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LARGE POST-SATURN LAUNCH VEHICLES: WHY? WHEN? WHAT?

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I. INTRODUCTION

The United States is presently committed to landing a man on the Moon within this decade. This is a formidable goal; however, to the National Aeronautics and Space Administration (NASA) it is not a final objective - it is just a beginning of real space exploration. Besides the major effort required by the APOLLO Program, it is necessary for NASA to start initial planning for the future, more ambitious missions.

Launch vehicles continue to be one of the major pacing items in the progress of space exploration. The largest launch vehicle now under development is the SATURN V; however, planning is underway for a Post-SATURN vehicle, which could greatly increase our capabilities for planetary exploration.

This planning effort must first determine under what conditions a Post-SATURN is justified. In other words, what is the size of space programs beyond which it is desirable to develop a launch vehicle larger than SATURN V. Then by having some indication of the future program, the questions of <u>why</u> we need a Post-SATURN, <u>when</u> we need it, and <u>what</u> is the best concept can be answered. The study effort presently underway is aimed at providing the necessary data to attempt to answer these questions. Because of the uncertainty in the development timing of the next large launch vehicle, a broad approach has been taken. The vehicle concepts under study are divided into four categories or classes. Each class is defined on the basis of the advancement in technology required to demonstrate technical feasibility or soundness of approach. This, of course, gives a wide range of possible availability dates - from 1974 to 1985.

II. POSSIBLE VEHICLE CONCEPTS

Conceptual design effort is being accomplished in all vehicle classes. The approach has been to start with all possible concepts in each class and narrow them down through further study and comparisons. In this manner, we can focus on the most promising concepts in each vehicle class. In order to proceed with the missions analysis work in parallel with the vehicle design effort, representative or baseline configurations were selected in each class. The selection of these baselines does not mean they are best in their class - only representative of the technology and availability offered by the class. It is then possible to make certain interclass comparisons with these baseline concepts.

Class I contains the concepts using current technology and are essentially within the present state-of-the-art. The configurations are expendable and use propulsion systems currently under development. These include the M-1, the large solid, and the F-1 or an uprated version of the F-1. The selected baseline for Class I is shown in Figure 1. This vehicle has 18 F-1 type engines (rated at 1.8×10^6 pounds of thrust) in the first stage and three M-1 engines in the second stage. 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 use separate tanks and are expendable.

Class II represents concepts using advanced technology. The principle areas of advancement are propulsion and recovery. New propulsion systems are considered using such features as high chamber pressure, up to 3,000 psia, and unconventional nozzles, achieving some degree of altitude compensation. Numerous trade off studies have shown the most attractive concepts in this class are two stage vehicles with a recoverable first stage. Recovery and reuse of the first stage can offer almost a 40 percent improvement in cost effectiveness for a launch rate of about 10 per year. Recovery of the second stage can offer further improvement of about 8 percent; however, the technical problems associated with recovery of items of this size from near orbital velocities are serious and at this time are not considered worth the potential gains for the Class II Post-SATURN.

Advanced propulsion concepts in themselves will improve the cost effectiveness of Class II over Class I in the order of 15 percent. This gain, combined with recovery, results in an improvement of cost effectiveness of about 50 percent going from Class I to Class II. The most desirable advanced propulsion system has not been determined to date, since a great deal of required experimental work is needed to verify the performance assumptions that have been used in the studies. A typical Class II concept is shown in Figure 2. Each stage is 70 feet in diameter, and the vehicle height is about 420 feet. The improvement in gross weight to payload ratio of this concept over the Class I baseline should be noted.

Class III concepts utilize very advanced technology, particularly in the areas of propulsion, structures, and recovery from near orbital velocity. The ideal Class III concept is a single stage to orbit, fully recoverable vehicle. Several configurations have been studied; however, analyses have shown the vehicle performance to be extremely sensitive to specific impulse and dry stage

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weight assumptions. At the present time, our confidence in the existing data is relatively low, because of the lack of experimental data to verify the assumptions made in the studies. In attempts to eliminate this sensitivity, several alternate concepts have been studied. These include expendable tanks, solid and liquid JATO units, flourine substitution, and expendable second stages. Conclusions concerning the most attractive concept cannot be made at this time.

