GEORGE C. MARSHALL SPACE FLIGHT CENTER
HUNTSVILLE, ALABAMA

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FUTURE PROJECTS OFFICE

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thrust Payload

Atlas 360,000 = 4,000
Nova 12,000,000 400,000 } 2 Meg.

SUMMARY REPORT

STATE OF THE ART AND DEVELOPMENT TRENDS IN SPACE TRANSPORTATION

A. Introduction

One of the key elements, if not the determining factor of our progress in the national space flight program, is the availability and capability of launch vehicles. Therefore, let us take a brief look at where we are today and where we are going.

Approval of the SATURN C-5 launch vehicle configuration and the decision to move ahead as rapidly as resources permit with a NOVA size vehicle, have set a definite pattern for what to expect in the area of ground launch vehicles during the next 10 years. This decade will find us concerned with quickly increasing the payload capability of launch vehicles and, thereby, our national mission capabilities. This approach is dictated by competition with the USSR for an early accomplishment of primary space flight objectives and appears to be a sound one for this decade. The question of economy, consequently, must rank second in priority.

What, then, can we expect to accomplish during this decade? We should have an operational capability for 10-ton orbital payloads (C-1) by 1964, which will increase to 100 tons (C-5) by 1967, and 200 tons (NOVA) by 1969-1970. This is an increase by two orders of magnitude over today's capabilities. [2 tons Atlas] The first research and development flights for these vehicles will begin approximately two years prior to these dates. Each of these vehicles is a two-stage, expendable rocket to low earth orbit, and a three-stage to escape velocity. In escape missions these vehicles will carry about 40 percent of their orbital payload when chemical stages are used, and approximately 75 percent if nuclear stages are employed. After 10 research and development flights, one can hope for two successful missions out of three attempts, with an increase to about three out of four after two operational years, and four out of five in the fourth operational year.

These vehicle sizes, payload capabilities and projected mission reliabilities will produce a specific transportation cost approaching 150 $/lb for direct operating cost (vehicle procurement, propellants, ground transportation, and launch operations) for transporting cargo from the earth surface to low earth orbits near the end of this decade. Ten times as much will be paid for each pound of cargo delivered to the moon, as long as chemical systems are used exclusively. There is little hope that the economy of earth-to-orbit transportation systems can be improved by introducing a nuclear upper stage during this decade. However, a nuclear third stage should make it possible to reach a specific transportation cost of about 600 $/lb for cargo transportation to the moon in the late Sixties.

Translating this state of the art into "round-trip tickets" for passenger transport, we must face a 300, 000 $/trip fare for earth-to-orbit flights and a 10 million $/trip fare for a lunar round trip around 1970. Obviously, we have a long way to go before we can speak of commercial space flight.

Then, what are we looking for? We would like to see, one of these years, earth-to-orbit trips as convenient and cheap as a trip to Europe, and a flight to the moon no more expensive than a trip around our own planet today. Then and only then will we be able to speak of commercial space travel in the true sense.

Translating this into figures, and using present air traffic fatality rates, we must average more than 49 successful flights out of 50 from earth to orbit and return, when we use a space vehicle carrying 50 passengers to orbit in one flight. We must also reduce the specific transportation cost to less than 5 $/lb of useful payload to make this economically attractive. For lunar flights with comparable fatality rates, approximately 24 out of 25 must be successful with 10 passengers per flight. The specific payload cost for such a trip to the moon must be reduced to less than 25 $/lb to even discuss commercial flights. Unfortunately, we do not have a workable concept for realizing this state of the art and, therefore, it may be 1980 or later before we can expect to open the first commercial space line to earth orbit and to the moon. The only hope for an earlier date is the possibility of a breakthrough.

While we are waiting for this breakthrough, however, we will improve the state of the art beyond our present SATURN and NOVA vehicle concepts, and, around 1970, we can expect to improve the specific transportation cost for orbital and lunar trips by, perhaps, a factor of five. This can be expected to be within the state of the art in the years 1970 to 1980. This is what we think we can do and what we consider to be "future projects" for the coming years.

