March 20, 1963

Internal Note M-FPO-1-63

EARTH-ORBIT TO MARS-ORBIT VEHICLE DESIGN

By

Harry O. Ruppe

FUTURE PROJECTS OFFICE
GEORGE C. MARSHALL SPACE FLIGHT CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
HUNTSVILLE, ALABAMA

ABSTRACT

Based on the mission of manned exploration of the planet Mars, a preliminary survey is given of typical mass data for orbit launched vehicles. Using nuclear heat exchanger propulsion systems and relatively short mission durations (one year), these vehicles are large - of the order of 10^3 tons. In the case of Mars, there are definitely "good" and "bad" launch time periods because of the eccentricity of its orbit. Limiting cases are discussed and remarks as to costs, schedules, and further study requirements are presented.

NOTE

The author was invited to present this paper at the Symposium on the Exploration of Mars sponsored by the American Astronautical Society on June 6-7, 1963 in Denver, Colorado. This paper does not represent official thinking of the George C. Marshall Space Flight Center or the National Aeronautics and Space Administration.

TABLE OF CONTENTS

TABLES AND ILLUSTRATIONS

I. INTRODUCTION

Manned exploration of the planet Mars is one of the major goals of astronautics. It can be expected that during the next decade men will travel to Mars and return safely to Earth.

It is impossible today to describe this first expedition in any great detail because too many elements are unknown. However, we can attempt a description that will convey an impression of the size of the task ahead based upon our present knowledge.

Let us agree on a mission profile:

Step 1 - Earth surface to a low, circular satellite orbit. Rendezvous, assembly, refueling, launch operation, etc., take place in this orbit as required. We will assume that a sufficiently large Earth launch vehicle is available, and that the Earth orbital technique is adequately developed.

Step 2 - Launch from that orbit with a propulsion system of sufficiently high thrust so that near-impulsive conditions prevail.

Step 3 - Free-flight periods to Mars interrupted only by vernier propulsion, course correction propulsion, and attitude control maneuvers.

Step 4 - Rocket braking to enter an orbit around Mars at an altitude of 1000 km.

Step 5 - Stay in that orbit for the Mars exploration period. A Mars excursion module (MEM) with a small crew is separated from the orbiting vehicle and descends to the surface using aerodynamic braking. The MEM ascends to the orbiting vehicle to transfer the crew for return to Earth.

Step 6 - Rocket maneuver to initiate return flight from Mars orbit.

Step 7 - Free-flight similar to Step 3.

Step 8 - Direct entry into the Earth's atmosphere and aerodynamic braking using a special Earth landing vehicle.

Other profiles are possible. The question of profile optimization will not be discussed in this paper. I will only given an estimate of the payload and speed requirements for the interplanetary transport ship, from which sizes will be derived. Different papers at this meeting discuss what I called Steps 1, 5, and 8. The combination of all this will give you a broad survey of the overall mission, viz., to get man safely to Mars and back. It goes without saying that other missions can be of interest, e.g., fly-by only or orbit only.

We will make the assumption here that nuclear heat exchanger type propulsion systems are available. It is not anticipated that more advanced propulsion systems will be operational in the early 1970's.

II. DESIGN PARAMETERS

The major design parameters that we have to establish are the payload and speed requirements for the interplanetary transporters. We will find that "good" and "bad" launch time periods exists, in one case because of the varying solar activity, and in the other because of the eccentricity of the Mars orbit.

Many of you will feel that the following data are unduely pessimistic, and I agree if you take the data at their face value. But a look at past history shows that "fairly exact" conceptual designs invariably turned out to be highly optimistic when compared to the actual article. A simple explanation is that an "exact" conceptual design is "exact" only as to the items considered. The many elements that are either unknown or not considered because they are too insignificant on the level of conceptual design, or plainly and simply forgotten, make the situation worse. In an attempt to compensate for these contingencies, I think it behooves us to be quite pessimistic on the main elements, hoping that the margins thus created will lead to near-correct final data.

