ILR Mitt. 352 (2001)
6.6.2001

NOVA AND BEYOND
A Review of Heavy Lift Launch Vehicle Concepts in the POST-SATURN Class

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Abstract
Heavy lift launch vehicles with a launch mass of several thousand tons, and payload capabilities in the order of the SATURN V class of launch vehicles, have been under study for half a century. The key event was the publication of the Mars Project by Wernher von Braun in 1952. The NOVA concept of Rosen / Schwenk in 1959 initiated a series of studies to find the best way to transport Astronauts to the Moon and back. The Russian N-1 Moon-rocket falls also in this category. After the decision to develop the SATURN V expendable launch vehicle in 1961, advanced reusable Heavy Lift Launch Vehicles (HLLV) with larger payloads for future missions were analyzed in depth and are presented in this documentation. The feasibility study of Space Solar Power Systems (SSPS) in the later seventies rekindled the interest in heavy lift, cost-effective launch vehicles, leading to a number of different concepts. - During the last decade HLLV studies concentrated on lunar space transportation systems for the logistic support of extraterrestrial facilities, such as a Lunar Base, and for human exploration of Mars. An affordable solution to the problem of large scale space transportation is not yet in sight, it depends more on a suitable market, much less on technology.
This report comprises 15 tables, 19 figures, 43 references on 42 pages.

Key words: Launch vehicles, space transportation, logistics, preliminary design, space solar power systems, lunar bases, manned space expeditions.

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1. Introduction

In 1949/51, while waiting for a new assignment in rocket development by the Department of Defense, Wernher von Braun, Krafft Ehricke and others of the Group working for the U.A.Army Ordenance Corps at Huntsville, Alabama, used this waiting period to study plans to send people to Mars[1,2]. In this context launch vehicles were required to transport the Mars-Ships to a departure orbit about the Earth. Not knowing that there was a radiation belt at that altitude, they selected the two hour orbit at about 1700 km altitude. This turned out to be an altitude not very practicable later when in 1958 the van Allen belt was discovered by EXPLORER 1, however, this did not change their conclusions.

Their launch vehicle concepts must be regarded as the **first heavy lift launch vehicles** ever designed, and thus they set the course of what was to come during the second half of the 20th century and is shown below!

The publication of the MARS Project in journals and books in 1951/55 initiated a first wave of space flight enthusiasm. It made people aware that there is a pioneering task waiting for mankind to be taken up in due time.

This report makes the attempt to describe the development of launch vehicle technology in the area of very large vehicles with take-off masses greater than 3,000 metric tons. The evolution of launch vehicles between the ICBM size and the SATURN family (500 to 3,000 metric tons) has been documented in a recent separate report and is thus not included[43].

The initial Russian leadership in space travel, demonstrated by the launch of the first artificial satellite in 1957 and orbiting the first human being in March 1961, prompted the United States to take up the challenge for preeminence in space. The first action was placing under development a bigger engine. This F-1 engine with a 1,500.000 lb thrust level was designed to close the booster gap. After this event, it took not much vision to conceive a rocket using a cluster of F-1 engines that was able to put people on the Moon. This vehicle concept was proposed by NASA staff-members M.Rosen and C.Schwenk in fall of 1959, at the 10th International Congress at London[3]. This was the actual birth of the NOVA launch vehicle concept for a direct landing of people on the Moon. The existence of this proposal was certainly an influential factor, when President Kennedy proposed to put a man on the Moon in May 1961. At that time the NOVA launch vehicle concept was recognized as one of the means to accomplish this goal.

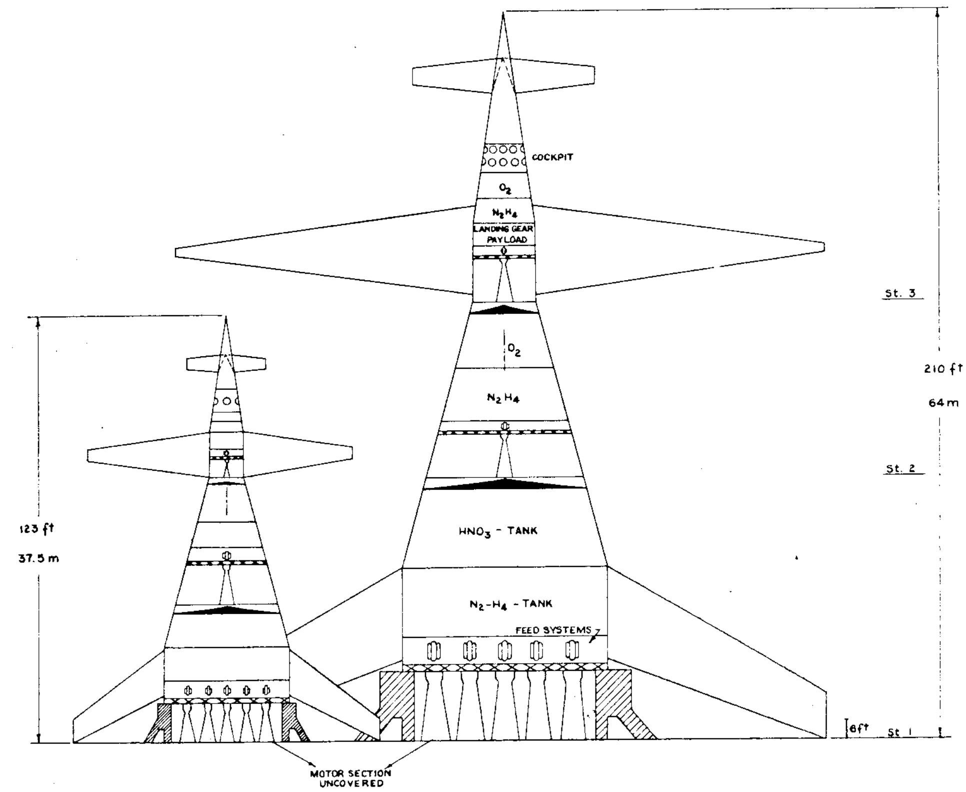
Designations and names have often changed during the last fifty years. Heavy Lift Launch Vehicles (HLLV) with take-off masses larger than 2.500 metric tons and payload capabilities to low Earth orbit of about 100 tons or larger, are classified as POST-SATURN Class Earth Launch Vehicles in this documentation. During the last forty years various studies were made of heavy lift launch vehicles in the payload class from about 200 to 500 metric tons to a low Earth orbit, representing different technologies expected to be available during the next decades. To document these efforts and compare the resulting vehicle concepts is the purpose of this report.

2. Initial Satellite Ship Studies

As pointed out in the introduction, Wernher von Braun was the first rocket designer to analyze large reusable launch vehicles in 1949/50 period in connection with his MARS Project[1]. At that time he demonstrated that a partly reusable launch vehicle, employing near term technology, could transport about 25 metric tons (t) of payload into a low Earth departure orbit with a launch mass of 6,400 t, leading to a growth factor of 6,400: 25 = 160 .

About the same time, also at Huntsville, Alabama, Krafft A.Ehricke analyzed various sizes of launch vehicles and published his version of a heavy lift launch vehicle in the official proceedings of the 3rd International Astronautical Congress in 1953 [2]. He compared two satellite ships of different size doing the same job of preparing a Mars expedition in the Earth departure orbit.

Figure 1: Satellite Ships designed in 1949/51



The drawing above illustrates the basic concept, but a set of typical data is required to describe and assess the state of the art envisioned by the authors. The essential technical data is summarized in table 1.

It took a lot of courage of a scientist in the years 1951/52 to go public with such ambitious plans for an expedition to our neighboring planet MARS. But the authors did realize that the public must be interested and convinced if their dreams should be realized one day in the future. The 21st century will probably and hopefully provide the means for the first human beings to put their feet on our neighboring planet.

Table 1: Characteristic Data for the v.Braun and Ehricke Concepts of orbital carrier vehicles

	W.v.Braun	K.A.Ehricke
1st stage:		
Thrust (t)	12,000	7,324
Launch mass (t)	6,400	4,884
Empty mass (t)	1,600	1,450
Propellant mass (t)	4,800	3,638
Exhaust velocity (m/s)	2,250	2,300
Mass ratio	4.0	3.92
Cut-off velocity (m/s)	2,350	2,087
Length (m)	29	23
Diameter (m)	20	18
2nd stage:		
Thrust (t)	1,600	876
Launch mass (t)	900	796
Empty mass (t)	70	60
Propellant mass (t)	700	609
Exhaust velocity (m/s)	2,800	3,000
Mass ratio	4.5	4.255
Cut-off velocity (m/s)	6,420	6,200
Length (m)	14	16
Diameter (m)	9.8/20.0	6/18
3rd stage:		
Thrust (t)	200	127
Launch mass (t)	130	127
Empty mass (t)	22	20
Propellant mass (t)	83	59
Exhaust velocity (m/s)	2800	3,000
Mass ratio	2.76	1.87
Cut-off velocity (m/s)	8,260	8.050
Length (m)	15	25
Diameter (m)	9.8/52 wings	6/56
Total vehicle:		
Payload (t) - (including reserve propellants)	25 (39.4)	25(28)
Propellants	5,583	4,306
Length (m)	60	64
Width (m)	52	57
Mass ratio	49	31.2

Characteristic velocity (m / sec)	10.160	9.17
Nominal growth ratio	256(162)	195(174)

These vehicle concepts can be regarded as the historical prototypes of partly reusable Heavy Lift Launch Vehicles! All vehicle concepts proposed in the decades to follow will and must be measured against this historical yardstick.

3. The original NOVA Concept

After the Sputnik shock and the creation of the "National Aeronautical and Space Administration" in fall of 1958, NASA began also to think about manned lunar missions. Alternative approaches were discussed in the committee of manned space flight in summer of 1959. Using the platform of an International Astronautical Congress in August 1959 at London, M.Rosen and C.Schwenk of NASA proposed an expendable launch vehicle concept, called NOVA, to demonstrate the requirements of a direct manned flight to the Moon[3].

This concept of a heavy lift launch vehicle was based on the new F-1 engine, which was placed under contract in January 1959 with ROCKETDYNE by NASA to close the booster gap. This vehicle was a four-stage expendable rocket to the lunar surface with high energy propellants in the upper two stages. The return vehicle was the 5th stage! NOVA diameter was 48 feet and its height about 220 feet. Only crude mass and performance analysis could be made, a preliminary design was not performed at that time. The launch mass of this conservative vehicle concept was estimated to be 3,015 t, placing a 16.2 t return vehicle (5th stage) on the lunar surface (growth factor of 186).

This was a very ambitious design concept, but This publication was instrumental to intensify the search for a rocket that could land people on the Moon. However, these efforts were conducted during the Eisenhower Administration, which was still hesitant on such a project and did not follow this line of thinking.

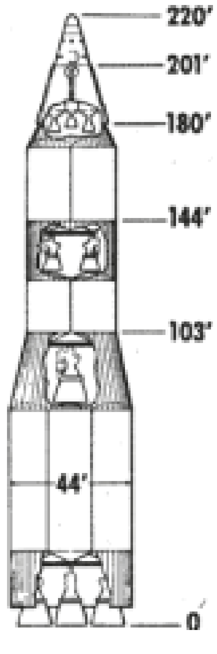


Figure 2:The 1959 NOVA concept

Not unrelated to this project was a proposal of the U.S.ARMY prepared in spring of 1959 of a lunar outpost, which used SATURN sized vehicles for the logistic support (Project HORIZON). However, after it was decided a few months later that the Huntsville team was to be transferred to NASA, the Army lost a chance to go to the Moon.

Table 2: NOVA Mass model of 1959 (1,000 pounds)- 8 t return payload

	Stage 1	2	3	4	5 return

Gross	6,700	1,700	600	102	36
Burn-out	2,000	678	146	49.1	13.7
Stage	5,000	1,100	498	13.1*)	3.8**)
Mass ratio	3.350	2.507	4.110	2.077	
Propellant mass fraction	0.600	0.622	0.715	0.802	
Specific impulse (s)	292	320	420	420	
Characteristic velocity (m/s)	3,462	2,885	5,818	3,011	
Thrust (lb)	9,000,000	1.500,000	600,000	60,000	
Thrust/launch mass	1.34	0.88	1.00	0.59	
Thrust/cut-off mass	4.50	2.20	4.10	(1.22)	

*) 13.1 empty stage, **) 3.8 empty stage

A re-check of the performance indicates that the vehicle as conceived by the authors originally would provide only 15,175 of the 16,575 m/s characteristic velocity required for a lunar flight, thus this was 1,400 m/s short. At that time little was known of the proposed mass of 8 t for the spacecraft returning to Earth would suffice.

Nevertheless, this NOVA proposal for a direct landing on the Moon, led to a detailed analysis by NASA teams in 1959/61 as one of the alternatives to achieve a manned lunar circumnavigation, or even a manned lunar landing. This evaluation was performed by the "Low" and "Fleming" Committees, in which the author participated as a member representing the Huntsville group.

4. Conventional NOVA Concepts of the early sixties[5,6,7]

After J.F.Kennedy came into office and assumed the U.S. Presidency in January 1961, the political environment with respect to rocket and space development improved rapidly. He had made the booster gap a campaign issue and had now to deliver. On top of this promise, the Soviet Union orbited their first Kosmonaut on April 12, 1961, illustrating the fact that the U.S. had to catch up in launch vehicle development. This positive trend motivated the Huntsville group to reassess the past views of MSFC in a new position paper. This was distributed within MSFC for general orientation in a time rapid changes were expected. The pertinent passages related to NOVA vehicle were formulated as follows:

The National Booster Program and Projected Activities of the George C.Marshall Space Flight Center - H.H.Koelle, April 25, 1961**.**

...

" Now let us discuss "What is NOVA?" For identification, we have used the terms NOVA-A; NOVA-B; and NOVA-C. NOVA-A is assumed to carry twice as much as SATURN C-2; NOVA-B, two and one-half times as much as NOVA-A; and NOVA-C, twice as much as NOVA-B. We do not have, at this time, the final answer on what the NOVA vehicle family should look like. Presently, we have nine studies in progress (representing an effort of more than 100 full time engineers, or one million dollars) to give us all the facts influencing the choice of the NOVA configuration and program. In one year we should be ready to make a recommendation with a high confidence factor.

If, however, we have to answer the question "what is NOVA, now?" then this is the best answer, stressing early availability and economy as parameters:

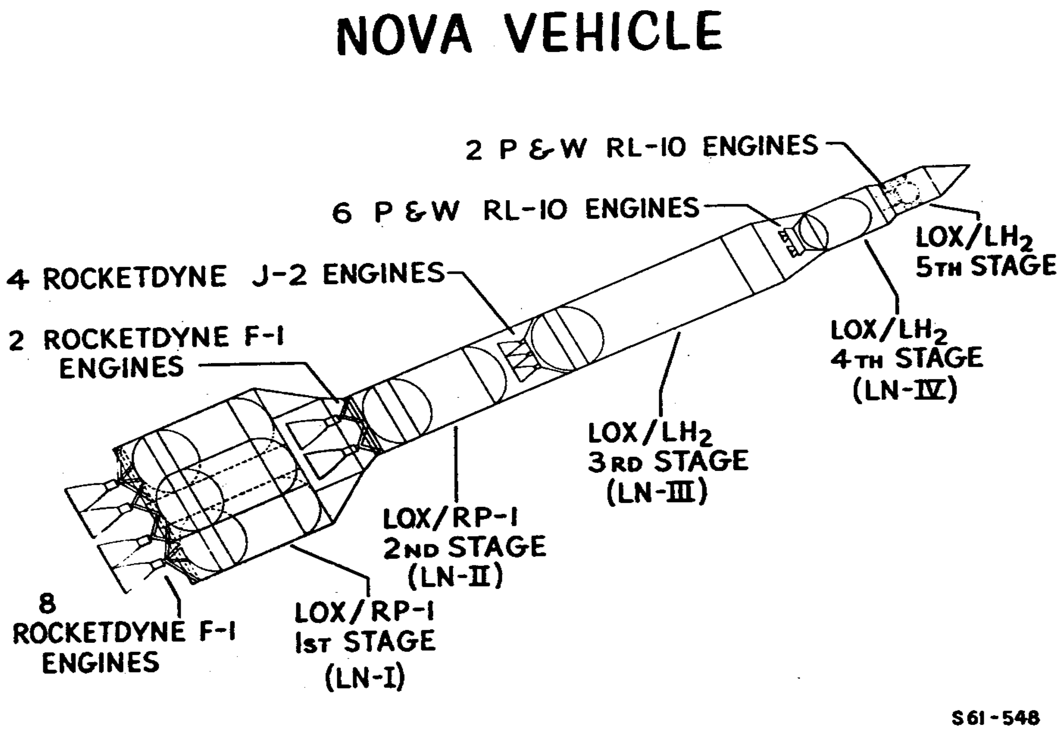
A basic NOVA module should be developed, using two F-1 engines and a single tank. This module and a lengthened SATURN S-II stage (called NOVA-A) offer a very effective two-stage orbital transportation system, particularly if one or both stages are reusable. No new engine is required and flight-testing could begin early in 1966. If three or four of these modules were clustered, the same two-engine module could be used as a NOVA base booster. Such a booster could be available a year later if desired. On the other hand, no decision on such a booster stage (N-I) is required for another three or four years. In the meantime, large solid rockets may have been demonstrated and might be an alternate choice of such a NOVA base booster. Adding the N-I stage (NOVA-B) doubles the payload capability. In this case, only the first and the third stage may be reusable. In comparison, a NOVA-A with two reusable stages would be the more economical vehicle and would probably be used in preference to NOVA-B.

