The Exploration of Mars Launch & Assembly Simulation

Grant Cates
The Aerospace Corporation
15835 Phillips Parkway
Eastern Range, FL 32925
321-867-7820
grant.r.cates@aero.org

Chel Stromgren / Bryan Mattfeld
Binera, Inc.
912 Thayer Avenue, Suite 209
Silver Spring, MD 20910
301-686-8571 / 301-579-5242
c.stromgren@binera.com /
b.mattfeld@binera.com

William Cirillo / Kandyce Goodliff
NASA Langley Research Center
1 North Dryden Street
Hampton, VA 23681
757-864-1938 / 757-864-4969
william.m.cirillo@nasa.gov /
kandyce.e.goodliff@nasa.gov

Abstract— **Advancing human exploration of space beyond Low Earth Orbit, and ultimately to Mars, is of great interest to NASA, other organizations, and space exploration advocates. Various strategies for getting to Mars have been proposed. These include NASA's Design Reference Architecture 5.0, a near-term flyby of Mars advocated by the group Inspiration Mars, and potential options developed for NASA's Evolvable Mars Campaign. Regardless of which approach is used to get to Mars, they all share a need to visualize and analyze their proposed campaign and evaluate the feasibility of the launch and on-orbit assembly segment of the campaign. The launch and assembly segment starts with flight hardware manufacturing and ends with final departure of a Mars Transfer Vehicle (MTV), or set of MTVs, from an assembly orbit near Earth. This paper describes a discrete event simulation based strategic visualization and analysis tool that can be used to evaluate the launch campaign reliability of any proposed strategy for exploration beyond low Earth orbit. The input to the simulation can be any manifest of multiple launches and their associated transit operations between Earth and the exploration destinations, including Earth orbit, lunar orbit, asteroids, moons of Mars, and ultimately Mars. The simulation output includes expected launch dates and ascent outcomes i.e., success or failure. Running 1,000 replications of the simulation provides the capability to perform launch campaign reliability analysis to determine the probability that all launches occur in a timely manner to support departure opportunities and to deliver their payloads to the intended orbit. This allows for quantitative comparisons between alternative scenarios, as well as the capability to analyze options for improving launch campaign reliability. Results are presented for representative strategies.**

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1. INTRODUCTION

The 'Exploration of Mars Launch & Assembly Simulation' has been developed to model launch operations for the next 40 years of human exploration of space. The model currently provides two capabilities. The first is the ability to analyze the success probability of the various launch campaigns being able to assemble Mars Transfer Vehicles that will be used to transport crews to Mars during discrete Trans-Mars-Injection windows that occur on an approximate 26-month cycle.

The second capability of the simulation is an animation feature that allows users to visualize mission operations from the perspective of looking down upon the solar system. This vantage point and compressed timescale enhances the ability to comprehend the scale and complexity of the Mars campaign options under study far more efficiently than can be done with PowerPoint charts or written reports.

NASA has been analyzing strategies for human exploration of Mars for many years. In 2009, NASA published "Human Exploration of Mars: Design Reference Architecture 5.0" (DRA 5.0) [1] along with a detailed technical addendum [2] that describe an operations concept for the first human missions to Mars. The Mars DRA 5.0 documents represent the most comprehensive study for human exploration of Mars published to date and now serve as the point of departure for continued studies.

There have been several key strategic changes since the 2009 timeframe including the cancellation of the Ares I launch vehicle; the replacement of the planned Ares V launch vehicle with the Space Launch System (SLS); and reductions to the ground processing architecture at the Kennedy Space Center (KSC). There will now be only a single string capability of one mobile launcher, one integration high bay, and one launch pad available for launching SLS. These changes have significant ramifications to the launch and assembly phase of missions to Mars.

The complex nature of Mars exploration, including launching and assembling all the required elements in a timely manner to support the planned departure window, makes reliability analysis challenging. To assist in the reliability analysis, NASA has been developing an integrated methodology to analyze launch and assembly reliability. This work builds upon previous analyses performed for the Space Shuttle and International Space Station Programs [3] [4] [5], the Constellation Program [6] [7], the Review of Human Space

Flight Plans Committee [8], studies performed in 2011 on launch and assembly reliability for human exploration missions to near-Earth asteroids [9], and studies performed in 2012 on launch and assembly reliability for human exploration of Mars [10].

