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POST-SATURN LAUNCH VEHICLE STUDY (PART II) CONDENSED SUMMARY REPORT

by W. G. HUBER
Future Projects Office

NASA

George C. Marshall Space Flight Center, Huntsville, Alabama

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ABSTRACT

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The purpose of this report is to summarize the results of studies to define, in as much detail as feasible, vehicle concepts for a large launch vehicle beyond Saturn V. The report outlines the scope and objectives of the Part II Post-Saturn study, presents the author's conclusions based on the resulting data, and gives recommendations for future work.

A wide range of concepts were investigated and were divided into three vehicle classes for study purposes. Class I represents current technology; Class II represents advanced state of the art; and Class III represents very advanced technology.

The recommended future work includes follow-on studies to perform a more detailed design of Class II, update Class I concepts, perform a concentrated mission analysis, further define required technology advances, and make a comparison of all promising Class III concepts. The role of the present M-1 engine and large solids should be determined, and the current technology program should be oriented to provide a sound base for further Post-Saturn investigations.

author

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FUTURE PROJECTS OFFICE

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SUMMARY

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SECTION I. INTRODUCTION

In August 1962, contracts were awarded to the Martin Company and General Dynamics/Astronautics to study the next large launch vehicle beyond Saturn V. The major objective was to define various vehicle concepts and to make systems comparisons to determine the most desirable concepts for a Post-Saturn vehicle.

At this time, an early manned Mars mission was of interest; therefore, the majority of the effort was spent on configurations that offered early availability. Upon completion of these Post-Saturn studies (Part I) and several mission studies, it was concluded that early (mid-1970's) planetary missions using new launch vehicles were impractical, since expected resources did not permit the required development work.

Therefore, in May 1963, the Part II Post-Saturn studies were started to concentrate on more advanced vehicle concepts that were more compatible with the expected resources and availability requirements. It is the purpose of this report to summarize the results and conclusions of the Part II studies. This effort was accomplished under contract to the Martin Company, Baltimore, Maryland (NAS8-5135), and General Dynamics/Astronautics, San Diego, California (NAS8-5135). The total cost of the Part II studies was $1,200,000 and the contract period was from May 1963 to October 1963.

The detailed work summarized in this report was documented in the following reports:

1. "NOVA Vehicle Systems Study," Part II (4 volumes plus 33 detailed technical reports), Report No. 12589, September 1963, Martin-Marietta, Space Systems Division, CONFIDENTIAL.

2. "NOVA Vehicle Systems Study," Part II (3 volumes plus 39 detailed technical reports), Report No. GDA63-0844, September 1963, General Dynamics/Astronautics, CONFIDENTIAL.

The technical supervision for this effort was provided by a management team made up of representatives from all MSFC laboratories, KSC, MSC, LeRC, NASA Headquarters, and the Air Force.

Since the date of development initiation of the Post-Saturn vehicle as well as its desired availability were not known, it was necessary to study a wide range of concepts representing various degrees of advanced technology and sophistication. These were divided into three vehicle classes for study purposes.

The vehicle concepts in Class I represent current technology. They are expendable configurations using propulsion systems either available or currently under development. These include the F-1, M-1, and large solids. A detailed program definition could be started on Class I immediately if desired; and availability would be in the early to mid-1970's.

Class II concepts represent advanced state of the art primarily in the propulsion area. Such features as high chamber pressure and altitude compensation are considered. Sub-orbital recovery is also included. Approximately one to two years of technology advancement work are needed prior to the start of a detailed program definition, with operational availability in the middle to late 1970's.

Class III considers very advanced technology with primarily single-stage-to-orbit concepts. Recovery from near-orbital velocities is included. Three years or more of technological effort are required before a concept could enter detailed program definition. These concepts represent availability times in the late 1970's and early 1980's.

SECTION II. SCOPE AND OBJECTIVES OF THE STUDY

The principle objective of the Part II Post-Saturn study was to define, in as much detail as feasible, the most desirable vehicle configurations in each vehicle class and to identify the advanced technology required to support these resulting vehicle concepts. The following were considered secondary objectives of the study:

1. Study of manufacturing plans, including the methods of fabrication, inspection, and test, as well as the facility and major equipment requirements.

