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MANNED MARS MISSION
COMMUNICATION AND DATA MANAGEMENT SYSTEMS

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ABSTRACT

A manned Mars mission will involve a small crew and many complex tasks. The productivity of the crew and the entire mission will depend significantly on effective automation of these tasks and the ease with which the crew can interface with them. The technology to support a manned Mars mission is available today; however, evolving software and electronic technology are enabling many interesting possibilities for increasing productivity and safety while reducing life cycle cost. Some of these advanced technologies are identified.

1.0 INTRODUCTION

The Communications and Data Management Systems for the manned Mars mission are part of a number of end-to-end information systems. The function of each of these systems is to transfer information between a user and a domain of interest. The user may be on the Earth or in space. The domain of interest may be a user investigation, an engineering subsystem, or a human being. The information transferred may be for control, monitoring or mutual interaction. This paper is aimed primarily toward the space data systems and the communication links involved with the transfer of information beyond the Earth's atmosphere.

Specific requirements for the communication and data systems to support a manned Mars mission depend largely on the mission objectives, mission duration, and the number of vehicles involved; however, the following general characteristics are required to support any manned mission to Mars:

- o Transparency: Users should not be forced to deal with complex embedded systems.
- o Reliability: The systems should operate in space for years with little or no maintenance.
- o User Responsive: The systems should provide for rapid and adaptive turnaround of pertinent easily understood information.

- o Cost Effective: Small gains in performance should not drive costs when adequate alternatives exist.

Key issues regarding flight Conmunication and Data Management Systems (CDMS) for a Mars mission are:

Communications

- o Extravehicular Space Links
  - Data relay versus direct links between a Mars base and the Earth
  - Frequency (Hz)
  - Communication coverage
  - Data rates
  - Communication security
- o On-Board Communications
- o Data Systems
  - Degree of Autonomy/automation
  - Data system architecture

2.0 COMMUNICATIONS

The number of communication links depends on the number of vehicles involved in the mission and the amount of communication coverage required. Figure 1 shows some potential communication links in support of a Mars mission. The engineering options identified include:

- o Data relay verus direct links between a Mars base and the Earth
- o Frequency of the communication links

2.1 DATA RELAY VERSUS DIRECT LINKS

Some concepts for a manned mission to Mars involve a habitable Mars orbiter (MO) that will remain in orbit around Mars while crewmen are on the surface of Mars. If a relay system is used for communications between a Mars base and the Earth, either the Mars orbiter(s) or a set of dedicated communication satellites in orbit around Mars can be used to provide the relay capability. If the Mars orbiter(s) (assumed to be in a highly elliptical orbit) is used as a communications relay, its orbital period must be the same as the rotation period of Mars and the phasing must be such as to permit its position to oscillate about the zenith of the Mars base. Figure 3 shows typical coverage provided for a single base by a single Mars orbiter. For the orbit and mission shown, communication coverage for the Mars base is approximately 40 percent of the time. Additional coverage could be provided by a second Mars orbiter or by a system of dedicated relay satellites.

Use of a direct link between the Mars base and the Earth will reduce the orbital parameter restrictions on the Mars orbiter and/or eliminate the cost of dedicated communication relay satellites. A direct link can provide communications for approximately 50 percent of the time, but the duration of a single blockage is approximately 76 percent greater than for a link using a single Mars orbiter as a relay. The direct link will also require more weight on the surface and consume more power from the surface elements than a relay link via an orbiting vehicle.

A relay system appears attractive for the primary communication link between a Mars base and Earth. Regardless of whether the relay or direct approach is chosen for the primary link, the alternate approach will probably be used as a backup.

2.2 FREQUENCY OPTIONS

Frequency options for communication links between Earth and Mars include S/X band, K_a or MM-wave communications and optical. The data rate requirement will be a major factor in the ultimate choice of transmission frequency. A comparison of these frequency options is shown in Figure 2.

The existing Deep Space Network (DSN) uses S-band for transmission to the spacecraft and S&X band for reception. An X-band uplink capability is being developed with planned evolution toward a unified X-band two-way system in the 1990's. An X-band system together with the planned 70-meter antenna subnet and reasonable spacecraft antenna size and power levels can support a Mars mission with data rates on the order of 10-30 Mbps or less provided the bandwidth of the DSN 70-meter subnet electronics is increased to support these rates.

