2

NASA's Plans

2.1 BACKGROUND

Remember that old saying "You can't tell the players without a score card"? Well it is hard to tell how we got to the current plan to go to Mars without a roadmap. There have been so many studies over the decades by so many people that one requires to be guided to the current plan. If that isn't difficult enough, this book proposes to change the plan, or at least to alter the sequence of events. But before that is discussed, it is important to understand how we got to where we are now. I don't think we need to go back more than a generation to understand that, but if you want to go back further, read *Humans to Mars: Fifty Years of Mission Planning, 1950–2000* by David S. F. Portree, published in 2011 by the NASA Headquarters History Office.

The table provides a chronology of key dates.

1991	"America at the Threshold, Report of the Synthesis Group on America's Space Exploration Initiative"
1993	1st Design Reference Mission (DRM), Space Exploration Initiative
1997	DRM 2.0 by a NASA Mars Exploration Study Team
1998	DRM 3.0, an addendum to the 1997 study
1998	DRM 4.0 examined Nuclear Thermal and Solar Electric Propulsion
1998	First module launch of the International Space Station (ISS)
2004	George W. Bush announced a new Vision for Space Exploration
2005	NASA Exploration Systems Architecture Study (ESAS), a report of 758 pages produced by 20 core team members collocated at Headquarters, supported by hundreds of Field Center staff over a period of three months
2006	Boeing selected to build the Orion heat shield, Lockheed Martin selected to build the Orion Crew Vehicle
2007	The Global Exploration Strategy: the Framework for Coordination
2009	The Augustine Panel described the "Flexible Path" option in "Seeking a Human Spaceflight Program Worthy of a Great Nation"

(continued)

Manfred "Dutch" von Ehrenfried, *Exploring the Martian Moons: A Human Mission to Deimos and Phobos*, Springer Praxis Books, DOI 10.1007/978-3-319-52700-0_2

2009	DRM 5.0, with an addendum in July and a second in 2014; the most current version and the one discussed herein
2010	NASA Authorization Act of 2010
2010	U.S. National Space Policy, mentioned Mars in only one sentence
2010	Constellation Program canceled
2010	NASA formally established planning teams at MSFC and JSC
2011	"Vision and Voyages for Planetary Science in the Decade 2013–2022" (National Research Council of the National Academies)
2011	Last flight of the Space Shuttle
2011	NASA adopts the Space Launch System design
2013	NASA Langley published "Considerations for Developing a Human Mission to the Martian Moons"
2014	Latest addendum to DRM 5.0
2015	NASA published "Journey to Mars: Pioneering the Next Steps in Space Exploration"
2015	The Planetary Society published "Humans Orbiting Mars"
2016	Third International Conference on Exploration of Phobos and Deimos

2.2 INTERNATIONAL INPUT TO THE PLANNING PROCESS

In May 2007, fourteen space agencies jointly released "The Global Exploration Strategy (GES): the Framework for Coordination." Many of these international space agencies are participating on the International Space Station and also on robotic missions to the planets. Many have space programs of their own. The agencies share a vision of coordination on human and robotic space exploration. The report identified a common set of very broad exploration themes and benefits, and called for a voluntary, non-binding coordination mechanism among the space agencies. This led to the establishment of the International Space Exploration Coordination Group (ISECG) in November 2007.

The ISECG is a forum to enable space agencies to identify ways to strengthen their individual exploration programs, to facilitate collaborations and to advance the GES by coordinating mutual efforts in space exploration. As a result of their coordination and workshops, they focus on non-binding products such as findings, recommendations, and consensus opinions. Decisions on how to implement specific mission scenarios are not made by the ISECG, however. These will follow national policy decisions and international consultation at multiple levels, informed by products such as architectures and mission designs developed collectively.

This organization produced a 26 page report "Benefits Stemming from Space Exploration" in 2013. It describes the fundamental benefits that are expected to flow from continued investment in the missions and activities described in the "Global Exploration Roadmap (GER)." Both these documents are available on line. While these are high level documents, they serve to strengthen governmental support for international cooperation in human and robotic space exploration and provide the technical basis for the information that will be needed to establish agreements by the space agencies and their governments.