There is another reason why I think that overly optimistic considerations will hurt our case: We want to show that manned exploration of the planets during the next decade is feasible within our technical and economic capabilities. Generally, we have broad opposition; we will just deliver more ammunition to their arguments if we are caught on unduely optimistic assumptions.

In all cases, I assume that two interplanetary vehicles of the same size leave from Earth orbit and enter Mars orbit. One of the two is manned (crew ship), the other one unmanned (cargo ship). Only the crew ship has the capability of returning to Earth. The cargo ship remains in Mars orbit; therefore, it can carry a relatively large amount of cargo -- usually sufficient for one or two MEM vehicles (Operationally, it appears to be mandatory

4. For the three year mission, 40 gr/cm^2 shielding is available from structures and equipment.

5. Under the most favorable conditions, total shielding requirements are 50 gr/cm^2, and 220 gr/cm^2 under the least favorable conditions.

The payload weights are summarized in Table 1. These masses have to be carried by the crew ship through the mission; therefore, a one-way cargo ship of the same initial size will deliver considerably more into the satellite orbit around Mars. It is apparent without further investigation that a MEM can be transported.

Table 1. Payload Mass in Tons

Item	1 - Year Mission 5 - Man Crew		3 - Year Mission 8 - Man Crew
	Quiet Sun	Active Sun	Average Sun
Crew and Comfort	1	1	5
Living Mod./Life Support	7	5	10
Control Equipment	2	2	2
Storage Room	2	2	2
Internal Power	2	2	2
Scientific Equipment	2	2	2
Environmental Shelter	10	20	150
Earth Entry Vehicle	6	6	7
TOTAL	32	40	180

B. Speed Requirements

A careful trajectory optimization is required for actual planning. For this survey it will suffice to make a good choice that could undoubtedly be further improved. Table 2 shows the data used.

Table 2. Speed Requirements in km/sec (includes estimated gravity loss)

Item	1-Year Mission 10-Day Stay Time		2.7-Year Mission (Hohmann) 450-Day Stay Time
	1971	1979	No Strong Variation (Year)
Launch from 97 min. Orbit	6.6	11.9	3.9
Mid-course Correction	0.1	0.1	0.3
Braking, 1000 km Mars Orbit	4.0	7.2	2.2
Launch, 1000 km Mars Orbit	6.4	7.6	2.2
Mid-course, Correction	0.1	0.1	0.4
Earth Entry, Aerodynamic	12.2	12.5	11.2

One of the ground rules used to select the trajectories was to maintain the Earth atmospheric entry speed at or below 12.5 km/sec.

Since 1971 represents very favorable conditions and 1979 unfavorable conditions, these trajectory choices represent limiting cases. To exaggerate this, we will assume that for 1971 the payloads for a "quiet sun" apply, and for 1979 those of an "active sun" apply. For this reason, from now on we will refer to simply "good" or "bad" years *.

III. DESIGN SAMPLES

I assume that all major propulsive maneuvers occur in a near impulsive fashion. It is well known that the same effect can be obtained with moderately low acceleration systems by the method of multi-burn pericenter impulses. I did not explicitly assume the use of this technique, but the mass data would not change noticeably if the multi-burn engine characteristics are assumed to be similar to those of a more standard engine.

This paper does not permit going into the astrionics aspect in any detail. Suffice it to say that MARINER II showed that the communication problems are well in hand, and that relatively simple guidance systems are adequate (inertial, either full or body mounted, together with Earth based radio guidance for injection and star reference for attitude). It goes without saying that more developments are required to obtain higher accuracy and longer lifetimes, to combine inertial and optical systems, to derive full benefit from the presence of the crew, etc. But, to repeat, astrionic systems do not seem to be the bottleneck for manned Mars missions.

---

* This is almost true since "quiet sun" is expected to occur approximately in 1974 and "active sun" approximately in 1978.

The "design samples" (Tables 3-6) are very simple breakdowns of mass distribution. They do not represent results of design studies; however, I still think the numbers are typical.

For the Hohmann mission, data are given for both chemical and nuclear propulsion. Because of these results, the one-year trips are evaluated for nuclear propulsion only.

