pt. Bravo loxing barge		3,000	6,000	2,000	--	8,000
Tracking and Range Safety Development		(3,000)	(6,000)	(800)	--	(6,800)
Flight Test Program		(454,900)	(909,800)	(112,820)	(137,100	(1,159,720)
Manufacture and check-out 10 complete vehicles		300,000	600,000	80,000	63,000	743,000

TABLE 5-5 (cont.)

	Seconds of Firing (Static)	Man-Months	COST: Labor* (Incl OH)	Materials and Equipment	Propellants	Total
Manufacture 4 dummy spacecraft		20,000	40,000	8,000	--	48,000
Manufacture 5 ballast units		10,000	20,000	24,000	--	44,000
Transport 10 vehicles to assembly lagoon		5,000	10,000	--	--	10,000
Assemble 10 vehicles		20,000	40,000	--	--	40,000
Transport 10 vehicles to launch site		5,000	10,000	--	--	10,000
Launch 10 vehicles		80,000	160,000	--	74,100	234,100
Attempt recovery of 10 vehicles (recoverable program only)		500	1,000	--	--	1,000
Refurbish 6 vehicles (recoverable program only)		12,000	24,000	800	--	24,800
Reduction of flight test data		2,400	4,800	20	--	4,820
Program Management		(6,000)	(12,000)	--	--	(12,000)
Systems Engineering		(6,000)	(12,000)	--	--	(12,000)
Reliability Program		(14,400)	(28,800)	(10,000)	(1,500)	(40,300)
Quality Control Program		(10,000)	(20,000)	(2,000)	--	(22,000)
Liaison		(2,200)	(4,400)	--	--	(4,400)

TABLE 5-5 (cont.)

	Seconds of Firing (Static)	Man-Months	COST: Labor* (Incl OH)	COST: Materials and Equipment	COST: Propellants	COST: Total
Reports and Documents		(1,600)	(3,200)	(400)	--	(3,600)
Field Technical Service Support		(4,000)	(8,000)	(1,000)	--	(9,000)
TOTALS	116,520	936,800	1,873,600	256,188	405,793	2,535,581
Spares and Contingency						300,000
TOTAL						$2,835,581

Total Development (recoverable)

Most Probable	$\$2,836 \times 10^6$	(from above table)
Pessimistic	$4,000 \times 10^6$	
Optimistic	$2,000 \times 10^6$	

Total Development (expendable)

Most Probable	$\$2,807 \times 10^6$	(from above table)
Pessimistic	$4,000 \times 10^6$	
Optimistic	$2,000 \times 10^6$	

*Average cost/man-month incl OH is taken at $2,000

TABLE 5-6

SUMMARY OF COST PARAMETER VALUES (CASE 1)

Summary of cost parameter values

Case I:
120 launches
Pessimistic values
Recoverable

Operational year →	1	2	3	4	5	6	7	8	9	10	Total Program
N	8	10	11	12	12	13	13	13	14	14	120
v_1	41.3	32.9	31.2	29.6	29.0	27.2	27.2	27.0	25.9	25.9	30.0
v_2	18.1	14.5	13.2	12.3	11.9	11.6	11.0	10.6	10.6	10.4	12.0
R_1	.78	.81	.83	.85	.86	.86	.87	.88	.88	.89	.87
R_R	.72	.88	.91	.91	.92	.92	.92	.92	.92	.92	.90
V	289.4	240.4	226.3	230.5	215.3	224.2	213.7	205.3	218.3	210.4	2,232
u_1										←	2.5
p_1										←	.440
u_2										←	3.5
p_2										←	.578
P	25.0	31.2	34.4	37.5	37.5	40.6	40.6	40.6	43.7	43.7	437.2
t_2										←	.05
t_1										←	.15
$t_{1,2}$										←	.02
T	1.085	1.135	1.160	1.360	1.215	1.315	1.300	1.285	1.385	1.355	12.36
l										←	2.5
L	20	25.	27.5	30	30	32.5	32.5	32.5	35.0	35.0	300
m_1										←	2.0
M	9.0	14.2	16.7	18.5	19.0	20.5	20.8	21.1	22.7	23.0	187.2
R	4.0	4.4	4.6	4.8	4.8	5.0	5.0	5.0	5.2	5.2	26.4
G	7	7	7	7	7	7	7	7	7	7	70
F	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	54
D	400	400	400	400	400	400	400	400	400	400	4,000
C	760.9	728.7	723.1	735.1	720.2	736.5	726.3	713.2	738.7	725.9	7,319.2
w										←	1.1
R_2	.78	.81	.83	.85	.86	.86	.87	.88	.88	.89	.87
W	5.35	7.22	8.34	9.54	9.76	10.58	10.82	11.07	11.93	12.20	99.91
E	142.2	100.9	86.7	77.1	73.8	69.6	67.1	64.4	61.9	59.5	73.3
no. of first stages produced $N(1-R_1R_R)$	3.5	2.9	2.6	2.8	2.5	2.7	2.6	2.5	2.7	2.5	26.4
R_1R_R	.56	.71	.76	.77	.79	.79	.80	.81	.81	.82	.78
$(1-R_1R_R)$	.44	.29	.24	.23	.21	.21	.20	.19	.19	.18	.22
O	344.5	311.9	306.1	317.9	303.0	319.1	308.9	300.8	321.1	313.5	3168.8
O/W	64.4	43.2	36.7	33.3	31.0	30.2	28.6	27.2	26.9	25.7	$\boxed{31.7}$ #/#

TABLE 5-7

SUMMARY OF COST PARAMETER VALUES (CASE 2)

Case II:
120 launches
Optimistic values
Recoverable

Operational year →	1	2	3	4	5	6	7	8	9	10	Total Program
N	8	10	11	12	12	13	13	13	14	14	120
v_1	27.5	19.7	19.6	19.5	18.4	18.4	18.0	18.0	17.5	17.5	21.0
v_2	10.9	8.7	7.9	7.4	7.1	6.9	6.6	6.4	6.4	6.2	7.2
R_1	.80	.86	.91	.94	.96	.97	.98	.98	.98	.98	.95
R_R	.87	.92	.94	.96	.97	.97	.98	.98	.98	.98	.96
V	153.2	128.4	116.3	112.2	100.7	104.1	95.2	92.6	99.4	96.6	1090.8
u_1										←	1.5
p_1										←	.360
u_2										←	2.5
p_2										←	.474
P	13.8	17.3	19.0	20.7	20.7	22.4	22.4	22.4	24.2	24.2	207
t_2										←	.012
t_1										←	.037
$t_{1,2}$										←	.005
T	.225	.248	.244	.248	.235	.250	.241	.241	.259	.259	2.436
l										←	.06
L	4.8	6.0	6.6	7.2	7.2	7.8	7.8	7.8	8.4	8.4	72
m_1										←	.06
M	3.4	4.7	5.7	6.5	6.7	7.3	7.5	7.5	8.1	8.1	65.5
R	4.0	4.4	4.6	4.8	4.8	5.0	5.0	5.0	5.2	5.2	26.4
G	4	4	4	4	4	4	4	4	4	4	40
F	4	4	4	4	4	4	4	4	4	4	40
D	200	200	200	200	200	200	200	200	200	200	2000
C	387.4	369.1	360.4	359.7	348.3	354.9	346.1	343.5	353.6	350.8	3544.1
w										←	1.3
R_2	.80	.86	.91	.94	.96	.97	.98	.98	.98	.98	.95
W	6.7	9.6	11.8	13.8	14.4	15.9	16.2	16.2	17.5	17.5	140.8
E	57.8	38.4	30.5	26.1	24.2	22.3	21.4	21.2	20.2	20.0	25.2
$N(1-R_1R_R)$	2.4	2.1	1.5	1.2	.84	.78	.52	.52	.56	.56	10.8
R_1R_R	.70	.79	.86	.90	.93	.94	.96	.96	.96	.96	.91
$1-R_1R_R$	.30	.21	.14	.10	.07	.06	.04	.04	.04	.04	.09
O	175.4	156.7	147.8	146.9	135.5	141.9	133.1	130.5	140.4	137.6	1437.7
O/W	26.2	16.3	12.5	10.6	9.4	8.9	8.2	8.1	8.0	7.9	$\boxed{10.2}$ \$/#

