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Manned Mars Mission Program Concepts

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Abstract

Of the several new initiatives being contemplated by NASA after the Space Station, a manned expedition to Mars is the most challenging, adventurous, and most rewarding. The Mars initiative envisions much more than just two or three fast trips to the surface of Mars to plant flags and return surface samples. This bold initiative is committed to the human exploration and eventual habitation of Mars, **Figure 1**. This paper briefly describes the SRS Manned Mars Mission and Program Analysis Study which supports this initiative. The results, to date, indicate the need for a earth-to-orbit transportation system much larger than STS, reliable long-life support systems and either advanced propulsion or aerobraking technology.

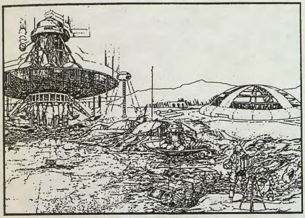

Figure 1

Introduction

The planning of Manned Planetary Missions is very complex and requires an understanding of the interrelationships of the many parameters associated with planetary orbits, launch windows, etc. This study envisions the transportation of many metric tons of spacecraft, propellant, and life support equipment to low Earth orbit for assembly at the Space Station into huge vehicles, **Figure 2**, for escapes from the Earth-Moon system on a trajectory that arrives months later at Mars. The geometry is complicated because of the orbits of Earth and Mars as indicated in **Figure 3**. This results in a variation in energy required, depending on the departure and arrival dates, travel time, and stay time at the planet. On some missions the stay time at the planet may be short (opposition class); other missions may require the astronauts to stay at Mars until the two planets are again in proper alignment to allow a low energy trip back to earth (conjunction class).

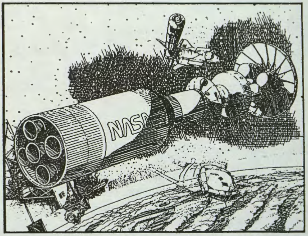

Figure 2

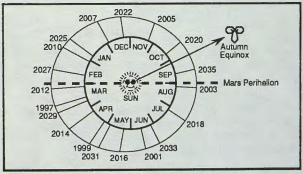

Figure 3

The complexity of the myriad of options for performing these missions, along with the equipment development lead times and logistics involved in fabrication, testing, and eventually transporting the elements to orbit, requires a rather sophisticated computer program to keep up with all the variables, **Figure 4**.

Software Modules

Under the sponsorship of NASA/MSFC, SRS is in the process of developing an interactive software package to determine the sensitivity of mass required in LEO, schedules, relative costs and risk, to various mission concepts and program options. The study considers the launch opportunities from 1999 to 2035. A VAX 11/780 is used to calculate the ΔVs required for various trajectories and stores them in the trajectory module data base. Data bases for launch vehicle design, fabrication, testing, and orbital assembly, are also being developed for the transportation module and the infrastructure module shown in **Figure 4**. Cost, schedule, and risk module data

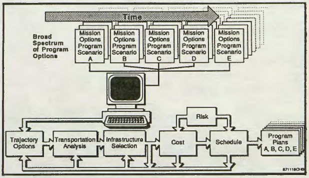

Figure 4

are being drawn from historical data on similar projects such as Saturn stages, LEM, Space Station, and OTVs. These modules, by necessity, are not overly detailed but they provide preliminary estimates for building to a program level with enough fidelity to ensure an understanding of the program drivers. As the designs and technologies mature, the various modules may be improved. In the meantime program sensitivity to various mission options such as cryogenic propulsion versus nuclear thermal propulsion, or aerobraking versus propulsive braking at Mars and Earth, can be compared.

Sensitivity Analysis

Five Manned Mars Programs have been defined for comparative analysis, each one emphasizing different objectives. They are as follows; (1) Early launch date emphasis with initial landings on Phobos/Deimos, (2) Early launch date emphasis using "split missions", (3) Mid-range launch date emphasis (referred to later as the reference program), (4) Delayed mid-range launch dates with stretched program duration, (5) Late launch date emphasis. Along with these program options several precursor mission options have been identified: 1) robotic missions, 2) manned flyby missions, 3) manned orbital missions, 4) manned Phobos/Deimos landing missions, 5) manned Mars landing missions, and 6) unmanned cargo missions. Each mission is constructed using various trajectory/orbit options (conjunction class, opposition class, Venus swingby, circular parking orbits, elliptical parking orbits); transportation node options (LEO, GEO, high Mars orbit, Ph/D, Mars surface, Lunar surface); and transportation approach options. **Figure 5** shows a typical options summary.

