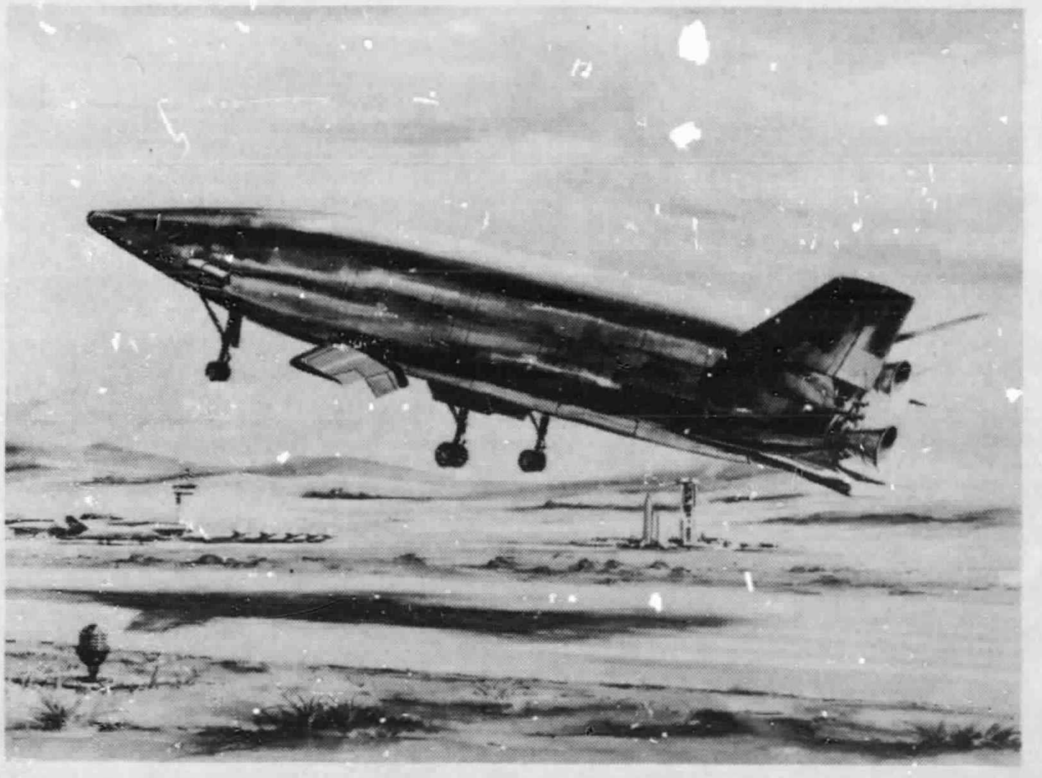
X70-13386
CR-102556

REPORT NO. GDC-DCB69-046
CONTRACT NAS 9-9207



SPACE SHUTTLE
FINAL TECHNICAL REPORT

VOLUME IX • GROUND TURNAROUND OPERATIONS AND FACILITY REQUIREMENTS

GENERAL DYNAMICS
Convair Division

054

REPORT NO. GDC-DCB69-046

SPACE SHUTTLE
FINAL TECHNICAL REPORT

VOLUME IX ✦ GROUND TURNAROUND OPERATIONS AND FACILITY REQUIREMENTS

31 October 1969

Prepared by
CONVAIR DIVISION OF GENERAL DYNAMICS
San Diego, California

FOREWORD

This volume of Convair Report No. GDC-DCB 69-046 constitutes a portion of the final report for the "Study of Integral Launch and Reentry Vehicles." The study was conducted by Convair, a division of General Dynamics Corporation, for National Aeronautics and Space Administration George C. Marshall Space Flight Center under Contract NAS 9-9207 Modification 2.

The final report is published in ten volumes:

Volume I	Condensed Summary
Volume II	Final Vehicle Configurations
Volume III	Initial Vehicle Spectrum and Parametric Excursions
Volume IV	Technical Analysis and Performance
Volume V	Subsystems and Weight Analysis
Volume VI	Propulsion Analysis and Tradeoffs
Volume VII	Integrated Electronics
Volume VIII	Mission/Payload and Safety/Abort Analyses
Volume IX	Ground Turnaround Operations and Facility Requirements
Volume X	Program Development, Cost Analysis, and Technology Requirements

Convair gratefully acknowledges the cooperation of the many agencies and companies that provided technical assistance during this study:

NASA-MSFC	Aerojet-General Corporation
NASA-MSC	Rocketdyne
NASA-ERC	Pratt and Whitney
NASA-LaRC	Pan American World Airways

The study was managed and supervised by Glenn Karel, Study Manager, C. P. Plummer, Principal Configuration Designer, and Carl E. Crone, Principal Program Analyst (all of Convair) under the direction of Charles M. Akridge and Alfred J. Finzel, NASA study co-managers.

PRECEDING PAGE BLANK NOT FILMED.

TABLE OF CONTENTS

TABLE OF CONTENTS, Contd

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS, Contd

LIST OF TABLES

PRECEDING PAGE BLANK NOT FILMED.

SUMMARY

Results of the ground turnaround and facility study are:

- By early and continuing attention to maintainability in vehicle and subsystem design, a two-week turnaround cycle for the reusable space vehicle is entirely feasible.
- By adopting the airline approach to maintenance, downtime may be greatly reduced.
- By refurbishing components on an equalized basis, a one-time-complete vehicle overhaul period could be eliminated.
- Maintenance manpower could be optimized by utilization of the crew concept of maintenance, thus reducing recurring labor costs.
- Onboard checkout equipment, inflight monitoring of specified subsystems, and an onboard engine diagnostic system are mandatory if timely service and maintenance are to be achieved.
- A preliminary study has been made of the use of Complex 39 as an operational facility for the space shuttle vehicle. With certain modifications, the study indicates that the prospect is entirely feasible and worthy of an in depth study.
- A preliminary comparison of two- and three-element vehicles verifies the obvious conclusion that less total time is required to turnaround FR-3 because the time to erect and mate two elements rather than three is proportionately less.

SECTION 1

INTRODUCTION

The ground turnaround requirements of a reusable space transportation system are key factors in maintaining a desired reuse or launch rate. Additionally, recurring costs such as maintenance, servicing and ground handling operations, must be kept at an economical level in order to realize the full potential of the system. The ground turnaround and facilities analysis contained in this volume was made with economy of time, manpower, and materials as the primary driving factors. The work statement for this analysis required that total ground turnaround operations (postlanding to prelaunch) and supporting facilities be investigated for a configuration of the reusable space vehicle. Convair considered it advisable to apply the broad operational experience of a major airline to the ground turnaround operations for the space shuttle. Pan American World Airways (PAA) is deeply interested in the future potential of the space shuttle and agreed to work with Convair by performing a PAA-funded study and analysis of the reusable space shuttle ground turnaround requirements. Details of the PAA/Convair agreement are contained in Section 2. PAA was furnished vehicle configuration data as early as possible so that the results of their analysis could be incorporated into this report. PAA completed an analysis for ground turnaround operation of orbiter and booster elements of the FR-1 reusable space vehicle configuration. This analysis incorporated the airline maintenance approach to turnaround operations. Although the analysis used the FR-1 three-element vehicle as a baseline, the majority of the tasks are applicable to the elements of the FR-3 and FR-4 vehicles. Certain ground handling and maintenance manhour requirements may vary, depending upon the number of vehicle elements, but ground turnaround tasks as identified herein will remain virtually the same. Section 2 of this volume presents an analysis of ground turnaround operations from recovery of a reusable-vehicle element on the runway to completion of ground launch operations for its reuse. Section 3 contains an analysis of the facilities and equipment necessary to support the turnaround cycle. Facility concepts have been included for both two- and three-element vehicles, and various methods of erection and mating are presented.

SECTION 2

GROUND TURNAROUND OPERATIONS

2.1 APPROACH TO TURNAROUND OPERATIONS

The reusable space vehicle enjoys a unique position in the new space age. It is both an aircraft and a vertical launch vehicle. Because of its aircraft mode, it constitutes a fully reusable vehicle and a relatively large number of launches and recoveries are planned for each year. Therefore, it is believed that an "airline" turnaround philosophy must be adopted for the functions and tasks to be performed during the ground time between missions. Although the vertical launch vehicle aspect might seem foreign to airline operations, such is not the case since many of the subsystems operate quite similarly to and contain the same type of components as an aircraft.

To bring operational airline experience into the ground turnaround analysis, Convair division of General Dynamics signed a letter of agreement with Pan American World Airways (PAA) which stated, "The Pan American effort for the reusable space vehicle (FR-1) study work is briefly described as a review of the proposed systems design with regard to cost of ground handling, maintenance, refurbishment, launch and turnaround time. A report based on Pan American's experience on the Boeing 707 aircraft giving cost and turnaround schedules for the reusable system will be prepared by Pan American." The turnaround analysis and subsequent report was company-sponsored by Pan American World Airways. The report (Reference 2-1) submitted to Convair by PAA is entitled "Airline Methods Applied to Space Shuttle System Turnaround Plan and Cost Analysis."

To provide a basis for the PAA analysis contained in Reference 2-1, Convair furnished to them a basic turnaround concept, vehicle preliminary design configuration data, and as much subsystem/component data as became available by preliminary design efforts. Particular emphasis was placed on providing information peculiar to the reusable space shuttle concept (i.e., thermal protective subsystem design, reusable rocket engine subsystems, and reusable environmental control subsystems). The majority of analytical and other data contained in this section was extracted from the PAA report. The PAA "airline" approach to ground turnaround, together with Convair aircraft and space vehicle experience, provide for the total ground turnaround philosophy, concept and analysis contained within this section.

2.2 METHODS OF ANALYSIS

As nearly as possible the ground operations were related to operations being carried out at the Eastern Test Range and MILA (Merritt Island Launch Annex) on the present systems. Conservative extrapolations for improvements in the design were considered. To estimate time to accomplish the functions, manpower, costs and ground support costs, extensive actual data on launch complex operational costs was used. The data presented in Section 2.6 is predicated on a concept of all maintenance being performed on elements in the horizontal position and with erection and mating of the elements occurring on the launch pad. A description of alternate methods of erection and mating is provided in Section 2.8. The method of analysis for maintenance of the vehicle elements is based upon a maintenance program formulated specifically for the vehicle, and on historical data for the B-707 aircraft at a 1200 flight hour service level. The use of B-707 data introduces a degree-of-complexity factor which accounts for differences in vehicle and operating environment. Based upon the B-707 data, PAA statistically analyzed individual tasks required to accomplish routine and nonroutine maintenance. Expected manhour figures and elapsed times were then derived from the task analysis. Routine maintenance may be identified from overall design and vehicle subsystem definition and may be prescheduled accordingly. Nonroutine maintenance requirements are normally derived from a reliability analysis of a vehicle and its subsystems. Subsystem definition for the reusable space shuttle is insufficient at this time to complete a reliability analysis. In order to predict nonroutine maintenance for the reusable space vehicle turnaround analysis, PAA utilized B-707 historical records. B-707 records show that the relationship between nonroutine and routine maintenance manhours is 0.6:1.0 at the 1200-hour service point, and 2.0:1.0 for all nonroutine work accumulated over the 1200-flight-hour period. An example of the routine versus nonroutine maintenance derivation, as extracted from Reference 2-1, is presented in Table 2-1.

2.3 EFFECT OF VEHICLE DESIGN UPON GROUND TURNAROUND OPERATIONS

The design of a reusable space vehicle has a decided impact upon the total ground turnaround requirements. Size, shape, tankage requirements, number and complexity of subsystems and components all must be considered when developing the vehicle/turnaround interface. Listed below are typical design considerations that must be incorporated into the design from the initial design stages onward. These design requirements are considered to have been satisfied for purposes of this analysis.

a. Landing gear must support towing of elements during turnaround cycle, including weight of payload. Both forward and backward towing capability is required.

b. Hard points for attachment of erection devices must allow the entire element to be lifted from the horizontal position to the vertical.

c. In a stowable wing design, the wing must be designed to be fully or partially retracted with the landing gear extended. This will reduce facility clearance requirements and simplify handling.

d. Cryogenic fill and drain valves and connections must be readily accessible with element in either vertical or horizontal position.

Table 2-1. Derivation of Nonroutine vs. Routine Manhour Relationships for B-707 Aircraft

1. At the 1200 flight hour service level (nonroutine mh)/(routine mh) = 0.6. Typical examples of B-707 (equalized) 1200 hour service historical data are:

	Routine Manhours (RMH)	Nonroutine Manhours (NRMH)	NRMH/RMH
	665.9	444.6	0.67
	663.7	669.4	0.90
	963.1	407.5	0.42
	616.3	279.1	0.39
	721.5	226.3	0.31
	826.4	682.3	0.83
	612.5	443.4	0.72
	714.2	390.4	0.55
Average	722.95	442.875	0.61

2. At the 1200 flight hour service level after accumulating nonroutine manhours for a 1200 period

$$\frac{\text{Nonroutine mh (accumulated over 1200 flight hours)}}{\text{Routine mh (at the 1200 flight hour service level)}} = 2.0$$

The above relationship was derived from the following service pattern and manhour figures which are typical for the B-707 operation over a 1200 flight hour period.

Services accomplished in 1200 hours of operation	Approx. Interval between service	Typical nonroutine MH per service	Total avg. 1200 flight hr
30 Transit (LOT) Services	100 hr	23	690
3 Terminal Services	300 hr	101	303
1 Equalized Service	1200 hr	450	450
		Subtotal	1443
Allowance for nonroutine work accomplished at Line Stations			120
		TOTAL NONROUTINE MANHOURS	1563

Typical figure for routine manhours at the 1200 flight hour service level = 723 hr

$$\frac{\text{NRMH}}{\text{RMH}} = \frac{1563}{723} \approx 2$$

e. Cargo doors and compartments must be accessible with element in either vertical or horizontal position.

f. Ready access must be available to areas containing expendables, i.e., batteries, pneumatics, hydraulics, pyrotechnics, etc.

g. Visual inspection access panels must be provided for specified component or critical structural area access.

h. Modular subsystem components must provide for incorporating maximum remove and replace concept.

i. Simplify subsystem components to minimize maintenance requirements.

2.4 GENERAL ASSUMPTIONS

To perform an analysis on a conceptual reusable space vehicle, certain design and operational assumptions must be made. Results of the PAA/Convair ground turnaround analysis as contained here and in Reference 2-1 were obtained using the following assumptions.

a. The system is fully operational.

b. Facilities and AGE are available.

c. Airline-type safety, maintenance and reliability requirements are built into the design on an equal par with performance.

d. Advanced technology is used: radiative heating - no ablation, integrated electronics, and autonomous checkout

e. One hundred launches/year are performed for a 10-year period.

f. Average flight times are 120 hours for the orbiter and two hours for the booster.

g. Booster engine life is 100 hours (5,000 restarts; overhaul cost at end of 100 hours is 25% of acquisition cost).

h. The fleet consists of seven boosters and five orbiters with one system-set on standby at all times.

i. Adequate inventory of spare parts is available.

j. Individual elements are vertically erected and mated on the launch pad.

k. The vehicle is compatible with air traffic control and other major FAA requirements (Federal Aviation Regulations).

l. The vehicle is designed for optimum maintainability.

m. The vehicle is designed for autonomous onboard checkout of all primary systems.

n. Operations, maintenance and facility personnel are trained and familiar with the ground turnaround tasks.

2.5 CONCEPT OF GROUND TURNAROUND OPERATIONS

In considering the various types of servicing and maintenance required for a reusable space vehicle it is necessary to consider servicing/refurbishment/maintenance and the turnaround cycle as being synonymous. For example, servicing of this type of vehicle starts shortly after landing and continues through the fueling operations immediately prior to launch. To provide an orderly flow of work and to place tasks to be accomplished in their proper perspective, a concept of turnaround cycle phases was established. Although servicing and even maintenance may occur as tasks within more than one phase, the phases provide a basis upon which to perform an analysis of specific tasks, assign manpower requirements, and identify specific facilities and equipment required to support the tasks.

Nine phases have been identified and are described in detail, along with elapsed time and manpower requirements based on PAA analysis, in Sections 2.6 and 2.7. The phases and their location within a hypothetical launch complex are as shown on Figure 2-1, and as applicable to ETR Complex 39 in Figure 2-2. In the PAA analysis the phases were treated as two main categories. Phases I, II, V, VI, VII, VIII and IX were considered as ground operations and Phases III and IV as maintenance. The phases were divided primarily to provide a functional manpower split for analysis purposes, so that vehicle maintenance crew requirements could be readily identified from vehicle operations personnel and facilities and equipment operations personnel. The manpower tabulations are presented in Section 2.7. The phases identified are applicable to a reusable space vehicle regardless of the number of elements involved or their general configuration, but the order in which they occur may differ depending upon the location chosen for erection and mating.

2.5.1 MAINTENANCE POLICY. Elements of the reusable space vehicle will be maintained using a continuous maintenance program based upon the condition-monitoring concept. For the purpose of the analysis, only one level of service (maintenance) is considered, i.e., the turnaround service which is accomplished after each mission. Maintenance performed after each mission will include nonroutine (repairing or removal and replacement of malfunctioned components) and routine (scheduled servicing, visual inspection, system checkout, and replacement and/or refurbishment of time-limited items such as those identified in Table 2-2). In other words, in addition to repair of malfunctioned parts, an equalized service is performed each time, allowing for full utilization of manpower and facilities. Components that need to be removed from the vehicle due to failure, substandard performance or time limit will be replaced with serviceable components. Components removed will be routed through local maintenance or subcontractor shops for repair or overhaul and retest.

2.5.2 EQUALIZED ROUTINE MAINTENANCE AND SERVICING. To avoid total vehicle overhaul and to best utilize available time and manpower, certain routine

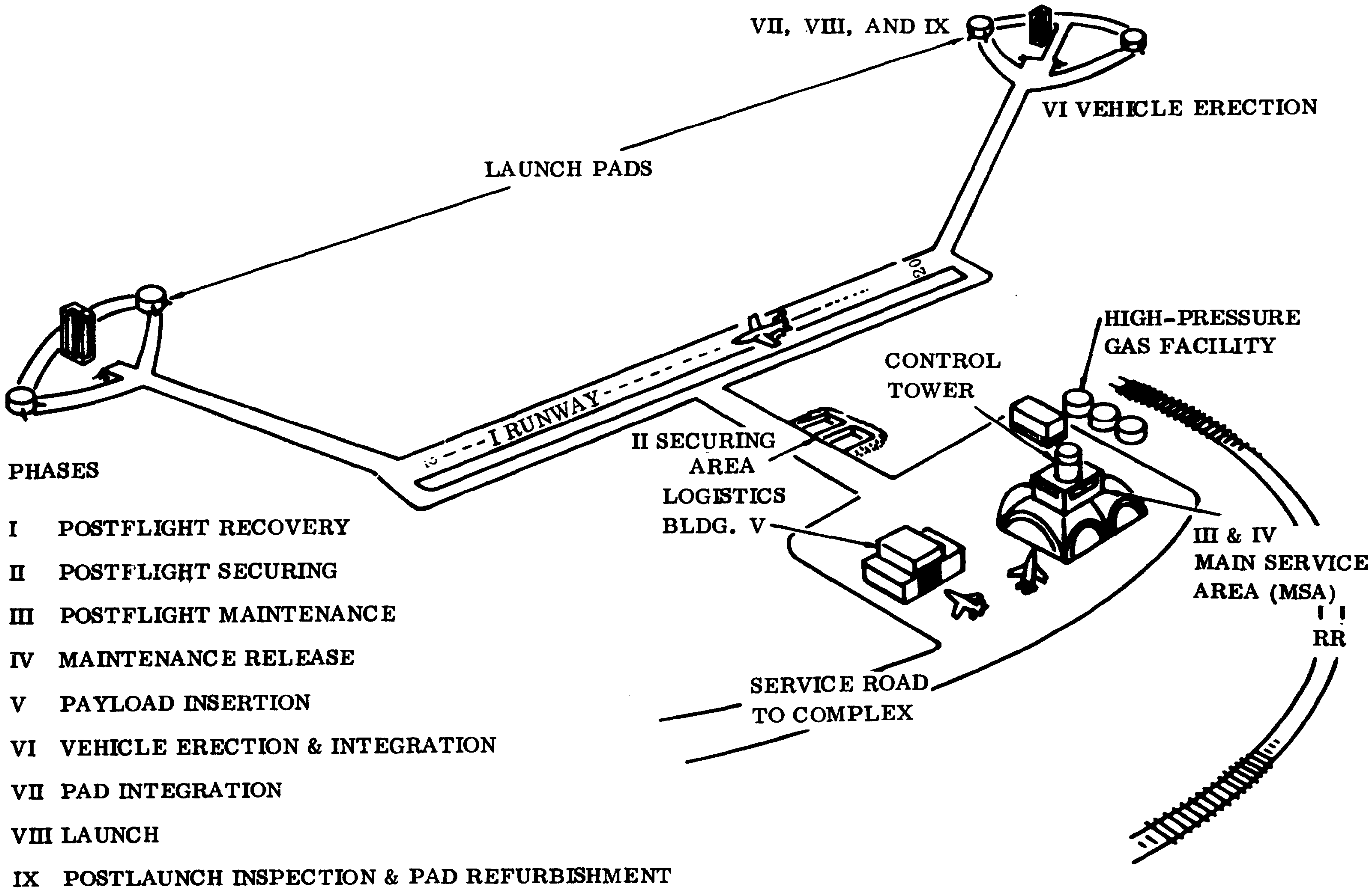


Figure 2-1. Turnaround Phases and Location

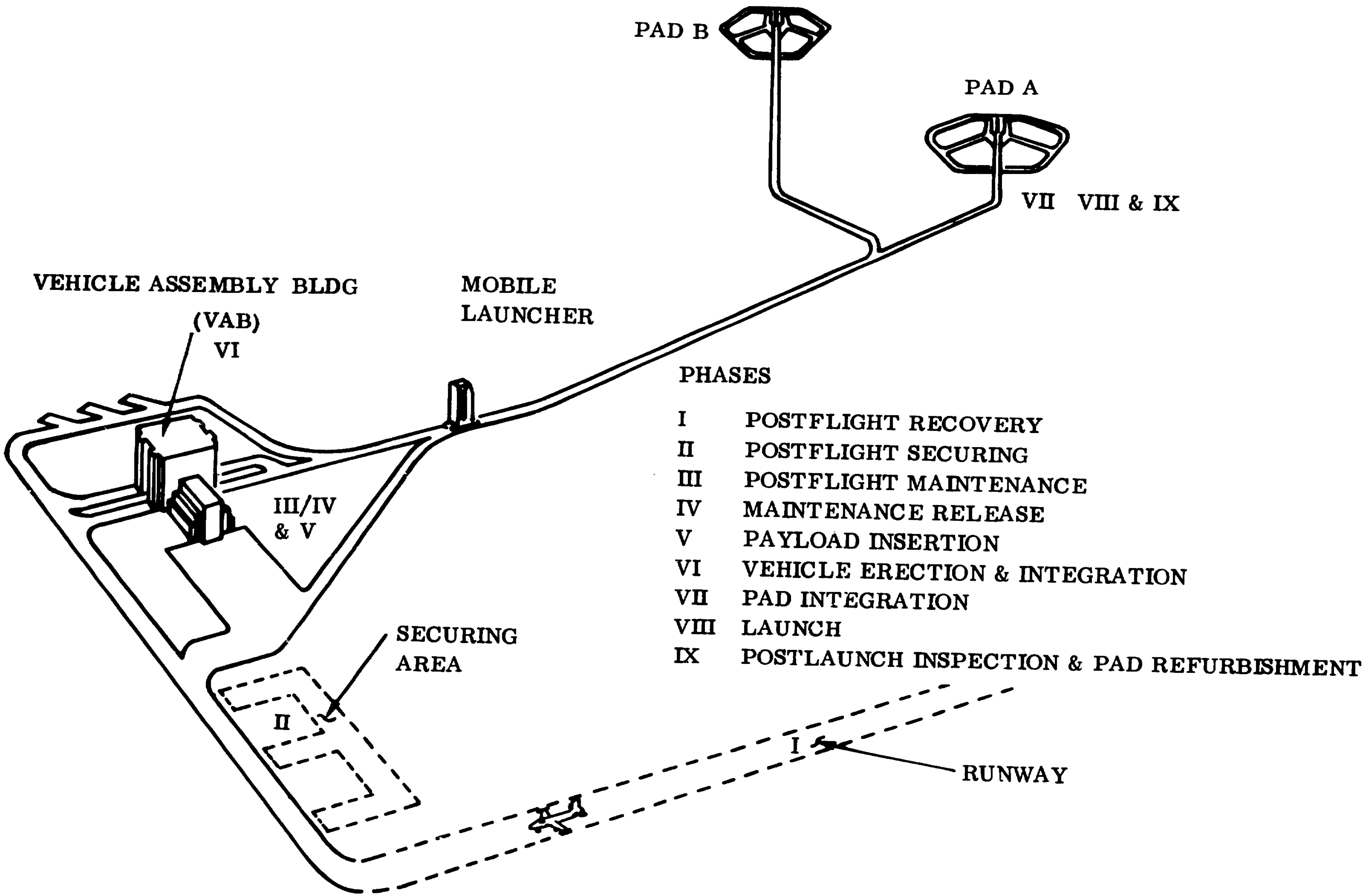


Figure 2-2. Turnaround Phases and Location as Applicable to Complex 39, ETR

Table 2-2. Typical Time-Limited Items

SUBSYSTEM AND COMPONENT	NUMBER OF MISSIONS BEFORE REPLACEMENT OR OVERHAUL
Environmental Control System	
Cryogenic (Supercritical) Storage Vessels	120
Gas Sensor and Control	120
Atmospheric Purification Loop	
Blower	30
Water Separator	30
Filter	6
Water Management	
Multifiltration Unit	1
Waste Management	
Feces Collector and Dryer	1
Activated Charcoal Filter	100
Personal Hygiene	
Activated Charcoal Filter	100
Thermal Control	
Pumps	120
Blower	30
Expendable Supplies	
O_2	1
N_2	1
Food	1
CO_2 Absorber Cartridge	1
Personal Hygiene Supplies	1
Electrical Power	
Fuel Cells	18
Stored Electrolyte Battery	1
Hydraulic System	
Servo Valves	90
Thermal Protective System (Orbiter)	
Nose Cap	50
Base Panel Contiguous to Nose Cap	10
Second Base Panel From Nose Cap	35
Base Leading Edges	10
Other Base Panel Material	50
Topside TPS Material	50

Table 2-2. Typical Time-Limited Items, Contd

SUBSYSTEM AND COMPONENT	NUMBER OF MISSIONS BEFORE REPLACEMENT OR OVERHAUL
Thermal Protective System (Orbiter) (cont'd)	
Leading Edge of Verticals	10
Remainder of Verticals	50
Propellant System	
Primary Feed Duct Staging Disconnects	1
Primary Feed Duct Staging Shut Off Valves	50
Gimbal Flex Duct Assemblies	10
Propellant Fill and Drain Valves	50
Boiloff and Relief Valve Packages	25
Staging Disconnects (Crossfeed)	25
Attitude Control System	
Catalyst Beds	10
Compressors/Motors	10

NOTE: Majority of vehicle subsystem components will be considered "on condition" and replaced when failure occurs or impending failure is indicated by trend analysis.

maintenance and servicing tasks should be scheduled to be accomplished after each mission. For example: it would require 52.9 manhours to lubricate each hinge, joint, actuator, and landing gear axle, etc., per reusable element. If total lubrication were accomplished on each element of a reusable space vehicle, each turnaround would require the full efforts of 10 men for 5.3 hours. Based upon airline experience, lubrication is not required for every hinge or axle every time (some specific areas do require lubrication each time and must be added to areas to be lubricated on an equalized basis). PAA, in their analysis, equalized the lubrication manhours after each flight in the following manner:

Optimistic "a" = total lubrication is equalized over 10 services.