TABLE 5-8

SUMMARY OF COST PARAMETER VALUES (CASE 3)

Case III:
120 launches
Most probable values
Recoverable

Operational Year →	1	2	3	4	5	6	7	8	9	10	Total Program
N	8	10	11	12	12	13	13	13	14	14	120
v_1	34.1	27.5	25.4	24.5	23.6	23.1	22.8	22.3	21.7	21.4	25.2
v_2	14.5	11.6	10.5	9.8	9.5	9.2	8.9	8.8	8.6	8.3	9.6
R_1	.78	.82	.86	.89	.91	.92	.93	.94	.95	.95	.91
R_R	.83	.90	.92	.92	.93	.93	.94	.94	.94	.95	.92
V	211.5	187.5	173.9	171.5	156.8	161.2	154.5	150.1	153.0	146.2	1,635.8
u_1											2.08
p_1											.401
u_2											3.1
p_2											.526
P	19.7	24.7	27.1	29.6	29.6	32.0	32.0	32.0	34.5	34.5	295.8
t_2											.025
t_1											.075
$t_{1,2}$											.010
T	.5	.57	.58	.61	.58	.62	.61	.60	.63	.63	5.88
l											1.2
L	9.6	12.	13.2	14.4	14.4	15.6	15.6	15.6	16.8	16.8	144.
m_1											1.0
M	5.2	7.4	8.7	9.8	10.2	11.2	11.3	11.4	12.5	12.6	100.8
R	4.0	4.4	4.6	4.8	4.8	5.0	5.0	5.0	5.2	5.2	26.4
G	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	55
F	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	47
D	284	284	284	284	284	284	284	284	284	284	2,836
C	544.7	530.8	522.3	524.9	510.6	519.8	513.2	508.9	516.8	510.1	5,146.7
w											1.2
R_2	.78	.82	.86	.89	.91	.92	.93	.94	.95	.95	.91
W	5.8	8.1	9.8	11.4	11.9	13.2	13.5	13.8	15.2	15.2	119.2
E	93.9	65.5	53.3	46.0	42.9	39.4	38.0	36.9	34.0	33.6	43.2
$N(1-R_1R_R)$	2.8	2.6	2.3	2.2	1.8	1.8	1.7	1.6	1.5	1.4	19.2
R_1R_R	.65	.74	.79	.82	.85	.86	.87	.88	.89	.90	.84
$1-R_1R_R$	.35	.26	.21	.18	.15	.14	.13	.12	.11	.10	.16
O	246.5	232.2	223.5	225.9	211.6	220.6	214.0	209.7	217.4	210.7	2,182.3
O/W	42.5	28.7	22.8	19.8	17.8	16.7	15.9	15.2	14.3	13.9	$\boxed{18.3}$ $/#

TABLE 5-9

SUMMARY OF COST PARAMETER VALUES (CASE 4)

Case IV:
240 launches
Pessimistic values
Recoverable

Operational Year →	1	2	3	4	5	6	7	8	9	10	Total Program
N	16	20	22	24	25	25	26	27	27	28	240
V_1	37.5	30.4	28.6	27.1	26.0	26.0	25.5	24.5	23.5	23.0	27.5
V_2	16.4	12.9	11.9	11.0	10.7	10.1	10.0	9.7	9.7	8.9	10.8
R_1	.79	.84	.86	.87	.88	.88	.88	.88	.89	.89	.87
R_R	.75	.91	.92	.92	.92	.92	.92	.92	.92	.92	.91
V	508.8	404.	393.8	393.6	390.	375.	387.4	388.8	375.3	364.	3984.
u_1										←	2.5
p_1										←	.440
u_2										←	3.5
p_2										←	.578
P	50.0	62.5	68.7	75.0	78.1	78.1	81.2	84.3	84.3	87.4	749.5
t_2										←	.05
t_1										←	.15
$t_{1,2}$										←	.02
T	.984	.720	.693	.720	.713	.713	.741	.770	.729	.756	7.56
l										←	2.5
L	40.	50.	55.	60.	62.5	62.5	65.	67.5	67.5	70.	600.
m_1										←	2.0
M	18.9	30.4	34.8	38.4	40.5	40.5	42.1	43.7	44.3	45.9	379.2
R	5.6	6.4	6.8	7.2	7.4	7.4	7.6	7.8	7.8	8.0	50.2
G	14	14	14	14	14	14	14	14	14	14	140
F	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	98
D	400	400	400	400	400	400	400	400	400	400	4,000
C	1048.1	977.8	983.6	998.7	1003	988	1007.8	1016.7	1003.7	999.9	10,008.5
w										←	1.1
R_2	.79	.84	.86	.87	.88	.88	.88	.88	.89	.89	.87
W	10.9	15.5	17.9	20.	21.3	21.3	22.1	23.0	23.5	24.4	199.8
E	96.2	63.1	55.0	49.9	47.1	46.4	45.6	44.2	42.7	41.0	50.1
$N(1-R_1R_R)$	6.6	4.8	4.6	4.8	4.8	4.8	4.9	5.1	4.9	5.0	50.4
R_1R_R	.59	.76	.79	.80	.81	.81	.81	.81	.82	.82	.79
$1-R_1R_R$	.41	.24	.21	.20	.19	.19	.19	.19	.18	.18	.21
O	618.7	547.6	553.	567.7	571.8	556.8	576.4	585.1	572.1	568.1	5,720.3
O/W	56.8	35.3	30.9	28.4	26.8	26.1	26.1	25.4	24.3	23.3	$\boxed{28.6}$ #/#

TABLE 5-10

SUMMARY OF COST PARAMETER VALUES (CASE 5)