In 1979, the World Administrative Radio Conference (WARC) allocated a 34 GHz/32 GHz (K_a) band for deep space use. NASA is currently pursuing K_a-band technology and the DSN expects to provide a K_a-band receive capability on 70-meter antennas in the early 1990's. A K_a-band system can be expected to support data rates of five to ten times (depending on system noise temperatures) the rates supported at X-band for the same antennas and power levels.

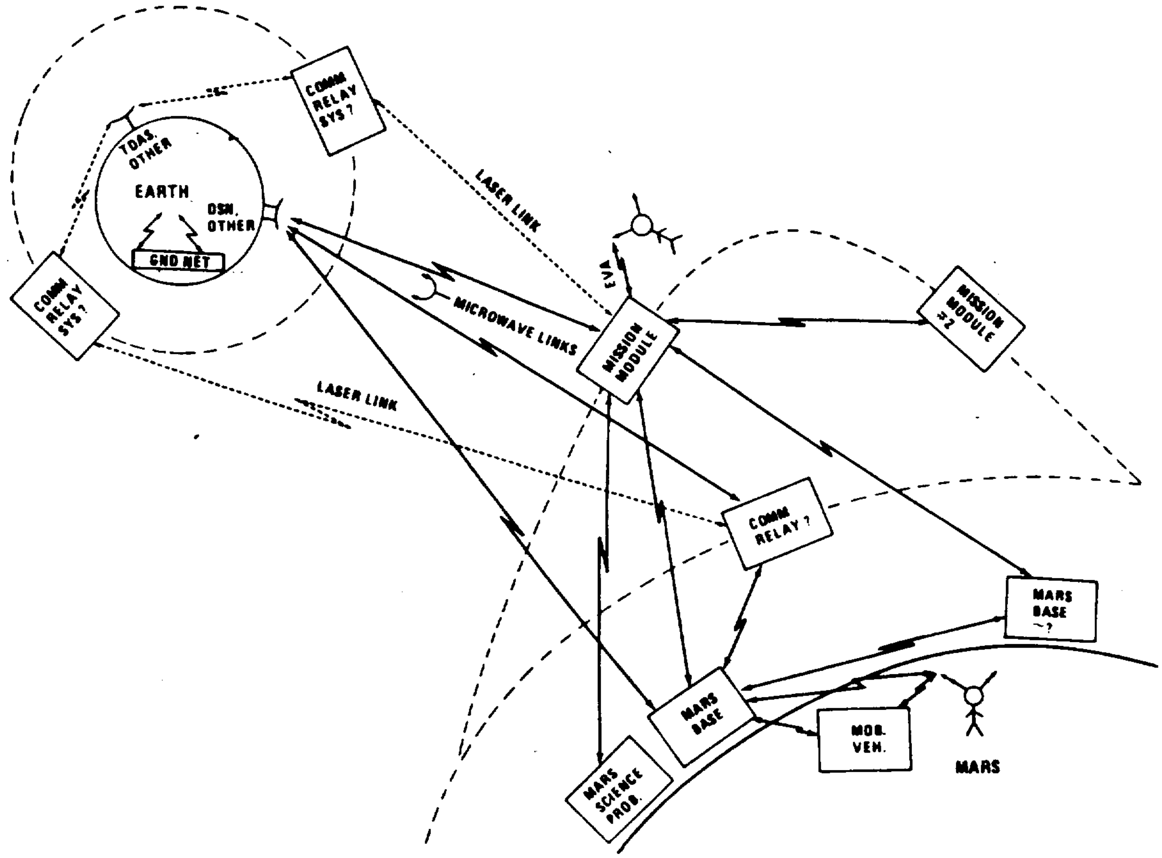

FIGURE 1. MANNED MARS MISSION
WHAT ARE THE COMMUNICATION LINKS?

