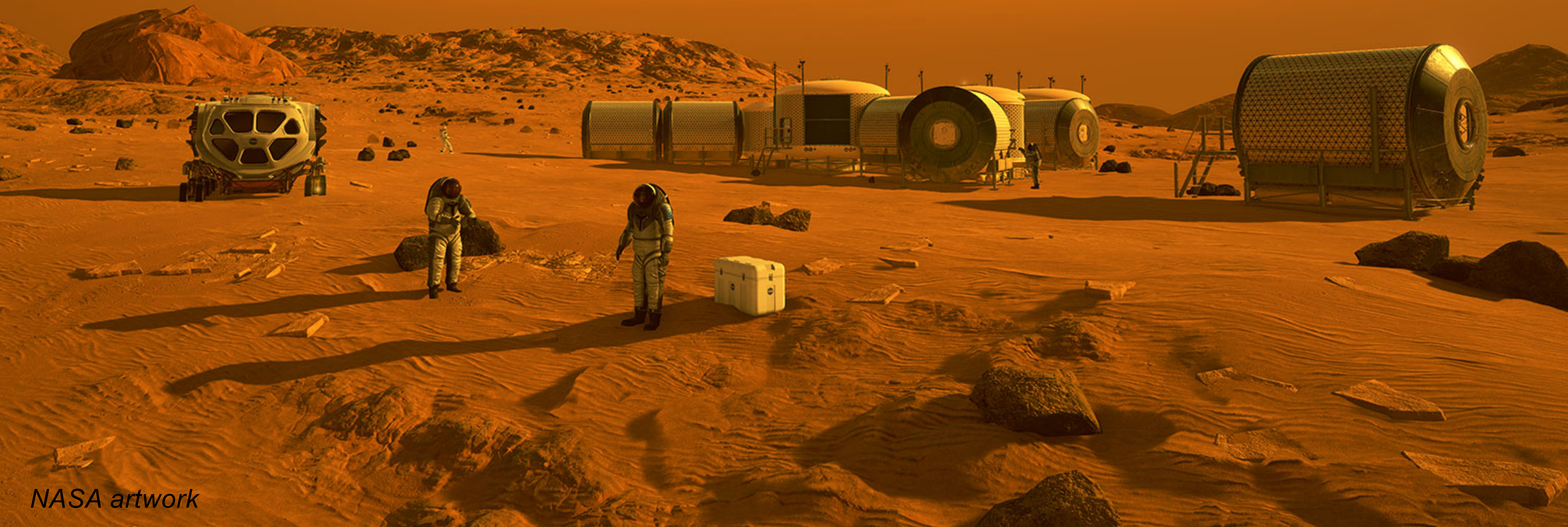


Humans to Mars, But How Many?

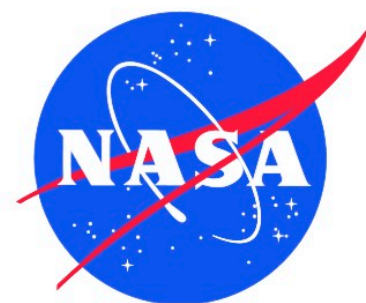
A historical review of crew size determinations for Mars missions

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Humans to Mars, But How Many?
A Historical Review of Crew Size
Determinations for Mars Missions

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... but make sure you
look for the subtitle
as well as the title.

Background to this study

In 2023 I conducted a historical review of studies of human Mars missions, with an emphasis on the thinking that went into each study's recommendations for crew size.

- This review was requested in support of an effort by the NASA Engineering Safety Center (NESC) to develop a tool to aid determination of optimum crew sizes for human Mars missions.

Human missions to Mars are so demanding and complex that NASA mission architect John Connolly and his colleagues have called them “the ultimate systems challenge.”

The NESC's crew-size determination tool was created out of the understanding that Mars missions stand apart from all previous human spaceflights:

- Because of the vast distances involved and the time required for radio signals to travel between the Earth and a Mars crew—up to 22 minutes each way—the enormous expertise of the teams the Mission Control Center (MCC) that all previous NASA flight crews have relied on will be unavailable in real-time.
- It will be critical to choose a crew size large enough to afford the necessary onboard expertise to solve unanticipated problems.