2. Determination of methods of achieving acceptable reliability with reasonable time and cost.

3. Study of testing programs and requirements for facilities.

4. Development of requirements for transportation and transport equipment.

5. Development of schedules and funding plans for the overall Post-Saturn system, including the advanced technology plan.

6. Definition of the potential mission spectrum and operational plan for meeting the mission objectives.

Due to the potential gains in the more advanced concepts and the expected availability of Post-Saturn development funding, a major portion (approximately 60 percent) was devoted to Class III. Only a small effort (approximately 5 percent) was spent on Class I, since the present confidence level of the existing data is relatively high. The remaining effort (approximately 35 percent) was devoted to Class II. This distribution of effort resulted from trying to define better the more advanced concepts to increase the confidence level and concentrate on the concepts that we know least about. In this manner, a better comparison of classes can be accomplished.

SECTION III. METHOD OF APPROACH AND ASSUMPTIONS

A. CONCEPTUAL DESIGN

In the vehicle systems design area, the following approach was used for Class I and Class III. Meetings were conducted to define candidate concepts in the various classes. All possible concepts were listed. A narrowing-down process was then undertaken by making comparisons between concepts. Some were eliminated after a pure engineering comparison, others involved the use of a simplified cost effectiveness consideration, while others were given a detailed comparison by use of a launch vehicle evaluation model. The baseline concept used for comparisons was the F-1/M-1 Class I configuration, which was the most promising Class I vehicle as determined by the Part I study.

A major consideration in the design approach used for the conceptual vehicles was to use consistent techniques in order to allow a proper comparison. In general, all vehicles were sized for the one-million-pound-to-orbit payload class, with suitable scaling laws generated to allow evaluations at other payload sizes.

B. RELIABILITY

In the reliability area, the approach was two fold. The first objective was to develop and provide, to the overall evaluation, detailed reliability estimates on all the concepts under study. The second objective was to establish design criteria important to vehicle design, development, and operation and to identify techniques for reducing failures and failure effects.

C. MANUFACTURING

The basic manufacturing effort, in support of the conceptual design studies, was the preparation of manufacturing operations plans for the various configurations and the analysis of specific structural design areas. The former was used in the schedule and cost evaluations, while the latter assisted in the selection of practical configurations. In addition to this general support, several specific studies were accomplished. These were an action plan for the Class I vehicle implementation and a comparison of multi-cell versus single-cell construction for a tandem stage, LOX-LH_2 vehicle based on the evaluations of the fabrication, assembly, and testing required.

D. QUALITY ASSURANCE

In support of the conceptual design studies, the greatest portion of the effort in this area was applied to the refurbishing of recovered vehicles. Consideration was given to assessment of vehicle condition after recovery, monitoring of work performed during the refurbishment cycle, and checkout and acceptance of the vehicle for subsequent missions.

The hardware technology program on welding, which was started in Part I, was completed. The welded specimens were examined by non-destructive menhods, such as radiography, ultrasonics, and eddy currents. Information was correlated with results obtained by tensile destruction of the samples. Detailed studies were also conducted on leak detection and contamination.

E. TEST AND EVALUATION

In this area, the effort was aimed at defining, in as much detail as feasible, the testing, and test facility requirements, launch operations and facilities, stage transportation, logistics including propellant supply, and the conceptual design of the ground support equipment. In the areas of test facilities and launch facilities, the study was supported by Martin/Denver under contracts NAS8-5159 (directed by KSC) and NAS8-5620 (directed by MSFC, Test Laboratory).

F. DEVELOPMENT PLANNING

The approach in this area was to develop overall schedules considering detailed analyses of the critical items, such as engine development, stage development and facilities, test operations, and leadtimes. The major consideration was determining what advanced technology activities are required to give sufficient confidence in any concept to consider starting a detailed program definition. This consideration was especially important in the more advanced concepts where detailed experimental data are necessary to verify feasibility and to increase accuracy of the conceptual data.