Pessimistic "b" = total lubrication is accomplished at every service.

Most Probable "m" = total lubrication is equalized over five services.

"a" = 52.9/10 = 5.3 manhours

"b" = 52.9/1 = 52.9 manhours

"m" = 52.9/5 = 10.6 manhours

By the equalized service approach, the maintenance turnaround lubrication task (Phase III, Task 6) provides for 10.6 hours of equalized lubrication plus 6.2 hours of "every time" lubrication for a total of 16.8 manhours after each flight instead of the 52.9 if the total task were accomplished every time. The PAA analysis also included certain partial subsystems checkout on an equalized manhour scheduling basis. Taken collectively, the time-limited items (Table 2-2) are also scheduled for equalized maintenance. For example: the thermal protective subsystem (TPS) panels are scheduled to be changed (according to time limits) as a part of the turnaround routine maintenance. When designated TPS panels are scheduled for removal so that structural inspection may be made (PAA analysis provides for removal of 20% of critical TPS area every fifth flight), the panels that are due for replacement because of identified time limitation will be prescheduled to mesh within the equalized 20% removed for structural inspection. Those items on Table 2-2 that are time limited to one mission will be scheduled as a part of the routine maintenance after each mission.

2.6 FUNCTIONAL TURNAROUND PHASES

As depicted in Figure 2-1, nine functional phases have been identified for the total ground turnaround cycle. For purposes of the turnaround analysis, Phase III (Post Flight Maintenance) and Phase IV (Maintenance Release) have been combined. Phase IX (Post Launch Pad Refurbishment) is not directly related to the vehicle, but is included in the turnaround cycle analysis because of the influence of launch pad readiness to accept the next vehicle launch. Tables 2-3 and 2-4 present the turnaround phases and tasks to be accomplished within each phase (as identified by PAA/Convair). Also included in Table 2-3 is the time to complete the tasks. Table 2-4 includes time

Table 2-3. Turnaround Cycle (Ground Operations)

Phases, Tasks, and Descriptions	Task Time (hr)
PHASE I — POSTFLIGHT RECOVERY	
Task 1 — Landing and Recovery	0.5
Task 2 — Movement of Vehicle to Securing Area. Element will land under aircraft control tower surveillance. (Normal airfield operation equipment will be available.) Access to the area will be controlled by security guards. Ground crew will be standing by with landing gear pins and tow tugs. Crew and passenger exit ramps (mobile, adjustable) and personnel transportation vehicle will stand by. Element will clear runway and shut engines down (alternative method is to taxi element directly to securing area and accomplish the following items at that location). Ground crew will insert gear locking pins and chock wheels, safe external ordnance switch, and position crew and passenger exit ramps. Ground crew will position tow tug and attach towing device. Crew will remove flight tapes and log. Crew/passengers disembark, chocks are moved, and vehicle is towed to securing area and positioned for cooling and purging. Ground crew, with exception of tug operator, will remain for second element. One ground crew will remain on standby for return of orbiter element.	0.5
PHASE II - POSTFLIGHT SECURING	
Task 1 — Cool, Vent, Purge, and Remove Ordnance. After element is positioned and chocked in securing area, the cooling system will be connected and TPS cooling will commence. The LH_2 tank vents will be connected to the facility H_2 vent system and gaseous purge lines connected. After cooling and when vent samples indicate H_2 vents are at a safe level, the ordnance crew will remove ordnance/pyrotechnics. If element is a booster, it will then be released to maintenance.	7.0
Task 2 — Unload Cargo From Orbiter Element. Cargo bay doors will be opened and cargo removed from cargo bay using specialized handling equipment and such other general supporting equipment (fork lifts, cranes, etc.) as may be required. Cargo will be expeditiously moved to logistics area. Orbiter will be released to maintenance.	3.0
PHASES III and IV — See Table 2-4.	
PHASE V — PAYLOAD INSERTION	
Task 1 — Tow Orbiter to Logistics Area. The orbiter vehicle will be towed from the maintenance area to the logistics building loading area and positioned for loading.	1.0
Task 2 — Insert Payload Into Orbiter. Vehicle loading compartment will be opened and modularized cargo inserted using specialized handling equipment. Cargo will be secured for flight.	4.0
Task 3 — Inspect and Secure Orbiter Cargo Compartment. Loaded cargo will be inspected for proper securing; cargo compartment will be closed and sealed.	0.5
Task 4 — Tow Orbiter to Erection Area. A tow vehicle will tow the loaded orbiter from the logistics area to the erection area and position for erection.	1.0

Table 2-3. Turnaround Cycle (Ground Operations), Contd

Phases, Tasks, and Descriptions	Task Time (hr)
PHASE VI — VEHICLE ERECTION AND INTEGRATION	
Task 1 — Erect Elements and Perform Mechanical Mating. The three individual elements will be towed to the launch pad area. Elements will be erected and the wings and landing gear fully retracted to the stowed position. Staging hardware will be positioned for mating elements.	12.0
Task 2 — Mechanical Mating of Vehicle to Launcher Assembly. Each of the three elements will be mechanically installed on the launcher assembly and properly aligned. Staging hardware will be connected and ordnance devices installed.	4.0
Task 3 — Mating and Leak Check of Fill/Drain Valves and Propellant Disconnects. Intervehicle propellant lines will be connected; a helium leak check will be made on completion.	6.0
Task 4 — Connection of intervehicle and vehicle-to-launcher electrical connections. Electrically actuated ordnance explosive bolts in the vehicle separation subsystem will be checked but not electrically connected.	4.0
Task 5 — Integrated Vehicle Systems Check. Proper operation of all vehicle systems will be automatically checked.	8.0
PHASE VII — PAD INTEGRATION	
Task 1 — Mechanically Mate Launcher Pivot Points With Pad Pedestals. The integrated vehicle and launcher will be moved into position over flame bucket, mated to the launch pedestals, and adjusted for proper alignment.	2.0
Task 2 — Connect Launcher Facility Electrical, Propellant, and Pneudraulic Supply Lines. All vehicle service lines will be connected to ground facility lines and leak checked where applicable.	10.0
Task 3 — Launcher-to-Launch-Control Compatibility Tests. An electrical compatibility analyzer will automatically perform preprogrammed tests to verify launcher-to-launch-control compatibility.	4.0
Task 4 — Cryogenic Leak Check of all Vehicle/Launcher/Facility Connections. Cryogenics will be flowed through facility lines to vehicle tanks, and systems will be pressure-checked for leaks.	4.0
PHASE VIII — LAUNCH	
Task 1 — Launch Countdown. Crew and passengers will be loaded. Preflight checking by the flight crew will be conducted using onboard checkout equipment. Vehicle ordnance will be electrically connected. Propellants will be loaded and replenishment continued until just prior to engine start. Service structure will be moved to a remote position. Crew will perform a final preflight check. Engines will be started and engine performance checked. Vehicle will liftoff.	6.0

Table 2-3. Turnaround Cycle (Ground Operations), Contd

Phases, Tasks, and Descriptions	Task Time (hr)
Task 2 — Recycle for Standby (If Applicable). Crew and passengers egress. Propellants and inert propellant systems are detanked. Ordnance is electrically disconnected and safety controls are removed. Vehicle will be in standby status to return to launch countdown, Phase VIII, Task 1.	(6.0)*
PHASE IX — POSTLAUNCH INSPECTION AND PAD REFURBISHMENT	
Task 1 — Pad Inspection. Propellant subsystems will be purged and inerted; refurbishment crews will enter pad area. Propellant and gaseous storage tanks will be replenished.	(4.0)*
Task 2 — Pad Refurbishment. Launcher and flame deflector are removed to respective refurbish areas and repaired as necessary. Necessary pad repairs are made and systems are validated to accommodate next launch vehicle	(8.0)*
TOTAL	77.5

* Not included in turnaround totals

Table 2-4. Turnaround Cycle Maintenance (Phase III - Postflight Maintenance and Phase IV - Maintenance Release)

	Tasks and Description	Task Time (hr)	Man Hours (Et)
Task 1 —	Accept Element at Securing Area and Move to Main Service Area (MSA). Block terminal checklist is accomplished and element is transferred to MSA.	0.6	1.7
Task 2 —	Receive Element at MSA. Element is received at MSA, positioned in maintenance bay, and supported upon jacks (if required by reported malfunctions). Work stands are positioned and the hangar facilities readied for maintenance activities.	1.4	13.2
Task 3 —	Open Access Doors and Plates and Remove Parts of Thermal Protection System (Routine). All required access doors and plates are opened; i.e., those that give access to structure, interior compartments, components, equipment, and systems installations requiring routine inspection and/or servicing. Portions of the TPS are removed; i.e., those parts that give access for the inspection of critical structural areas that are inspected on a sampling basis.	7.0	41.7
Task 4 —	Perform the Check-In Inspection. The complete exterior of the vehicle and specific interior compartments are visually inspected for discrepancies. Inspection result write-ups are issued for corrective action as required. The areas of the vehicle to be inspected are:	15.8	189.2

Exterior	E(t)
Fuselage, including visible primary structure, vehicle mating points, TPS, windshield, and doors	49.2
Nose gear, attach structure, doors, and well	2.2
Flyback engine, cowlings, engine attach structure, doors, and engine compartments	51.3
Wings, flaps and spoilers and wells, wing attach structure, operating mechanism, wing doors, and wells	26.1
Main landing gear, attach structure, doors, and wells	9.3
Empennage, including TPS, visible primary structure, stabilizers and TPS, control surfaces, attach structure, and wells	11.8
Stabilizer and rocket engine (attach structure)	8.4
Rocket engines	4.3

Table 2-4. Turnaround Cycle Maintenance (Phase III - Postflight Maintenance and Phase IV - Maintenance Release) Contd

	Tasks and Description		Task Time (hr)	Man Hours (Et)
		E(t)		
	Interior			
	Control cabin, including equipment check	7.9		
	Equipment bay (aft of control cabin) and tunnel	8.0		
	Cargo compartment and auxiliary tanks	10.7		
	Total	189.2		
Task 5 —	Perform Non-Routine Work. Inspection check-in completed, in-flight performance monitoring data reduced and analyzed. Accomplish non-routine work as indicated/uncovered by inspection (Task 4), flight analysis, and log-book discrepancy items.		19.4	381.2
Task 6 —	Routine Servicing. The vehicle is serviced to replenish expendables/consumables; i.e., fluids, gases, foods (if scheduled for launch in 24 hours) and batteries. Clean cabins, lubricate scheduled areas. The vehicle is serviced as follows:		7.8	62.0
		E(t)		
	Service ECS/LSS and replace expendables:			
	Replace CO_2 absorbers, debris traps, and filters			
	Replace O_2, N_2, and He bottles			
	Service water separators and sublimators	9.0		
	Flush, disinfect and replenish potable H_2O. Service personal hygiene units. Flush and disinfect waste tanks	16.5		
	Service Electric/Avionics Systems:			
	Replace batteries	8.5		
	Replace flight tapes and flight spares as required	3.0		
	Service Hydraulic and Emergency System			
	Service accumulators and reservoirs as required	3.1		
	Replace emergency pneumatic bottles as required	1.0		
	Service Landing Gear (tire pressures)	1.8		
	Service cabin interior (clean and deodorize)	2.3		
	Lubricate scheduled areas	16.8		
	Total	62.0		

Table 2-4. Turnaround Cycle Maintenance (Phase III - Postflight Maintenance and Phase IV - Maintenance Release) Contd

	Tasks and Description	Task Time (hr)	Man Hours (Et)
Task 7 —	Systems Checkout. Check out systems as required; i.e., hydraulic system pressure and leak check, flight control response check, ACS check, avionics operational check, rocket engine malfunction system check, engine turbopump seal leak, and torque check.	7.0	41.6
Task 8 —	Close Access Doors and Plates, and Install Removed TPS Parts. Reinstall all access plates, TPS panels, stow wing flaps, and retract spoilers.	7.0	42.0
Task 9 —	Remove Jacks and Workstands. Jacks are removed and workstands are moved clear in preparation for towing vehicle out of maintenance area, tow assembly is attached, and tow tug hooked up.	1.3	13.2
Task 10 —	Move Element to Runup Area and Perform Jet Engine Runup. Tow element to runup area and position for runup. Fuel element and run up engines. Secure engines, visually check, and retract engines and doors	1.1	3.2
Task 11 —	Element Cleared for Release to Ground Operations. Perform final element sign off/certification and release element to ground operations personnel for next phase.	0.5	0.5
	Total	68.9	789.5

Note: This table covers maintenance of the orbiter element. Booster element tasks are reduced in lapsed time and manhours for maintenance and are indicated in Reference 2-1 and the turnaround summary (Paragraph 2.7, this section).

to complete the tasks and manhours required. Table 2-5 presents a summary of the phases, tasks and task time. Manpower requirements for the phases in Table 2-3 are derived from two sources of manpower (vehicle operations personnel, and facilities and equipment operation personnel) as previously stated in Section 2.5. Tables 2-6 and 2-7 present the ground operation manpower (maintenance manpower treated separately) as derived from the PAA analysis and as applicable to Table 2-3. A total manpower requirements summary is contained in Section 2.7.2

Special consideration from a ground operations standpoint has been given to certain of the characteristics and functions of the reusable space vehicle, since it is neither totally an aircraft nor totally a space vehicle, but a unique combination of both. Enumerated in the following paragraphs are special considerations which were used in the turnaround and facility requirement analysis contained in this volume and in Reference 2-1. These considerations are listed under applicable functional phases.

a. Phase I — Postflight Recovery

   1. Visibility of pilot to taxi the element and observe follow-me vehicle.

   2. Location of securing area to hold taxi time to a minimum.

   3. Necessity for safing landing gear for future towing operations.

   4. Temperature of outer surface of orbiter element.

   5. Rapidly clearing active runway to allow for landing of second booster element.

   6. Ability to receive and position two elements in rapid succession.

b. Phase II — Postflight Securing

   1. The booster elements omit payload removal task.

   2. Each element must be rendered safe from propellant and ordnance hazards prior to being placed in a fully enclosed maintenance building.

   3. Engine manufacturers advise purging of engine feed lines and valves prior to visual inspection or performance of unscheduled maintenance.

   4. The requirement for a cover over securing area has been investigated from a TPS insulation protection standpoint. The orbiter element will be in the securing area some ten hours and adverse weather may be a factor in protecting TPS insulation and cargo unloading operations when element is in the horizontal position.

   5. Cargo removal in this phase affords early access to possibly critical or classified payloads; therefore, an unloading device would be required. As an alternative the orbiter element (after cooling and purging) could be towed to lotistics area and unloaded, eliminating need for mobile unloading device.

Table 2-5. Summary of Phases and Tasks for Reusable Space Shuttle Ground Turnaround Cycle (Orbiter Element)

PHASE AND TASK	ELAPSED TASK TIME (HR)
PHASE I — POSTFLIGHT RECOVERY	
Task 1 — Landing and Recovery	0.1
Task 2 — Movement of Element to Securing Area	.9
PHASE II — POSTFLIGHT SECURING	
Task 1 — Cool, Vent, Purge, and Remove Ordnance	7.0
Task 2 — Unload Cargo From Orbiter Element	3.0
PHASE III AND IV — POSTFLIGHT MAINTENANCE AND MAINTENANCE RELEASE	
Task 1 — Accept Element and Move to MSA	0.6
Task 2 — Receive Element at MSA	1.4
Task 3 — Open Access Doors and Plates and Remove Parts of TPS	7.0
Task 4 — Perform Check-In Inspection	15.8
Task 5 — Perform Nonroutine Work	19.4
Task 6 — Routine Servicing	7.8
Task 7 — Systems Checkout	7.0
Task 8 — Close Access Doors, Plates, and Install Removed TPS Parts	7.0
Task 9 — Remove Jacks and Workstands	1.3
Task 10 — Move Element to Run-Up Area and Perform Engine Run-Up	1.1
Task 11 — Element Cleared for Release to Ground Operations	0.5
PHASE V — PAYLOAD INSERTION	
Task 1 — Tow Orbiter to Logistics Area	1.0
Task 2 — Insert Payload Into Orbiter	4.0
Task 3 — Inspect and Secure Orbiter Cargo Compartment	0.5
Task 4 — Tow Orbiter to Erection Area	1.0

PHASE AND TASK	ELAPSED TASK TIME (HR)
PHASE VI — VEHICLE ERECTION AND INTEGRATION	
Task 1 — Erect Elements and Perform Mechanical Mating	12.0
Task 2 — Mechanical Mating of Vehicle to Launcher Assembly (Accomplished With Task 1)	4.0
Task 3 — Mating and Leak Check of Fill/Drain Valves and Propellant Disconnects	6.0
Task 4 — Connection of Electrical Disconnects, Adjustment of Separation Actuators/Lanyards, and Installation of Ordnance	4.0
Task 5 — Integrated Vehicle Systems Check	8.0
PHASE VII — PAD INTEGRATION	
Task 1 — Mechanically Mate Launcher With Pad Pedestals	2.0
Task 2 — Connect Launcher to Facility Electrical, Propellant, and Pneudraulic Supply Lines	10.0
Task 3 — Launcher to Launch Control Compatibility Tests	4.0
Task 4 — Cryogenic Leak Checks of All Vehicle/Launcher/Facility Connections	4.0
PHASE VIII — LAUNCH	
Task 1 — Launch Countdown (Onboard Systems Check, Fueling, Insert Crew and Passengers, Purge Compartments, Move Service Structure and Launch)	6.0
TOTAL	146.4
PHASE IX — POSTLAUNCH INSPECTION AND PAD REFURBISHMENT	
Task 1 — Pad Inspection	4.0
Task 2 — Pad Refurbishment	8.0

Table 2-6. Vehicle Ground Operations Manpower Requirements

Phase	Task	Hours to Complete Task	Men Required	M/H Per Phase Per Operation	Number of Operations	M/H Per Year
I		1	6	6	300	1,800
II		3	3	9	100	900
V	1	1	1	1	100	100
	2	4	6	24	100	2,400
	3	0.5	2	1	100	100
	4	1	1	1	100	100
VI	1	12	4	48	100	4,800
	2	4	6	24	100	2,400
	3	6	6	36	100	3,600
	4	4	8	32	100	3,200
	5	8	16	128	100	12,800
VII	1	2	12	24	100	2,400
	2	10	9	90	100	9,000
	3	4	8	32	100	3,200
	4	4	8	32	100	3,200
VIII	1	6	30	180	100	18,000
	2	6	24	144	50	7,200
					TOTAL	75,200

75,200 MH/1,560 MH Per Year =

Elect/Mech Manyear Requirements	48
Supervisor Manyear Requirements	6
Quality Control Manyear Requirements	12
Admin/Engrg Manyear Requirements	7
Total Vehicle Manyear Requirements	73

Table 2-7. Manpower for Vehicle Operation Support and Operation and Maintenance of Ground Support Facilities and Equipment

O & M	Direct	On Call	Indirect	Total
	----------(Manyears Per Year)----------------			
Industrial Support				
Painting	14.0	10.0	1.00	25.00
Grounds	10.0	4.0	1.00	15.00
Custodial	15.0	5.0	2.00	22.00
Carpenter/Mason		2.0		2.00
Machine Shop		6.0		6.00
Technical Support		3.0		3.0
Engineering				
Liquids	50.0	10.0		60.00
Solids	4.0			4.00
Gases	24.0	5.0		29.00
Chemical Cleaning		4.0		4.00
Sampling	4.0	2.0		6.00
Meteorology		0.5		0.50
Range Ops/Tower Operator		0.5		0.50
Physical Standards		3.0		3.00
Non-Destruct Testing		0.5		0.50
Launch Complexes				
L.C. Engineering			2.00	2.00
Operations	70.0			70.00
Support Operations				
Fire Department		10.0		10.00
Fire Prevention		1.0		1.00
Security Police	30.0	2.0	0.50	32.50
Supply	10.0			10.00
Medical		2.0		2.00
Utilities & Transportation				
Equipment Operators		2.0	0.25	0.25
Heavy Equipment	4.0	2.0	0.25	6.25
Vehicle Maintenance		1.0	0.50	1.50
High Voltage		1.0	0.25	1.25
Electric Shop		4.0	0.10	4.10
Air Conditioning	10.0	3.0	0.10	13.10
Mechanical Utilities		8.0	0.10	8.10
Pump Station	5.0		0.10	5.10
Quality Control	12.0		0.50	12.50
Facilities Engineering	3.0	13.0	0.25	13.25
TOTAL MANYEARS PER YEAR	265.0	101.5	8.90	375.40

6. Positive GN_2 pressure must be left in cryogenic tanks and feed lines (providing no propellant malfunction had occurred) throughout remainder of turnaround cycle to prevent air/moisture accumulation.

c. Phases III and IV — Postflight Maintenance and Maintenance Release

1. Size of the 50K lb payload reusable element was a factor in arriving at scheduled maintenance manpower and elapsed time, particularly in inspection of the thermal protective subsystem of the orbiter element. The external surface cannot be monitored by onboard checkout; therefore, personnel and necessary equipment must be available to inspect 23,000 ft^2 of outer surface.

2. The fact that launch rate or other variables may cause an element to be placed in storage in excess of 48 hours will require that replenishment of food and potable water be delayed until element is called upon to be launched.

3. The maintenance facility must be designed to remove and replace major components such as engines and landing gear assemblies.

4. At a launch rate of 100 vehicles per year there will be from two to four elements in the maintenance area at all times.

5. The availability of a computer facility in or adjacent to the MSA (main service area) is required for processing flight data tapes and storing element maintenance history and subsystem/component data in order to provide system operating trends and equalized service tasks.

d. Phase V — Payload Insertion

1. An orderly turnaround cycle flow of the elements and logistic handling facilities point to loading the orbiter in the horizontal position on its landing gear. Payload insertion on the pad in the vertical position was considered; however, a large tower or crane would be required to place the cargo in the payload bay at a height of 150 feet. Additionally, logistics effort would have to cease during actual launch.

2. Four basic payload types relative to ground handling requirements were identified for this phase. These types are: dry cargo modules containing cargo for space station and/or satellite replenishment of supplies; wet or propellant cargo; passengers; and emergency rescue packages. Some of these cargo types may be dual in nature; i.e., a propulsive stage would be considered as dry cargo up to the point of fueling its tanks, when it would be also classed as a wet cargo type. Propellant modules would also be dry cargo until fueling commenced at the launch pad.