In no case were detailed investigations performed in areas such as hydrogen storage or reliquefaction, meteoroid protection, etc. It is hoped that the quite liberal assumptions for inert weights will compensate for this omission.

Table 3. Eight-Man Hohmann Mars Mission (Chemical)

Payload Weight (tons)	180
Third Stage	
Performance -	
Specific Impulse	425 sec
Thrust	100 tons
Weights (tons) -	
Propulsion System	3
Structure	20
Propellants	184
TOTAL	207
Interstage Weight (tons)	4
Second Stage	
Performance -	
Specific Impulse	425 sec
Thrust	250 tons
Weights (tons)	
Propulsion System	5
Structure	35
Propellants	313
TOTAL	353
Interstage Weight (tons)	7

First Stage

Performance -	
Specific Impulse	425 sec
Thrust	1000 tons
Weights (tons) -	
Propulsion System	15
Structure	75
Propellants	1369
TOTAL	1459
Orbital Launch Mass	2210 tons

A. Table 3 Comments. I estimate that orbital launch mass for a favorable year will be 1,500 tons, and for an unfavorable year the mass will be 3,000 tons. Since two such vehicles will have to be launched for a landing mission, it is apparent that a tremendous effort is involved. This is the reason no further investigation will be made as to the use of chemical propulsion system.

Table 4. Eight-Man Hohmann Mars Mission (Nuclear)

Payload Weight (tons)	180

Third Stage

Performance -	
Specific Impulse	800 sec
Thrust	75 tons
Weights (tons) -	
Propulsion System	7
Structure	8
Propellant (H_2)	80
TOTAL	95
Interstage Weight (tons)	3

Second Stage

Performance -	
Specific Impulse	800 sec
Thrust	75 tons
Weights (tons) -	
Propulsion System	7
Structure	10
Propellant (H_2)	103
TOTAL	120

Interstage Weight (tons)	4
First Stage	
Performance -	
Specific Impulse	800 sec
Thrust	400 tons
Weights (tons)	
Propulsion System	25
Structure	25
Propellant (H_2)	303
TOTAL	353
Orbital Launch Mass	755 tons

B. Table 4 Comments. I estimate that orbital launch mass for a favorable year will be 530 tons, and for an unfavorable year the mass will be 1, 100 tons.

Table 5. Five-Man One-Year Mars Mission (1971)

Payload Weight (tons)	32
Third Stage	
Performance -	
Specific Impulse	800 sec
Thrust	40 tons
Weights (tons) -	
Propulsion System	4
Structure	6
Propellant (H_2)	59
TOTAL	69
Interstage Weight (tons)	1
Second Stage	
Performance -	
Specific Impulse	800 sec
Thrust	100 tons
Weights (tons) -	
Propulsion System	8
Structure	9
Propellant (H_2)	86
TOTAL	103
Interstage Weight (tons)	2

First Stage	
Performance -	
Specific Impulse	800 sec
Thrust	400 tons
Weights (tons) -	
Propulsion System	25
Structure	30
Propellant (H_2)	359
TOTAL	414
Orbital Launch Mass	621 tons

Table 6. Five-Man One-Year Mars Mission (1979)

Payload Weight (tons)	40
Third Stage	
Performance -	
Specific Impulse	800 sec
Thrust	50 tons
Weights (tons) -	
Propulsion System	4
Structure (tankage)	8
Propellant (H_2)	85
TOTAL	97
Interstage Weight (tons)	1
Second Stage	
Performance -	
Specific Impulse	800 sec
Thrust	150 tons
Weights (tons) -	
Propulsion System	10
Structure (tankage)	20
Propellant (H_2)	247
TOTAL	277
Interstage Weight (tons)	3

First Stage

Performance -	
Specific Impulse	800 sec
Thrust	1000 tons
Weights (tons) -	
Propulsion System	50
Structure (tankage)	80
Propellant (H_2)	1852
TOTAL	1982
Orbital Launch Mass	2400 tons

C. Table 6 Comments. Even though quite favorable propulsion parameters are assumed, the initial mass is very high. This points out that investigations to alleviate this situation are urgently needed. Improvements may be realized from the following:

1. Reduction of payload.
2. Increase of accepted risk, leading to structural weight reductions.
3. Reduction of mission objectives, e.g., no landing.
4. Rigorous trajectory optimization.
5. Aerodynamic braking to establish Mars satellite orbit.
6. Permit very high Earth arrival speeds by, e.g., partial rocket braking.
7. Propulsion improvements.
8. Increase in mission duration.
9. Elliptic capture orbits.
10. More effective staging, e.g., tank staging only.