	S/X BAND	KA/MM-WAVE	OPTICAL
BANDWIDTH	FEW MBPS	INCREASED	MUCH INCREASED
ANTENNA GAIN	REFERENCE	INCREASE OF 12 dB OR MORE OVER X-BAND	INCREASE OF 60–80 dB OVER KA
IMMUNITY TO INTERCEPTION & JAMMING	POOR	BETTER	EXCELLENT
SIGNAL ACQ.	EASY	SATISFACTORY	DIFFICULT
PTG. ACCURACY	FEW ARC MIN	ARC SEC RANGE	ARC SEC-TO-SUB ARC SEC RANGE
LIFE TIME	OK	OK	SHORT LASER LIFETIME
COMPATIBILITY WITH EXISTING SYSTEMS	YES	NO	NO
TECHNOLOGY STATUS	MATURE	IMMATURE (TECH. DEV. PLANNED)	IMMATURE (SOME RISK)

FIGURE 2. FREQUENCY OPTIONS

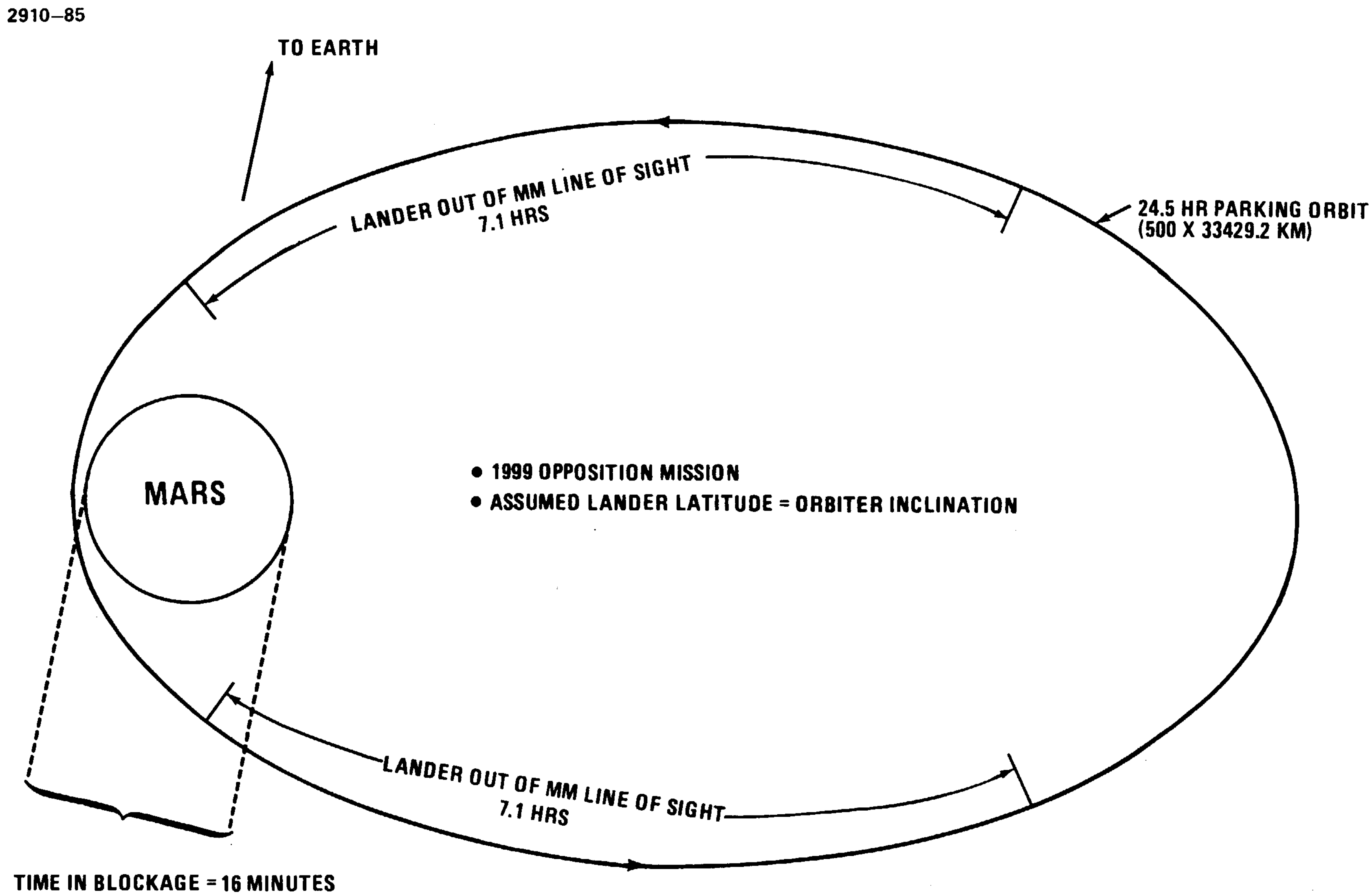

FIGURE 3. EARTH COMMUNICATIONS BLOCKAGE FOR A MISSION MODULE (MM) IN ORBIT AROUND MARS

For data rates greater than 100 Mbps, lasers should be considered as an alternative to the more conventional microwave links. Lasers can support large data rates with small transmitting/receiving apertures. However, some of the characteristics which make laser communication links attractive also make them difficult to use. The high gain which makes possible small apertures also requires very accurate pointing systems. Atmospheric attentuation, which together with narrow beamwidth makes unauthorized access to the communication links more difficult, requires a relay system of satellites orbiting the Earth in order to provide dependable communications with Earth based stations. A similar situation exists at Mars where a dust storm could block laser communication links. Therefore, it is envisioned that a laser link would be used only for communications between vehicles in Earth and Mars orbit with lower frequency communications to the surfaces.

For present near-term planning, a K_a-band system appears attractive for communications between the Earth and Mars. A K_a-band system can support moderate data rates, providing dependable communications with the Earth without a data relay system in orbit around the Earth.

2.3 COMMUNICATION COVERAGE

The amount of communication coverage required is a key factor that will influence the overall communication system architecture and the design of individual communication links. Figure 3 shows the communication coverage for a 1999 opposition mission that could be provided for a Mars base via a Mars orbiter in a highly elliptical 24.5 hour orbit of Mars. Because of orbit geometry and relative motion, the orbiter will drop below the horizon of the Mars base twice daily for approximately 7 hours each time. In addition, direct communications between the orbiter and the Earth will be blocked