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Paper Session III-B - Potential European Involvement in the US Pathfinder Program

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Potential European Involvement in the US Pathfinder Program

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Keywords

Martian exploration, space probes, mission-requirements/opportunities, modular vehicle concepts, orbital operations, aerobraking, advanced space launchers, ferry-vehicle roving vehicles, landers, logistics, regen. life support systems (CELSS), Future International space programme. Apollo-program, Phobos, Cassini.

Abstract

In conjunction with a long-range space programme planning also in Europe ideas exist for planetary exploratory missions, such as for Mars and the necessary infrastructure and technologies, required. Of course, this can only be realized in international cooperation as proposed by NASA with the pathfinder initiative.

Europe has been engaged in a number of unmanned scientific missions, some of them still have to be flown - such as Galileo, Ulysses, and/or Cassini - and further unmanned explorations of Mars will still have to be done as well as experiences to be gained on longer-duration stays of man in space before a manned exploration of Mars can be realized. Also advances in technologies have to be made such as for energy and life support systems, required for such long-duration space missions.

Since Europe already has been engaged in the manned Spacelab programme and a further involvement in the US Space Station programme has been decided - together with European programme in the area of advanced launchers with manned reentry capabilities - it is believed that Europe can also play an adequate role eventually in the pathfinder programme.

In the paper alternatives for an efficient transport to the Moon and/or Mars and the return to Earth will be discussed, showing the logistics for certain assumptions with respect to the evolutionary missions. Some efforts will also be devoted to the various technologies, which will have to be gradually developed and demonstrated before the actual goal of a manned exploration of Mars can take place with a certain degree of efficiency. It surely will be a big challenge for international cooperation in space in the 21st century.

1. Introduction

Even though medium-range space programs such as for the development of a permanently manned space station and improved launcher systems have been decided or are underway in the US and in Europe (COLUMBUS and ARIANE-V/HERMES) longer-range program decisions will have to be made. There seems to be a need for setting a longer-range goal in the western space world such as for pathfinder, the preparation for possibly resuming manned lunar missions and/or to prepare for the manned exploration of Mars. Such a program will be very expensive (50 ÷ 100•10⁹ $) and it would be a great challenge to share the efforts between the various international space nations US, USSR as well as the European space community (ESA) and Asia, in order to be able to raise the required funds easier and/or to realize a joint international cooperation for an old dream of humans on earth.

Considerable accomplishments have been made in US and USSR already in the 1960's based on unmanned space probes and fly-by missions to the moon as well as to Mars and Venus (Ranger, Surveyor, Lunik, Mars, Mariner, Voyager) and finally by the manned Apollo program of the US. Even more unmanned exploratory missions will have to be undertaken, but for manned return missions to Mars proper advances in life-support-, energy- as well as transportation systems will have to be reached for a reliable and reasonably efficient accomplishment.

In this paper an attempt is made to reiterate relevant past accomplishments, which could be good examples for the new endeavour, which should be based on present and/or new technologies in accordance with the target dates for individual missions to be agreed upon for a time period from say 2005 till 2020 (30).

2. Past plannings and accomplishments (US and USSR)

In the mid 1960's/early 1970's the US were leading in the field of planetary space probes as well as in the manned lunar exploration. The Apollo Program, based on Saturn 5, was an excellent achievement in accordance with the national goal set by president John F. Kennedy. Unfortunately, this program has not been continued after Apollo 17 (1972) and it will take some time in order to be able to repeat such a program which costed ~25•10⁹ $. Of course, today, more advanced technologies exist, but a lot of the past experiences from the Apollo program should be used for the initial manned Martian exploration.

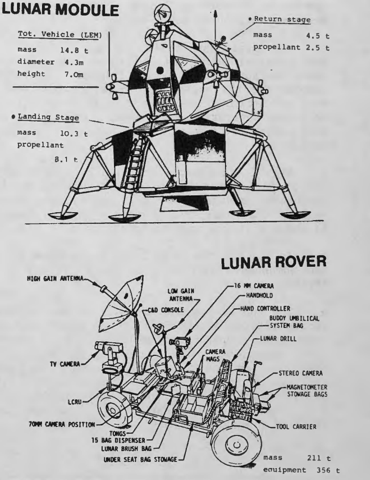


Fig. 1 Lunar Excursion Module and lunar roving vehicle (Apollo program)

In the following an excursion into the past may be allowed to show the origins of the Apollo Program at MSFC-NASA in Huntsville, Ala. In the early 1960's Saturn 1 has been successfully developed and plans existed to increase it's payload capability by advanced upper stages. There were two group of engineers in the future planning offices and in industry when the manned lunar return mission was announced. The one group thought of geometrical scaling of the existing launchers to meet the new (extreme) requirement, leading to the so called "NOVA" or "Super-NOVA" launchers, based on huge (L-1 and/or M-1) engines. The other group followed the idea that an extreme mission should be split into reasonable submissions, utilizing a medium sized launcher more often. In this case the vehicle, required for a more extreme mission, such as the lunar landing and return mission, would be put together from individual modules, which are delivered into low earth orbit by such launchers, via orbital assembly operations, requiring a Flight Support-Facility of a space station and EVA. It also can be envisioned that the fully assembled vehicle will be transported into LEO to be fuelled by subsequent tanker flight missions (orbital refuelling).