Mars being occulted by the Moon in 2003 (image by the author)

This review includes 15 Mars crew size assessments from 1948 to 2021

Year	Title	Author / NASA sponsor	Contractor	Crew (total)	Crew (landed)
1948	The Mars Project	Wernher von Braun	n/a	70	50
1956	The Exploration of Mars	von Braun and Ley	n/a	12	9
1963	Manned Mars Landing and Return	NASA ARC*	TRW Space Technology Laboratories	6	2
1963	Manned Mars Landing and Return	NASA ARC*	North American Aviation	3-10	?
1963	Study of Subsystems Required for a Mars Mission Module	NASA MSC**	North American Aviation	4-6	2
1963	Study of a Manned Mars Excursion Module	NASA MSC**	Philco Corp. Aeronutronic Division	4-6	3

25-year gap for studies that considered crew size

Year	Title	NASA Originator	Crew (total)	Crew (landed)
1988	Human Expeditions to Mars	NASA HQ Office of Exploration	8	4
1988	Lunar Outpost to Early Mars Evolution	NASA HQ Office of Exploration	8	8
1993	Mars Exploration Study Workshop II	NASA HQ	6	6
1997	Human Exploration of Mars: The Reference Mission of the NASA Mars Exploration Study Team	NASA HQ	6	6
1999-2000	Operations Concept Definition for the Human Exploration of Mars	Human Exploration Operations Team / NASA HQ Office of Exploration	4	4
2005	Exploration Systems Architecture Study	NASA HQ	6	?
2009	Design Reference Architecture 5.0	Mars Architecture Steering Group, NASA Headquarters	6	6
2014-2016	The Evolvable Mars Campaign	Human Exploration and Operations Mission Directorate	4	4 (TBR)
2021	Strategic Analysis Cycle 2021	Mars Architecture Team	4	2

* Ames Research Center ** Manned Spacecraft Center (later renamed Johnson Space Center)