3. Access to payload with the vehicle erected and mated at the launch pad was also considered. If operational or emergency requirements dictated complete payload access at the pad, then a vehicle mating or stacking arrangement must be such that the top of the orbiter element would be fully exposed and not obstructed by booster elements or launch pad structures; additionally,

a 150-foot-high payload handling structure or module tower would be required at the pad. Stacking arrangements not exposing the top of the orbiter would require demating, de-erecting process and towing the orbiter back to the logistic area where a new payload could replace the loaded one, or another orbiter element could be rapidly substituted at the pad.

4. Ancillary functions of the separate logistics area would be the receiving and handling of air, rail, or road delivered payload items. These items must be prepackaged in cargo modules and ready for insertion into the orbiter.

5. The type, size and shape of payload would dictate the actual time required for loading. An average figure for the presently identified payload is used for the analysis.

e. Phase VI — Vehicle Erection and Integration

1. Use of the landing gear to transport elements to the launch pad area and as tie down points to secure the element to the erection platform is a major consideration. The landing gear, by design, is capable of withstanding total vehicle loads and should be capable of withstanding erection loads.

2. The possible requirement for rotation of one or more elements while in the vertical position will be dictated by the final stacking method selected.

3. A clean-type pad with no massive umbilical tower requires the adapting of service-line connections at the base of each element.

4. Provision of a portable service structure to facilitate insertion of explosive bolts for mating of elements.

5. Clearance required for erection and mating, due to width of the element's vertical stabilizer.

f. Phase VII — Pad Integration

1. Positive vehicle cryogenic tank and propellant feed line pressure must be maintained from Phase II (Postflight Securing) throughout the intervening phases (maintenance, etc.) until fueling on the pad is underway.

2. Flame deflector must be in place prior to moving launcher into position.

3. Height of crew ingress position with vehicle in vertical position (230 ft) requires tower or other device to provide access at that height for loading and rapid egress of crew/passengers.

4. Tower or other loading/service device must be movable to provide for clean pad at launch.

5. For possible standby missions, the vehicle must be readied in all respects except crew/passenger loading and fueling which are considered in final "launch" phase.

g. Phase VIII — Launch

1. Vehicle and crew in standby position without the hazards of prefueled situation so that vehicle may launch in less than two hours from an unfueled standby state.

2. Provision of dual crew/passenger loading and egress capability.

3. Vehicle autonomous launch operation with fuel cutoff, engine start, engine throttling, and vehicle-induced signal for disconnecting holddowns when desired thrust is reached.

4. Rapid fueling by means of a single point connection or manifolded ground system providing three lines from central pumping source (crossfeed versus no crossfeed).

5. Pad area clear of personnel during fueling.

6. Clean pad condition by moving loading tower away in a matter of minutes.

7. Desire for minimum AGE at launch pad.

8. Crew of all elements must be embarked simultaneously to facilitate early vehicle integrated checkout and shorten time on launch pad.

h. Phase IX — Postlaunch Inspection and Pad Refurbishment

1. Availability of alternate movable flame deflector to accommodate high launch rates.

2. Size and structure of flame trench.

3. Protection of breakaway holddowns and service lines.

2.7 TURNAROUND ANALYSIS SUMMARY

The ground turnaround analysis for a reusable space vehicle configuration had certain constraints. The first constraint was that the turnaround effort should not exceed two weeks. However, the two weeks stipulated did not include down time (nonroutine maintenance) or major overhaul. The second constraint was that the two weeks were to be considered on a 40-hour work week basis. In this analysis, the orbiter vehicle elapsed turnaround time is 146.4 hours. This figure includes expected nonroutine (downtime/unscheduled) maintenance and the vehicle will not be overhauled per se, but will receive component overhaul on an equalized basis. On a two-shift per day basis, the vehicle can be turned around in 9.15 working days. Sections 2.7.1 and 2.7.2 present summaries of elapsed turnaround time and manpower requirements respectively.

2.7.1 ELAPSED TIME SUMMARY. Figure 2-3 shows the elapsed time necessary to process both an orbiter element and a booster element through the maintenance cycle (Phases III and IV). Since the maintenance tasks for booster and orbiter elements would be the same as previously discussed, only manpower, AGE and facility

TASK	ELAPSED TASK TIME (HOURS) ORBITER	ELAPSED TASK TIME (HOURS) BOOSTER
1. ACCEPT ELEMENT AND MOVE TO MSA	0.6	0.6
2. RECEIVE ELEMENT AT MSA	1.4	1.4
3. OPEN PLATES AND REMOVE TPS	7.0	6.6
4. PERFORM CHECK-IN INSPECTION	15.8	14.9
5. NONROUTINE WORK	19.4	15.5
6. SERVICE AND LUBRICATE	7.8	1.9
7. SYSTEMS CHECK-OUT	7.0	6.5
8. CLOSE PLATES AND RE-INSTALL TPS	7.0	6.6
9. REMOVE JACKS AND WORK STANDS	1.3	1.3
10. MOVE VEHICLE TO RUN-UP AREA	1.1	1.1
11. RELEASE VEHICLE TO GROUND OPERATIONS	0.5	0.5

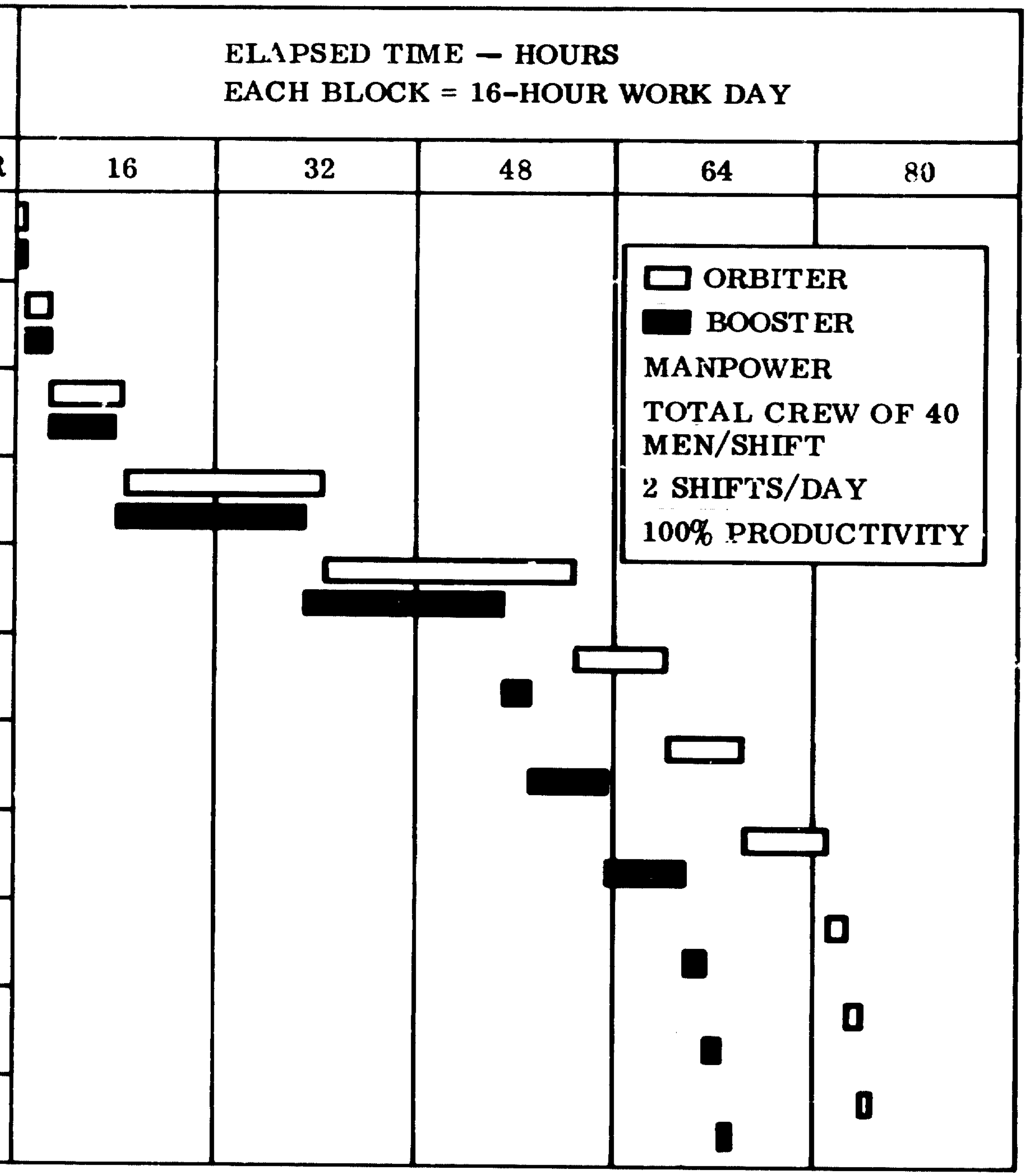


Figure 2-3. Maintenance Service Elapsed Times

requirements would be affected by a launch rate of 50 versus 100 per year. These factors — manpower and facilities — are discussed in Section 2.7.2 and Section 3 (Facilities). Figure 2-4 presents an elapsed time composite of the maintenance and ground operation phases of the total turnaround cycle. The order of phases presented in Figure 2-4 depicts the concept of erection and mating of the vehicle on the launch pad. Flow diagrams of an alternate erection and mating concept are presented and discussed in Section 2.8. Figure 2-5 is a flow diagram showing the elapsed time the element/vehicle spends at its various stop points.

2.7.2 MANPOWER REQUIREMENTS. Manpower required for the turnaround of a reusable space vehicle is considered to consist of three categories as follows:

a. Vehicle ground operations.

b. Vehicle operations support and maintenance and operation of ground support facilities and equipment.

c. Vehicle (three element reusable space vehicle) maintenance.

Manpower requirements for the first two of these categories are presented in Tables 2-6 and 2-7 based on 100 launches per year. The manpower required for vehicle maintenance consists of two 40-man crews, one crew per shift, two shifts per day (80 men per 16-hour workday) to process one element through Phases III and IV (Postflight Maintenance). By using a crew concept, the skills of maintenance personnel will allow them to process one element and then move to the next element when it enters the maintenance phase. Therefore, the number of crews need not be doubled for more than one element, but some additional crews of slightly smaller size would be required if a steady flow of elements was being processed. Such is the case for a launch rate of 100 vehicles per year. To determine the total manpower (including vehicle maintenance) required for vehicle turnaround at a 100 per year launch rate, it is necessary to calculate the number of maintenance personnel required and add them to the number of personnel required in the other two categories. Table 2-8 presents a manhour summary of the turnaround cycle for a complete vehicle. Mathematically analyzing the manhour requirements indicated in Table 2-8 for the total vehicle turnaround cycle, the maintenance manpower requirements for 100 launches per year would be 135. This figure was derived as follows:

Manpower Per Vehicle	=	9104.7 Manhours (Table 2-8)
Launches Per Year	=	100
Vehicle Ground Operations Personnel	=	73 (Table 2-6)
Vehicle Operations Support and Operation and Maintenance of Ground Support Equipment	=	375 (Table 2-7)
Available Hours/Manyear	=	1560 (Table 2-6)

$9104.7 \times 100 \div 1560 = 583$ men required (including direct maintenance)

TASK	TASK TIME (hr) ORBITER	TASK TIME (hr) BOOSTER	ELAPSED TIME (hr) DAY 1 16 HR	DAY 2 32 HR	DAY 3 48 HR	DAY 4 64 HR	DAY 5 80 HR	DAY 6 96 HR	DAY 7 112 HR	DAY 8 128 HR	DAY 9 144 HR	DAY 10 160 HR
PHASE I Task 1. Landing & Recovery Task 2. Move Vehicle to Securing Area	1.0	1.0										
PHASE II Post Flight Securing	7.0	7.0										
PHASE III Task 2. Unload Orbiter	3.0											
PHASE III & PHASE IV Accept Element and Move to MSA	0.6	0.6										
Receive Element at MSA	1.4	1.4										
Open Plates and Remove TPS	7.0	6.6										
Perform Check-in Inspection	15.8	14.9										
Nonroutine Work	19.4	15.5										
Service and Lubricate	7.8	1.9										
Systems Check-out	7.0	6.5										
Close Plates and Re-install TPS		6.6										
Remove Jacks and Work Stands	1.3	1.3										
Move Vehicle to Run-Up Area	1.1	1.1										
Release Vehicle to Ground OPS	0.5											
PHASE V Tasks 1-4. Tow Orbiter to Logistics Area, Load, Inspect, Secure and Tow to Pad												
PHASE VI Tasks 1 & 2. Erect Elements, Perform Mechanical Mating and Mate to Launcher Assembly	VEHICLE 16.0											
PHASE VI Tasks 3 & 4. Mating & Leak Check of Vehicle Propellant Line and Connection of Vehicle & Vehicle/Launcher Electrical Lines	10.0											
PHASE VI Task 5. Integrated Vehicle Systems Check	8.0											
PHASE VII Tasks 1 & 2. Mechanically Mate Launcher to Pad and Connect Launcher to Facility Supply Lines	12.0											
PHASE VII Task 3. Launcher to Launch Control Compatibility Test	4.0											
PHASE VII Task 4. Cryogenic Leak Check	4.0									LAUNCH		
PHASE VIII Task 1. Launch Count Down	6.0											
PHASE IX Tasks 1 & 2. Postlaunch Pad Inspection and Refurbish for Next Launch												

NOTE: On-pad erection in Phase VI, Task 1 & 2 is delayed 21.5 hours awaiting orbiter because of load, unload and longer maintenance times for orbiter. Spare orbiters would reduce total elapsed time by this 21.5 hours.

Figure 2-4. Elapsed Time Estimate for FR-1 Turnaround Cycle

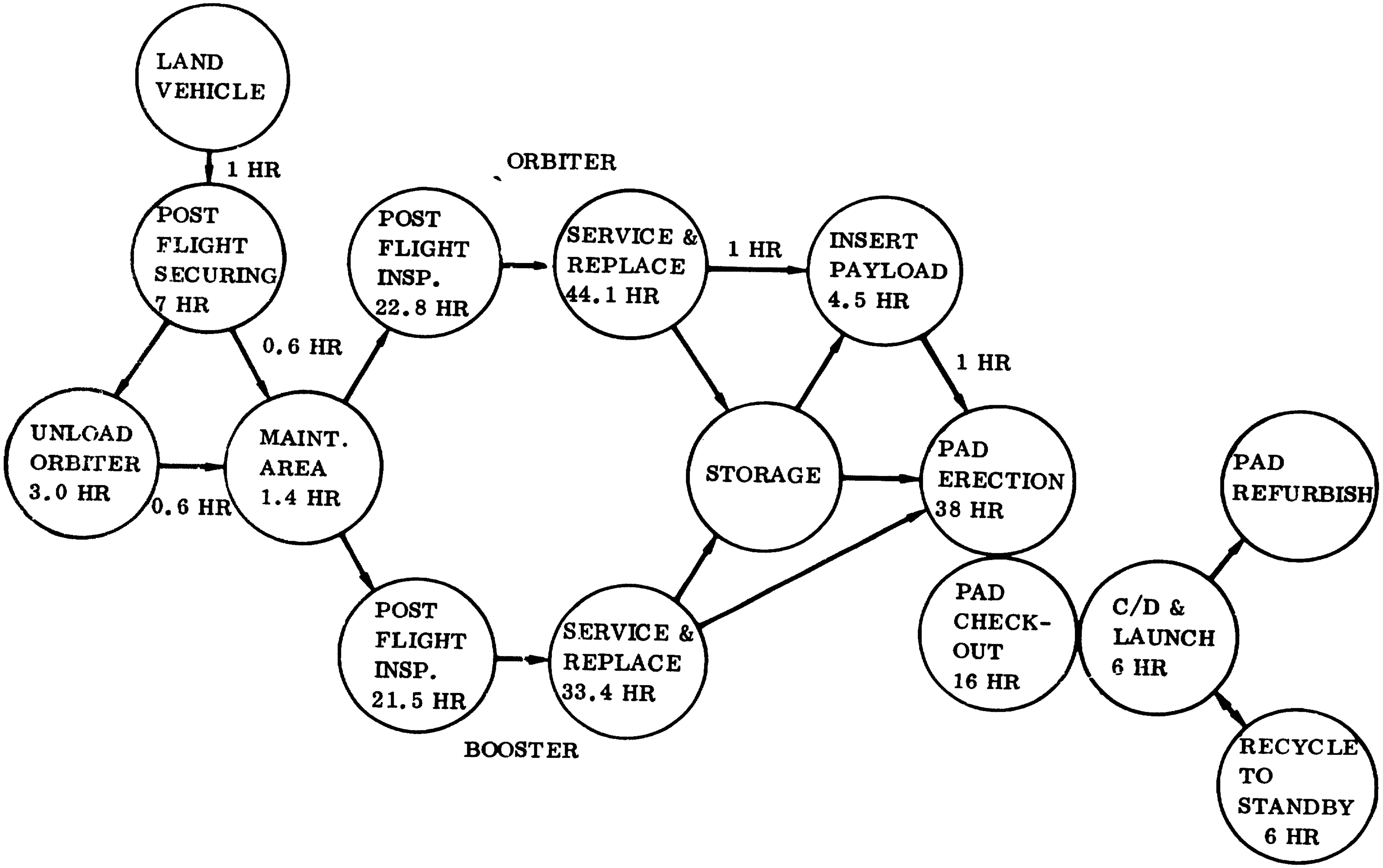


Figure 2-5. Elapsed Time Flow for FR-1 Turnaround Cycle

Table 2-8. Manhour Summary for FR-1 Vehicle Turnaround Cycle

	Orbiter	Boosters
Vehicle Ground Operations	379.6	379.6
Vehicle Operations Support and M&O Ground Support Facilities and Equipment	1,955.2	1,955.2
Vehicle Maintenance	789.5	655.4
TOTAL MANHOURS	3,124.3	2,990.2

Notes:

a) 9,104.7 manhours (3124.3 + 2990.2 ×2) per flight are required to accomplish the FR-1 vehicle turnaround cycle.

b) These are order of magnitude values; detail cost figures for reusable space vehicle system maintenance and operations cannot be made until vehicle system design becomes more definitive.

73 + 375 = 448

583 - 448 = 135 direct maintenance personnel

Applying a standard factor of 1:1 for maintenance support personnel, we find 270 total maintenance personnel required. Therefore, a minimum of 718 (73 + 375 + 270 = 718) personnel are required to directly support ground turnaround operations of a three-element reusable space vehicle (FR-1) at a launch rate of 100 vehicles per year. This analysis is not applicable to launch rates lower than 100 per year because the maintenance personnel requirement (40 men/shift, two shifts/day) is a minimum for an element and certain facility operation and maintenance and vehicle operations personnel are required regardless of the launch rate. Further analysis of total task and facility requirements for a 50 per year launch rate indicates that a minimum of 628 personnel would be required.

2.8 ALTERNATE METHODS OF ERECTION AND MATING OF ELEMENTS

The primary turnaround analysis effort was predicated on erection and mating of the reusable space vehicle in the launch pad area. This method provides for towing of individual elements to an erection platform or erection tower with hoists, located in the launch pad area, and erecting and mating the elements on a mobile launcher. The mobile launcher with the vehicle attached in the vertical position is then moved only a short distance to the launch pad and mated with the fixed pad pedestals over the flame bucket. See Section 3, Facilities, for detailed description and drawings of this erection method.

An analysis was made of an alternate method of erection and mating of the three-element vehicle which provides for erection and mating to be accomplished in or adjacent to the Main Service Area (MSA) where Phase III and IV maintenance is accomplished. Upon release by maintenance, the elements are received by ground operations personnel and erected by means of an overhead crane and dolly assembly. The crane slings are attached to hard points provided on the element structure and the dolly assembly is attached to the aft stress structure of the element Each element is placed upon the mobile launcher and secured to it as well as to each other element (separation actuator assemblies are secured together). The mobile launcher is transported to the launch pad area and positioned directly over the flame bucket. Although no appreciable difference in the total vehicle turnaround time occurs between the two erection and mating methods, there is a significant difference in the length of time a launch pad is occupied. Figures 2-6 and 2-7 show flow diagrams of the two erection and mating methods and the launch pad times involved.

Advantages of off-pad erection and mating are:

a. Fast launch pad cycle time.

b. Integrated vehicle systems checked prior to leaving maintenance area.

c. Elements covered during erection process.

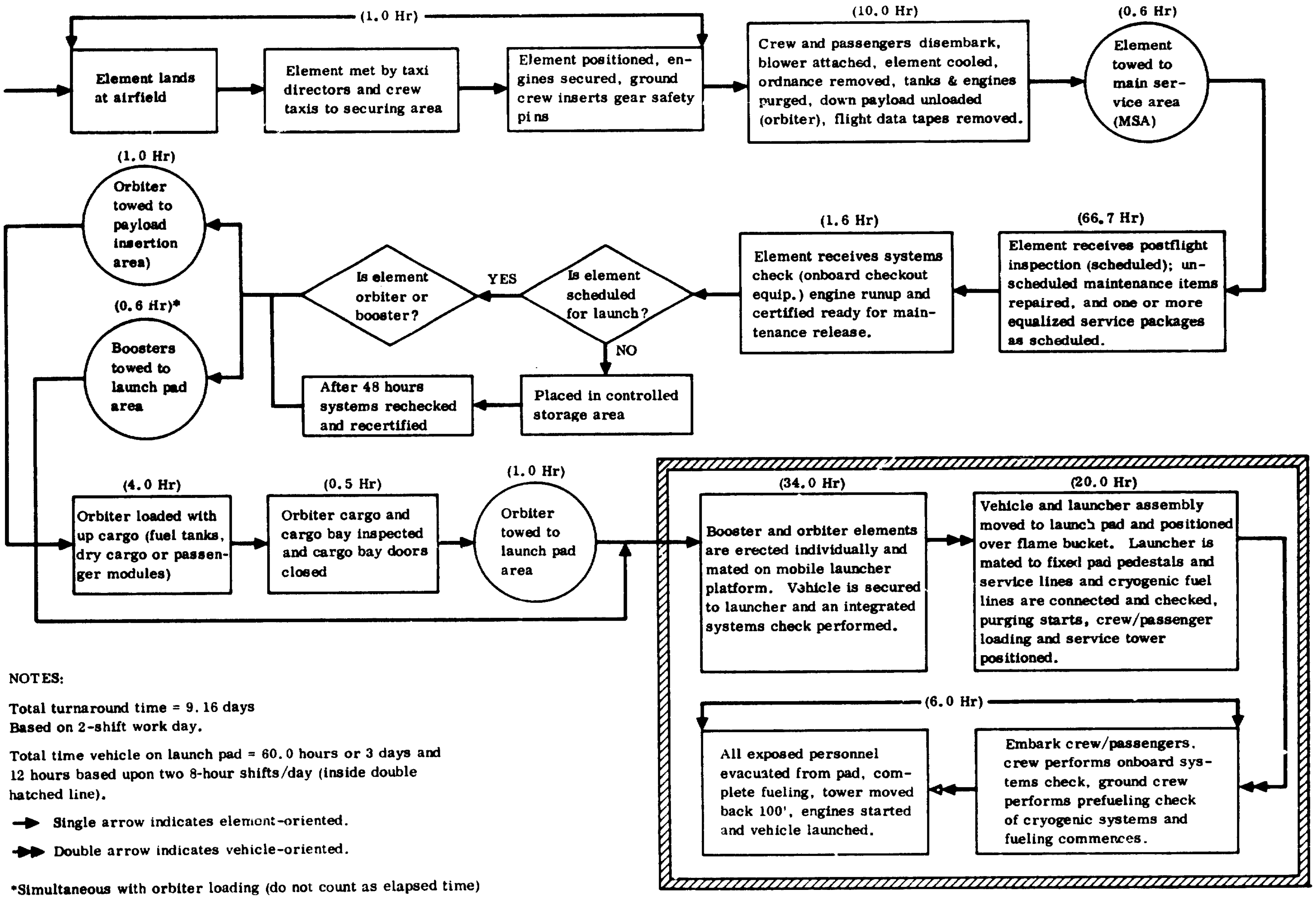
d. No special erection device required at the launch pad.

Advantages of on-pad erection and mating are:

a. Elements may be towed to launch pad; no transporter is required.

b. No large vertical assembly building (similar to VAB at Complex 39 KSC) is required.

A procedure to launch the reusable space vehicle in two hours from a standby status has also been analyzed and the task in the last two blocks of the flow diagram, Figure 2-7, have been changed (inside the dashed line in Figure 2-7) to illustrate the method whereby a two-hour launch from a standby status could be accomplished. Although the total turnaround cycle remains the same, the vehicle can be brought to an advanced condition of readiness and the ground fuel system (cryogenic) could be pre-prepared by maintaining a continuous chilldown in a standby status. The cost of maintaining such a ready status would be directly related to the time standby condition is maintained, the number of men retained on duty, the amount of cryogenics required to maintain chilldown of the ground fuel system, and the amount of purging gases required to maintain a continuous purge pressure in the engine and other compartments of the vehicle.