In Fig. 3 two vehicle concepts are shown for the lunar return mission, using such orbital operation-techniques. Fig. 4 gives a survey on the launch vehicle capabilities, including orbital operations and/or new launcher developments as it was seen in 1960 at MSFC, NASA.

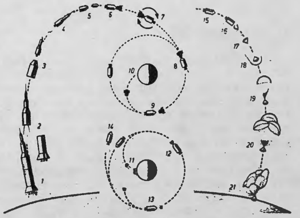
The target date (1970) for the Apollo mission was a certain surprise and an extensive orbital operation approach (7 Saturn flights) appeared too complex for the beginning. Therefore the development of Saturn V has been decided, necessitating only one separation- and docking-operation, however, in an orbit around the moon, which was quite daring!

Fig. 2 illustrates the Apollo flight profile and in Fig. 1 the lunar landing and return stage (excursion module LEM) by Grumman Aerospace as well as the lunar roving vehicle (Boeing Company) is shown with the main technical data.

In Fig. 5 the USSR lunar probe (Luna 16) and the unmanned roving vehicle (Luna 17) are illustrated.

The Apollo program, as well as the automatic lander mission of the USSR on the moon, of course have been prepared by quite a number of unmanned probe missions, which were not all successful. Good data on the planet Mars have already been obtained by various fly-by- and/or landing probe-missions. In the USSR Luna 16 and 17, Mars 2, 3, 5-7, Vega 1/2 and Phobos 2 shall be mentioned, ranging in weight classes from 3,5 up to 6 t.

Fig. 2 Apollo Mission profile



Apollo Mission-profile

1 Launch 2 Ignition 3 Separation 2nd stage 4 departing 5 Separation of 3rd stage 6 Transfer to the moon 7 preparation for braking 8 entry into target-orbit 9 separation of LEM 10 landing 11 launch from lunar surface 12 Rendezvous with orbiter 13 Separation of lunar ascent vehicle 14 Return-flight 15 approach to earth atmosphere 16 Separation of service module 17 turning of Reentry capsule 18 Entry into earth atmosphere 19 Stabilization by drogue chute 20 descent on main chutes, landing (water)

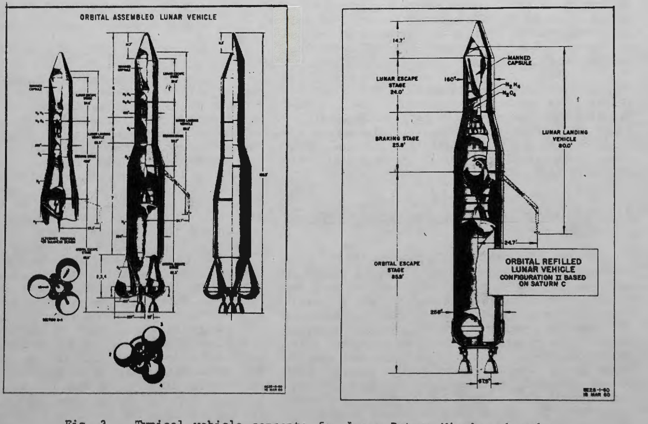


Fig. 3 Typical vehicle concepts for Lunar Return Mission, based on Saturn C and orbital operations (original plannings, MSFC)

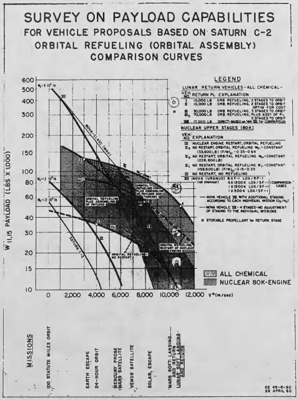


Fig. 4 Options for Transportation Systems and orbital operations for various mission requirements (MSFC 1960)

Phobos 1 which also contained German and French experiments got lost on its way to Mars (human controlling error), however, Phobos 2 is expected to land on Phobos in 1989 (Lander and Frosh) and to send valuable data back to earth with respect to the atmospheric conditions as well as the landing sites of the red planet for proper planning of the eventual manned exploration mission.