I would expect that a drastic reduction of the 2,400 tons is possible; it will not come easy and may very well require the development of unorthodox techniques, e.g., points 5, 7 (ORION), or 9 above.

IV. EMPIRE RESULTS*

One of the EMPIRE study contracts, namely Contract No. NAS8-5026 with General Dynamics/Astronautics, outlined a minimum Mars landing mission. The main parameters established are:

A. Nuclear propulsion is used for Earth departure, Mars capture, and Mars departure.

B. Chemical propulsion is used to establish a highly elliptic orbit around Earth upon return.

C. Vehicle and life support system (shielding) are highly integrated.

D. Optimum benefit is derived by designing the vehicle for the space environment.

E. A minimum Mars excursion module is carried aboard the crew ship, i.e., crew and cargo ships are not separated.

F. The crew consists of eight men.

G. Mission duration is 450 days and Mars capture period is 20 days.

H. Earth orbit launch mass for 1973 is 880 tons and for 1975 is 1,250 tons.

These data are not inconsistent with our simple results derived earlier.

V. ADDITIONAL REMARKS

After looking at some typical mass distributions, it is apparent that we are still a long way from a true conceptual design. However, it should be noted that the results described in Section IV are based on considerable detail and might rightfully be called a conceptual design. Then, what is missing is work leading to a preliminary design, which certainly goes far beyond the scope of this paper.

No paper such as this would be complete without mentioning two more subjects: cost and schedule.

---

*The abbreviation "EMPIRE" refers to contracts listed under LITERATURE, numbers 10.10, 10.11, and 10.12.

Figure 1 shows the results of an attempt to construct a schedule. Even such a simplified and naive try leads to the conclusion that a first mission attempt will at best be made in 1973 and more probably in 1975.

It is quite dangerous to outline costs of a program such as this because costs are to a large degree dependent upon bookkeeping. Let us look at two extreme examples and a "balanced" or more reasonable example:

A. One might say that the cost of the interplanetary program is equal to the cost of the space flight program til 1980, assuming an interplanetary program is conducted; minus cost of the space flight program til 1980, assuming no interplanetary program is conducted. From this point of view, the cost will be low; I would guess hardly more than $\$10 \times 10^9$ and possibly even zero dollars.

B. The other extreme is to say that the cost of the interplanetary program is equal to the sum of all programs that assisted, in any way, the interplanetary program. From this point of view, almost the total national space flight program cost is charged to manned exploration of the planets; thus, we may obtain a cost figure like $\$100 \times 10^9$.

C. A more balanced point of view is represented by the following information which represents expenditures from 1966 to 1979:

1. Development of the interplanetary ships equals $\$9 \times 10^9$. This includes crew cabin, Mars excursion module, and Earth entry vehicle. Excluded are all propulsion systems, Earth surface to orbit vehicles, and orbital operations.