NOTES:

Total turnaround time = 9.16 days
Based on 2-shift work day.

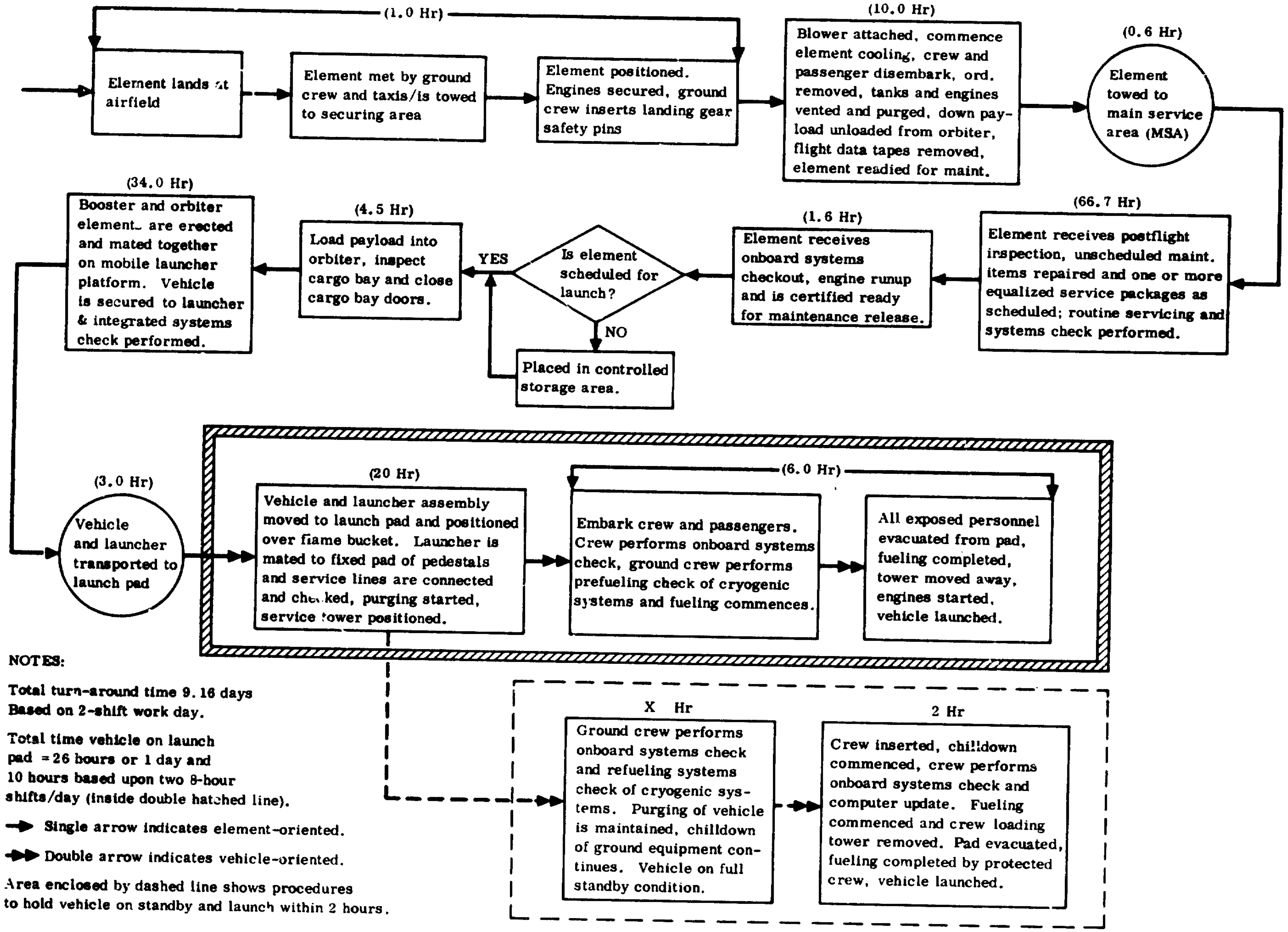
Total time vehicle on launch pad = 60.0 hours or 3 days and 12 hours based upon two 8-hour shifts/day (inside double hatched line).

→ Single arrow indicates element-oriented.

⇒ Double arrow indicates vehicle-oriented.

*Simultaneous with orbiter loading (do not count as elapsed time)

Figure 2-6. Reusable Space Shuttle Ground Turnaround Flow Diagram No. 1 (Erection and Mating in Launch Pad Area)



NOTES:

Total turn-around time 9.16 days
Based on 2-shift work day.

Total time vehicle on launch pad = 26 hours or 1 day and 10 hours based upon two 8-hour shifts/day (inside double hatched line).

→ Single arrow indicates element-oriented.

→→ Double arrow indicates vehicle-oriented.

Area enclosed by dashed line shows procedures to hold vehicle on standby and launch within 2 hours.

Figure 2-7. Reusable Space Shuttle Ground Turnaround Flow Diagram No. 2 (Erection and Mating in Main Service Area)

2.9 EFFECT OF ALTERNATE VEHICLE DESIGN ON TURNAROUND REQUIREMENTS

As previously stated, the turnaround analysis contained in this volume was made on the FR-1 three-element vehicle with crossfeed. Configuration changes do not alter significantly the turnaround phases or tasks defined for the FR-1 vehicle. However, the number and size of elements of a given configuration will have an effect upon facility and equipment requirements. Section 3 describes the effects of the FR-3 and FR-4 vehicles on facilities. The maintenance effort, Phases III and IV of the turnaround cycle, will be somewhat affected by the vehicle subsystem requirements and design incorporated in the FR-3 and FR-4 vehicles. A preliminary analysis was made of the FR-3 and FR-4 maintenance requirements, as well as ground operation, using the FR-1 vehicle analysis as a baseline; the results are depicted in Table 2-9. A description of subsystem requirements and their effect on maintenance is presented in the following paragraphs. Elapsed time changes are based on the same number of personnel being available for the FR-3 and FR-4 vehicles as previously presented for the FR-1.

2.9.1 FR-4 VEHICLE (THREE ELEMENTS WITHOUT CROSSFEED). The increased number of rocket engines on the booster element will cause an increase in maintenance inspection time. The orbiter element, having one less flyback engine than the FR-1, will have reduced inspection time, further reduced by the absence of propellant crossfeed connection and seals. A slightly smaller wetted area on the orbiter element will reduce the TPS inspection time accordingly. Deletion of the crossfeed connection also shortens the vehicle integration time because the time to connect them is eliminated. All other turnaround tasks remain the same.

2.9.2 FR-3 VEHICLE (TWO ELEMENTS OF DIFFERENT GEOMETRY). Although there is only one booster element it is larger in wetted area and has 15 rocket engines and four flyback engines. These characteristics cause an increase in engine and external surface inspection time for the one element as against one booster element of the FR-1. The fact that only one booster and one orbiter element require erection and mating shortens the time required in that phase of the turnaround cycle.

2.10 CONCLUSIONS AND RECOMMENDATIONS

Based upon the detailed analysis of a single configuration of the reusable space vehicle (FR-1) and a preliminary analysis of alternate configurations the following conclusions and recommendations are made from a ground turnaround standpoint.

2.10.1 CONCLUSIONS

a. By early and continuing attention to maintainability in vehicle and subsystem design, a two-week turnaround cycle for the reusable space vehicle is entirely feasible.

b. By adopting the airline approach to maintenance, downtime may be greatly reduced.

Table 2-9. Ground Turnaround Analysis of Preliminary FR-3 and FR-4 Vehicle Configurations

Ground Turnaround Phase	Major Configuration/Subsystem Differences Affecting Turnaround			Elapsed Task Time in Hours					
	FR-1 (Baseline)	FR-3	FR-4	FR-1 (Baseline) Orbiter	FR-1 (Baseline) Booster	FR-3 Orbiter	FR-3 Booster	FR-4 Orbiter	FR-4 Booster
Phase I — Post Flight Recovery	2 Boosters Arrive Together	1 Booster Arrives	No Change	1.0	1.0	1.0	1.0	1.0	1.0
Phase II — Post Flight Securing		No Change	No Change	10.0	7.0	10,0	7.0	10.0	7.0
Phases III and IV — Post Flight Maintenance and Maintenance Release	2 Rocket Engines Each Element	15 Rocket Engines on Booster, 3 Rocket Engines on Orbiter	9 Rocket Engines on Boosters, 3 Robket Engines on Orbiter	68.9	56.9	68.0	64.0	67.9	60.4
	3 Flyback Engines Each Element	4 Flyback Engines on Booster, 3 Engines on Orbiter	3 Flyback Engines on Booster, 2 Engines on Orbiter						
	Crossfeed Interconnects	No Crossbeed	No Crossfeed						
	Fuel Lines and Valves to Feed 2 - 2 - 2 Rocket Engine Configuration	Fuel Lines and Valves to Feed 15 - 3 Rocket Engine Configuration	Fuel Lines and Values to Feed 9-3-9 Rocket Engine Configuration						
	20,235 Ft^2 Wetted Area for Booster, 20,232 Ft^2 for Orbiter	26,598 Ft^2 Wetted Area for Booster, 14,891 Ft^2 for Orbiter	18,421 Ft^2 Wetted Area for Booster, 16,893 Ft^2 for Orbiter						
Phase V — Payload Insertion		No Change	No Change	6.5	--	6.5	--	6.5	--
				Integrated		Vehicle			
Phase VI — Vehicle Erection and Integration	Crossfeed Interconnects 3 Elements	No Crossfeed Interconnects 2 Elements	No Crossfeed Interconnects 3 Elements	34.0		28.5		33.5	
Phase VII — Pad Integration		Smaller Launcher Platform	No Change	20.0		18.0		20.0	
Phase VIII — Launch		One Less Crew to Embark	No Change	6.0		5.8		6.0	
			TOTAL	146.4	124	137.8	124.3	144.9	127.9

c. By refurbishing components on an equalized basis, a one-time-complete vehicle overhaul period could be eliminated.

d. Maintenance manpower could be optimized by utilization of the crew concept of maintenance, thus reducing recurring labor costs.

e. Onboard checkout equipment, inflight monitoring of specified subsystems and an onboard engine diagnostic system are mandatory if timely service and maintenance are to be achieved.

2.10.2 RECOMMENDATIONS

a. Airline management, engineering, and maintenance personnel should continue to work closely with potential manufacturers of reusable space vehicle.

b. Design should emphasize maintenance and ground operations on a par with performance, from the conceptual stages onward.

2.11 REFERENCES

2.1 Airline Methods Applied to Space Shuttle System Turnaround Plan and Cost Analysis, Pan American World Airways, 6 October 1969.

SECTION 3

OPERATIONAL FACILITY REQUIREMENTS

3.1 INTRODUCTION

Analysis has determined the operational facilities required to support the launch, recovery, and refurbishment of the reusable space shuttle vehicle. These facilities have been established in conjunction with requirements generated by the aircraft turnaround philosophy. This philosophy assesses the phases and tasks required to render the space shuttle system ready to reuse with expenditure of minimum time and manpower after its return from a mission. Facilities described in the following pages provide maximum support of that philosophy.

3.2 NEW LAUNCH COMPLEX REQUIREMENTS

Facilities to support the nine turnaround phases described in Section 2 are:

Phase I	Aircraft Runway
Phase II	Revetted Securing Area
Phases III & IV	Maintenance and Service Building
Phase V	Payload Assembly/Insertion/Removal Facility
Phase VI	Vehicle Erection Facility/Equipment
Phases VII, VIII, & IX	Integrated Launch Pad

Figures 3-1 and 3-2 are conceptual layouts of complete operational facilities incorporating these buildings or facilities.

The concept shown in Figure 3-1 provides maximum support of ground turnaround operations at minimum cost. For instance, the taxiways paralleling the main runway provide motor vehicle access to and from all parts of the complex, and access roads to the launch pads are reduced to minimum distances.

The two launch pads shown are mandatory if higher launch rates are attained and/or if standby space rescue operations requirements are to be met. It should be noted that the configuration shown allows for future growth without invalidating any previous construction. Siting of the various service facilities within the complex allows a straight-through flow, both in and out, for the space shuttle vehicles.

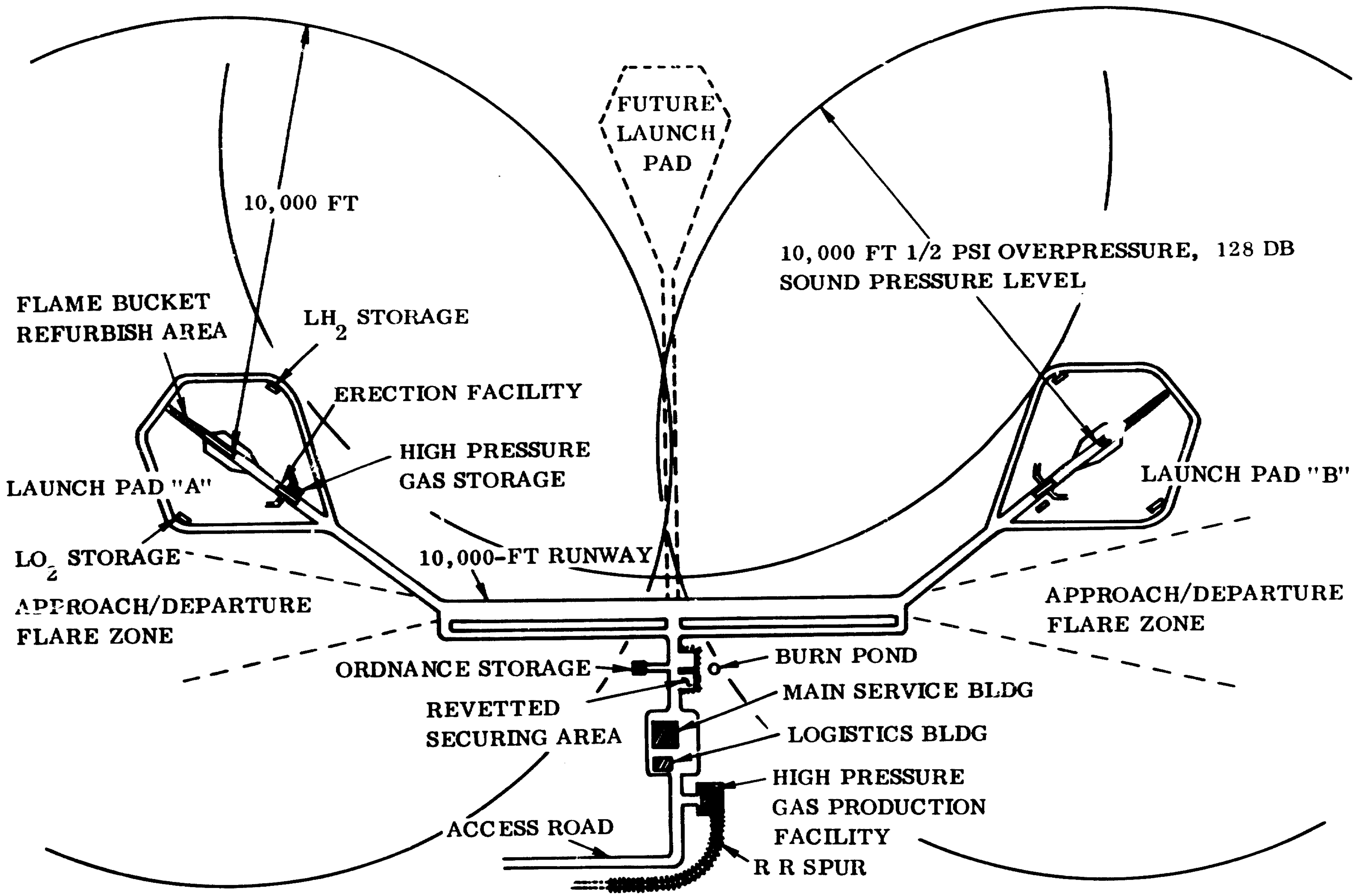


Figure 3-1. New Space Shuttle Vehicle Launch/Recovery Facility Concept A

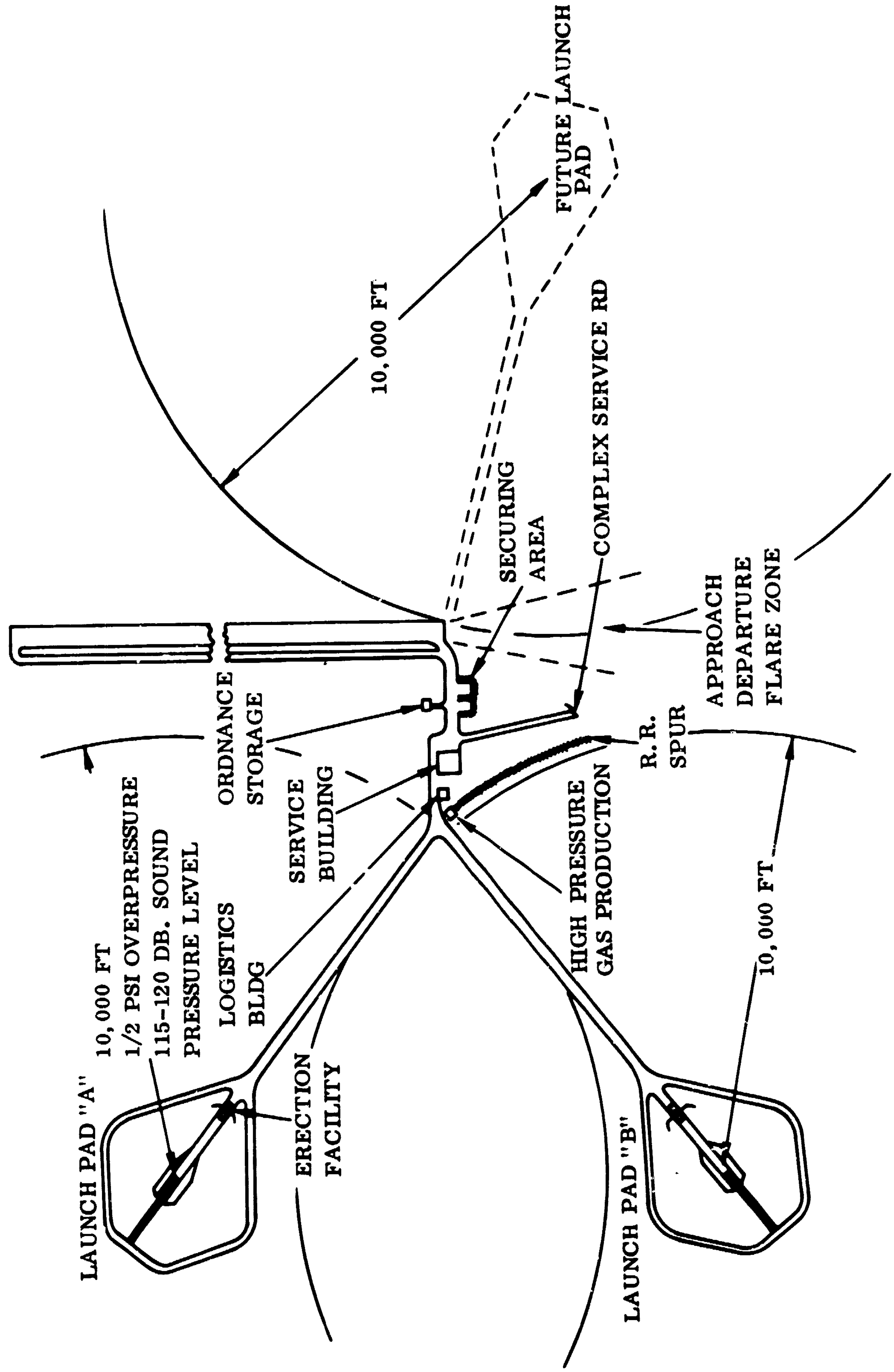


Figure 3-2. New Space Shuttle Vehicle Launch/Recovery Facility Concept B

The concept shown in Figure 3-2 is a previous approach where the service operations were grouped at the end of the runway. It provides a straight-through vehicle flow and correct separation distances. Disadvantages are:

a. Longer service roads.

b. One-way landing pattern.

c. Larger amount of real estate required, especially if future growth is considered.

The concept shown in Figure 3-1 is the preferred approach.

The following detailed description, by turnaround phase, of operational facility requirements incorporates design criteria, where positively identified.

3.2.1 PHASE I, AIRCRAFT RUNWAY. A 10,000-foot runway is designed for a wheel loading of 28,000 lb, with an adjacent taxiway leading to the vehicle securing area. The runway will require a control tower, runway lighting, and approach lighting, with fully instrumented all-weather capability. All normal airfield support such as fire and crash trucks, ambulance, payload and crew removal equipment and vehicles should be provided.

3.2.2 PHASE II, SECURING AREA. A proposed facility for the securing area is shown in Figure 3-3. It consists of two 200 ft x 250 ft paved areas, revetted on three sides, with two 50 ft x 50 ft reinforced concrete tool and equipment storage igloos located in the center revetment. The facility will be designed in accordance with all regulations covering the handling and storage of hazardous propellants. A small magazine will be provided in the same general area for storage of vehicle pyrotechnics (not in excess of 100 lb).

The purpose of this facility is to provide a safe area where the returning spececraft can be cooled, purged of hazardous fuel or onboard ordnance, and generally made safe for transfer to the main service building.

3.2.3 PHASES III AND IV, MAINTENANCE & SERVICING BUILDING. A conceptual layout of a proposed maintenance and servicing building is shown in Figure 3-4. This 300,000 sq ft building is a major facility requirement. Preliminary studies by Convair indicate that a very advantageous layout can be obtained by constructing this building on a hexagonal plan with a hyperbolic paraboloid roof covering each bay. Each hyperbolic paraboloid will be triangular shaped, approximately 325 ft on a side, which approximates the envelope of the space vehicle when nosed into the facility on the 60-degree axis. The nose area is surrounded on three sides by maintenance and service shops.

The area over the tail section will be approximately 85 ft high, allowing room for work docks and an overhead crane. The height over the fuselage is 60 ft, which will permit clearance for the 50 ft (approx) height of the spacecraft in a jacked position. Hangar doors need be only 45 ft high with two small rolling doors above for tail slots.

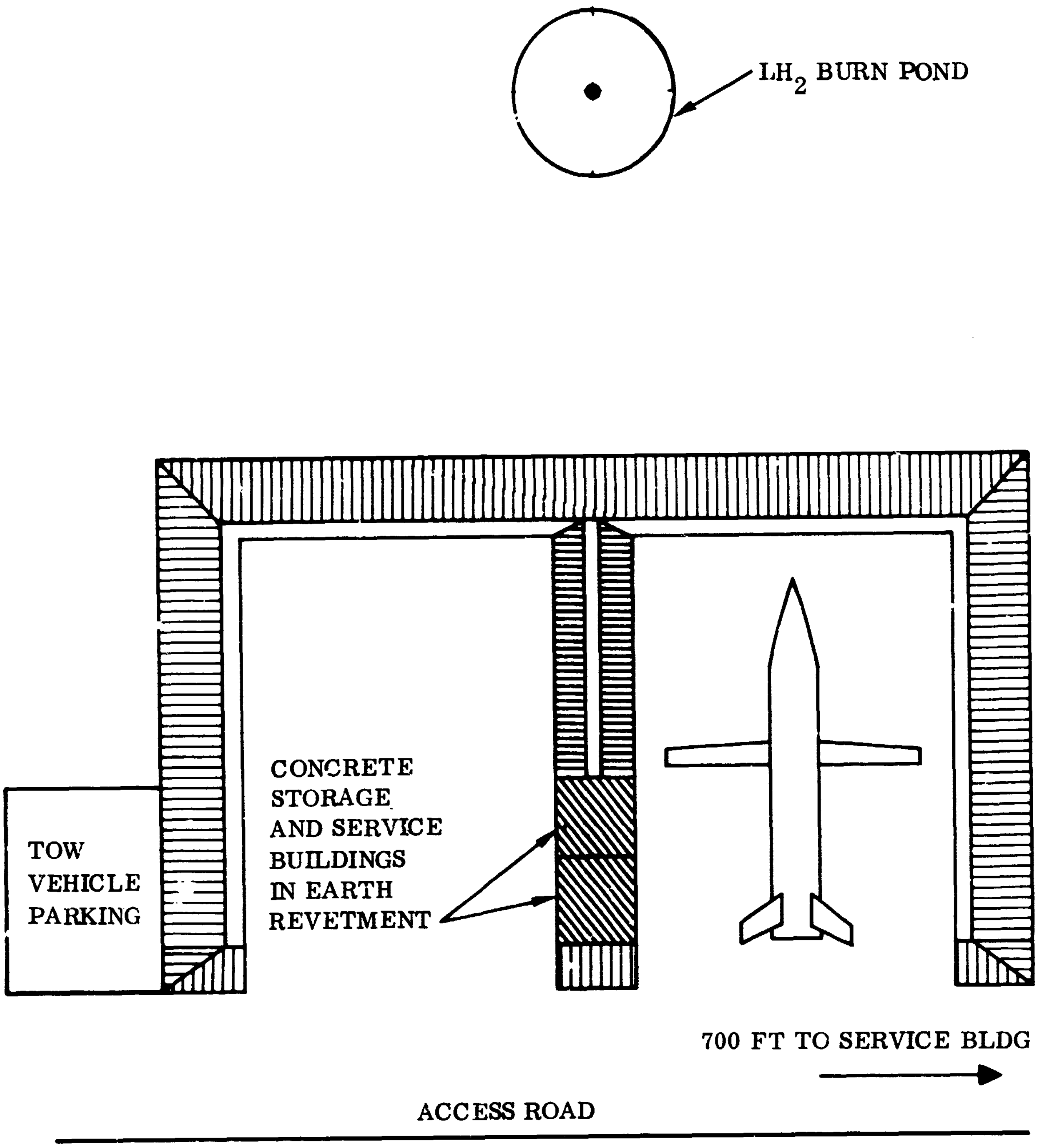


Figure 3-3. Securing Area

The service shops will in general occupy the first two floors. Overhaul and checkout of cabin fuselage equipment will be done from the second deck, which is close to the deck level of the spacecraft.