G. COST

The subject of cost was approached jointly by the contractor and MSFC. The cost derived reflects the MSFC experience on the current Saturn I, I-B, and V programs. Allowances were made for items which normally cause increased cost, such as program changes, schedule slippages, and unusual or unexpected design problems. Because of the parametric nature of the study and in order to permit the comparison of a large number of concepts on an equal basis in a short time, a cost model was programmed on the IBM 7094 computer.

H. EVALUATION

To assess the relative merits of the various Post-Saturn configurations, a number of effectiveness figures were used. Primarily, cost effectiveness was used on both a direct cost and total cost basis. These were calculated for four different mission models reflecting large and small programs. If the cost effectiveness criteria did not differentiate between concepts, other criteria were used. For the purpose of studying uncertainty in the design and cost data, and in the development risk, a second computer program was devised to perform a Monte Carlo sampling of the estimated input distributions. This approach permitted statistical measures to be studied which showed the sensitivity of the various input parameters.

SECTION IV. BASIC DATA GENERATED AND SIGNIFICANT CONCLUSIONS

A. CLASS I

As previously stated, the limited effort spent on Class I was essentially an updating of the F-1/M-1 configuration developed in the Part I study to serve as a baseline. This vehicle has 18 F-1 type engines (rated as 1.8 to 10^6 pounds of thrust) in the first stage and 3 M-1 engines in the second stage (Fig. 1). The first stage diameter is 65.5 feet; the second stage diameter is 60 feet; and the vehicle height is approximately 460 feet, including payload. Both stages are expendable. In this study, (Part II), no comparison was made of the possible alternative concepts within Class I.