Before NASA: Wernher von Braun's ambitious Martian visions

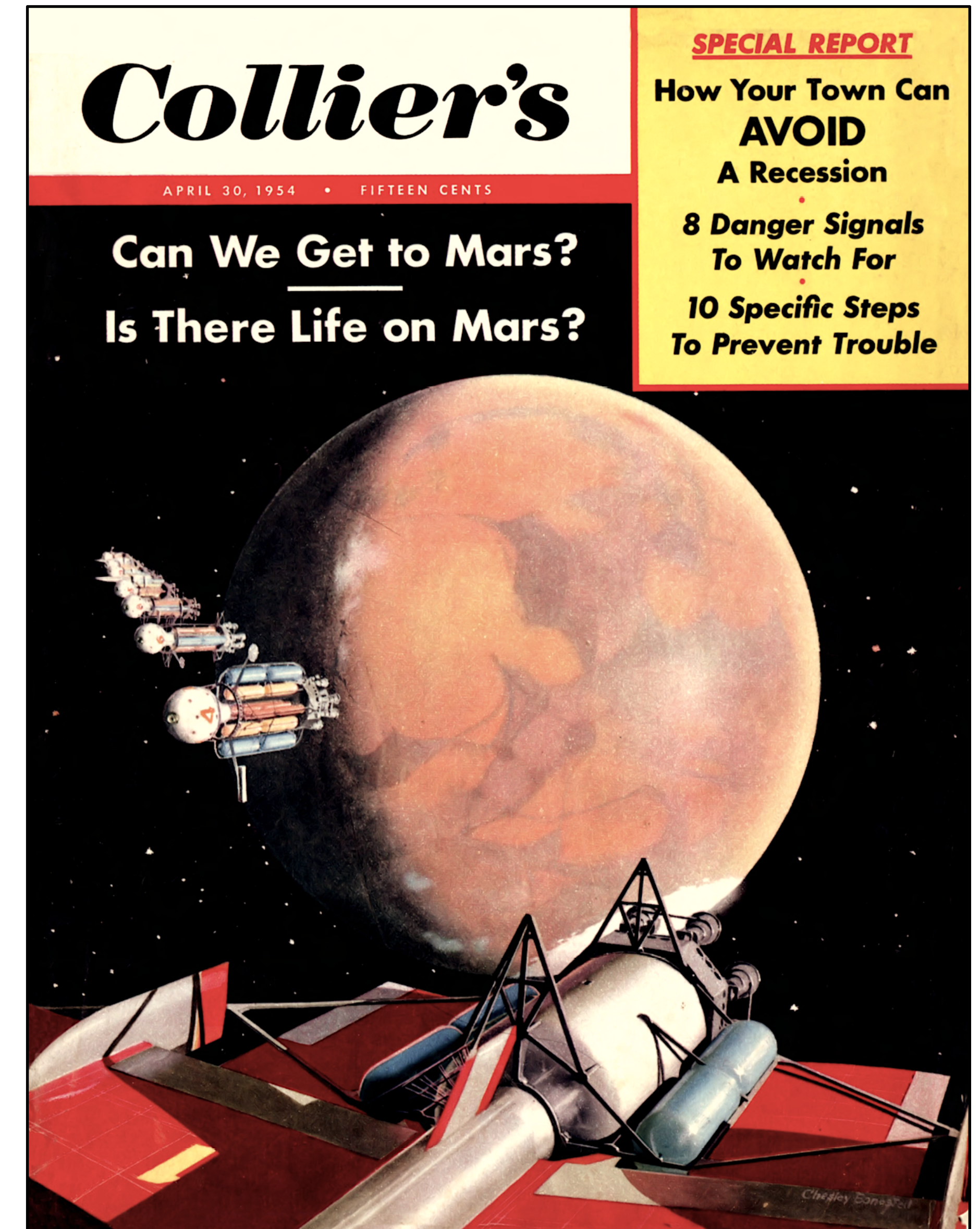
1948: Wernher von Braun conducted the first engineering study of a human Mars mission, later published as *The Mars Project*.

- Possibly influenced by contemporary Antarctic expeditions, von Braun envisioned a crew of 70, with 50 landing on the surface.
- Total expedition mass = 88 times the completed ISS

1954: Millions of readers learned about the plan in the pages of *Collier's* magazine.

1956: In the book *The Exploration of Mars* von Braun scaled back the expedition to a crew of 12 with 9 landing on the surface.

- Interestingly at this early date, von Braun noted the possibility that any crewmember be incapacitated by illness or injury, necessitating cross-training.
- He also advised that 3 of the 9-person surface crew should be trained in “medicine and simple dentistry”



Wernher von Braun's Mars expedition as envisioned by artist Chesley Bonestell for the April 30, 1954 issue of Collier's magazine.

Early NASA Mars mission studies mention crew workload

1963: NASA's Ames Research Center (ARC) and Manned Spacecraft Center (MSC)* funded contractor teams to study human Mars missions.