Case V:
240 launches
Optimistic values
Recoverable

Operational Year →	1	2	3	4	5	6	7	8	9	10	Total Program
N	16	20	22	24	25	25	26	27	27	28	240
v_1	24.4	19.3	18.0	18.0	18.0	18.0	18.0	16.4	16.4	16.4	19.5
v_2	9.8	7.7	7.2	6.6	6.4	6.1	6.0	5.8	5.8	5.4	6.5
R_1	.82	.91	.96	.98	.98	.98	.98	.98	.98	.98	.96
R_R	.89	.95	.97	.98	.98	.98	.98	.98	.98	.98	.97
V	262.4	208	187	175.2	177.5	170	174.2	175.5	175.5	170.8	1,896
u_1										←	1.5
p_1										←	.360
u_2										←	2.5
p_2										←	.474
P	26.0	32.5	35.8	39.0	40.6	40.6	42.3	43.9	43.9	45.5	390
t_2										←	.012
t_1										←	.037
$t_{1,2}$										←	.005
T	.16	.10	.06	.04	.04	.04	.04	.04	.04	.04	.62
l										←	0.6
L	9.6	12	13.2	14.4	15	15	15.6	16.2	16.2	16.8	144
m_1										←	0.6
M	7.0	10.3	12.3	13.8	14.4	14.4	15.0	15.6	15.6	16.1	138.2
R	5.6	6.4	6.8	7.2	7.4	7.4	7.6	7.8	7.8	8.0	50.2
G	8	8	8	8	8	8	8	8	8	8	80
F	7	7	7	7	7	7	7	7	7	7	70
D	200	200	200	200	200	200	200	200	200	200	2,000
C	525.8	484.3	470.2	464.6	469.9	462.4	469.7	474	474	472.2	4,769
w										←	1.3
R_2	.82	.91	.96	.98	.98	.98	.98	.98	.98	.98	.96
W	14.0	21.5	26.4	30.0	31.2	31.2	32.9	33.7	33.7	35.0	287.5
E	37.6	22.5	17.8	15.5	15.1	14.8	14.5	14.1	14.1	13.5	16.6
$N(1-R_1R_R)$	4.3	2.8	1.5	1.0	1.0	1.0	1.0	1.1	1.1	1.1	16.8
R_1R_R	.73	.86	.93	.96	.96	.96	.96	.96	.96	.96	.93
$1-R_1R_R$	.27	.14	.07	.04	.04	.04	.04	.04	.04	.04	.07
O	305.2	262.9	248.4	242.4	247.5	240.	247.1	251.2	251.2	249.2	2,568.8
O/W	21.8	12.2	9.4	8.1	7.9	7.7	7.6	7.5	7.5	7.1	$\boxed{8.9}$ \$/#

TABLE 5-11

SUMMARY OF COST PARAMETER VALUES (CASE 6)

Case VI:
240 launches
Most probable values
Recoverable

Operational Year →	1	2	3	4	5	6	7	8	9	10	Total Program
N	16	20	22	24	25	25	26	27	27	28	240
v_1	31.2	25.4	23.8	22.9	22.0	21.4	20.7	20.6	20.3	20.0	24.0
v_2	13.1	10.3	9.5	8.8	8.6	8.1	8.0	7.8	7.8	7.1	8.6
R_1	.80	.87	.91	.92	.95	.95	.95	.95	.95	.95	.92
R_R	.86	.92	.93	.94	.94	.95	.95	.95	.95	.95	.94
V	364.8	308	288.2	288	280	262.5	267.8	272.8	270	260.4	2,856
u_1											2.08
P_1											0.401
u_2											3.1
P_2											0.526
P	39.4	49.3	54.2	59.2	61.6	61.6	64.1	66.5	66.5	69.0	591.5
t_2											.025
t_1											.075
$t_{1,2}$											.010
T	.9	1.0	1.0	1.1	1.1	1.1	1.1	1.2	1.2	1.2	11.0
l											1.2
L	19.2	24	26.4	28.8	30	30	31.2	32.4	32.4	33.6	288
m_1											1.0
M	11.0	16.0	18.7	20.6	22	22.3	23.1	24	24	24.9	206.4
R	5.6	6.4	6.8	7.2	7.4	7.4	7.6	7.8	7.8	8.0	50.2
G	11	11	11	11	11	11	11	11	11	11	110
F	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	84
D	284	284	284	284	284	284	284	284	284	284	2,836
C	744.3	708.1	698.7	708.3	705.5	688.3	698.3	708.1	705.3	700.5	7,037.1
w											1.2
R_2	.80	.87	91	.92	.94	.94	.94	.94	.94	.94	.92
W	12.3	18.2	21.9	24.4	26.5	26.5	27.6	28.6	28.6	29.7	243.8
E	60.5	38.9	31.9	29.0	26.6	26.0	25.3	24.8	24.7	23.6	28.9
$N(1-R_1R_R)$	5.0	4.0	3.3	3.4	3.0	2.8	2.9	3.0	3.0	3.1	33.6
R_1R_R	.69	.80	.85	.86	.88	.89	.89	.89	.89	.89	.86
$1-R_1R_R$	.31	.20	.15	.14	.12	.11	.11	.11	.11	.11	.14
O	435.3	398.3	388.5	397.7	394.7	377.5	387.3	396.9	394.1	389.1	3,952.9
O/W	35.4	21.9	17.7	16.3	14.9	14.2	14.0	13.9	13.8	13.1	$\boxed{16.2}$ $/#

TABLE 5-12

SUMMARY OF COST PARAMETER VALUES (CASE 7)

Case VII:
120 launches
Most probable values
Expendable

Operational Year →	1	2	3	4	5	6	7	8	9	10	Total Program
N	8	10	11	12	12	13	13	13	14	14	120
v_1	29.0	23.2	21.1	19.7	19.0	18.5	16.9	17.5	17.2	16.6	19.2
v_2	14.5	11.6	10.5	9.8	9.5	9.2	8.9	8.8	8.6	8.3	9.6
R_1	.78	.82	.86	.89	.91	.92	.93	.94	.95	.95	.91
R_R	0	0	0	0	0	0	0	0	0	0	0
V	348	348	347.6	354	342	360.1	335.4	341.9	361.2	348.6	3,456.
u_1											2.08
p_1											.401
u_2											3.1
p_2											.526
P	19.7	24.6	27.1	29.6	29.6	32.0	32.0	32.0	34.5	34.5	295.8
t_2											.025
t_1											.075
$t_{1,2}$											.010
T	.88	1.1	1.21	1.32	1.32	1.43	1.43	1.43	1.54	1.54	13.2
l											1.2
L	9.6	12	13.2	14.4	14.4	15.6	15.6	15.6	16.8	16.8	144
m_1	0	0	0	0	0	0	0	0	0	0	0
M	0	0	0	0	0	0	0	0	0	0	0
R	4.0	4.4	4.6	4.8	4.8	5.0	5.0	5.0	5.2	5.2	26.4
G	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8	58
F	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	42
D	281	281	281	281	281	281	281	281	281	281	2,807
C	673.2	681.1	684.7	695.1	683.1	705.1	680.4	686.9	710.2	697.6	6,842.4
w											1.2
R_2	.78	.82	.86	.89	.91	.92	.93	.94	.95	.95	.91
W	5.8	8.1	9.8	11.4	11.9	13.2	13.5	13.8	15.2	15.2	119.2
E	116.1	84.1	69.9	61.0	57.4	53.4	50.4	49.8	46.7	45.9	57.4
O	378.2	385.7	389.1	399.3	387.3	409.1	384.4	390.9	414	401.4	3,909
O/W	65.2	47.6	39.7	39.0	32.5	31.0	28.5	28.3	27.2	26.4	$\boxed{32.8}$ $/#

