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COST STUDIES OF MULTIPURPOSE LARGE LAUNCH VEHICLES

VOLUME I

SUMMARY

FINAL REPORT

SEPTEMBER 15, 1969

NASA DOCUMENT NO.

CR-73328

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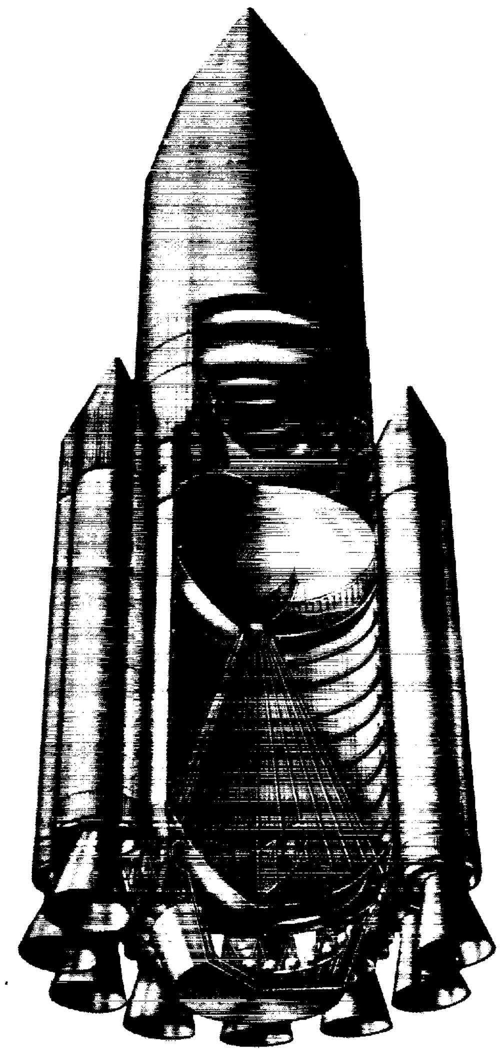

PREPARED UNDER CONTRACT
NAS 2-5056

BY THE BOEING COMPANY
AEROSPACE GROUP
SOUTHEAST DIVISION

(BOEING DOCUMENT NO.
D5-13463-1)

FINAL REPORT
FOR
COST STUDIES OF MULTIPURPOSE LARGE LAUNCH VEHICLES

VOLUME I
SUMMARY

PREPARED UNDER CONTRACT NAS2-5056
FOR
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
OFFICE OF ADVANCE RESEARCH AND TECHNOLOGY
MISSION ANALYSIS DIVISION

SEPTEMBER 15, 1969

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ABSTRACT

This summary volume is one of nine volumes which constitute the final report for "Cost Studies of Multipurpose Large Launch Vehicles" (MLLV), NASA/OART Contract NAS2-5056.

The MLLV is a family of vehicles consisting of a single-stage-to-orbit configuration plus other configurations combining a main stage (as used for the single-stage-to-orbit configuration) with various quantities of 260 inch diameter solid rocket motor (SRM) strap-on stages and/or injection stage modules. The main stage employs LOX/LH_2 propellant with either a multichamber/plug or toroidal/aerospike engine system. The single-stage-to-orbit can place approximately 500,000 pounds into a 100 nautical mile earth orbit. The addition of strap-on stages and/or injection stage modules will incrementally increase this payload capability to as much as 1,850,000 pounds.

The contract consisted of four study phases. Phase I was a detailed cost analysis of an Advanced Multipurpose Large Launch Vehicle (AMLLV) family as previously defined in NASA/OART Contract NAS2-4079. (The various configurations of the AMLLV family will have approximately twice the payload capability of equivalent configurations of the MLLV family.) Costs for vehicle design, test, transportation, manufacture and launch were defined. Resource implications for the AMLLV configurations were determined to support the cost analysis.

Phase II was a conceptual design and resource analysis Multipurpose Large Launch Vehicle (MLLV) family.

Phase III was a detailed cost analysis of the MLLV family. Costs for vehicle design, test, transportation, manufacture and launch were determined.

Phase IV was an overall assessment of the study results. Implications on performance, resources and cost of vehicle size, program options, and vehicle configuration options were determined. The study results provided data in sufficient depth to permit analysis of the cost/performance potential of various options and/or advanced technologies.

KEY WORDS

Advanced Multipurpose Large Launch Vehicle (AMLLV)
Half Size Multipurpose Large Launch Vehicle (MLLV)
Single-Stage-to-Orbit
Multichamber/Plug Engine System
Toroidal/Aerospike Engine System

ABSTRACT (Continued)

KEY WORDS

260 Inch Solid Propellant Rocket Motor (SRM)
Orbital Injection Stage
Contract NAS2-4079
Contract NAS2-5056
Payload to 100 NM Orbit
Cost
Resources
Zero Stage Vehicles
Parallel Stage Vehicles
Main Stage Throttling

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FOREWORD

This volume summarizes the results of a twelve month study, "Cost Studies of Multipurpose Large Launch Vehicles," NASA/OART Contract NAS2-5056. The objectives of this study were to define costs, cost sensitivities, and cost/size sensitivities of potential future launch vehicles to aid in the guidance of current and future technology programs.

The vehicles considered were:

a. The Advanced Multipurpose Large Launch Vehicles (AMLLV) as defined by a prior NASA/OART Contract, NAS2-4079.

b. The Multipurpose Large Launch Vehicles (MLLV) as defined by this contract.

The study documentation includes this volume plus eight other volumes designated as follows:

Volume I	Summary
Volume II	Half Size Vehicle (MLLV) Conceptual Design
Volume III	Resource Implications
Volume IV	Baseline AMLLV Costs
Volume V	Baseline MLLV Costs
Volume VI	Cost Implications of Vehicle Size, Technology, Configuration, and Program Options
Volume VII	Advanced Technology Implications
Volume VIII	Flight Control and Separation, and Stress Analysis (Unclassified Appendices)
Volume IX	Propulsion Data and Trajectories (Classified Appendices)

Supporting data on solid propellant rocket motors were obtained from the Aerojet General Corporation. Data on advanced liquid propulsion systems were obtained from the Pratt and Whitney Division of the United Aircraft Corporation and from the Rocketdyne Division of the North American Rockwell Corporation. These data, which were provided at no cost to the contract, encompassed technical, resources, schedules, cost and advanced technology information. This support materially aided The Boeing Company in the preparation of a complete and meaningful study and is gratefully acknowledged.

FOREWORD (Continued)

This study was administered by NASA/OART Mission Analysis Division, Ames Research Center, Moffett Field, California under the direction of the technical monitor, Mr. Edward W. Gomersall.

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1.0 INTRODUCTION

Manned planetary space missions, extended lunar exploration, and large orbital space stations are potential future space activities which may require uprating of existing launch systems or development of new launch systems. Under the auspices of NASA/OART, studies have been and are currently being conducted to provide effective data for guidance of technology programs and for planning for possible development of future large launch vehicles.

Such studies have dealt primarily with the design and performance aspects of potential future systems. Specifically, a previous study activity conducted under NAS2-4079, "Advanced Multipurpose Large Launch Vehicles (AMLLV)" defined an attractive design concept for a large launch vehicle family in terms of performance and payload capability. This concept will make use of the operational simplicity of a single-stage-vehicle to transport payload to earth orbit. The Saturn V/Apollo program and related activities have advanced the technology base to the point that such a system is now feasible and can be developed and implemented within the current state-of-the-art. The use of strap-on stages and injection stage modules in conjunction with the main stage (as developed for the single-stage-to-orbit application) will provide a family of vehicles capable of providing a range of payloads extending four fold from that of the single-stage-to-orbit configuration.

To evaluate the overall attractiveness of such a design concept, in terms of its performance and economical potential, it was necessary to define costs and cost sensitivities to vehicle size and to configuration, program and technology options. To meet these objectives, this current activity, drawing on the results of the previously completed AMLLV study and similar related studies, provided the following:

a. Conceptual design of a similar half size (MLLV) vehicle family (Volume II).

b. Resource implications and cost for development, procurement and operation of the baseline AMLLV vehicle family as defined in NAS2-4079 (Volumes III and IV).

c. Resource implications and cost for development, procurement and operation of half size (MLLV) vehicle family (Volumes III and V).

d. Relationship of cost to overall system size (Volume VI, Section 4).

e. Cost effectiveness of feasible configurations and options (Volume VI, Section 5).

f. Methodology which can be applied to assess cost effectiveness of advanced technology applications to the vehicle system (Volume VI, Section 6).

1.0 (Continued)

The design studies which investigated the applicability of the design concept to vehicle size showed that "optimal" design features will not be affected by size. For example, the concept is applicable not only to large vehicles for manned planetary missions but to smaller vehicles such as might be required for lunar or for earth orbital missions.

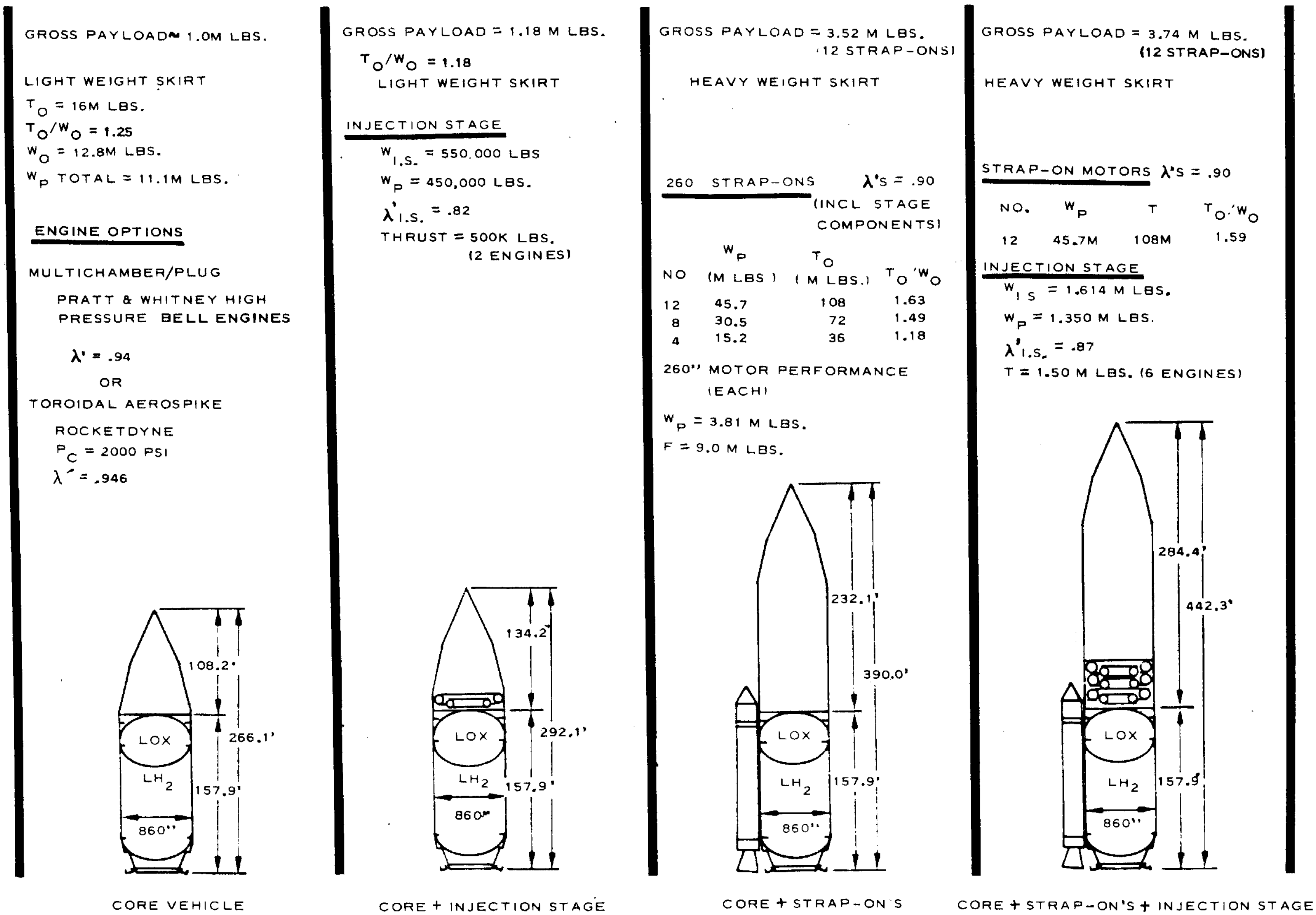
The costing activities and the associated comprehensive resource plans have provided insight into the costs not only of the various vehicle components, but of the individual operations required to develop, produce, test and operate these components. Costs have been identified as they relate to design options, program size, production and launch rate, and program philosophy. With this insight, cost effectiveness can better be built into future programs during the planning phases. Additionally, the results of this study provide a comprehensive reference for any subsequent study, design and development activities.

As the resource and cost data were developed in accordance with current operational philosophies and costing procedures, the results are directly comparable to existing data for current systems. The results define a fixed yardstick against which program alternatives to improve performance or minimize cost can be measured. With the resulting data and the methodology developed for its use, the priorities for improving technology can be assessed relative to their cost/performance potential.

2.0 BASELINE AMLLV FAMILY

Four representative configurations of the AMLLV family, which was used as a reference for this study, are shown in Figure 2.0.0.0-1. The AMLLV main stage, sized to deliver one million pounds as a single stage to a 100 N.M. earth orbit, has 16.0 million pounds of sea level thrust (provided by either a toroidal/aerospike or a multichamber/plug engine system) and contains 11.1 million pounds of propellant. The main stage burn-out weight (stage drop weight) of 634,000 pounds will result in a stage mass fraction of approximately 0.946 (numbers quoted are for the toroidal/aerospike main stage). The main stage structure, designed for use with all potential configurations, employs Saturn V/S-IC type skin-stringer-frame construction of 2219-T87 aluminum for the propellant tanks and 7075-T6 aluminum for the forward skirt and thrust structure. The design has a forward LOX tank separated from the LH_2 tank by a common bulkhead of sandwich aluminum construction.

For increased payload capability, the AMLLV main stage can be augmented with from two to twelve strap-on 260-inch solid motors each containing 3,810,000 pounds of propellant and providing an initial thrust of 9,000,000 pounds. To minimize the structural impact, solid motor thrust is reacted in the main stage forward skirt. Interchangeable heavy weight forward skirts are used on the



* ALL PAYLOADS SHOWN FOR ρ · 5 LBS. FT^3 100 NAUTICAL MILE CIRCULAR ORBIT

FIGURE 2.0.0.0-1 ADVANCED MULTIPURPOSE LARGE LAUNCH VEHICLE BASELINE FAMILY

2.0 (Continued)

main stages of configurations with strap-on stages.

An injection stage module, sized to not excessively penalize the vehicle lift-off thrust-to-weight, can be used atop the main stages. The module contains 450,000 pounds of LOX/LH_2 propellant in concentric toroidal tanks. Two high pressure bell engines, with extendible nozzles, provide the module with 500,000 pounds of vacuum thrust. For configurations with strap-on stages, one or two fuel modules can be stacked atop this module. Each fuel module also contains 450,000 pounds of propellant but has no engines. Two additional engines will be added to the thrust ring of the lower module for each fuel module. Mass fractions of 0.82 and 0.87 were defined for single module and three module injection stage configurations, respectively.

A total of twenty-six configurations can be developed from the main stage, strap-on stages, and injection stage modules to provide an incremental range of payloads for the 100 nautical mile (N. M.) earth orbit mission of from one million to 3.74 million pounds. The payload capabilities of typical AMLLV configurations relative to their launch weights are shown in Figure 2.0.0.0-2.