Another two or three years later, when the progress of nuclear propulsion permits, the third stage of NIOVA-B could be replaced by a nuclear stage, thus considerably increasing the payload again (NOVA-C). This approach then would permit us to double our payload capabilities every two years for the next ten years. This, we feel, is necessary to keep pace with (and hopefully surpass) the growth of the Russian launch vehicle capabilities which are presently much more rapid than those suggested here. If a major effort is desired, a NOVA-B capability could be reached by the years1967/68. This appears possible if a decision were made within three months. ...

It seems feasible to start flight testing the NOVA N-II stage in 1966 and a NOVA N-I stage in 1968 or earlier, if desired."

This was the initial thinking on the NOVA concept!

Figure 3: NOVA Vehicle concept as of 1961



Barely four weeks later, on **May 25,1961** President Kennedy proposed the Lunar Landing Program to Congress as a demonstration that the U.S. is second to none! The reaction of NASA was to resubmit within weeks the budget proposal for FY 1962. Major General Don R.Ostrander, at that time Director of NASA launch vehicle Programs, presented considerably increased budget requirements of NASA in a hearing before the Committee of Astronautical and Space Sciences U.S.Senate on June 8, 1961. Most of the material he used originated from MSFC. The following statements were related to the NOVA program[4]:

"As discussed on previous occasions, the total thrust required to land a man on the Moon and return is beyond the anticipated capability of the SATURN vehicle. So as a result additional funds in the amount of $48 -1/2 million are being requested for the development of this multi-million pound thrust vehicle, to be initiated during fiscal year 1962 as Project NOVA.
....
The total thrust of NOVA first stage, will probably turn out to be in the order of 12 million pounds. We are currently studying several configurations of NOVA. Under our current planning, specifications for this S-II stage have been revised also to assure a stage that is basically adaptable for future use with the NOVA vehicle. The source selection process for this contract is currently under way.
The increased effort in component technology will be used for advancing the art in areas of critical importance, primarily to the NOVA project. For example, in case of the NOVA, we have a vehicle that is several times larger than our current boosters, and consequently we are going to have to perfect new construction techniques, which will minimize weight and at the same time insure adequate strength.
...

Now, the NOVA vehicle has been under study in NASA since 1959. Many components for NOVA, such as the F-1 and J-2 engines, have been under development for some time. This revised NASA budget requests funds to initiate the development of a fully integrated four-stage NOVA vehicle system, including all of the components not already under development. It included also an extensive supporting technology program, and a major facilities construction program to provide the large static test facilities and launch facilities that will be required for this project.

Two versions of NOVA will be pursued initially on an equal priority basis. One will employ solid propellant rockets, and the other liquid propellant rockets, in the first stage or possibly first two stages. However, for both approaches, a modified SATURN S-II stage, with enlarged tanks, is planned for the third stage, and a modified SATURN S-IV stage for the fourth stage. In case of the all-liquid propellant NOVA eight F-1 engines will probably power the first stage and provide 12 million pound thrust. This illustration (figure 3) shows one of several versions of the all-liquid NOVA, which are currently under intensive study.
..."

It may be interesting to follow the developments in some detail how rapidly things evolved. During the year of 1961 NOVA was one of the vehicle concepts competing for the lunar landing job. It was de-emphasized in mid 1962 after the Lunar Orbit mode using the SATURN C-5 was selected as the reference mission architecture. The source of relevant NOVA information are taken from the Weekly Notes of the Director, FPO to Director, MSFC:

November 20th, 1961:
NOVA PRELIMINARY DESIGN
Work has been started to prepare a composite plan leading to the definition of NOVA.The Plan will include in-house, as well as contractor effort, and will be coordinated with the Divisions. After finalization, it will be sent to you for forwarding to Mr.Holmes so we can get the 2.3 million for NOVA presently in the financial operating plan.
The effect of a nine-month delay in a NOVA decision on the first launch date was studied for the LLVPP (GOLOVIN Committee) and the results forwarded for inclusion into the final report. For the 8xF-1 plus 8xJ-2 configuration a delay of 9 months in program approval caused a four month delay of the first flight.

January 15,1962:
NOVA
We are now preparing an action plan concerning NOVA efforts (spending approximately two million dollars in the next eight months) in order to produce a firm NOVA configuration and development plan. We should be ready to present our proposal to a special "Technical Board Meeting" on or about January 22 in the hope that this meeting will produce a Marshall position, which you could present to the next Management Council meeting in Washington late in January.
February 5,1962
NOVA
F.L.Williams spent two days in Washington talking with Mr.Canright, Mr.Rosen and Norm Rafel about future activities in the area of NOVA. The Headquarters people are in general agreement with the plan as proposed by MSFC; however, they would like to get a hardware contractor onboard 4 to 8 months earlier than indicated in the MSFC plan. Several possibilities were discussed, such as performing the study program as outlined in the MSFC proposal and telescoping the hardware RFQ, evaluation, etc. into the concluding time period of the study program. A second possibility would be having a shorter study program, approximately 4 months. The first of the above possibilities seems to be more attractive at this time. It is

anticipated that it will be approximately one month before NOVA money is released to MSFC for action.

February 19, 1962
NOVA
We received the Headquarters draft of the rewritten work statement on the NOVA Preliminary design study. They have made considerable changes to our proposal. We are willing to go along with many of them in accordance with our desire to create a good team spirit. However, there are approximately 13 mandatory and 8 desirable changes, which we will submit in writing February 20, by special delivery.

March 19,1962
NOVA
As scheduled, Frank Williams presented the NOVA study plan to Mr.Holmes and Dr.Seamans. Each, in turn, signed off on the plan. Both are very happy with the support that MSFC was giving to NOVA. Dr.Seamans is expected to formally approve the Phase I study effort and release the $ 2.3 M on Monday, March 19. Present plans call for release of RFQ between March 23 and 27.

As long as NOVA was a contender for the lunar landing mission, activities at MSFC concentrated on the performance issues, primarily on the question of margin for error and risk. The following MSFC Position on NOVA was sent to Mr.Brainerd Holmes, Director, Office of Manned Space Flight, NASA signed by Dr.von Braun: MSFC/FPO Memorandum M-FPO-601-62, March 28, 1962 [6]:

Subject: NOVA Configuration

1. The NOVA configuration presently advertised by NASA Headquarters, and described to Congress, is a three stage vehicle with 8 x F-1 engines in the first stage, 4 x M-1 engines in the second stage and one J-2 stage in the third stage. Present calculations show that this base point vehicle has a two-stage payload capability of 4,000,000 to 4,120,000 lb for a low orbit, using the same assumptions as made for the SATURN C-5. It is concluded that this performance is marginal for the direct approach, and does not offer a margin for error that is large enough to cover the unforeseen eventualities.
2. Excess performance is required in the order of 25% over and above present minimum requirements to allow the following options:
a. Increase in spacecraft weight.
b. Engine out capability in both stages if engine reliability is less than expected.
c. Increase in shielding of crew against major solar flares.
d. More doglegging and increased launch window time on the ground and in orbit.
e. Reduction in transfer time.
f. Greater amount of emergency supplies and equipment to be carried by the spacecraft to the lunar surface.
g. More abort flexibility.
h. Trade-off possibilities of performance against funding and schedule.
i. In case the M-1 engine should run into major difficulties, a cluster of 8 J-2 engines should offer an acceptable alternate propulsion system for the second stage within the available performance margin.
3. It is recommended, therefore, to select a configuration that has a 500,000 lb payload capability into low altitude orbit and not less than 180,000 lb to escape.
The most promising configuration to satisfy this requirement is a three-stage vehicle with 10 F-1 engines in the first stage, 2xM-1 engines in the second stage and one J-2 engine in the third stage. This configuration is particularly

attractive as a base point design under these conditions, because of the following reasons:

a. The 25% performance margin would be obtained with basically no additional cost and at no increase of vehicle length, if compared with the present reference vehicle (8+4+1).
b. Mission reliability should be equal or better because of the first stage hold down feature.
c. Hydrogen requirements would be reduced.
d. Separation dynamics would be improved because of increased separation altitude.
e. Second stage acceleration would be decreased which would result in a more precise cut-off velocity vector.
f. NOVA would offer a double backup to the orbital operations mode, in case
(1) Rendevouz develops major problems, and
(2) Spacecraft weight increases considerably.

4. Recommendation

To secure Headquarter approval to select the (10+2+1) NOVA configuration as the primary vehicle to be studied in the preliminary design contracts to be let in the near future (mid May 1962).

<u>Total vehicle:</u>
Vehicle propulsion reliability: 0.847
Total vehicle length: 361-406 feet
Development cost: 3.538 B $
Cost per flight (veh.no.11): 67 M $
1st flight date: 52 months from N-I go-ahead
1st flight date of two-stage vehicle: 65 months from M-1 go-ahead
Specific transportation cost at 0.95% reliability: 67 M $: 522,723:0.95 = 135 $/lb

- 10 + 2 + 1 configuration has a 25% margin for error with respect to APOLLO performance requirements
- Use of 10 J-2 in the second stage would allow first flight of 2nd stage vehicle in 48 months after contract go-ahead, an engine out capability would probably be necessary

Table 3: Interim Reference NOVA Configuration (10 F-1, 2 M-1, 1 J-2)

	Stage I	Stage II	Stage III
Lift-off weight - lb	12,000,000	2,872,722	700,536
Dry weight - lb	582,300	161,900	23,000
Cut-off weight - lb	3,682,600	715,796	213,492
Mass fraction	0.912	0.918	0.914
Propellant weight - lb	9,118,285	2,349,998	301,833
Thrust - lb	15,000,000	2,400,000	200,000
Diameter - in	600	600	260
Max q - kg/m2	3,490	46	0
Gross payload		522,723	205,630
Net payload - lb		**507,463**	203,821
Engine system reliability	0.9045	0.9506	0.9850

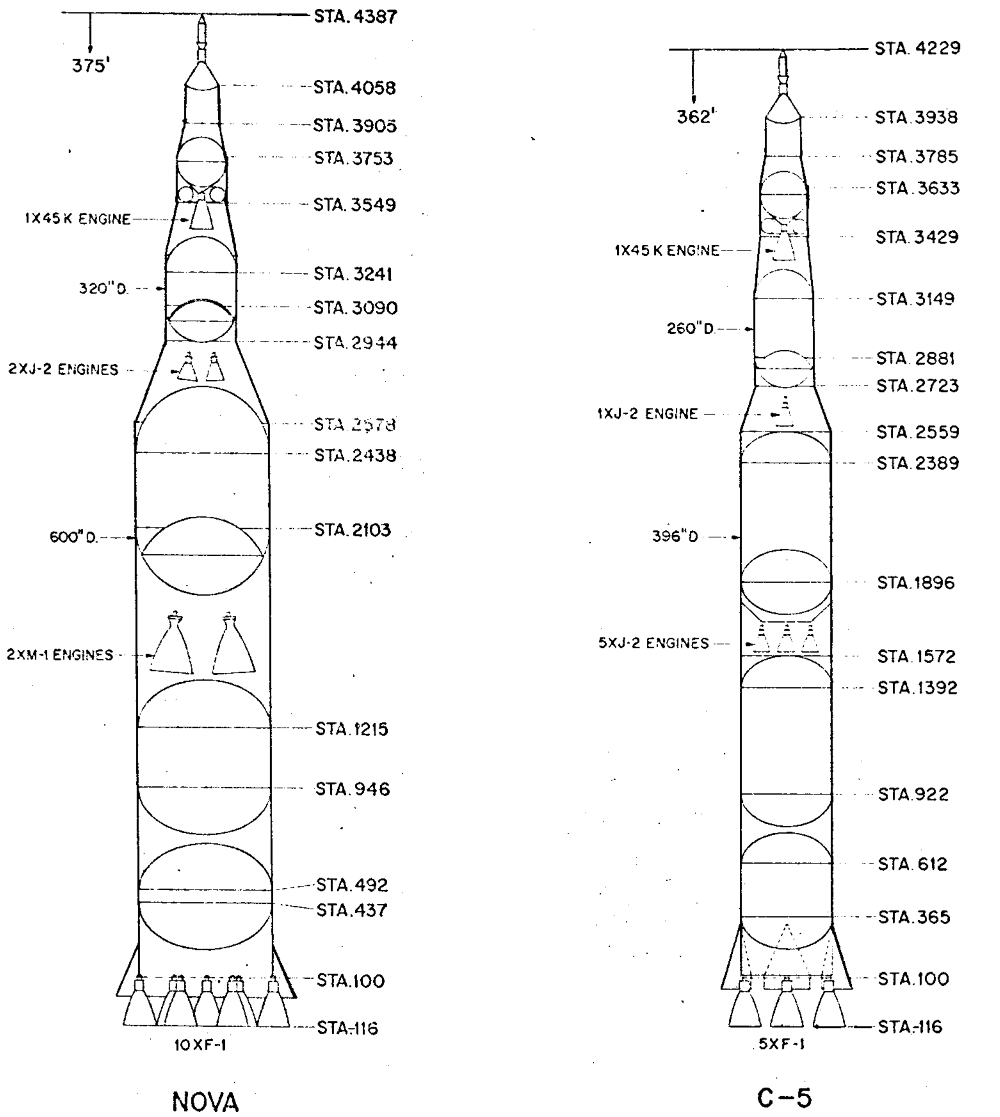


Figure 4: Conventional NOVA Concept as of April 1963 compared with the SATURN C-5

NOTE: Already in January of 1962 NASA announced that the SATURN C-5 was selected as the launch vehicle that would transport the Astronauts to the Moon in conjunction with the APOLLO spacecraft. After the Lunar Orbit Rendevouz (LOR) mission mode was approved in June of 1962 the NOVA launch vehicle studies landed on the "back burner". This prompted a reorientation of the NOVA studies that were continued at a reduced level of effort and with the number and type of engines reopened.

5. The Russian Heavy Lift Launch Vehicles

5.1 Moonrocket N-1

In July 1960 the Soviet Government decided to develop a new class of launch vehicles for military purposes and possibly for later manned Mars missions (N-1, N-2). The chief designer of the Russian launch vehicle program Korolyov, taking the American plans seriously, proposed formally a manned lunar landing program by letter on July 27,1963. It took several months, before he was finally authorized (February 1964) to begin respective preparations. The Soviet manned lunar program began officially only on August 3, 1964 after approval by the President. After some budgeting difficulties, and alarmed by the American progress, the top priority was assigned to the lunar program only on February 4, 1967. It comprised the N-1 as a launcher for lunar missions and the Chelomei manned spacecraft UR500/LK1. The design and performance specifications of the vehicle are summarized as follows (# payload of 5th stage assumed to be 3.5t):

Table 4: Characteristics and Data of the Moon-Rocket N-1 (Source: astronautix.com)

Stage	1	2	3	4	5
Gross mass (t)	1880	560.7	188.7	61.8	18.2
Empty mass	130	55.7	13.7	6.0	3.5
Propellants	1750	505	175	55.8	14.7
Propellant fraction	0.93	0.90	0.93	0.90	0.81
Mass ratio	2.823	2.56	2.87	3.305	2.6(#)
Characteristic velocity (m/sec)	3258	3190	3650	4138	3270
Vacuum Thrust (t)	5130	1432	164	45.48	8.5
Specific impulse (s)	284/330	346	353	353	349
Burn time(s)	125	120	370	443	600
Diameter (m)	10.3	6.8	4.8	4.4	2.9
Span (m)	12.9	9.8	6.4	4.4	2.9
Length	30.1	20.5	14.1	9.1	2.9
Engines	NK-19	NK-15V	NK-21	NK-19	RD-58
No of engines	30	8	4	1	1

The engine designations are listed differently in published sources. One description is as follows:

The N-1 launch vehicle had a sea level thrust of 4.620 tons, 105 meters high, core diameter 10.0 m. It had 43 engines, including 30 NK-33 engines with 154 metric tons thrust. Of these, 24 were arranged in an outer circle, six in an inner circle. Propellant consumption was 500 kg/sec per engine with a mixture ration of 2.8 oxygen :1 kerosene. The specific mass of the engine is 8.1 kg mass/t thrust. The combustion chamber has a diameter of 430 mm and a throat diameter of 281 mm. Chamber pressure was 148.9 kg/cm2. Engine mass when fueled was 1340 kg. First stage burning time was 110 sec., it did have an engine out capability!

