Humans To Mars, But How Many?

Trade Space Analysis for Mars Mission Crew Size

2025 Human Research Program Investigators' Workshop

Team Members

Name	Discipline	Organization
Core Team		
Dr. Cynthia Null	NESC Lead	LaRC
Dr. Donna Dempsey	Technical Lead	JSC
Dr. Alan Hobbs	Human Factors	ARC/ San Jose State University Foundation (SJSU)
Dr. Kara Latorella	Human Factors	LaRC
Dr. Ruthan Lewis	Human Factors	GSFC
LCDR Amanda Lippert	Human Factors	United States Navy (USN)
John Karasinski	Human Factors	ARC
Robert Sargent	Human Factors	Huntington Ingalls Industries
Terrence Tyson	Human Factors	ARC
Peter Robinson	Intelligent Systems	ARC
Dr. Zhaofeng Huang	Reliability and Statistics	The Aerospace Corporation
Marta Durham	Space Flight Operations	JSC/KBR Wyle Services, LLC
Christopher Niemann	Space Flight Operations	JSC/KBR Wyle Services, LLC
Thera Shear-Tungol	Space Flight Operations	JSC/KBR Wyle Services, LLC
Mr. Andrew Chaikin	Space Historian and Author	Andrew Chaikin LLC
Student Interns		
Megan Dempsey	Student Intern	University of Central Florida
Sydney Hughs-Baird	Student Intern	Georgia Institute of Technology
Kyle Keyzer	Student Intern	Rice University
Jessica Maddox	Student Intern	Purdue University
Spencer Pak	Student Intern	University of California, Riverside
Consultant		
Lauren Landon	Industrial Organizational Psychology	JSC/KBR Wyle Services, LLC
Business Management		
Austin DeLaHunt	Program Analyst	LaRC/MTSO
Becki Hendricks	Program Analyst	LaRC/MTSO
Assessment Support		
Missy Strickland	Project Coordinator	LaRC/AMA
Linda Burgess	Planning and Control Analyst	LaRC/AMA
Erin Moran	Technical Editor	LaRC/AMA
Jonay Campbell	Technical Editor	LaRC/AS&M

Bottom Line Up Front

A NASA Engineering and Safety Center (NESC) assessment team recommended a methodology for performing trade space analysis for crew size determination for Mars missions. The methodology uses quantitative data from human performance modeling.

The assessment team did NOT make recommendations on the number of crew, rather the recommendations are on the trade space analysis methodology.

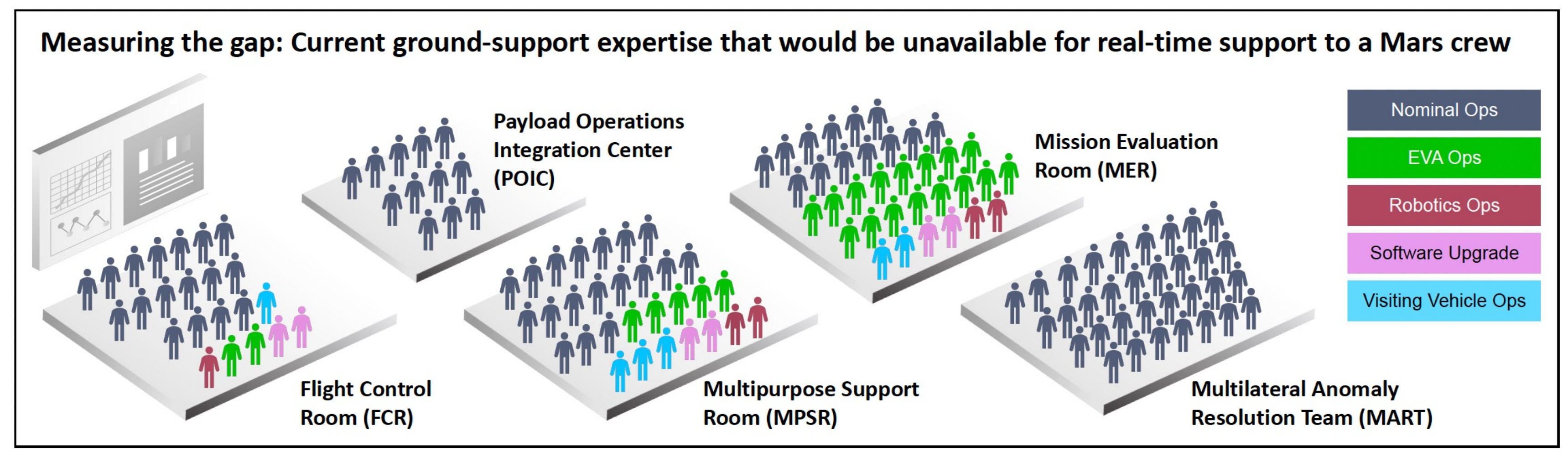
This presentation includes:

- A methodology for using human performance modeling to provided quantitative data of workload and expertise in support of crew size determination
- Results from three human performance models using IMPRINT
- Results from a custom-built model of crew expertise, based on training requirements
- A discussion on trade space analysis for Mars crew size

NESC Trade Space Analysis Assessment

To date, crewmembers onboard NASA's human spaceflight missions have been able to rely on real-time expertise and support from personnel in control centers on Earth to successfully accomplish their missions. For ISS missions, the MCC, the MER, and the POIC personnel, team with the crew to monitor and control the vehicle, vehicle systems, and payloads and provide expertise as needed.

Because of the distance-induced communication delay/blackout with Earth (e.g., up to ~22 minutes one-way and ~2 to 3 weeks each mission), Mars missions will differ from all previous human spaceflight experience in that the crew will be required to operate independently from the large and highly experienced teams on the ground.



Panontin, T. L., Wu, S. C., Parisi, M. E., McTigue, K. R., & Vera, A. H. (2021) *Human-Systems Integration Architecture Needs Analysis: On-Board Anomaly Resolution During Autonomous Operations*. NASA's Human Research Program Technical Report.

Donna Dempsey| donna.l.dempsey@nasa.gov

NESC Trade Space Analysis Assessment

Without a systematic, repeatable process to determine the number of crew necessary to successfully accomplish these missions, NASA increases the risk in that crew sizes may be too small to meet mission objectives under nominal conditions and, more consequentially, the crewmembers may not have the expertise needed to successfully respond to unforeseen failures without the real-time expertise in MCC on which NASA has come to rely.

Proposed Solution

To define a methodology for performing trade space analysis for crew size determination for future missions to Mars using quantitative data from human performance modeling.

Gather Mars Mission Information

Document Mission Parameters
The Mars environment, mission objectives, and architecture information.

Determine Use Cases to Model

Develop Mars Master Task List
Listing of candidate crew-assigned duties and tasks.

Determine Critical Use Cases* to Model
Nominal and off-nominal.

** Tasks or mission segments identified by SMEs that likely require high mental workload, high manpower, or a high level of expertise in such a way that may drive crew size requirements.*

Create a Trade Space Evaluation Framework

Create Evaluation Framework
Across dimensions of the trade space – across mission design parameters.

Conduct Human Performance Modeling

IMPRINT Modeling
Human performance modeling of workload for a task or mission segment.

CQRM Modeling
Modeling of expertise based on a crew qualifications and responsibilities matrix (CQRM).

SME Reviews
Reviews for each model.

Perform Trade Space Analysis

Evaluate Crew Size
Using quantitative modeling results, evaluate different crew sizes across trade space dimensions.

Recommendations
Provide decision-makers recommendations on crew size.

Militello et al. (2019). *Towards and Optimally Crewed Future Vertical Lift Vehicle: Crewing Strategy and Recommendations*. Prepared for U.S. Army Combat Capabilities Development Command Aviation & Missile Center.

Lippert, A.F. , Scripture, B. L., "A Review of Department of Defense Manpower Analysis to Inform Crew Size Determination for NASA's Manned Missions to Mars" (Master of Human System Integration Capstone). Naval Postgraduate School, Monterey, CA. (2021)