2. Production and procurement of all systems equals $\$2 \times 10^9$.

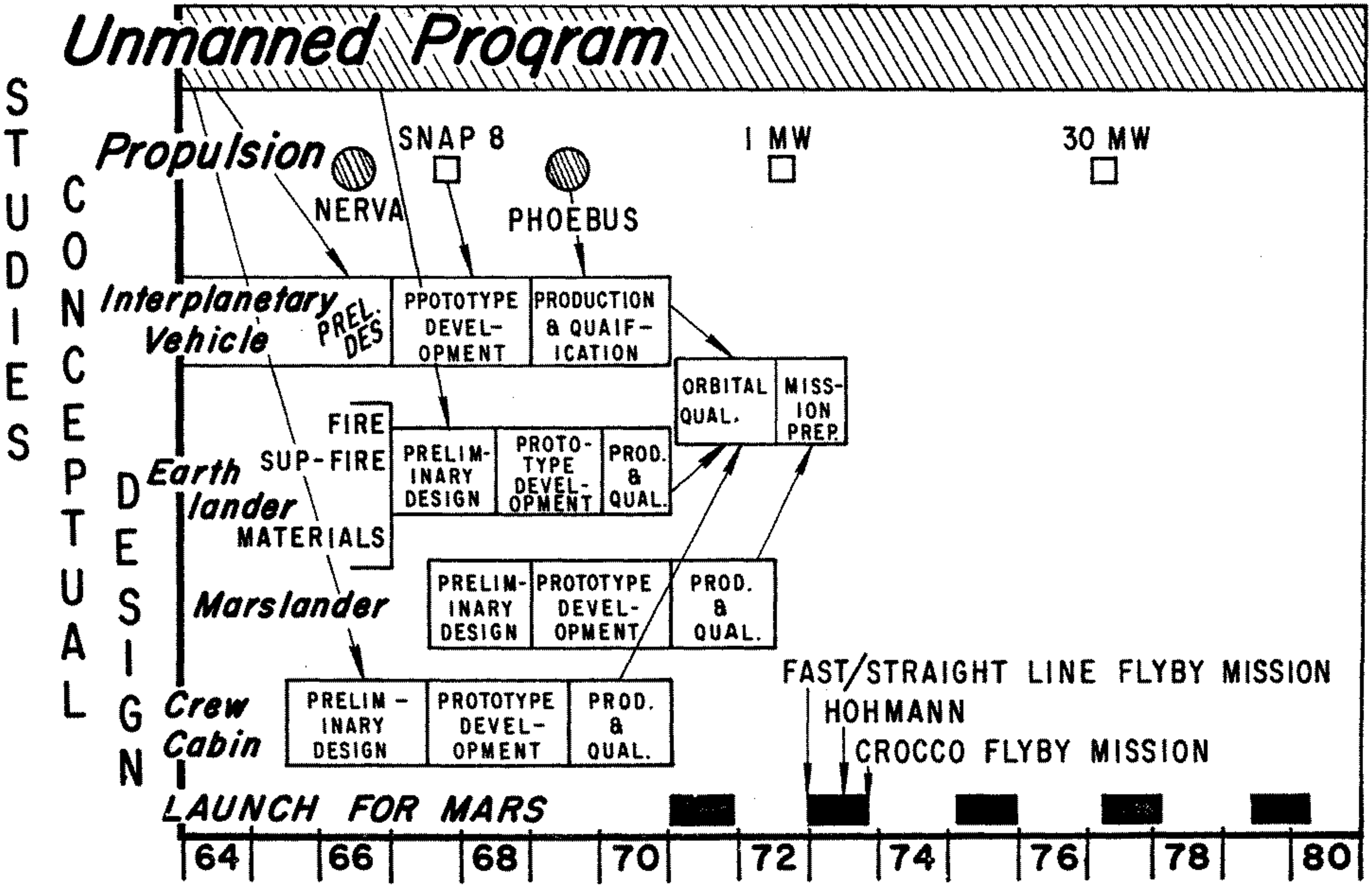
3. All operational costs equal $\$5 \times 10^9$. This includes Earth surface to orbit transport and orbital operations.

4. The sum of 1, 2, and 3 is $\$16 \times 10^9$.

Electrically propelled manned interplanetary vehicles may be developed and utilized by 1979, at the earliest. Based on this, approximately $\$5.5 \times 10^9$ should be added to the above total.

As explained above, an interplanetary program might cost about $\$20 \times 10^9$ spread over a 13-year period. This equals approximately 20 percent of the NASA budget planned for this time period which looks quite reasonable.

FIGURE I SCHEDULE



How good are electric propelled vehicles for the interplanetary transportation task? Without going into detail because their period of operation is in the distant future, I will give some general information in Table 7 below.