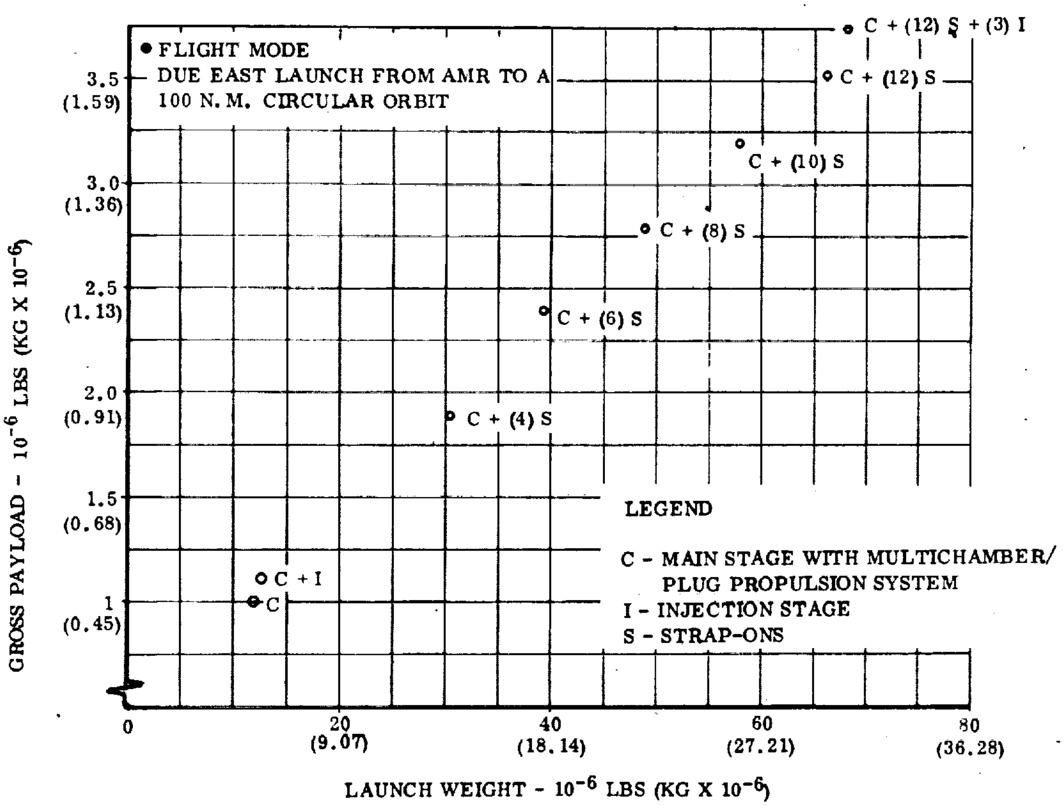


FIGURE 2.0.0.0-2 AMLLV PAYLOAD VERSUS LAUNCH WEIGHT

3.0 HALF SIZE (MLLV) FAMILY

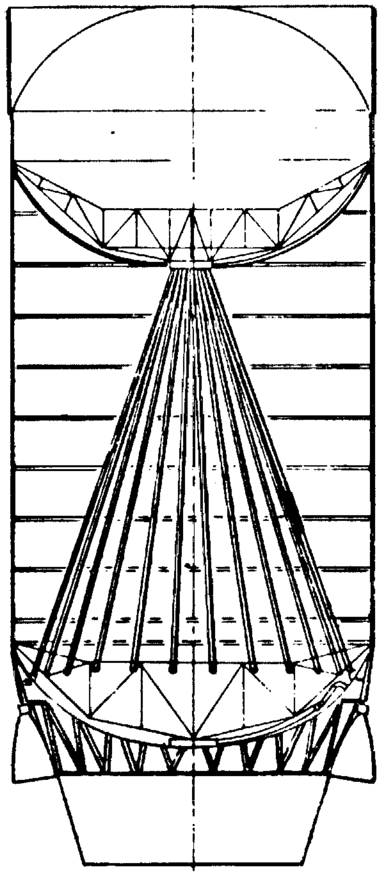
The configurations of the half size (MLLV) family, by definition, will have one-half the payload capability of similar configurations of the AMLLV family. Trade studies of the MLLV main and injection stages showed that the weight of propellant and thrust values should be equivalent to one-half those specified for equivalent AMLLV stages.

Figure 3.0.0.0-1 shows the basic elements of the MLLV family. Four representative configurations incorporating these elements are shown in Figure 3.0.0.0-2. The payload capabilities of typical MLLV configurations are shown in Figure 3.0.0.0-3.

Trade studies indicated that a mass fraction of approximately 0.93 to 0.94 could be obtained for the MLLV main stage if the major linear dimensions of the AMLLV main stage were proportionally reduced. Trajectory analyses showed that the same flight profiles used for the AMLLV vehicles will optimize the trajectories for the half-size (MLLV) vehicles. To maximize payload, vehicles without injection stages will require throttling of the main stage engine prior to burn out. Optimal design features for the MLLV main and injection stage structures, propulsion systems, pressurization profiles, mixture ratio, etc. proved to be the same as those previously identified for the AMLLV main stage.

Use of the injection stage as part of the transportation system to a 100 nautical mile earth orbit will provide only a nominal increase in delivered payload. The major advantages of the injection stage are the capability of fine control for orbital injection, capability for altitude or plane changes in orbit, and significantly increased payload for higher energy missions. Use of the injection stage will impose only a minor structural penalty to the main stage in the forward skirt area.

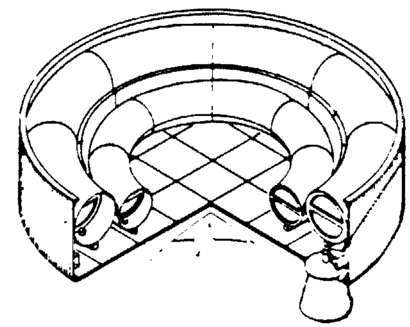
Either 156 or 260 inch solid propellant rocket motors (SRMs) will be acceptable for the strap-on stages. The 260 inch diameter SRM, however, was selected to minimize the number of components and to provide comparable SRMs to those of the AMLLV for subsequent cost analyses. Main stage structural penalties will be minimized by reacting the solid motor thrust into the main stage forward skirt. Eight 260 inch SRMs were selected to augment the MLLV main stage for the maximum payload configuration. The total values for propellant weight and thrust of these eight SRMs will be one-half those total values specified for the twelve SRMs of the AMLLV maximum payload configuration.



DIAMETER-56.67 FEET (17.27 METERS)
LENGTH-137.7 FEET (41.97 METERS)
WEIGHT-357,688 POUNDS (162,247 KG)

- STRUCTURE-218,305 POUNDS (99,023 KG)
- ENGINES-116,613 POUNDS (52,896 KG)
- SYSTEMS-22,770 POUNDS (10,328 KG)

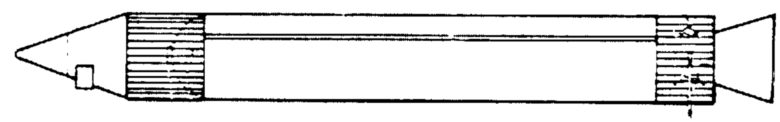
MAIN STAGE CONFIGURATION



DIAMETER-56.67 FEET (17.27 METERS)
LENGTH-15 FEET (4.57 METERS)
WEIGHT-49,955 POUNDS (22,660 KG)

- STRUCTURE-41,380 POUNDS (18,770 KG)
- ENGINES-3,860 POUNDS (1,751 KG)
- SYSTEMS-4,715 POUNDS (2,139 KG)

SINGLE MODULE INJECTION STAGE CONFIGURATION



DIAMETER-260 INCHES (6.60 METERS)
LENGTH-155.17 FEET (47.30 METERS)
WEIGHT-3,221,500 POUNDS (1,461,272 KG)

- PROPELLANT-2,900,000 POUNDS (1,315,440 KG)
- STRUCTURES-321,500 POUNDS (145,606 KG)

STRAP-ON SOLID MOTOR STAGE CONFIGURATION

FIGURE 3.0.0.0-1 BASELINE MLLV STAGE CONFIGURATIONS, KEY DIMENSIONS AND WEIGHTS

GROSS PAYLOAD*

M/C PLUG	471,000 LBS.
LOW PRESS. TOR	472,000 LBS.
HIGH PRESS. TOR.	492,000 LBS.

LIGHT WEIGHT SKIRT

T_O = 8 M LBS

T_O/W_O = 1.25

W_O = 6.4 M LBS.

W_P TOTAL = 5.55 M LBS.

ENGINE OPTIONS

MULTICHAMBER PLUG
PRATT & WHITNEY HIGH PRESSURE BELL ENGINES

λ' = .936 M/C PLUG

OR

TOROIDAL/AEROSPIKE

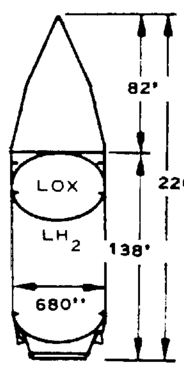
ROCKETDYNE

P_C = 2000 PSI (HIGH PRESS. TOROIDAL)

P_c = 1200 PSI (LOW PRESS. TOROIDAL)

λ' = .943 TOROIDAL (HIGH PRESS)

λ' = .945 TOROIDAL (LOW PRESS)



CORE VEHICLE

GROSS PAYLOAD = 554,000 LBS

T_O/W_O = 1.18

λ' CORE = .936 (M/C PLUG)

LIGHT WEIGHT SKIRT

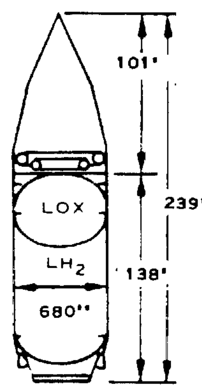
INJECTION STAGE

$W_{I.S}$ = 287,000 LBS

W_P = 225,000 LBS.

$\lambda'_{I.S.}$ = .785

THRUST = 250,000 LBS. (2 ENGINES)



CORE + SINGLE INJECTION STAGE MODULE

GROSS PAYLOAD = 1.76 M LBS (8 STRAP-ONS)

HEAVY WEIGHT SKIRT

T = 8 M LBS

λ' CORE = .931

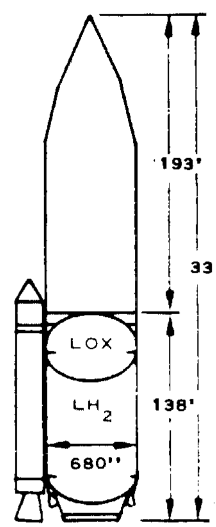
260 STRAP-ONS λ'_S .90

NO	W_P (M LBS.)	T_O (M LBS)	T_O/W_O
2	5.8	12.9	1.59
4	11.6	25.8	1.29
6	17.4	38.7	1.44
8	23.2	51.4	1.58

260" MOTOR PERFORMANCE (EACH)

W_P 2.9 M LBS

F 6.45 M LBS



CORE + 8 STRAP-ON'S

GROSS PAYLOAD = 1.85 M LBS

HEAVY WEIGHT SKIRT

T = 8.0 M LBS.

λ' CORE = .931

STRAP-ON MOTORS λ'S = .90

NO	W_P	T	T_O/W_O
8	23.2	51.4M	1.50

INJECTION STAGE

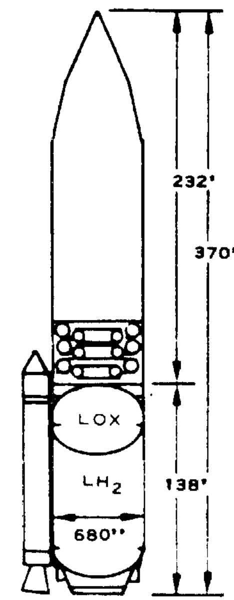
$W_{I.S}$ 805.5K LBS

W_P 675 K LBS

$\lambda'_{I.S.}$ .838

T = 750 K LBS

T_O/W_O = 0.282



CORE + 8 STRAP-ON'S + 3 INJECTION STAGE MODULES

* ALL PAYLOADS SHOWN FOR ρ = 5 LBS/FT³ 100 NAUTICAL MILE CIRCULAR ORBIT

FIGURE 3.0.0.0-2 HALF SIZE (MLLV) BASELINE VEHICLE FAMILY

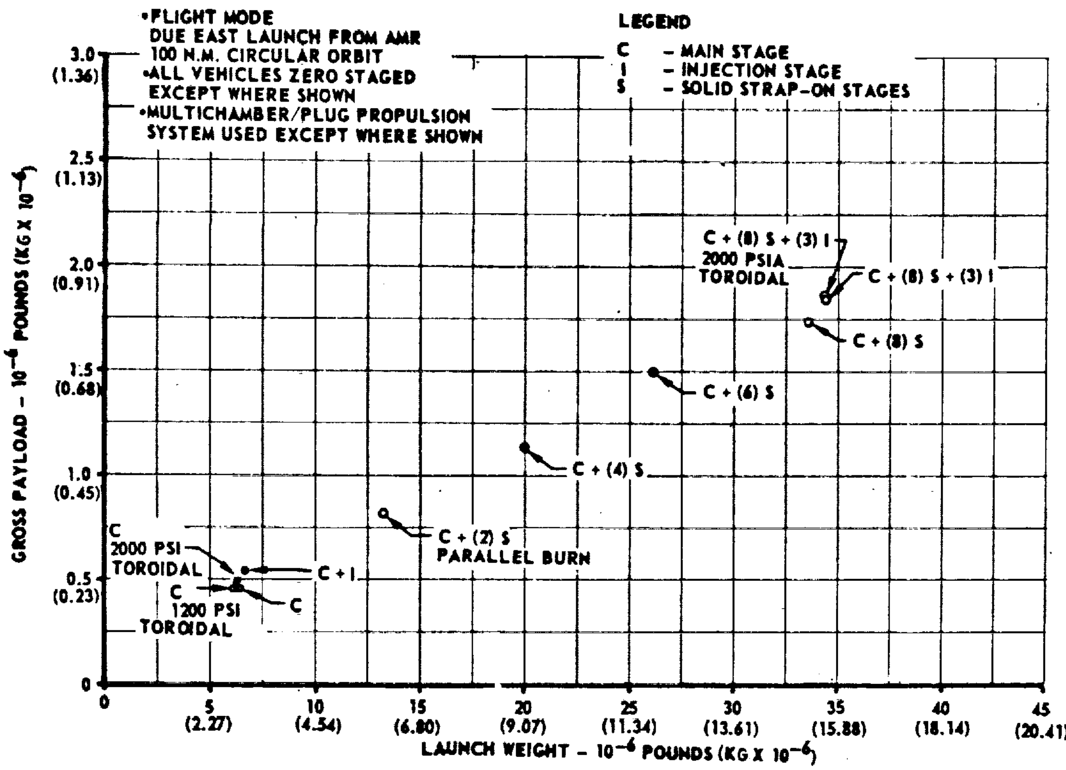


FIGURE 3.0.0.0-3 MLLV PAYLOAD VERSUS LAUNCH WEIGHT

3.1 SINGLE-STAGE-TO-ORBIT

The MLLV single-stage-to-orbit with the multichamber/plug propulsion system will have a payload of 471,000 pounds. Alternative use of the 2,000 psia or the 1,200 psia toroidal/aerospike propulsion system will provide payloads of 492,000 and 472,000 pounds, respectively. The multichamber/plug engine system performance will be higher but its weight will be greater than those of the toroidal/aerospike propulsion systems. The 2,000 psia toroidal/aerospike will offer the best combination of engine weight and engine performance and will result in the larger payload capability. Although the 1,200 psia toroidal/ aerospike will have the lowest weight, its lower specific impulse will offset this advantage.

The main stage will be 56.7 ft. in diameter and 138 ft. tall. It will use LOX/ LH_2 propellants at a mixture ratio of 6:1 by weight, respectively. The total propellant weight will be 5.55 million pounds. The mass fraction for the single-stage-to-orbit main stage with the multichamber/plug engine system will be 0.936 (0.943 for the main stage with the 2,000 psia toroidal/aerospike

3.1 (Continued)

engine system). Liftoff thrust will be 8,000,000 pounds. The mass flow required to provide this thrust will be maintained from liftoff until 89% of the main stage propellant has been depleted. At this point, the mass flow will be throttled to 10% of the original mass flow and maintained at this rate until orbital injection.