From the United States the following successful Martian probe missions shall be mentioned:

Mariner 4-Nov. 64 ÷ July 65, based on Atlas Agena (Fly-by mission) Mariner 6, 7 and 9 (1969 ÷ 1972) ranging from 261 kg up to 998 kg, Viking 1/2 (orbiter and lander based on Titan III E/Centaur) Viking 1 was quite successful, operating from 1975 until 1982.

(Viking 2 operated from 1976 till 1980) - the lander weighed 663 kg with a payload mass in the order of 550 kg. The mass of the orbiter was approximately 2230 kg. Also analyses from the atmosphere and from soil-samples (Martian surface and from the moons) were made. The following instruments were onboard: TV cameras, IR measurement system, pressure- and Temperature-sensors, manipulator arm and a remote biolab. The funding of the Viking program was in the order of 1 billion dollars.

Fig. 6 illustrates the US Martian Lander (Viking), the USSR project Phobos and a current US/European project called "Cassini".

3. European preparation for the Explorations of Mars

It has already been stated that also German and French experiments are onboard the USSR space probe Phobos. The German Max Planck Institutes for Aeronomie in Lindau/Harz and extraterr. phyiscs in Garching are involved with several experiments (investigation of solar wind and of cosmic rays). The German DFVLR Institut for optoelectronics is co-experimenter in the USSR camera-experiment to take pictures from the moon Phobos (60 km down to 50 m) with high resolution (6 cm) and to later evaluate the obtained data. Other Experiments on Phobos will be LIMA-D for Laser-analysis from soil (USSR, Bulgaria, FRG, DDR, Austria and Tscheches-lovacia). Also the international experiment "Fregat" shall be mentioned, consisting of TV cameras and spectrometer for mapping of the surface of Phobos and Mars.

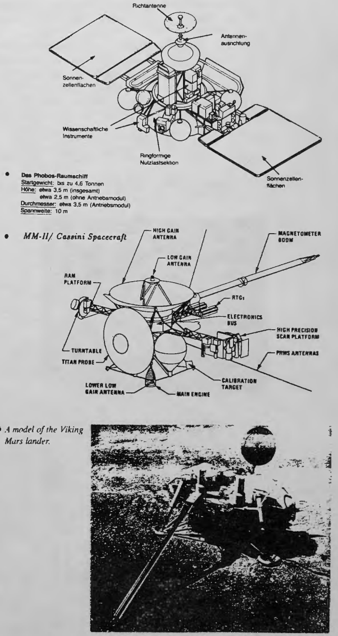
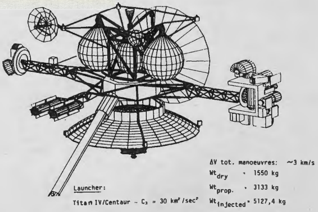


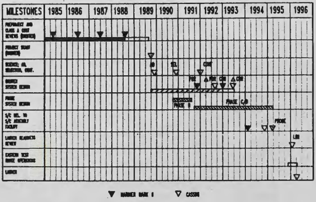
Fig. 6 USSR/US and European planetary probes

Fig. 7 Techn. Data of the Cassini Spacecraft



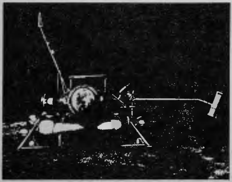
Another interesting joint program between NASA and ESA, oriented towards further expoloration of the environmental conditions of Mars, especially it's atmosphere is the project Cassini. The launch is foreseen by 1996 and it is based on the Mariner MK2 spacecraft and the Titan IV/Centaur launch system. Fig. 8 gives an illustration of this project as well as the time schedule.

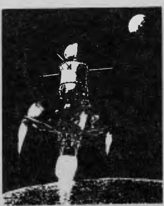
Other European/German contributions to deep-space research such as Halley, Galileo and/or Ulysses shall be also mentioned as well as the participation in the "Post Apollo-program (Spacelab and IPS) and the present Columbus program, including EVA and the proper technology developments. So it can be stated, that Europe will be qualified also for a proper involvement in the exploration of Mars.