Table 7. Orbital Launch Weights in Tons

	Hohmann Trip	Fast Trip
Nuclear Heat Exchanger	755	621
Ionic Propulsion	330	250

In each case, this is a reduction by a factor of more than two. Furthermore, the electrically propelled vehicles appear to be less sensitive to the "good" and "bad" astronomical constellations for Mars flights. On the other hand, the tremendous task of developing a man-rated electric system must not be underestimated. More study is needed to asses the relative economy, instead of the relative performance, of the competing systems.

I think another remark is in order to focus attention on the difficulties introduced by the change in performance requirements with year of launch for Mars missions. It is apparent that we cannot develop an interplanetary ship for 1973, another for 1975, etc. Therefore, the selected design must have inherent flexibility to cope with requirements that fluctuate widely, and this may for example, require rigorous use of tank-staging methods as proposed by Mr. K. Ehricke. As a fringe benefit, multiple use of the same propulsion system would come natural with such a design.

Another significant thought comes to mind; the experts do not agree whether artificial gravity is required or not. However, they do agree that our design task becomes considerably more difficult if the answer is "yes." Personally, I think, or hope, that the answer is "no." I feel that the available information points in this direction, and even if the astronauts required special medical treatment after the mission, this appears to be the simplest solution by far. In case the answer is "yes," the next question is, how much artificial gravity is needed? I feel quite sure that 1/10 g or so will suffice. This will at least simplify the problem.

VI. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions. The main conclusions of this study are:

1. Orbital launch masses using nuclear heat exchanger propulsion systems are large - of the order of 1,000 to 5,000 tons for various years.

2. Electric propulsion systems may reduce these weights by a factor of considerably more than two.

3. Orbital operations appear to be required at both Earth and Mars.

4. No problems impossible to solve have been encountered.

5. No problems have been detected that would require state of the art advancements far beyond APOLLO technology.

B. Recommendations. Some typical recommendations for further study are:

1. Detail conceptual design studies of the interplanetary vehicle with special emphasis upon close overall mission integration.

2. What missions can be performed with chemical propulsion systems?

3. Careful overall optimization of the trajectory profile.

4. Careful study of the mission profile, i.e., the where, how, and why of mission staging; mission duration; etc.

5. Special study of how to alleviate the problem of the "difficult" time period - 1975 - 1983.

6. Further systems analysis regarding the tasks involved, resources, and schedules.

7. What is the proper role of electric propulsion in the area of manned interplanetary flight?

8. Define more advanced propulsion systems that may play a role. What role will mixed high-low acceleration propulsion have from orbit?

9. Detail definition of mission staging operations that are required. This should be input for studies such as orbital operations, and must be closely integrated with NOVA studies.

10. Sub-systems such as the life support systems, MEM, Earth entry vehicle, and other support vehicles require detailed conceptual design effort.

<u>C. Concluding Remarks</u>. In summary, let me restate our position as I see it: We are beginning to understand the problem. We can ask sensible questions, but are quite far away from establishing a firm plan on how to explore the planets with manned flights. We should be in a much better position in perhaps a year from now if we work hard at it. Let's get going!

LITERATURE

These more than 60 references represent only a fraction of the literature directly applicable to this subject.

1. Environment

1.1 Aerospace Environments and Missions, NAS8-2550, Northrop Space Lab., 1962.

1.2 Venus as an Astronautical Objective, P. Moore et al., Advances in Space Science and Technology, Vol. 3, Academic Press, 1961.

1.3 Mars as an Astronautical Objective, S. L. Hess, Advances in Space Science and Technology, Vol. 3, Academic Press, 1961.