Example Program Analysis

The first step in program analysis is to identify the program option to be analyzed. The reference program (mid-range Mars emphasis) was chosen for this example. Each program has several options as indicated in **Figure 5**. Guidelines and assumptions for the reference program begin by specifying a time span for study from 1999

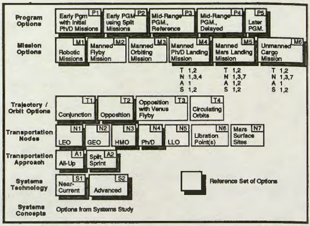

Figure 5

through 2035. The reference program should build progressively through an outpost, base, and multiple bases (or colonization). The first three manned landings are exploratory and occur at different sites. An "outpost" is accomplished when a surface habitation and laboratory module is in place and intermittently manned. A base is accomplished when three surface habitation and laboratory modules are in place and permanently manned. The capability to utilize Mars produced water, O2, H2, and propellants (LOX/LH2 or methane) occurs at the IOC of the base. The capability to export Mars produced water, O2, H2, and propellants (LOX/LH2 or methane) occurs two years after the IOC of the base. Additionally, certain events should trigger the need for technologies, i.e., the IOC of a base triggers the need for an advanced power generation system and transportation rates (lbs/year) trigger the need for advanced propulsion. In addition to these guidelines and assumptions, milestones for the program options are shown in **Figure 6**. This information will allow the analyst to identify major missions and payloads (**Figure 7**) and create a program definition (**Figure 8**). A preliminary schedule is defined using trajectory opportunity data from the trajectory database. Attributes of both nominal missions and payloads are identified. (Attributes for missions and payloads are their mass, dimensions, mission type, origin, destination, flight event schedule, and precursors.) Program definition is also impacted by technology. Technology required by the reference program is compared to technology projections given in the technology database. Technologies associated with the reference program include: advanced propulsion nuclear power generation, long-term cryogenic storage, long-term exposure to the space environment, Closed Ecology Life Support System (CELSS), communications, and surface-to-orbit and orbit-to-surface payload capabilities (both at Earth and Mars). The transportation element of the reference program involves sizing of the spaceship(s), the Mars ascent and descent vechicles (manned and unmanned), and the other tranportation system infrastructure elements. Hardware and propellant masses are estimated based on sizing algorithms which use scaling factors, known masses, and

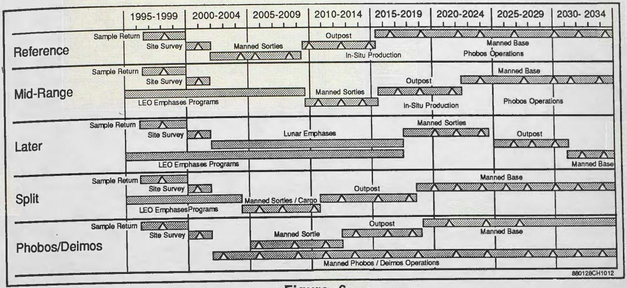

Figure 6

Mission Payloads for Reference Program

Manned MSS (M)
Cargo MSS (C)