3.2 MAIN STAGE PLUS INJECTION STAGE

The use of a single injection stage module atop the main stage with the multichamber/plug engine system will provide an orbital payload capability of 551,000 pounds. Only one module may be used on this configuration because of liftoff thrust to weight limitations.

This configuration will employ the same main stage, as discussed above. The injection stage module will contain 225,000 pounds of LOX/hydrogen propellant, at a mixture ratio of 6:1, contained in two concentric toroidal tanks. This module will incorporate two high pressure bell engines with extendible nozzles, each delivering 125,000 pounds of vacuum thrust. The 15 foot tall module will be the same diameter as the main stage. The mass fraction will be 0.785.

3.3 MAIN STAGE PLUS STRAP-ON STAGES

The use of two through eight 260-inch SRM strap-on stages with the MLLV main stage employing the multichamber/plug engine system will provide a range of payloads from 842,000 to 1,757,000 pounds.

A zero stage flight mode, where the SRMs are ignited at lift-off and burned out prior to main stage ignition, will generally maximize payloads of configurations having strap-on stages. For the configuration consisting of a main stage plus two strap-on stages where the thrust of the strap-on stages will not be sufficient for lift-off, it will be necessary to ignite the strap-on stages and main stage simultaneously. Throttling of the main stage engines will be desirable for all configurations without injection stages.

These configurations will have main stages which are the same as described for the single-stage-to-orbit vehicle except that they will use heavier forward skirts. The strap-on stages will be attached to the main stage such that the thrust will be reacted by the main stage forward skirt. Each strap-on stage will contain 2.9 million pounds of propellant and have a mass fraction of 0.90. The thrust of each stage will be 6.45 million pounds at liftoff. The thrust will be regressive (i.e., the final mass flow will be one-half the initial mass flow).

3.4 MAIN STAGE PLUS STRAP-ON STAGES PLUS INJECTION STAGE MODULES

The maximum payload configuration will consist of a main stage and eight strap-on stages, as described above, plus a three module injection stage. The payload capability of this vehicle, with the multichamber/plug propulsion system on the main stage, will be 1,851,000 pounds.

The three module injection stage will consist of an engine module and two fuel modules each containing 225,000 pounds of LOX/LH_2 propellant. The fuel modules will employ the same tankage arrangement as the lower engine module. Thrust will be provided by six 125,000 pound thrust engines mounted on the lower engine module. The 32.3 foot tall stage will be the same diameter as the main stage. The mass fraction will be 0.838.

4.0 DESIGN REQUIREMENTS

A "worst condition" design envelope for the main stage was defined by combining the anticipated flight environments for the various configurations of the MLLV family. This loads envelope was generally defined by the single-stage-to-orbit configuration and the configuration consisting of the main stage plus eight strap-on stages plus a three module injection stage. The forward thrust reaction of the strap-on stages minimized the relative differences in main stage loads for the various configurations. Increased loads, other than those associated with the thrust reaction of the strap-on stages, will primarily be due to increased tank pressures in the full main stage tanks at SRM burnout.

The maximum required gimbal angle for the main stage propulsion system will be 3.9° as established for control of the main stage plus single module injection stage configuration during the maximum dynamic pressure flight regime (max $q\alpha$). The maximum required control gimbal angle for the strap-on stages stages will also be 3.9° as established by the control requirements of the configuration with the eight strap-on stages plus the three injection stage modules at the time of max $q\alpha$. This gimbal angle must be provided by the strap-on stages as the main stage will be inoperative at this time.

Insulation will be required in the forward skirt area to minimize heating from shock impingement from the nose cones of the strap-on stages and to protect the forward skirt from aerodynamic heating.

The base plug region will be cooled during operations of the main stage engine by circulating liquid hydrogen through cooling tubes. For configurations with strap-on stages, cooling of the base plug will require an overlay of cork insulation or operation of the main stage engines in a throttled mode to circulate hydrogen.

5.0 VEHICLE DESIGN FEATURES

A drawing of the MLLV is shown in Figure 5.0.0.0-1. The main stage tanks will be of 2219-T87 aluminum in a skin-stringer-ring frame construction. The skin panels will consist of weldments of milled plate with integral longitudinal T-stiffeners. Lateral ring frames will be mechanically attached to the internal tank cylinder for stability and slosh control. The common bulkhead will be approximately four inches thick and will be of aluminum honeycomb construction. Both forward and aft bulkheads will be weldments of machined gore segments. The common and aft bulkhead designs will have a 30^{o} frustum modification to the theoretical 0.707 elliptical bulkhead to eliminate cramped intersections with the tank walls. Ring frame stiffeners will react the radial forces caused by the non-tangent bulkhead intersections. Closed cell polyurethane foam with freon filler will be used to insulate the exterior of the LH_2 tank walls and lower bulkhead, the LH_2 side of the common bulkhead and the LOX ducts.

The forward and aft skirts will be of 7075-T6 aluminum built-up skin-stringer-frame construction. To eliminate major weight penalties to the main stage, the forward skirt will be used for core vehicle support at launch.

The heavy weight forward skirt, for use with strap-on stages, will employ spherical ball connections to react SRM thrust and lateral loads. The aft skirt/strap-on stage interface hardware will consist of aft end torsion stabilizer tubes and an aft end lateral restraint incorporating a longitudinal slip-joint. This slip joint will not allow longitudinal loads to be reacted at the aft attachment.

The core vehicle, of configurations with SRM strap-on stages, will be supported for launch by the SRM stages at the main stage forward skirt.

Main stage propulsion will be provided by either a 24 module multichamber/plug engine system or a toroidal/aerospike engine system. Thrust vector control (TVC) with the multichamber/plug engine system will be provided by hinging the engine modules. TVC with the toroidal/aerospike engine system will be provided by injection of LOX through ports in the base plug. Roll control for both systems will be provided by deflecting the base bleed gases.

The main stage structures for use of either of the engine systems will generally be identical. However, due to the method of reacting the thrust, the thrust skirt for use with the multichamber/plug propulsion system will be heavier than, and the design will differ from that for use with a toroidal/aerospike system.

The MLLV injection stage will use a modular tankage arrangement identical in concept to that defined for the AMLLV. The concentric toroidal LOX and LH_2

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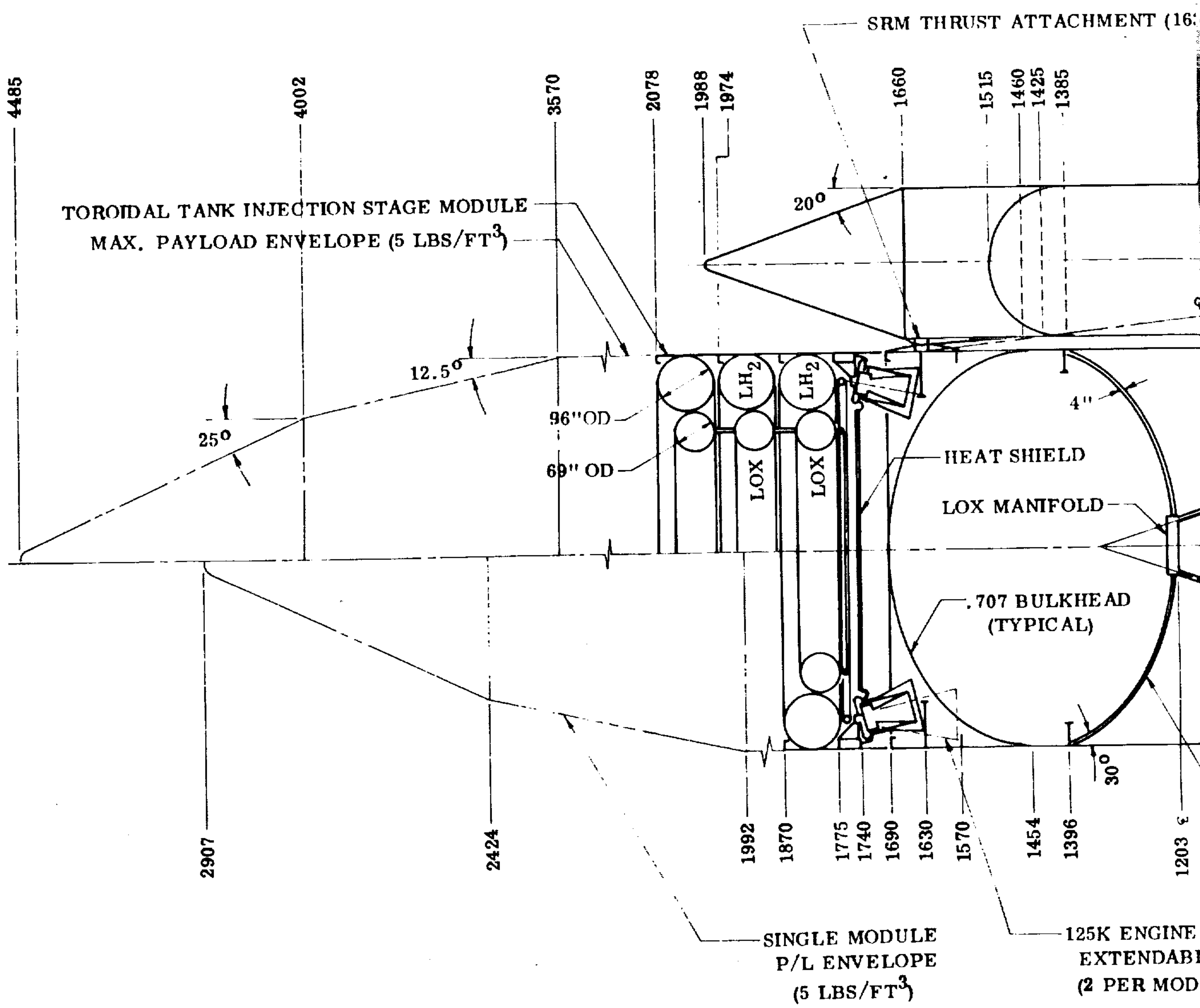

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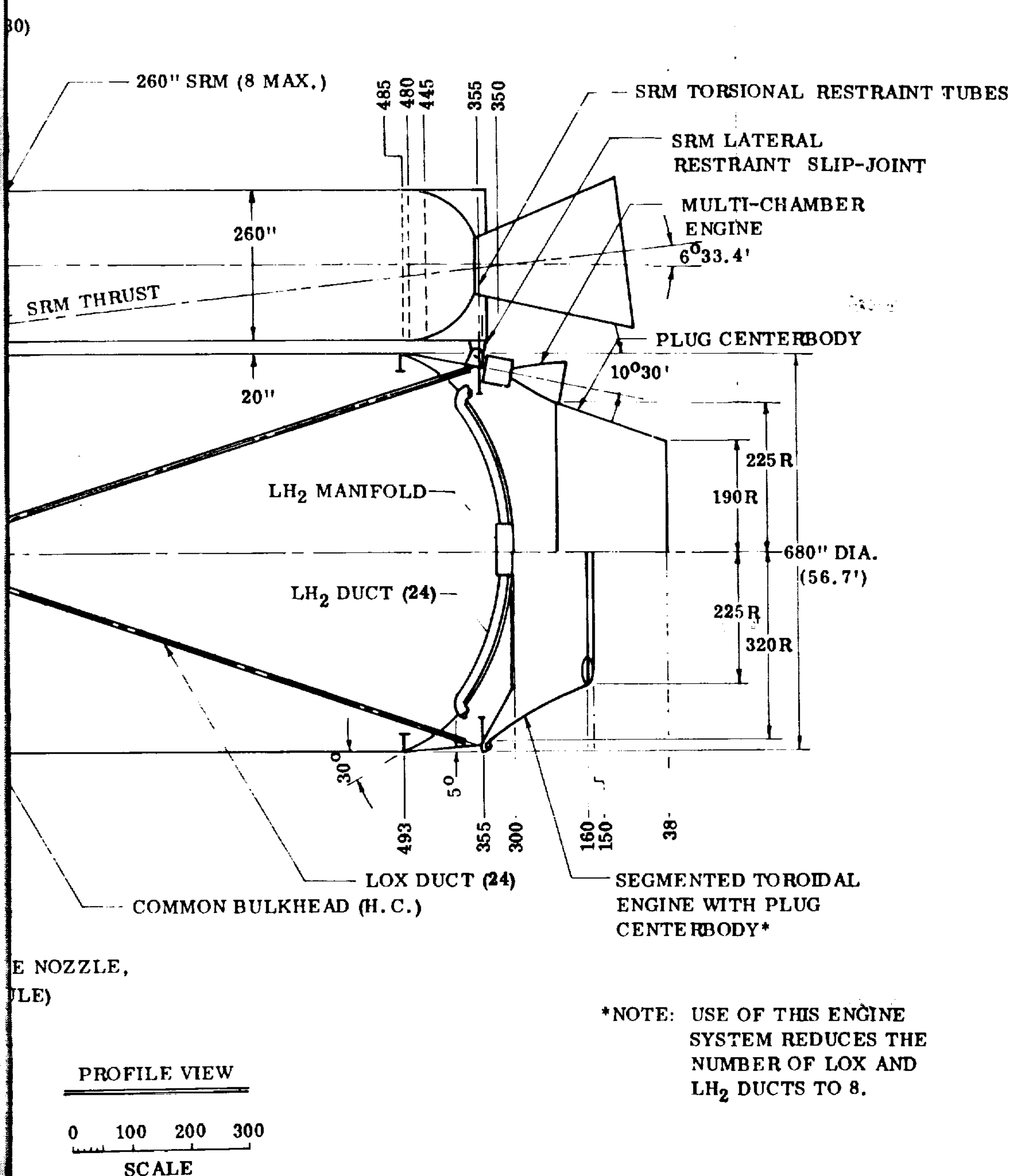

FIGURE 5.0.0.0-1 LINE DRAWING FOR BASELINE MLLV CONFIGURATIONS

5.0 (Continued)

tanks will be of 2219-T87 aluminum in a semi-monocoque construction. Honeycomb sandwich web panels inside the tanks (on a 45° spacing) will provide torsional rigidity and stiffening shear ribs will maintain the cross-section circularity. The inner torus (the oxidizer tank) will hang from a fiberglass cylindrical skirt attached to the outer torus. The outer torus (the LH_2 tank) will be circumferentially shear pin connected with circular bearing fasteners to the outer shell. The skirt for each module will be skin-stringer-frame structure of 7075-T6 aluminum. The thrust structure for the lower injection stage module will consist of two restraining ring frames with six cantilevered thrust posts attached to the skirt. High pressure bell engines, with extendible nozzles will be mounted to the thrust posts. As only two engines will be required for each module, four thrust posts will be vacant for the single module applications. As additional modules are added, additional engines will be added to these remaining thrust posts. Propellant will be provided to the engines from toroidal manifolds fed by the lower module tanks to these manifolds. The engines, with the extendible nozzles retracted, will be nested into the forward skirt area of the main stage to reduce stage length. The nozzles will be extended and gimballed outward after main stage separation.

The strap-on stages will be complete stages in themselves requiring only command signals from the vehicle instrument unit (i.e., all necessary power, TVC systems, instrumentation, emergency detection systems, destruct systems, etc., will be contained in the strap-on stages). Each strap-on stage will incorporate a cylindrical forward skirt (constructed of HY-140 steel) for attachment of the strap-on stage to the main stage and for housing of some of the stage accessories. This skirt will transmit the SRM loads into a vertical shear post, for subsequent reaction into the ball fitting in the main stage. Atop this cylindrical skirt will be an aerodynamic nose cone. HY-140 cylindrical aft skirts will provide connections for aft attachment and will house the TVC mechanisms and other stage accessories. Assembled vehicles with strap-on stages will be supported for launch by these aft skirts. Each SRM will use a monolithic combustion chamber fabricated of 18 percent nickel maraging steel. The composite propellant grain of polybutadiene, acrylic acid and acrilonitrile (PBAN) terpolymer fuel with ammonium perchlorate oxidizer will be ignited by a head end igniter motor. TVC will be provided by a flexible seal moveable nozzle system. The nozzle will consist of an ablative liner for insulation housed within a nozzle structure consisting of a maraging steel partial shell with a reinforcing fiberglass exit cone.