2.3 DESIGN REFERENCE ARCHITECTURE AND MISSIONS

The terms “architecture” and “mission” are a bit confusing at first. During the first two decades of conceptual Mars mission planning, the term “Design Reference Mission (DRM)” was used. Around 2009, the term “Design Reference Architecture” was introduced to encompass the entire sequence of missions and related supporting infrastructure. Keep in mind that over the years, the conceptual studies became better defined and served as input to trade-off studies and to identify technology needs. They were used to identify system “drivers” that needed further study. They often included broad, high level strategies but also identified specific types of hardware such as a nuclear thermal and solar electric propulsion system. The time constant between some of these concepts and reality could be decades. In some cases, related DRMs were produced; for example an “Austere” DRM for a Mars mission or a Lunar DRM.

In the DRM 5.0, dated July 2009, the Mars Architecture Working Group (MAWG) says that the report should not be viewed as constituting a formal plan for the human exploration of Mars. Instead, the report provides a vision of a potential approach for human Mars exploration based upon the best available knowledge. From 2009 to 2015 the emphasis switched to the necessary technology for the conceived Mars mission. The near term capabilities for the heavy lift launch vehicle, the ground-based checkout systems, and the spacecraft, became well defined. The result was the Space Launch System, the checkout and launch processing systems to be created at the Kennedy Space Center, and the Orion spacecraft. The longer term systems became the focus of the Human Spaceflight Architectural Team (HAT).

It became clear that the systems which required much more research and definition as well as funding would have to be postponed until later; in some cases much later. But studies continued for many areas that fall within NASA’s space exploration research and the roles and specialties of the NASA Centers. The systems relating to the initial Mars landing/long stay mission require much more research, much more money, and much more time. This is one of the main reasons to pursue a Mars Orbital Mission as a precursor.

2.3.1 From Three Missions to Three Phases

In the 2009 DRA 5.0 three missions were defined by the Mars Exploration Program Analysis Group (MEPAG) for exploration of Mars. It was thought that this effort could be completed in approximately 10 years. Each of the missions used the conjunction class (long stay) trajectory option. This concept used pre-deployment of assets up to two years prior to a crewed mission. This concept also called for a nuclear thermal rocket, a surface nuclear power source, use of in situ Martian resources, descent/ascent vehicles, surface habitats, and more. Six years later, this concept had been superseded by a more strategic three phased approach that included lunar and asteroid missions.

In 2015, NASA published “Journey to Mars: Pioneering Next Steps in Space Exploration.” This 36 page document picks up all of the input from the National Space Policy, the National Space Act of 2010, the Global Exploration Roadmap, and the current work of the Centers and laboratories. It is fundamentally a strategic overview document, but presents the status of space exploration plans in a format which is very readable. It focuses on high level concepts such as the approach, principles, programs, plans and challenges, and presents them using beautiful art work. It is not a design reference mission document.

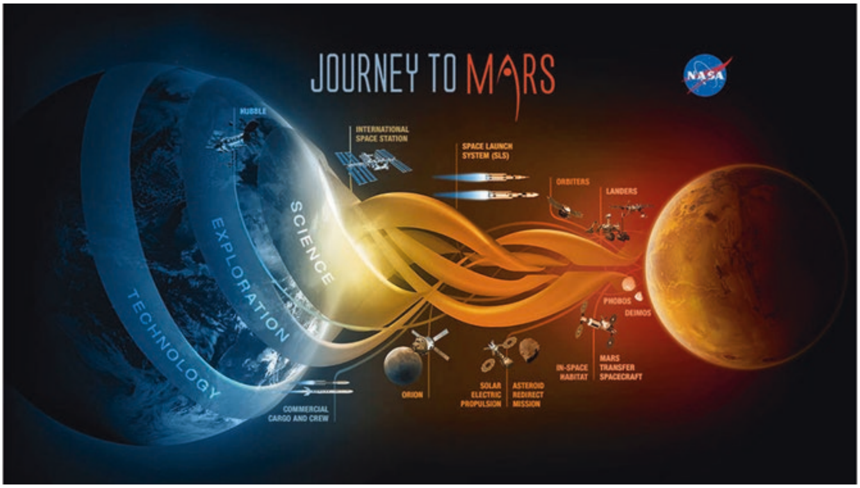

Fig. 2.1 The journey to Mars. (Photo courtesy of NASA)