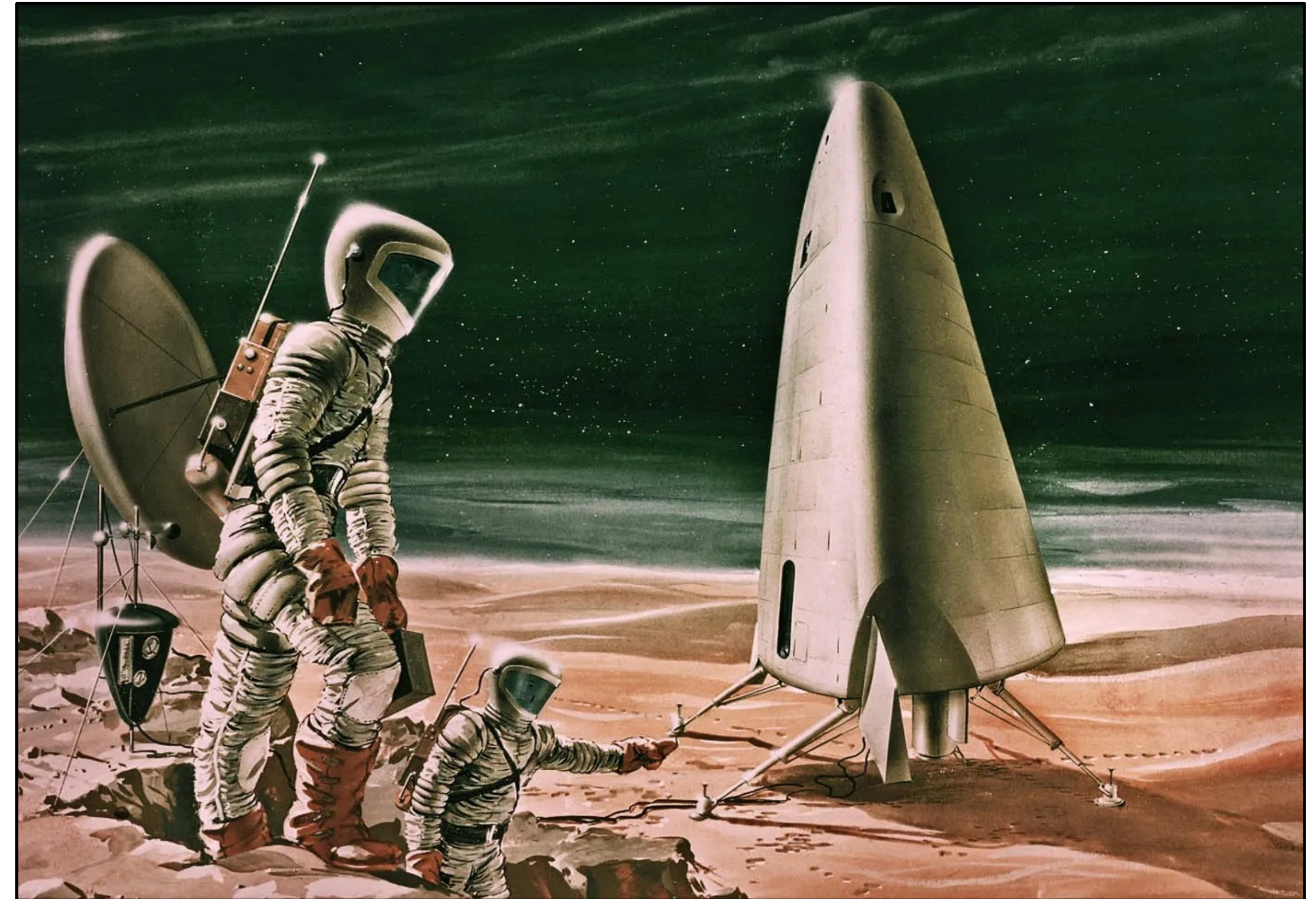
As part of its study, one contractor team conducted “a brief human factors study” including an analysis of crew tasks. The team concluded that an 8-person crew was “desirable” and 7-crew was “a minimum,” but they set a baseline of 6-crew.

- The team noted that improved reliability of spacecraft subsystems could allow smaller crew sizes.

Another contractor study, of a Mars transit vehicle, warned that maintenance tasks could overwhelm the crew's time at the expense of science activities.

A third contractor team studying a Mars lander contradicted the 2-crew baseline they were given (apparently by NASA) and said 3-crew would be required to obtain “a reasonable scientific and engineering data return from the surface of Mars.”

* *Later renamed the Johnson Space Center (JSC)*



Artwork used to illustrate the Philco Corporation's 1963 study of a Manned Excursion Module for a Mars mission. (NASA)

1993: Skill Mix Gains New Importance for Crew Size

ARC human factors specialist Yvonne Clearwater analyzed the minimum crew size needed “to achieve the combined science and habitability objectives of the Mars surface mission.”