One of the possible features of a Class III Post-SATURN vehicle could be a variable payload capability. This capability is of interest, since it would provide greater payload design and mission planning flexibility. However, at this time it is not possible to determine the desirability of this feature, since the specific mission requirements cannot be defined. For the purposes of the mission analysis studies, a representative Class III configuration was selected and is shown in Figure 3. This is a basic single-stage to orbit, fully recoverable concept with 826,000 pound payload capability. For larger payload missions, an expendable second stage can be added, which gives a 1,250,000 pound capability. The vehicle is about 120 feet in diameter and 220 feet high with second stage and payload.

Class IV represents the combination of a Class II or Class III chemical first stage with an advanced nuclear upper stage. The application of these configurations is primarily two-stage to Earth escape. The work in this area has been aimed at determining the capability of the Post-SATURN chemical first stage to accommodate solid core, gaseous core, and nuclear pulse upper stage when, and if, they become available.

III. MISSION ANALYSIS

To this point the question of what possible configurations of a large Post-SATURN vehicle are of interest has been discussed. The questions of why and when do we need it can only be answered after some potential missions and schedules are established. In order to attempt to determine the role of a Post-SATURN vehicle, four different mission plans or models were developed. These represented a large space program on an optimistic schedule, a large program on a pessimistic schedule, a minimum space program on an optimistic schedule, and a minimum program on a pessimistic schedule. These were developed in such a manner as to try to bracket the actual space program for the future which, of course, cannot be defined at present.

The missions assumed covered the orbital, lunar, and both the manned and unmanned planetary categories, and were constructed to represent possible follow ons to existing programs. The time period under study is 1970 to 1990.

Figure 4 is included to give an indication of the magnitude of the small and large programs without going into detail. Besides varying the number of missions, the size of each mission was varied in the manned planetary area. As an example, the initial manned Mars landing was assumed to be with a fleet of four ships for the large programs and only two ships for the small programs. Shown in Figure 5 is the effect of schedule on the programs. For simplicity the two extremes are shown. It shows, for example,on the optimistic schedule a Venus flyby which was assumed in 1973. For the programs on the pessimistic schedule, the time was 1979. It can be seen that there is the same variation of the selected missions with schedule. For example, a Mars capture mission was assumed for the small programs, but not for the large ones. For the small programs, the most ambitious mission selected was a manned Mars landing. Both the large programs included a Mars Synodic Base, and for the one on an optimistic schedule, another even more advanced mission was assumed.

Each set of assumed mission objectives was then accomplished with four different combinations of present and future launch vehicles. All vehicle mixes used the SATURN IB, SATURN V, and the 10-passenger reusable orbital transport, which was assumed to be available in 1978 for the optimistic schedule programs and 1982 for the pessimistic. An improved capability of 300,000 pounds to orbit was assumed for the SATURN V vehicle.

The following are the vehicle mixes used:

No. 1 - SATURN IB, SATURN V, 10-passenger

No. 2 - No. 1 and Post-SATURN Class I

No. 3 - No. 1 and Post-SATURN Class II

No. 4 - No. 1 and Post-SATURN Class III

With these combinations, it should be possible to determine the role of a Post-SATURN launch vehicle in the overall space program. The flow diagram shown in Figure 6 shows the logic used for the calculations. For each mission objective, the spacecraft and the required space propulsion systems were identified, sized, and costed. A mode of accomplishment was then selected, i.e., either a direct flight, as in the case of the lunar missions, or via orbital operations, as in the case of most manned planetary missions. Orbital operations burden rates were then assessed to those missions through orbit. The sum of the direct flights, the mission flights to orbit, and the flights needed for orbital support gives the total launch requirements versus time. From these launch rates the number of launch vehicles could be calculated. For expendable vehicles, of course, the launch rate equals the number required; however, for reusable vehicles suitable reuse rates, turn around time, and refurbishment cost were assumed. The program cost was determined by adding the spacecraft and space propulsion costs, the launch vehicle costs, and the orbital operations support costs. This was done on both a direct operating and total operating cost basis; the latter including development and facilities.

From the mission objectives and the proper reliability analysis the mission yield in terms of number of pounds delivered, number of men, number of manyears, etc., are known. By combining these yields with the appropriate cost, the various indices of performance are determined. Following this procedure for various mixes of launch vehicles and various mission objectives, produces sets of indices of performance, which can then be compared to determine the most efficient vehicle or vehicle mix for each set of mission objectives or space programs.