1.4 The Atmospheres of Mars and Venus, National Accademy of Science, Pub. No. 944, 1961.

2. Life Sciences

2.1 NASA Life Sciences Data Book, NASr-89, 1962.

2.2 Radiation Shielding, L. E. Wallner et al., NASA TND-681, 1961.

3. Earth Orbital Operations

3.1 Orbital Launch Operations, NAS8-852, Douglas, 1961.

3.2 Orbital Launch Operations, NAS8-853, Chance-Vought, 1962.

3.3 Orbital Flight Manual, ER 11648, The Martin Company, 1961.

3.4 Flight Performance Manual, NAS8-861, Northrop Corporation, 1961.

3.5 Flight Performance Handbook, NAS8-863, Space Technology Lab., Inc., 1961.

3.6 Orbital Storage of Liquid Hydrogen, T. R. Olivier et al., NASA TN D-559, 1961.

3.7 Cryogenic Storage, G. R. Smalak et al., Aero/Space Engineering, June 1960.

3.8 Estimation of Weight Penalties Associated with Alternate Methods of Storing Cryogenic Propellants in Space, A. A. Fowle, NAS5-664, A. D. Little, Inc., 1962.

3.9 Orbit Launched Vehicles, NAS8-1535, Convair-Astronautics, 1961.

3.10 J. W. Brice Jr, A Method for Determining Orbital Launch Windows for Interplanetary Trajectories, Vought Astronautic June 63

4. Earth-Surface Launched Vehicles

4.1 NOVA System Studies, NAS8-5135, Martin Company, 1963.

4.2 NOVA System Studies, NAS8-5136, General Dynamics/Astronautics, 1963.

4.3 Post-NOVA Launch Vehicle, NAS8-5021, Douglas, 1963.

4.4 Post-NOVA Launch Vehicle, NAS8-5022, General Dynamics/Astronautics, 1963.

4.5 Post-NOVA Launch Vehicle, NAS8-5023, RAND, 1963.

5. Astrionics

5.1 An Analysis of the Corridor and Guidance Requirements for Supercircular Entry, D. R. Chapman, NASA TRR-55, 1960.

5.2 Interplanetary Navigation System Study, MIT, NASw-130.

5.3 Recent Advances in Attitude Control of Space Vehicles, W. Haeussermann, ARS Journal, February 1962.

6. Entry

6.1 Deceleration and Heating of a Body Entering a Planetary Atmosphere from Space, C. Gazley, Jr., Vistas in Astronautics, Vol. 1, Pergamon Press, 1958.

6.2 Atmospheric Entry, R. M. Wood, Douglas Engineering, Paper No. 1246, 1961.

6.3 Manned Entry Missions to Mars and Venus, R. L. Lowe et al., ARS preprint 2158, 1961.

6.4 Effects of Mars Atmospheric Uncertainties on Entry Vehicle Design, J. M. Spiegel, Aerospace Engineering, December 1962.