After burnout, the strap-on stages will be expelled laterally from the main stage by staging rockets mounted in the forward nose cone and the aft skirt. Separation will be provided by explosive mechanisms located within the attach struts. The separation rockets and the explosive release mechanisms will

5.0 (Continued)

be actuated simultaneously when the main stage acceleration exceeds the individual acceleration of all of the strap-on stages.

6.0 RESOURCE IMPLICATIONS

To provide a firm basis for the subsequent cost analyses, the resources necessary to implement and operate the AMLLV and MLLV vehicle families were developed in terms of comprehensive design, development and test, manufacturing, transportation, launch operations and schedule plans. These resource plans were based on current Saturn V philosophies to the maximum extent possible. No attempt was made to tailor the program for cost optimization. A production and launch rate of two vehicles per year was assumed.

Inputs for these plans, which are summarized below, were received from functional organizations within The Boeing Company and from propulsion contractors (Aerojet General, Pratt and Whitney, and Rocketdyne).

6.1 DESIGN PLAN

Engineering requirements for initial design, R&D support and sustaining engineering during production and launch will be limited to manpower requirements as adequate facilities and equipment are considered to be available. Engineering manpower requirements do not appear to be proportional to vehicle size or weight. Complexity appears to be the parameter that best determines the required design effort. As the AMLLV and MLLV are of comparable complexity, the design manhours are almost identical.

6.2 DEVELOPMENT AND TEST PLAN (NON-RECURRING AND RECURRING TESTS)

The Development and Test Plan defined the non-recurring R&D and the recurring acceptance, static firing and pre-launch test activities. The major R&D tests identified were as follows:

<u>Manufacturing Mockup Tests</u> will consist of building a mockup vehicle and its use for initial manufacturing facility layout, evaluating procedures, and training of manufacturing personnel.

<u>Checkout of the Tooling, Facilities, and GSE</u> will be accomplished by building and processing a facility checkout vehicle through the respective test and launch facilities. This "F" vehicle will consist of a main stage, a single module injection stage, a single SRM strap-on stage loaded with inert propellant, and a mockup payload with a simulated instrument unit.

6.2 (Continued)

The Component and Subsystems Test Program will consist of those development and qualification tests required for vehicle components and subsystems (including purchased or procured items) exclusive of the liquid engine systems and the solid rocket motors.

A Systems Development Breadboard (SDF) will be used as a tool to evaluate component and subsystem interactions and compatibility.

A Structural Load Test Program will consist of tests wherein each major structure will be loaded to failure. More than a complete set of load carrying flight type structural components will be required to support this test program.

Dynamic Tests will be conducted on the main stage and on the injection stage. SRM stages will not be provided, but their interactions will be simulated during the dynamic tests by providing programmed inputs to hydrodynamic shakers located at the SRM stage attach points to the vehicle.

Engine Development and Qualification Tests will be required for the main stage and the injection stage engine systems.

The SRM Stage Development and Qualification Tests will consist of ten firings of the full size solid rocket motor. Four of these firings will be for development of the solid rocket motor and the remaining six for qualification.

Two R&D Flight Vehicles will be required in the development test program. By the ground rules, the R&D flight configuration will be the maximum size configuration to be used for any specific program.

6.3 MANUFACTURING PLAN

The main and injection stage manufacturing plans are, where practicable, an extrapolation of fabrication techniques developed for the S-IC stage. Structure fabrication and assembly of these stages will be accomplished in a new facility located on a navigable waterway. The sizes involved will require a major initial expenditure for tooling. No unique fabrication methods were identified other than those for the common bulkhead of the main stage and the toroidal tanks of the injection stage. The liquid engines will be built and tested at the engine contractor's facility and shipped to the manufacturing facility for assembly to the stages.

The SRMs will be supplied by a SRM subcontractor. The necessary structures to convert the motor into a stage, i.e., the nose cone, forward skirt, aft skirt and attachment fittings, will be fabricated at the main stage manufacturing facility and sent to the SRM contractor's facility for final assembly of the complete stage.

6.4 TRANSPORTATION PLAN

Transportation of the main stage and injection stage will be accomplished by pneumatic tire towed units within the confines of the manufacturing facility. Towed barges will be used to transport the stages to the launch facility.

No land transportation of the SRM stage will be required, as it will be lifted directly from the casting and assembly pit and placed directly aboard a barge for towing to the launch facility.

At the launch facility, all stages will be lifted directly off their barges, as required for vehicle assembly, and placed in the selected location by a large traveling gantry hoist; therefore, no additional transportation equipment will be required.

6.5 LAUNCH OPERATIONS PLAN

Launch of the AMLLV or MLLV vehicles with SRM strap-on stages will require completely new facilities and operational procedures. A fixed, rather than a mobile system as used for the Saturn V, was selected. The launch pad will serve as the static firing stand for the main and injection stages, the refurbishment facility, the vertical assembly and checkout facility and finally as the launch pad.

For stage lifting and transport, a traveling gantry crane, similar to those used in shipyards, will be used. The gantry will use roll ramp actuators for hoisting its cross head and the attached load. Horizontal motion will be accomplished by wheeled trucks on rails under each leg.

6.6 SCHEDULE PLAN

Timelines and/or detail schedules, as developed for all of the previously discussed plans (design through launch) are integrated into the master program schedule shown in Figure 6.6.0.0-1. This schedule, for a maximum payload vehicle, shows a total time period from program go-ahead through flight of the second R&D flight test vehicle of 8 1/2 years. The critical time path through this schedule proceeds from vehicle design and construction of the manufacturing facility through fabrication of the facilities test ("F") vehicle. The facilities test vehicle then must be used sequentially to check out the dynamic test facility and the launch facility. After checkout of the launch facility, launch of the two R&D flight tests will require the final eighteen months. This schedule is conservative and could be compressed by as much as two years by shortening the fabrication cycle, the facility checkout cycle and the time for R&D flight tests.

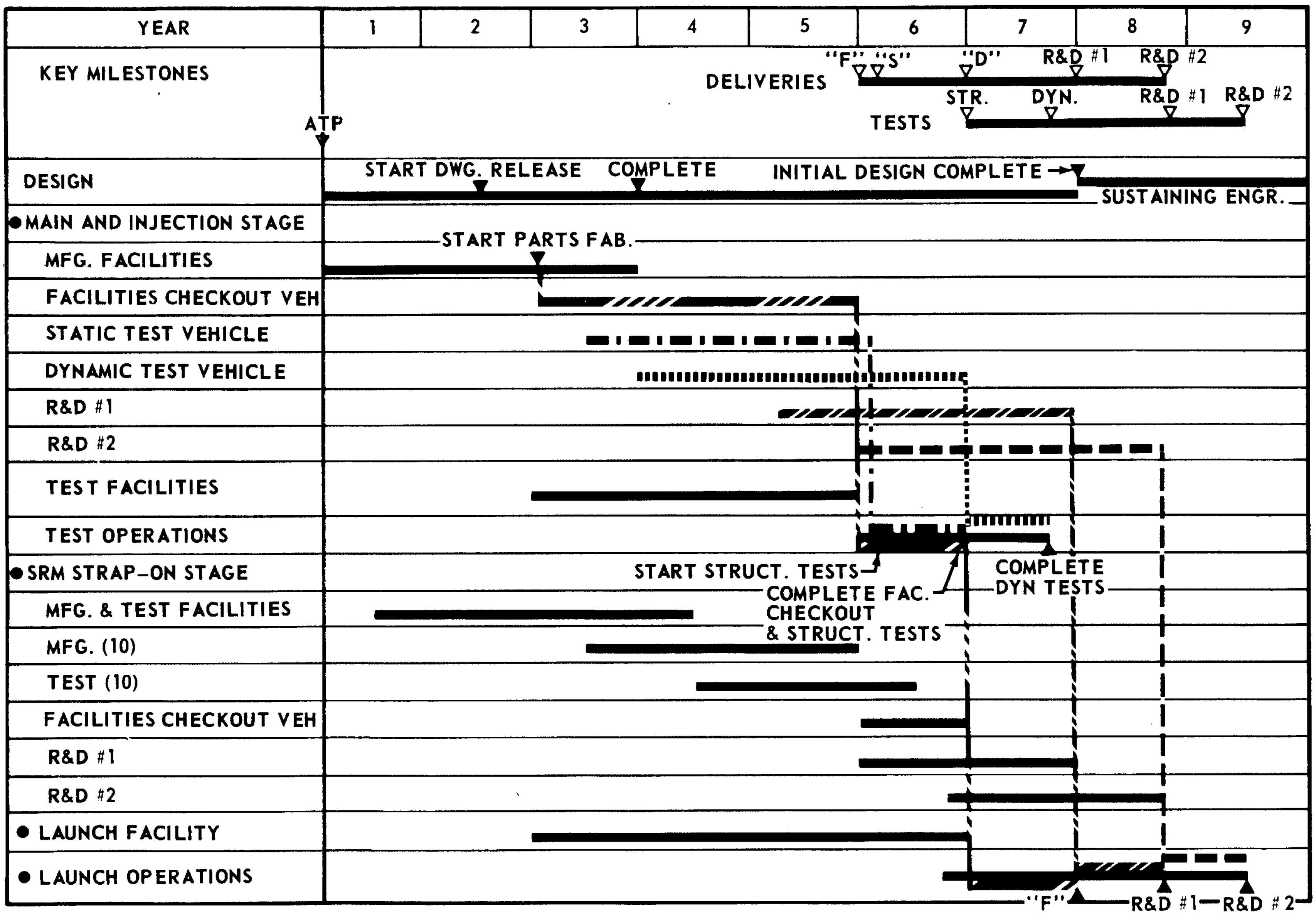

FIGURE 6.6.0.0-1 MASTER PROGRAM SCHEDULE

7.0 BASELINE AMLLV AND MLLV COSTS

From the resource requirements, cost data were developed in sufficient depth such that individual costs attributable to component, to cost categories and to functional operations could be clearly identified. The resource requirements were generally received from the effected working organizations in terms of required direct manhours, materials, tooling, equipment and facilities. These requirements were developed into cost data by the addition of direct and overhead labor rates and factored items. Direct cost increments were sequentially totaled with factored indirect and support costs. (Indirect and support costs include costs for quality control, program management, planning, training, instructors and other program associated elements; overhead and/or burdened costs; and G&A.)

Costs (and supporting resource data) were categorized by three program phases as follows:

Phase "A" "Get Ready" Phase

This category includes non-recurring costs for vehicle design, and for the tooling, equipment and facilities required to produce and launch a vehicle.

Phase "B" Development Test Phase

This category includes the non-recurring costs, including costs of test specimens, for all development test activity required to develop the launch vehicle, its components and the associated support hardware.

Phase "C" Operational Program Phase

This category includes all of the recurring costs for manufacture and launch of the operational vehicles.

Collection of the cost data in the manner presented above and tabulation of the data by phase, element, or category will permit this data to be an effective tool in assessing new technology cost implications.

The obvious question relating to the results of a cost study are "What will the vehicles cost?" A direct answer, without all of the qualifying statements and without a fixed cost reference; however, is meaningless. Specific objectives of this study, therefore, were to define the cost elements relative to an existing cost reference, the Saturn V, and to specify all of the qualifications that contributed to the costs, such as production and launch rate, program philosophy, learning curve effects, program size, etc.

7.0 (Continued)

Figure 7.0.0.0-1 shows a general summary of the costs for the MLLV and AMLLV maximum payload vehicle configurations. The non-recurring costs (costs for Phases A and B) will be \$4.1 billion and \$5.1 billion for the MLLV and AMLLV, respectively. Considering a two per year production and launch rate, the total recurring costs for the first operational flights of these MLLV and AMLLV maximum payload configurations will be \$372 million and \$486 million, respectively. The corresponding values of operational cost effectiveness are 201 and 131 dollars per pound of payload considering the respective payload capabilities of 1.85 million and 3.74 million pounds.

This figure also shows that the recurring costs for the first operational MLLV and AMLLV single-stage-to-orbit vehicles will be \$251 million and \$293 million, respectively. The corresponding values of cost effectiveness are 530 and 285 dollars per pound considering the respective payload capabilities of .472 million and 1.028 million pounds.

For a two stage Saturn V vehicle, considering the same position on the learning curve and the two per year production and launch rate, the recurring costs would be approximately \$233 million per flight. The corresponding cost effectiveness value cost would be 890 dollars per pound.

Figure 7.0.0.0-2 shows the AMLLV and MLLV cost data distributed by program phases and also shows the effects of vehicle size on the relative cost distributions. The percentages of overall program costs attributable to each of the program phases does not appear to be influenced by vehicle size as the distributions are approximately the same for both the AMLLV and MLLV programs. Generally, the non-recurring costs (the sum of the A and B costs) will be approximately 11 times those of the first operational unit cost. The Phase A Get Ready costs will be approximately 4 1/2 times and the Phase B Development Test costs will be 6 1/2 times those of the first operational unit. Relative distribution of costs by program phase also does not appear to be sensitive to complexity. For example, relative distribution of the costs for the three program phases will be relatively constant for the main stage, the injection stage and the solid rocket motor strap-on stages.

Figures 7.0.0.0-3 and 7.0.0.0-4 show the AMLLV and MLLV Phase A cost data broken down by cost element and distributed by cost category, respectively. Similar data for the Phase B and Phase C costs are shown in Figures 7.0.0.0-5 through 7.0.0.0-8.

As indicated by these figures, magnitude of costs will be primarily influenced by the complexity of the structure or system to be built and secondarily influenced by size. For example, the cost for an injection stage module will be approximately the same as that for a strap-on solid rocket motor (SRM) stage even though the

(DOLLARS IN BILLIONS)

	MAIN STAGE	THREE MODULE INJECTION STAGE	FULL COMPLEMENT OF STRAP-ON STAGES	2 R&D FLIGHTS	TOTAL
GET READY "A" COSTS	\$1.104 / \$1.325	\$.198 / \$.249	\$.328 / \$.400	N/A / N/A	\$1.630 / \$1.974
DEVELOPMENT TEST "B" COSTS	\$.939 / \$1.210	\$.294 / \$.413	\$.180 / \$.214	\$1.049 / \$1.313	\$2.462 / \$3.150
TOTAL NON-RECURRING	\$2.043 / \$2.535	\$.492 / \$.662	\$.508 / \$.614	\$1.049 / \$1.313	\$4.092 / \$5.124

1ST OPERATIONAL VEHICLE "C" COST (THIRD FLIGHT UNIT)	\$.251 / \$.293	\$.043 / \$.055	\$.078 / \$.138	N/A / N/A	\$.372 / \$.486