IV. RESULTS

The average yearly expenditure for the small program ranged from $3.3 billion to $3.9 billion depending on schedule and vehicle mix. For the large program the range was from $4.6 billion to $7.0 billion. These expenditures appear to bracket the FY 64 NASA budget for the portion of the overall program under consideration in this paper. The variation of this average annual cost, as a function of vehicle mix, is shown in Figure 7. Since the mission yield is relatively constant for each combination of launch vehicles, these costs represent a measure of effectiveness. For the large program on either the optimistic or pessimistic schedule, the combination of SATURN V and a Class II Post-SATURN (Mix No. 3) appears to be the most efficient. The large program is too large for SATURN V only. The Class III Post-SATURN (Mix No. 4) is closer to the minimum cost for the pessimistic schedule, since its late availability comes closer to matching the manned planetary mission schedule. The more the mission schedule is compressed, the more off-minimum the Class III vehicle mix.

For the small programs, the SATURN V only (Mix No. 1) represents minimum cost because of the reduced number of mission requirements. However, on the pessimistic schedule, the Class II Post-SATURN (Mix No. 3) is not far from the minimum cost, since its availability is more compatible with the planetary missions.

Another aspect to be considered is the resulting launch rates needed to meet the assumed mission objectives. These are shown in Figure 8 in terms of average annual requirements. For the large programs, SATURN V only (Mix No. 1) results in very high launch rates. The addition of any Post-SATURN can greatly reduce these rates. In all cases the SATURN V requirements increase, when the introduction of a Post-SATURN capability is delayed from Class I to Class II to Class III.

As a last point of consideration, the cost effectiveness of the various vehicle mixes is of interest. In an attempt to put all programs on an equal basis, an orbital equivalent cost effectiveness was calculated. This represents the cost effectiveness of the various transportation systems, if all launches were made to Earth orbit. The results are shown in Figure 9 in terms of both direct operating cost (DOC) and total operating cost (TOC), which includes facilities and development. The numbers shown represent the average of the combination of vehicles in each mix. For example, the effectiveness of Mix No. 4 is an average of all the SATURN IB, SATURN V, and Post-SATURN Class III vehicles required to meet the assumed mission objectives. The 10-passenger reusable orbital transport vehicle flights have been excluded in the calculation, since they are used to carry personnel and not cargo. For the large program, Mix. No. 3 (Post-SATURN Class II) is favored from both the direct and total cost effectiveness standpoint. It can be seen that the direct cost effectiveness becomes greater for Mixes No. 1 and 2 with a stretch out in schedule, whereas it improves for Mixes No. 3 and 4. This is because the stretched out programs are more compatible with the later availability of the Class II and III Post-SATURN. The SATURN V only is the most effective from a total cost standpoint for the small program on an optimistic schedule, even though the Post-SATURN Class II mix is best on a direct cost basis. If the small program schedule is stretched, then Mix No. 3 becomes the most efficient.

V. CONCLUSIONS

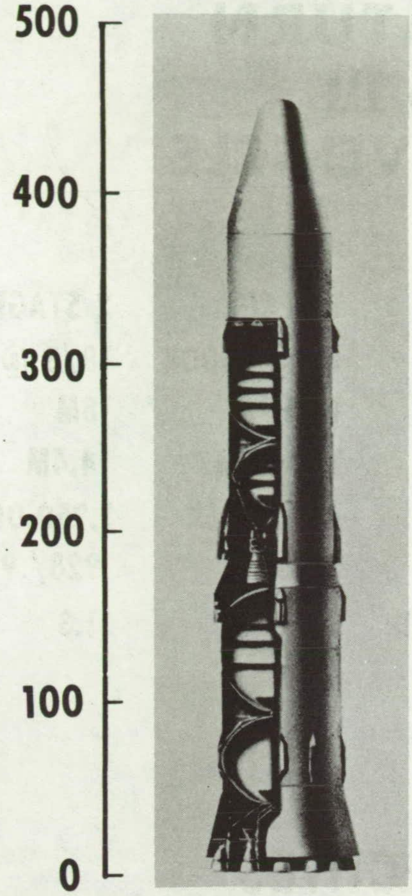
The preliminary data available at this time and summarized in this paper cannot be used to answer explicitly the questions of Why, When, and What about Post-SATURN; however, some interesting trends are apparent. It appears that a Post-SATURN capability is desirable, if we are going to have manned planetary exploration. Even the small program on a stretched out schedule showed Post-SATURN to be the most effective.