The second stage had eight NK-43 Lox/kerosene engines, similar to the NK-33, but a larger nozzle with an exit diameter of 2.5 m. Its thrust was 8 x 179 = 1.432 metric tons (force), specific impulse 346 seconds, specific mass 7.8 kg mass/ton thrust. The 3rd stage engine NK-39 had a thrust of 41 t and a specific impulse of 352. Chamber pressure was 100 atmospheres. The stage had 4 engines = 164 t. The NK-31 fourth stage engine could move the thrust vector in two planes and had two roll nozzles.

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LEO payload of the N-1 was planned to be initially 70 t to a 225 km orbit at 51.6 degrees, design goal 95 t to LEO. This performance would be sufficient for a lunar landing and return mission, however, with a rather small manned return capsule of about 4 metric tones. Flyaway cost are quoted $ 604 M per vehicle for the year 1985.

The design goal of a 45t payload was later increased to 75t for orbital missions and 25 t for Mars missions. It took, however, several years before the actual development was officially initiated.

The first launch attempts had only three active stages, not fully loaded and higher empty mass than planned. The vehicle failed in four flight attempts between 21 February 1969 and 23 November 1972. The first flight test ended with an engine failure after 57 seconds at an altitude of about 30 km. The second launcher exploded on the ground. The third flight (July 3,1969) experienced a control system function in the first stage. The 4th test ended 104 seconds, after a leak in the propellant lines.

The unsuccessful program was discontinued in 1974[31].

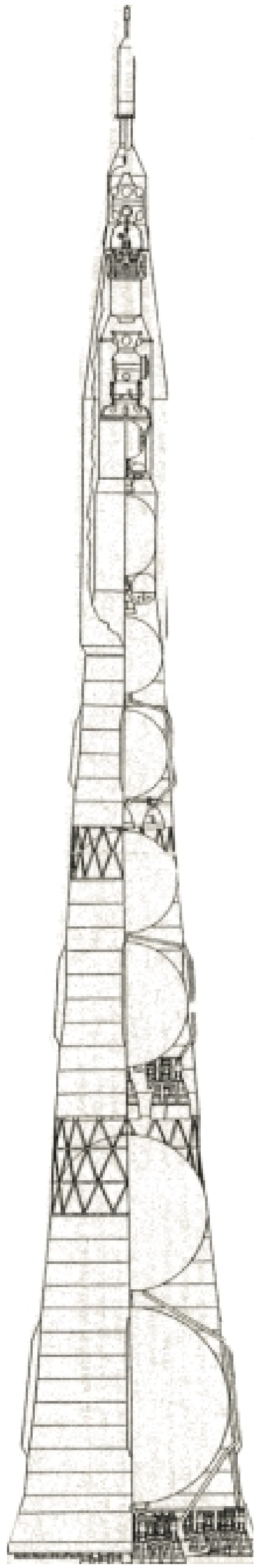

Figure 5: The Russian Moon Rocket N-1

5.2 ENERGIA

The second attempt of Russia to develop a HLLV was successful. Its development was initiated about 1980 in connection with the plans of a semi-permanent space station (MIR). The developer was OKB ENERGOMASH, a space company founded by S.P.Korolyow.

This HLLV was intended to launch military satellites and a manned space shuttle (BURAN). It was a two-stage orbital launch vehicle that uses high-energy propellants in the second stage. Its first launch on 15 May 1987 was successful, a heavy satellite reached orbit, but with a very short lifetime. The second launch on 15 November 1988 carried an unmanned BURAN shuttle that was automatically landed and a full success. After modification the second BURAN vehicle was scheduled for the year of 1993 to support the MIR space station.

However, the dissolution of the Soviet Union in 1991 led to a shortage of public funds, and in this context consequently to an end of the ENERGIA/BURAN program.

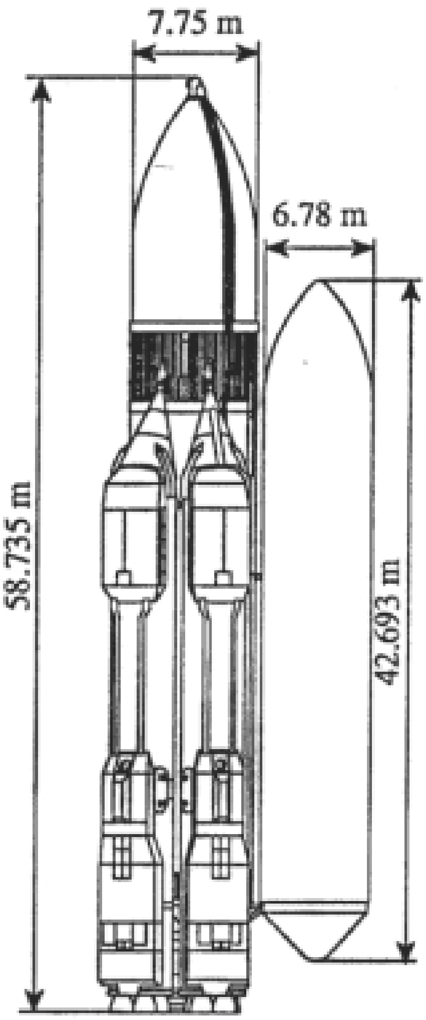

Fig.6: ENERGIA HLLV

Its characteristics can be summarized as follows:

Table 5: Characteristics of the Russian ENERGIA HLLV

	Booster	Core stage	Total vehicle
Propulsion sys. Mass (t)	13.8	8.755	
Dry mass (t)	54.0	18.3	
Engines	RD-170	RD 200	
Propellants (t)	319	820	
Burning time(s)	145		
Thrust (kN)	7907	4x1962	
Exhaust velocity (m/s)	3295	4454	
Launch mass (t)			2222

Payload mass to LEO (t)			100
Length (m)			58.735
Diameter (m)			7.75

6. Advanced NOVA Concepts of the Sixties [7 thru 22]

After it was officially decided by the NASA top management in January 1962 that the original NOVA would not be selected for the lunar landing program, as discussed in chapter 4. The question that remained was: "what happens after the lunar landing?" At that point in time (1962!), it was completely open how the space program would continue. The possibility of extended lunar operation and/or manned planetary flights was analyzed. This was in preparation for program changes and future surprises. This task prompted the search for the next generation of large launch vehicles and their potential missions. The respective activities are documented in the Weekly Notes to Dr.von Braun:

April 30, 1962
ALTERNATE NOVA
Because of the recent decision of postponing the preliminary design study of the proposed (10+2+1) configuration, it is now unlikely that this configuration will ever materialize. I am now setting my goal higher for a NOVA which can carry twice as much, namely 1,000,000 lb or more to orbit at a specific transportation cost of 50 $/lb or less. NOVA specific transportation costs were estimated at approximately 250 $/lb total operation cost.
The most promising concept which seems to satisfy this requirement appears to be Bob Truax's sea launch concept of a pressure fed two stage to orbit reusable vehicle. ... I would like to give you a short briefing on this very soon. We are about to begin three studies with RAND, General Dynamics/Astronautics, and possibly Douglas on conceptual designs of vehicles that, up to now, have been called "POST-NOVA Class". Another point to be discussed in this connection is what we propose should be done with 2.3 M $ earmarked for NOVA. I do have a proposal to offer. Let us make sure that we do not lose this money.

May 14, 1962
CONTRACTOR SELECTION - POST NOVA STUDY
The evaluation of the proposals received was carried out by a team of eight specialists, chaired by myself. Five proposals were received: NAA, GD/A, Lockheed, STL and Douglas. The preferred sequence is: (1) GD/A, (2) Douglas, (3) Lockheed, (4) NAA, (5) STL. We strongly recommend GD/A and Douglas. They are the best and the cheapest. Furthermore, these two companies have been unsuccessful in winning any of the other FPO contracts and we do want to keep contact with their preliminary design groups.

May 21,1962
NOVA
The NOVA System Study Source Evaluation Board will be rescheduled for June 20, if it meets your approval. We feel, we want to make a selection of a study contractor for a NOVA baseline study, regardless of which way the decision (on the APOLLO mission mode) goes. Even if NOVA is dropped from the initial lunar mission, we need a point from which to depart in order to come up with a bigger and more efficient NOVA. It is logical to have one study along this line, since it was originally proposed for this very purpose, to establish a base point.

June 25,1962
SOLID BOOSTED NOVA
We have reviewed with Boeing the progress during the first 1/3 of the present study. We have dropped all plans to have the study augmented by a design using 8 x 156" rocket motors, instead,

we are adding a task for a parametric study for payload capabilities in excess of 500,000 lb using 260" motors. Baseline design will have a 500,000 lb payload to a low Earth orbit.

July 16, 1962
NOVA
Headquarters approved the recommendation of the NOVA Source Evaluation Board on July 10th and it was announced on Friday July 13, that GD/A and Martin had been selected for contract negotiation. The original NAVA management team has been reactivated and agreed on a schedule leading to a kick-off on August 15 and final presentation of results in mid April 1963.

September 17,1962
NOVA CLASS VEHICLE
In our advanced NOVA study, Krafft Ehricke presented a new approach to the problem. He proposed to study in detail a single stage reusable vehicle compatible with very voluminous payloads, such as nuclear propelled Mars ships. His design is the first launch vehicle I have seen which has a larger diameter than length. It looks like one of the better approaches to the problem.

October 8, 1962
M-1 NGINE
It will be April 1963 before we will know what NOVA we might want, and only then we will be able to specify what kind of engine we want. My best guess at this time is: Thrust level maximum 3,000,000 lb, down to 50% throttled; advanced nozzle which can operate at sea level as well as at altitude, combustion pressure 3,000 psi, designed for multiple reuse. You might want to spread the word that we would like to keep the door open for a complete change of M-1 specifications.
EARLY MANNED PLANETARY FLIGHTS
I just returned from the mid-term reviews of our planetary study contracts at GD/A, Aeronutronic and Lockheed. These are important for NOVA size and timing. One thing comes out loud and clear: We are in a box! This is not yet a crisis, but soon may become one. There is a definite launch window for Mars in the early seventies (1973, may be 1975), as the energy requirements will go up rapidly in the early seventies due to the eccentricity of the Mars orbit. The solar flare minimum is in the years 1972/74. On the other hand, we need a high thrust nuclear engine with about 700K to make a fast (1- 1/2 year) roundtrip, which takes 10 years to develop. If we do not get a decision next year for the facilities for this engine, we will probably not make the 1973 launch date. For the 1975 date we need a 900 sec specific impulse. A 30K lb thrust tungsten reactor would have a development lead-time of about 12 years. If we miss this launch window (1973/75) we might have to wait 14 years (!) for another chance. By next April we should be able to come up with alternatives for NOVA, as well as the early manned planetary exploration. - *(Dr.v.B.comment: Interesting. Suggest, rather than just ringing alarm, you prepare several alternate proposals, none over ten pages thick. Should be geared to whatever NOVA we'll come up with, of course.)*

October 15, 1962
NOVA
After the provocative Aerojet Advanced-Engine Meeting last Tuesday, a meeting was held between MSFC propulsion people and the Lewis people who were here to discuss the M-1 situation and NOVA. As a result of the meeting it was decided: (1) Not to attempt at this time to make any drastic changes on the M-1 program but wait for a NOVA decision; (2) get an in-house effort underway, both here and at Lewis, to evaluate the various advanced engines; and (3) set March 1st as a target date for selecting a NOVA configuration and deciding on where we go from here with the M-1 program.

October 22,1962
NOVA
As a result of our discussion with you and the 2nd Quarterly Review (OMSF released the remaining $ 1.2.M) the GD/A and Martin contracts will be extended into July/August 1963 with March 1st as a target date to select a basic configuration.

October 29,1962
NOVA

Frank Williams and several Division representatives are visiting Martin and GD/A this week to review in detail the progress on the NOVA studies. With your approval, we are reorienting the effort towards more advanced NOVA concepts, and we have postponed the date for a selection of a particular configuration at least until March 1,1963. We are also continuing our study contract with Boeing on the solid boosted NOVA in the amount of $ 200,000. The main problem of the solid version seems to be the length. If we use a cluster of four 260" solid rockets in the first stage and want a million lb payload capability, we get a 700 feet long vehicle and a free-free first bending frequency of 1 cps, forcing us to increase the diameter of the vehicle.

November 13, 1962
NOVA
...
Due to recent budget exercises (FY 1964) the study schedule has been changed as follows:
a. Completion of Conceptual Phase on April 1,1963. At this time we should be in a position to narrow the number of configurations to one and initiate the preliminary design phase. However, we have the choice of keeping the two most desirable configurations and putting them through a parallel preliminary design phase and make the one selection in August 1963, then start the detailed preliminary design phase.-- At this time the latter seems to be the best choice.
b. Complete preliminary design and system definition phase by August or, if we choose the alternate plan above, select one vehicle and initiate a detailed preliminary design in August 1963. It would be completed along with systems definition by March 1964. This would give several months for hardware RFQ, evaluation, and contractor selection for program initiation early in FY 1965. This study modification is in line with our discussions of early October.

November 26, 1962
ADVANCED NOVA STUDIES
I have just returned from the midterm reviews of our studies with GD/A, Douglas and RAND. Krafft Ehricke's concept of a large reusable NOVA still looks very promising because of its basic simplicity. It does require a new engine of the Aerojet (Beichel) type and probably solid RATO's as insurance for adequate performance. Douglas has done a very good systematic comparison of various concepts and is now concentrating on reusable concepts called ROOST and RHOMBUS.
...

December 12, 1962
NEXUS LAUNCH VEHICLE CONCEPT
The advanced NOVA studies brought out one outstanding vehicle concept of a reusable NOVA size vehicle in the one million pound payload class. It is a reusable vehicle, one stage to orbit with solid rocket assistance during take-off. This GD/A concept has all the elements of a potential breakthrough in launch vehicles. It does require a new hydrogen/oxygen engine and, therefore, could not be available for flight test prior to 1971/72. I have about 20 slides describing this concept and would appreciate an opportunity to present these slides to you and/or the board at your earliest convenience, because it can influence greatly our thinking on NOVA.

Program Reorientation:

MEMORANDUM FOR RECORD [9]
SUBJECT: Course of Action for Next Phase of NOVA Studies
TIME and LOCATION: MSFC Director's Office, **January 23,1963,** 4:00 to 5:00p.m.
PARTICIPANTS: Dr.von Braun, H.H.Koelle

1. Background:
The original NOVA concept was developed in the years 1959 to 1961, with the goal of providing a direct flight capability of a 10,000 lb capsule to the Moon and return to Earth. The desired schedule dictated the selection of a concept within the present state of the art, essentially represented by the Advanced SATURN, which now does have a single flight capability to the Moon by

adopting the LOR mode of operation and thus satisfies the original NOVA requirement. The final selection of the APOLLO mode made the original NOVA concept obsolete, since the potential mission assignments, as well as the most likely operational time period has shifted drastically. Moreover, it becomes more and more apparent that resources during the next few years will not permit the development of any large launch vehicle at a rapid pace with an early availability goal. This situation demands a reassessment of present plans and probably some reorientation of existing study activities.

2. Present Activities:
Present study activities are centered at the Martin Company and General Dynamics/Astronautics Division with considerable support from MSFC, representing a level of effort of approximately 400 direct engineering man-years. In addition, supporting study contracts are in effect with Douglas and GD/A in the areas of "advanced" launch vehicle concepts, and Boeing on "solid boosted" large launch vehicles. Mission oriented studies on lunar and planetary missions of very large launch vehicles are currently in progress at Lockheed, Vought, CD/A and Ford Aeronutronics. These supporting studies approximated an expenditure of nearly one million dollars during FY 1962 and are being continued at about the same level during FY 1963. All these studies are coordinated, directed, and integrated by the Future Projects Office, MSFC, with participation by other NASA Centers and respective Program Offices. The main objective of the past effort was to take a new look at the overall situation, the state of the art, potential mission requirements, and to determine and select the most promising vehicle concepts and attractive program approaches recommended for further study. This "conceptual design phase" for the next large launch vehicle will be concluded March 31, 1963 and will result in the selection of two to three attractive approaches for further study.

3. Planned Activities
The Director, OMSF, has approved an amount of 1.2 M $ for Phase II of the NOVA class launch vehicle studies, and an amount of 0.5 M $ for supporting test facility studies at MTF. This Phase II study is expected to last about 6 month. The proposed procedure is as follows: both contractors (Martin and GD/A) will continue their studies with emphasis on advanced vehicle concepts; this will permit a double quantum jump in single launch payload capability as well as in economy. Partially or fully reusable concepts with an orbital payload capability in the one million pound range and a cost effectiveness of $50/lb or better will be the design goal. These new concepts will permit the development of new propulsion systems, integrated into the airframe for optimum performance, and sacrifice, if necessary, early operational availability for a low obsolescence rate. The possible requirement of meeting an early planetary launch window will be considered only of secondary importance.