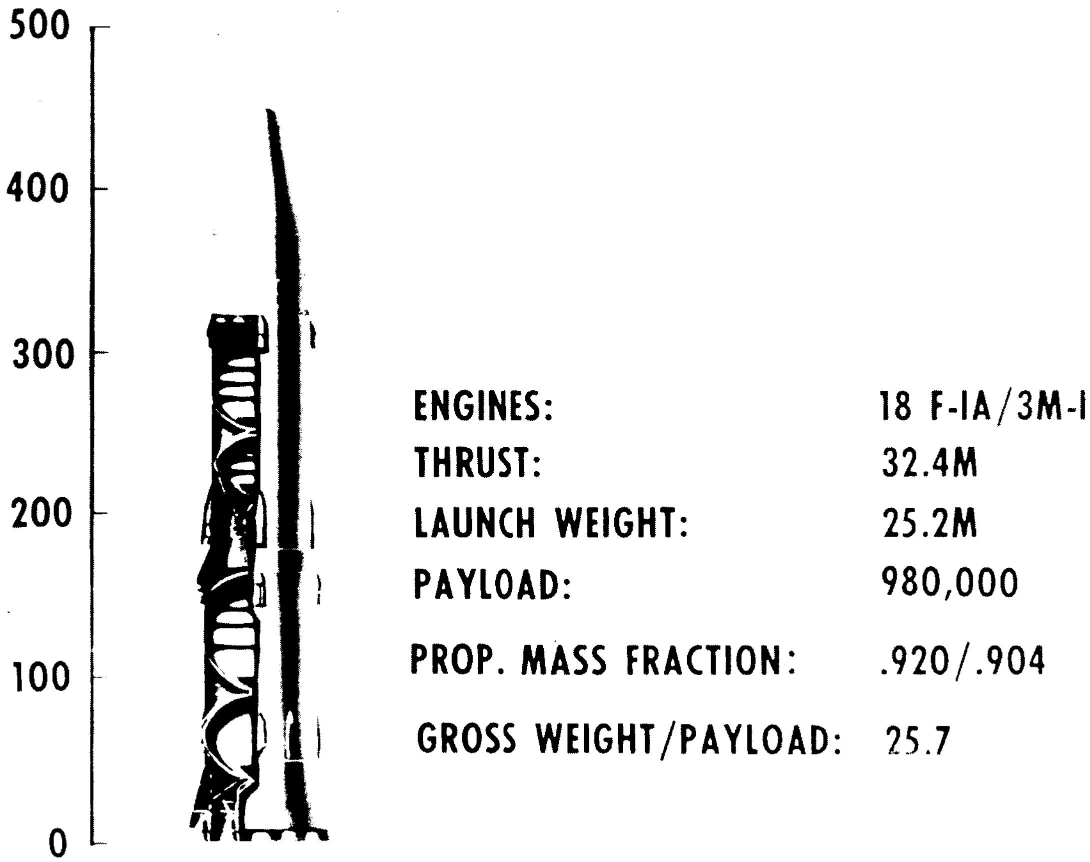


FIGURE 1. POST-SATURN CLASS I BASELINE VEHICLE

It has been concluded that the critical technology required for a Class I Post-Saturn is within the current state of the art and represents essentially just a larger version of Saturn V. If a Class I concept were desired, a detailed program definition could start immediately, thus leading to a first development flight in mid-1972, and operational availability in late 1974.

B. CLASS II

Before attempting to select the most desirable Class II concepts, it was necessary to conduct several vehicle trade-off studies. An analysis was made of reentry shapes for the first stage, since it is recoverable. It was found that positive, hypersonic static stability margins could be achieved with cylindrical shapes by the use of inflatable stability augmentation devices at an appreciable reduction in launch weight and drag over a fixed flare. This cylindrical shape showed a performance and cost effectiveness advantage over the tapered shape.

Another consideration was 1 $^1/_2$- or 2-stage vehicles. Here, no significant cost difference existed; however, the two-stage concept was favored because of its lower sensitivity to variations in performance parameters. Two-stage vehicles were sized from 420,000 pounds to 1,140,000 pounds payload capability, and then compared with the best available estimates for the planetary missions requirements. The conclusion, based on cost effectiveness and orbital operations considerations, was that the larger size vehicles were superior. Therefore, a baseline value of one million pounds to orbit has been established for the Post-Saturn studies.

The effect of various degrees of recovery was studied, and the results showed that a two-stage vehicle, with a recoverable first stage, was 35 percent better from a cost effectiveness standpoint than a completely expendable vehicle. The fully recoverable two-stage vehicle offered about a 9 percent improvement over the recoverable first stage concept, but the technical problems associated with near-orbital velocity recovery of the second stage were considered to fall in the Class III technology area; therefore, for Class II the recoverable first stage, with an expendable second stage, was selected. However, if the development of a Class II vehicle should be undertaken, it is recommended that, during its design, consideration be given to the addition of second stage recovery at a later date, as growth potential.

The primary trade-off studies involved propulsion systems and propellant combination selection. Since Class II represents advanced technology, many advanced propulsion concepts were investigated. Figure 2 shows the benefits derived from altitude compensation and the use of higher chamber pressures. These are given as a ratio of payload improvement. For a single-stage-to-orbit vehicle, both high chamber pressure and altitude compensation give a large improvement in performance; however, for a two-stage vehicle only small gains can be achieved, using these technology advancements in the first stage. At this time, no conclusion has been reached concerning the most desirable propulsion system for the Class II vehicle. Before firm conclusions can be drawn, hardware technology work must be conducted to obtain experimental data. Such questions as the following must be answered before the most desirable propulsion system can be selected: What degree of altitude compensation can be realistically achieved? What overall performance does a plug nozzle produce? What happens to plug performance if an engine is lost? These problems are recognized by both OMSF and OART, and some technology work is presently underway in these areas.

After realistic advantages of the advanced propulsion systems are determined, these must be compared with engines under development such as the M-1. No firm conclusions have been reached concerning the role of the M-1 engine.