These past efforts were focused upon determining the likelihood of being able to launch and assemble one crewed exploration vehicle. The new Exploration of Mars Launch & Assembly Simulation expands this capability to look at the totality of launch and assembly campaigns related to NASA's Evolvable Mars Campaign (EMC). EMC represents an "ongoing series of architectural trade analyses to define the capabilities and elements needed for a sustainable human presence on the surface of Mars" [11]. Architectures currently being explored within the purview of EMC extend from the present to the first several crewed exploration missions to the Mars system.

The current version of the simulation evaluates only ground operations, launch, and ascent risks and does not include the in-space spacecraft operations and reliability risks, Micrometeoroid and Orbital Debris (MMOD) risks, and crew health risks that could result in a loss of mission prior to the Trans-Mars-Injection burn. This functionality will be added in later versions of the simulation, leveraging the earlier work.

Section 2 of this paper describes the complexities and risks inherent to launch and assembly of Mars missions. Section 3 provides a brief overview of Evolvable Mars Campaign (EMC) options. Section 4 describes the discrete event simulation model used to perform the quantitative analysis. Section 5 presents results for EMC options. Conclusions and forward work are addressed in Section 6.

2. COMPLEXITY AND RISKS OF LAUNCH AND ASSEMBLY

Most concepts for crewed missions to Mars require multiple launches to assemble one or more Mars transfer vehicles. Preparation of launch vehicles and flight hardware, launch operations, and in-space assembly of MTVs will be a complex endeavor, which will require significant time.

The integrated launch and assembly reliability methodology evaluates operations starting with flight hardware manufacturing and ending at the final departure of a Mars Transfer Vehicle (MTV) from the Earth assembly orbit. Pertinent risk factors are accounted for within a stochastic discrete event simulation for each integrated launch and assembly campaign.

There are several constraints that will directly impact the launch and assembly reliability. Foremost of these constraints is the limited duration of the window of opportunity for MTV departure from the Earth assembly orbit. Minimum energy departure opportunities to Mars are available from an assumed Earth-vicinity location for an assumed period of approximately 30 days every 26 months. The assumed duration is similar to other NASA Mars mission opportunities. NASA's Curiosity rover had a three-week launch opportunity. The Earth departure opportunity for NASA's next mission to Mars called InSight lasts 27 days from March 4 to March 30, 2016. The actual duration of the departure window may vary depending upon the delta velocity capacity of future MTVs and the launch opportunity. The assembly sequence will begin long before the opening of the departure window. However, if the MTV is not assembled and ready to depart in time to meet the window, the opportunity is missed. MTV elements stranded in Earth orbit would not likely be suitable for a Mars mission after an additional 26 month loiter. Consequently, that investment would be considered lost.

Constraints in addition to the limited departure opportunities include: the reliability of the launch vehicles, the reliability and on-orbit lifetime capacity of the elements being placed in Earth orbit (which, as previously stated, are not included in this iteration), and variability in the performance of the ground processing architecture and workforce in preparing launch vehicles and their respective payload elements.

The types of risks involved in the launch and assembly of the MTVs can be divided into two major categories: Pre-Launch Risks and Post-Launch Risks. Pre-Launch Risks are those that occur prior to ignition of the main engines of the launch vehicle for any launch that supports the mission. These risks involve all of the activities required to manufacture, deliver, assemble, and prepare each vehicle for launch. The analysis presented in this paper includes those risks. Post-Launch Risks are those that occur after the ignition of the main engines of the launch vehicle and involve all of the activities required to position and assemble elements, deliver the crew to the MTVs, and prepare for departure. Only the launch vehicle ascent reliability risk has been included in the current analysis. For more in-depth information on the risks, please refer to References [9] [10] [14].

During the period that Mars DRA 5.0 was developed, NASA was planning on a robust ground processing architecture that made use of multiple launch vehicle integration high bays in the Vehicle Assembly Building (VAB) at the KSC along with multiple mobile launchers and two launch pads. Since that time, NASA has scaled back the plans such that only a "single-string" capacity is being put in place. This means that there will only be one mobile launcher, one launch pad, and one launch vehicle integration high bay. This concept essentially precludes parallel processing of multiple launch vehicles, necessitating longer intervals between subsequent SLS launches.