- Presented at the 1992 Mars Exploration Study Workshop II held at ARC, published in 1993.
- Identified a wide range of required tasks and roles and conducted “a workload analysis” (no details were given about the methodology used for the analysis).
- Concluded that “the surface mission can be conducted with a minimum crew size of five, based on technical skills required.”
- Each astronaut would be assigned a primary role with at least one other crew member serving as a backup.
- However, “Loss or incapacitation of one or more crew could significantly jeopardize mission success. Therefore, a minimum crew size of seven or eight may be required to address the risk issues.”
- The workshop baselined 6-crew

Surface Mission Skills		
Specialized Operations and Services	Focused Objectives	In-Common
<ul style="list-style-type: none">• Mechanical systems operations, maintenance and repair• Tool-making	<ul style="list-style-type: none">• Geology• Geochemistry• Paleontology• Geophysics incl. meteorology and atmospheric science	<ul style="list-style-type: none">• Management / planning• Communications• Computer sciences• Database management• Food preparation<ul style="list-style-type: none">-- routine greenhouse ops.-- plants to ingredients-- ingredients to meals• Vehicle control• Navigation• Tele-operated rover control
<ul style="list-style-type: none">• Electrical systems operations, maintenance and repair• Electronics systems operations, maintenance and repair	<ul style="list-style-type: none">• Biology• Botany• Ecology• Agronomy• Soil Science	
<ul style="list-style-type: none">• General practice medicine• Surgery• Psychology	<ul style="list-style-type: none">• Biomedicine• Psychology	

Skills required for a Mars surface mission as identified by Yvonne Clearwater for the 1992 Mars Exploration Study Workshop II at ARC.

1997: NASA publishes a mission plan for Mars

NASA published *Human Exploration of Mars: The Reference Mission of the NASA Mars Exploration Study Team* in 1997. Also known as the Design Reference Mission, this was intended as a kind of foundation for future humans-to-Mars planning.

- The report essentially repeated the crew-size recommendations of the 1992 Ames workshop, baselining a 6-person crew but acknowledging that a larger crew may be necessary to reduce risk.
- However, the report focused mostly on tasks that would have to be accomplished during the transit to and from Mars and in orbit around the planet, while surface activities received relatively little attention.
- The authors noted that “highly autonomous” systems would be required because of the lack of real-time support from Earth. They added that the level of system automation achieved would be an important consideration for crew size.
- They also cautioned that any crew needs not anticipated before the mission would “significantly challenge the management and operations systems to support the crew”



Lander and pressurized rover concept from the 1997 Design Reference Mission (NASA)

1999-2000: Cost concerns spark a challenge to the 6-crew paradigm

In the late 1990s the NASA HQ Office of Exploration recruited members of JSC's Mission Operations Directorate, along with other specialists from JSC and the Kennedy Space Center (KSC), to form the Human Exploration Operations Team to carry out a human Mars mission study, with a requirement that the mission be "economically feasible." This mandate led them to challenge the 6-person crew baselined by the 1997 Design Reference Mission.

The team examined whether it would be possible to conduct Mars surface EVAs safely and successfully with a 4-person crew. They based their conclusions on past U.S. and Soviet / Russian EVA [extravehicular activity] experience in low Earth orbit. Their report was issued within NASA in 1999 and revised in 2000.

- The team envisioned that Mars surface EVAs would be conducted by 2 pairs of astronauts on alternating days. "While one pair was outside," they wrote, "the second pair would remain inside, with *one individual performing IV [intravehicular] support, and the other monitoring vehicle health/status.*" (emphasis added)
- The team concluded that 4-crew is "operationally sufficient" and "does not incur a substantial increase in exploration/EVA risk to the crews."
- However, after a team member challenged this conclusion for being too success-oriented, caveats were added acknowledging that a 4-person crew "may not be optimal for mission success" due to the possibility of illness or incapacitation. Furthermore, adding another crewmember might be required to handle the spectrum of required skills, but "to realistically determine the crew size, a trade must be made between the cost associated with one additional crew member and the level of risk which is considered acceptable for achieving mission success."