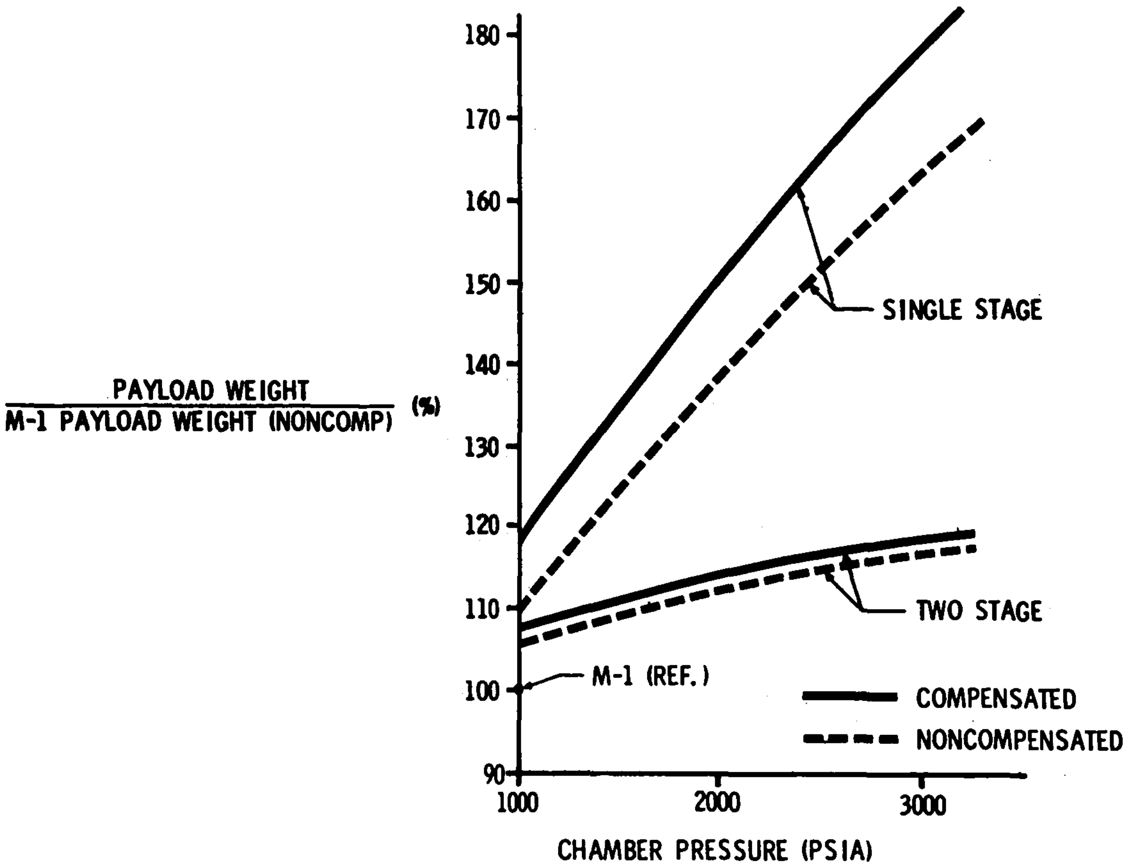
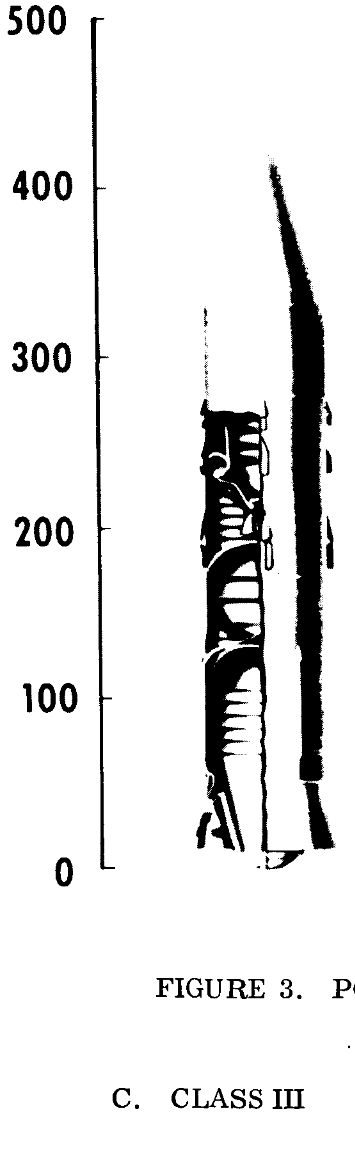


FIGURE 2. PAYLOAD VERSUS CHAMBER PRESSURE

Several propellant combinations for the second stage were studied; however, based on the current vehicle systems, LOX/LH_2 was selected. If current technology work on LF_2 or FLOX shows promise, these could of course be used in any Post-Saturn vehicle. The selection of propellants for the first stage has not been resolved at this time, and will receive a concentrated effort in the Part III study. LH_2 as a fuel offers higher impulse, a lighter vehicle, no combustion residue for refurbishment, the possibility of using the same engine module in both stages, and the potential of using the first stage as a single-stage-to-orbit vehicle. On the other hand, RP-1 gives a better propellant bulk density, smaller vehicle size, slightly lower cost, and simpler launch operations.