Launch timeliness reliability is a significant issue for all Mars campaigns given the number of launch vehicles required and the constrained Earth departure window. DRA 5.0 acknowledged this fact by concluding that approximately 90-180 days of margin should be inserted in the launch campaign between the last launch of the campaign and the opening of the Earth departure window. However, given the new reality of a single-string ground processing architecture, the difficulty in launching a large number of vehicles in a timely manner is increased. Therefore, it is not clear that 90-180 days of margin will be adequate to ensure overall launch campaign reliability.

The constraints and risks described herein require that missions be designed in a way that the total achieved launch and assembly reliability will result in an acceptable probability of mission success. The reliability and the timing of launch and assembly events must be carefully evaluated in order to identify and mitigate those risks. Consequently, NASA will need the capability to measure and manage the probability of being able to launch and assemble the MTVs.

3. EVOLVABLE MARS CAMPAIGN CONCEPTS

The Evolvable Mars Campaign is looking at a number of different concepts for eventual and sustained human exploration of Mars [11]. One of these concepts is based upon the use of solar electric propulsion (SEP) to deliver cargo to the Mars system and chemical propulsion to deliver the crew. This concept is referred to as the 'Split' option [12], since crew and cargo each utilize different propulsion systems. A second concept, referred to as the 'Hybrid' option [13], utilizes a joint SEP and storable chemical propulsion stage to deliver both crew and cargo to Mars. The Hybrid option also allows for refueling and reuse of in-space propellant stages, reducing the need to launch new stages for subsequent crewed missions to Mars. These concepts and others are being continuously revised. Consequently, it is not the intent of this paper to present the entirety of NASA's Evolvable Mars Campaign efforts, but rather just to highlight how one particular tool is being used in support of the effort.

NASA developed notional launch manifests for each of the two options described above. That information is initially communicated in Power Point charts showing the planned launches by fiscal year and within Excel files showing the planned launch dates and dates for subsequent in-space activities including the Trans-Mars-Injection dates. Figure 1 depicts a notional EMC campaign manifest for the Split option. The years 2014 through approximately 2027 are referred to as the "Proving Ground" era by NASA and included a mixture of approved missions and those still in the planning phase.