TABLE 5-13

SUMMARY OF COST PARAMETER VALUES (CASE 8)

Case VIII:
240 launches
Most probable values
Expendable

Operational Year →	1	2	3	4	5	6	7	8	9	10	Total Program
N	16	20	22	24	25	25	26	27	27	28	240
v_1	26.2	20.6	19.1	17.5	17.1	16.2	16.0	15.6	15.6	14.3	17.2
v_2	13.1	10.3	9.5	8.8	8.6	8.1	8.0	7.8	7.8	7.1	8.6
R_1	.80	.87	.91	.92	.94	.94	.94	.94	.94	.94	.92
R_R	0	0	0	0	0	0	0	0	0	0	0
V	628.8	618	629.2	631.2	642.5	607.5	624	631.8	608.4	599.2	6,192
u_1											2.08
p_1											.401
u_2											3.1
p_2											.526
P	39.4	49.3	54.2	59.2	61.6	64.1	64.1	66.5	66.5	69.0	591.5
t_2											.025
t_1											.075
$t_{1,2}$											.010
T	1.76	2.2	2.42	2.64	2.75	2.75	2.86	2.87	2.97	3.02	26.4
l											1.2
L	19.2	24	26.4	28.8	30	30	31.2	32.4	32.4	33.6	288
m_1	0	0	0	0	0	0	0	0	0	0	0
M	0	0	0	0	0	0	0	0	0	0	0
R	5.6	6.4	6.8	7.2	7.4	7.4	7.6	7.8	7.8	8.0	50.2
G	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	118
F	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	77
D	281	281	281	281	281	281	281	281	281	281	2,807
C	995.3	1000.4	1019.5	1029.5	1044.8	1009.8	1030.3	1042	1018.6	1013.3	10,150.1
w											1.2
R_2	.80	.87	.91	.92	.94	.94	.94	.94	.94	.94	.92
W	12.3	18.2	21.9	24.4	26.5	26.5	27.6	28.6	28.6	29.7	254.5
E	80.9	55.0	46.6	42.2	39.4	38.1	37.3	36.4	35.6	34.1	39.9
O	689.2	693.5	712.2	721.8	736.9	701.9	722.2	733.7	710.3	704.8	7,097.9
O/W	56.0	38.1	32.5	29.6	27.8	26.5	26.2	25.7	24.8	23.7	$\boxed{27.9}$ #/#

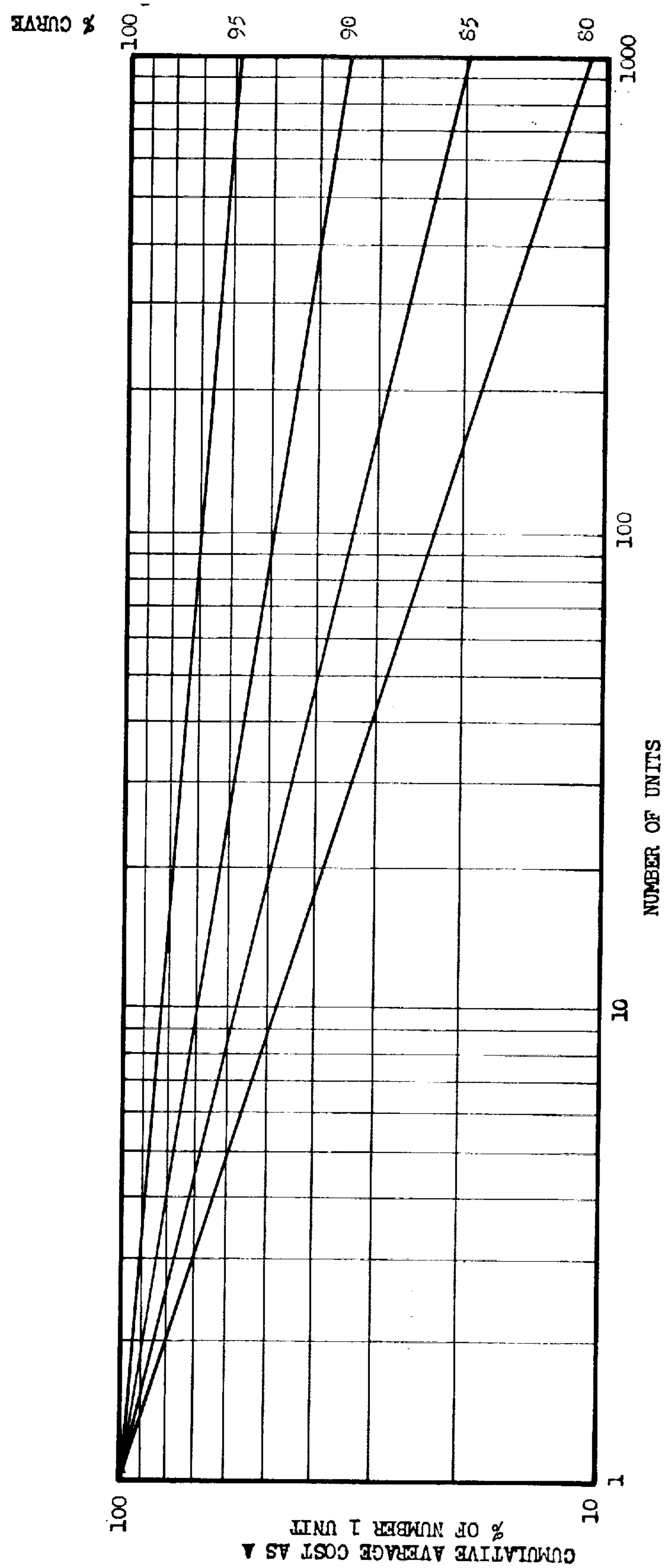
TABLE 5-14

EFFECTS OF VARYING COST PARAMETERS

Cost Parameter	Basic * Values	Values of E when each cost parameter is independently varied to indicated % of its basic value									
		20%	40%	60%	80%	100%	120%	140%	160%	180%	200%
V	2,856	19.5	21.9	24.3	26.6	28.9	31.2	33.5	35.9	38.3	40.6
P	591	27.0	27.4	27.9	28.4	28.9	29.4	29.9	30.4	30.8	31.3
T	11	28.9	28.9	28.9	28.9	28.9	28.9	28.9	28.9	28.9	28.9
L	288	28.0	28.2	28.4	28.7	28.9	29.1	29.4	29.6	29.8	30.1
M	206	28.2	28.4	28.6	28.7	28.9	29.1	29.2	29.4	29.6	29.8
R	50	28.7	28.8	28.8	28.9	28.9	28.9	29.0	29.0	29.1	29.1
G	110	28.5	28.6	28.7	28.8	28.9	29.0	29.1	29.2	29.3	29.4
F	84	28.6	28.7	28.8	28.8	28.9	29.0	29.0	29.1	29.2	29.2
D	2,836	19.6	21.9	24.3	26.6	28.9	31.2	33.5	35.9	38.2	40.5
C	7,037	5.8	11.6	17.4	23.1	28.9	34.7	40.5	46.2	52.0	57.8
W	244	144.5	72.3	48.2	36.2	28.9	24.1	20.6	18.1	16.1	14.5