In conclusion, Figure 3 shows a typical Class II Post-Saturn. It is a two-stage vehicle with a recoverable first stage. The vehicle height, including payload, is about 420 feet and each stage is 70 feet in diameter. One to two years of advanced technology work, primarily in the areas of propulsion and recovery, would be required prior to starting a detailed program definition. This would result in a first flight in mid-1974 and operational availability in early 1977.



ENGINES:	**18/2 @ 1000K**
THRUST:	**18M**
LAUNCH WEIGHT:	**14.4M**
PAYLOAD:	**942,000**
PROP. MASS FRACTION:	**.897/.883**
GROSS WEIGHT/PAYLOAD:	**15.3**

FIGURE 3. POST-SATURN CLASS II BASELINE VEHICLE

C. CLASS III

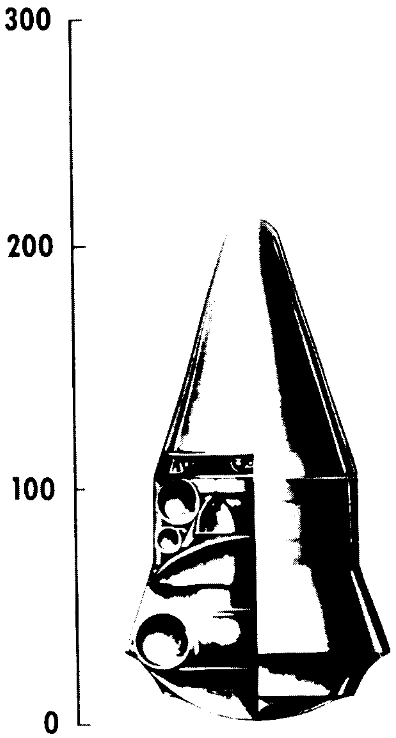
Considering the concepts that were investigated and the data available at this time, it is not possible to select a most promising concept; however, certain conclusions can be reached. The goal in Class III is a single stage, fully recoverable vehicle. In the investigation, it became apparent that these vehicles were in two distinct categories of technology with the recovery ground rule: Those which used pure rocket propulsion and ballistic reentry techniques, and those in which the atmosphere was used to varying degrees in the propulsion system and for the development of lift.

Primary interest in the second category was the use of air augmentation. The air augmentation configurations, in spite of optimisitc assumptions, showed no design region in which a performance advantage could be achieved over an equivalent rocket system. The degradation in vehicle performance, due to the inert weights of the ducted system, was found to more than offset the performance improvement, due to the augmented specific impulse.

In the rocket propulsion category, considerable effort was devoted to the problem of obtaining a variable payload capability with a basic single-stage-to-orbit vehicle. This capability is of interest, since it would provide greater payload design flexibility and mission planning. It also appears possible to improve the cost effectiveness sensitivity to variations in the payload distribution spectrum. However, at this time it is not possible to make conclusions on this feature, since only a quantitative definition of the Post-Saturn payload capability was investigated. The studies included off-loading to obtain lower-than-design payloads, the addition of solid and liquid JATO's, strap-on tanks, expendable second stages, and the substitution of flourine for oxygen in varying degrees to obtain higher-than-design payloads. The flourine substitution and the expendable second stage showed a significant payload augmentation advantage over either the liquid or solid JATO's. These conclusions, of course, depend on the basic vehicle size and payload requirements distribution.

From a propulsion standpoint both high chamber pressure and altitude compensation are required to achieve single-stage-to-orbit capability (Fig. 2). Also, advanced structural concepts and tankage configurations are relatively important. The payload sensitivity of this vehicle concept requires state-of-the-art advances in all areas of technology; however, the most important are propulsion and the problems associated with orbital or near-orbital, velocity reentry, recovery, and re-use.