B. Earth-to-Orbit Transportation Systems

The key to economical earth-to-orbit transportation seems to be the reusable vehicle. Eventually we must abandon the concept of expendable vehicles which is only a very good shortcut to a rapid increase of payload capabilities. We must design a vehicle that can be reused at least 100 times. For passenger comfort, it is preferred that this vehicle not exceed more than 2 g's in a standard ascent or descent trajectory. That means we must accept a concept similar to the rocket airplane or aerospace plane. We should also try to approach the operational concept of jet liners to make space travel attractive and acceptable to the average passenger. It appears feasible to develop two-stage rocket airplanes for earth-to-orbit traffic. A vehicle in the C-5 class, for example, using the same basic propulsion system, would offer a payload capability of 100,000 to 150,000 pounds. The weight of the recovery gear results in a payload reduction of approximately 100,000 pounds as compared to the present expendable C-5 with a 200,000 to 250,000 pound payload capability.

Later we might find ways and means to take advantage of the oxygen in the air, resulting in a single stage earth-to-orbit aerospace plane. However, the approach seems to limit the size of the vehicle and appears to be attractive only if it does not require too complex an engine system. The present launch operations concept should also be reviewed to see if there is a way to reduce the initial high risk of vertical takeoff for personnel-carrying vehicles and, at the same time, reduce the tremendous cost of vertical checkout and launch facilities. There is no conclusive evidence, at this time, that horizontal takeoff, with some assistance on the ground, is not feasible. Admittedly, it puts some of the burden on the flying hardware, but it could be that improved propulsion systems may make this acceptable.

We cannot hope to introduce space flight to the general public unless we find an operational mode and operational cost acceptable to the "high-income taxpayer." If we are successful in developing a single or two stage chemical rocket aerospace plane and learn to fly it 100 times or more before it is worn out, we should be able to achieve a specific transportation cost to earth orbit of about 20 $/lb or less. It is also obvious that the trend toward the reusable vehicle concept does favor the liquid rocket systems rather than the solid propellant engines. While the solid system might offer an alternate method to gain large payloads fast, it does not seem competitive with the reusable liquid vehicle in the long run. This is obvious when one considers the fact that solid propellants cost one dollar/lb, and liquid propellants two to five cents/lb or, for high energy liquids, up to 25 cents/lb. Propellant costs become a dominant factor for vehicles with high reusability rates.

C. Lunar Transportation Systems

It is obvious that orbital operations will play a major role in future space applications and systems. The term, orbital operations, includes such activities as: rendezvous, docking, refueling, maintenance and repair, checkout, personnel and cargo transfer, orbital launch operations, orbital assembly and construction, operation of space stations, etc. These techniques will be developed in this decade. The GEMINI and APOLLO programs will make use of orbital operations. It is likely that one or more space stations will also operate in earth orbit during this decade. Thus, it is concluded that orbital operations is a thing to come and to stay; not only earth orbital operations, but also lunar and planetary orbital operations.

The same basic concept of reusable vehicles appears to be feasible and attractive for advanced lunar transportation systems. Such systems would make use of a chemical reusable rocket aerospace plane to orbit, a reusable nuclear ferry from earth orbit to lunar orbit and back, and a local chemical (single stage) lunar shuttle carrying cargo and personnel between the lunar orbit and the lunar surface. The nuclear ferry vehicle would be refueled in earth orbit and the lunar shuttle in lunar orbit. Preliminary investigations show that lunar round-trip costs can be reduced to about $3 million per man using such a system. If and when we learn to manufacture propellants on the surface of the moon, this system can be further improved--possibly to a point when one round trip costs less than $1 million per person. The alternate method for developing an economic earth-lunar transportation system is the all-nuclear rocket. However, we must find a way which offers specific impulses considerably better than the 800 to 1000 seconds which is now being discussed and is in the early development stage. It is very hard to say when we might be able to do this; this might be the breakthrough mentioned earlier in this discussion. It is quite likely, therefore, that we will proceed with the development of an all-reusable three phase earth-lunar transportation system unless, of course, we find a better way of doing it. The first portion of such a system would be a reusable chemical rocket aerospace plane from the earth surface to orbit and return.