2009: A note of uncertainty about crew size

In 2009 NASA released a revised Mars mission plan called *Human Exploration of Mars: Design Reference Architecture 5.0*.

- Like the 1997 Design Reference Mission, the 2009 report baselined a 6-person crew, calling it “a reasonable compromise” between costs and the level of onboard expertise required to successfully carry out the mission.
- However, an addendum to the report included both the 1997 DRM’s 6-crew finding and the 1999 4-crew assessment and then noted that “no final conclusion has been reached regarding the required number of crew....”
- It added that the mix of skills required for a Mars crew “continues to be analyzed and will be dependent on needs driven by the objectives that are set for this crew.”



*Illustration from the 2009 Design Reference Architecture.
(NASA)*

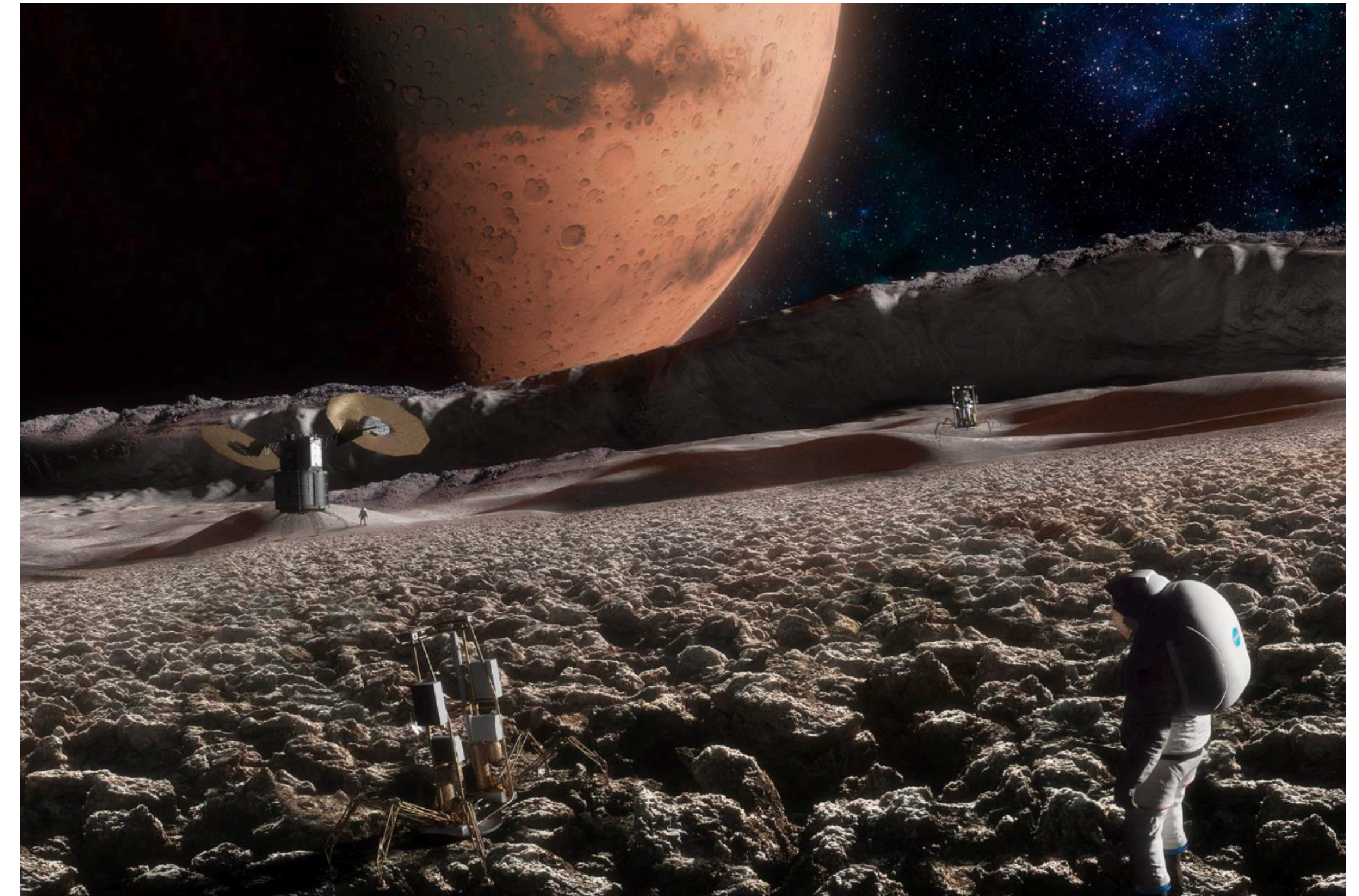
2014-2016: Four Crew is Specified, Despite Opposition