Figure 4 shows a typical Class III Post-Saturn concept. The data shown in the left column is for the basic single-stage vehicle and on the right, the addition of an expendable second stage. This concept gives a payload from 460, 000 to 1, 250, 000 pounds. The vehicle with second stage is about 220 feet high and 115 feet in diameter.



	1 STAGE	2 STAGE
ENGINES:	18 @ 1000K	18/3 @ 1000K
THRUST:	18M	18M
LAUNCH WEIGHT:	12-14.4M	14.4M
PAYLOAD:	460K-826K	1,250,000
PROP. MASS FRACTION:	.928	.928/.922
GROSS WEIGHT/PAYLOAD:	14.5	11.3

FIGURE 4. POST-SATURN CLASS III BASELINE VEHICLE

About three to four years of concentrated technology work (depending on the concept) should be accomplished before a detailed program definition is undertaken on a Class III Post-Saturn. This would result in a first flight in the 1976-1977 period and operational availability about 1980.

D. INTERCLASS COMPARISON

In addition to the work and conclusions previously described for each Post-Saturn vehicle class, some interclass comparisons were made. Since all vehicles have been sized for the same payload capability, the comparisons were made from both a performance and a cost effectiveness standpoint.

In reviewing Figures 1, 3, and 4, which illustrated representative concepts, it was shown that the gross-weight-to-payload ratio, which is a measure of the vehicle efficiency, improves from 25.7 to 15.3 to 14.5, going from Class I to II to III. This, of course, reflects the advancement in propulsion and structural design. For the same payload, the more advanced concepts offer smaller vehicles, less thrust; and, in turn, easier operational problems at both the test site and launch site, due to noise and explosive hazards.

From the cost effectiveness standpoint and based on a launch rate of approximately eight per year, Class I showed a direct cost effectiveness of about $100 per pound of payload delivered to orbit. An equivalent number for Saturn V would be about $200 per pound. Class II could further reduce the cost to about $50 per pound. Class III cost effectiveness is in the $40 to $50 per pound range; however, this class has the potential for further reductions through the use of payload variation capability.

SECTION V. RECOMMENDED FUTURE ACTIVITIES

Based on the results of the Post-Saturn studies and the results of various mission studies and technology activities, the following is recommended:

1. A follow-on study be conducted with the following objectives:

a. More detailed design of Class II, concentrating on areas of greatest uncertainity and those that have the greatest effect on overall vehicle (50%).

b. Concentrated effort in mission analysis area to define better why we need a Post-Saturn, when we need it, and what it should be capable of doing (40%).

c. Updating of Class I concepts (5%).

d. Further definition of required technology (5%).

(A 12-month contract was awarded to Martin-Marietta in October 1964 for $1,499,000 to accomplish this work).

2. A follow-on study be conducted to compare all of the promising concepts for Class III, including those developed under the Post-Nova contracts with General Dynamics/Astronautics and Douglas and any new concepts that may be proposed. It is important to have these compared under the same ground rules and under the same assumptions.

3. A concentrated effort be made to determine the role of the present M-1 engine or define the design changes desirable from a Post-Saturn vehicle viewpoint. (Work is currently underway at Lewis Research Center and MSFC, as well as Martin-Marietta and Aerojet, to clarify this question.)

4. Further work be accomplished to better define the Post-Saturn applications of large solid motor.

5. The current technology program be oriented to provide a sound base for further Post-Saturn study activities. Advances in all areas are needed to increase the confidence level of Class II designs and to prove the feasibility of some of the Class III concepts.

The above considers only the delivery of payload to orbit. In the case of manned planetary missions, orbital assembly, refueling, and other operations are required. These represent additional cost prior to departing orbit. Studies have shown this orbital burden rate to vary from approximately $900 per pound (departing orbit) for Saturn V, down to $240 per pound using Post-Saturn vehicles. In conclusion, Post-Saturn not only provides reduced orbital delivery costs, but also offers additional savings through minimized orbital operations. For manned planetary missions, the cost associated with orbital support operations exceeds the orbital delivery costs.

NASA TM X-53010 APPROVAL April 10, 1964

POST-SATURN LAUNCH VEHICLE STUDY (PART II)
CONDENSED SUMMARY REPORT

By W. G. Huber

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified. This report also has been reviewed and approved for technical accuracy.

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