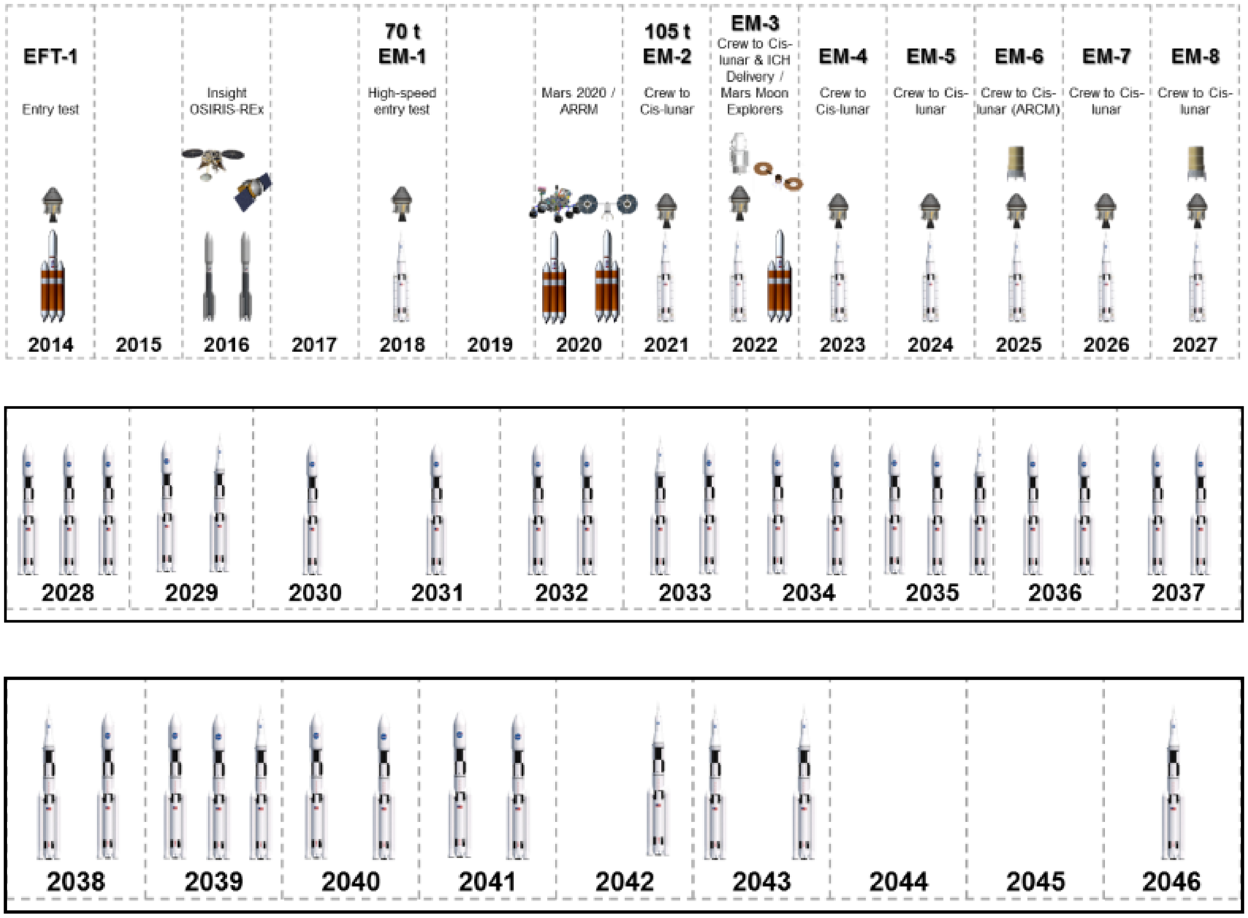


Figure 1: Notional EMC 'Split' Option Campaign Manifest

Embedded within this particular campaign manifest are three conceptual individual crewed Mars exploration missions that begin in earnest in approximately the 2028 timeframe. These include a mission to Phobos with a crew Trans-Mars-Injection (TMI) opportunity in 2033 and two missions to the surface of Mars with crew TMI opportunities in 2039 and 2043. Because launch periods for the three missions overlap and the missions will all be utilizing the same ground infrastructure at KSC, the launch reliability of the overall campaign must be evaluated as a whole, rather than simply evaluating independent missions. Of primary interest is estimating the likelihood of successfully launching all elements in time to support the discrete departure opportunities.

As part of the analysis process the provided launch manifest information was used to create Gantt charts for each of the three Mars exploration missions. Figure 2 shows a portion of the Gantt chart for launches beginning with the first launch after the Phobos 2033 opportunity and ending with launch of the crew for the Mars 2039 opportunity. Blue bars in the Gantt chart represent the planned launch to launch critical path timeline of 107 days for ground processing, based upon a 5 day per week, 3 shifts per day processing capability. White bars indicate available schedule margin or slack between launches. Note also that the Gantt chart includes the launch that will be used to send up an Orion to pick up the crew returning from the Phobos 2033 mission and launches being conducted in support of the Mars 2043 opportunity.

4. DESCRIPTION OF SIMULATION MODEL

A stochastic discrete event simulation model was created using Rockwell Automation's Arena simulation software [15]. Figure 3 provides a high level overview of the model, which includes linkages to Excel files for inputs and results. The model logic includes entity routing to reflect all of the major processes and operations in the launch and assembly sequence from manufacturing completion through readiness and performance of the Earth departure burn, as shown in Figure 4.

The simulation is run for 1,000 replications, with each replication representing one possible manifestation of the launch and assembly sequence. The only difference between the replications is the random number generation used to drive the various risk models.

Delay Risk Models—All elements for the Evolvable Mars Campaign manifest, including MTV elements, launch vehicles, and propulsive elements must be manufactured, tested, and delivered to their respective space centers. Delays in these activities would delay the launch and assembly schedule.

The risk of SLS manufacturing related delays was quantified using Space Shuttle historical data. Processing capabilities for the SLS at the KSC are limited by facilities and personnel constraints. These constraints dictate the planned launch schedule for elements. Delays in completing element processing and launch vehicle assembly could significantly impact the launch and assembly schedule. Delay risks through launch for the SLS launch vehicle have been previously described in detail [9] and were used again for this analysis. Likewise, the SLS launch countdown delay risk models used for this analysis are the same as previously described [14].