In addition to these advanced launch vehicle concepts, one vehicle representing the conventional expendable NOVA will be carried along and updated, so that it can serve as a yardstick for comparison with more advanced concepts. It is likely that a solid boosted NOVA vehicle in the 8000,000 to 1,000,000 lb orbital payload class will be selected for this purpose as a base-point vehicle, since it is considered to be one of the best solutions for an e a r l y expendable vehicle in this payload class. This vehicle can also be considered as "insurance" against a new situation, where a major reorientation of the national space program would become necessary, demanding a large payload capability at the earliest time.

The main objective of the 6 month Phase II study is to identify problem areas of large advanced reusable launch vehicles, which demand aggressive research and development activities, such as advanced nozzles, high pressure engines, thrust augmentation, integration of airframe and propulsion systems, structural fatigue, engine lifetime, etc. An attempt will be made to arrive at a preliminary design of such an advanced reusable large launch vehicle concept that will be typical of the state of the art of the early seventies. This vehicle can than serve as a focal point for two or three years of intensive component and research activity, and for the development of detailed test and development plans including facility planning. At the end of this phase it should also be possible to reorient the M-1 engine development program, so that it can contribute in the most effective way toward the goal of a greatly improved advanced launch vehicle. Additional studies in the mission area will relate the mission capabilities of the next generation large launch vehicle to potential applications for lunar and planetary missions.

4. System Criteria (Why, When and What)

The justification for a new large launch vehicle will have to be based on the following points:
(1) The vehicle has to offer significant new mission capabilities,
(2) It may offer mission accomplishments considerably earlier than alternate systems,
(3) It must offer greatly improved cost effectiveness over an advanced SATURN V.

The timing of the availability of a new large launch vehicle will be primarily be governed by:
(1) Availability of resources,
(2) Availability of technology to make a quantum jump in payload capability and economy, and
(3) Chances for major mission accomplishments.

The selection criteria for a specific design concept have been chosen tentatively in order of priority as follows:
1. Obsolescence rate
2. Mission capability
3. Cost effectiveness
4. Development risk
5. Development cost
6. Reliability potential
7. Availability.

5. Name:
The question was raised as to the advisability of dropping the name NOVA at this time, as it is normally related to a large expendable vehicle concept that competed for the APOLLO mission. It also gives the impression of an approved launch vehicle program. It was agreed to ask for guidance from OMSF on this aspect.

6. Schedule:
In early April, a MSFC team will brief OMSF on the results of the Phase I NOVA study and the proposed plan of action for Phase II. By October 1963 the studies should have progressed to a point where those state of the art

development programs, which are long lead time problems or most promising areas with respect to overall system improvements based on the investment required, can be identified.
The overall concept and system aspects should have been sufficiently clarified at that time to permit a tentative decision on how to proceed with the development program with a reasonable degree of confidence, provided a decision is desired at that time.

7. OMSF Approval:
It was agreed to make this memorandum for record the basis of an official planning document to be submitted to Mr.B.Holmes within 10 days for concurrence and/or approval.

Excerpts of the MINUTES OF ADVANCED NOVA MEETING at MSFC-
January 29,30,1963

A review meeting was held January 29&30,1963 at MSFC on ADVANCED NOVA Study contracts, involving the following companies: RAND, Douglas, STL, Aerojet, GD/A. Representatives of the Martin and Boeing Company were invited as visitors. A total of 31 NASA staff members and 31 industry representatives participated in this review meeting.

Introduction (H.H.Koelle)
The objective of the ADVANCED NOVA studies is to find a vehicle concept that would provide a double quantum jump when compared to the SATURN V launch vehicle, in the 1970 to 1980 time period, i.e. carry 4 times as much payload at 1/4 of the cost.
Each study contractor will report in this session on one concept that will meet the primary objective of these studies with the exception of RAND Corporation. RAND will report on the systems aspects and comparison of various candidates. STL/Aerojet will report on the Sea Launch Concept, GD/A will report on the NEXUS concept, and Douglas will report on the ROMBUS concept. All of these systems will be limited to chemical propulsion systems.
It is necessary to make a basic assumption that there is not going to be any large sum of development money available for the next 2-3 years. Therefore, our immediate goals are to identify areas of advanced technology where modest sums of dollars can be efficiently applied and select representative vehicle concepts.
Our current milestones are as follows:
April 1963 - Select 2 or 3 candidate vehicles for further study
October 1963 - Finalize advanced technology program and attempt to reduce number of candidate vehicles to one. After the formal presentations we will attempt to determine the following:

a. Firm conclusions;
b. Tentative conclusions;
c. Critical areas; and
d. Areas of concern.

To make sure that I was in full agreement with Dr.von Braun on the next steps to be taken, I did send him the following note to obtain his concurrence on the position paper in preparation:

April 8, 1963:
NOVA REDIRECTION
As a result of our discussion on Wednesday, April 4 and your directives, we are now reorienting our study efforts in the direction of u n c o n v e n t i o n a l r e u s a b l e NOVA concepts. We will issue new guidelines to the contractors this week along the following lines:
A. Sixty percent 0r more of the total study effort will be applied in the area of operations analysis and conceptual design leading to and approaching the greatest practical extent of an "ideal NOVA" as defined below.
(1) NOVA must have a multiple mission capability, preferably in all of the following areas:
- Earth to low orbit heavy cargo delivery,
- Earth to orbit cargo delivery in connection with doglegging into high orbit inclinations and/or inter-orbital transfer to high altitude orbits,
- Global logistic transport for cargo and personnel,
- Lunar logistic transport for mixed cargo and personnel,
- Planetary logistics for cargo and/or personnel,
- High velocity space probes.
(2) The "ideal" NOVA concept might have most of the following features: Single-stage, land and sea recovery, design lifetime of 1000 flights, terminal guidance, wide payload range capability, acceptable acceleration limits in case of personnel transport, compatibility with nuclear upper stages.
B. The rest of the effort will be used to up-date conventional, expendable or partially reusable NOVA vehicles, in the latter case with first stage recovery as a minimum goal. This data will be used to evaluate the advantages offered and price to be paid by various "ideal NOVA's" we hope to come up with.
Does This Formula interpret your instructions close enough so that we can proceed?
(Dr.von Braun comment: Precisely. You may proceed on this basis. Capt.Freitag also agrees. Make sure you get Dr.Shea on board also (thru Doug Lord).- B 4/13)

The presentations of the contractors and the discussion to follow brought out significant information about the state of the art to be expected. Including the results of further meetings with contractors, the current status of the relevant technology and concepts, derived for a heavy lift launch vehicles larger than the SATURN V, now developed, were summarized by the Director, Future Projects Office in a Status Report quoted below. This Status report included also the latest directives and the results of MSFC in-house studies which were presented by the NOVA team to the Development Board on April 20,1963.

SUMMARY OF NOVA STUDIES by H.H.Koelle, Director,FPO, **May 1, 1963**

A. Introduction

In the area of NOVA size launch vehicles, the following subjects have been studied during the past year:
1. Conventional chemical vehicles by the Martin Company, GD/A and Boeing

2. Chemo-nuclear vehicles by GD/A and Douglas

3. Sea launched vehicles by Aerojet, STL, Douglas and RAND

4. Advanced chemical launch vehicles with emphasis on vehicle recovery by GD/A, Martin Company, Douglas and RAND.

Seven contractors were awarded contracts totaling $4,760,000, with additional effort by the contractors in the amount of $2,000,000. The RAND contract was terminated in February 1963, and the STL, Aerojet and Boeing efforts will be terminated in May 63.This leaves the following contractors as the major contributors in the NOVA study project:GD/A, Martin Company and Douglas.

The present knowledge on the next large launch vehicle is grouped into two subjects: *Conclusions to Date* and *Critical Areas.* This information is summarized in the following sections along with a synopsis of our planned effort in the next six months.

B. Conclusions to Date

1. A new large launch vehicle in the 500-ton orbital payload class cannot be justified, unless one or more of the following requirements materialize:
a. A large lunar base, b. manned planetary flight, c. military orbital, or d. global cargo missions.

2. The complexity of planetary flight forces us to accept, within reason, a certain degree of complexity on the ground or in the launch vehicle whenever we can, thereby simplify the remainder of the mission.

3. A new large launch vehicle in the 500 tone orbital payload class will lead to take-off weights in the range of 15 to 40 million pounds, with two stage expendable pump-fed vehicles leading the low take-off weight class.

4.The development time required for a large launch vehicle in the 500-ton payload class will be in the range of seven to nine years, based on an orderly development. This includes a development flight phase.

5. The development cost, including facilities, for a large launch vehicle in the 500-ton orbital payload class will be in the range of five to eight billion (1963) dollars. This is an expenditure averaging one billion dollars per year for several years.

6. Very large launch vehicles in the 500 t orbital payload class, if partly or fully reusable, will result in transportation efficiencies that should make manned planetary flight economically possible. Even expendable launch vehicles in this class, though with less cost-effectiveness, still make extensive manned planetary flights an attractive proposition.

7. The vehicle concept chosen must be compatible with the requirement of carrying very large space ships with a density in the 2 to3 lb/ft^3 range and diameters not less than 60 ft. Structural penalties to the payload will have to be minimized, which calls for rather short payloads.

8. A reusable, truly one stage rocket launch vehicle appears desirable, but is too marginal to be acceptable from the viewpoint of development risk. One or more of the following features are required to make a single stage vehicle non-marginal:
(a) Solid or liquid JATO's;
(b) Thrust augmenting by air scooping;
(c) Tank staging.

9. At least one new high performance engine development program appears likely to achieve a 500 t single flight orbital capability. This engine development will most probably pace the entire vehicle development program.

10. Because of the tremendous resources required, it will not be possible to pursue the development of several vehicle concepts through prototype status or even through partial development. The choice of a particular concept will, therefore, of necessity be connected with a relatively high development risk.

11. The sea-launch concept, while it appears to be feasible, does not show enough evidence at this time, that it is greatly superior in cost-effectiveness to other partially or fully recoverable launch vehicle concepts, if all system aspects are included. As far as the operational viewpoint is concerned, NASA vehicle launch operations and payload personnel definitely prefer the land-based concept. This suggests that land-launch concepts should be emphasized at this time for further detailed study in connection with the NOVA system definition effort.

12. Chemo-nuclear launch vehicles, using solid core reactors in the second stage, show no advantages with respect to cost or availability over other high performance chemical launch vehicles for orbital missions, and have undesirable operational characteristics. However, chemo-nuclear vehicles do show considerable payload improvement for lunar and planetary missions, and therefore warrant further study as very advanced NOVA concepts.

13. Vehicle size does not change the mission reliability appreciably. Reusable vehicles should have a higher reliability potential.

14. Hydrogen/oxygen propulsion systems are prime candidates for single stage concepts and for second stage applications.

15. Any concept of a large launch vehicle in the 500-ton orbital payload class will have greater manufacturing problems than have been experienced to date in launch vehicles. However, these manufacturing problems can be overcome if proper efforts are applied.

16. A basic compatibility with reuse, at least of the first stage, is a very desirable objective, resulting in an option to employ the reuse feature at any time during the program.

17. Specific direct operating cost of 30 to 60 $/lb (1963 dollar value) appear to be achievable for large traffic volumes (approximately 10,000 ton orbital payload or more per year over a 15 year period) for reusable systems, even if the number of reuses is limited (e.g. 5 to 10 times). This figure will increase to about 45 to 65 $/lb for partially reusable systems and 70 to 90 $/lb for expendable systems.

18. It would be very desirable to design a first stage of NOVA in such a way it is compatible with nuclear upper stages, possibly including the use of a nuclear pulse propulsion system.

19. Solid boosters for NOVA class vehicles might be competitive with liquid boosters, but are not expected to be superior in cost-effectiveness.

20. No amount of effort in this area of vehicle technology can eliminate the risk factor involved in the selection of a particular concept; however, a strong effort in this area will reduce the risk factor considerably. A decision on the vehicle concept will probably be required before all new features can be proven.

C. Critical Areas

The following areas will be studied with priority:
1. Propulsion specific impulse
2. Stage mass fraction
3. Take-off and landing transients
4. Cost-effectiveness
5. Manufacturing procedures
6. Vehicle flight control
7. Recovery operation and refurbishment
8. Optimization of number of engine modules in propulsion system
9. Throttling characteristics of high pressure engines
10. Growth potential and compatibility with nuclear upper stages for direct lunar and planetary flight
11. Payload assembly operation and payload penalties for handling constraints
12. Performance penalties arising from compatibility with reuse
13. Vehicle turn-around-time
14. Compatibility with the potential requirement of military fast global cargo transportation
15. Potential of large launch vehicle in the 500-ton class for military orbital operations
16. Vehicle concepts not yet considered.

D. Future Effort

During the next six months the major effort will be applied in the areas of operations analysis and conceptual design leading to and approaching, to the greatest extent, an "ideal NOVA" defined as:

1. NOVA must have a multiple mission capability, preferably in all of the following areas:

a. Earth-to-low orbit heavy cargo delivery

b. Earth-to-orbit cargo delivery in connection with doglegging into high orbit inclinations and / or inter-orbital transfer to high altitude orbits

c. Global logistic transport for cargo and personnel

e. Lunar logistics transport for mixed cargo and personnel

f. High velocity space probes

2. The "ideal NOVA" concept might have several of the following features:

a. Single stage

b. Land and sea recovery

c. Design lifetime of 100 flights

d. Terminal guidance

e. Wide payload range capability (100 to 500-tons to low orbit)

f. Acceptable acceleration limits in case of personnel transport

g. Compatibility with nuclear upper stages.

In fall of this year, we hope to be much closer to the point were we will be able to single out one or more concepts for detailed preliminary design and be ready with a recommendation as to which type of propulsion system should be developed for NOVA.

Some selected Weekly Notes to Dr.von Braun illustrate the highlights occurring in the months following this redirection of the study effort:

May 13,1963
NOVA
Last week we gave four presentations in Washington on the status of the NOVA studies to:
a. OMSF (Captain Freitag attending); b. National Aeronautics and Space Council (Dr.Sheldon, Max Hunter, Tom Dolan); c. OART (Milt Ames and center representatives),
d. AirForce Systems Command.
Milt Ames made a strong plea that other Centers join in on the NOVA problem and help seek solutions. He will give them a little time to think about the problem and call on them again.

July 15, 1963
NOVASTUDY
As you might expect, there is some discussion in OMSF relative to the FY 1964 NOVA budget.

We had asked for $ 5 M to continue, at the same level of effort, the GD/A and Martin contracts. Bill Lee and Doug Lord, in Dr.Shea's Office, would like to cut it back to $2M. Freitag, however, is in favor of continuing with the $5M proposed by Dr.Seaman's office and used by MFSC. ...

August 12, 1963
NOVA
It is expected that Dr.Seamans will approve a $ 2.5 M allotment to continue the NOVA study. In addition to this we expect $ 1.0 M for studies in the area of a very advanced chemical and chemo-nuclear launch vehicles, which will give an indication of the operational lifetime and growth potential of the elements of the NOVA system.
We have now arrived at an approach as to how to implement the NOVA study program this fiscal year, specified the objectives, funding distribution and management approach. I would welcome an opportunity to present our plans to you....

October 28, 1963
NOVA ORIENTATION MEETING
On October 31 and November 1, we will have our orientation meeting with Martin/Baltimore on the next phase of the NOVA study (12 months, $1.5 M). You remember that this will emphasize the application and justification of a large launch vehicle in contrast to the previous phases that concentrated on design trade-offs.

May 25, 1964
POST-SATURN REVIEW
Last week we had a two-day review of our POST-SATURN activities, including trade-offs, mission analysis, test facilities at MTO, and launch facilities at MILA. We now have enough information to concentrate our conceptional design on a "base line" configuration that can be described as follows:
First stage: 18 modified hinged M-1 engines around a plug nozzle, recoverable stage, individual tanks.
Second stage: 12 high-pressure engines in the 315 K thrust range, possibly torroidal airspike integrated propulsion system for maximum performance, plug used as reentry body.
Total vehicle:
Concept: Fully recoverable and reusable, all LH2/LO2 propellants, two stage to orbit,
Three-stage to escape (modified S-II stage is a suitable third stage);
Launch weight: 18,000,000 lb
Diameter: 75 ft
Payload: approximately 1,000,000 lb
Operational target date: 1980
(1963) Cost effectiveness to orbit: 60 $/lb direct, 120 $/lb total
Facilities: Two test stands for each stage at MTF, 2nd stage sectional R&D testing at MSFC in large IC test-stand (modified in about 1972). - Three launch positions at the Cape in hybrid fashion (enclosed tower serves as assembly building and launch site).
We will make additional trade-off studies and probably modifications to this base line as we go along. However, for the planning exercise for the President, it is our desire to make competitive study for SATURN V doing the same missions, which is the reason for selecting a base line concept at this time. -
... It might interest you that all the guidelines which we have received from headquarters do require a POST-SATURN launch vehicle by about 1980 for manned planetary landing and capture missions.