NOTE: MLLV COSTS / AMLLV COSTS

FIGURE 7.0.0.0-1 COST SUMMARY - AMLLV/MLLV BASELINE FAMILY

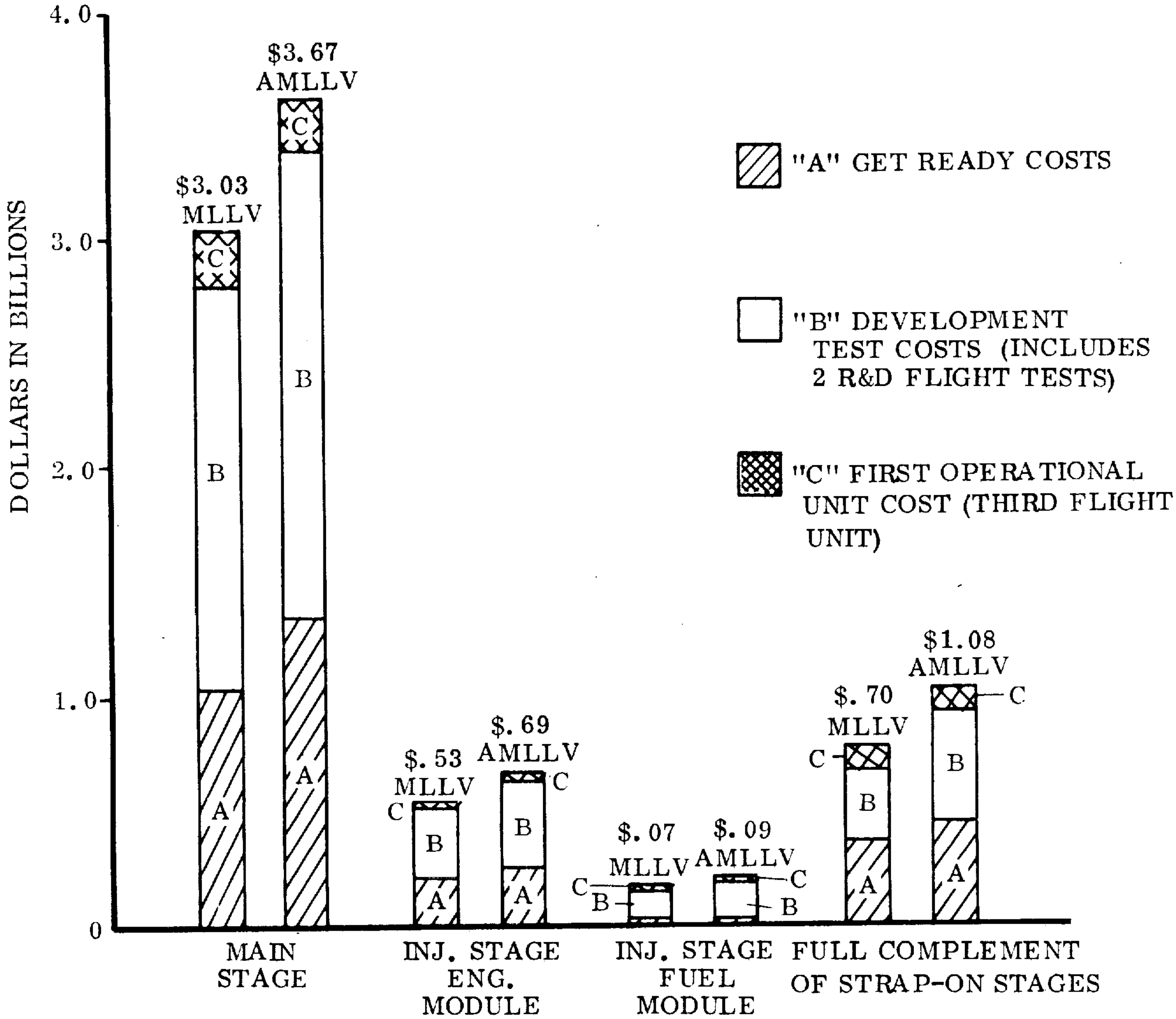

FIGURE 7.0.0.0-2 APPORTIONMENT OF STAGE COSTS BY VEHICLE STAGES AND PROGRAM PHASES

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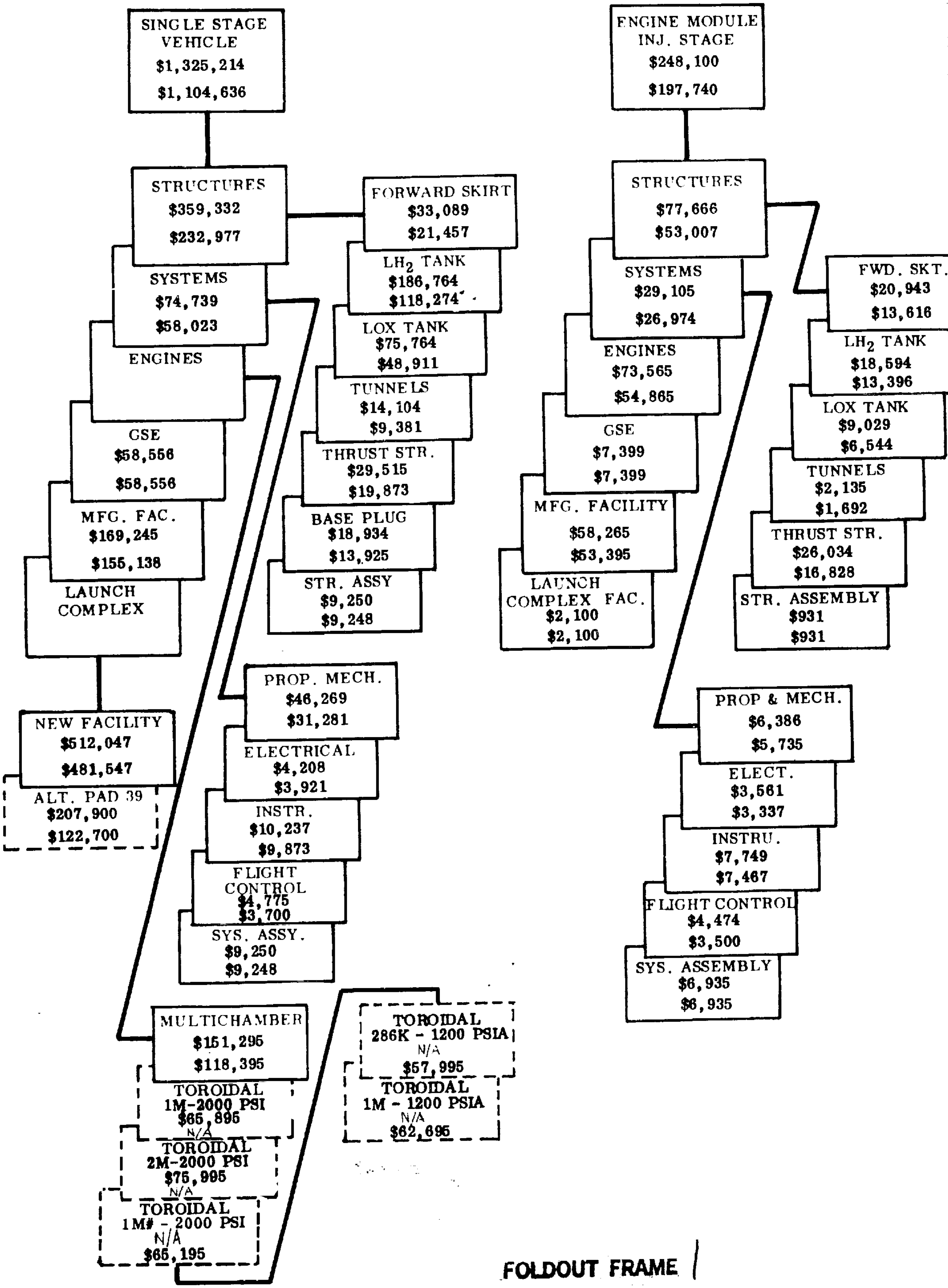

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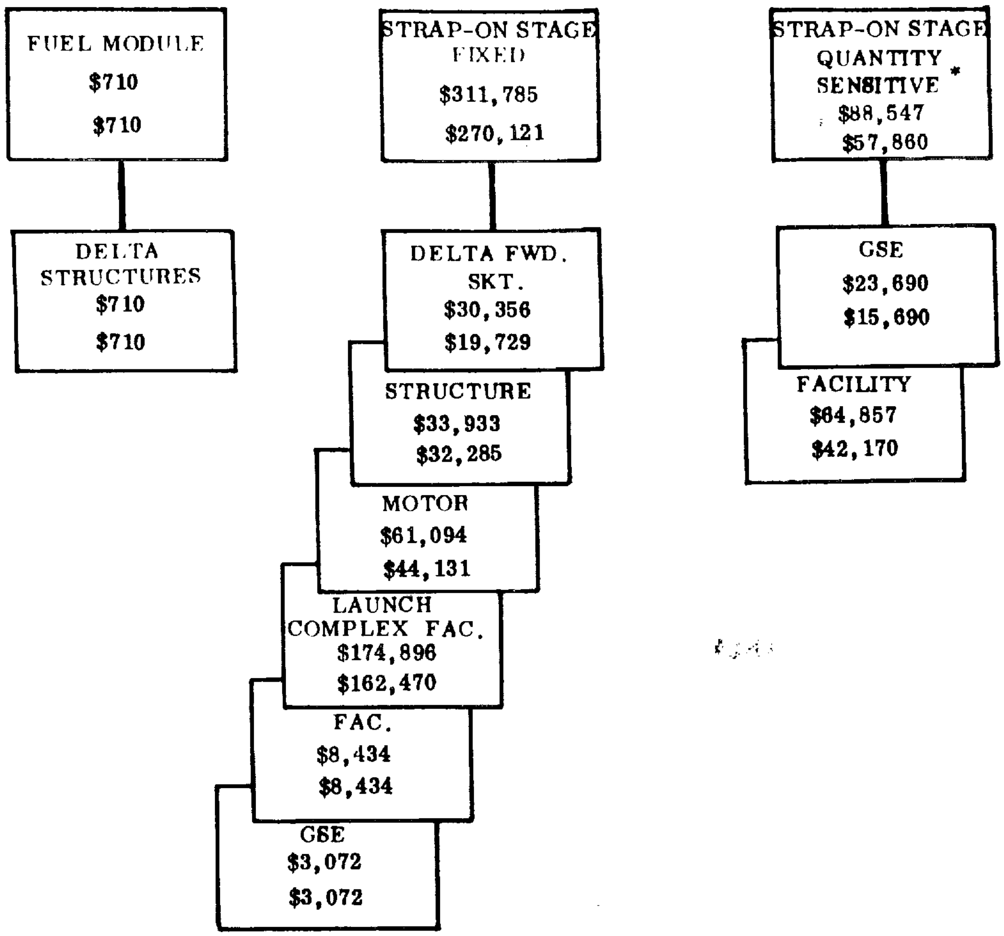

NOTES: ALTERNATE SYSTEMS.
DOLLARS ARE IN THOUSANDS.
AMLLV COST SHOWN ON
MLLV COSTS SHOWN ON BOTTOM

*NOS. SHOWN ARE FOR A FULL COMPLEMENT (12 OR 8) OF STRAP-ON STAGES. IF LESS THAN A FULL COMPLEMENT WILL BE USED, THESE NOS. SHOULD BE REDUCED BY THE RATIO OF THE NUMBER OF STRAP-ON STAGES PER VEHICLE TO THE NUMBER OF STRAP-ON STAGES IN A FULL COMPLEMENT

FIGURE 7.0.0.0-3 "GET READY" COST ("A" COST) SUMMARY

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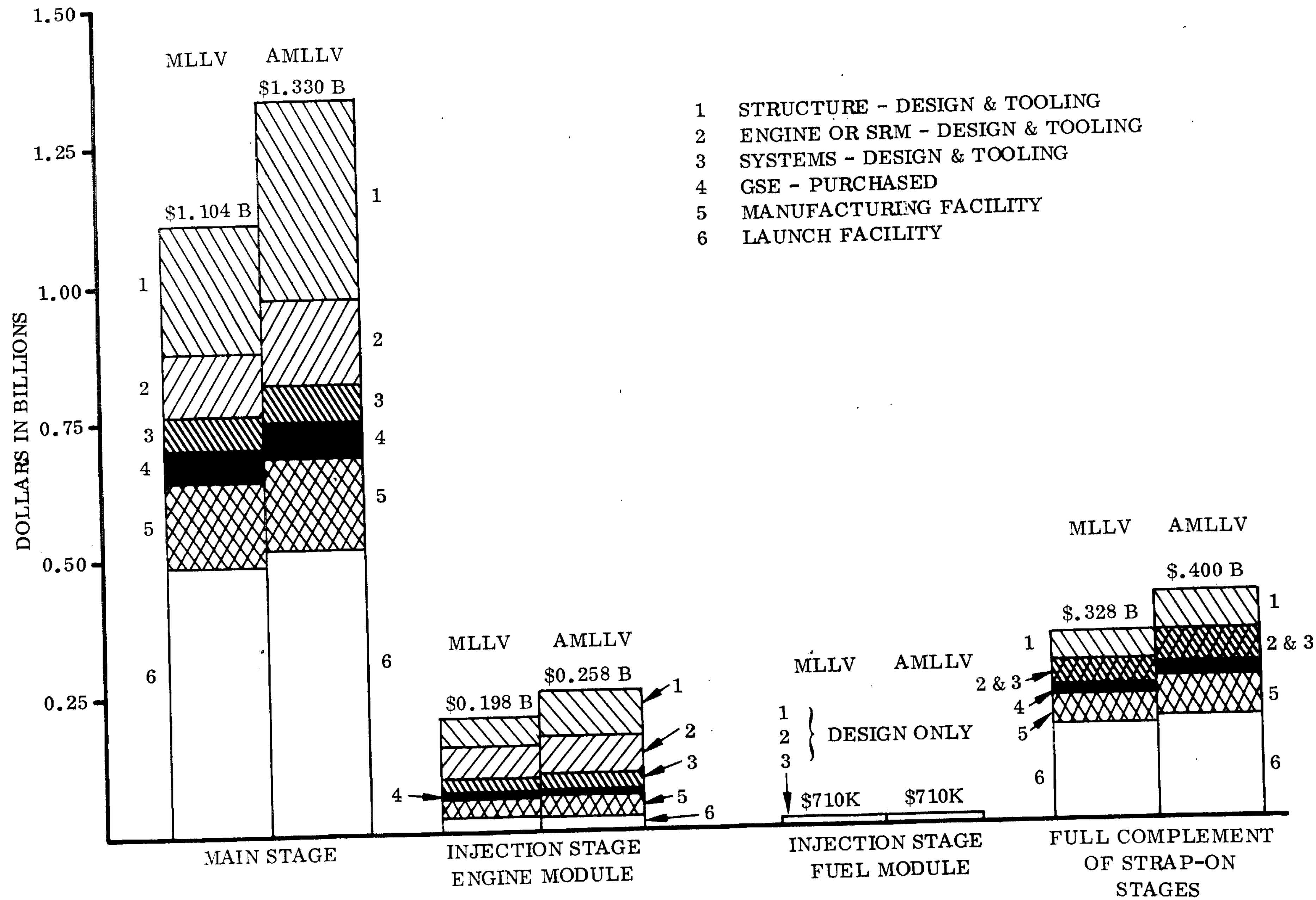
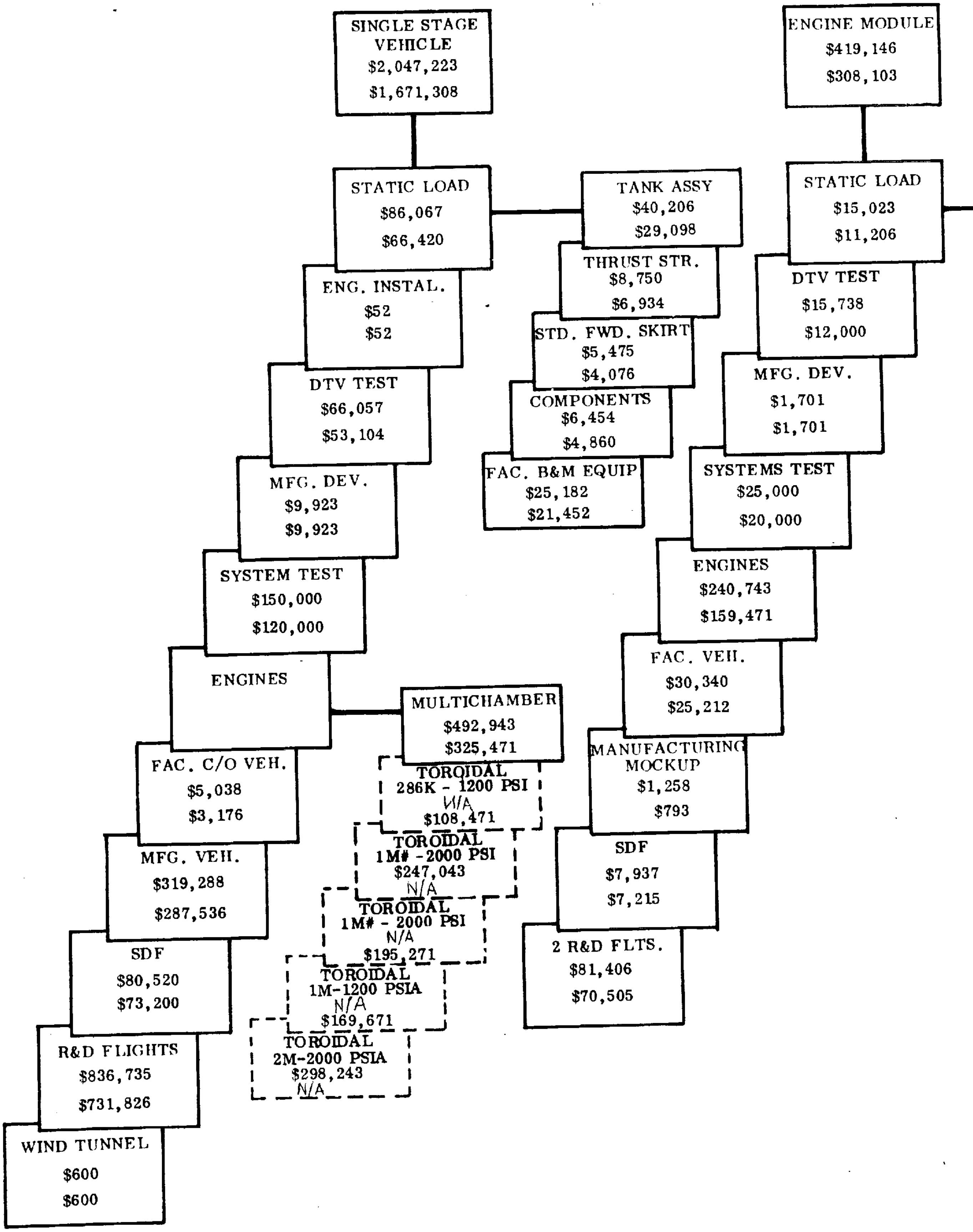