This document argues that the journey to Mars crosses three thresholds, each of which poses increasing challenges as humans move farther from Earth. NASA manages these challenges by developing and demonstrating capabilities in incremental steps.

Briefly, the three thresholds are:

- *Earth Reliant*. This is basically research onboard the ISS and at the Centers, including commercial participation.
- *The Proving Ground*. This involves missions in cislunar space to validate capabilities required for Mars. It envisages both Exploration Mission-1 scheduled for 2018 and the Asteroid Redirect Mission in 2020.
- *Earth Independent.* Building on what is learned from the above two thresholds, this calls for missions to the vicinity of Mars; perhaps a Mars Orbital Mission and possibly visiting Deimos and/or Phobos. Of course, the ultimate mission is to the surface of the planet and staying there for an extended period until conditions are right to return to Earth. This also describes in situ resource utilization and advanced communications.

According to William H. Gerstenmaier, Associate Administrator for Human Exploration and Operations at NASA Headquarters, this three phase approach "connects near-term activities and capability development to the journey to Mars and a future with a sustainable human presence in deep space" and it "charts a course toward horizon goals while delivering near-term benefits and defining a resilient architecture that can accommodate budgetary changes, political priorities, new scientific discoveries, technological breakthroughs and evolving partnerships."

In view of all the documents developed over the past decades this statement makes a lot of sense, because a Mars Exploration Program will take so long (decades) to achieve the ultimate goal that it will likely be subject to the varied priorities of several Presidents and very different Congresses. Similarly, the participating nations could revise their participation.

And there may be new knowledge about Mars from the many ongoing robotic missions, and critical advances in technology that will change the mission design of the day.

As these events take place, the reference architectures will evolve and the ultimate mission as well as other missions will eventually be defined. It is to be hoped that along the way, conditions will oblige NASA to undertake the Mars Orbital Mission option as a precursor, with Deimos and Phobos as targets of investigation.

2.4 GOALS, OBJECTIVES AND CHALLENGES

NASA states that its goal is not a single destination. They seek a capacity for humans to work, operate, and sustainably live safely beyond Earth for extended periods of time. While they may say this, to most people the goal is Mars, not an asteroid.

Underlying the desire to go to Mars is the basic challenge of developing capable and reliable transportation systems, providing the basic capability to live and work for long periods in deep space, and staying healthy while doing so.

Living in space for a year or more has only been accomplished by four cosmonauts on Mir. Contrary to popular belief, Scott Kelly and Mikhail Kornienko only spent 340 days on the ISS. Spending two years in deep space without resupply (or even with it) will be quite another thing entirely. Living on the surface of Mars for over a year can be imagined, but it is almost beyond our current capability. The challenge is more about funding than it is about will, technology, or capability. The conceptual technology for all the vehicles, equipment, and resources needed has an astronomical price tag and therefore must be spread out over time.

Despite the shift in 2015 to the three thresholds, the general goals and objectives identified in the DRM 5.0 are still valid, albeit rather better defined. They will necessary be adjusted as more knowledge comes in from robotic missions and other fundamental research. In general, the goals relate to planetary science, preparation for sustained human presence in space and on the surface, and ancillary science in addition to that related directly to Mars. The latter category includes the interplanetary environment, and observations of the Sun and Earth while the crew is traveling to Mars and returning to Earth. The details of these goals and objectives will be documented by the study groups of the various NASA Directorates. These have changed slightly since the DRM 5.0 was published.