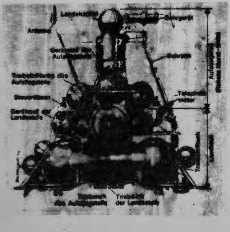


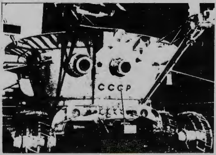
Cassini development schedule

Fig. 5 The USSR Lunar probe (Luna 16) and roving vehicle (Lunachod 1)







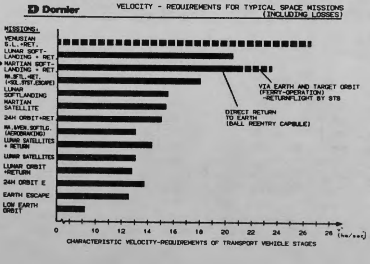


4. Various Mission objectives and logistics

For the manned Martian exploration several trajectories can be used, depending upon the target-date (technology available, minimum-energy opportunities), the actual mission-objective (desired stay time) as well as overall logistics/ economy considerations.

Roughly, a characteristic velocity in the order of 20.9 up to 23.5 km/sec will be required by the individual stages (see also Fig. 10 with respect to the characteristic velocity requirements for various space missions). This includes the launch into low earth orbit (LEO). The difference in velocity-requirement for the Martian Mission can also be explained with the degree of aerodynamic braking, used either for the landing vehicle and/or for the ferry vehicle between Earth and Martian orbits. For initial missions it is recommended not to use too sophisticated technologies even though a higher characteristic velocity has to be taken into account. In conjunction with the development of the US space station it is assumed that the mission shall start from low earth orbit and that the crew might be taken back to earth by the New Space Shuttle, which has plenty of comfortable return capability by then. Initially, the vehicle to be assembled, fuelled and launched from LEO should use chemical propulsion and be designed in a modular way in order to fit the PL-capability of large transport systems, planned for the future in the USSR and US. This would lead to a "ferry"-type approach which could be done in duplicate (US and USSR), delivering the proper modules of the Martian Lander and Return Vehicle into Martian orbit and to take back the crew and payload into earth orbit. The Lander & Return Vehicle will be separated in martian orbit and soft-landed on a preselected landing site on the surface of Mars - very similar as the Lunar Excursion module, LEM. Also a Martian roving vehicle can be envisioned, which will be brought to the Martian surface for extended exploration missions (also the use of balloons and/or light aircraft may be envisioned at a later time). The return vehicle would also take-off from the landing stage, which will then stay on the Martian surface. After docking with the orbiting ferry-

Fig. 10



vehicle and changing into the crew-habitat the earth-orbit will be reached after a relatively long total trip over nearly 2 years. Of course, the proper life-essentials must be provided, adjusting to the Martian environmental conditions (considering the relatively long stay-times on mars) and in the space vehicle itself. (For a shorter-duration stay similar to the Apollo missions (~ 30 days) 15 + 20 kg per man day may be assumed, reaching 150 kg for an eventual Martian base mission).

In Ref. [19] mission opportunity-data, more accurate ΔV-requirements and proper flight durations are given for the various types of missions, such as Flyback, sprint, swingby, conjunction and low-thrust/aerobrake which must be considered in the actual layouts of the vehicles.

In Fig. 11 the two basic mission-options, resulting in specific vehicle concepts and economics are illustrated:

A) Departure to Mars (via Martian orbit) from LEO-with direct return to earth, and

B) Same outbound flight, however returning to LEO (Space-Station), using the New Space Shuttle for the final return of the crew to earth. This is the "Ferry"-approach, which seems to be the solution for a continuous operation - even though the energy requirements are somewhat higher. On the other hand the ferry vehicle can be reused over and over if provisions have been made for a corresponding "flight-support facility" as an outgrowth of the permanently manned (international) space station.

In Case A a reentry capsule would be required for the crew in order to withstand the Reentry heat load, returning directly back to earth (as it was the case in the Apollo program).

The Conceptual layout for the Martian Landing and Return Vehicle is illustrated on the upper right. The mass ranging between 30 and 55 t, depending on the actual requirements. (Other conceptual approaches are shown in Fig. 13 (Ref. [3])). The Ferry-vehicle is shown as a single Tank-vehicle in the lower right. However, - due to the limited PL-capabilities of the launchers - it seems logical, to break-up the vehicle in individual modules by clustering of tanks. This is indicated under C) in the Fig. 11. Furthermore, it depends mainly on the eventual agreement between US and USSR as to how the ferry vehicle will be broken-up, depending upon the PL-capabilities of the individual launchers, used. The more bulky modules preferrably could be handled by the Energia-Launcher (USSR), similar to the former Saturn V-Launcher, which is not available anymore. Since for Redundancy-reasons the ferry-operation should be doubled probably 2 vehicles will be developed (the US Vehicle being more modular than the one by USSR, adjusting to the PL-capability of the new Shuttle C or heavy launch vehicle, HLV).