POST-SATURN FPO Study Plan for FY 1965
(approved by Dr.von Braun June -10,1964)

A. *Definition of Problem*

1. Do we need a launch vehicle larger than SATURN V (and improved versions of it) at all?

2. It the answer is *yes*, which size and type of program would justify the development of a Post-SATURN?
3. If the answer is *yes*, when do we need the capability and when do we have to make a decision?

B. *Evidence available*

1. D i r e c t operational cost effectiveness to orbit expected for SATURN V at high launch rates is about 200 $/lb, as compared with total operating cost of about 120 $/lb for a typical POST-SATURN and 60 $/lb for direct operating cost. Including orbital operations burden (required for assembling big Mars-Ships) the specific cost (based on weight departing orbit) are approximately:
SATURN V: 200+2,000 = 2,200 $/lb
POST-SATURN 120 + 500 = 620 $/lb
2. Short orbital stay-time enhances probability of mission success.
3. Large diameters in launch vehicles are more compatible with high performance nuclear systems and planetary spacecraft.
4. There is room at the Cape for up to 4 launch positions of a Post-SATURN vehicle. This is adequate for even the most ambitious program under consideration.
5. There is room at MTF for two test positions for each stage with some sound suppression.
6. The present M-1 program calls for a 1971 PFRT date and about 300 M $ expenditure through PFRT. Strong political pressures are behind this project.
7. Considerable Momentum is developing for a high-pressure engine in the 300-400 K class, with uses in the advanced SATURN IB and V, and in the second stage of a reusable transport. We are starting a preliminary design of this engine this fiscal year.
(Note: This became the SSME engine for the Shuttle).
8. If new large launch vehicles are developed, they ought to be reusable. They have better cost effectiveness potential and better reliability potential. They have better sales potential and smaller obsolescence rate.
9. If the philosophy of "reusable space vehicles" is adopted in principle, the question of "solids versus liquids" is easier to answer.
(NOTE: All manned transportation that have found a permanent place in the daily life of mankind- for several thousand years - have been reusable systems!)
10. There is very little to choose from in vehicle and stage concepts, if the size and utility versus time of the reusable launch vehicle is determined. Particularly, the type of propulsion system selected for the first stage makes very little difference in overall cost-effectiveness.

C. Present Philosophy adopted by FPO
1. Continue efforts to verify role of Post-SATURN in the future space program.
2. Pick one of the better concepts as the base line to focus design effort.
3. Study the vehicle system and associated facilities and development problems in some detail.

4. Support OART and Lewis Research Center in providing vehicle data and inputs to the M-1 development program.
5. Determine development effort, time and funds required and the phasing of its development within the expected funding restraints.
6. Improve system through trade-off analysis and determine growth potential.
7. Compare with alternative solutions, such as maximum SATURN V growth and development of orbital operations.
8. Search for completely new ideas!

D. Base-Line Concept

Based on the studies to date, the most promising concept is a two stage, all hydrogen/oxygen launch vehicle. The first stage is reusable and uses 18 M-1 engines around a plug nozzle. For the second stage there is an option:
(1) A cluster of 300K high pressure engines, or the 300K hardware repackaged around a plug. This would be a recoverable stage re-entering on the plug. This stage offers the greatest potential and, therefore, will be emphasized in our studies because this approach meets the concept of a fully reusable vehicle best.
(2) The alternative is a conservative approach, using 2 M-1 engines in an expendable stage. Studies have shown that clustered tanks of S-II and S IVB diameter are near optimum from a performance standpoint and, of course, have some advantage in the area of manufacturing. -

The advantages of selecting this base-line concept are: (a) it defines a near optimum role for the M-1 engine; (b) it makes maximum use of existing and planned hardware; (c) it puts advanced propulsion in the second stage where the payoff is greater, and the amount of thrust or size is smaller, easing development; (d) it offers a completely reusable system; (e) it represents a significant advancement in the state-of-the-art and yet within the near-term technology.

E. Proposed FY 1965 Effort

The effort being proposed for FY 1965 falls into three categories shown below.
1. Mission Analysis ($600,000)
a. Needed to determine if we need Post-Saturn and when we need it
b. Represents a major contribution to the integration of all mission requirements.
2. Preliminary Design of Baseline Vehicle ($900,000)
a. Needed to define critical problem areas
b. Provides guide to technology programs
c. Needed to support M-1 development
3. Conceptual design on Advanced Concepts ($400,000)
a. Look for more attractive concepts
b. Provide guide to technology programs

F. *Schedule*

Latest mission planning indicates 1981 as the most likely date for a manned Mars landing. The enclosed schedule and funding data is geared to this tentative mission date. Every effort has been made to keep early funding requirements to a minimum and to conduct as much testing on the ground as possible.

Milestones:

N-I contractor selection 1970, ground systems testing 1974/75

N-II contractor selection 1971, ground systems testing 1976/77
Vehicle flight demonstration 1977/78
Orbital testing 1979/81
Budgeting:
1966: 3- 67:5 - 68:22 - 69:43 - 70:85 - 71:270 - 72: 525 - 73: 780 - 74: 940 - 75: 825 - 76: 640 - 77: 415 - 78: 330. –
Total Estimate. 4,883 M $

This guideline did not find the necessary support at NASA Headquarters due to general political development outside of NASA. Study funds were greatly reduced. Manned planetary missions were postponed for a decade and the need for a launch vehicle in the 1,000,000 lb payload class was not apparent. Thus the intended studies were only partly done with in-house resources.

RESULTS of the POST-SATURN performed in the mid sixties[19,22]:

POST-SATURN: Class I

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

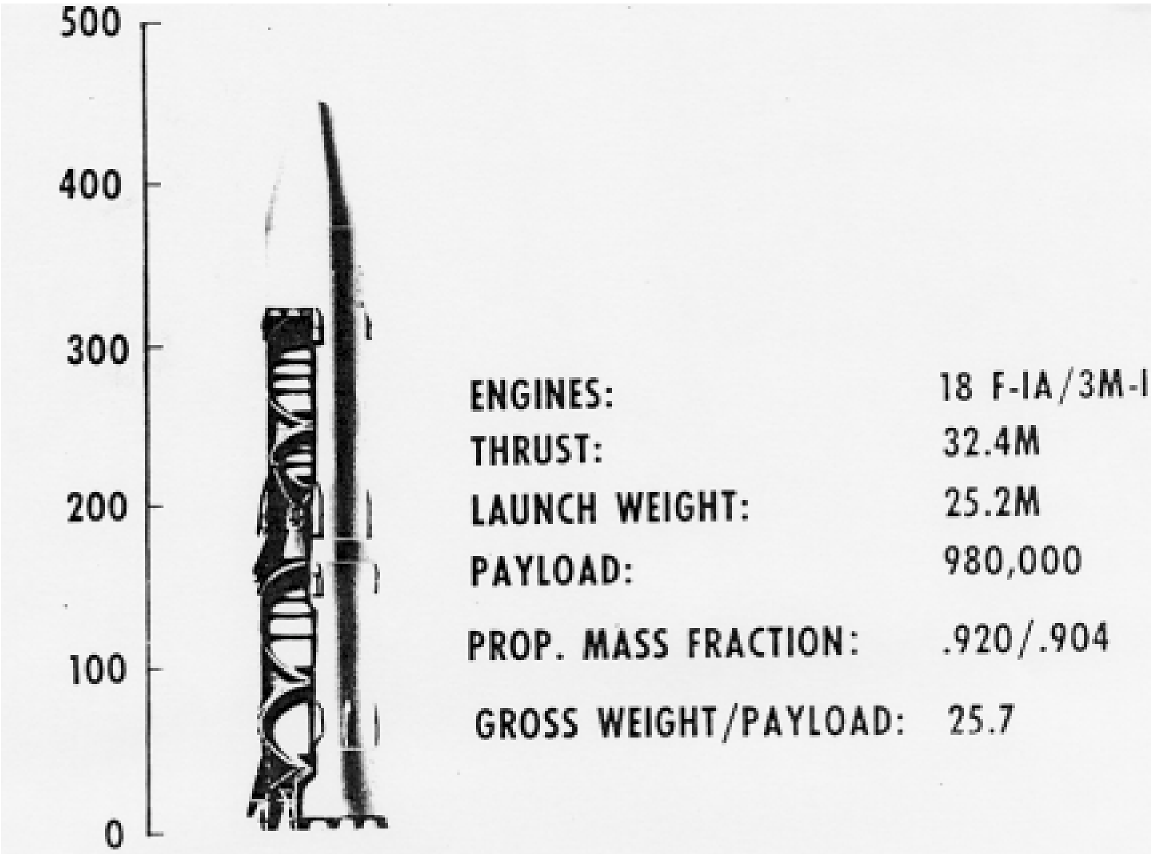

Figure 7: POST-SATURN Class I Baseline Vehicle

POST-SATURN: Class II

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 of the first stage is also included. Two-stage vehicles were sized from 200 to 500 ton payload capability, and then compared with the best available estimates for manned planetary mission requirements. The conclusion, based on cost effectiveness and orbital operations considerations, was that the larger size vehicles were superior. Therefore, a baseline value of 450 tons to orbit has been established for the POST-SATURN studies. The primary trade-off studies involved propulsion systems and propellant combination selection. Several 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.

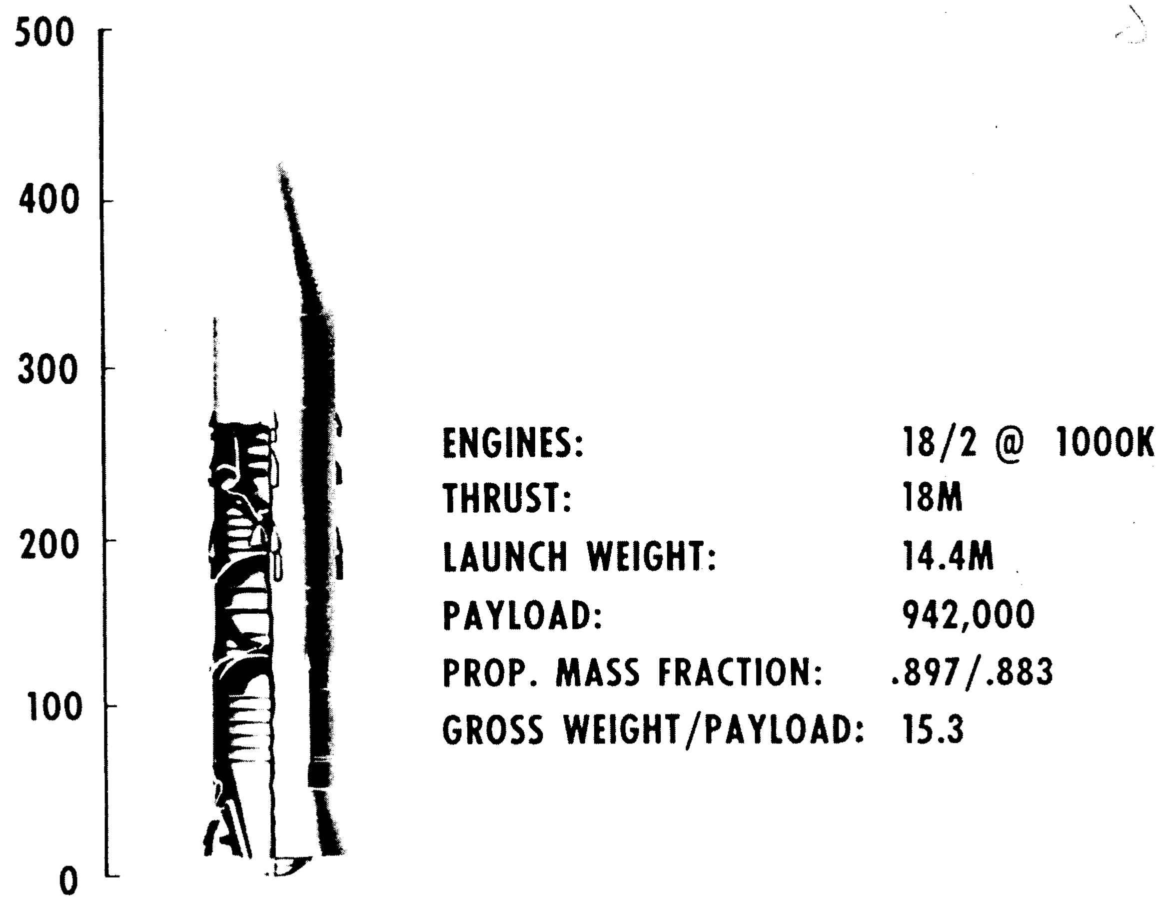

Figure 8: POST-SATURN Class II Baseline Vehicle

POST-SATURN: Class III

Class III considers very advanced technology with primarily single stage to orbit concepts. Recovery from near-orbital velocities is included. The alternative of air-augmentation during the early part of the flight was analyzed. It was found that the degradation in vehicle performance, due to the inert weights of the ducted system, more than offset the performance improvement due to augmented specific impulse. Technology advancements would be required in propulsion, re-entry at orbital speed, recovery and re-use of flight vehicle hardware. Three years or more of technological effort are required than for Class II vehicles, before a balanced concept could enter detailed program definition. These concepts represent availability times in the 1980's.

In reviewing and comparing these three 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 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 about eight per year, Class I vehicles showed a direct cost effectiveness of about 100 (1964) $/lb payload delivered to low Earth orbit, which would compare to the 200 $/lb currently estimated for SATURN V. Class II could further reduce the cost to about 50 $/lb and Class III possibly to 40 $/lb.

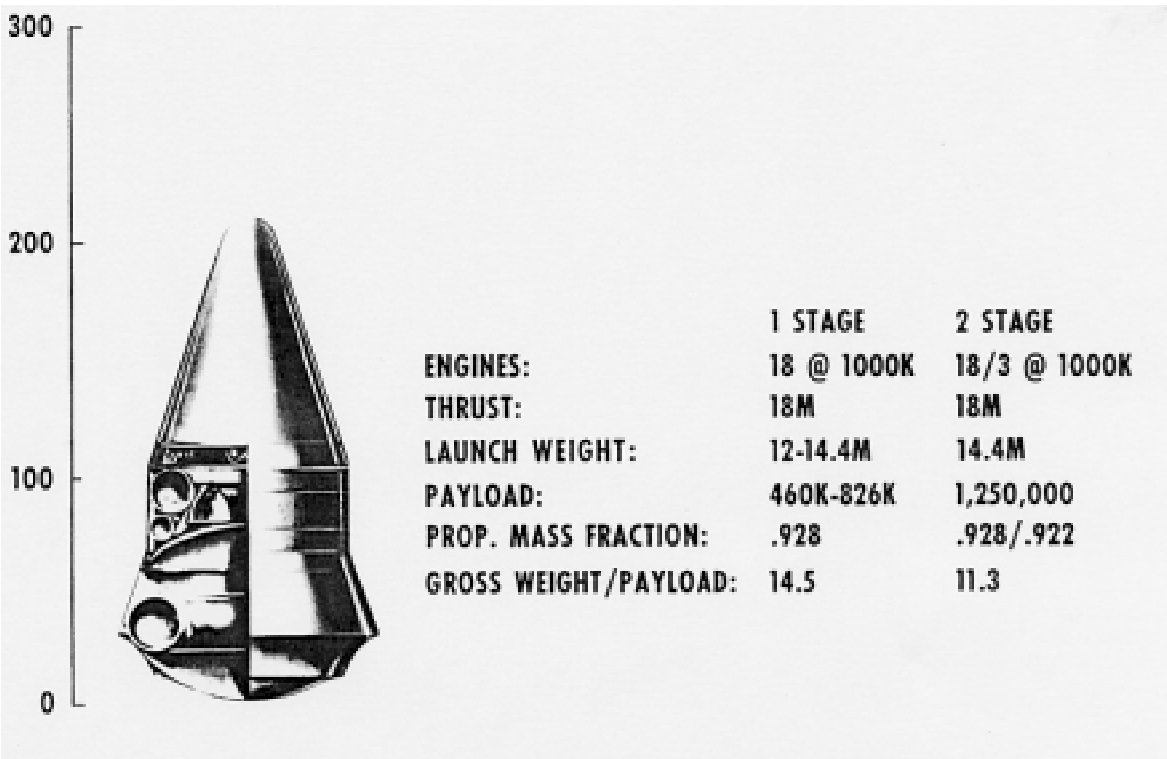

Figure 9: POST-SATURN Class III Baseline Vehicle

In a 12 months contract with Martin-Marietta (awarded in October 1964 in the amount of $1,499,000) the following tasks were to be performed to round off the picture:
a. More detailed design of class II, concentrating on areas of greatest uncertainty and those that have the greatest effect on overall vehicle (50%).
b. Concentrated effort in mission analysis area to define better the need of a POST-SATURN, when it is needed, and what should it be capable of doing (40%).
c. Updating of Class I concepts (5%)
d. Further definition of required technology (5%)

In addition to the all-chemical vehicle systems described in Class I through III, the potential of chemo-nuclear systems was explored to complete the overall picture of the foreseeable future. These were classified as Class IV vehicle concepts.