Formal development of Design Reference Architecture ceased after cancellation of Constellation in 2010.

In 2014 NASA's Human Exploration and Operations Mission Directorate (HEOMD) chose a new direction for humans-to-Mars planning called the Evolvable Mars Campaign (EMC).

The EMC was described as “not a specific plan” but a “framework” for future missions including human voyages to the Martian moons and surface beginning in the mid-2030s.

- Study teams were given a ground rule of a four-person crew.
- Despite objections by some team members, the EMC studies effectively overturned the 6-crew paradigm.
- Nevertheless, other team members acknowledged the potential pitfalls of a small crew size. “With limited abort options,” they wrote, “the ability to maintain systems will be critical. There is potential that repair activities could overwhelm available crew time.”



Mission to the Martian moon Phobos depicted in a 2016 paper by EMC team members. (NASA)

2021: A split-crew Approach for the First Mars Landing Mission

In 2021 NASA's Mars Architecture Team (MAT) was tasked with finding way to accomplish the first human Mars landing “as fast—and as soon—as practical.”

The MAT's plan calls for a 4-person crew split into 2 pairs, one of which remains in orbit in the Transit Habitat while the other lands in their pressurized rover for a month-long surface stay.

The astronauts in Mars orbit would be responsible for an array of roles:

- Operation and maintenance of the Transit Habitat
- Supporting the surface crew during EVAs and providing a communications relay to Earth
- Possible additional roles include teleoperating robotic assets at the landing site and participating in analyzing data and planning future activities in coordination with experts on Earth

The feasibility of this ambitious agenda for the specified crew size remains to be addressed.



Astronauts in their pressurized rover on Mars. (NASA)

Additional concerns

Interviewees for this historical review identified a number of concerns and unknowns for human Mars missions that can be addressed using NESC's new analytical capability, including:

What is the knowledge base and workload required for onboard maintenance and repair of the Mars Transit Habitat?

- NESC analytical tools can help guide designers to create a transit habitat whose operation and maintenance requirements would not overtax the crew.

What are the pre-mission training requirements?

- The the NESC has laid out a systematic approach to estimating training requirements with an analytical model.

ISS experience has shown there are very real limits to the amount of information that can be retained by the crew on a multi-year mission. This directly impacts the adequacy of any given crew size, and points to the need for onboard information and diagnostic capabilities to assist the crew.

- The NESC capability includes modeling of the onboard expertise required to meet primary mission objectives.

Past experience in Apollo and ISS missions shows that a Mars crew is likely to encounter unforeseen problems for which the crew would not have information onboard to find solutions. This can become critical for serious problems requiring rapid response, without real-time support from Earth.

- The NESC capability addresses the onboard expertise necessary to respond to these unforeseen failures.

Words of wisdom

“Humans are the most valuable mission asset for the Mars exploration program and must not become the weak link.”

— NASA ARC human factors specialist Yvonne Clearwater, 1993

“A Mars mission is more than just Apollo on steroids; there is a quantum difference from any of our previous spaceflight experience.”

— NASA JSC systems engineer and Mars mission architect Steve Hoffman, 2023

Discussion

(end)