L. Shattuck, N. Shattuck, P. Matsangas. Personal communication with NPS researchers. (2020)

Mars Transit Crew Model

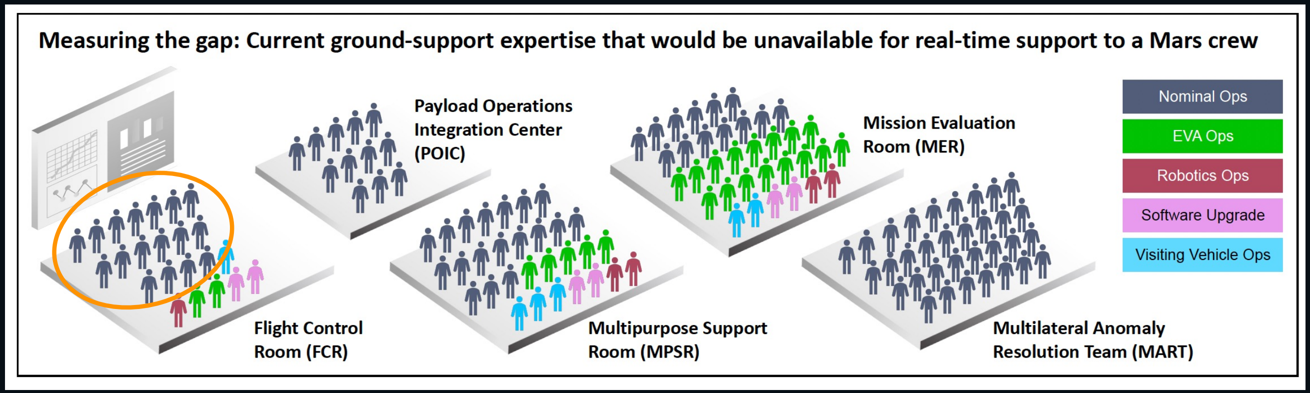
Dr. Donna Dempsey, Robert Sargent, Dr. Zhaofeng (Carl) Huang,
Peter Robinson, Marta Durham, Kyle Keyser, Sydney Hughs-Baird

Conduct Human Performance Modeling

IMPRINT Modeling
Human performance modeling of workload for a task or mission segment.

CQRM Modeling
Modeling of expertise based on a crew qualifications and responsibilities matrix (CQRM).

SME Reviews
Reviews for each model.



This model is designed to consider the crew daily workload on the transit to Mars, assuming continual but communication-delayed support from MCC.

Real-Time Tasking Shifted to Mars Crew

Conduct Human Performance Modeling

IMPRINT Modeling
Human performance modeling of workload for a task or mission segment.

CQRM Modeling
Modeling of expertise based on a crew qualifications and responsibilities matrix (CQRM).

SME Reviews
Reviews for each model.

Assumptions for Mars based on Flight Director and Payloads Operations Director interviews:

- MCC is prime for nominal planning.
- MCC is prime for nominal commanding with a communication delay.
- MCC and POIC are prime for resource allocation (e.g., power, thermal, bandwidth, data, 0_2, N_2, vacuum access,…).
- MCC is prime for console analytic tools that can be performed with a comm. delay.
- Crew is prime for commanding for tasks requiring real-time or near real-time verification.
- Crew is prime for tasks with time constraints.
- Crew is prime for go-no-go calls requiring real-time data (e.g., crew lock depress).
- Crew is prime for tasks requiring real-time monitoring (e.g., some robotics operations).
- Crew is prime for tasks requiring real-time communication (e.g., IV crew).
- Crew is prime for tasks with bandwidth limitations.
- Crew is prime for console analytic tools impacted by the comm. delay or bandwidth limitations.

Model Scope and Data Sources

Conduct Human Performance Modeling

IMPRINT Modeling
Human performance modeling of workload for a task or mission segment.

CQRM Modeling
Modeling of expertise based on a crew qualifications and responsibilities matrix (CQRM).

SME Reviews
Reviews for each model.

The assessment team built an IMPRINT Force model of daily workload to assess what crew size is needed to accomplish a defined set of work.