Mission #		P / L Description	Payload Mass
1	M	Mission Module, MEM, Probes	291,400 lbs. (132.177 mt)
2	M	Mission Module SVC, MEM, Probes	218,400 lbs. (99.065 mt)
3	M	Mission Module SVC, MEM Probes	218,400 lbs. (99.065 mt)
4	M	Mission Module SVC, MEM, HAB, LAB / LOG, Probes	298,400 lbs. (135.352 mt)
5	M	Misson Module SVC	60,000 lbs. (2.722 mt)
	C	MEM, HAB, LAB / LOG, Mars Resource Pilot Plant, LMDV	338,334 lbs. (153,466 mt)
6	M	Mission Module SVC	60,000 lbs. (2.722 mt)
	C	MEM, HAB, LAB / LOG, Mars Resource Production Plant, LMDV	443,934 lbs. (201.365 mt)
7	M	Mission Module SVC	133,000 lbs. (60.328 mt)
	C	MEM, Power Plant, Crane, Soil Mover, Boring / Mining, Phobos Resource Pilot Plant, LMDV	321,494 lbs. (145.827 mt)
8	M	Mission Module	60,000 lbs. (2.722 mt)
	C	MEM, HAB, LAB / LOG, Pressurized Rover, Agriculture & Fertilizer Plant, LMDV	680,634 lbs. (308.730 mt)

Figure 7

Earth and/or Mars orbital energy requirements. The sizing algorithms were developed assuming a most probable mission sequence.

Now that the program definition has advanced to the stage where a first cut at the mission model is complete, a capture analysis is performed. First, the launch vehicle fleet and upper stage fleet are defined. Sizing of the launch vehicles and launch vehicle fleet depends on their

Reference Program — PROGRAM DEFINITION — Page 4

Mission Number	Mass Delivered by UCV (mt)	US., OTV, etc. Required	Number of UCV's Lauched	Number of US., OTV, Etc.
1	1211.078	OMV	12	2
2				
3				
4				
5				
6				

Reference Program — PROGRAM DEFINITION — Page 3

Mission Number	Spaceship Mass (mt)	Payload Mass to LEO (mt)	MSS Propellant to LEO (mt)	MSS Resupply Mass (mt)	Assembly Mass (mt)
1	1044.585	133,084	902,746	10.875	765.02
2					
3					
4					
5					
6					

Reference Program — PROGRAM DEFINITION — Page 2

Mission Number	Earth Departure	Mars Arrival	Mars Departure	Earth Arrival	Outbound Time	Stay Time	Inbound Time	Total Time
1	4/7/03	9/12/03	10/12/03	6/30/04	158	30	262	450
2								
3								
4								
5								
6								

Reference Program — PROGRAM DEFINITION — Page 1

Mission Number	Manned/ Cargo	Trajectory Class	Trajectory Description	Mission Desciption	Payload Description
1	Manned	Opposition	HT-450-30 AB	Sortie	Mission Module, MEM
2	Manned	Oppostion	HT-550-30 AB	Sortie	Mission Module, SVC.., MEM
3	Manned	Oppostion	HT-730-60 AB	Sortie	Mission Module SVC., MEM
4	Manned	Oppostion	HT-730-60 AB	Sortie, Begin Base Buildup	Mission Module SVC., MEM, HAB, LAB / LOG Module
5	Manned	Opposition	HT-730-40 AB	Base Buildup	Mission Module SVC
	Cargo	Opposition	HT-730-40 AB	Cargo Flights	MEM, HAB, LAB / LOG
6	Manned	Opposition	HT-836-238 AB	Base Buildup	Mission Module SVC
	Cargo	Opposition	HT-836-238 AB	Cargo Flights	MEM, HAB, LAB / LOG

Figure 8

capability to deliver mass to various orbits from various launch sites. Upper stage fleet elements are upper stages, space vehicles, and spacecraft. Upper stage fleet definition depends on their capability to transfer mass between orbits, planets, and moons. Fleet definition for launch vehicles or upper stages requires defining their structural mass, propellant mass, initial operational capability (IOC), end of life (EOL), expendability/re-usability, and manned/unmanned rating. **Figure 9** summarizes the fleet definition for the reference program. The launch vehicle fleet has an unmanned cargo vehicle, the shuttle C and a manned vehicle, the STS. The Shuttle C will be used to deliver all payloads, upperstages, propellant, etc., that do not have a requirement to fly on a manned launch vehicle. For the Large Mars Transfer Vehicle (LMTV), both cryogenic propulsion and electric propulsion can be configured for manned or unmanned