It is felt, that the first manned mission to Mars could be realized by 2005-assuming a 1 month-stay. This should be followed by further extended exploratory-type missions, leading to a Martian outpost and/or base by 2020 (30). These programs will have to be defined in more detail, including relevant cost-estimates. Based on the funding actually obtained, which depends on international cooperation, avoiding unnecessary duplication, the actual missions and their target-dates can be decided. In addition to that it takes a political will by some politicians to set a certain goal for a common international cooperation such as it was the case in the old days of the Apollo program.

Data comparison of Mars Expedition seen by Dr. W. v. Braun and 40 years later

	1953 W. v. Braun	1988 present expectants for 2005/10
Crew members (-)	70 !	8
total duration of expedit. (days)	969	580 - 600
travel time earth-mars (days)	260	260
stay time on Mars/persons (days)	400/50	30/4
waiting time in Mars-orbit (days)	449	40
travel time mars-earth (days)	260	260
payload in Mars-orbit (t)	600	185 (130)
payload on Mars (t)	150 !	25
Number of space ships	10	4+7 (3+5) *)
" " landing boats	3	1 (2)
" " ferry vehicles	46	2
" " ferry flights	950 !	2 (3)
launch wt. from earth orbit (Kt)	—	0,43 - 1,200
Total weight on earth (Kt)	64	16 - 20

*) Energia (USSR)
Shuttle-C (US)

Fig. 3

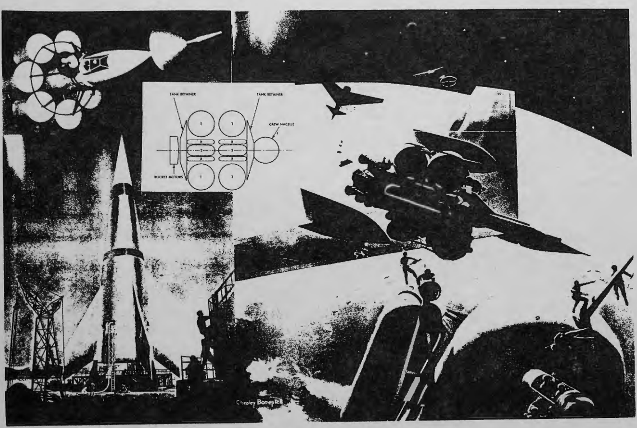


Fig. 8 Mars Project by Dr. Wernher von Braun (1953)

5. Survey on the transportation system layout and the potential program evolution

The selection of the transportation systems, required for an early manned martian exploration mission should be based on already available experiences (US Apollo program) and on not too advanced technologies which can be envisioned on a longer-range view. (The latter technologies may be introduced for follow-on missions with even more ambitious perspectives such as the Martian outpost).

Also for the propulsion systems more or less conventional systems should be used (H_2/O_2) while even storable propellants (Hydrazine) could be selected either for the soft landing (retro thrust) or even for the departing stage (as an option). (The latter case, however, will increase the LEO-mass requirement considerably!) Even though there seems to be a potential mass-saving in the order of 25 % the initial application of of aerobraking for the ferry vehicle might also be just an option. A through trade between the addi-

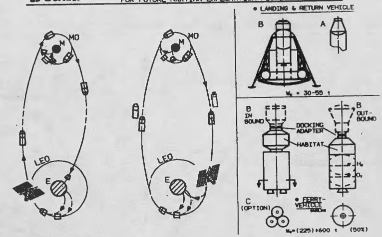


Fig. 11 Mission and typical vehicle concepts for a future Martian Exploration Mission

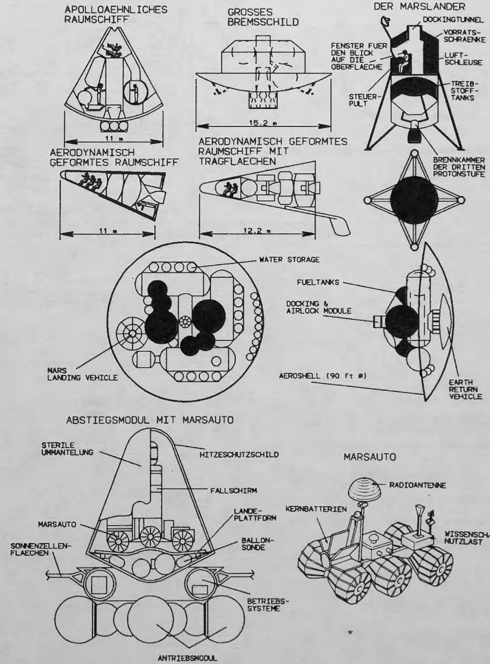


Fig. 13 Vehicle/Concept options for Mars Landers and roving vehicles (Literature)