Checkout and inspection of landing gear, rocket and jet engines, and other exterior equipment will be conducted from the first floor shops. The third floor will be used for computerized checkout equipment, storage, and administration. Airline experience with service operations conducted from levels above the second floor have proved inefficient.

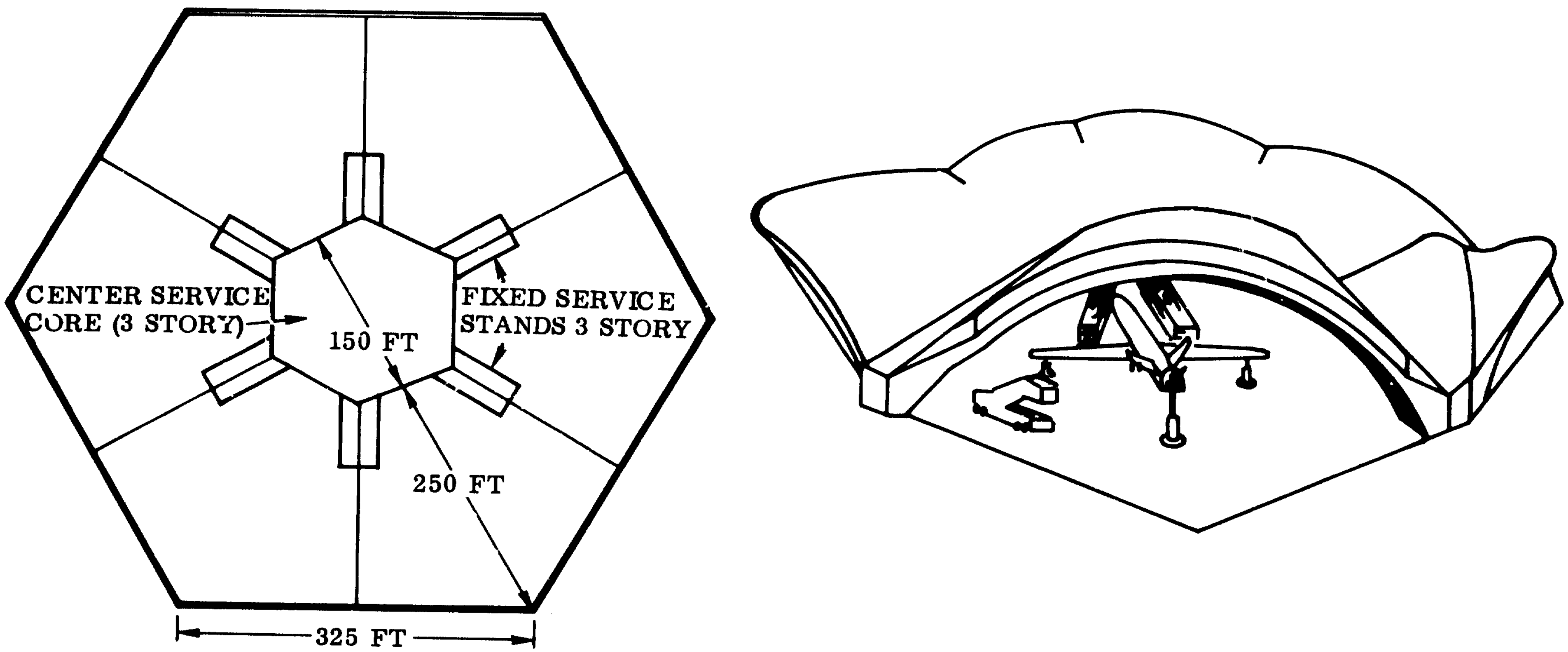


Figure 3-4. Main Service Building

Selection of a hyperbolic paraboloid structure over a conventional box hangar will result in a saving of approximately 50% in building volume with its attendant saving in operational cost (heating, air conditioning). In addition, the estimated delta cost between paraboloid and conventional construction for the same floor area is approximately $2.3 million in favor of the former. Requirements other than normal utilities for this facility are a supply of high pressure gases, primarily helium and nitrogen, to support the maintenance operation.

A requirement also exists for an airbreathing jet engine run-up stand with a "hush house" of sufficient size and capability to service the spacecraft flyback engines. This stand should be located adjacent to the main service building. Other service equipment will be similar to that used in airline service, supplemented with rocket-engine-and-space-operation-peculiar tools.

3.2.4 PHASE V, PAYLOAD INSERTION (LOGISTICS BUILDING (Figure 3-5)). The necessity for a logistics facility has been dictated by the following operational requirements.

a. An area is required to house and service classified payloads.

b. Weather protection is required for payloads.

c. Logistics work needs to be executed on a round-the-clock basis.

d. Storage requirements for payload and launch vehicle spares.

e. The need to handle, service, and install payload modules of varying types and sizes ranging up to 15 feet in diameter by 60 feet long with a maximum gross weight of 50,000 pounds.

The concept illustrated is a 250 ft x 240 ft steel framed, sheet metal covered building having a 120 ft x 250 ft x 90 ft high bay. The high bay will allow straight-line towing of the spacecraft through the facility before and after payload insertion. Payloads will be installed by the use of two 20-ton bridge cranes spanning the high bay and working in tandem if required.

The two 60-ft wide by 30-ft high low bays will house payload service shops and stores, launch vehicle spares, and administrative offices.

From a facility standpoint there are only three types of payloads: wet, dry, or a combination of both. All payloads, except hazardous liquids and passengers, will be installed within this facility. If the payload is a hazardous liquid, the tank module will be installed in the logistics building, but tank fill will be accomplished at the launch pad. Similarly, passenger modules will be installed in the logistics building, but passengers will embark at the launch pad.

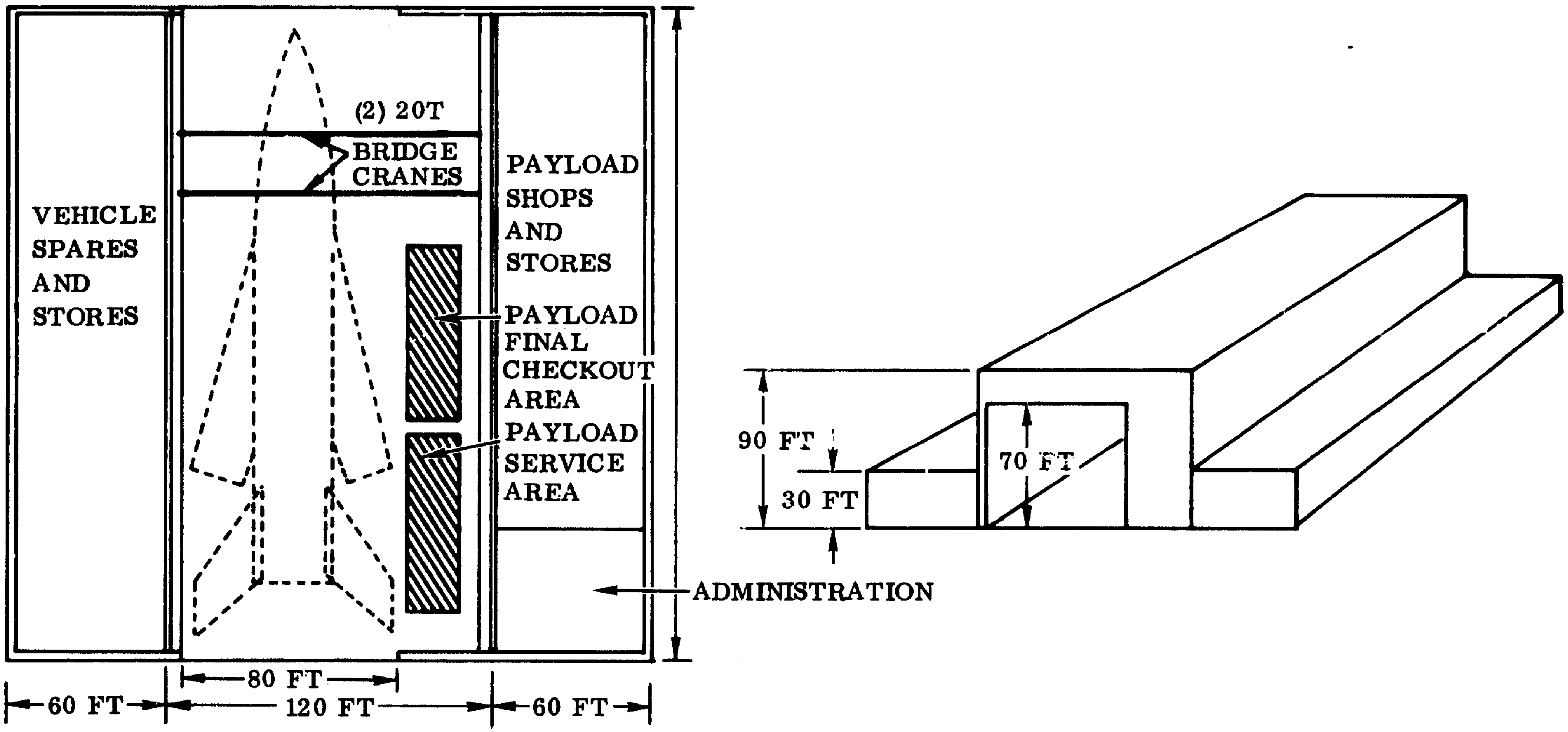


Figure 3-5. Logistics Building

Payloads involving the use of propellants will require the use of purging and pressurizing gases; therefore, in addition to normal utilities, the facility will be provided with high pressure gaseous helium and gaseous nitrogen.

To facilitate maintenance of reusable segments of payload modules, a data link with the main service building computer appears to be desirable but not mandatory.

3.2.5 PHASE VI, VEHICLE ERECTION AND MATING. Vehicle erection facility configurations are considerably influenced by the selection of stacking methods. Figure 3-6 illustrates three possible stacking configurations for a three-element vehicle. Configurations A and B preclude any possibility of payload bay access once the vehicle is erected and mated. Configuration C does provide such access. Stacking configurations for a two-element vehicle are shown in Figure 3-7; payload bay access is provided by either of these configurations.

3.2.5.1 Vehicle Erection and Integration in Maintenance Area. The concept of maintenance area erection has been studied mainly because similar methods have been successful on current programs such as Saturn V and Titan 3C. Both programs in effect use the Integrated Test and Launch philosophy.

To apply this philosophy to the space shuttle vehicle, Convair has developed a conceptual launch complex which is illustrated in Figure 3-8. The concept requires landing and securing facilities similar to those described in Sections 3.2.1 and 3.2.2. Vehicle service, logistics, erection and integration could be combined in one contiguous facility as shown in Figure 3-9.

The service building is octagon-shaped and of construction similar to the Maintenance Facility described in Section 3.2.3. It allows six elements to be in position at any one time, four boosters and two orbiters or other combinations. The logistics area, constructed along one of the "unused" sides of the octagonal perimeter, allows the orbiter elements to be towed into position for payload installation. This installation is accomplished with the aid of a pair of truss-mounted 25-ton bridge cranes working in tandem. Erection and integration cells are constructed adjacent to the end of the logistics area. Except for physical dimensions, they closely resemble the high bay cells of the Complex 39 VAB at KSC.

Erection and mating procedures are as follows: One booster element is towed from the maintenance area to a nose-in position in the erection area, a pivoting tail dolly positioned, and hoisting slings attached. The booster is hoisted by the 200-ton crane and positioned and secured on a mobile launch platform located within the tower. The process is repeated for the orbiter, which approaches from the opposite direction. The third booster is then transported and handled in the same manner as the first booster. All stacking configurations shown in Figures 3-6 and 3-7 can be accomplished within this facility.

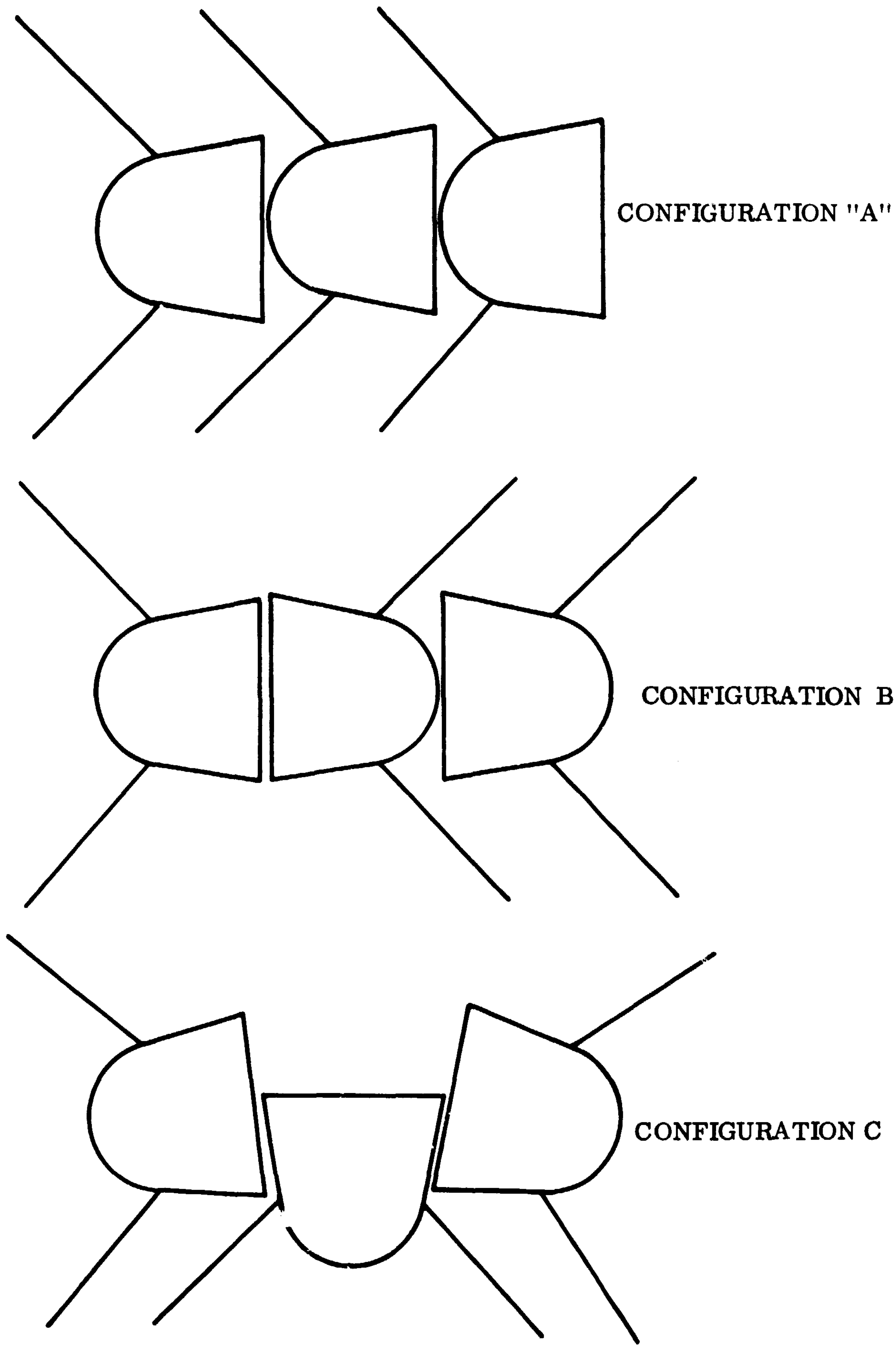
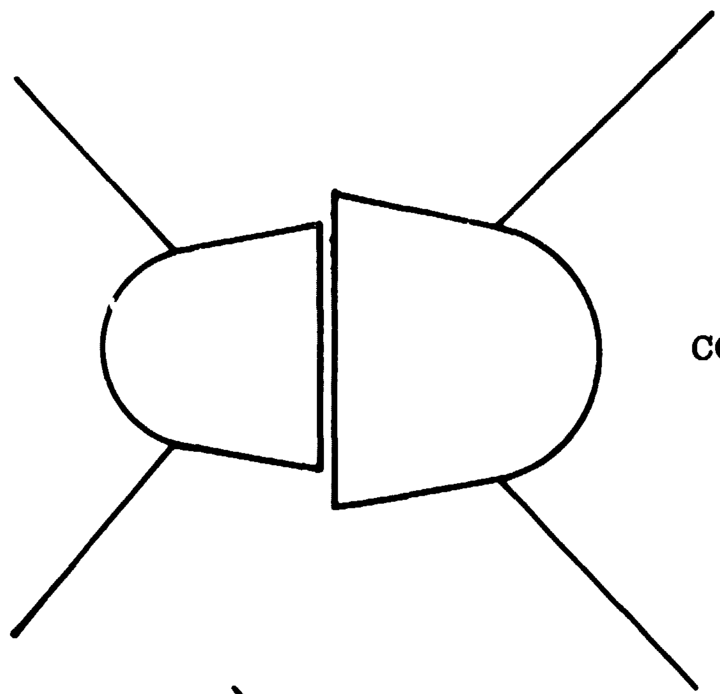
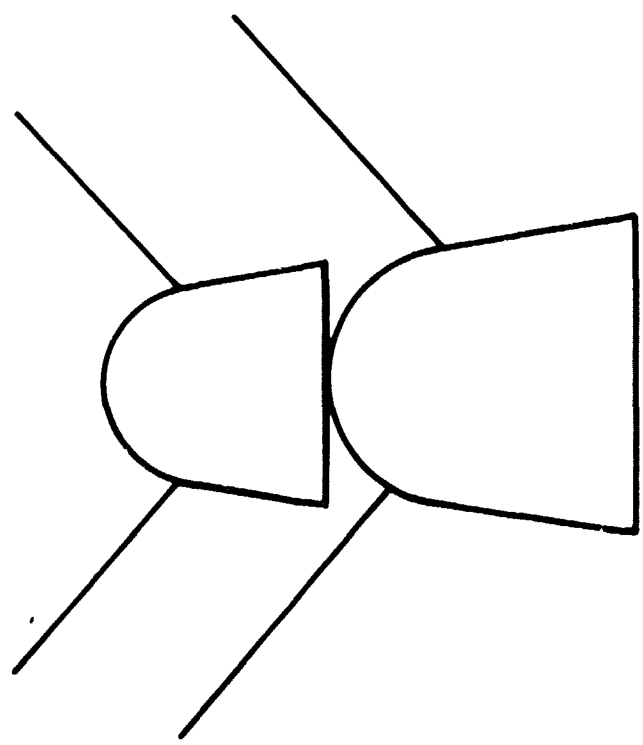


Figure 3-6. Stacking Configurations



CONFIGURATION 2A



CONFIGURATION 2B

Figure 3-7. Stacking Configurations for Two-Element Vehicle

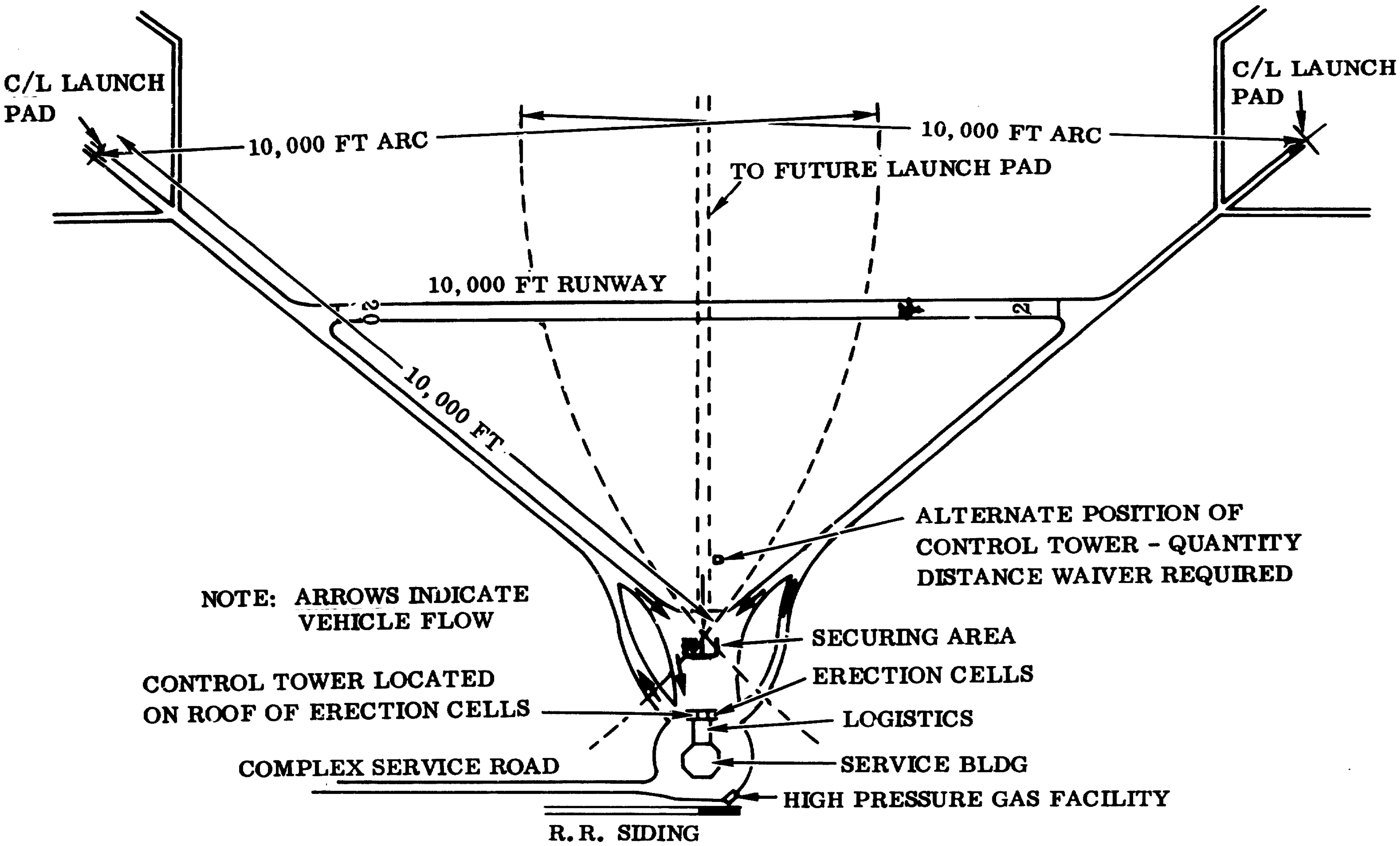


Figure 3-8. Conceptual Launch Complex Layout for Service Area Erection

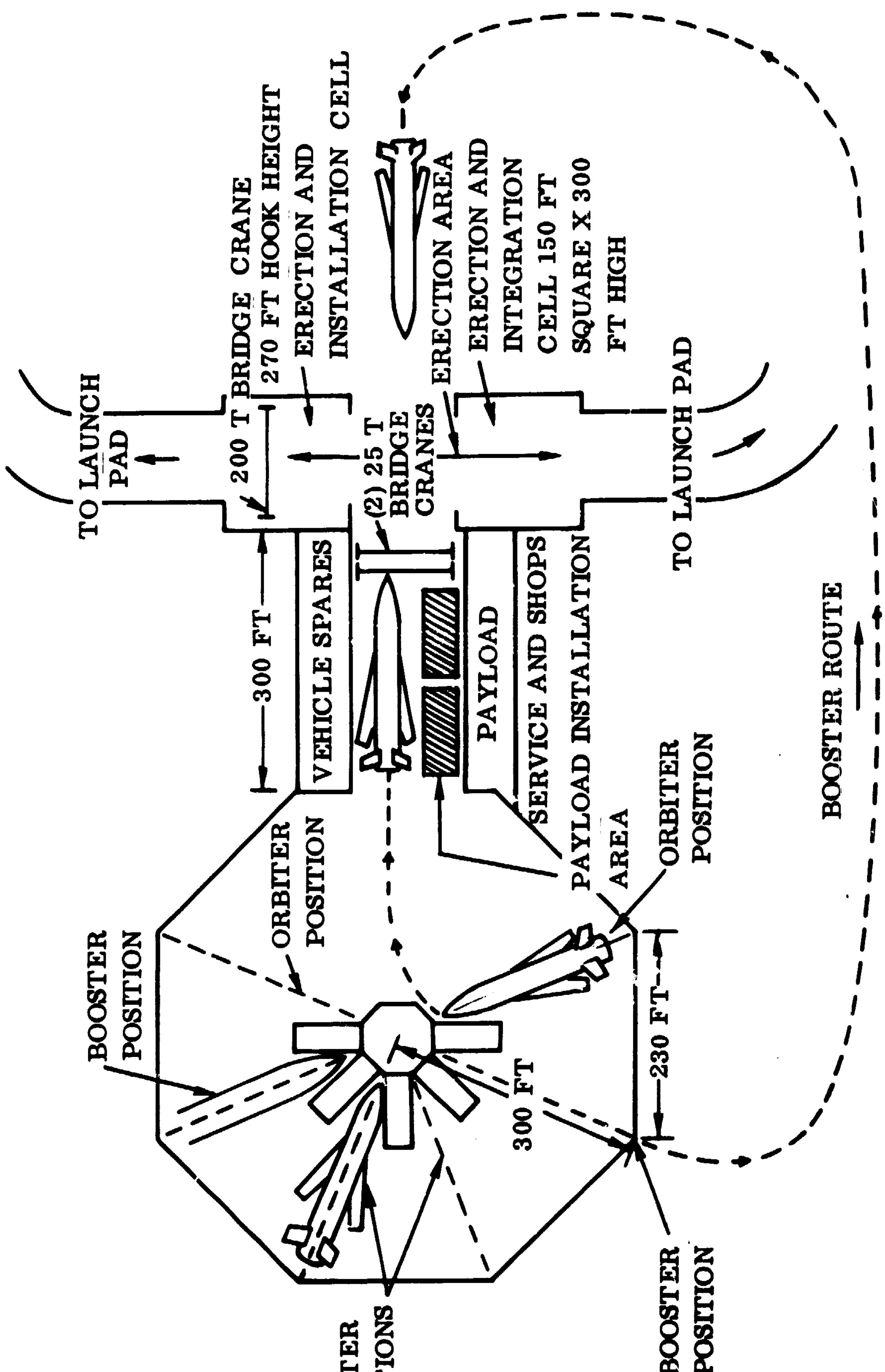


Figure 3-9. Vehicle Service, Logistics, Erection and Integration in One Common Facility

The mobile launch platform mentioned in the previous paragraph is comparable to the platform used for Saturn V; however, there are some major differences. The space shuttle vehicle has no requirement for the sophisticated checkout equipment mounted on the launcher/umbilical tower (LUT). Further, as all ground fueling and electrical connections are at the base of the spacecraft there is no requirement for an umbilical tower as part of the launcher platform.