for approximately sixteen minutes per day as the orbiter swings behind Mars with respect to the Earth. If the communication coverage provided by a Mars orbiter is unacceptable to mission planners, direct links between the Earth and the Mars base together with relay via the Mission Module will reduce blockage to approximately 7.3 hours per day. If this amount of blockage is unacceptable, an additional relay system in orbit about Mars must be provided.

2.4 DATA RATES

The data rate requirement for each of the various communication links used to support a manned Mars mission is needed not only to size the system in terms of antenna size and power levels, but also to determine applicable technologies such as microwave versus optical transmissions. For a manned Mars mission, the data rate requirements will probably be driven by the science requirements and the video requirements. Data compression should be used on data from both sources to avoid the transmission of redundant or unneeded data. The degree to which data compression is used will be a major factor in determining the data rate for transmission. Figure 4 shows some communication links and the equivalent of the data rate in terms of color TV transmission assuming a data compression equivalent to 1 bit per pixel.

2.5 COMMUNICATION SECURITY (COMSE)

Communications links may require protection from unauthorized access, electronic deception and intelligent jamming. The extent of protection will impact the communiction system design. Early COMSE planning should include:

- Identification of the treat environment
- Degree of protection required
- Assessment of required crypotography techniques, authentication methods, and anti-jamming features.

2.6 ON-BOARD COMMUNICATIONS

On-board communication systems include closed circuit TV, internal audio, the routing of scientific data, and interfaces with external communication links. For mobility, it is assumed that each crew member will be provided with a wireless communication set. Some of the issues/options that must be addressed for each manned vehicle are analog versus digital distribution of audio and video, dedicated versus multiplexed channels, electrical versus optical distribution, and centralized versus distributed control of these systems. The architecture and sizing of the on-board communication systems depend heavily on the data rates that they must support.

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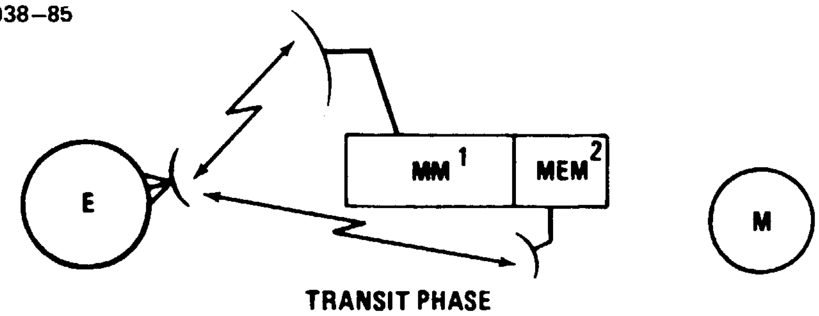