Up to this point in the development of space systems, it has been quite difficult to sell the idea of reusable vehicles because it can be easily shown that (1) these systems are fairly expensive to develop, and (2) this development will take several years. Thus, reusable systems will be acceptable only if it can be shown that there will be a real market for space travel. Recent studies indicate that space flight can become cheap enough to lay the foundation for the development of a large market. From the economic viewpoint, it is probable that, if enough requirements develop, this market will increase rapidly during the Seventies. Thus, chances are good that the next space vehicles, following the present family of expendable launch vehicles, will be reusable.

D. Planetary Transportation Systems

The goal of astronautics can be easily described: namely, exploration and/or utilization of natural or artificial celestial bodies other than Earth. The structure of the universe, however, imposes certain development steps in the process of realizing this broad goal. These steps can be aptly identified by the maximum distance each leads us from home: first, the immediate earth environment; second, the moon; third, the planets--and here our technological knowledge stops us for the time being.

With the means becoming available, we can explore and utilize the solar system. A different technology appears to be required to bring the stars within reach, and subsequently more to open up flight between galaxies.

We live at the beginning of the early planetary phase, and our goal is to put a small expedition on the planets. Of course, there are intermediate steps: to put a man into orbit, to reach the moon--to name some outstanding targets. But we should not mistake the intermediate targets for the ultimate goal.

If we review our present efforts in light of our goal, they fall into place as important steps in the evolution of space flight: The manned satellite is the first cautious step; man on the moon is the important test operation. Parallel to these is the development of various means of nuclear propulsion, of advanced navigation, of novel operational concepts. All are geared to one goal--to open up the solar system for man.

What elements are missing to put man on the planets? Transportation-wise, NOVA plus orbital operations plus nuclear propulsion can perform the task. Environmental protection, life support, power supply, navigation and communication, earth landing systems, and the systems supporting the planetary operations must, also, be developed or improved greatly over what is required for the lunar enterprise.

What can be done today toward the development of planetary transportation systems? Certain current hardware programs will contribute; for example, NOVA or RIFT. Besides these long leadtime items, one major element is missing: a long range program which clearly spells out--this is the goal; these are the ways to reach it; this is the way we shall try. To take a major step toward finding the facts to formulate such a long range plan, sufficient information must be available. To generate this is the immediate goal of the interplanetary portion of the FPO study program. In progress, or to be initiated soon, are a study resulting in two-way trajectory computation methods, evaluations and, finally, a manual on this subject; another study on the role of nuclear-electric compared to nuclear-heat-exchanger propulsion systems; and a third on the systems aspects of a proposed "first" interplanetary manned mission, which is possibly "only" a Crocco round trip, but which will signal that the greatest and most decisive period of the planetary phase has begun.

E. Summary

What, then, are the trends? Here is a teletype-style summary: We must find ways to make space transportation faster, more reliable, and more economical.

1. communication
2. good design
3. production

We can expect to continue along the following lines:

1950 - 1960	10	Decade of Preparation
1961 - 1965	5	First Manned Satellites
1965 - 1970	5	First Large Manned Space Stations
1967 - 1970	3	First Manned Lunar Expedition
1970 - 1975	5	Lunar Base Construction
1970 - 1980	10	First Manned Planetary Exploration

The year, 2000, should find humanity well along the road toward utilizing all the resources of the solar system, and traveling within the solar system should become fairly routine. To put man on the moon, on the planets, or anywhere within the solar system wherever his environment can be controlled: This is the goal. This can be done. More is not feasible now, but nothing less will suffice.

Seattle missed the boat