Fig. 12 Vehicle Requirements Nomogram for a manned exploration of Mars

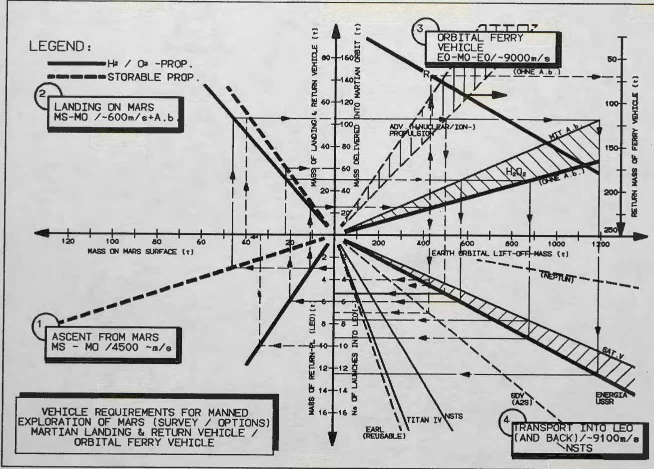
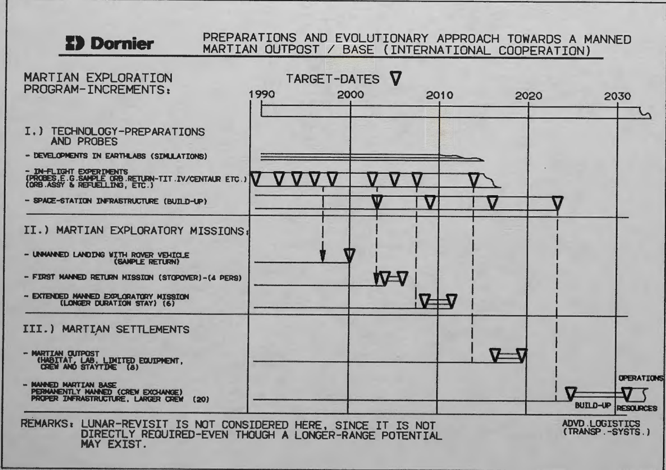


Fig. 14 Scheduling for preparations and evolutionary approach leading to a martian outpost



tional weight, required for the heat shield versus propulsive thrust will have to be done after initial results from flight tests (NASA) and space probes have become available.

With respect to the flight-trajectory to be selected various possibilities exist, which are also based on trade-studies, especially w.r.t. flight-duration, i.e. life-essentials for the crew.

It also has been assumed, that the return-flight should end in low earth-orbit (US Space Station) since the advanced STS has sufficient return-capability for crew and cargo.

This means preference will be given to a logistics concept, which uses a Martian Landing and Return Vehicle and a Orbital Ferry-Vehicle for transport between earth and martian orbits with a velocity-requirement in the order of 14.4 km/sec not counting the ascent to low earth orbit (9.1 km/s) and for the return flight to earth. (The minimum characateristic velocity, required for the Martian Return mission using aerobraking for the ferry and direkt return to earth could be in the order of 11 km/sec (see also Ref. [20], etc.).

In Fig. 12 a survey on the resulting vehicle options for the above mission assumptions is given:

Assuming a 30 day mission on Mars with a crew of 4, depending upon the actual mission (Martian roving vehicle and range to be covered) a mass between 10 and 20 t must be landed on Mars if a H_2/O_2 propulsing system for the ascent is used. In case of using storable propellant (Hydrazine) approximately 40 ÷ 50 tons would result (see subgraphs 1 and 2). This would lead to a mass for the martian Landing & Returnvehicle, separating from the delivered mass into martian orbit, in the order of 30 ÷ 65 tons for the 2 cases. In subgraph 2 the difference between storable and H_2/O_2 propellant is also shown for the soft landing retro thrust, while assuming initial aerobraking.

Subgraph No. 3 concerns the mass- and performance situation of the orbital ferry-vehicle. Here mainly the use of H_2/O_2 propulsion has been assumed, applying Aerobraking as an optional case. However, also the effect of using H_2 nuclear and/or ION-propulsion systems is indicated (future options). Furthermore - on the scale at the right handside - the mass of the returning ferry vehicle, loaded with fuel can be determined for the various cases in question. This leads to the required lift-off mass of the vehicle(s) departing from low earth orbit and - assuming a certain payload - capability of the respective launchers - to the number of launches, required into low earth orbit for assembly of the vehicles.

Based on the examples marked in Fig. 12 it can be stated, that an early manned Mars Return mission would require approximately 4 launches of the largest chemical space transport systems of the Saturn V-class (Energia) or approximately 7 ÷ 14 submission for the Shuttle derived Launcher (SDV, Shuttle C) and/or the new Space Shuttle planned in the US (NSTS).