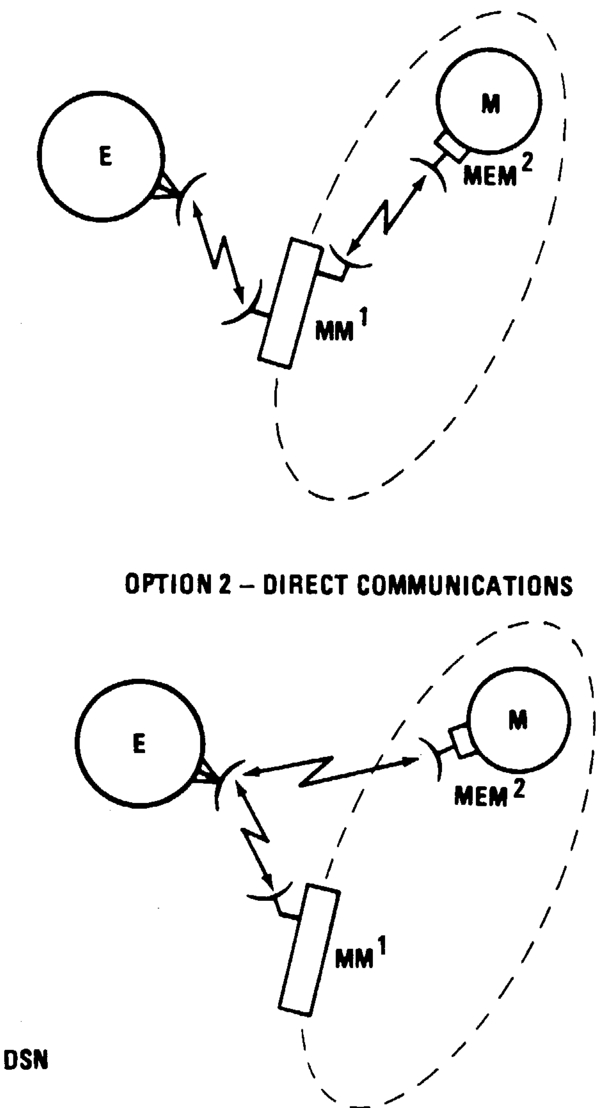

RETURN LINK REFERENCE CAPABILITY* @ X–BAND

	RANGE	DATA RATE (MBPS)	EQUIV COLOR TV TRANSMISSION**		ANT DIA (FT)	RF POWER (WATTS)
			FRAMES/ SEC.	SPATIAL RESOLUTION (PIXEL)		
RELAY OPTION						
●TRANSIT PHASE						
– MM	1 AU	9.2	30	640x480	16	230
– MEM	1 AU	.0528	~.2	640x480	4.3	20
●MARS ORBIT PHASE						
– MM	1 AU	SAME AS TRANSIT PHASE				
– MEM	33,000KM	10.0	32.5	640x480	4.3	20
DIRECT OPTION						
– MM	1 AU	SAME AS FOR RELAY OPTION				
– MEM	1 AU	8.0	26	640x480	16	200

* ASSUMES 2.3dB ADVERSE TOLERANCE FOR CLOUD COVER AND 1.9 dB IMPROVEMENT IN DSN

** ASSUMES DATA COMPRESSION EQUIV TO 1 BIT PER PIXEL

1 MISSION MODULE

2 MARS EXCURSION MODULE

FIGURE 4. RF LINK PERFORMANCE

3.0 DATA SYSTEMS

3.1 DEGREE OF AUTONOMY/AUTOMATION

For this paper, the word "autonomy" refers to the independence of the flight systems (those systems in space including the human systems) from Earth based support. The term "automation" refers to operations performed by machines, computers, etc., that otherwise would have to be done by humans. Automation is required implement autonomy for systems in space because of the limited number of flight crew personnel.

Except for the resupply of a long-term Mars base, the only support of the flight systems from Earth must be support that can be provided via the communication links. Because of the distances involved in a Mars Mission (up to 2 A.U.) and corresponding signal propagation delays, the onboard systems must at a minimum be capable of operating acceptably independent of Earth based support for periods of approximately 30 minutes plus some turnaround time on Earth. Beyond this basic requirement, the degree of autonomy and automation is a major issue that must be considered.