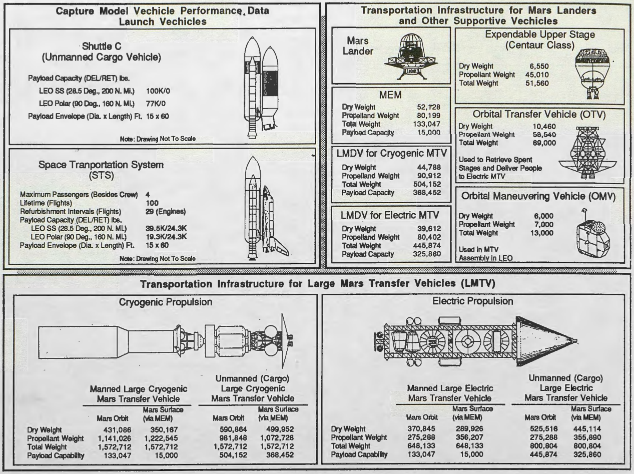

Figure 9

trips to Mars orbit or Mars surface. Manned Mars descent/ascent vehicles and unmanned Mars landers are used to deliver crew and payloads to Mars surface. Other expendable upper stages, orbital transfer vehicles (OTV) and the Orbital Maneuvering Vehicle (OMV) also support the program in LEO assembly, LEO to GEO transfer, and in some cases Earth to Mars transfer. Total flight events per year, total payload mass per year, total propellant mass per year, or any similar summary is provided as a part of the capture analysis. The updated program definition now consists of a mission model and the associated capture analysis.

The existence of a mission model and capture results make cost analyses and/or schedule analyses possible. Typical schedules of development, life cycles, operations, etc., are found in the schedule data base and are integrated into a real timeline to yield a master schedule for the program. Network analysis, resource allocations, timelines, etc., are now generated. Precursor and/or successor relationships for missions and payloads are identified. Relative cost and scheduling is a major consideration in program analysis. Relative cost analysis is done using mission and payload cost estimating relationships (CER's), mission types, flight life, learning curve rate, facilities costs, RDT&E cost, operations cost, first unit cost, and cost spreads. Outputs from the cost analysis include payload costs, and transportation cost.

At completion of program definition, it is reviewed to determine if it has met its defined goals. For the reference program, several iterations were made to fine-tune the program. It is important to remember that this process is flexible and expandable, thus, allowing for additional analysis. **Figure 8** is a good example of final program definition.

Sensitivites, Parametric Outputs, and Program Definition Selections

Sensitivities to various factors exist throughout the program analysis process. Simply by flying a payload one year later could result in a less desirable opportunity, thus requiring more propellant, longer trip time, more launch vehicle support, adverse scheduling of ground facilities and transportation nodes, delay successor missions, and increase cost. Since "n" number of sensitivities are possible, it is best to identify some major areas of concern when defining program goals and assumptions. For the reference program, vehicle sizing was comprehensively analyzed, varying launch dates, stay-time durations, total trip times, drop masses, and planetary capture options (aerobraking-versus-propulsive braking).

Parametric outputs resulting from program analyses can be useful tools. For example, for a given mission, vehicle configuration, and trip time/stay time, propellant mass required in low Earth orbit can be plotted versus the Earth departure launch window. This information is useful in determining the permissable allowances for schedule slippage.

Selection of a program definition is left up to the program analyst(s). The program definition may be iterated until a desired program is identified.

Summary

Capabilities and advantages of an interactive software package for mission/program analysis has been presented. A user can employ an interactive computer terminal to investigate the impact of various changes on the program. This software is flexible and useful in assessing the interaction of the defined program and technologies with other programs such as Space Station, Launch vehicle, lunar base, etc. To date, several parameters have been indentified as program drivers: 1) The mass in LEO requires a major improvement in cost of delivery to orbit; 2) aerobraking has a significant inpact on the mass but probably requires on orbit assembly capability approaching the complexity of the Space Station; 3) new technology in the fields of advanced propulsion, electrical power sources, and material processing will dictate the rate of build-up of the Mars base.

References

1. SRS Technologies Mid-Term Progress Review, "Manned Mars Mission and Program Analysis", NASA (MSFC) Contract NAS8-36653, December 1987.

2. Manned Mars Mission, NASA M002 Vol. I and II, June 1986.