Currently, NASA Headquarters has four Mission Directorates as follows:

- Aeronautics Research Mission Directorate.
- Human Exploration and Operations Mission Directorate.
- Science Mission Directorate.
- Space Technology Mission Directorate.

Every NASA Center has elements involved in Human Space Exploration that coordinate with one or more of these Headquarters organizations. In addition, there are two Advisory Groups in the form of the NASA Advisory Council and the Aerospace Safety Advisory Council.

It is important to understand that the planetary science realm, which has been involved with robotic missions to Mars for at least 40 years, has a current set of goals which address issues of planetary science first and foremost, and crewed space exploration only where that activity can provide answers to their own more fundamental questions.

The Mars Exploration Program Analysis Group (MEPAG) at the Jet Propulsion Laboratory has very well defined objectives, sub-objectives, and investigations. They even undertake cross-cutting investigations. This group is a community-based forum to provide science input from the broad scientific community to NASA for planning and prioritization of Mars future exploration activities, and thereafter to facilitate the distribution of NASA Mars Program information to its members. It reports to the NASA Advisory Council.

Given their planetary science experience, one would expect MEPAG to be far more specific in regards to the planetary science of Mars than those related to Human Space Exploration. The summary of the MEPAG 2015 goals and objectives in order of priority are:

- Goal I: Determine if Mars ever supported life:
  A. Objective: Determine if environments having a high potential for prior habitability and preservation of biosignatures contain evidence of past life.
  B. Objective: Determine if environments with high potential for current habitability and expression of biosignatures contain evidence of extant life.
- Goal II: Understand the processes and history of climate on Mars:
  A. Characterize the state of the present climate of Mars's atmosphere and surrounding plasma environment, and the underlying process in the current orbital configuration of the planet.
  B. Characterize the history of Mars's climate in the recent past and the underlying processes in different orbital configurations.
  C. Characterize Mars's ancient climate and underlying processes.
- Goal III: Understand the origin and evolution of Mars as a geological system:
  A. Document the geological record preserved in the crust and interpret the processes that have created that record.
  B. Determine the structure, composition and dynamics of the Martian interior, and how it has evolved.
  C. Determine the manifestations of Mars's evolution as recorded by its moons. (*My emphasis: Deimos and Phobos to be discussed later in a Mars Orbital Mission.*)
- Goal IV: Prepare for Human Space Exploration:
  A. Obtain knowledge of Mars sufficient to design and implement a human mission to Mars orbit with acceptable cost, risk and performance. (*My emphasis: Mars orbit.*)
  B. Obtain knowledge of Mars sufficient to design and implement a human mission to the Martian surface with acceptable cost, risk and performance.
  C. Obtain knowledge of Mars sufficient to design and implement a human mission to the surface of either Phobos or Deimos with acceptable cost, risk and performance. (*My emphasis: The sub-objectives and investigations will be addressed in a later section as it applies to a crewed mission.*)
  D. Obtain knowledge of Mars sufficient to design and implement a sustained human presence on the Martian surface with acceptable cost, risk and performance.

It was clear by 2015 (and restated in 2016) that planetary scientists had not only realized the value of exploration of Deimos and Phobos, they had also identified specific subobjectives and investigations. The logical next step would be for those involved with the mission planning for a crewed mission to these moons to design a reference mission. This will be discussed in Part Two of this book.