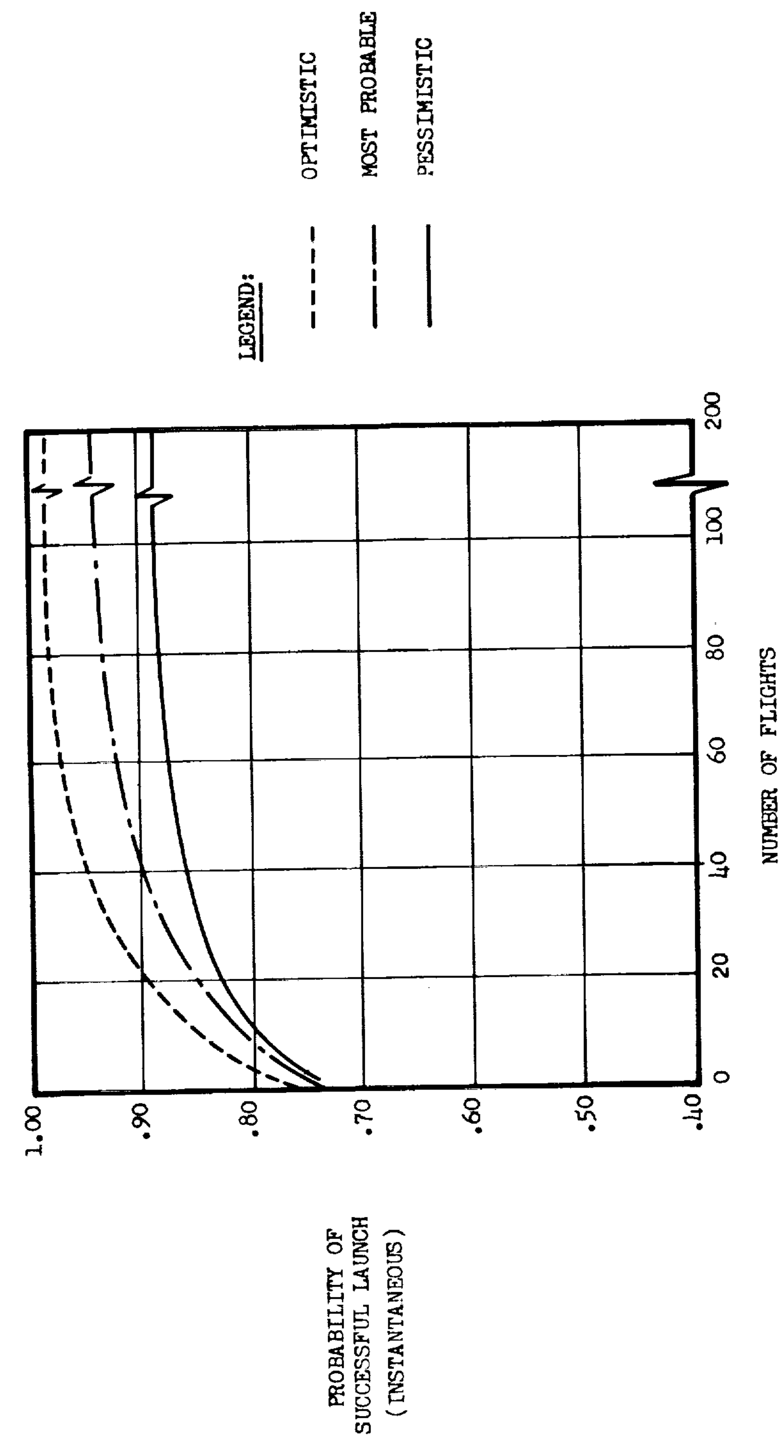
* Basic values are taken from program labeled "240 launches, most probable values, recoverable"