FIGURE 7.0.0.0-4 STAGE ELEMENT COST DISTRIBUTION FOR PHASE A



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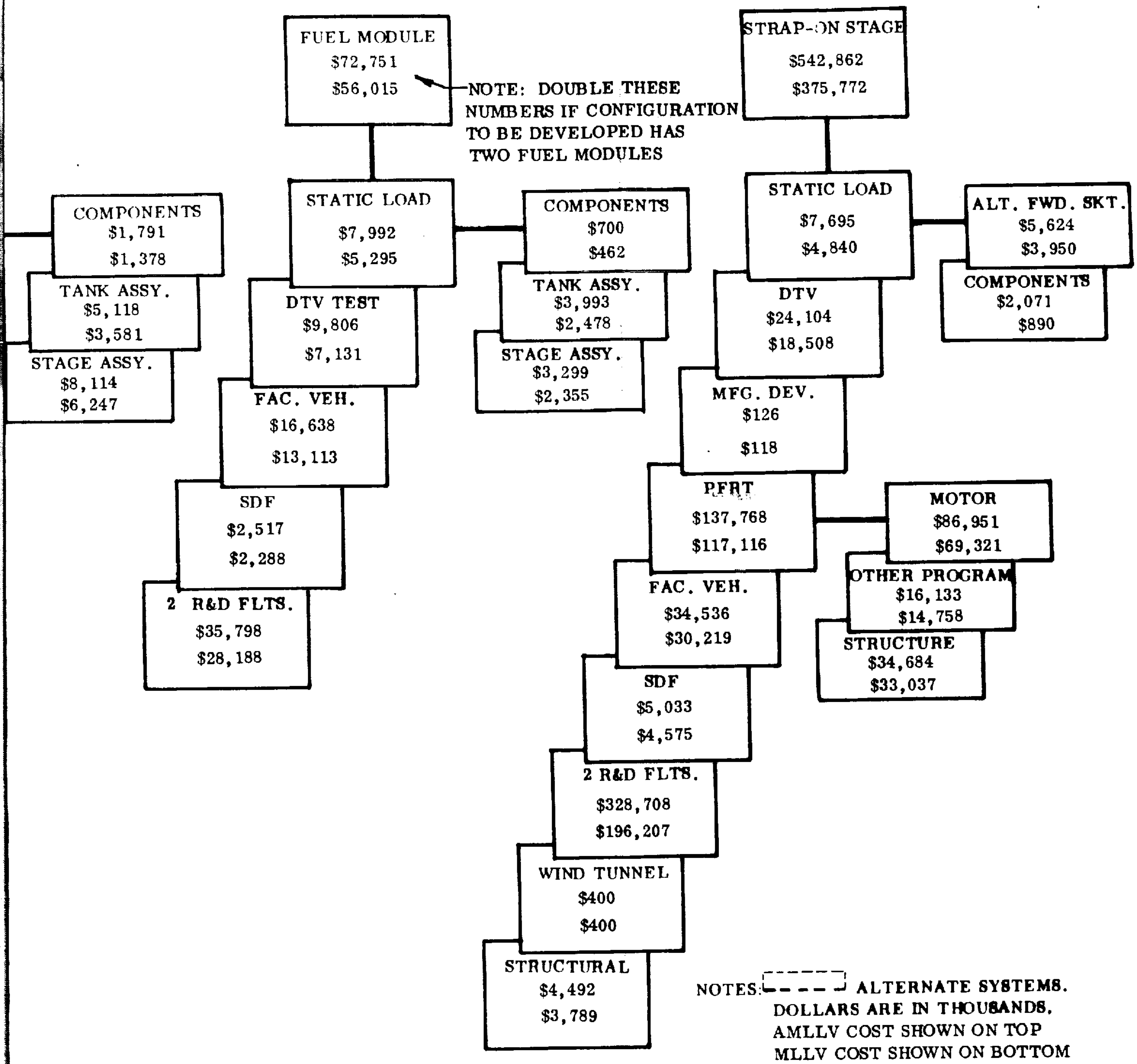

FIGURE 7.0.0.0-5 DEVELOPMENT TEST COST ("B" COST) SUMMARY

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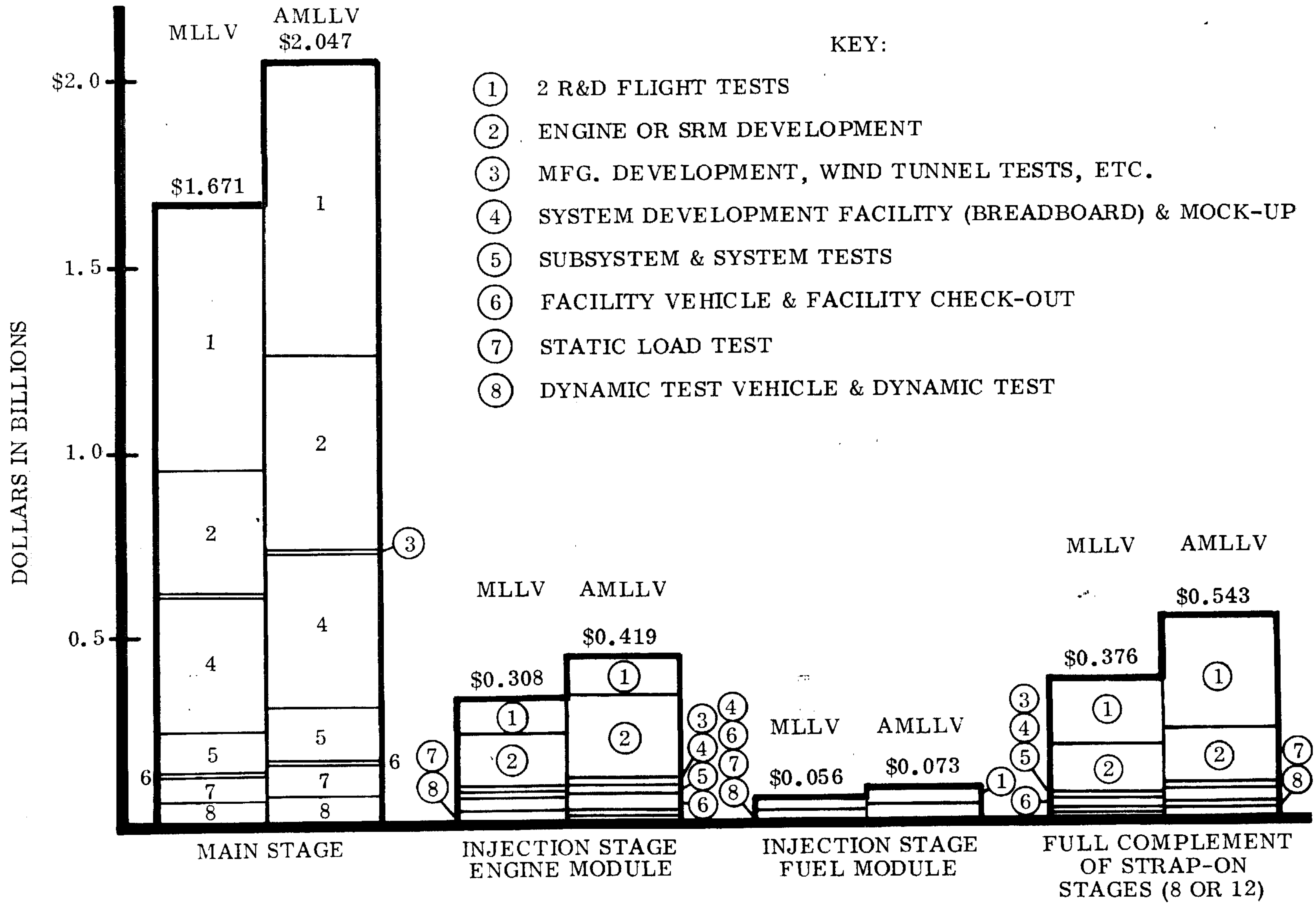
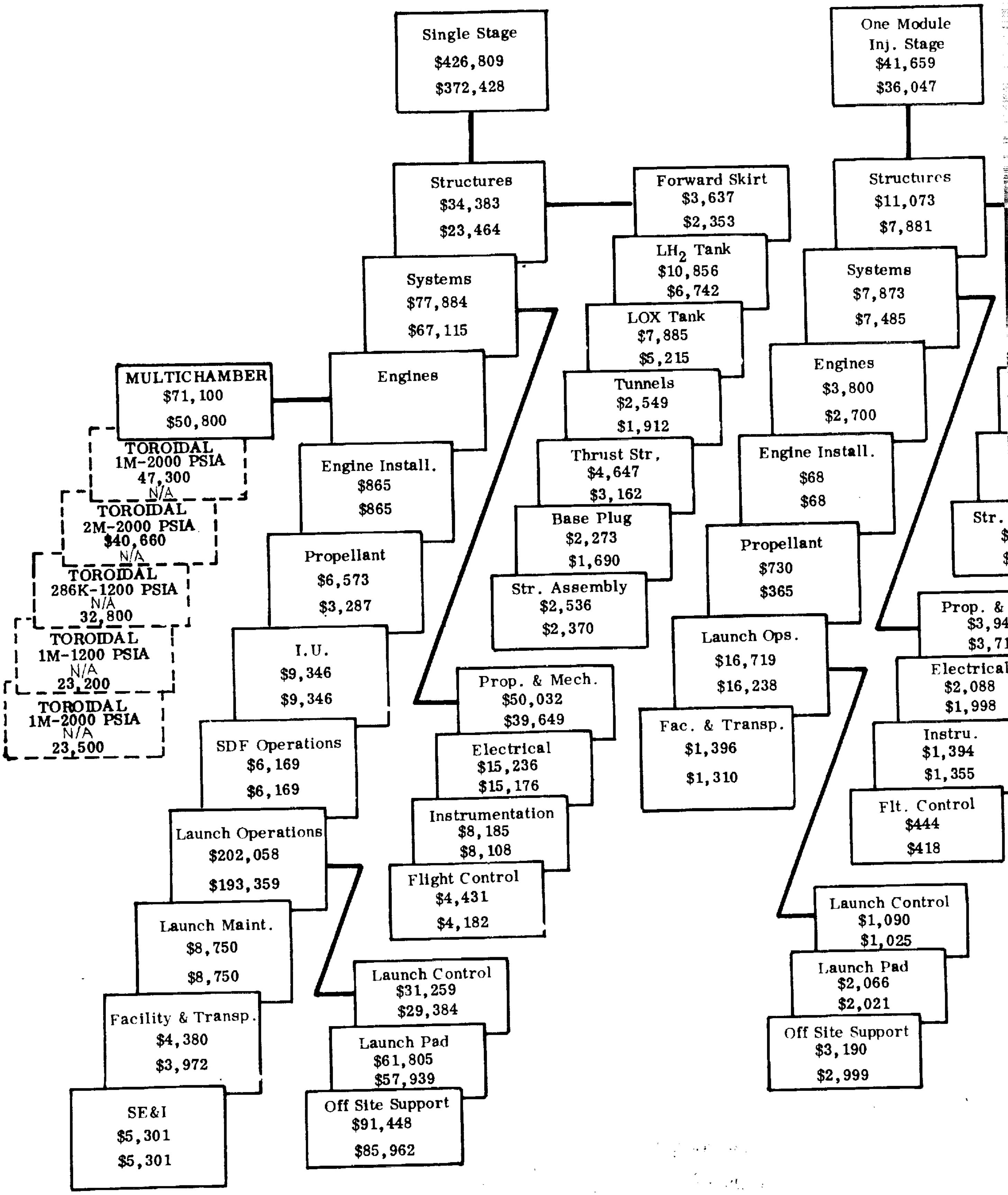


FIGURE 7.0.0.0-6 STAGE ELEMENT COST DISTRIBUTION FOR PHASE B



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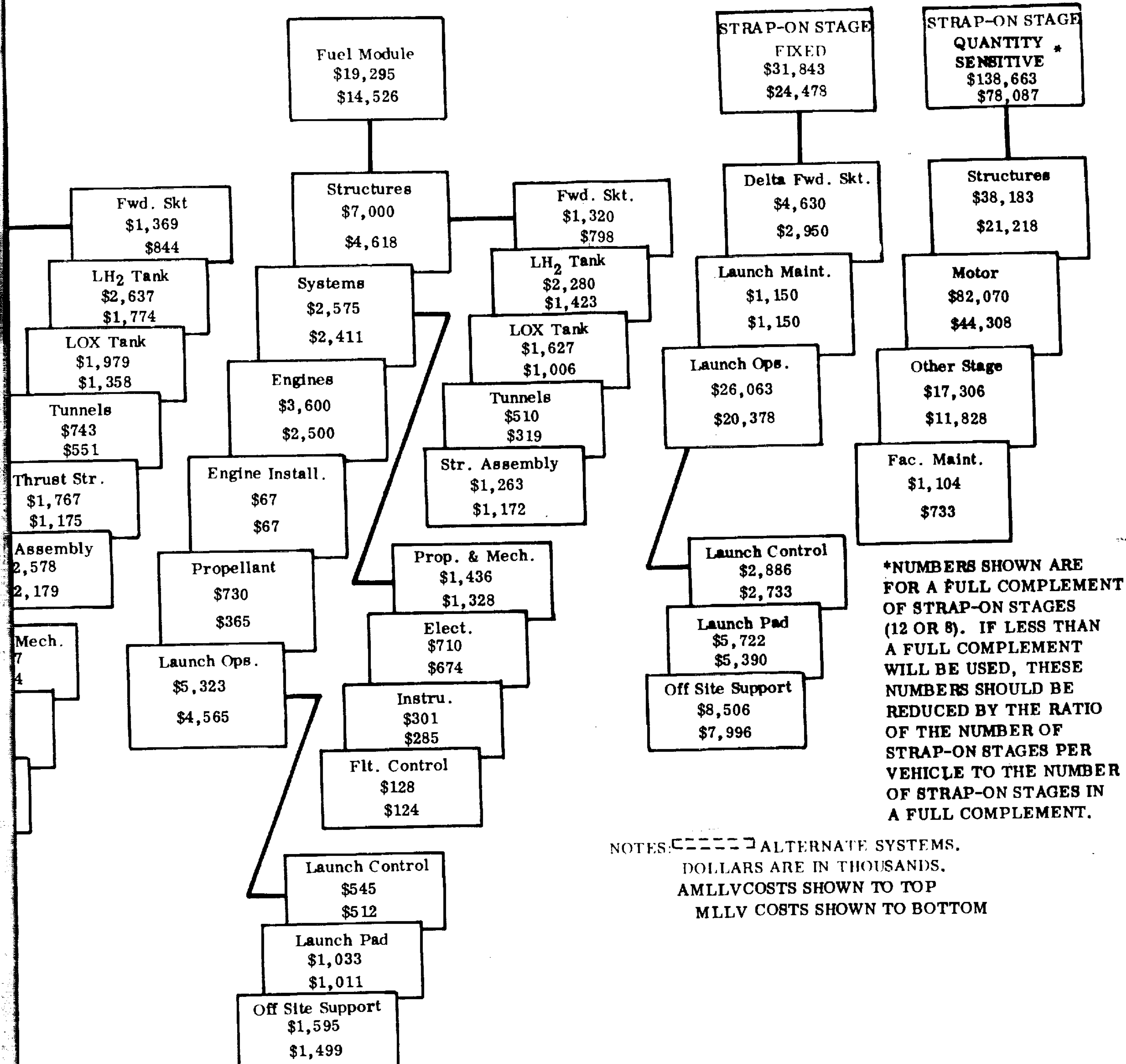