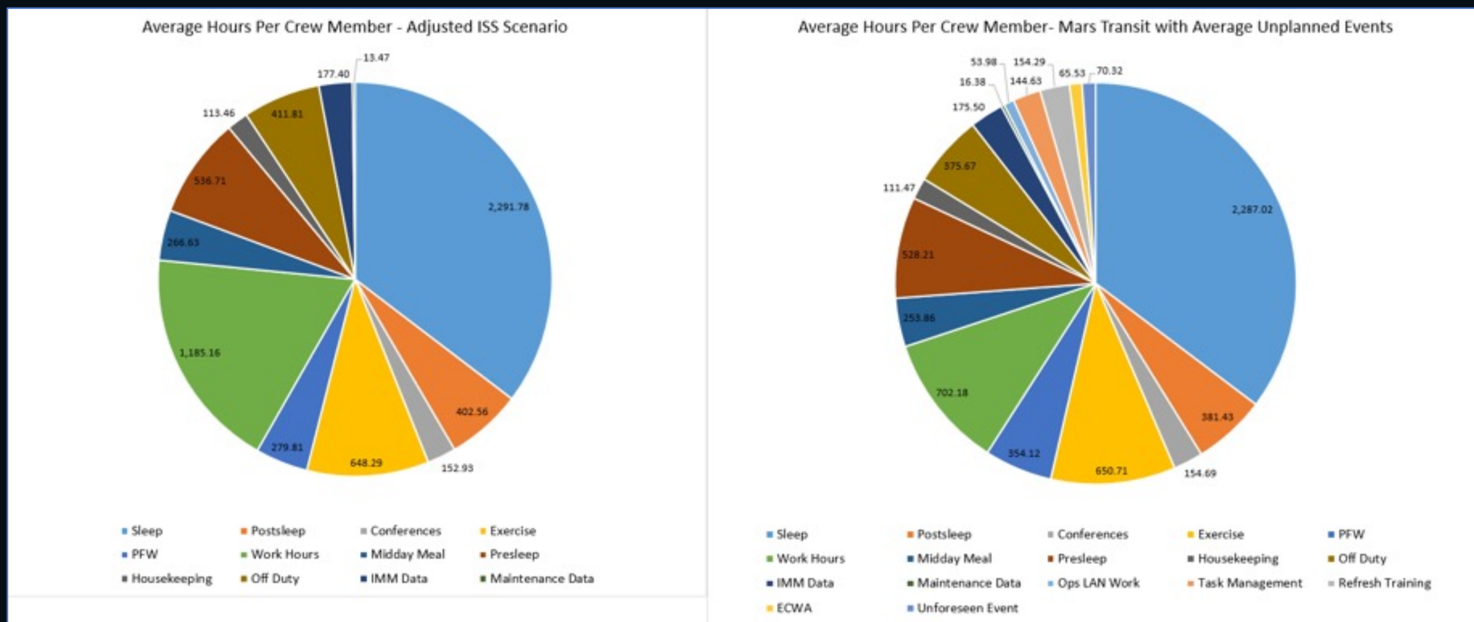
- Gathered data sets, conducted SME structured interviews, and/or conducted statistical analysis
  - Time for likely medical events and their impact on crew workload using results from NASA's Integrated Medical Model (IMM)
  - Increased time for likely maintenance and repair w/o real-time support from MCC
  - Increased time for nominal MCC tasks reallocated to the crew
  - Increased time for emergency, warning, caution and advisory off-nominal response
  - Increased time necessary to respond to unforeseen failures
  - Increased time to maintain expertise via onboard refresher training

Objective: To determine how daily workload impacts crew size

- Perform same work hours on transit to Mars as a 4-person crew on ISS
- Maintain ~ 8.5 hours of sleep and maintain ~2.5 hours of daily exercise

Average Hours Per Crewmember

Adjusted ISS Scenario (with nom. Maintenance and IMM data)
compared to Mars Transit with Average Unplanned Events



Mars Transit Crew Model using ISS-equivalent task assumptions and assuming continual time-delayed communication throughout the mission

F-12. IMPRINT modeling predicts that average rates for unplanned events will reduce the available time for a four-person Mars crew to perform work by 41% compared with a four-person ISS crew.

Findings: Mars Transit Crew Model

using ISS-equivalent Task Assumptions

Conduct Human Performance Modeling

IMPRINT Modeling
Human performance modeling of workload for a task or mission segment.

CQRM Modeling
Modeling of expertise based on a crew qualifications and responsibilities matrix (CQRM).

SME Reviews
Reviews for each model.

The assessment team developed a formula to compute the number of crewmembers needed on a Mars mission to accomplish the same amount of work as an ISS 4-person crew.

Mars Transit Crew Model using ISS-equivalent task assumptions and assuming continual time-delayed communication throughout the mission

F-14. IMPRINT modeling predicts that more than six crewmembers will be needed to achieve the same number of work hours on a Mars transit as on a four-person ISS mission given average rates for all unplanned events.