6.5 Some Aerothermodynamic Considerations for Martian Entry, M. G. Boobar, IAS paper 62-163, 1962.

6.6 Lift Entry of Manned Space Vehicles, Douglas, Report SM-42120, August 1962.

7. Trajectories

7.1 Study of Interplanetary Transportation Systems, NAS8-2469, Lockheed Missiles and Space Co., 1962.

7.2 Optimization of Interplanetary Stopover Missions, R. V. Ragsac et al., ARS preprint 2725-62.

7.3 Astrodynamic Constants, H. G. L. Krause, MSFC-MTP-P&VE-F-62-12, 1962.

7.4 Interplanetary Rocket Trajectories, D. F. Lawden, Advances in Space Science, Vol. 1, Academic Press, 1959.

7.5 Optimal Powered Arcs, D. F. Lawden, ARS Journal, April 1961.

7.6 Three-dimensional Trajectory Analysis, G. Knip, Jr. et al., NASA-TN-D-1316, 1962.

7.7 Three-dimensional Trajectory Analysis, C. L. Zola et al., NASA-TN-D-1319, 1962.

7.8 Analysis of Trajectory Parameters, J. F. Dugan, Jr., NASA-TN-D-470, 1960.

7.9 Analysis of Trajectory Parameters, J. F. Dugan, Jr., NASA-TN-D-281, 1960.

7.10 Optimum Midcourse Plane Changes, W. R. Fimple, United Aircraft Corp. Research Lab., A-110058-3, 1962.

8. Propulsion-High Acceleration

8.1 Nuclear Engine Requirements, H. O. Ruppe, MSFC-FPO-62-1, 1962.

8.2 Perigee Propulsion, P. G. Johnson et al., NASA-TR-R-140, 1962.

9. Propulsion - Low Acceleration and Mixed Acceleration

9.1 A Consideration of the Problems of Electric Propulsion Systems (C), NAS8-2672, RAND, 1962.

9.2 Plasma Propulsion, Camac, Advances in Space Science, Vol. 2, Academic Press, 1960.

9.3 Electrostatic Propulsion, E. Stuhlinger et al., Advances in Space Science, Vol. 2, Academic Press, 1960.

9.4 Low Thrust Flight, Irving, Chapter 10, Space Technology, J. Wiley and Sons, 1959.

9.5 Fast Interplanetary Missions with Low-Thrust Propulsion Systems, W. E. Moeckel, NASA TRR-79, 1960.

9.6 Payload Optimization for Power-Limited Vehicles, W. G. Melbourne, NAS7-100, Jet Propulsion Lab., 1962.

9.7 The Use of High and Low Thrust Propulsion, T. N. Edelbaum, Journal of Astronautical Sciences, Summer 1962.

9.8 Comparison of Nonchemical ......, T. N. Edelbaum, United Aircraft Corp. Research Lab., R-1383, October 1960.

9.9 Dual Electric-Nuclear Rockets, M. Levoy, IAS paper 62-117, 1962.

10. Systems Oriented Papers

10.1 The Boomerang Project, E. Fonseca, Centro de Estudos Astronáuticos Portugal, 1960.

10.2 In-Transit Rendezvous, C. E. Kaempen, XI IAC, Stockholm, 1960.

10.3 Comparison of Several Propulsion Systems for a Mars Mission, R. S. Kraemer et al., ASME paper 59-AV-46, 1959.

10.4 Rescue from Space, K. Ehricke, Physics and Medicine for the Atmosphere and Space, Wiley and Sons, 1960.

10.5 Das Mars Proje~~c~~kt, W. von Braun, Umschau Verlag (German), 1952.

10.6 Exploration of Mars, W. von Braun et al., Viking Press, 1956.

10.7 Interplanetary Man, H. O. Ruppe, unpublished, 1962.

10.8 Systems Analysis of Fast Manned Flights to Venus and Mars, K. Ehricke, Transactions on the ASME, February 1961.

10.9 Study of Manned Nuclear ......, S. C. Himmel et al., Aero/Space Engineering, July 1961.

10.10 EMPIRE, NAS8-5024, Lockheed Missiles and Space Co., 1962.

10.11 EMPIRE, NAS8-5025, Ford/Aeronutronics, 1962.

10.12 EMPIRE, NAS8-5026, General Dynamics/Astronautics, 1962.

Books

1. Die Erreichbarkeit der Himmelskoerper, W. Hohmann ~~and~~ R. Oldenbourg, 1925 (German).

2. Wege zur Raumschiffahrt, H. Oberth ~~and~~ R. Oldenbourg, 1929 (German).

3. The Exploration of Space, F. Godwin, Plenum Press, 1960.

4. Introduction to Astrodynamics, R. M. Baker et al., Academic Press, 1960.

5. Propulsion Systems for Space Flight, W. R. Corliss, McGraw-Hill, 1960.

6. Handbook of Astronautical Engineering, ed. by H. H. Koelle, First Edition, McGraw-Hill, 1961.

7. Space Flight, Vol. 1, 2, and 3, K. Ehricke, D. V. Norstrand, 1961 and 1962.

8. Introduction to Astronautics, H. O. Ruppe, Wiley and Sons, 1964 (planned).

DISTRIBUTION

M-DIR
- Dr. von Braun
- Mr. Rees

M-AERO
- Dr. Geissler
- Mr. deFries (3)

M-ASTR
- Dr. Haeussermann
- Mr. Digesu

M-P&VE
- Mr. Goerner
- Dr. Krause
- Mr. Jordan (2)

M-RP
- Dr. Stuhlinger
- Mr. King

M-FPO
- Mr. Koelle
- Mr. Gradecak
- Mr. Smith
- Mr. Carter
- Mr. Huber
- Mr. Williams
- Mr. Sharpe
- Mr. Ruppe (25)