FIGURE 7.0.0.0-7 FIRST UNIT COST ("C" COST) SUMMARY (APPLICABLE TO FIRST R&D FLIGHT VEHICLE ONLY)

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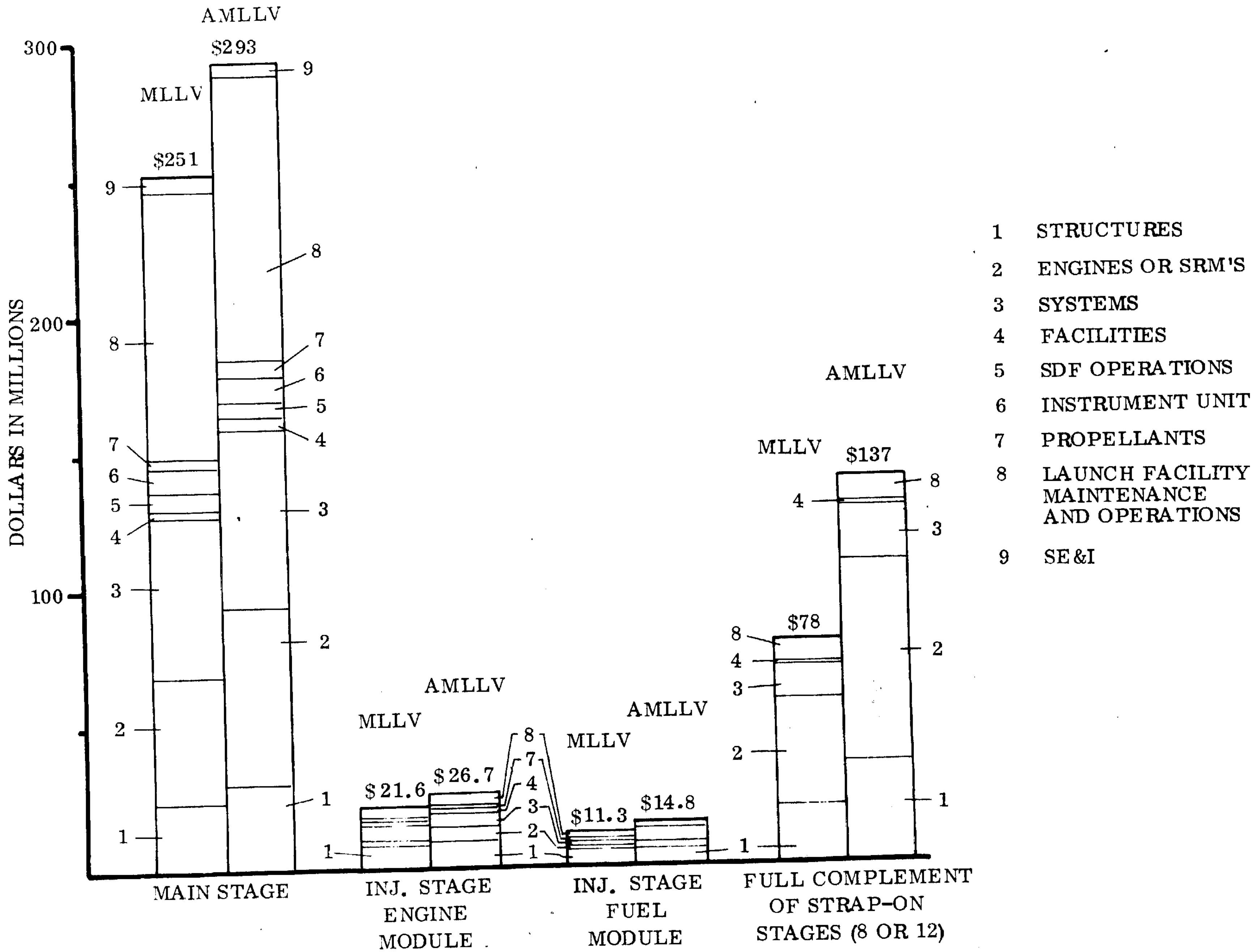

FIGURE 7.0.0.0-8 STAGE ELEMENT COST DISTRIBUTION FOR FIRST OPERATIONAL UNIT (3RD FLIGHT UNIT) "C" COST

7.0 (Continued)

weight of an individual SRM stage will be approximately seven times that of a fueled injection stage module.

The overall magnitude of the costs will be significantly larger for the main stage as the main stage not only is the more complex stage but is also the primary stage of the launch vehicle and, therefore, must absorb a significant portion of the costs for program management, system engineering, launch facilities and liquid stage manufacturing and test facilities.

The magnitudes of costs will not be significantly influenced by the relative size of similar articles. For example, costs of the half size (MLLV) main stage will be approximately 85 percent of those of the full size (AMLLV) main stage.

The magnitude of component costs in Phases A and C, however, will be more nearly directly related to the quantity required per operational vehicle. For example, the magnitude of engine and SRM costs per vehicle will be related to the number required per vehicle. The magnitude of the component costs for Phase B will not be sensitive to the quantity required per vehicle. For example, the development test costs for the SRM stage will be approximately the same regardless of the quantity to be used per vehicle.

The distribution of Phase A costs by cost categories (i.e., manpower, material, tooling, facilities and equipment), as shown on Figure 7.0.0.0-4, indicates that a significant portion of the costs will be attributable to facilities and equipment. A major portion of the Phase A costs will be involved in the provision of the launch facility. These costs will represent approximately 45 percent of the total Get Ready costs for the MLLV and AMLLV single-stage-to-orbit vehicles. As the injection stage will be the same diameter as the main stage, and will fit atop the main stage without significantly increasing the length of the vehicle, its effect on launch facility costs will be negligible. For use of the SRM strap-on stages, however, a significant increase in the launch facility cost will occur. The increased launch facility costs, attributable to the SRM strap-on stages, will be approximately 50 percent of the total Phase A costs for the SRM strap-on stages. The next largest cost category will be tooling. Tooling costs will be the most sensitive to vehicle size, even though they will be reduced by only 28 percent as the vehicle size is reduced by 50 percent.

The two R&D flight tests specified for the development test program will represent approximately 25% of the overall non-recurring costs required for either of the two vehicle systems. If useful payloads could be flown on the R&D test flight vehicles, program cost effectiveness could be substantially improved.

The addition of either injection stages or SRM stages to the primary main stage will not significantly increase the non-recurring program costs. For example,

7.0 (Continued)

non-recurring costs for the main stage alone will be 86 percent of the combined costs of the main stage and SRM stages.

Slightly more than 50% of the recurring single-stage-to-orbit costs will be associated with the hardware while the remaining costs will be associated with launch operations and SE&I. Modification of the design concept to provide for recovery of the hardware from orbit could reduce program production costs while automated launch techniques coupled with on-board test and checkout would significantly reduce the operational costs.

8.0 COST IMPLICATIONS OF VEHICLE SIZE, TECHNOLOGY, CONFIGURATIONS AND PROGRAM OPTIONS

The design, resources and cost data developed for the AMLLV and MLLV configurations were assessed to determine the relationships of program costs to vehicle configuration, vehicle size and program size. Effects of production and launch rates were evaluated. Alternative strap-on stage systems, main stage propulsion systems and launch modes were investigated. Parametric cost and performance data were developed to assess alternative technology cost effectiveness. Cost reduction analyses were conducted to define potential program cost savings from design revisions and/or changes in design, test, manufacture and launch philosophy.

8.1 COST EFFECTIVENESS OF PROGRAM AND CONFIGURATION OPTIONS

In Figure 8.1.0.0-1, the values for operational costs for a specific program using anyone of the possible configurations in the MLLV family are compared (1) to those for using anyone of the configurations in the AMLLV family, and (2) to those for using the two-stage Saturn V vehicle or its potential uprated derivatives employing 156 inch and 260 inch diameter SRM strap-on stages. This comparison shows that, <u>for a given payload per launch requirement, costs will not be significantly influenced by the choice of the launch vehicle configuration.</u> (A specific amount of energy in whatever package will cost the same amount.) This conclusion assumes that all possible configurations will be produced and operated within the same program philosophy, limitations and ground rules.

The figure also shows that the operational cost per pound of delivered payload generally will decrease as the required payload weight per launch is increased. For example, the lower payload, single-stage-to-orbit vehicles will be the least cost effective vehicles in the MLLV and AMLLV families. Cost effectiveness will improve as SRM strap-on rocket motors are added to the main stage. This

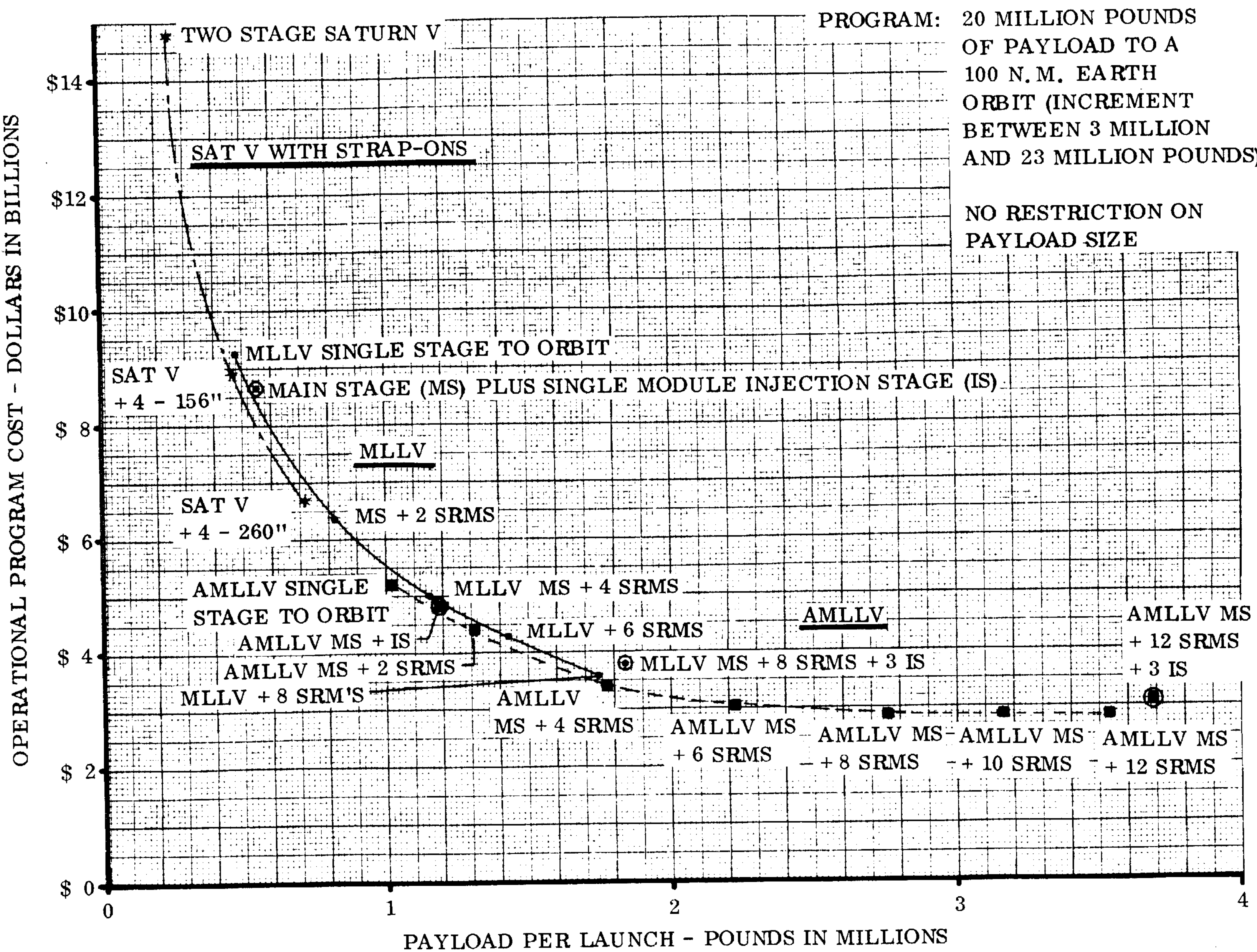

FIGURE 8.1.0.0-1 OPERATIONAL PROGRAM COST VERSUS VEHICLE CONFIGURATION

8.1 (Continued)

conclusion is based on the assumption that whatever size vehicle is used, the same production and launch rate will be maintained.

A review of the above data relative to non-recurring program costs showed that only small operational programs will be required to effectively amortize the costs for development and implementation of the strap-on stages (i.e., programs requiring three million pounds of payload to orbit for the MLLV and six million pounds of payload to orbit for the AMLLV).

Use of the injection stage as a propulsive element to increase payload to a 100 N.M. orbit will never be as cost effective as utilization of the SRM strap-on stages or an increase in the size of the main stage. For this reason, use of the injection stage should be considered only after achievement of orbit for payload maneuvering or for missions beyond earth orbit.

This study, as well as prior experience with the Saturn V and other programs, shows that the cost of a launch vehicle will be significantly affected by the production and launch rate. Figure 8.1.0.0-2 shows that data previously shown in Figure 8.1.0.0-1 as normalized by a requirement for a fixed quantity of payload delivered per year rather than a fixed launch rate. A primary factor causing increased cost at low rates is the inflexibility within the current manufacturing and launch philosophy relative to the use of personnel and skills. The costs for a full complement of personnel and skills, required at the production and launch facilities regardless of the rate, significantly increase the unit cost at low rates. A major factor in reducing costs would be an increase in the production and launch rate from approximately two vehicles per year to approximately six vehicles per year.

The cost trades of engine options showed that program costs will be only slightly affected by the various possible adaptations of either the multichamber/ plug or toroidal/aerospike engine systems in terms of size of the engine systems, operating pressure, number of modules, etc. Lower operational cost will result from the use of the larger and/or higher performance engine options with either the single-stage-to-orbit vehicles or the vehicles with strap-on stages. For example, operationally it will be more cost effective to use the higher performance 2000 psi toroidal/aerospike engine with eight modules, each rated at two million pounds thrust, than to use either the lower performance 1200 psi toroidal engine with eight modules, each rated at two million pounds thrust, or the higher performance 2000 psi toroidal/aerospike engine with 16 modules, each rated at one million pounds thrust.

For small operational program sizes which cannot effectively amortize the higher non-recurring costs of the larger high performance systems, the lower performance, lower thrust systems will be more cost effective as the non-recurring costs for these systems will be lower.