Because of the long mission duration and the distances involved, a high degree of automation including "expert" and other knowledge based systems is highly desirable. Automation of functions should result in the following benefits: (1) Relief of the flight crew or Earth based personnel from time-consuming tasks, thus improving productivity, (2) Enhancement of reliability and safety via continuous monitoring of system health, (3) Enhancement of system performance via faster or more consistent response, and (4) Reduction of operating cost.

Potential functions for automation (including system, subsystem and application functions) must be identified and the benefit of automating them must be assessed against the potential risks and implementation costs.

Assuming a high degree of automation, the next question is: Where should the automation be performed? Should the automation be performed by the flight data systems (autonomously) or by systems on Earth? The most critical factor in determining whether automation should be performed by the flight systems versus based systems is the response time requirement. Many functions will not tolerate the delays involved in an Earth communications loop. For these functions, the question is a nonissue. For other functions, trades must be performed to determine the desirability of implementing them with Earth based processing nodes versus the flight systems. Factors that must be considered include the cost of flight versus Earth based processing systems, differences in performance and safety levels, and cost differences for communication systems required to support different degrees of autonomy.

For missions using vehicles that orbit Mars in addition to those that land on the surface, a similar issue exists regarding the location of processing support for Lander functions; i.e. what support capability is left in the orbiter versus being carried in the lander.

3.2 DATA SYSTEM ARCHITECTURE

A manned mission to Mars may involve several vehicles, each having its own data system. The vehicles may vary from a module transferring men and materials to Mars to a Mars surface rover to intelligent robots. The architecture of each data system is influenced by vehicle configuration, data throughput requirements, and criteria for system operational reliability. An example of a hierarchical data system architecture potentially applicable to a manned vehicles for a Mars mission is shown in Figure 5.

Before selecting a data system architecture, the design engineer must consider a large number of options and trades.

- Processing Architecture: The data systems for the manned vehicles used for a Mars mission will utilize distributed processing to provide high througput, lower integration costs, and operational flexibility. However, the degree and type of distribution must be studied. Trade studies include hierarchical versus non-hierarchical, the number of levels in a hierarchical system, module-oriented versus subsystem oriented architectures, etc.

- Number of Physical Buses: Are all data routing functions performed by the same physical network or are separate buses used for the data management, audio, video, and science functions? Are timing and mass memory distributed on the same bus with realtime computer data, etc.?

- Bus Topologies: Major factors that influence the selection of network path structure include transmission medium, data rate, number and type (active versus passive) of bus interface units, growth, bus