In accordance with the literature [5] astronaut Collins proposed that such a mission should be done jointly between USSR and the US (with European and Asian Japan/China) participation. This would mean, that 2 ferries should be launched in parallel from LEO to be composed of 2 payloads of the largest vehicle class, each or 3 + 7 payloads of the planned medium class (US) launchers (or a mix of the two). The payload capability of the planned future European Launchers (EARL, Sänger) would not allow a reasonable application for the manned Return mission, since an excessive amount of submissions would be required, but this doesn't exclude the launch of one-way payloads and/or probes to Mars - also the roving - and/or the martian ascent vehicle as well as modules of the ferry vehicle could be a reasonable European contribution, except from scientific experiments.

Vehicle Concept options

In Fig. 13 various vehicle concepts from literature [3, 5] have been compiled, which could be selected for one or the other mission-objectives depending on the target date. 3 basic concepts can be distinguished:

- The Apollo-type lander
- The aerobraking vehicle (with a large heat-shield), and
- The aerodynamically shaped (winged) lander.

In the middle an US proposal Ref. [5] is shown using a 90 ft diameter aeroshell for the ferry vehicle.

The lower portion of the illustration shows a USSR decent module with a martian roving vehicle.

In this conjunction also the views by Dr. Wernher von Braun for the Mars exploration mission from 1952 may be injected - Ref. [2] which already had interesting features for using the atmosphere of Mars for the landing vehicle. In Fig. 8 his concepts are illustrated and a table Fig. 9 is added to show the differences in efforts, using to-day's or future technologies versus the assumptions made in the 1950's. (The comparison is not quite valid, however, since the mission objective by von Braun was rather ambituous - assuming a crew of 70 with 50 persons to be landed on the martian surface).

Evolutionary approach

It is clear that all the fine ideas for improving performance cannot be realized in one big step! A gradual approach with proper technological preparation and space qualification, using good existing experiences, seems to be the best choice, also considering the limited initial funding. In Fig. 14 a survey is given as to the individual tasks to be performed before the utmost objective of a manned Martian base can be reached (2030).

In principle we have 3 Blocks of activities, leading to permanent operation of a martian base:

Block I:

Consists of the technology development in earth-laboratories, using simulation techniques and test equipment to proof the desired performance of the systems and components. Also flight-experiments will have to be performed (e.g aerobraking, etc.). Also the launching of unmanned space probes with sample analysis (as it is already planned - Phobos, Cassini, etc.) is foreseen. In addition also the necessity for growth of the space station, e.g. establishment of the proper flight-support- and/or assembly/check-out- and launch facilities must not be forgotten.

The technology to be developed in facilities on earth concern the following disciplines:

- advanced life support systems (CELSS)
- medical equipment for the crew
- regenerative fuel cells
- advanced nuclear power generators
- advanced engine developments (H_2/O_2, electrical propulsion)
- long-term cryo storage of H_2/O_2 propellants
- aerobraking/rescue and safety systems
- EVA-suit and equipment simulations of orbital
- operations, etc.

Considering flight-testing it shall not be forgotten that medical investigations on long-term effects under zero gravity will have to be done in order to provide for the proper equipment especially considering the utmost goal of a martian base. Here a variable - g tether - facility in conjunction with the space station seems to be rather promising.

Also the orbital-operations will have to be extended for the eventual assembly and check-out and/or fuelling of the ferry- and the Martian Landing & Return vehicles.

Furthermore, proper facilities will have to be provided at the space station for the crew returning from their Martian Mission to get reconditioned and examined before flying back to earth.

Not all of this will apply for the first Martian missions - therefore, several milestones are indicated on the bar for the space station-infrastructure (detailed planning still will have to be done).

Block II indicates the first martian exploratory missions, showing an unmanned landing mission with a roving vehicle, possibly to return automatically soil samples from various locations by 2000. Then, by 2004/5, an initial Martian Landing and Return-mission could be envisioned, if the proper funding can be raised - using mostly the experiences, gained from the Apollo program. A crew of 4 would stay for a maximum time of 1 month. By 2010 a extended stay of a crew of 6 persons might be anticipated, possibly using aerobraking- techniques to a larger degree and preparing for a martian outpost, using a roving vehicle and/or an ultralight aircraft for initial tours.