POST-SATURN: Class IV

Class IV is a chemo-nuclear launch vehicle with very advanced technology in both the chemical and nuclear stages. A chemical first stage is combined with a nuclear upper stage. While it is unlikely that vehicles of this type will ever be developed for launch from the Earth, they represent the highest performance theoretically possible. Three types of nuclear propulsion systems are analyzed: solid core reactors, gas-core reactors and nuclear pulse engines.

The study showed that solid core reactor systems in the thrust range of 250 to 900 Klb impose severe limitations on the Earth launch vehicle design. They do not offer any advantage over chemical systems and thus should be disregarded.
Gas core reactors with specific impulses of up to 1500 sec might be possible, if they have a closed cycle (light bulb design) avoiding the pollution of the upper atmosphere. This type of vehicle would lead to increases of the gross payload by about 140 percent for Earth orbital missions, but up to 200% for escape type missions. Nuclear pulse missions show even better performance, but it appears inconceivable that these propulsion systems will be ever permitted to operate in the near Earth environment.

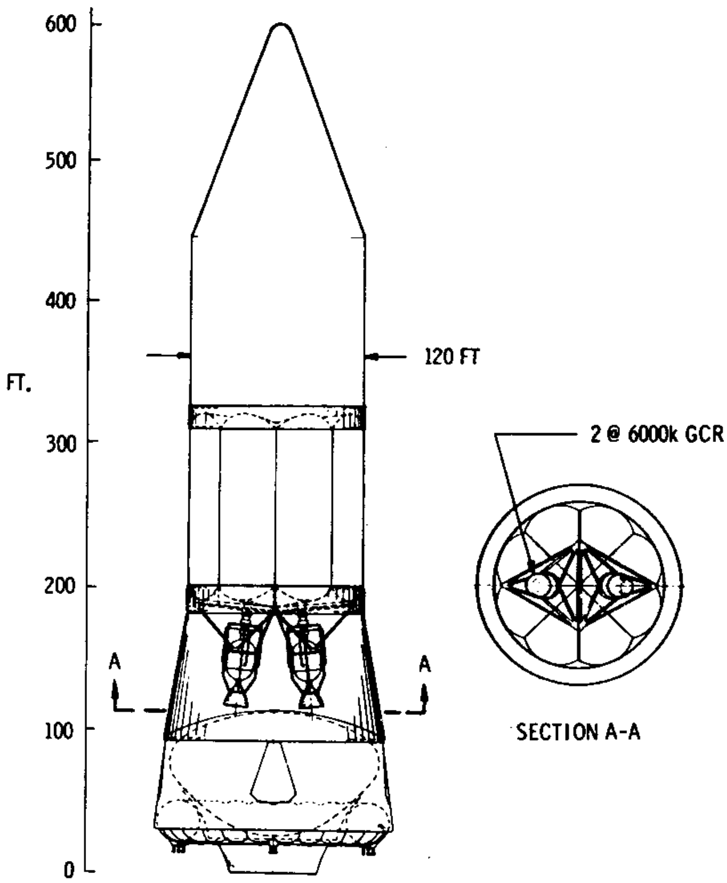

Figure 10: POST-SATURN Class IV Vehicle with gas core reactor in the second stage

7. POST-SATURN Concepts of the late sixties and seventies [23 thru 27]

There was very little interest in the area of heavy lift launch vehicles after this series of studies. This was the result stopping the production of the SATURN vehicles in 1968, the conclusion of APOLLO missions in 1972, and when the Vietnam War was dominating the minds of the people and the actions of the U.S.GOVERNMENT during those years. Publications on NOVA/POST-SATURN size became rare due to the lack of interest.

Boeing was the only American company who offered a concept for a heavy lift launch vehicle during the late sixties. This industry activity, sponsored and by NASA/AMES Research Center, was performed to establish a basis for technology developments. The vehicle concept was based on a building block technique, featuring a main core capable of single stage to orbit, and a set of solid boosters for increased payload capability.

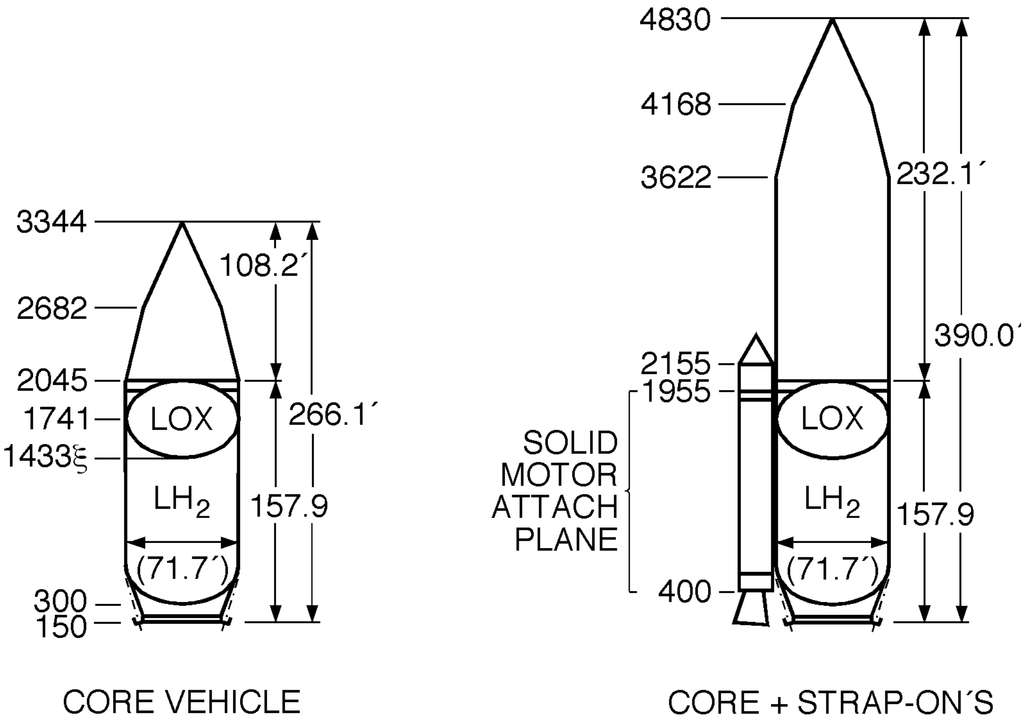

Figure 11: Boeing/Ames Heavy Lift Launch Vehicle of 1968

Table 6: Characteristics of Boeing HLLV of 1968

	SSTO	Two-stage Vehicle
Gross payload (lb)	1,000. 000 (?)	3,000.000(?)
Lift-off mass (lb)	12,800.000	66,257,000
Propellant mass fraction core	0.94	0.94
Length/diameter	2.20	
Sea level thrust	16,000.000	12x 9,000.000
Strap on motors	-	12 x 260"
Mass fraction of solids		0.90
Usable Propellants (lb)	11,110.000	12x3.810.000
Growth ratio	12.8?	18.9?

The core had a 71.7 ft diameter, using a multi-chamber, plug, oxygen-hydrogen engine. The stage was 157.9 ft high. It was supposed to place to 1 M lb into a 100 nautical mile orbit, a figure that does not look right. With 12x 260" strap on boosters the payload capability could theoretically be increased to 1 to 2 million lb. A second LH2/Lox stage with torroidal propellant tanks, and an extendable nozzle high-pressure engine could be added to the core, with the same diameter as the core stage.

Several years later (1974/76), the Boeing Company conducted a Future Transportation System Analysis for NASA, investigating several concepts of launch vehicles in the payload class of over 200 tons to low Earth orbit. The single stage vehicle to orbit described above, resurfaced again in a different, more modest version.

The 24 LOX/RP-1 main engines (1 M lb thrust each) were to shut down after 127 seconds of flight, and the 24 LOX/H2 engine (0.5 M lb thrust each) would continue alone until a 92.6 x 500 km orbit is achieved. A small separate stage then would inject the payload into orbit. After discharging the payload, the vehicle would de-orbit and reenter. Final deceleration for landing would be done by restarting the engines to decelerate the vehicle down to near zero velocity. The vehicle was designed to retro into a specially constructed 5 km diameter fresh water pond adjacent to the launch site. It would be refurbished and reused.
The payload capability is given as 228 t. The main-stage has a gross mass of about 10.188 t. The launch mass, including the kick-stage, is 10.423 t.

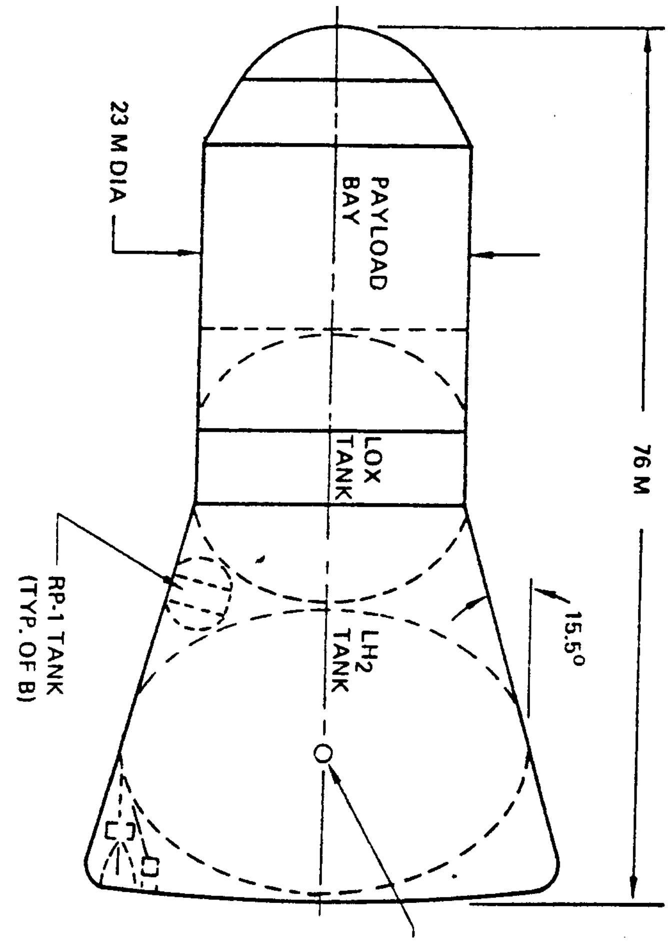

Figure 12: Boeing HLLV concept of 1975

This launch vehicle should have specific transportation cost to low Earth orbit in the order of 20 to 50 $/lb (1974 dollar value), at launch rates required by a Space Solar Power System. The vehicle shape, similar to the Apollo capsule, provides a large payload bay in the upper cylindrical area and a controllable shape for ballistic entry. The same heat shield is used for both the ascent and descent with the maximum base heating occurring during ascent. The heat shield is a double wall concept with water- cooling between the walls. A reusable two stage ballistic launch vehicle was studied as an alternative for two different payload capabilities: 450 and 900 metric tons. The first stage used Lox/RP-1 propellants, the 2nd stage Lox/LH2. The characteristics of these vehicles are shown in figure 12 with a SATURN V for comparison. Both stages make a water landing after re-entry.

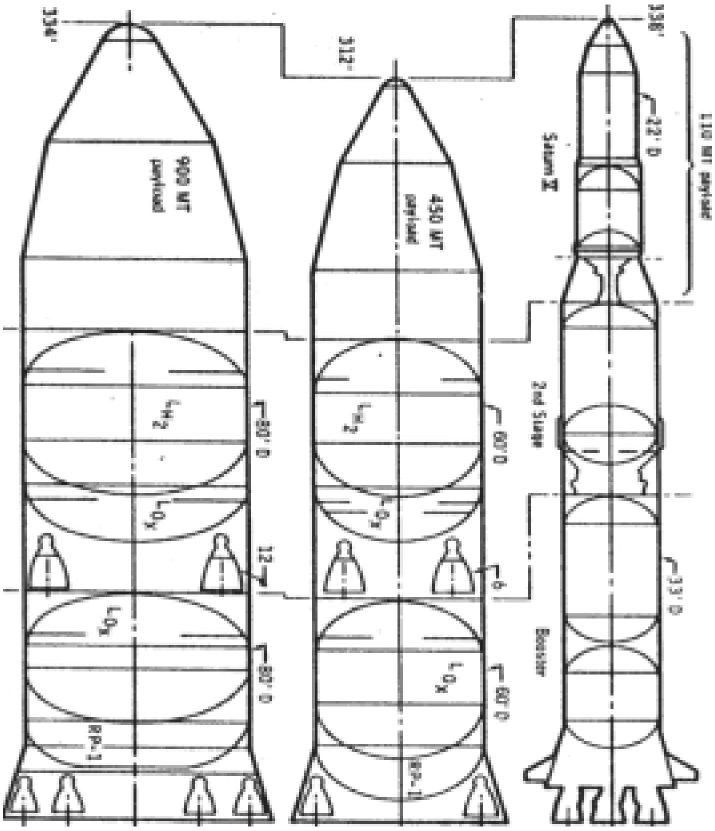

Figure 13: Concept of two-stage ballistic vehicle (Boeing /JSC 1975)

Table 7: Characteristic data of two-stage ballistic vehicle (Boeing /JSC 1975) Smaller and larger vehicle cocepts

Payload capability	454	907
Stage 1 empty	500	889
Stage 1 propellants	4441	8236
Stage 2 empty	233	400
Stage 2 propellants	1937	3599
Gross lift-off mass	7565	14031
Number of engines 1st stage	12	24
Number of engines 2nd stage	6	12
Staging altitude (km)	43.4	43.5
Staging velocity (m/s)	1840	1910
Booster maximum downrange (km)	381	396
Growth ratio	16.7	15.5

As the concept of a Space Solar Power System was developed during the seventies various ballistic and winged launch vehicles were studied for heavy lift duties to the geo-stationary orbit. A tandem two-stage winged reusable launch vehicle to low Earth orbit in combination with a space ferry from LEO to GEO was the favored concept among those studied. The cargo vehicle concept tentatively selected for the reference Space Solar Power system was a two stage tandem winged vehicle as shown in figure 14.

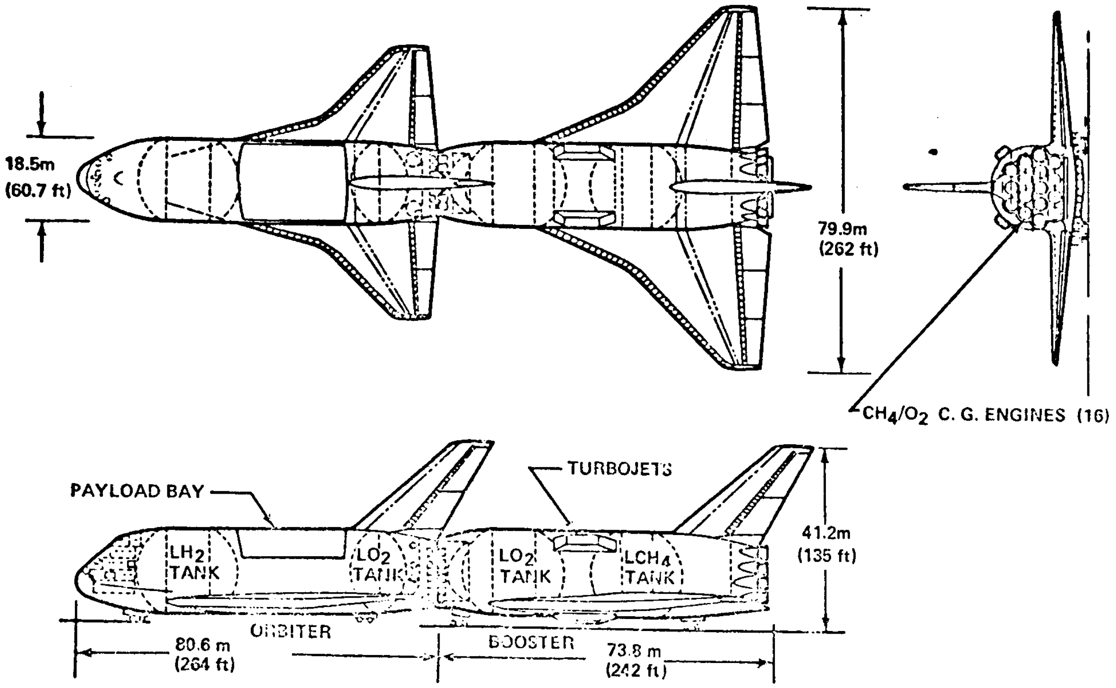

Figure 14: Two-stage Reusable Tandem VTO Winged SPS Launch Vehicle

It uses 16 LCH4/Lox engines on the booster and 14 standard SSME's on the second stage. The booster engines employ a gas generator cycle and provide a vacuum thrust of 9.79 M Newtons each. The SSME engines have a vacuum thrust of 2.09 M Newtons. The gross lift-off of an HLLV is 11,040 metric tons with a payload of **424 t to LEO**. This is a growth ratio of 26! A return payload of 63.5 t was assumed for the orbiter entry and landing condition. Its landing weight is 934 tons. The launch is in vertical position, vehicle length is 164 m, the booster wing span is 60.6 m. The orbiter uses a glide back landing and has a weight of 439 tons.