F-15. IMPRINT modeling predicts that more than seven crewmembers will be needed to achieve the same number of work hours on a Mars transit as on a four-person ISS mission given 75% confidence level rates for all unplanned events.

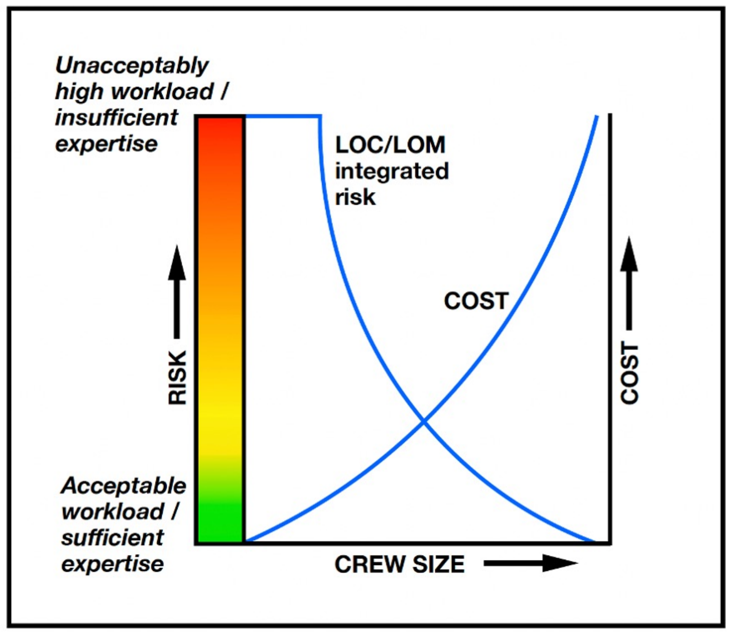
Perform Trade Space Analysis

Perform Trade Space Analysis

Evaluate Crew Sizes
Using quantitative modeling results, evaluate different crew sizes across trade space dimensions.

Recommendations
Provide decision-makers recommendations on crew size.

Provide recommendations to decision-makers as they consider the potentially competing factors in deciding on crew size for future missions to Mars.

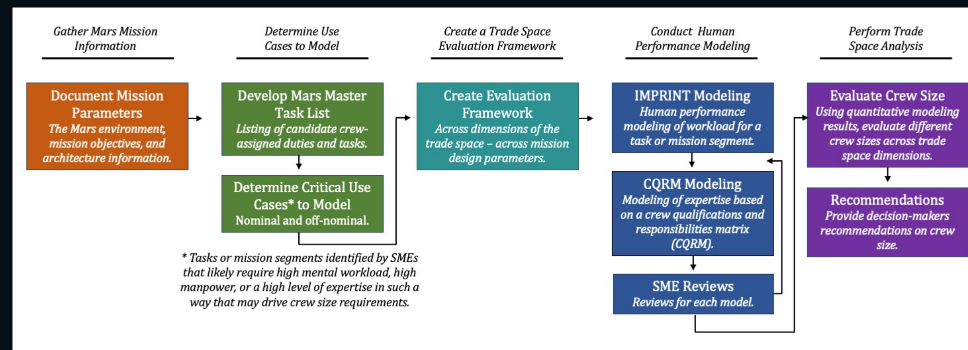


Notional curves convey the relationship between crew size, risk, and cost. Crew sizes too small to handle mission workload or respond successfully to unforeseen failures due to insufficient onboard expertise result in increased risk to mission success and crew safety (left curve). Increases in crew size, which reduce these risks, may likely drive mission costs prohibitively high (right curve).

Summary

The NESC assessment team:

- Defined a methodology for trade space analysis for crew size determination using quantitative data from human performance modeling
- Developed an evaluation framework
- Built human performance models that output workload and expertise based on Mars mission use cases
- Discussed trade space analysis of crew size using modeling results



The assessment team is NOT making recommendations on the number of crew, rather the recommendations are on the trade space analysis methodology.

R-1. Agency decision-makers should consider the crew workload and expertise within the crew necessary to accomplish primary mission objectives and respond to unforeseen failures when considering trades for crew size for Mars missions.

Donna Dempsey| donna.l.dempsey@nasa.gov