The questions of When and What should be considered together. The Class I type vehicle did not look favorable for any of the programs studied. This is true for two reasons: (1) it does not offer sufficient cost effectiveness over SATURN V, and (2) it was available prior to the planetary mission requirements. The Class II concept gave the best direct cost effectiveness under all programs considered and the best total cost effectiveness in all but the small program on an optimistic schedule. This class offers significant improvement over SATURN V and at a time that is compatible with the planetary missions. The Class III vehicle did not produce favorable results because of its late availability. Programs with more pessimistic schedules would permit better utilization of Class III, and would therefore produce better cost effectiveness.

It can be concluded that with a relatively large space program, there is a role for Post-SATURN. The exact size and composition of the program that economically justifies a large launch vehicle remain to be determined. The exact vehicle concept eventually selected will depend on the state-of-the-art at the time of development initiation, but will probably include some degree of advanced propulsion and some form of recovery and reuse.

Figure 1

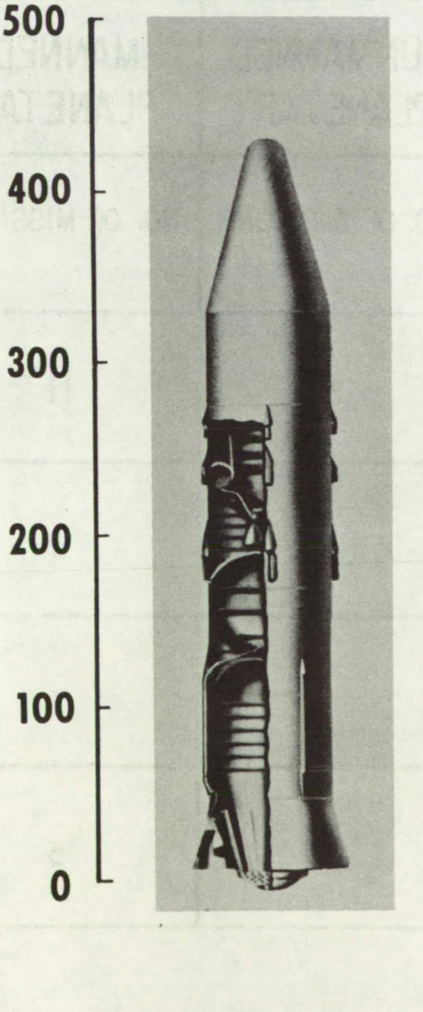
POST-SATURN CLASS I BASELINE VEHICLE



ENGINES:	**18 F-IA/3M-I**
THRUST:	**32.4M**
LAUNCH WEIGHT:	**25.2M**
PAYLOAD:	**980,000**
PROP. MASS FRACTION:	**.920/.904**
GROSS WEIGHT/PAYLOAD:	**25.7**

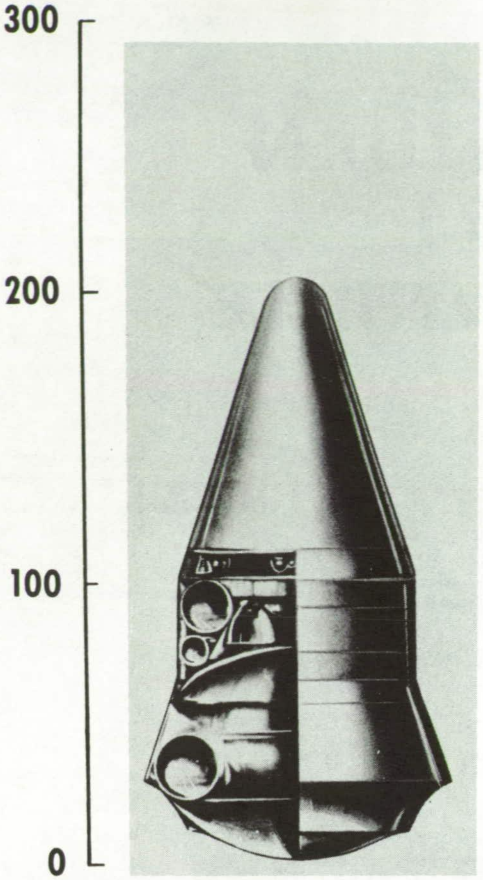
Figure 2

POST-SATURN CLASS II BASELINE VEHICLE



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 III BASELINE VEHICLE

	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

ASSUMED MISSION OBJECTIVES

	ORBITAL	LUNAR	UNMANNED PLANETARY	MANNED PLANETARY
	NO. OF MANNED SPACE STATIONS	MAX. SIZE OF BASE (NO. OF MEN)	NO. OF MISSIONS	NO. OF MISSIONS
LARGE PROGRAM OPTIMISTIC SCHEDULE	24	80	37	11
LARGE PROGRAM PESSIMISTIC SCHEDULE	24	80	37	7
SMALL PROGRAM OPTIMISTIC SCHEDULE	10	12	18	8
SMALL PROGRAM PESSIMISTIC SCHEDULE	10	12	18	5