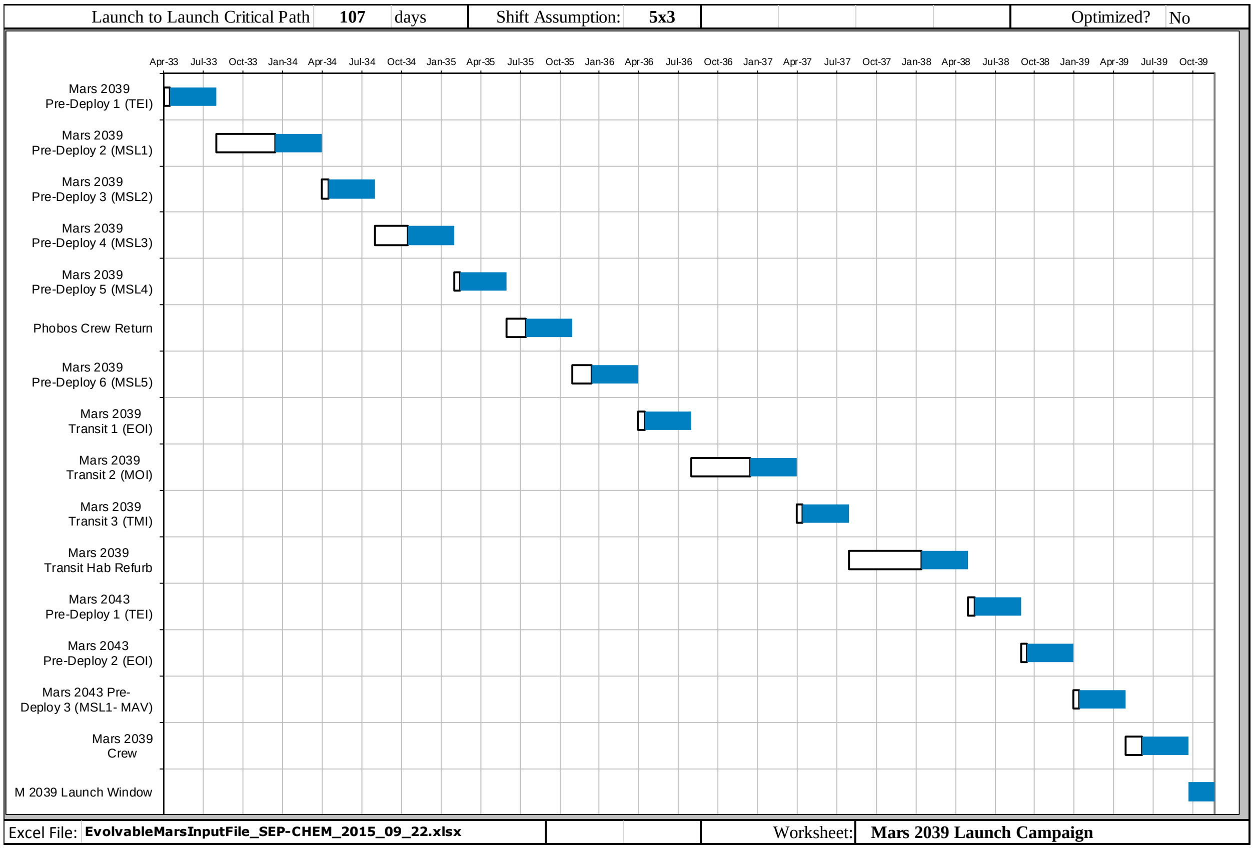
These projections are subject to a fair amount of uncertainty today and to change in the future, given that the SLS and payloads to be flown have not yet been developed, let alone established a launch history. For the time being they are believed to represent a reasonable estimate.

Ascent Loss of Mission Risk—The launch and ascent of a vehicle into LEO is typically one of the most risky phases in any space mission. Conducting multiple launches into low Earth orbit (LEO) to support the mission exposes the assembly campaign to this risk multiple times.