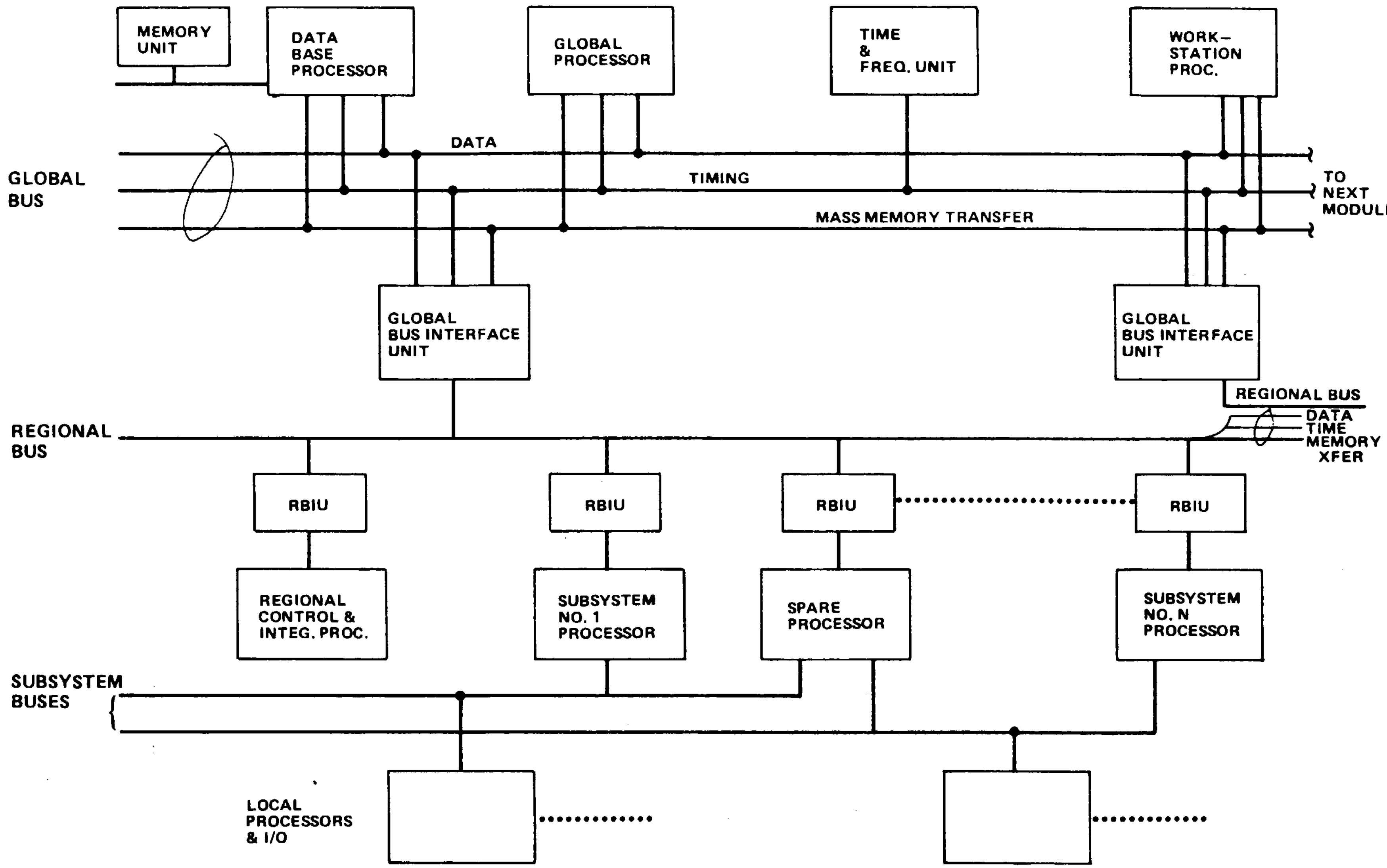

FIGURE 5: HIERARCHIAL DATA SYSTEM ARCHITECTURE

protocol, bus length, and system reliability. Options include rings, stars, serial buses, graphs, and various variations and combination of these.

- Data Bus Medium: One must trade the advantages and technology and cost uncertainties of optical fibers versus wire.

- On-Board Data Base: The data base management system becomes larger and more complex with increasing autonomy. Issues include management, degree of distribution, on-orbit versus Earth based storage, replication, and type of storage device.

Two studies are currently being performed by TRW and McDonnel Douglas Aircraft Corporation to recommend a data system architecture for the Space Station. Since the Space Station will utilize distributed data systems with a high degree of autonomy to support manned space missions for a long duration, the results of these studies should have application to the manned Mars mission.

4.0 CDMS TECHNOLOGY

No new or advanced communication and data management technologies have been identified as enabling for a manned Mars mission. However, the use of a number of advanced technologies to improve productivity and safety and to reduce mission cost is highly desirable. The following is a list of advanced technologies that are applicable or potentially applicable to a manned Mars mission.

- o Fault and Damage Tolerant Distributed Data Systems
  - Processors
  - On-Board Communication Network (e.g., Fiber Optic Networks)
  - Large Mass Memories (e.g., Bubble, Optical Memories)
  - Software
- o On-Board Data Reduction and Processing Techniques
  - Artificial Intelligence/Expert Systems
  - Video and Science Data Compression
- o Man-Machine Interfaces
  - Solid State Multifunction Color Displays
  - Voice Recognition and Natural Language Understanding

- o Laser Communications
  - High Power Solid State Lasers
  - Pointing Systems
- o Reliable High Power RF Amplifiers
  - Approximately 200 Watts at X-Band
  - Approximately 100 Watts at K-Band

REFERENCES

1. JPL (1984), "Autonomous Systems: Architecture and Implementation", JPL D-1656, August.
2. JPL-NASA (1984), "Long-Range Plan for the Deep Space Network", JPL-NASA Report, October.
3. NASA (1985), "Advancing Automation and Robotics Technology for the Space Station and the U.S. Economy", Volume II - Technical Report, NASA Advanced Technology Advisory Committee, NASA-TM 87566, March.