In terms of 2000 dollars, the cost per flight estimated was 180 Man-years or $ 36 M at fairly high launch rates required for the SPS.

Features:
- LOX/RP-1 1st stage
- LOX/LH2 (dual mode) 2nd stage
- Propellant cross-feed, parallel burn
- Staging velocity 2377 m/sec
- Staging altitude 61 km
- Launch mass (GLOW) 6804 t
- Booster lift-off mass 5443 t
- Propellants first stage 4627 t
- Upper stage lift-off mass 1134 t
- Propellants 2nd stage 966 t
- Payload **227 t**
- Growth ratio 30

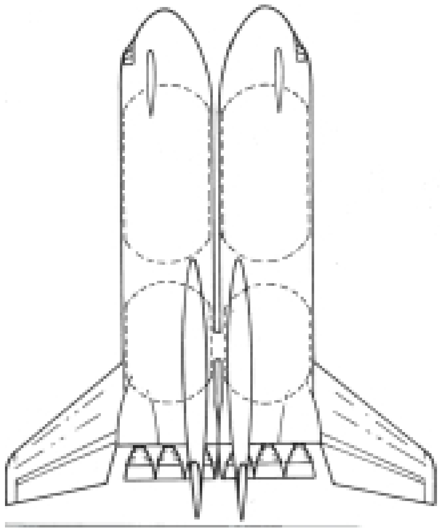

Figure 15: Rockwell Concept

NASA has asked to study also a smaller version of the vehicle concept as shown in figure 14, because to some NASA people the proposed vehicle seemed to be to big. The resulting HLLV-125 had a launch mass of 4 034 t with a LEO payload capability of **126 t**. This is a growth ratio of 32! First stage propellant mass was
2 260 t, net mass 296, dry mass 235 t including 4 jet engines for fly back after reentry. 20 rocket engines with 3 750 kg mass each, were used for propulsion. The 2nd stage used 14 SSME's with a mass of 1380 kg each, propellant mass was 1130 t, net mass 222, dry mass with crew was estimated to be 180 t. The launch costs of this vehicle were estimated to be about 50 Man-years, or $ 25 M in year 2000 dollars. - Rockwell International studied a similar 2-stage winged vehicle in the same year, shown in figure 15.

8. Current Concepts

Vehicles of the POST-SATURN class have been analyzed in the USA already in
the sixties and seventies as described in the previous chapters. Concepts such as NOVA, RHOMBUS, NEXUS, SEA DRAGON and others have become known. The NEPTUNE HLLV, a conservative concept in this vehicle class studied since 1967 at the Aerospace Institute of the Technical University Berlin, has been designed for cargo and passenger transportation to be operational no earlier then the year 2015. Its development period should take 6 to 8 years depending on the availability of resources.

An *Earth launch vehicle* is the key to any space transportation system, but it is not the whole *space transportation system* and must thus be designed to take into consideration all aspects of the system. It is very likely, that a near state-of-the-art fully reusable space transportation system would be using chemical propellants only, and incorporate available or modified subsystems from the Space Shuttle and other existing programs.

Aside from spaceports on the Earth and the Moon, the heavy lift lunar space transportation system (LSTS), when used for lunar base logistics as a typical mission mode, is comprised of three elements the Earth launch vehicles, a space operations center (SOC) in near Earth or lunar orbit and a lunar landing and launch vehicle (LUBUS). Thus any launch vehicle design concept must take account of the interfaces to the other elements of the space transportation system. That has been done in developing the NEPTUNE launch vehicle design concept.

The data describing the NEPTUNE **heavy lift Earth launch vehicle** was taken from the most recent studies available on a vehicle of this type and size by H.Arend[28] and Th.Altmann and O.Kerinnis, H.H.Koelle, in 1989[29]. The only change in design since then, is the replacement of a single SSME in the third stage by eight RL10A3 engines. This was done primarily to improve the reliability of the vehicle and to achieve a higher degree of compatibility with the lunar landing and launch stage (**LUBUS**) which uses the same engine.

The data shown are representing the *advanced version* of the original vehicle studied, because the development period is now anticipated ten years later then assumed in the late eighties. In this model, the development begins now after the year 2005 when the results of the NASA launch vehicle technology and development program are already available. At that time the state-of-the-art in light weight structures should have born fruit and be available for the HLLV also[30,32].

Typically, on a standard mission profile, the Lox propellant is lunar produced liquid oxygen refueled in lunar orbit at the space operations center. the LH2 is taken out of the HLLV payload reducing it from 100 t to 95 t. This leaves a 20 t margin for taking LH2 along which is needed by the LUBUS for its roundtrip from the lunar orbit space operations center (LUO-SOC) to the lunar spaceport and an additional 25 t of cargo in a mixed passenger/cargo flight.

In the case of cargo flights between Earth and lunar orbit 15 t of propellants (12 Lox +3 LH2) are required for the return flight of the empty 3rd stage. If the LH2 is taken out of the payload and Lox refueled in lunar orbit, then 100 - 3 = 97 t remain for the actual payload and LH2 propellants for the LUBUS. Alternatively the Lox can be taken out of the payload also, leaving room for 85 t of cargo.
The present configuration of the NEPTUNE launch vehicle is shown in figures 15 and 16 giving some details on the design of this vehicle. The empty room on the top is available for the payload, this is a rather large volume if compared with
contemporary vehicles.

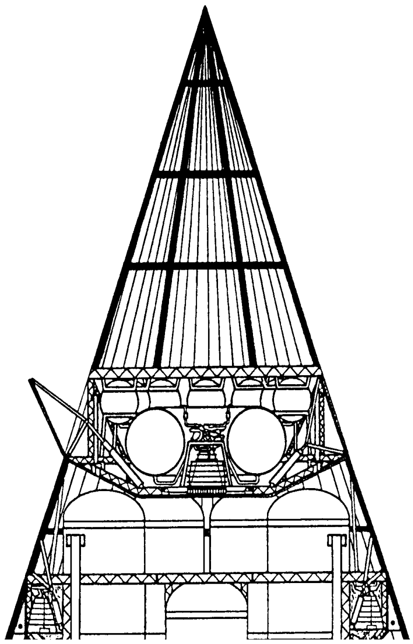

Figure 16: Longitudinal cross section of basic three-stage NEPTUNE launch vehicle

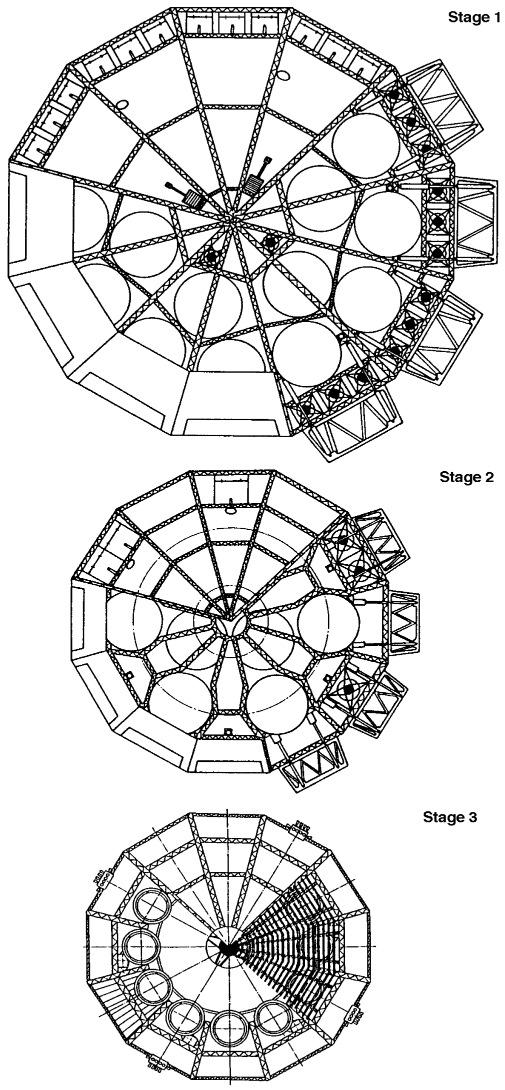

Figure 17: Cross sections of the three stages of the NEPTUNE launch vehicle

Table 8: Primary characteristics of the NEPTUNE heavy lift launch vehicle (HLLV)[34,35,36]

Masses : (t)	stage 1	stage 2	stage 3 (cargo)
launch mass	6000	1658	426
payload mass LEO	1658	426	372 gross / 350 net
payload mass LUO	1648	416	108 gross / 100net
payload shroud	-	-	2
instrumentation	9	4	2
structure	358	84	18
engines	80	25	8
recovery equipment	39	21	15 LEO / 18 LUO
residuals	38	11	3
propellant reserves	56	16	3
propellant consumption	3762	1072	16 LEO / 249 LUO
cut-off mass	2238	586 LEO / 576 LUO	411 LEO / 153 LUO
dry mass	486	133	36 LEO / 40 LUO

net mass	580	160	39 LEO / 45 LUO
Dimensions and mass ratios:			
width (m)	41	29	22.4
height (m)	38	21.2	33.4
cross-section (m2)	1 ,355	676	403
top structure(m2)	1 ,985	800	400
with shroud(m2)	-	-	1 ,165
bottom structure(m2)	3, 317	1 467	427
volume (m3)	40 ,327	11 977	4 742
nose radius (m)	29	18	14
mass ratio r	2.680	2.828	1.036 LEO mission
prop. mass fraction	0.889	0.894	0.360
propellant ratio stage	0.626	0.646	0.038
payload ratio stage	0.277	0.258	0.878
growth ratio stage	3.619	3.892	1.323
growth ratio vehicle			18.61
engine sea level thrust	1,845 kN per engine	1,802 kN	-
vacuum thrust	2,082	2,167	200kN
number of engines	40 SSME	9 SSME	8 RL10A3
nozzle area ratio	20	120	200
sea level spec.imp. (s)	400	388	-
vacuum spec.imp.(s)	451	469	469
engine mass flow	470 kg/s	470	43.5
engine mass (kg)	2,000 per engine	2800	300
tot. prop. sys. mass(t)	80	25.2	2.5

In case of crewed flights between Earth and lunar orbit, a 50 t crew cabin (including the mass of the relieved crew and a few tons of cargo) is required. It is an integrated part of the nominal 100 t payload of the 3rd stage of the HLLV which is operating as a *space ferry*. It flies to the LUO-SOC and returns to the Earth spaceport requiring 30 t propellants (25 t Lox, 5 t LH2). A typical mass breakdown of the crew module attached to the 3rd stage of the HLLV space ferry has been developed by J.Laßmann[32] as follows:

Table 9 : Mass model of the NEPTUNE crew module

structural elements	26,590 kg
power supply	7,560
life support equipment	1,820
crew systems	3,030
instrumentation	1,000
basic vehicle dry for LEO missions	40,000
additional heat protection equipment	5,000 (for GEO or lunar missions)
crew and luggage	5,000
total crew cabin loaded	50,000 kg

Vehicle Acquisition Cost

The development cost for the prototype cargo vehicle, using a modular design and available technology, such as modified Shuttle engines and other

available subsystems, have been estimated and are presented below. These can be used as preliminary guidelines for planning purposes, but have to be recalculated in a specific development scenario. If a back-up or pre-production vehicle is required before the operational period begins, these cost will have to be added to the total, only one flyable prototype vehicle is included in the development cost.
The acquisition cost for the first set of ground facilities such as landing platform, propellant tanker, launch platform, launch control facility, transport ship for stages, maintenance facilities, integration facility and general support facilities (some have to be modified only) have been estimated to be in the order of 2.5 B (2000) $. However, this is a rough estimate(ROM).

The development cost of the original crew module was estimated to be 17,275 MY = 3,455 million (2000) $. If corrected for additional heat protection equipment (TPS) compatible with a 11 km/s entry velocity, it should be closer to 18,520 MY or 3,700 M $. Its first unit cost was estimated to be 1,726 MY = 345 M $ or corrected for additional TPS increased to 1,933 MY or 387 M $, assuming a great deal of commonality with previously developed crew modules. An other 650 M $ are added for specific ground support equipment and facilities respectively, totaling 4.7 B $ initial cost as shown in table 3.

Table 10 : Estimated Development Cost of the launch vehicle NEPTUNE with cargo and passenger capabilities (M 2000 $) including one prototype vehicle

Subsystem	stage 1	stage 2	stage 3	total
cold structure	1,247	391	253	1,891
hot structure	224	194	42	460
tanks	699	428	336	1,462
equipment	1,916	1,110	752	3,777
engine modifications	374	242	75	691
recovery equipment	97	65	62	225
sub total vehicle subsystems	**4,556**	**2430**	**1,519**	**8,505**
tooling	102	33	87	223
system engineering				2,475
prototype production				3,445
ground facilities - first set				2,550
crew module development & 1st unit				4,695
cargo container & tooling for payloads				293
total RDT&E cost HLLV and payloads				**24,330**

First unit cost have been estimated considering the effects of commonality and pre-production of already available hardware, including some learning for the large number of engines and tanks used in this concept. This is based partially on advanced materials available by the year 2005, and resulted in the following estimates:

Table 11 : First unit cost of prototype vehicle without payload modules (M 2000 year $)

subsystem	stage 1	stage 2	stage 3	total
structure	978	414	108	1,497
tanks	136	49	18	203
equipment	212	114	73	400
engines	528	153	31	712
recovery eq.	348	161	122	632
1st unit total	**2,203**	**889**	**352**	**3,445**

The unit production cost will decline with number of units produced, strongly depending on the learning achieved. The sectionalized design philosophy of this vehicle will lead to a reasonable learning factor at low vehicle production rates.

Table 12: Standard low Earth orbit performance and cost-effectiveness of a reusable ballistic two stage heavy lift launch vehicle of the NEPTUNE type, supporting a multi-mission space program as a function of program size

Launches p.a. (cum.no. during life-cycle)	Accumulative LC cargo to low Earth orbit (t)	Total average Launch cost per flight (M $)	Specific Transport Cost ($/kg)
4 (100)	33,000	380	1,150
8 (200)	66,000	214	650
16 (400)	132,000	139	420

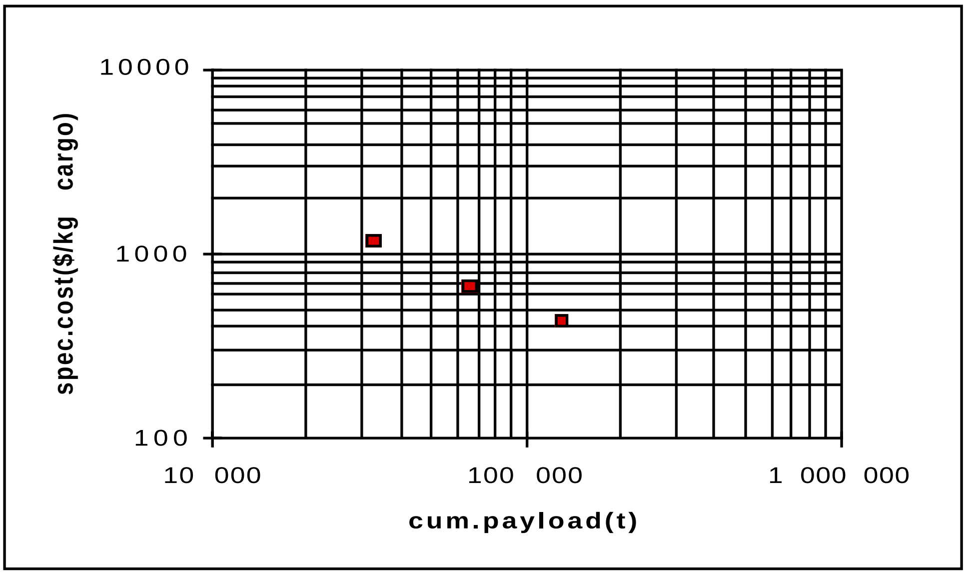

Figure 18: Expected cost trend for the delivery of cargo by HLLV's to low Earth orbits

These numbers are in good agreement with the estimates made during the study efforts the sixties if adjusted to the current dollar values!