As presently conceived, the launch platform is a box-shaped structure equipped with spacecraft-peculiar launcher mechanisms, flex line connections for hookup to pad-mounted supply lines, and retractable hydraulic mounting legs for mounting at the erection area and the launch pad.

The transporter operates in the same manner as that used for Saturn V. Due to a considerable difference in the combined gross weight of the space shuttle vehicle and launch platform, when compared to the Saturn V/LUT combination, it appears that a simpler, faster, and more maneuverable transporter, possibly wheel mounted for movement on the taxiways/runway, would be economically desirable.

The main advantages of such a concept are:

a. The vehicle would be serviced, erected, mated, and checked out in a controlled environment prior to being moved to the launch pad.

b. Once the assembly is complete the vehicle is transported in the erect position without disconnecting launcher/space vehicle connections and umbilicals.

c. Major checkout equipment, located remote from the launch pad, would be protected from launch pressures by distance.

d. All major operations, except launch, are performed in one contiguous facility.

Principal disadvantages are:

a. The high cost of construction of the complex.

b. Transportation requirements eliminate the advantage gained by the inherent capability of the elements to be towed over roads or taxiways.

3.2.5.3 Vehicle Erection and Integration at the Launch Pad. The concept of erection and integration at or near the launch pad reduces facility cost and also takes advantage of the mobility inherent in the design of the vehicle elements.

During the study, several methods were evaluated. Briefly these were:

a. Horizontal mating remote from the pad, erection of all three elements at one time over the pad on an erection platform similar to one side of a bascule bridge.

b. Single element erection over the pad using a rail-mounted gantry crane spanning the launch area.

c. Single element erection adjacent to the launch pad, by a special purpose erection platform, with the vehicles mounted on a mobile launcher platform.

d. Single element erection with a rail-mounted whirly crane at the launch pad.

The first two methods were discarded, the first because of the difficulty in physically handling a combination of three 230 ft long elements having a total weight of approximately 450 tons, and the second because of cost of the crane and the fact that it could not be used for any purpose other than vehicle erection. The latter two methods, using the three stacking configurations shown in Figure 3-6, are presented in detail in the subsequent paragraphs.

Configuration A — Uniform Stacking. This method provides for the least complex erection facility, as shown in Figure 3-10. The basic facility consists of a pivoting erection platform cantilevered over a concrete retaining wall, working in conjunction with a rail-mounted launcher platform. The vehicle elements are towed in a tail-first position onto the erection platform, and attached to suitable hydraulically actuated anchoring devices. These devices, located in the general area of the rocket engine mounts, the main landing gear, and the nose wheel mounts, firmly position the vehicle on the erection platform. The rail-mounted launcher platform, driven by a rack-and-pinion drive similar to that used on a mountain railway, is positioned in a positive-stop area beneath the erection platform. The erection platform is then tilted from the horizontal to the vertical position with the vehicle attached. Drive mechanisms for the tilting operation may be electro-mechanical or hydraulic. A relatively simple method of speed control would be the use of water-ballasted tanks at either end of the platform with pumps and controls of sufficient capacity to maintain any equilibrium desired.

Configuration B — In-Line Stacking, Nonuniform Mating. This method (Figure 3-11) is similar in many respects to that proposed for uniform stacking; the first booster and the orbiter are erected in the same manner. A requirement exists, however, for the third (booster) element to be rotated 180 degrees. This is accomplished by the use of a split launcher platform and a rotating turntable. The booster is mounted on the 1/3 section of the launch platform in the same manner as the previous two elements. In this case, however, the platform is rotated 180 degrees prior to the installation of the booster. After the booster has been installed, the entire 1/3 section is again rotated 180 degrees and mated to the platform containing the two previously erected elements. Stage separation devices are installed and the vehicle is then ready for connection to the service tower.

Configuration C — Nonuniform Stacking. Erection of vehicle elements under this stacking arrangement is the most difficult to accomplish of all methods. The elements have no common centerline, ruling out any possibility of in-line erection procedures. The simplest concept evaluated is shown in Figure 3-12 and contemplates the use of a rail-mounted 150-ton whirly crane similar to that used in many shipyards. The crane

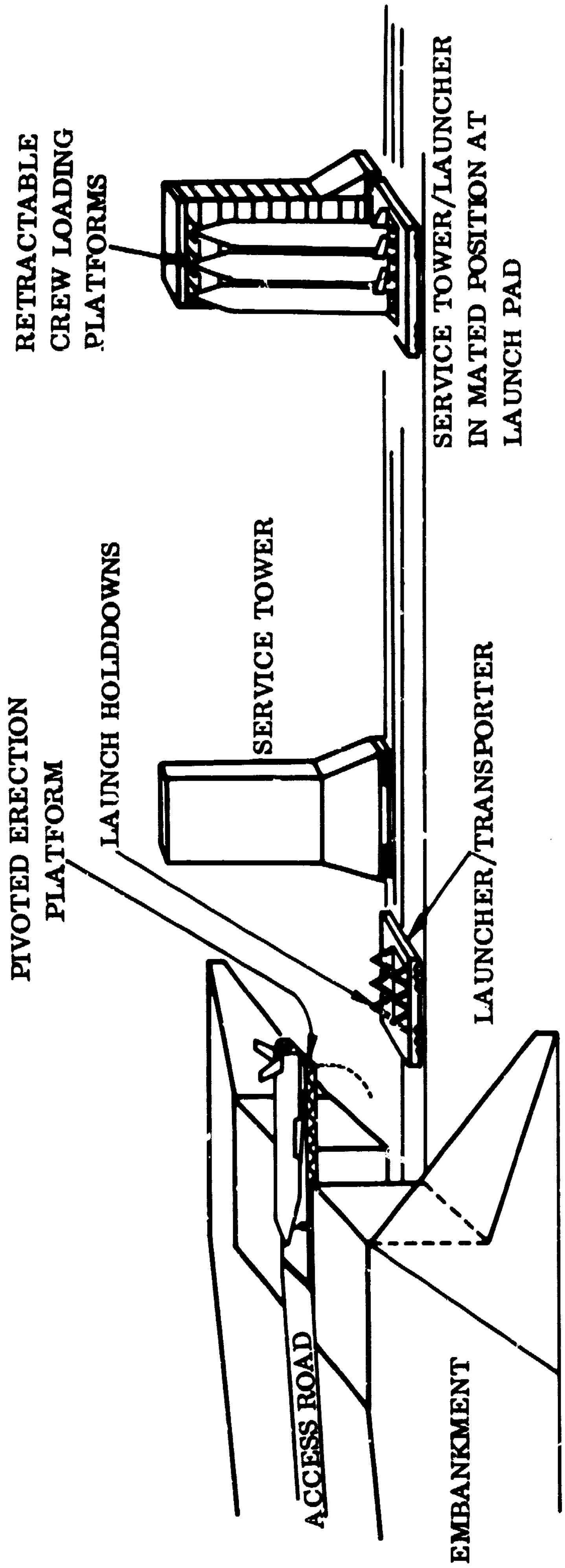


Figure 3-10. Erection Facility Stacking — Configuration A

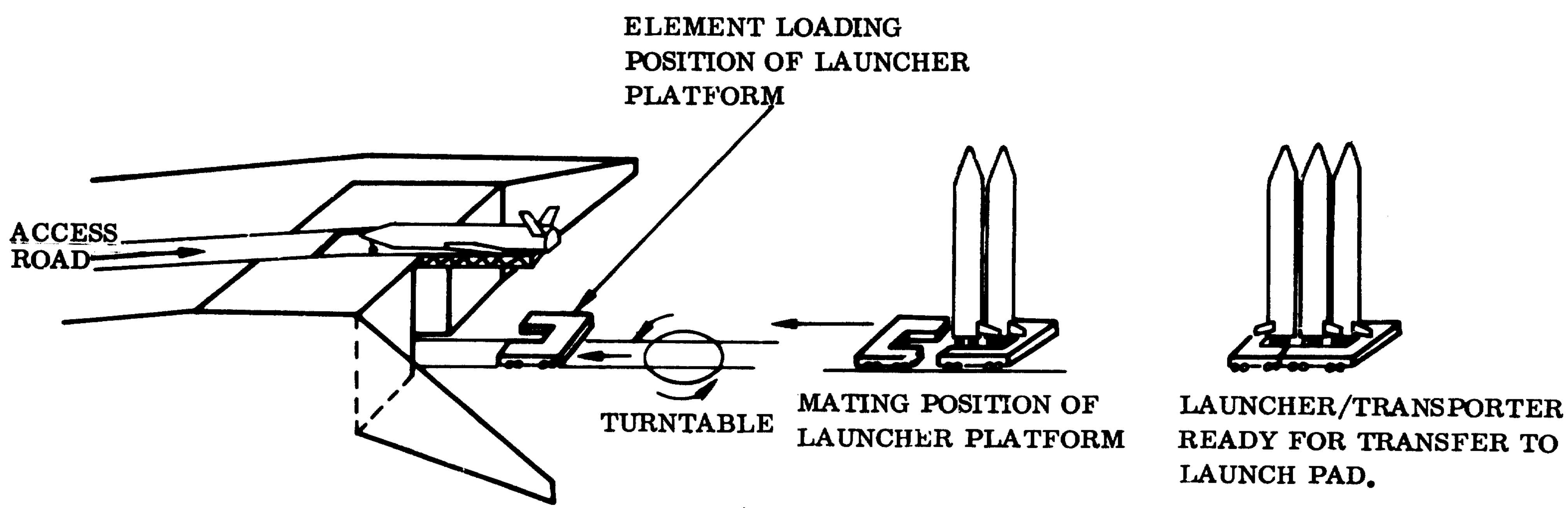


Figure 3-11. Erection Facility Stacking — Configuration B

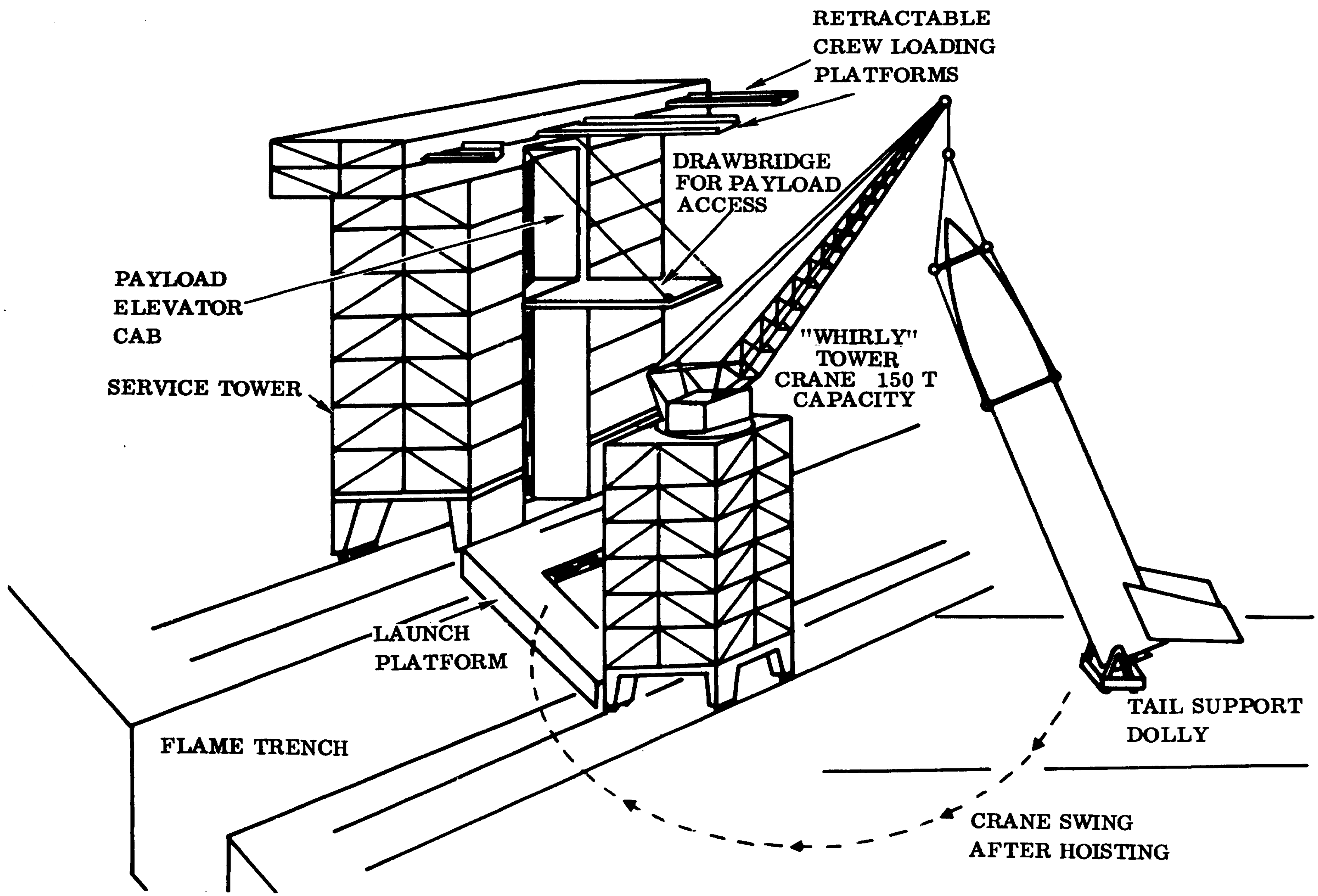


Figure 3-12. Erection Facility Stacking — Configuration C

is tower-mounted with a boom and cab capable of a 360-degree swing. Vehicle elements are towed to an erection pad adjacent to the crane, jacked up, and wheels and wings fully retracted. A tail dolly is mounted to the tail section and suitable slings and other rigging installed to hard points on the exterior of the element. The crane hoists the element into the vertical position and the tail dolly is removed. The crane then swings around 180 degrees on its own axis, depositing the element on the launch pad holddowns. After the element is secured, the slings and rigging are removed and the process repeated for the second and third elements. Under this concept the launcher platform and the service tower may be fixed units. The concept, while practical, calls for great care by the crane operator during erection procedures, and suitable temporary restraints must be provided to prevent any pendulum effect when the crane is rotated 180 degrees. Consideration was given to the possibility of combining the whirly crane with the service tower. This, however, was abandoned because of the large overturning moment engendered by mounting the crane some 250 feet above the ground.

Service Tower Requirements. Considerable effort was expended in an attempt to provide a clean-pad approach to launch operations. This effort was largely invalidated by the constraints requiring:

a. Access to payload when in a vertical position.

b. Crew and passenger loading in the vertical position.

c. Crew and passenger emergency egress.

Figure 3-12 depicts the use of a service tower in meeting the above constraints.

Under stacking Configuration A and B the tower would be mobile. Under stacking Configuration C, the tower may be a fixed installation. Tower design would be similar for A and B, but different for C. For stacking methods A and B the basic overall dimensions above pad level are 110 ft x 50 ft x 250 ft high. The tower will be equipped with a high speed elevator and escape chute similar to that provided for Saturn/Apollo. Three extendable platform/walkways are required for crew loading at approximately the 230-ft level. Two extendable platforms are required at the 150-ft level for installation of mating assemblies and explosive ordnance. A single extendable platform is required for access to the orbiter passenger hatch at approximately the 160-ft level. Air conditioning ducts and equipment are required for equipment and payload cooling.

Fueling and electrical/signal connections will not be installed on the tower, but will be fixed installations adjacent to the launch pad. These utility and fuel connections will be compatible with connections to be provided on the launcher/transporter. For stacking Configuration C, a hammer-headed tower is proposed with basic dimensions of 100 ft x 60 ft at the base and 140 ft x 60 ft at the head, and an overall height of approximately 260 ft. The high speed elevator, escape chute, and three crew-loading platforms will be as previously described. A heavy-duty elevator of 50,000-lb capacity and a cable-operated draw bridge are required to load and unload payloads. The elevator cab requires a 20 ft x 20 ft floor area and must be capable of handling 60 ft long loads. Elevator floor level at maximum lift corresponds with the floor level of the payload compartment when the orbiter is in the vertical position.

3.2.6 PHASE VII, VIII, AND IX, INTEGRATED LAUNCH PAD. The launch pad will be a pentagon-shaped site approximately 3600 ft in diameter with a service road encompassing its perimeter, and the launch area located in the approximate center (Figure 3-13).

3.2.6.1 Launch Pad Structure. The pad will be a cellular reinforced concrete structure which may be elevated above the surrounding terrain or located at terrain level. A study beyond the scope of this report is needed to ascertain the advantages/disadvantages of both methods. Obvious constraints are:

a. If elevated, a ramp may be required from the erection area to the pad center.

b. If elevated, the bottom of the flame trench could correspond with existing grade, but large quantities of fill would be necessary.

Orientation of the longitudinal axis of the pad also cannot be made until sites have been selected.

Beneath the concrete deck, separate rooms provide functional space to house environmental control equipment and pad terminal connection equipment. On the surface of the pad are interface structures to provide service to the launcher and service tower. A flame trench approximately 60 ft wide and 500 ft long bisects the pad. In this trench is a rail-mounted flame deflector. At the end of the flame trench, a flame deflector refurbish facility is required. Two flame deflectors are necessary to each pad, one in use and the other in the refurbishment cycle, predicated on the launch rate.

An escape chute leading to a hardened room provides for crew safety in event of a hazardous malfunction during the launch phase. A slide-wire system provides the primary escape approach.

3.2.6.2 Fuel System Facilities. Storage facilities for 1.3 million gallons of liquid hydrogen and 800,000 gallons of liquid oxygen are required, with the tank farms placed at diametrically opposite points on the perimeter service road. Separation distance is approximately 3600 ft. Airbreathing engine fuel may be supplied to the pad fueling points by mobile tank truck.

The LH_2 facility consists of a spherical storage tank, a vaporizer/heat exchanger for tank pressurization, a vacuum-jacketed transfer line, and a burn pond venting system. Transfer of LH_2 to the elements is accomplished by pressure generated by a vaporizer/heat exchanger.

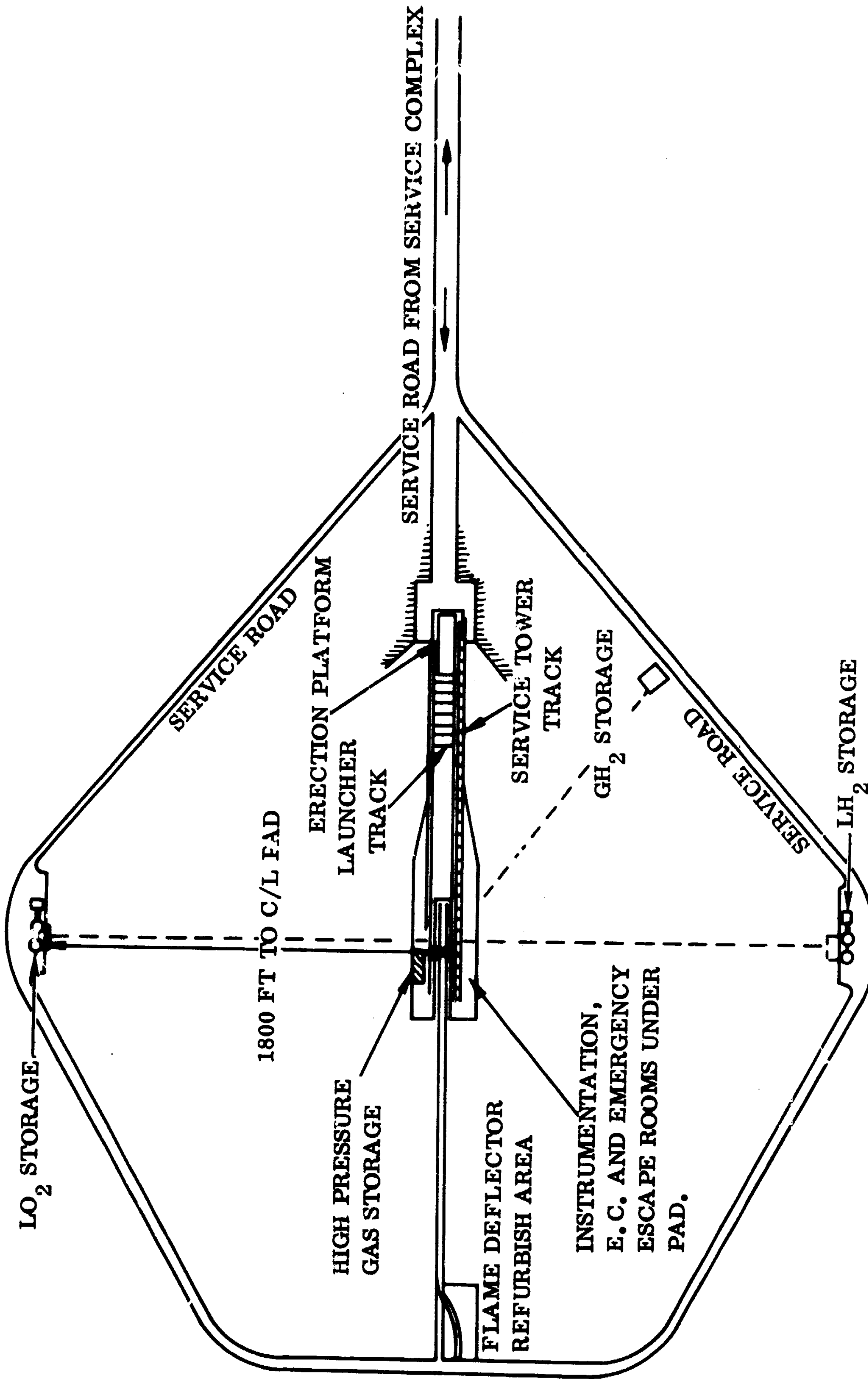


Figure 3-13. Launch Pad Layout

The LO_2 facility consists of an 800,000 gallon spherical storage tank, an LO_2 vaporizer, unjacketed transfer line, vacuum-jacketed topping line, pumps, and a dump pond for draining and venting.

The rapid turnaround requirement and the two-hour emergency standby/rescue requirements impose a heavy demand on the fueling facilities. To meet these demands it is necessary to transfer both fuel and oxidizer at a rate closely approaching 20,000 gpm.