Figure 5

MANNED PLANETARY MISSIONS

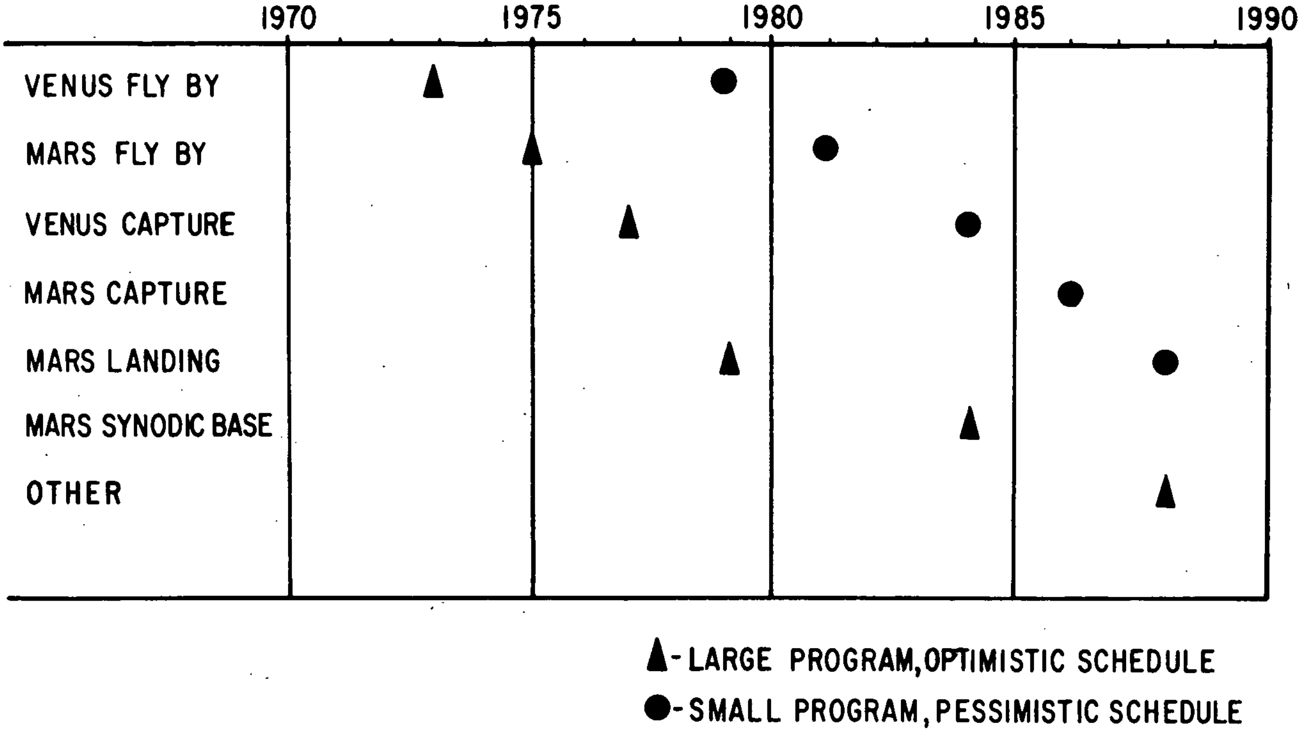


Figure 6

GENERALIZED FLOW DIAGRAM

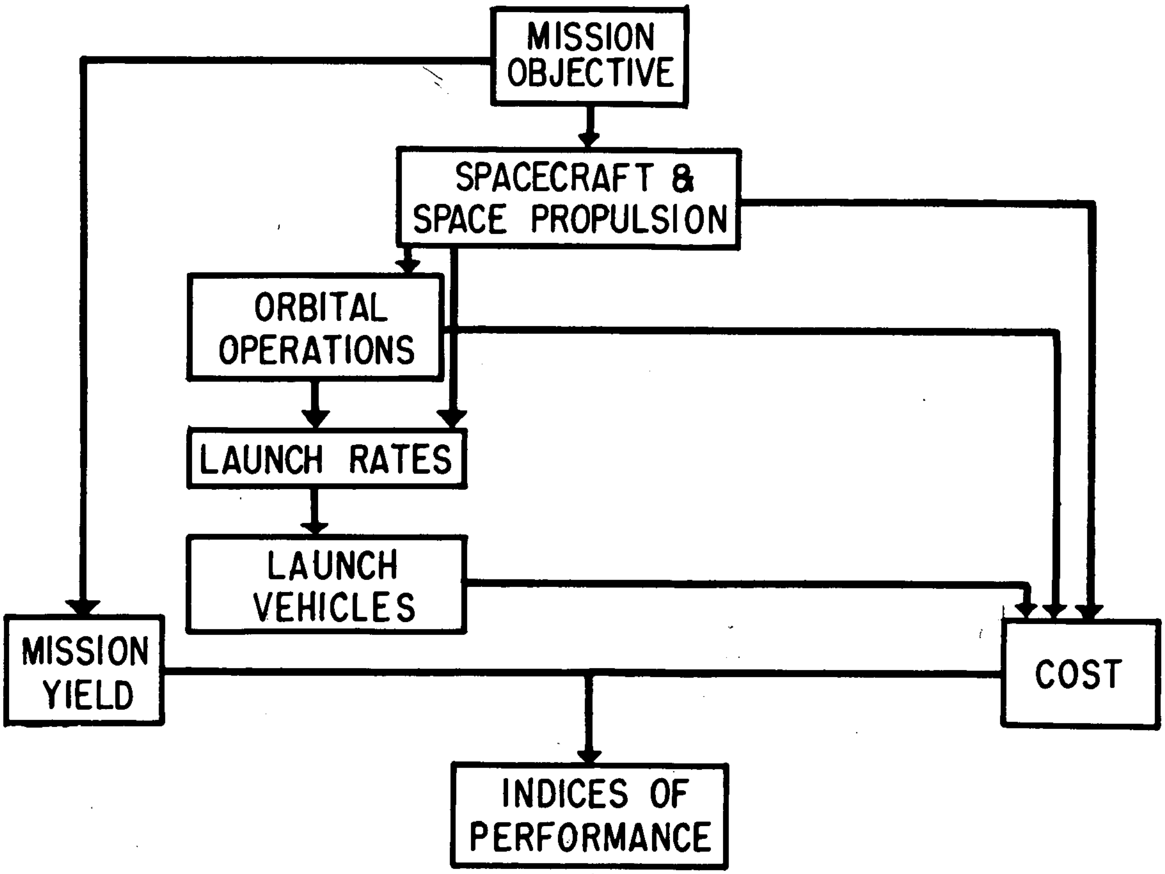


Figure 7

AVERAGE ANNUAL EXPENDITURE
(IN BILLIONS OF DOLLARS)

MIX	SPACE PROGRAM	OPTIMISTIC SCHEDULE	PESSIMISTIC SCHEDULE
1	LARGE	6.97	5.37
2		6.67	4.95
3		6.13	4.60
4		6.27	4.64
1	SMALL	3.33	3.40
2		3.88	3.62
3		3.78	3.51
4		3.76	3.55

Figure 8

AVERAGE ANNUAL LAUNCH REQUIREMENTS

MIX	SPACE PROGRAM	OPTIMISTIC SCHEDULE		PESSIMISTIC SCHEDULE	
		SATURN V	POST-SATURN	SATURN V	POST-SATURN
1	LARGE	62.7	0	47.0	0
2		8.9	11.2	4.0	9.1
3		8.9	11.9	5.7	9.3
4		11.9	10.0	8.8	7.7
1	SMALL	20.4	0	15.0	0
2		4.4	3.9	3.0	2.9
3		4.6	4.0	3.2	3.0
4		6.1	3.3	4.9	2.3

Figure 9

EQUIVALENT ORBITAL COST EFFECTIVENESS
(dollars per pound)

MIX	SPACE PROGRAM	OPTIMISTIC SCHEDULE		PESSIMISTIC SCHEDULE	
		DOC	TOC	DOC	TOC
1	LARGE	116.5	141.3	123.3	150.3
2		107.6	152.8	109.4	161.6
3		70.3	114.6	65.8	117.1
4		76.4	122.8	69.8	124.9
1	SMALL	100.2	129.4	156.6	195.6
2		129.1	208.5	133.3	238.3
3		89.0	168.7	91.6	190.8
4		95.1	182.9	107.0	217.5