Basic equation: $E = \frac{C}{W} = \frac{V + P + T + L + M + R + G + F + D}{W}$



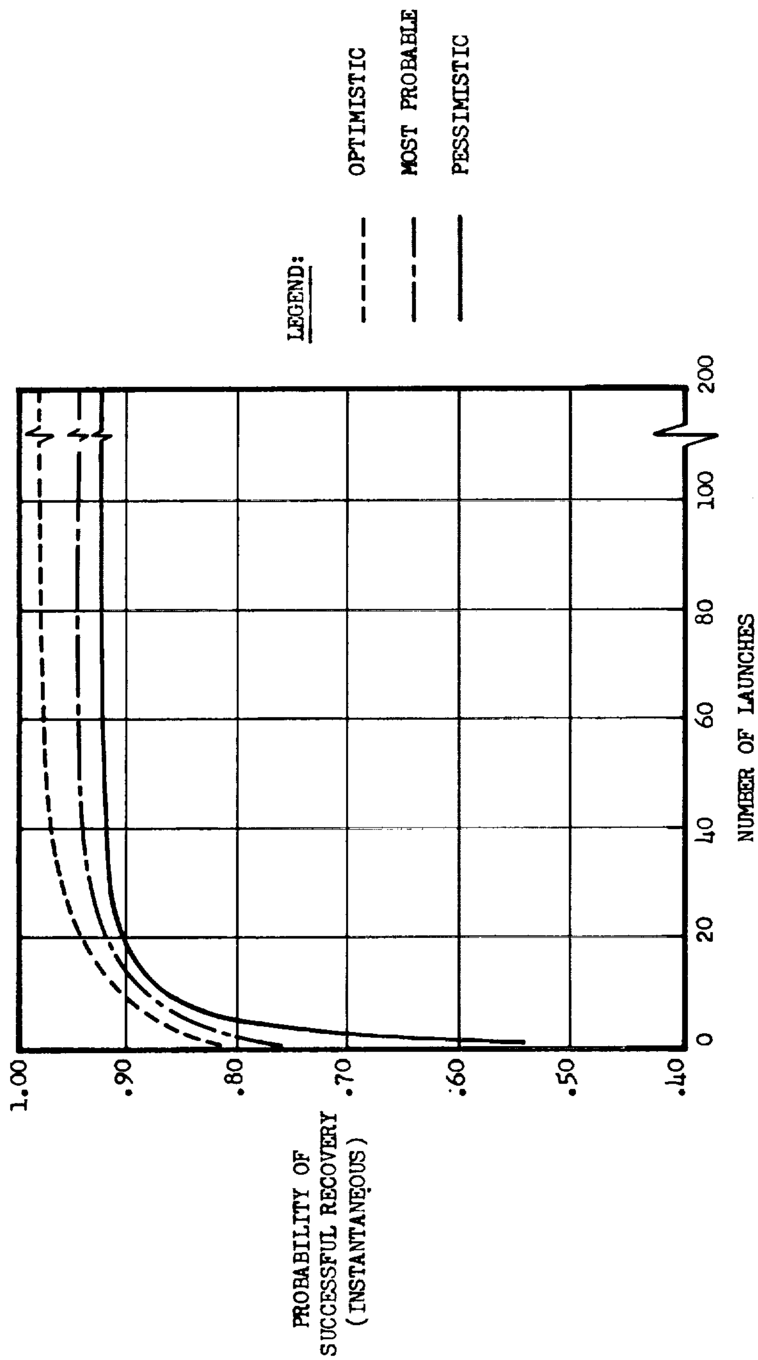
Unit Straight Line Learning Curve

Figure 5-1



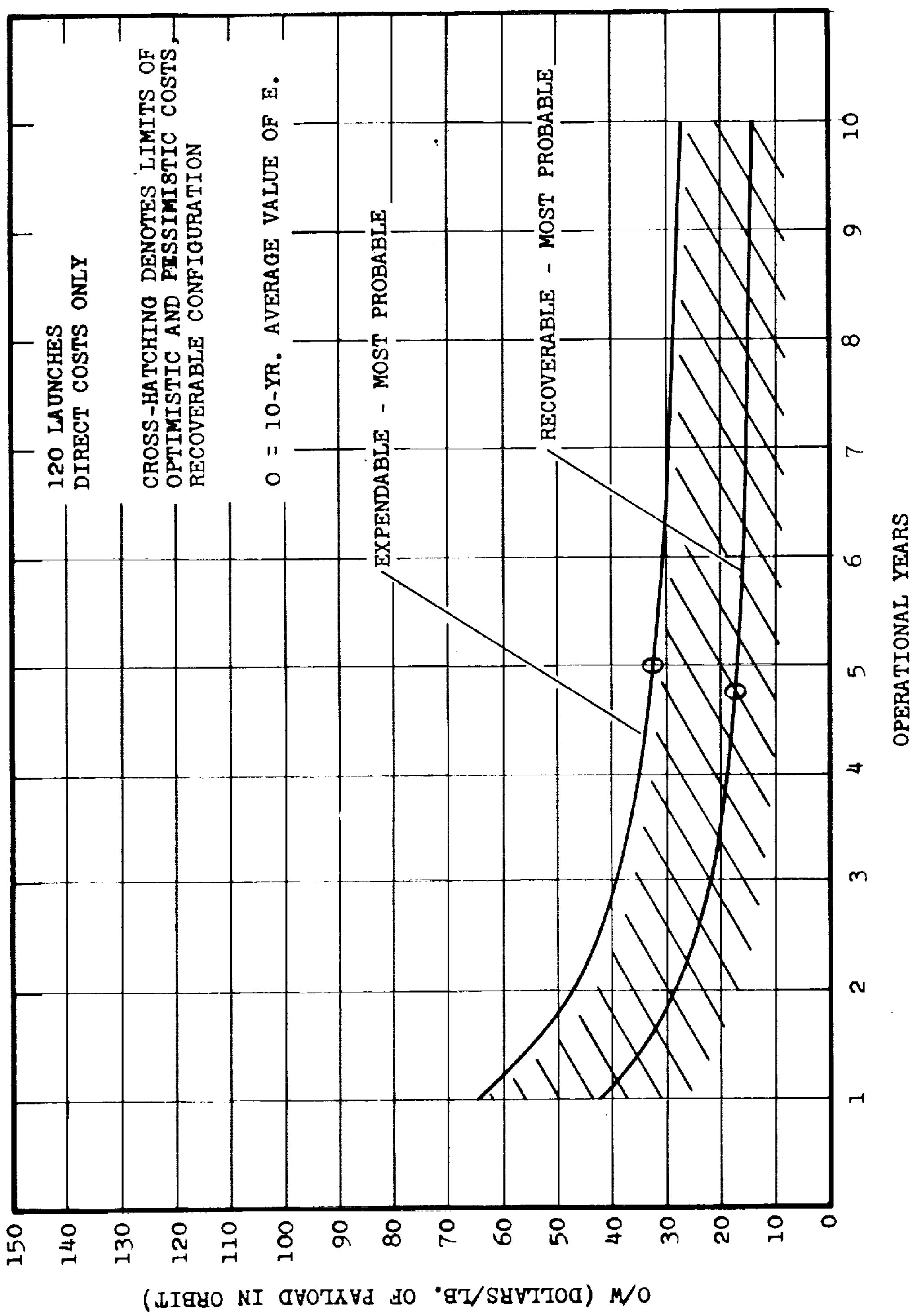
Estimated Operational Reliability of Sea Dragon First and Second Stages