Table 13: Cost of 50 year operational NEPTUNE program using standard learning factors

Average annual launch rate and life-cycle cumulative missions	Accumulative cargo to lunar orbit (1000t)	Development cost including product improvement (M$)	Production cost including Subsystem replacements (M$)	Operation cost Manpower and spares - (M$)	Life-cycle system cost (M$)
3/150	15	22,521	21,675	8,643	52,839
9/450	45	22,521	31,455	22,292	76,268
18/900	90	22.521	42,199	40,902	105,622
36/1800	180	22,521	74,780	74,445	171,745

Average launch rate p.a. & LC cumulative missions	Number of vehicles produced	Number of vehicles retired	Number of vehicles lost	Average cost per primary flight (M$)	**Average specific cost of cargo delivery to lunar orbit ($/kg)**
3/150	6	4	0	352	3,523
9/450	8	5	1	170	1,695
18/900	8	3	2	117	1,174
36/1800	12	5	5	95	954

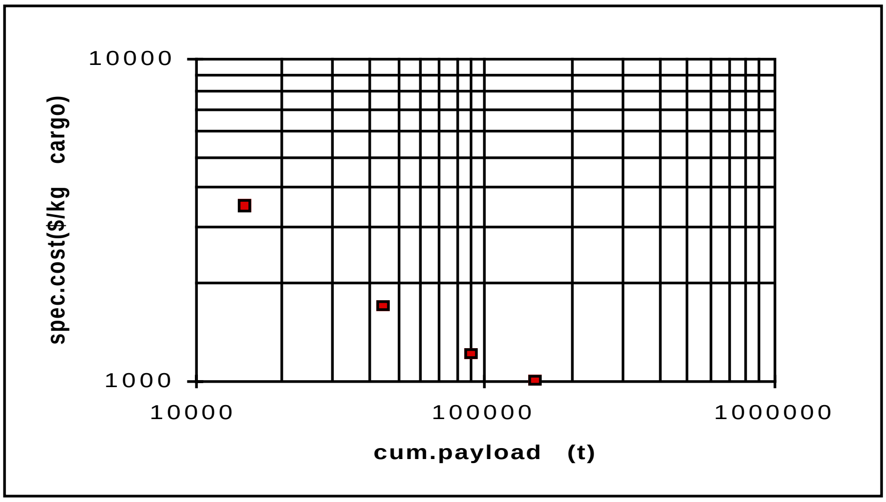

Figure 19: Expected cost trend for the delivery of cargo by HLLV's to GEO or lunar orbits

The specific transportation cost to a lunar base are strongly dependent on the share and production cost of lunar propellants used. As a first approximation the specific cost will be doubled. A representative example in shown in the table below.

Table 14: Performance and cost effectiveness of HLLV + LUBUS lunar space transportation system supporting a lunar base

Launches p.a.	Payload to LUS	LC system cost	Cost per mission	Specific cargo cost

2 = 50 LC	3, 500 t	52, 318 M $	1, 046 M $	14.9 M $/t
4 = 100 LC	7, 000 t	61, 598 M $	616 M $	8.8 M $/t
8 = 200 LC	14, 000 t	75, 395 M $	377 M $	5.4 M $/t

9. Comparison of Concepts

Concepts of Heavy Lift Launch Vehicles (HLLV's) in the POST-SATURN Class have been compiled in this report, as far as they have become known. The published data is neither complete, nor comparable. However, presenting the available data in the form of an overview may be of help to judge the state of the art as function of time in a somewhat crude manner. The prevailing views in the period during and following the lunar landing program, have the highest density and allow good insight into the options available at that time. Also, nuclear propulsion for the upper stage of near Earth transportation systems were considered, but can be ruled out for the next decades. It became clear, that they do not offer advantages for applications in the cis-lunar range. Cost, risks and availability are the criteria that exclude the nuclear option for missions to Earth orbits or the Moon. On the long run, however, they might find application in planetary transportation systems leaving from libration points or lunar orbits.

It appears certain that among the candidates LOX/LH2 chemical propulsion systems, in combination with reusability of vehicle stages, are the most promising concepts. Solid propulsion systems in the first stage will be the exception rather than the rule. In case of marginal performance they might be employed selectively for thrust augmentation and/or stage separation. The engines from current programs such as the SSME and RL 10 versions, would be satisfactory, there is no need to develop new ones, redesigning them for mass production would be desirable. It is also clear, that vehicles should be optimized to achieve low production cost, because these are more important than vehicle shape or development cost. The learning curves will receive more attention than in the past. The available payload volume will probably shape the vehicle configuration, since low density modules and hydrogen propellants will have to be transported to the Moon and possibly planetary destinations.

Reusable Lox/LH2 vehicles in this class will have growth ratios of about 20 for LEO missions, 60 for GEO or lunar orbit missions, and 100 for lunar cargo delivery missions. Payload capabilities in the order of about 300 tons to low Earth orbit, 100 tons to GEO and lunar orbits, and 50 tons to lunar or Mars surface seem to satisfy most mission requirements. If these launch vehicles develop satisfactory mission reliability they might even be used later on for commercial tourist operations to Earth orbiting facilities and eventually to the Moon. But this can materialize only at high traffic volumes!

The data presented below for the purpose of comparison are rough estimates. They must be re-calculated and refined for a specific program size and duration!

Table 15: Comparison of HLLV's s in the POST-SATURN Class

	NOVA-A	NOVA-B	Class I	Class II	Class III
Year	1959	1962	1965	1965	1965
No. of Stages	4	3	2	2	1
No. of engines	6	10/2/1	18/3	18/2	18
Propellants	Lox/RP-1 Lox/LH2	Lox/RP-1 Lox/LH2	Lox/RP Lox/LH2	Lox/LH2	Lox/LH2
Landing Method	-	-	-	Vertical	Vertical
Expendable /reuse	Expendable	Expendable	Exp/exp	Reuse/exp	Reuse
Stage mass fraction	0.60/0.62/ 0.72/0.80	.912.918/ .914	.920.904	.897.883	.928
Sea level thrust (KN)	39726	52968	143 000	79450	79450
Launch mass (t)	3 015	6 750	11 340 t	6480 t	5 400 /6 480
Payload (t)	16.2 LUS	228 LEO 92 escape	441	424 t	207 to 372
Growth ratio	186 LUS	30/74	25.7	15.3	14.5
Height (m)	66	112	140	126	66
Diameter (m)	15	50	20	24	35

	Boeing SSTO	Boeing Ballistic	Boeing Winged	Neptune	Class IV
	1975	1976	1976	1995	1965
Number of Stages	1	2	2	2/3	2
Number of engines	24+24	12/6	16/14	40/9/8	18/2GCR
Propellants	Lox/RP-1 Lox/LH2	Lox/RP-1 Lox/LH2	Lox/CH4 Lox/LH2	Lox/LH2	Lox/LH2 U2/ H2
Landing method	Vertical	Vertical	Horizontal	Vertical	Vertical
Expendable /reuse	Reuse	Reuse	Reuse	Reuse	Reuse-exp
Stage mass fraction	.94	.90/.893	?	.889/.894/ .36 Leo	.928/.114
Sea level thrust (KN)	159 000	97 000	150 000	73 800	63 600
Launch mass (t)	10 188	7 565	11 040	6 000	6 480
Payload (t)	228	454	424	350 LEO 100 LUO	738
Growth ratio	45	16.5	26	17.1/60	8.8
Height (m)	76	95	164	92	180
Diameter (m)	42/23	18	29/80	41	50/36

10. Summary

Heavy lift launch vehicles have been studied since about 1950. The launch vehicles with the highest mass that have ever been developed, were the American SATURN V and the Russian N-1. The former had 13 successful missions the letter experienced four launch attempts, none of them successful. Both vehicles were designed as expendable vehicles specifically for a lunar landing mission.

The expendable vehicles of this class do not have the cost-effectiveness required for sustained logistic space operations, thus the search for reusable launch vehicles has gone on during the last decades and has not yet come to an end. In this process also nuclear upper stages have been considered due to their high performance, but they do not offer practical solutions because of their undesirable operational characteristics, their high development cost, their high production cost, their long development time, and their environmental impacts. Thus, the nuclear alternatives can probably be excluded for application during the current century.

HLLV's in the POST-SATURN class (i.e. launch masses over 3 000 metric tons) will be required if any of the following mission requirements would be confirmed by a potential user:

- Space Operations Center in Geo-stationary Orbits
- Space Operation Center in Lunar Orbit or Libration Points
- Logistic support of a Lunar Base
- Human Mars Expeditions
- Logistic Support of a Mars Outpost

Recommended ground rules and/or criteria:

- Size of the HLLV to be developed should be compatible with the highest payload requirement, e.g. the return vehicle from Mars orbit to the Earth.
- Mission and program concept should keep human extra-vehicular activities to a minimum: *Do on Earth what you can do on Earth*!
- Launch cost are not a valid measure for comparison, rather the total cost to the point of destination, including operations in space, unloading and assembly of space facilities must be included.
- Make use of available and proven subsystems, e.g. there is no need to develop new engines

Based on the insights available to-date, the next HLLV's would probably have the following design features:

- Suitable of transporting cargo and humans,
- Two-stage to Earth orbit, three stage to GEO and Lunar Orbit,
- Vertical take-off,
- Ballistic recovery,
- Engines using liquid oxygen and liquid hydrogen propellants,
- Reusability of all stages with more than 100 flights per vehicle,
- Vehicle design life times of 30 years,
- Mission reliabilities of 98% for cargo, and 99% for passenger missions,
- Vehicle losses less than 5 per 1000,
- Broad base diameter to enhance reusability and low payload density,
- Clustered tanks to reduce production and operating cost,
- Multi-sectional structures, to reduce production cost.

The main problem is not the lack of appropriate technology or financial resources, but the lack of a program deemed socially and politically desirable !

References:

(1) W.von Braun: "Das Marsproject", Umschau Verlag, 1952, 82 S.
"The Mars Project", University of Illinois Press, Urbana, 1953,91pp
(2) K.A.Ehricke: "Establishment of Large Satellites By Means of Small Orbital Carriers", Proceedings, 3rd International Astronautical Congress, Stuttgart, October 1952, (H.H.Koelle,Ed.), p.111-145
(3) M.W.Rosen, F.C.Schwenk: "A Rocket for Manned Lunar Exploration", Paper presented to the 10th International Astronautical Congress, London, August 1959, Preprint 16 pp.
(Summary: missiles & rockets, August 31, 1959. pp.24-25)
(4) Don R.Ostrander: "Statement to the Committee of Asronautical and Space Sciences, United States Senate, June 8,1961
(5) I.Stone: "Offshore NOVA Launch Facility Studied", Aviation Week, June 19,1961, pp.32, 33
(6) H.H.Koelle:"NOVA Configuration", FPO Memorandum to Director, MSFC, March 28,1962
(7) H.H.Koelle: "Course of Action for next Phase of NOVA Studies", MSFC Memo for Record January 23,1963, 4 pp.
(8) H.H.Koelle, J.Sanders: " Minutes of Advanced NOVA Meeting, MSFC, January, 1963, 16 pp.
(9) H.H.Koelle: "Summary of NOVA Studies", Memo for Record, 7 pp; NOVA Statement of Work. 10 pp., May 1, 1963,
(10) R.Truax: "Water-Based Launch for Moon Vehicles?", missiles & Space, Jan. 1962, pp.14-17
(11) Ph.Bono: "Future Boosters - NOVA and beyond", Douglas Paper 1544, Presented at the 8th Annual Propulsion Meeting, Cleveland,Ohio, 7 March 1963, 18pp
(12) Ph.Bono: "ROMBUS - An integrated Systems Concept for a reusable Orbital Module", Paper No.63-271, AIAA Summer Meeting, LA, CA, June 17-20,1963, 20 pp.
(13) A.Kalitinsky: "NOVA Launch Vehicle Design Studies", Paper presented at the AAS Symposium on the Exploration of Mars, June 6-7,1963, Denver, CO.
23 pp.(Summary in Aviation Week & Space Technology, June 10,1963,pp 34-36
(14) Martin-Marietta, Systems Division: "NOVA Vehicle Systems Study" Part II, (3 volumes plus 33 technical reports), Report No.12589, September 1963
(15) General Dynamics/Astronautics: "NOVA Vehicle Systems Study, Part II
(3 volumes and 39 technical reports), Report GDA63-0844, September 1963
(16) K.A.Ehricke, F.D'Vincent: "The NEXUS Concept", Astronautics & Aeronautics, Jan.1964, pp.18-26
(17) Ph.Bono: "The ROMBUS Concept", Astronautics & Aeronautics, Jan.1964, pp.28-34

(18) J.C.Moise,C.S.Henry, R.S.Swanson: "The Astroplane Concept", Astronautics & Aeronautics, Jan.1964, pp.35-41
(19) W.G.Huber: "Post-SATURN Launch Vehicle Study (Part II) Condensed Summary Report", NASA TM X-53010, April 10,1964, 15 pp.
(20) Douglas Aircraft Company: "Post-Saturn Class II and IV Launch Vehicle Study (Phase III", Report No.SM-45804 (7 volumes), March 1964
(21) General Dynamics/Astronautics "Post-Saturn Launch Vehicle Study (Phase III), Class IV Vehicles", Report No. GD/A OK-64-009 (5 volumes), May 1964
(22) J.L.Sanders: "Advanced Post-SATURN Earth Launch Vehicle Study- Executive Summary Report", NASA TM X-53200, February 3,1965, 21pp.
(23) W.J.Normyle: "Large Launcher Study Stresses Flexibility", Aviation Week & Space Technology, Aug. 12, 1968
(24) "Future Space Transportation Systems Study", Boeing Aerospace Corporation, D180-20242, Contract NAS9-14323, December 2976, Volumes 1 to 3
(25) "Solar Power Satellite System Definition Study", Contract NAS9-15196, Part I, Vol.V, SPS Transportation: Representative System Descriptions, D180-20689-5,July 28,1977
(26) "Satellite Power System (SPS) Concept Definition Study", Rockwell International, Contract NAS8-32475, Volume V Transportation and Operation Analysis, Report SD-78-AP-0023-5,April 1978
(27) "Satellite Power System- Concept Development and Evaluation Program", US Department of Energy and National Aeronautics and Space Administration, Report DOE/ER-0023, October 1978, 223 pp.
(28) H. Arend: "Systemanalyse und Kostenoptimierung wiederverwendbarer ballistischer Trägerraketen", Dissertation, TU Berlin, 1986
(29) Th.Altmann, O.Kerinnis, H.H.Koelle: "NEPTUNE - 2000 PLUS - Concept of a Heavy Space Freighter for the 21st Century", Report ILR Mitt 229(1989), Aerospace Institute,Technical University Berlin
(30) B.Johenning, H.H.Koelle: "A Multi-Vehicle Space Carrier Fleet Cost Model for a Multi-Mission Scenario", Aerospace Institute, Technical University Berlin, Report ILR Mitt 240(1990),
(31) B.I.Gubanov: "ENERGIA- NRW Soviet Launch Vehicle", 39th IAC, Oct.8-15,1988 Bangalore, India, Paper IAF-88-172, 3 pp.
(32) J.Lassmann: "Low Cost Heavy Lift Launch vehicle for Lunar Exploration Based on the ENERGIA Launcher", 43rd IAC, Aug.28-Sep5, 1992, Washington, D.C., Paper IAA-92-0173, 8pp.
(33) G.Petrov: "Trudnaya sudba rakety N-1" (The Difficult Fate of The N-1 Rocket), Nauka, Zhizn, May 1994, p.21
(34) Craig Covault :"Soviet Union Reveals Moon Rocket Design That Failed to Beat U.S.to Lunar Landing",Aviation Week & Space Technology, Feb 18,1991, pp. 58,59
(35) C.Covault: "Russions Reveal Secrets of MIR,BURAN,Lunar Landing Craft", Aviation Week & Space Technology, February 10,1992, pp.38,39
(36) J.M.Lenorovitz:"TRUD offering Liquid-fueled Engines from N-1 Program", Aviation Week & Space Technology, March 30, 1992, pp.21-23
(37) ASTRONAUTIX com
(38) H.H.Koelle: "NEPTUNE 2015 - A Workhorse for Cis-lunar and Planetary Space Projects", Aerospace Institute, TU Berlin, ILR Mitt.309 (19996), Aug 1,1996, 26 pp.
(39) H.H.Koelle: "Comparison of Future Launch Vehicles for Cargo Transportation to Low Earth Orbit and Lunar Destinations", Aerospace Institute ,TU Berlin, ILR Mitt.314(1997), 1.3.1997, 39 pp.
(40) H.H.Koelle, B.Johenning:" Space Transportation Simulation Model (TRASIM 2.0)", Aerospace Institute, TU Berlin, ILR Mitt. 319 (1997), May 5,1997
(41) H.H.Koelle: "On the Size Optimization of Heavy Lift Space Transportation System", Aerospace Institute,TU Berlin, ILR-Mitt.325(1997), 1.Sept.1997, 29pp.
(42) H.H.Koelle: "Role of Launch Vehicles in Moon-Mars Exploration Program", J.Aerospace Engineering, Vol.11, No.4, October 1998, pp.119-123
(43) H.H.Koelle: "Birth, Life and Death of the Saturn Launch Vehicles ", Aerospace Institute, TU Berlin, ILR-Mitt.350 (2001), 4.4.1997, 29pp.