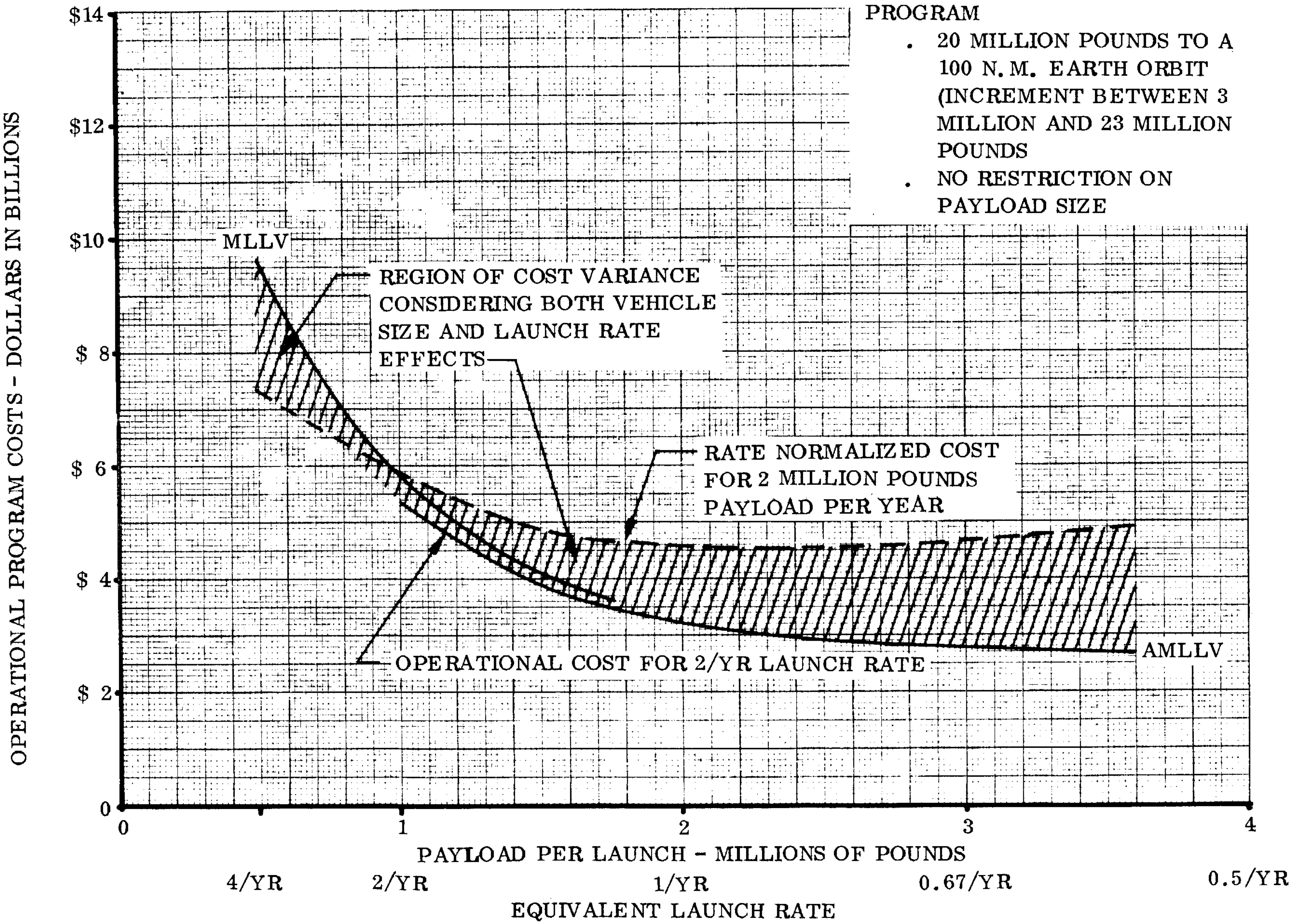

FIGURE 8.1.0.0-2 EFFECT OF LAUNCH RATE BIAS ON OPERATIONAL COSTS

8.1 (Continued)

If low cost liquid stages can be developed and procured at the same price as the SRM strap-on stages, a minor reduction in program cost will occur from their utilization. This lower cost will be attributable to easier transportation and handling of the lighter weight (empty) liquid stage. The transportation and handling costs for use of either of these stages will be so nearly the same, however, that no significant cost advantages can be attributed to either system.

The use of 260 inch diameter SRMs will be more cost effective than the use of equivalent performance 156 inch diameter SRMs for an operational program. The non-recurring costs for the 156 inch SRMs will be less than that of the 260 inch SRMs. As program size increases, however, the lower production costs of the 260 inch solid rocket motor will make it be more cost effective. Again, as with the liquid engines, the cost trades tend to favor the use of larger sizes rather than the smaller sizes.

The baseline program calls for use of the solid rocket motor strap-on stages in a "zero" stage mode wherein all of the SRMs will be ignited at liftoff and separated at the same time after SRM propellant burn out. A sequential staging concept (such that approximately 3/4 of the SRMs would be ignited at launch and the remaining 1/4 of the SRMs ignited after burnout of the initial 3/4) will in effect provide a three stage vehicle and increase the payload capability by better than ten percent. This alternative concept would provide a significant improvement in payload without substantially increasing cost and is, therefore, an attractive option for the vehicle system.

8.2 COST EFFECTIVENESS OF ALTERNATIVE TECHNOLOGY APPLICATIONS

Application of technology alternatives to the main stage of either the MLLV or AMLLV families should result in a change of the overall vehicle weight for a given payload requirement. This change in vehicle weight will be reflected in the weight or size (and associated costs) of the major elements comprising the vehicle and of the required supporting facilities, equipment and tooling. Application of the relationships of technology, size and cost with the proper methodology will give the cost/performance potential of alternative technologies.

The following tools for evaluation of the cost/performance potential of alternative technology applications to the baseline MLLV and AMLLV families were provided.

a. Relationship of required main stage size, for a given payload, as a function of specific impulse (I_{sp}) and mass fraction (λ').

b. Relationship of costs to main stage size.

8.2 (Continued)

c. Methodology for use of (a) and (b) above for cost effectiveness evaluation of alternative technology applications.

Through the use of these tools, the maximum dollars which can be expended for an advanced technology alternative, without increasing overall cost for a specified program, can be determined. For example, Figure 8.2.0.0-1 shows total dollars which can be expended for an advanced main stage structure to improve the main stage mass fraction by 0.01 without increasing program cost. This improvement will reduce the required size (and cost) of the other vehicle elements for a given payload requirement. This reduced cost, or cost saving, when added to the cost of the baseline structure will give the total dollars available for the new structure. This figure shows that for a program consisting of development and operation of sufficient AMLLV single-stage-to-orbit vehicles to place thirty million pounds of payload in orbit, 1.5 billion dollars will be available for developing and producing the required sets of the new advanced structure. Should the new structure cost more than this, it would not be cost effective.

Figure 8.2.0.0-1 also indicates that the MLLV and AMLLV single-stage-to-orbit vehicle will derive the maximum cost benefit from increases in mass fraction. For a given required cumulative amount of payload above 12 million pounds, the MLLV will have more total program dollars available for improved structures than will the AMLLV. A similar improved cost benefit will occur for the MLLV strap-on configuration, relative to the AMLLV strap-on configurations for programs requiring in excess of 110 million pounds. The programs with single-stage-to-orbit vehicles will be more sensitive to improvement or degradation in mass fraction than those programs employing vehicles with strap-on stages.

Similar analyses showed that the AMLLV and MLLV single-stage-to-orbit configurations will be more cost sensitive than will configurations employing strap-ons to changes in specific impulse. For a given improvement in specific impulse, relative to a program requiring a fixed amount of payload in orbit, the MLLV configuration will have a larger program dollar saving than the AMLLV configurations.

8.3 COST REDUCTION ANALYSIS

Program cost reductions on the order of 30 to 40 percent can be achieved through configuration modifications and/or changes in program philosophy relative to design, manufacturing, test and launch. Changes in program philosophy will, however, be much more effective in reducing costs. Philosophy changes which would reduce costs, but which also will increase program risk, include such things as utilization of the two R&D flights to deliver unmanned but useful payloads; modification to the manufacturing and launch procedures

NOTES:

- MULTICHAMBER/PLUG ENGINE SYSTEM
- PAYLOAD TO A 100 N. M. EARTH ORBIT
- CHANGE IN λ' = +0.01

LEGEND:

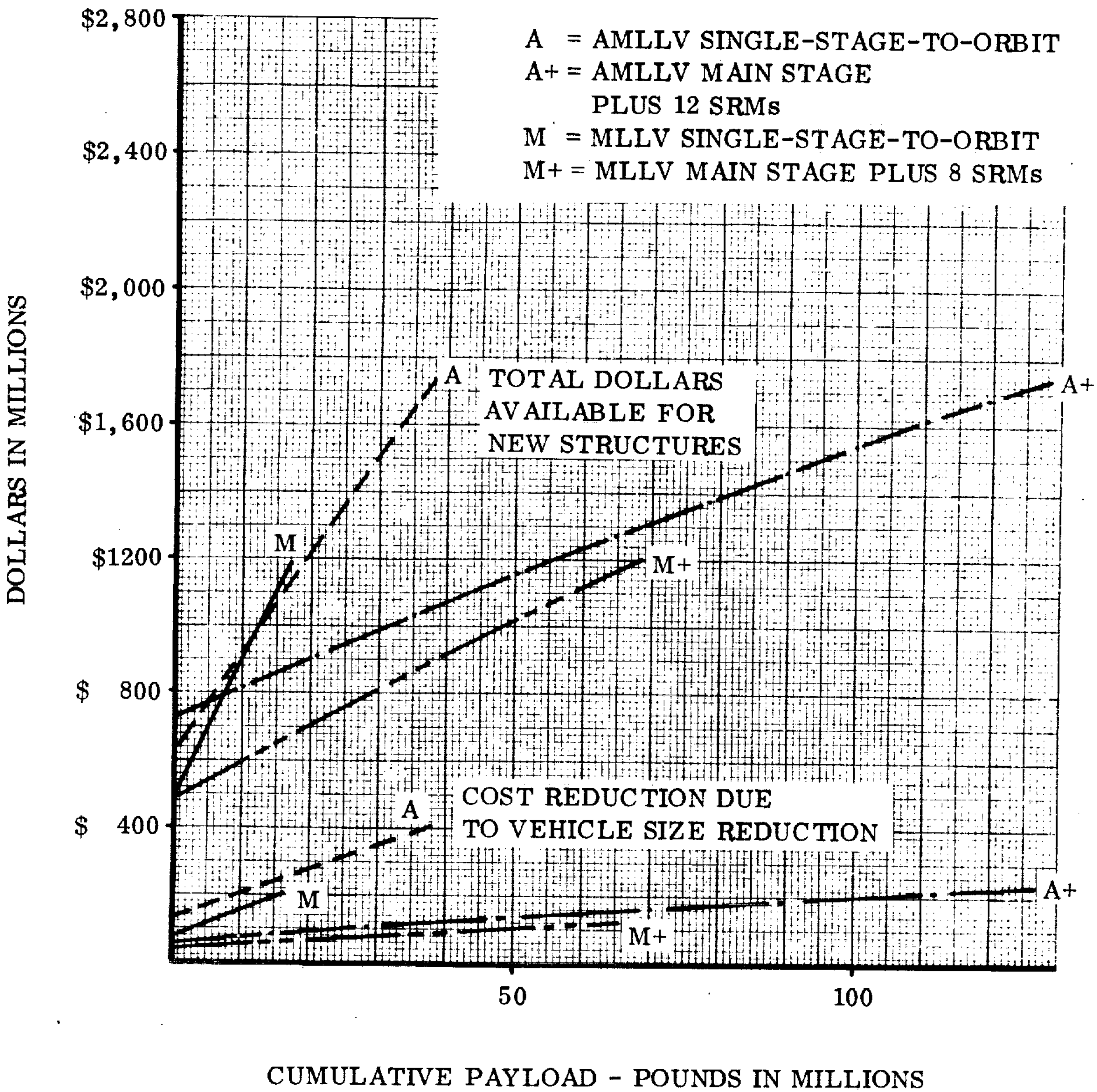

FIGURE 8.2.0.0-1 COST IMPLICATIONS OF A 0.01 IMPROVEMENT IN MASS FRACTION

8.3 (Continued)

used with low production and launch rates to provide more effective utilization of personnel and skills; deletion of the facility checkout vehicle (the first R&D flight vehicle would be used for facility checkout); reduction in instrumentation; deletion of redundant components; reduction of post-manufacturing checkout; deletion of dynamic tests; deletion of static firing acceptance tests; reduction of tolerances, and reduction of the safety factor from 1.40 to 1.25.

Preliminary design studies of the AMLLV vehicle family (in the previous study) indicated that a recoverable and reusable single-stage-to-orbit vehicle, using the AMLLV design concepts, was feasible. Such a system would use a ballistic re-entry mode with aerodynamic decelerators and would land on water. As the stage would be called down on command from orbit, landing could be made in the near vicinity of the launch facility to minimize recovery costs. Preliminary estimates indicate that a 30 to 40 percent operational cost saving, exclusive of the other above savings, could be realized by this approach.

9.0 RECOMMENDATIONS

After completion of the study activities, an assessment of the study results was made by the study manager and members of the study team to identify and recommend desirable areas for follow-on study activity. The more significant recommendations are discussed below.

The AMLLV/MLLV configurations with SRM strap-ons will encounter several unique launch conditions which should be further studied. These are: (1) the exhaust gas handling and thermal protection requirements; (2) launch acoustic impact; (3) siting criteria; (4) SRM handling, checkout and assembly to the vehicle; and (5) the effect on launch operations and personnel requirements of the on-board test and checkout system. As the launch costs will be more than 30 percent of the production and operational costs, efforts should be made to eliminate, simplify and/or reduce launch facility timelines and costs.

Even though an on-board test and checkout system was specified for the design concept, the impact of such a system on the resource requirements could not adequately be assessed by this study. Such a system should drastically reduce launch operations costs. Incorporation of the on-board test and checkout system, however, would increase the initial cost for the design and development of the vehicle systems and would also increase costs for manufacturing and installation of the systems. Additional studies are required to define in detail (1) the specific requirements for each of the on-board test and checkout elements as they relate to their assigned subsystems, (2) the interface and integrated operation of the combined on-board test and checkout elements and (3) the necessary procedures and operations which should be associated with producing, testing, and launching vehicles incorporating such systems.

Additional study is required to more adequately define the thermal environment in the base region during the flight regime. The best method of cooling this region should be defined through further design studies.

The multichamber/plug and the toroidal/aerospike systems have several propulsion alternatives (plug deletion, two position nozzles, and low cost turbomachinery) which require further investigations to determine engine operation and sequence requirements, hydraulic and electrical system requirements and associated thermal environments.

Prior to implementation of systems such as the AMLLV and MLLV, many advances probably will be made in new materials and processes. The potential of these materials should be identified and studies conducted to show the proper methods for incorporation of these materials into the vehicle systems. Detailed resource plans similar to those provided for the baseline vehicles (with aluminum structures) should be prepared for selected structural material alternatives. Associated costs should then be determined and compared to the baseline costs. Such studies should be accomplished on a recurring periodic basis.

To improve the facility for similar cost analyses in the future, it is recommended that computer storage of the cost data be provided with the provision for easy access and updating of the data as required. In conjunction with the storage, a computer program with the capability of performing at least all of the calculations shown in Volume VI of this document should be provided. With this tool and the methodology developed by this study, detailed cost analyses could be run on a variety of systems in a matter of hours with minimal error (as compared to manual computation). The effects of changing costs due to improved design, different philosophy or changes in pricing factors could be evaluated expeditiously by changing the data in storage, machine computation of the problems, and selected data print-out.

The studies indicated, that while costs can be affected by certain design or configuration improvements, operational and implementation philosophies primarily will determine the program costs. The one time use of the expendable vehicle components is a major cost driver. Further studies should be accomplished to cost optimize the vehicle design, to define low cost implementation and operational philosophies and to consider the potential of recovery and re-use of the main stage hardware.