Figure 5-2



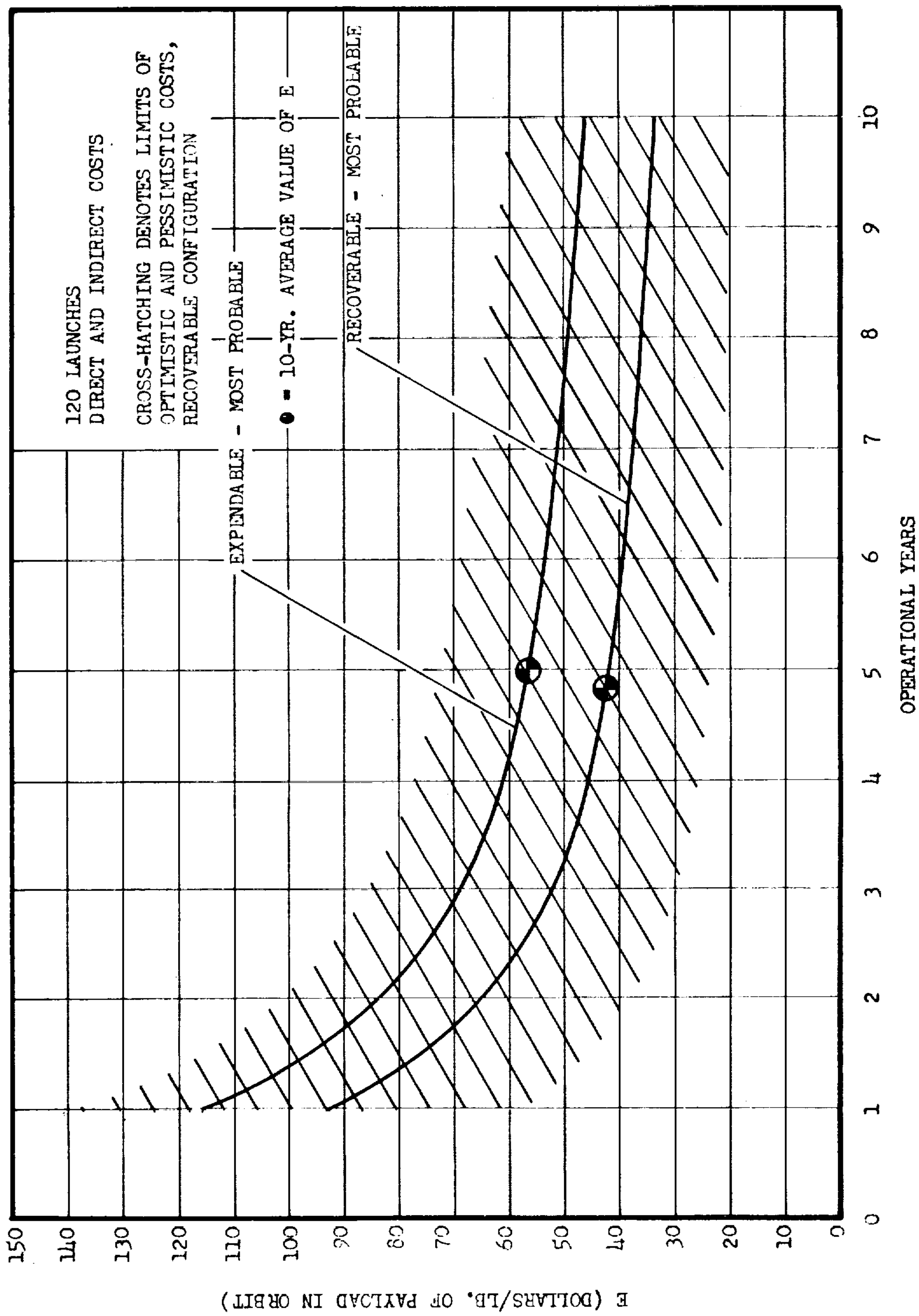
Estimated Reliability of Sea Dragon Recovery

Figure 5-3



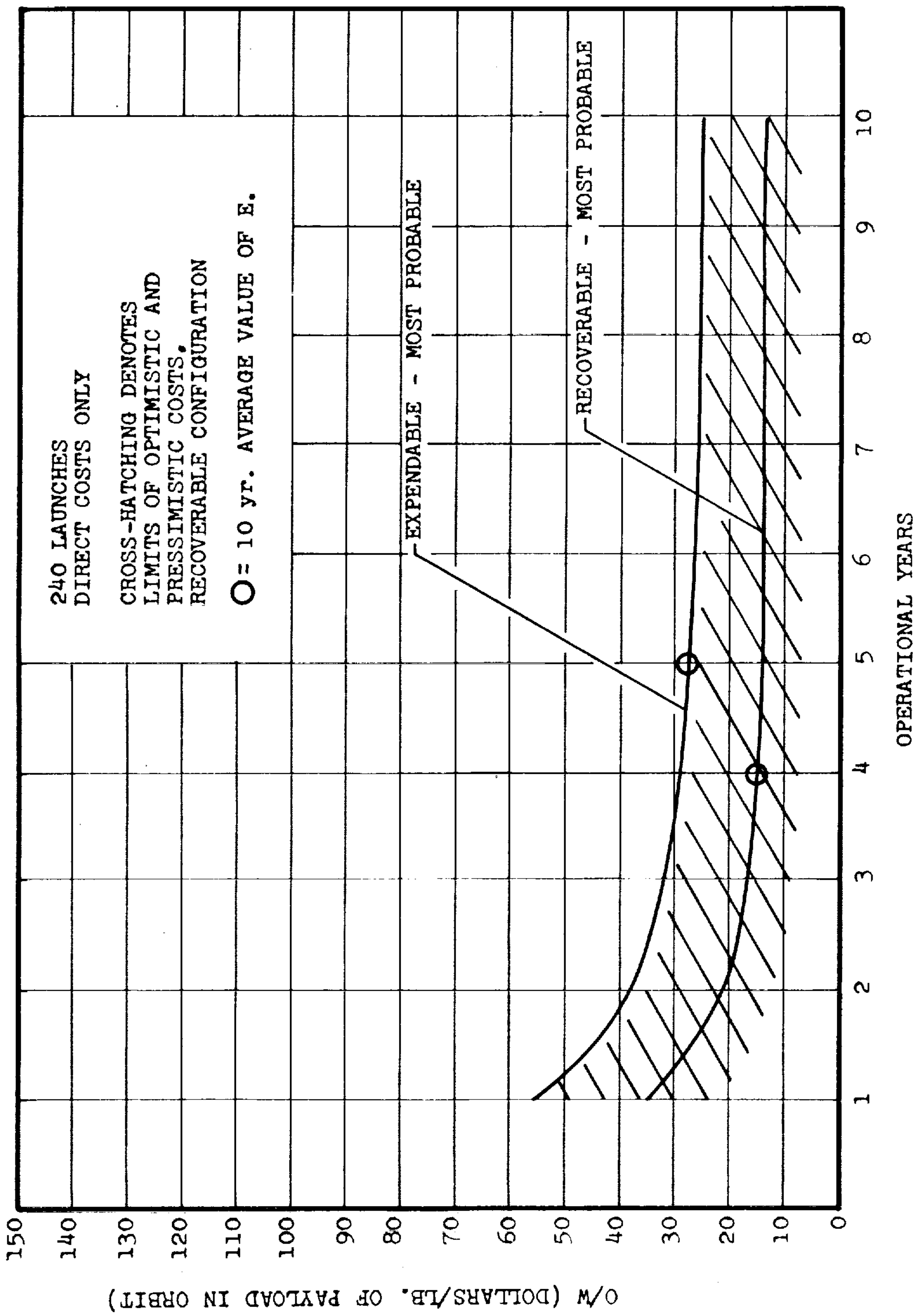
O/W--Dollars/lb of Payload in Orbit vs Operational Year (240 Launches)