As previously stated, LH_2 can be transferred by a gas pressure system at a pressure of approximately 100 psi. A mechanical pumping system for LO_2 delivery at 20,000 gpm is not available, though it could be developed. There are two methods of overcoming this problem. A pumping rate of 20,000 gpm is required to fill the three elements of the system: If three 10,000-gpm pumps were used, each connected to one element, the rate obtained would be 30,000 gpm. This is more than required, and entails the use of three transfer lines. A preferable solution is to provide two 10,000-gpm pumps manifolded to one large supply line to the launch pad with three connections at the pad to supply the three vehicle elements. Power demand for these pumps would be heavy; approximately 10,000 hp would be required to drive them.

3.2.6.3 High Pressure Gas Storage. High pressure gases are required for purging, leak testing, pre-pressurization and thrust chamber jacket childown. A preliminary estimate of the quantities required is:

Gaseous Nitrogen - 9000 cu ft at 6000 psi

Gaseous Helium - 18,000 cu ft at 6000 psi

These storage tanks may be located under the launch pad and supplied from a central converter compressor facility described in Section 3.2.7.

3.2.6.4 Quantity, Distance, and Acoustic Effects. The total propellant stored at each launch pad will be 8.58 million pounds. This figure includes allowances for system childown, boiloff, transfer loss and an emergency reserve.

Storage tanks will contain 624,000 pounds of LH_2 and 6.648 million pounds of LO_2. Actual amounts to be loaded into the vehicle are 3.88 million pounds of combined propellant. As the LH_2 and LO_2 are spaced 3600 feet apart, the major hazard is from a catastrophic explosion of a fully fueled vehicle. The TNT equivalent of the propellant in a loaded vehicle is 2.33 million pounds. The unbarricaded distance of this quantity per Table 5-17 of AFM 127-100F is 9500 ft. Calculation of peak overpressure from such an explosion, per AFM 127-100H.0534.5, indicated that 1/2 psi would be encountered at 9900 ft under such circumstances; it is recommended that launch pad/occupied building distances be a nominal 10,000 ft.

Acoustic effects have been examined from two viewpoints, sonic boom and acoustic noise generated at liftoff. A typical boost trajectory was used to examine the sonic boom problem. As the boost configuration reaches Mach 1 (the onset of sonic boom generation), the flight path is still close enough to vertical so that the shock wave propagates away from the ground and is thus not heard at ground level. As the boost continues and the flight path is depressed, a point is reached some three miles downrange where the shock wave does intersect ground level, and a very mild boom having overpressure of only 0.7 psf is felt. At a downrange distance of some six miles, the sonic boom is so weak that it is not heard at all at ground level.

Noise generated by the rocket engines during the boost phase of the space shuttle system is of concern because of the possible detrimental effects on the vehicle itself and on persons near the launch site. Data abstracted from Saturn static tests (NASA TN D-611 and NASA TN D-1502) in conjunction with a typical trajectory profile were used to generate the noise level as a function of vehicle range. The relationship is shown in Figure 3-14. Noise of approximately 180 db at liftoff reduces to the threshold of pain (140 db) at a range of 1400 ft, and the threshold of discomfort (120 db) at 13,000 ft. Quantity distance requirements dictate a separation distance of 10,000 ft between the launch pad and inhabited buildings. At 10,000 ft the noise level is 128 db. This is assumed to be acceptable as the buildings at this range would be those associated with the space shuttle system and not privately owned business or personal dwellings. However, determination of launch facility location should include analysis of the noise level, using actual locations.

3.2.7 COMPLEX OPERATIONAL SUPPORT UTILITIES. The following utilities are required to support the launch/recovery/refurbishment complex.

3.2.7.1 Facility Electrical Power. The complex will be fed from a 69 kV substation which supplies switching stations stepping the power down to 13.8 kV. From these switching stations power will be distributed to 13.8 kV/480 V substations, which will be located at strategic points throughout the complex. Primary distribution from these stations will be 480 V with stepdown transformers providing 120/208 V power as required; 400 cycle power will be provided by AGE.

3.2.7.2 High Pressure Gas Production. To supply GN_2 and He to both launch pads, the main service building, and the logistics building, it is recommended that a centrally located high pressure gas converter compressor facility be constructed. This facility is shown on the complex facility layout (Figures 3-1 and 3-7) as being located adjacent to the logistics building. Siting considerations are primarily road and railroad access.

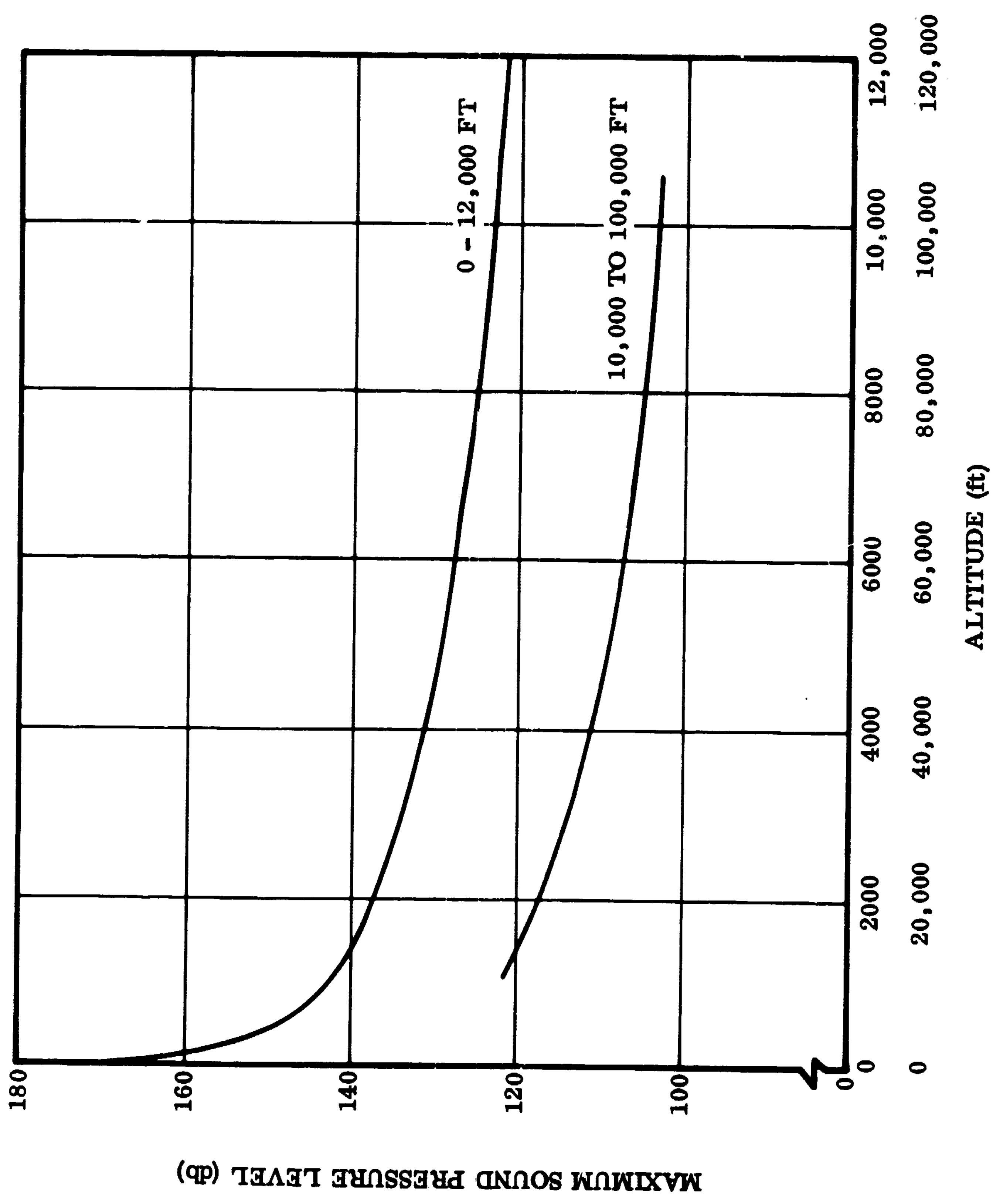


Figure 3-14. Noise Level of FR-4 Vehicle During Booster Phase

The facility consists of a 700,000 gallon LN_2 storage tank, a tank vaporizer, a high pressure LN_2 pump and vaporizer unit, a high pressure helium compressor, and helium and nitrogen gas purifiers. GN_2 is vaporized and compressed to 150/6000 psi and distributed to the required areas.

Helium is stored in railroad mounted tank cars, and manifolded to the helium compressors. The compressors boost pressure to 6000 psi for distribution to the storage receivers at the pads and service areas.

3.2.7.3 Water System. A requirement exists for water facilities to provide water to the area for fire protection, cooling, and quenching. The system requires a 1.5-million-gallon reservoir and distribution to an industrial water system, flame deflector cooling system, launcher and service tower fogging, and all fire hydrants and firex systems at propellant storage facilities.

3.2.8 LAUNCH RATE/FACILITY REQUIREMENTS. Facility requirements outlined in this report have been based on 100 launches per year. A planned decrease to 50 launches or a planned increase to 150 launches would have a marked effect on facility requirements, as shown in Table 3-1.

3.3 APPLICATION OF ETR COMPLEX 39 FOR GROUND OPERATIONS

A preliminary study has been made of the use of Complex 39 as an operational facility for the space shuttle vehicle. The study indicates that, with certain modifications, the prospect is entirely feasible and worthy of an in-depth study. This preliminary study, based on the nine phases of the servicing and turnaround analysis enumerated in the first portion of the operational facility study, is detailed in the following paragraphs.

3.3.1 PHASE I, POSTFLIGHT RECOVERY. Postflight recovery assumes the availability of a 10,000 foot all-weather runway. Complex 39 does not have such a runway. Conversion of the existing Cape Kennedy skid strip has been examined, but distance from Complex 39 and the complications inherent in transferring a vehicle approximately equal in size to the C-5A, weighing 140 tons, over the Cape road system, led to a quick abandonment of the possibility. From examination of area maps, it appears feasible that such a facility could be constructed with the end fairly close to the VAB and is shown as such in Figure 3-15.

3.3.2 PHASE II, POSTFLIGHT SECURING. Revetted postflight securing areas as shown in Figure 3-3 do not exist at Complex 39. However, new construction adjacent to the end of the proposed new runway would satisfy this requirement.

3.3.3 PHASES III & IV, POSTFLIGHT INSPECTION/MAINTENANCE. The low bay of the VAB has been examined for this purpose, but its use cannot be recommended. This is mainly due to the inadequate size of the cells, and the requirement of having from two

Table 3-1. Effect on Facility Requirements of Varying Launch Rate from 100 Per Year

FACILITY	LAUNCH RATE PER YEAR	
	50	150
Runway	No Effect	No Effect
Securing Facility	No Effect	No Effect
Service Building	Reduce Number of Service Bays to Four	Increase Number of Service Bays to Eight
Logistics Building	No Effect	Doubles Payload Loading Area for Two Orbiters
Erection Facility	If Maintenance Area Erection Chosen, Reduce Erection Tower to One	No Effect
Launch Pad	No Effect	One Additional Launch Pad Required
Tank Farms	High Pumping Rate Not Required. Reduces Pumps to One; Reduces Line Sizes	
Gas Storage	Smaller Storage Facilities	
Gas Production	Smaller Production Requirements	

to four of the spacecraft elements in the refurbishment cycle at one time for a 100-vehicle-per-year launch rate.

It is recommended that a new maintenance/servicing facility be constructed to the north of the VAB with access to the center aisle of the high bay (Figure 3-16).

3.3.4 PHASE V, PAYLOAD INSERTION (LOGISTICS). This operation can be performed in the low bay of the VAB. Space, crane capacity, and support equipment are adequate. Some modification would be required to the stage separation and checkout cells as well as to the work platforms to provide the necessary storage and handling facilities and equipment to service the payload modules. The orbiter, in this instance, would enter from the high bay transfer aisle into the low bay aisle, and remain parked in the aisle until the payload was installed. It would then move to the high bay for erection and mating.

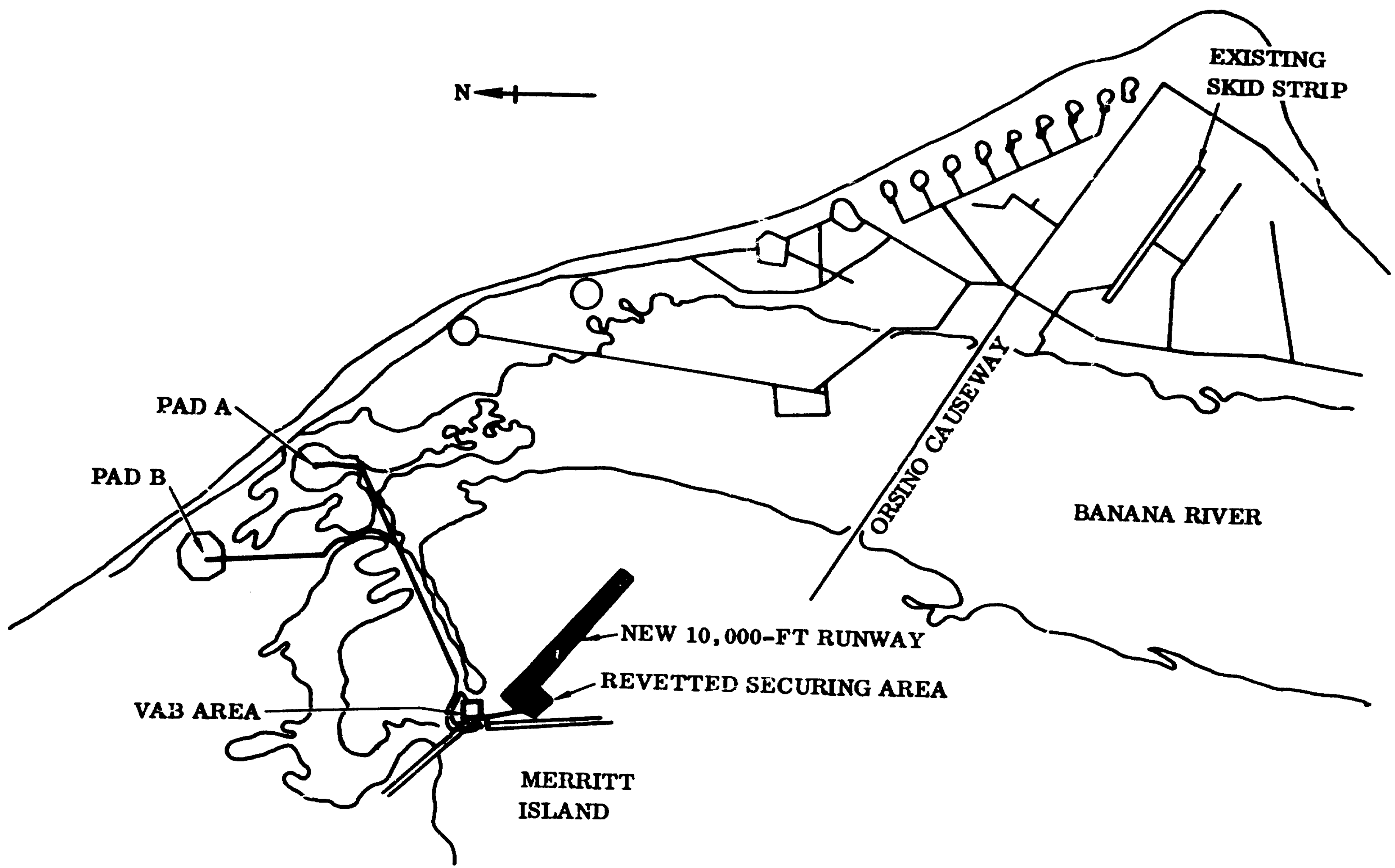


Figure 3-15. Merritt Island Area Plan Showing New Runway and Securing Area

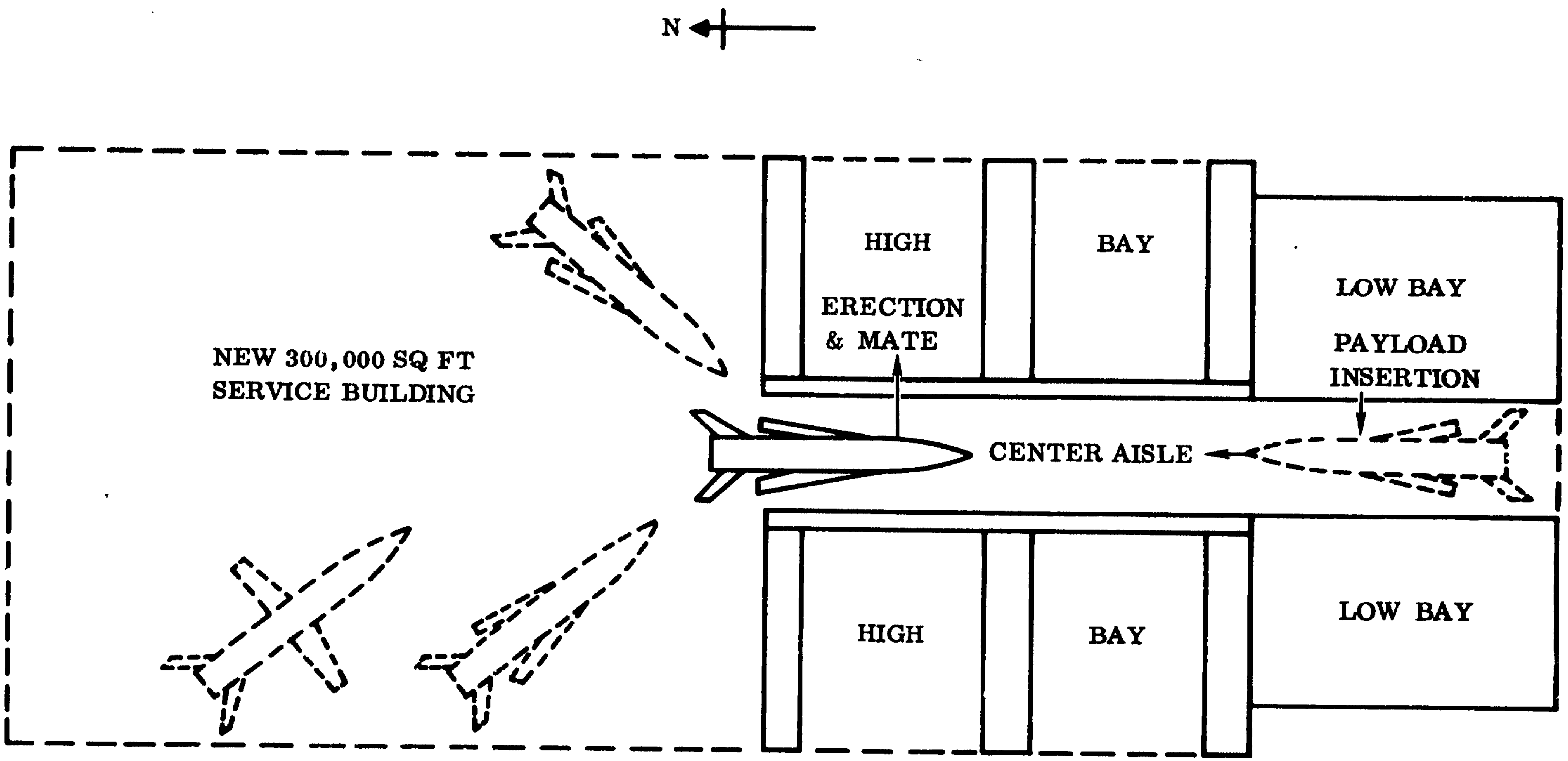


Figure 3-16. Space Shuttle Vehicle Servicing, Erection and Mating in VAB Area

3.3.5 PHASE VI, VEHICLE ERECTION AND INTEGRATION. The high bay of the VAB test cell No. 2 is suggested for this purpose. Erection procedures would follow the same general routine established for Saturn V (Figure 3-17). The actual floor area within the high bay cells is adequate, in that the space shuttle system, when erected, does not require a larger space than that occupied by the Saturn V launcher platform.

The launcher umbilical tower (LUT) as designed for Saturn V is not readily adaptable to the space shuttle system. Problem areas are 1) the hole in the deck for the exhaust, 2) position and size of the umbilical tower, and 3) dead weight on the crawler. The space shuttle dry weight is 836,850 lb as opposed to the Saturn's 500,000 lb. However, if a new LUT were constructed to suit the space shuttle system, and the VAB high bay doors widened above elevation 75 ft 0 in., the space shuttle system could readily be accommodated and erected within the facility.

The new LUT mentioned in the previous paragraph would be relatively unsophisticated compared to the Saturn V. Required height would be approximately 250 ft as opposed to 380 ft required for the Saturn. The need for umbilical service arms is eliminated, as the space shuttle vehicle has all connections through the base. The primary use of the tower would be for crew and passenger loading (assuming payloads are inserted in the VAB), crew emergency egress, and installation of explosive stage-separation devices. VAB crane capacities and hook heights are adequate. Ground support systems, power electrical checkout support, gases, etc., are available within the building, but will require extension to the area of space shuttle craft.

3.3.6 PHASES VII, VIII, AND IX. Pads A and B at Complex 39 can be used essentially as is. Certain modifications are required to umbilical connections for compatibility with the space vehicle configuration, LH_2 storage requires a supplemental tank of some 350,000 gallon capacity, and a new mobile flame deflector is required. High pressure gas storage may require additional capacity. In general, all other existing pad equipment can be readily adapted for use with the space shuttle vehicle.

The new LUT should provide all the access points needed to service the space shuttle system while on the pad; therefore, it is perhaps possible to eliminate use of the existing mobile service tower.

While not strictly applicable to the various phases discussed, use of the existing Complex 39 launch control building would provide an invaluable adjunct to the coordination and control of the sequence of operations inherent in the space shuttle vehicle turnaround cycle.