In Block III the larger exploratory tasks on Mars are put together. Here, more equipment will have to be installed which can be left for a subsequent visit or even the infrastructure with more comfortable habitats, advanced power-generation, greenhouses, advanced surface-transportation etc., for a permanently manned martian base and a crew of up to 20 can be anticipated. This will not take place before the 2020/2030 time period-the use of resources from Mars and/or the moons will have to wait until such a permanent martian base is being is established. After that a different and more efficient logistics-scheme for the transport to and back from Mars can be envisioned which will reflect upon the vehicle concepts to be used (e.g. Methan could be produced from the CO_2-rich atmosphere of Mars, water could be electrolysed to obtain O_2 and H_2 for life support and energy supply, using solar heat. Also the moon could be introduced into the logistics scheme in order to improve economy for advanced applications (lunar mining, etc.).

Figure 15 shows an artists view concerning the expected life in a martian settlement and the greenhouses for a long-duration stay of the crew in a Martian base [Ref. 3], reminding of O'Neill and Krafft Ehricke's long-range space program-ideas.

6. Advanced Technologies

As has been discussed before, eventually considerable advances in Technology can be envisioned to make the martian base more economical and/or confortable and to utilize resources which are available on the site or on the moons. However, for the initial manned mission to Mars (2005/10) with a limited stay-time the deviation from the Apollo-program and the state of the art of today (US Space Station/Columbus) should not be too large in the interest of reliability/safety.

Still, there is to improve on technologies which presently exist or which are under development already. In the following some of the most important topics shall be given:

- Cryotank insulation for longer stay-times/ utilization of boil-off gases
- aerobraking and advanced Reentry materials
- advanced propulsion systems H_2/O_2 and H_2 nuclear or el. (MPD, ION) systems for improved economics)
- advanced power-systems (batteries, APU's, regen. fuel cells)
- advanced life-support system (regnerative CELSS)
- Laser docking systems
- advanced communication-and data systems
- automatic landing systems

- Space suit

- EVA & Robotics systems, tools (and relevant software and simulation facilities for orbital operations)

- Equipment for Flight-support facility in space (check-out, fuelling, assembly, launch, etc.)

- Human performance (medical and physiological research) - fitness and health-control for long durations

- Crew-safety and artificial intelligence/sensors

- Radiation monitoring- and protection devices (shelters)

- Surface-transportation on Mars (Roving vehicle concepts)

- Automatic sample acquisition, analysis and preservation concepts

- Manned variable μ-g Experiments (tether-facility for space station)

- Closed ecosystem (biophysics) testing of a larger crew in closed confinement *)

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*) BIOS 3, Arizona, USA and Siberian Branch of the USSR Academy of Sciences (Since 1965)

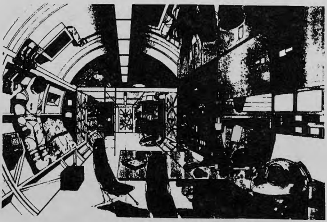

Fig. 16 Typical Martian Habitat (artists view)

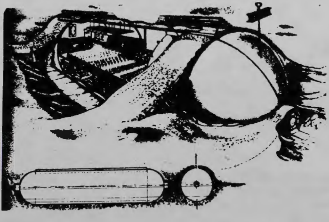

Fig. 15 Martian Greenhouse/Radiation protection

7. **Final remarks** (conclusions)

In conclusion the following can be stated:

- The manned Martian Exploration must be thoroughly prepared by unmanned probe-missions, such as Phobos and Cassini and by relevant technology-developments, especially in the areas of advanced life support systems for long duration stay, safety and radiation-protection and monitoring systems. Furthermore, the space stations have to be provided with proper facilities for the intended orbital operations.

- An evolutionary approach with respect to increasing mission objectives seems to be logical, using existing experiences and/or infrastructures, such as the Space Station and advanced (planned) transportation systems to a large extent.

- the initial manned application should be based or the good experiences of the US Apollo program. The stay time should be limited to approximately 30 days for a crew of four (2005/10).

- The utmost goal could be a permanently manned Martian base for a crew of up to 20 for the time frame 2020/30. This goal should be approached in logical steps, introducing gradually advanced technologies as they become available. For the latter time-period also advanced propulsion systems and space vehicles with a larger degree of aerobraking can be anticipated, using potential resources available on Mars and/or the moons in order to reach economy-improvements for the extended applications. Also greenhouses (BLSS) and advanced surface transportation vehicles and energy systems can be anticipated for that time period.

- The Exploration of Mars should be undertaken in International Cooperation of all the space nations on earth (USA, USSR, Europe and Asia) since there is a lot still to do and the funding will always be limited. Unnecessary duplications and international law problems can thereby be avoided.

- Europe is already involved in relevant preparations such as by Phobos, Cassini, and the Columbus Programme and will certainly play it's role by a proper committment in due time.

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