2.5 RESOURCES REQUIRED

The basic resources planned for a crewed mission to Mars were identified over a decade ago. NASA knew they needed a new spacecraft, the Orion; a new, more powerful heavy lift launch vehicle, the Space Launch System (SLS) – initially with the interim cryogenic upper stage but later with a more capable upper stage that could be rated safe to carry a crew. They would also need new resources to fly a variety of conceived missions into deep space. The major elements would satisfy different types of crewed missions but there are only so many places humans can venture in the next half century; namely in low Earth orbit, onto or in the vicinity of our Moon, to the Lagrangian points of various gravitational systems, to near-Earth asteroids, and to Mars. In addition, other more capable systems are envisioned that require advanced technologies such as nuclear thermal and solar electric propulsion vehicles, but these will require much more money. As soon as Mars mission scenarios address the descent, landing, and surface operations for long stays on the planet, a whole new set of resources are required. The cost and time to create these will take as much effort and money as to develop the systems simply to reach Mars orbit. This is one of my justifications for inserting a Mars Orbital Mission into the schedule prior to a landing mission. One of my concerns is the $20 trillion in national debt, and the annual servicing of that debt. It may become more of a drag on future exploration missions than most would ever think. Just the "daily" increase of the national debt is $2.5 billion. To put that into perspective, that is equivalent to the entire eight year cost of the Curiosity mission in terms of hardware, software, launch, and mission operations!

There are vast resources and capabilities needed here on Earth to support those in space. For example, the new SLS will require a major effort at the Kennedy Space Center to test, checkout, and launch the vehicle(s). Similarly, the boosters and engines need to be designed and checked out at the Marshall Space Flight Center and the Stennis Space Center. All of the NASA Centers are involved in the design, development, test and certification of a great number of systems and subsystems. The Johnson Space Center is involved in the design of new human related systems such as new spacesuits, new environmental life support system, new parachutes, and others. A more detailed description of these systems and technologies is provided later in this book.

2.6 RISKS AND SAFETY ISSUES

While all the NASA and contractor organizations are involved at some level in analyzing risks and safety issues, the ultimate oversight falls upon the Aerospace Safety Advisor Panel (ASAP) which reports to the NASA Administrator and Congress. It reviews safety studies and operations plans, and advises on hazards related to proposed or existing facilities and operations. Each year, it reports on its findings and concerns. It is highly focused on Exploration Systems Development (ESD) and Commercial Space Development (CSD). The design of these systems will have direct impact on the Exploration Program for at least the next 40 years. Program management requires to balance cost, schedule and performance to deliver the product with the highest quality while minimizing schedule delays and budget overruns, and while managing risk and assuring safety performance.

The ASAP acknowledges that space exploration cannot be undertaken free of risk. It states that in a heathy environment of risk management, risks should be deliberately and thoroughly evaluated. They should be balanced against the gain to be expected from taking the risk, and acknowledged candidly and with clear accountability and documentation. That said, as of this writing, the panel has stated its concerns in the following areas:

- Processes for Managing Risk with Clear Accountability not adequately addressed.
- Many open items on changes to the Orion spacecraft.
- Deletion of certain pyrotechnic shock/separation testing at the integrated system level of the ascent abort system.
- The Launch Orbit System is only operational on the first crewed flight.
- Changes in the Orion heat shield to a "molded block Avcoat" needs testing.
- Planned use of the new environmental control and life support system on the first crewed flight to deep space without a LEO flight test.
- Resolution of certain "zero fault tolerant" failure modes of certain components of the Orion Service Module.
- Interim Cryogenic Propulsion Stage's vulnerability to micrometeoroid and orbital debris and not crew-rated.
- A new crew-rated Exploration Upper Stage is not yet funded and must be built, tested, and certified prior to a crewed flight.
- Concern for holding to the schedule for the first crewed flight for 2021.
- Concern about balancing the budget environment with schedule and mission content.
- Concern that specific mission plans have not been developed.
- Concern that planning for only one SLS flight per year will not support a serious Mars Exploration Program.
- Concern that the budgets will not allow some missions and capabilities until the end of ISS operations currently planned for 2024 but could be as late as 2028.

While these are just the current ASAP concerns, some will be worked off and others will be added as the program matures. There will be no end to risk and safety issues and concerns, but that is the nature of human space flight.

Given a Preliminary Mars Orbital Reference Mission and funding, the depth of detail will generate the system level and operational trade-offs. As the detailed planning, engineering, test, and qualification moves toward a Mars Orbital Mission to the moons, more hardware and more operational concepts will generate even more issues.

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