3.4 OPERATIONAL FACILITIES AT WESTERN TEST RANGE

A preliminary siting study has been made for an operational facility at WTR (Figure 3-18). The only immediately obvious solution is to use the existing 10,000-ft runway

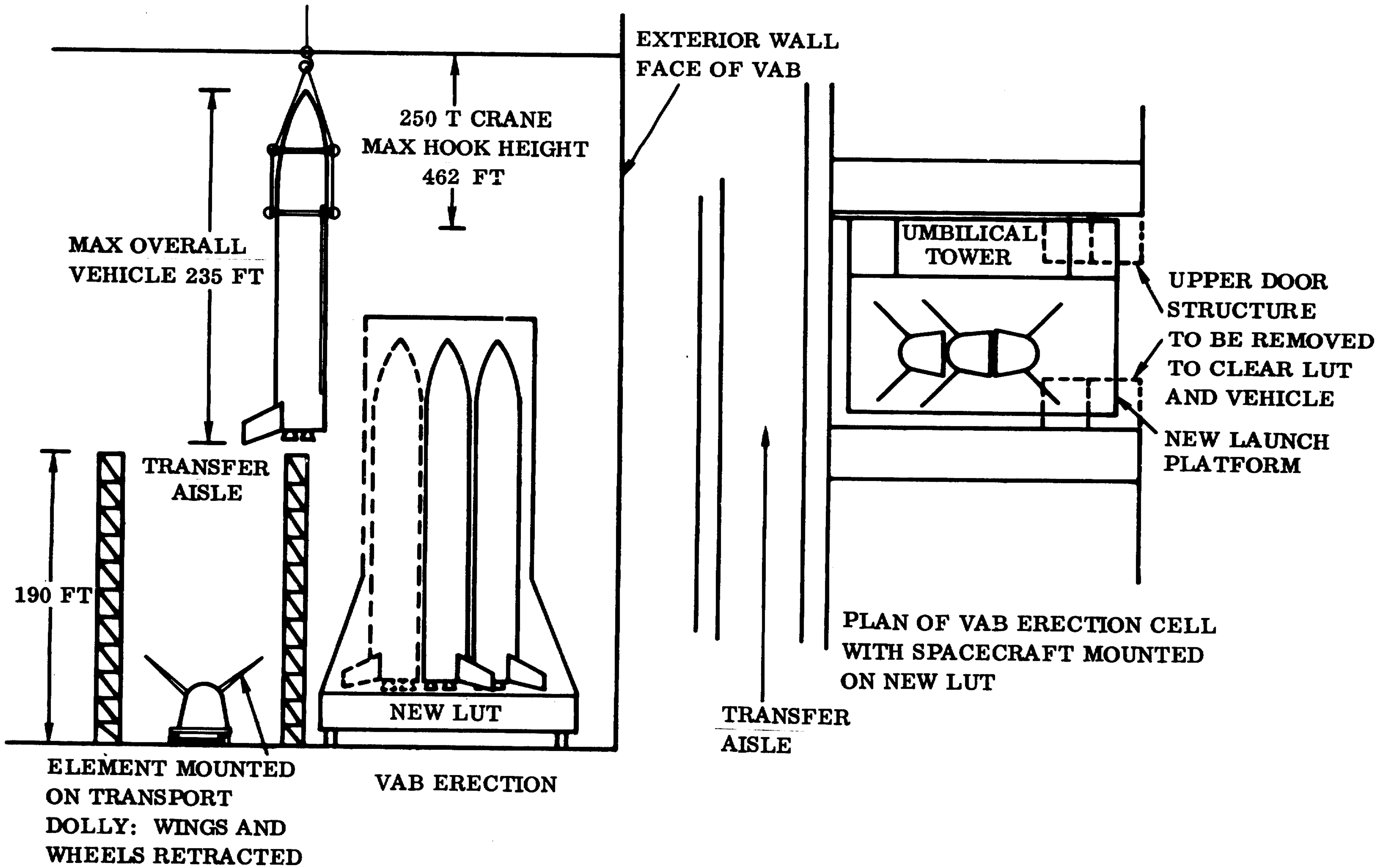


Figure 3-17. Vehicle Erection and Integration in VAB, Complex 39

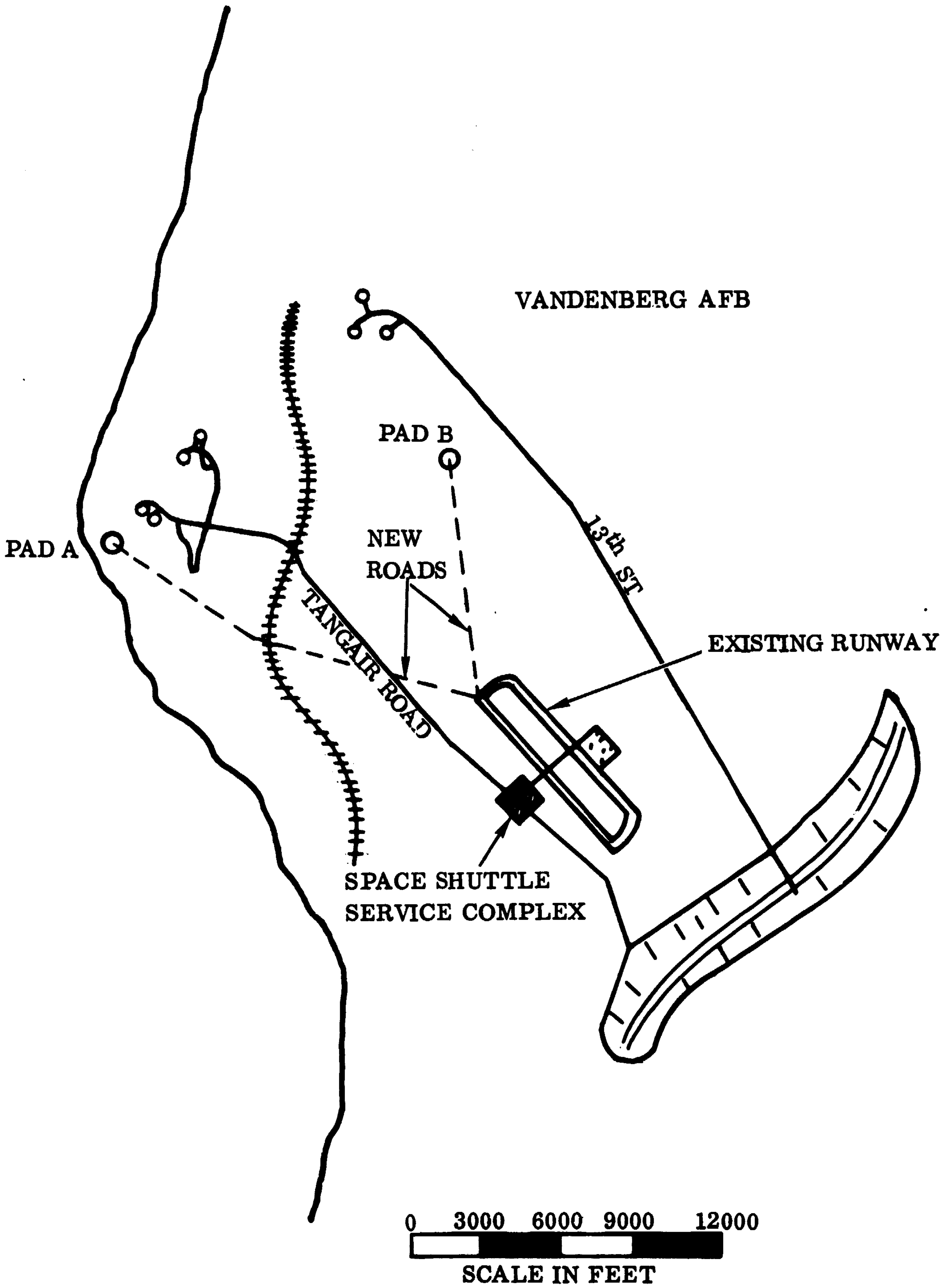


Figure 3-18. Operational Facility Plot Plan, WTR

for recovery operations and to angle off the runway with a Y configuration leading to the launch pads. This would place the pads in the same general area as the 576A Atlas pad and Complex 75 Thor pad. It is realized that these pads are still operational but the projected IOC date for the space shuttle vehicle would probably not conflict with operational plans for using these facilities.

3.5 EFFECT OF VEHICLE DESIGN ON FACILITY REQUIREMENTS

FR-1/FR-4 vehicle facility requirements, based on 100 launches per year, as delineated in the preceeding paragraphs, form the baseline for requirements for the FR-3. The FR-3 vehicle, consisting of two elements of varying size, would follow the same basic flow pattern through launch and recovery as has been described for the FR-1/FR-4. The marked differences in element sizes, however, have an impact on facilities required. This impact is outlined in the ensuing paragraphs.

3.5.1 AIRCRAFT RUNWAY. Weight of the booster element will require an increase in the design wheel loading of the runway.

3.5.2 SECURING AREA. Although normal traffic flow indicates a requirement for only one revetted securing area bay, any mission abort would necessitate the use of two. It is recommended that the securing area be the same as described for the FR-4 vehicle.

3.5.3 SERVICE BUILDING. Only four bays are required for servicing: two booster bays and two orbiter bays. Bay sizes would not vary considerably from those described for the FR-4.

3.5.4 LOGISTICS BUILDING. A reduction in the length of this building could be considered. The FR-4 orbiter has an effective length of 210 feet, while the FR-3 is only 179 feet. All other requirements would be the same as for FR-4.

3.5.5 ERECTION FACILITY. Should main service area (MSA) erection and mating be considered desirable, no change would be required to the erection cells, except that crane capacity would increase to 300 tons. The two-element configuration would require a different launcher platform and launcher holddowns, sized to suit the configuration and weight. The erection principle would, however, be unchanged. Should pad erection and mating be chosen, erection Configuration B (shown in Figure 3-11) or Configuration C (Figure 3-12) could be used; Configuration B is preferred.

3.5.6 LAUNCH PAD. Two launch pads will still be required for the FR-3 complex. Fuel (LH_2) storage requirements will change to 0.9 million gallons. LO_2 will be unchanged. Changes would be required to the configuration of the flame deflector. Gas storage capacity would be slightly reduced.

3.5.7 LAUNCH RATES. Launch rate changes would have the same general effect on facilities as noted for the FR-4 vehicle.

3.5.8 APPLICATION OF COMPLEX 39 TO FR-3 OPERATIONS. Feasibility of adapting ETR Complex 39 for the FR-3 turnaround cycle has been analyzed. It is eminently feasible and extremely attractive from a cost standpoint.

Requirements would still exist for the runway and securing areas outlined previously and the addition of a four-vehicle-bay service building adjacent to the VAB would be required. Erection of the two elements would follow the same procedures as outlined for the FR-4. It is believed, however, that the existing Saturn V LUT (launcher umbilical tower) could be adapted for use with the FR-3, since only the booster engines are fired at launch, and from a facility standpoint is equivalent to the launch of a single element. As the booster engine envelope is contained in an area approximately 37 feet by 41 feet and the exhaust chamber in the LUT is 45 feet square, it follows that with some relatively minor changes the launcher platform could be adapted. Examination of this possibility should bear in mind the fact that the orbiter element is not supported by any launcher mechanisms, and is in effect carried piggyback by the booster. A plan and elevation of the FR-3 vehicle superimposed on to the LUT is shown in Figure 3-19.

Newly designed launcher mechanisms would be required on the launch platforms, but it is believed that the basic existing Saturn V launcher design would be adapted to suit the configuration of the FR-3 booster.

Some modification would be required to the platform fueling and electrical connections to meet fueling requirements for the two elements.

The umbilical tower would also require some modification, principally in the areas of extendable platforms for crew and passenger loading, and for access to the payload bay.

The existing hammerhead crane is of sufficient capacity to handle the maximum design payload should on-pad installation or removal of payloads be required. A method of inserting/releasing the payload from the cargo compartment must be incorporated into the vehicle design in order to accomplish crane-assisted loading or unloading.

Complex 39 Launch Pads A and B could be used almost as is. Some modification would be required to fueling and electrical connections to suit revisions made to the LUT. The existing LH_2 tank farm would require supplemental storage capacity of approximately 100,000 gallons. Additionally, pumping capacity and lines for both fuel and oxidizer systems would have to be increased to meet the rapid turnaround requirements of the space shuttle vehicle.

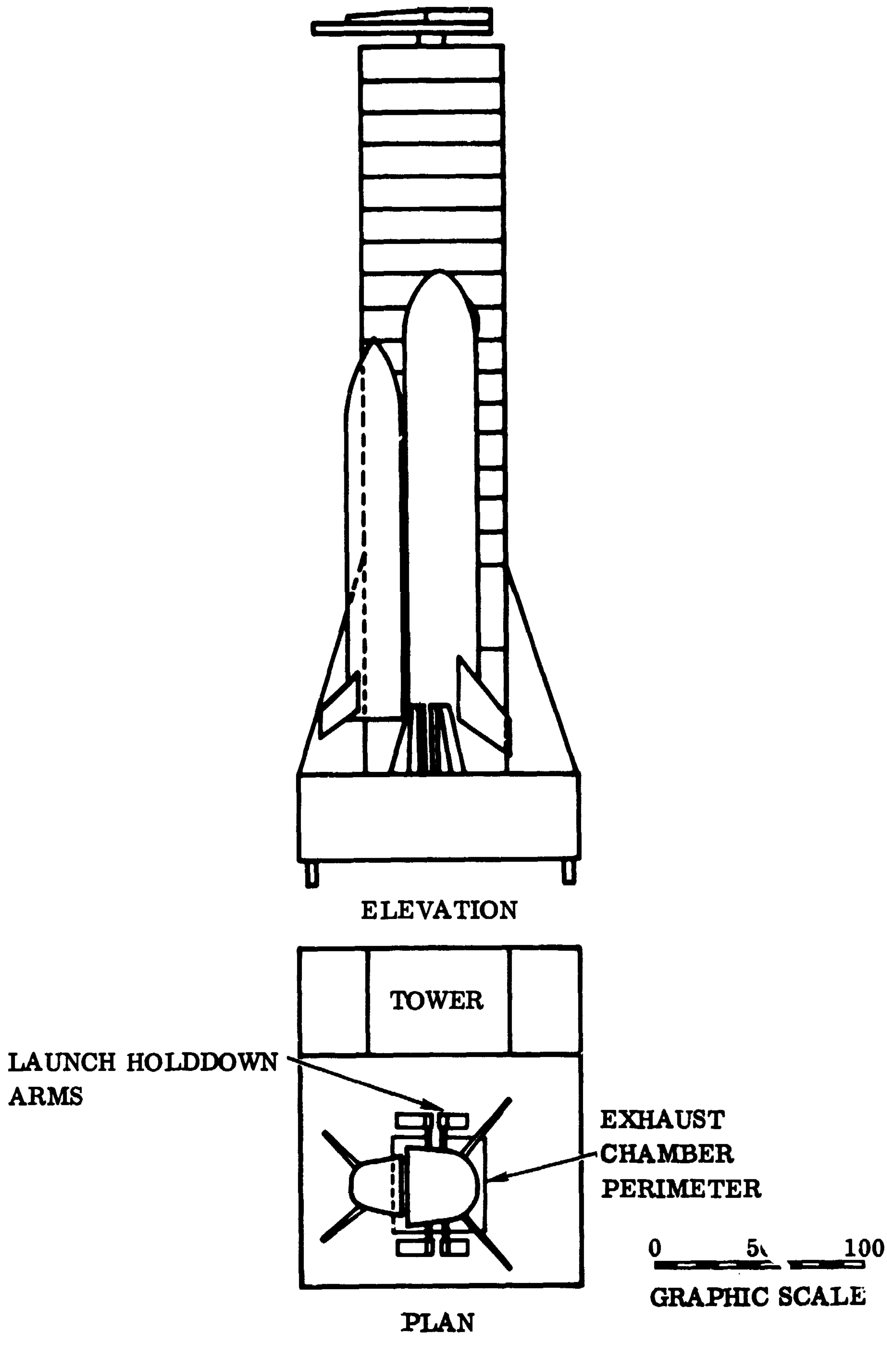


Figure 3-19. FR-3 Space Vehicle Superimposed on Saturn V LUT

It is obvious that as far as the FR-3 vehicle is concerned, the modification and use of Complex 39 for the turnaround cycle would be most attractive from both a cost and schedule standpoint. Table 3-2 is an analysis matrix of facility requirements for the FR-3 and FR-4 vehicles. This table shows 1) facility items and associated costs for a new facility, and 2) facility items and costs applicable to the modification and use of Complex 39.

Conflict would possibly occur with projected Saturn V schedules, primarily in the use of the LUTs and launch pads. It is recommended that a study be initiated to determine the feasibility of combining future projected Saturn V and space shuttle vehicle launches assuming joint use of the Complex 39 facilities.

3.6 AEROSPACE GROUND EQUIPMENT (AGE) REQUIREMENT

Based upon preliminary reusable space vehicle design and in conjunction with the supporting facilities identified, an analysis was made relative to AGE requirements for ground turnaround operations. Table 302 is a list of AGE with estimated cost. The AGE listing does not represent complete AGE requirements. It is presented as a preliminary analysis of the sizes and types of major AGE required to support reusable space vehicle operations using a two-launch-pad complex. AGE in Table 3-3 is shown relative to the ground turnaround phases previously discussed.

Table 3-2. Facility Requirement Summary

FR-3 & FR-4 Vehicles Assuming New Facilities			
Facility	FR-3 Vehicle	Cost ($Million)	FR-4 Vehicle
Aircraft Runway	10,000-ft, All-Weather	6.00	10,000-ft, All-Weather
Revetted Securing Areas	(1) 300 ft × 250 ft, (1) 250 ft × 200 ft + Magazine	.70	(2) 250 ft × 200 ft Areas + Magazine
Maintenance & Service Building	200,000 ft^2	12.00	300,000 ft^2
Logistics Building	230 ft × 180 ft	2.10	250 ft × 180 ft
Access & Service Roads	80,000 Linear ft	4.00	80,000 Linear ft
Launch Pads (2)	3600-ft dia Pentagon	26.00	3600-ft dia Pentagon
LH_2 Storage & Piping(2) LO_2 Storage & Piping(2)	900,000 gal LH_2 550,000 gal LO_2	42.00	1.3-Million gal LH_2 800,000 gal LO_2
High Pressure Gas Convertor Compressor Facility (1)	500,000 gal LN_2 Tank Vaporizers, Compressors, etc.	10.00	700,000 gal LN_2 Tank Vaporizers, Compressors, etc.
Erection Facility (2)	See Drawings	19.20	See Drawings
Mobile Launcher/Tower (2)	Similar to Saturn LUT	20.00	New Design Required
Transporters (2)* (Not used with integrated erection/mobile launcher concept of erection at pad)	Not Used		Not Used
Flame Deflectors & Refurbish Areas	New Design Required	3.00	New Design Required
Utilities, Complex Service Shops, Intercom RF Shielding, etc.		20.00	
		155.00	

FOLDOUT FRAME #1

FC

		FR-3 & FR-4 Vehicles Assuming Use of ETR Compl		
FR-4 Vehicle	Cost ($Million)	Facility	FR-3 Vehicle	Cost ($Million)
0-ft, All-Weather	6.00	Aircraft Runway	10,000-ft, All-Weather	6.00
0 ft × 200 ft Areas + zine	.54	Revetted Securing Areas	(1) 300 ft × 250 ft, (1) 250 ft × 200 ft + Magazine	.70
00 ft^2	18.00	Maintenance & Service Building	200,000 ft^2	11.50
× 180 ft	2.10	Logistics Building	Use Low Bay VAB	.50
0 Linear ft	4.00	Access & Service Roads	To VAB from Runway 2000 ft	.30
ft dia Pentagon	26.00	Launch Pads	Use Existing Pads A & B	.30
illion gal LH_2 00 gal LO_2	46.00	Fuel & Oxydizer Storage and pumping facilities	Existing; Use AS-15 Increase pumping rates	1.00
00 gal LN_2 Tank izers, Compressors, etc.	10.50	High Pressure Gas Facility	Existing - No Cost	0.00
rawings	16.40	Use High Bay VAB Crane	Existing - No Cost	0.00
esign Required	24.00	Mobile Launcher Tower	Existing - Modify (2)	6.00
sed		Transporter Crawler	Existing - No Cost	0.00
esign Required	3.50	Flame Deflector & Refurbish Areas	Existing Unsuitable New Design Required	2.70
	20.00	Utilities, Shops, etc.	All Existing - No Cost	0.00
	177.04			29.00

FOLDOUT FRAME #2

FOLDOUT FR

FR-3 & FR-4 Vehicles Assuming Use of ETR Complex 39 (Modified)

	FR-3 Vehicle	Cost ($Million)	FR-4 Vehicle	Cost ($Million)
/	10,000-ft, All-Weather	6.00	10,000-ft, All-Weather	6.00
ng Areas	(1) 300 ft × 250 ft, (1) 250 ft × 200 ft + Magazine	.70	(2) 250 ft × 200 ft Areas + Magazine	.54
ervice	200,000 ft^2	11.50	300,000 ft^2	17.50
ng	Use Low Bay VAB	.50	Same	.60
e Roads	To VAB from Runway 2000 ft	.30	Same	.30
	Use Existing Pads A & B	.30	Same	.30
Storage ilities	Existing; Use AS-15 Increase pumping rates	1.00	Add 550,000 gal LH_2 Storage Increase pumping rates	2.20
as	Existing - No Cost	0.00	Increase Capacity	.20
AB Crane	Existing - No Cost	0.00	Existing - No Cost	0.00
Tower	Existing - Modify (2)	6.00	New Design Required	24.00
wler	Existing - No Cost	0.00	Existing - No Cost	0.00
&	Existing Unsuitable New Design Required	2.70	Existing Unsuitable New Design Required	3.00
etc.	All Existing - No Cost	0.00	All Existing - No Cost	0.00
		29.00		55.64

FOLDOUT FRAME #3

Table 3-3. Reusable Space Shuttle Ground Turnaround AGE Requirements

AEROSPACE GROUND EQUIPMENT REQUIRED	NUMBER OF UNITS	COST PER UNIT ($)	TOTAL AGE COST ($)
PHASE I — POST FLIGHT RECOVERY			
Follow-Me Vehicle	1	3,500	3,500
Standard Airport AGE Equipment	-	-	-
PHASE II —			
Low Pressure, High Volume Blower (Mobile)	2	5,000	10,000
GN_2 Purge Cart	2	20,000	40,000
H_2 Purge Cart	2	20,000	40,000
Personnel Off-Loading Stairs and Platform (Mobile) (35-ft Height)	2	10,000	20,000
Crew and Passenger Transport Vehicle	1	15,000	15,000
Towmotors (Small)	2	2,000	4,000
Crane, 30-Ton Capacity (Mobile with 100-ft Boom)	1	40,000	40,000
Trailer and Tractor (60 ft Lowboy Bed)	1	15,000	15,000
Payload Handling Loadbar (30 - 60 ft)	3	1,500	4,500
Jet Fuel Defueler	1	6,000	6,000
Work Stands (Adjustable to 30 ft Height)	4	4,000	16,000
Tow Tractor and Towbars	2	40,000	80,000
PHASE III AND IV			
Jacks, Tripod, 100-Ton Capacity	6	2,500	15,000
Jacks, Alligator, 100-Ton Capacity	6	1,000	6,000
Hydraulic Test Stands (4000 psi, 200 gpm capacity)	2	50,000	100,000
Empennage Work Stands (501 High 25 × 60 ft Base, 5 Levels, Stairs and Hoist, Mobile)	2	20,000	40,000
Fuselage Work Stands (35 ft High 20 × 20 ft Base, 3 Levels, Stairs, Mobile)	4	20,000	80,000
Engine Removal Stands (Jet and Rocket Engines)	4	20,000	80,000
Cabin Access Stairs (Mobile, 35 ft High, Adjustable)	2	4,000	8,000
Engine Maintenance Stand (Jet Engine)	1	8,000	8,000
Engine Parallel Rail Transporters Jet and Rocket Engines	2	2,000	4,000
Landing Gear Removal Dollies	2	15,000	30,000
Wing Hinge Pin Puller/Installer	1	15,000	15,000
Thermal Panel Transport Dollies	2	5,000	10,000
Load Bar (50 ft for Wing Removal and Installation)	1	10,000	10,000
Wing Transport Dolly	1	5,000	5,000
Attitude Control Engine Handling Load Bars	2	1,000	2,000
Generator Test Stand (40 kVA)	1	60,000	60,000
Pneumatic Test Stand (5000 psi)	1	20,000	20,000
Hydraulic Bench Test Equipment	1	20,000	20,000
GN_2 Service Cart	1	20,000	20,000

Table 3-3. Reusable Space Shuttle Ground Turnaround AGE Requirements, Contd

AEROSPACE GROUND EQUIPMENT REQUIRED	NUMBER OF UNITS	COST PER UNIT ($)	TOTAL AGE COST ($)
PHASE III AND IV (cont'd)			
He Service Cart	1	20,000	20,000
Engine Cowling Cradle	1	2,000	2,000
Jet Engine Test Stand With Silencer	1	100,000	100,000
Blast Deflectors for Ground Runup	1	50,000	50,000
Jet Engine Starting Carts	2 sets	20,000	40,000
Landing Gear Shaft Puller	1	5,000	5,000
Wheel and Brake Servicing Cart	1	5,000	5,000
Electrical Test Set (Mobile) (Similar to Air Force DITMCO)	1	100,000	100,000
Tire Mounting Unit (Main)	1	2,000	2,000
Tire Mounting Unit (Nose)	1	2,000	2,000
Miscellaneous Slings and Dunnage for Use With Facility Cranes	2 sets	75,000	150,000
X-Ray Equipment (300 kV Industrial)	1	20,000	20,000
Motor Generator (400 Hz, Portable)	1	5,000	5,000
PHASE V — PAYLOAD INSERTION			
Load Bars (Assorted Sizes)	6	1,500	9,000
Cargo Module Airlock Test Cart	1	20,000	20,000
GN_2 Service Cart	1	10,000	10,000
He Service Cart	1	10,000	10,000
Motor Generator (400 Hz, Portable)	1	5,000	5,000
PHASE VI — VEHICLE ERECTION AND INTEGRATION			
Hydraulic Pressurization and Power Unit (4000 psi)	2	10,000	20,000
Motor Generator (400 Hz)	2	5,000	10,000
GN_2 K-Bottle Racks	2	800	1,600
He K-Bottle Racks	2	800	1,600
Launcher Assemblies	2	3,000,000	6,000,000
PHASE VII — LAUNCH PAD VEHICLE INTEGRATION			
Fuel Indicating Equipment and Control Panel	2	300,000	600,000
Pneumatic Checkout Racks (GN_2, He, H_2)	2	100,000	200,000
Pneumatic Consoles	2	40,000	80,000
Hydraulic Pressurization and Power Unit (4000 psi)	2	100,000	200,000
Gas Head Exchanger	2	30,000	60,000
Motor Control Center	2	20,000	40,000

Table 3-3. Reusable Space Shuttle Ground Turnaround AGE Requirements, Contd

AEROSPACE GROUND EQUIPMENT REQUIRED	NUMBER OF UNITS	COST PER UNIT ($)	TOTAL AGE COST ($)
PHASE VII (cont'd)			
Crew/Passenger Loading/Service Tower (Facility)			
Elevators High Speed	2	100,000	200,000
Rapid Egress System (Cars, Cable, and Controls)	2	50,000	100,000
Environmental Control System	2	150,000	300,000
Communications Equipment	2	300,000	600,000
PHASE VIII — LAUNCH			
Utilizes Equipment Listed for Phase VII			
PHASE IX — PAD INSPECTION AND REFURBISH			
Diesel Locomotive/or Chain Driven Mechanism for Flame Deflector Installation and Removal	2	100,000	200,000
Portable Air Compressor (150 cfm)	2	4,000	8,000
Welding Machine and Flame Cutting Equipment	4	1,000	4,000
MIG Welding Equipment	2	2,500	5,000
Gunite Pump	2	3,500	7,000
Sand Blasting Equipment	2	1,000	2,000
Work Stands	8	2,500	20,000
Portable Paint Spray Equipment	2	1,500	3,000
Pipe Bending Machines	2	3,000	6,000
Total Estimated AGE Costs for One Reusable Spare Shuttle Vehicle Launch Complex With Two Launch Pads Operating			9,984,200

NOTE: This preliminary AGE list contains many items currently available within the NASA inventory.