Figure 5-4



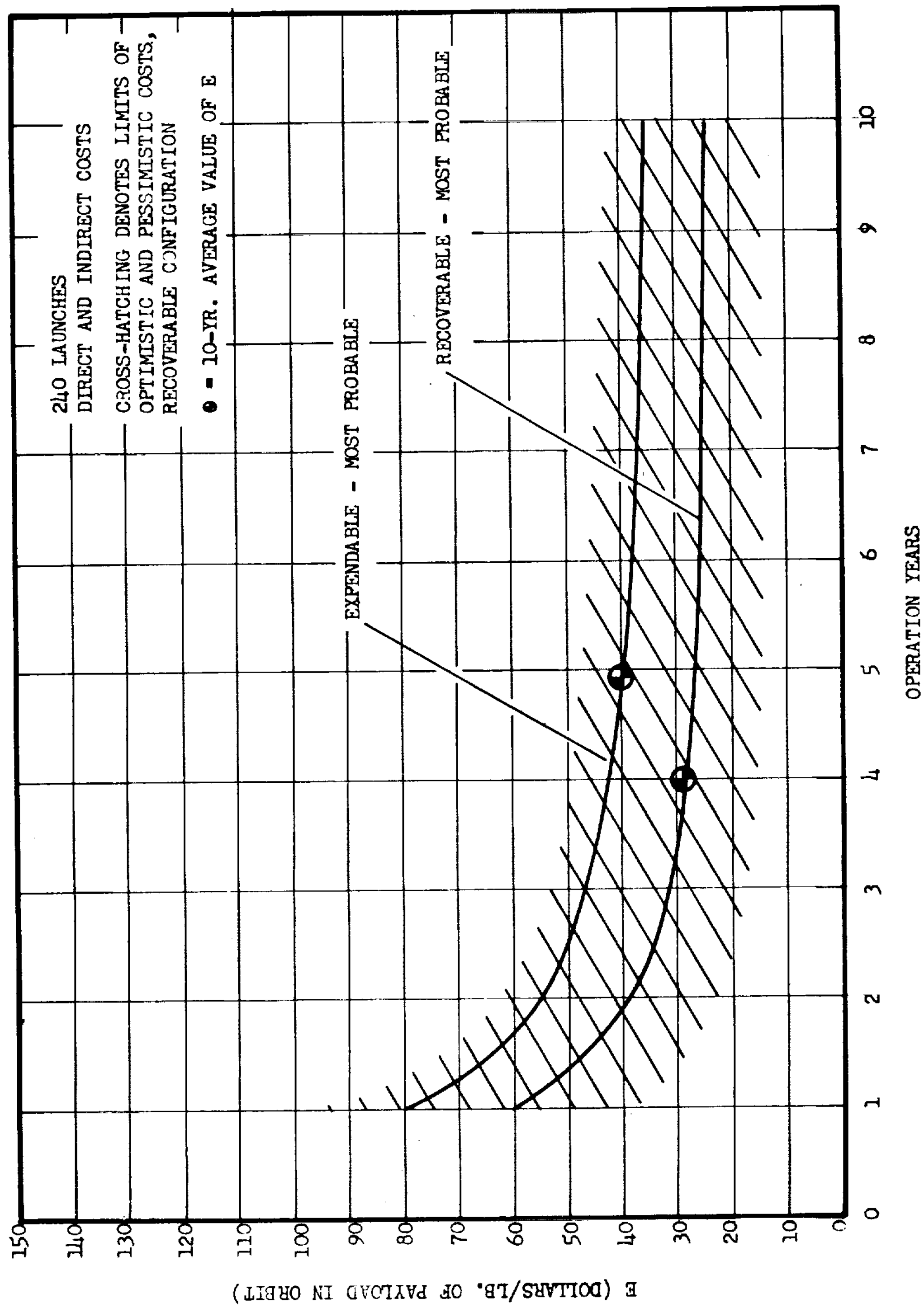
E--Dollars/lb of Payload in Orbit Versus Operational Year (120 Launches)

Figure 5-5



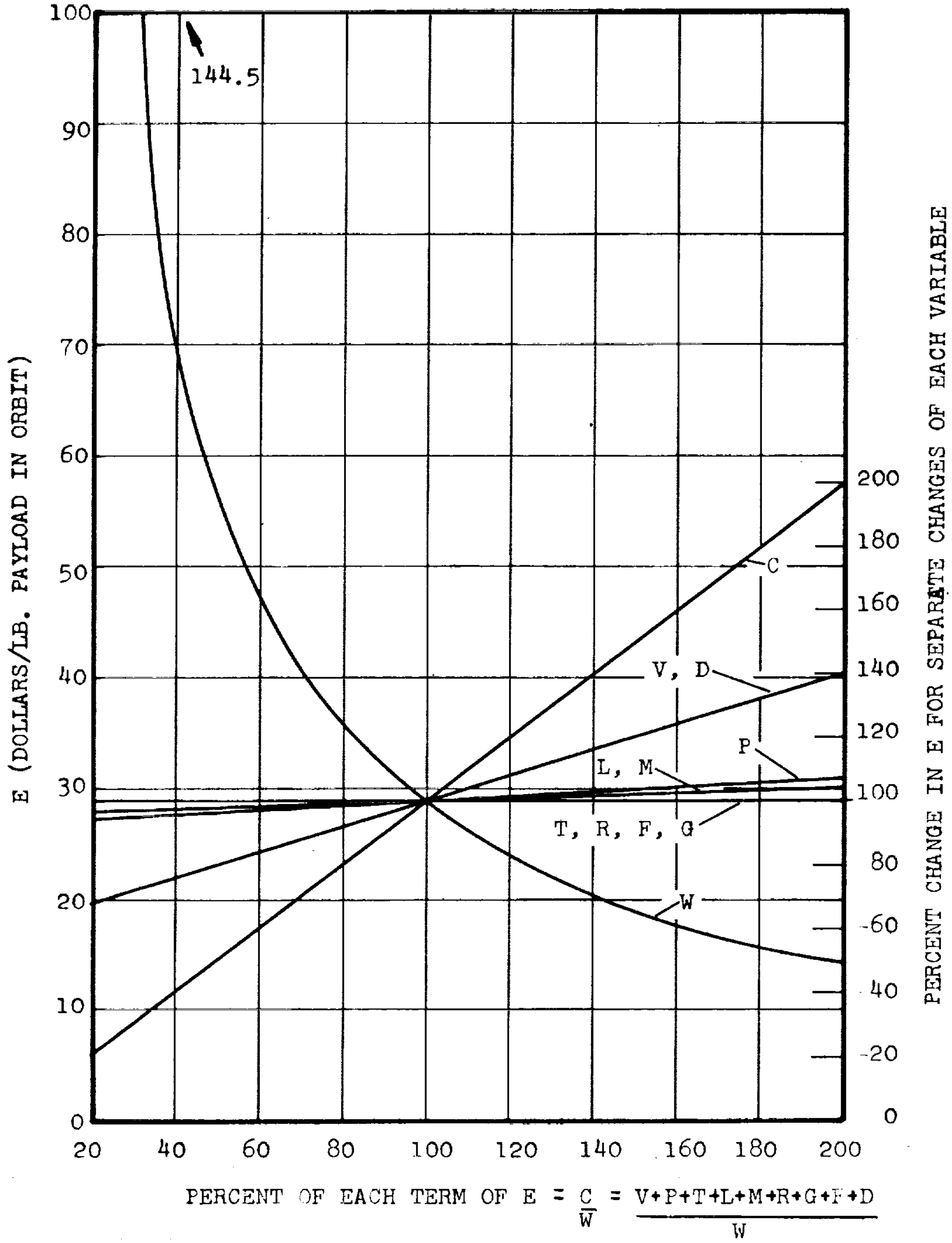
O/W--Dollars/lb of Payload in Orbit Versus Operational Year (240 Launches)

Figure 5-6



E--Dollars/lb of Payload in Orbit Versus Operational Year (240 Launches)

Figure 5-7



Effects of Varying Cost Parameters

Figure 5-8