For this analysis, the assumption of each launch subject to a 2% chance of an ascent failure was utilized. This value assumes that the Space Shuttle derived SLS will be able to achieve a reliability level similar to that achieved by the Space Shuttle. The model allows alternative values to be used so that sensitivity analysis can be performed. It is potentially viable to mitigate the risk of ascent failures by having spare launch vehicles and spare payload elements available. However, there must also be sufficient time to account for the post-failure investigation and return-to-flight activities. These durations can range from many days to over a year. The model allows this duration to be varied so sensitivity analysis can be performed.

Running the Model

1,000 replications of the simulation are executed to obtain a large data set to analyze. Each replication begins with the launch of the Exploration Flight Test (EFT)-1 mission in 2014 and ends after all missions have been launched. After each replication, the model records results in an Excel output file, including the achieved launch dates for each mission and whether or not the TMI opportunities were achieved. In addition to writing the results to the output file, the deterministic inputs and assumptions that were used during the analysis are also recorded. All output graphics and analysis are then produced in Excel.



Launch to Launch Critical Path **107** days

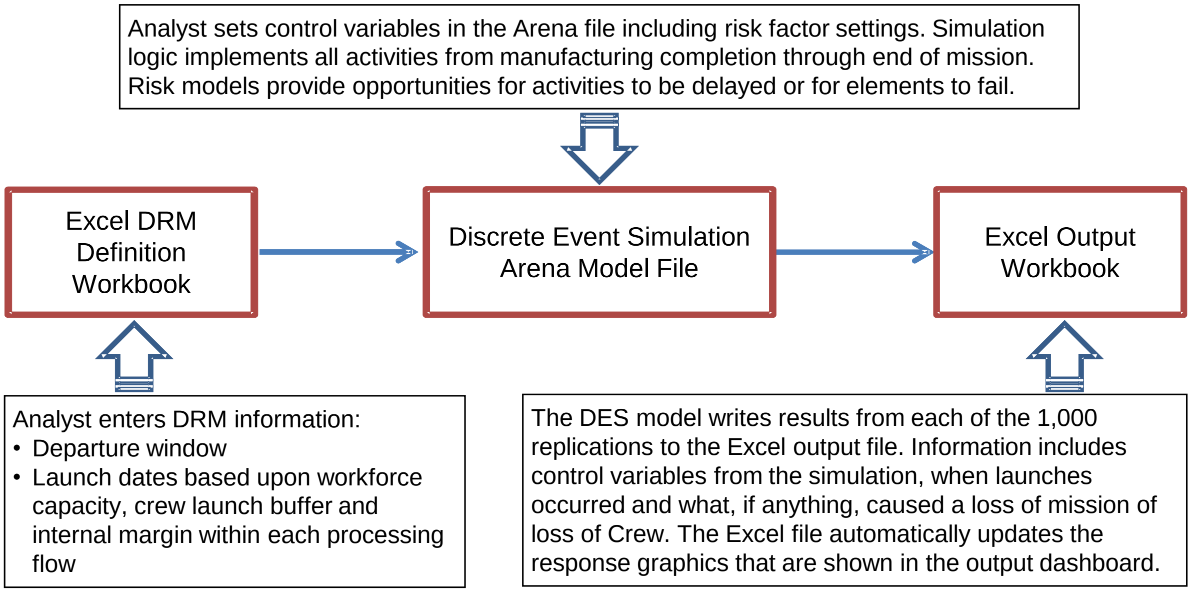
Shift Assumption: **5x3**

Optimized? No

Excel File: **EvolvableMarsInputFile_SEP-CHEM_2015_09_22.xlsx**

Worksheet: **Mars 2039 Launch Campaign**

Figure 2: Gantt Chart for Mars 2039



Analyst sets control variables in the Arena file including risk factor settings. Simulation logic implements all activities from manufacturing completion through end of mission. Risk models provide opportunities for activities to be delayed or for elements to fail.

Analyst enters DRM information:

- Departure window
- Launch dates based upon workforce capacity, crew launch buffer and internal margin within each processing flow

The DES model writes results from each of the 1,000 replications to the Excel output file. Information includes control variables from the simulation, when launches occurred and what, if anything, caused a loss of mission of loss of Crew. The Excel file automatically updates the response graphics that are shown in the output dashboard.

Figure 3: Model Overview

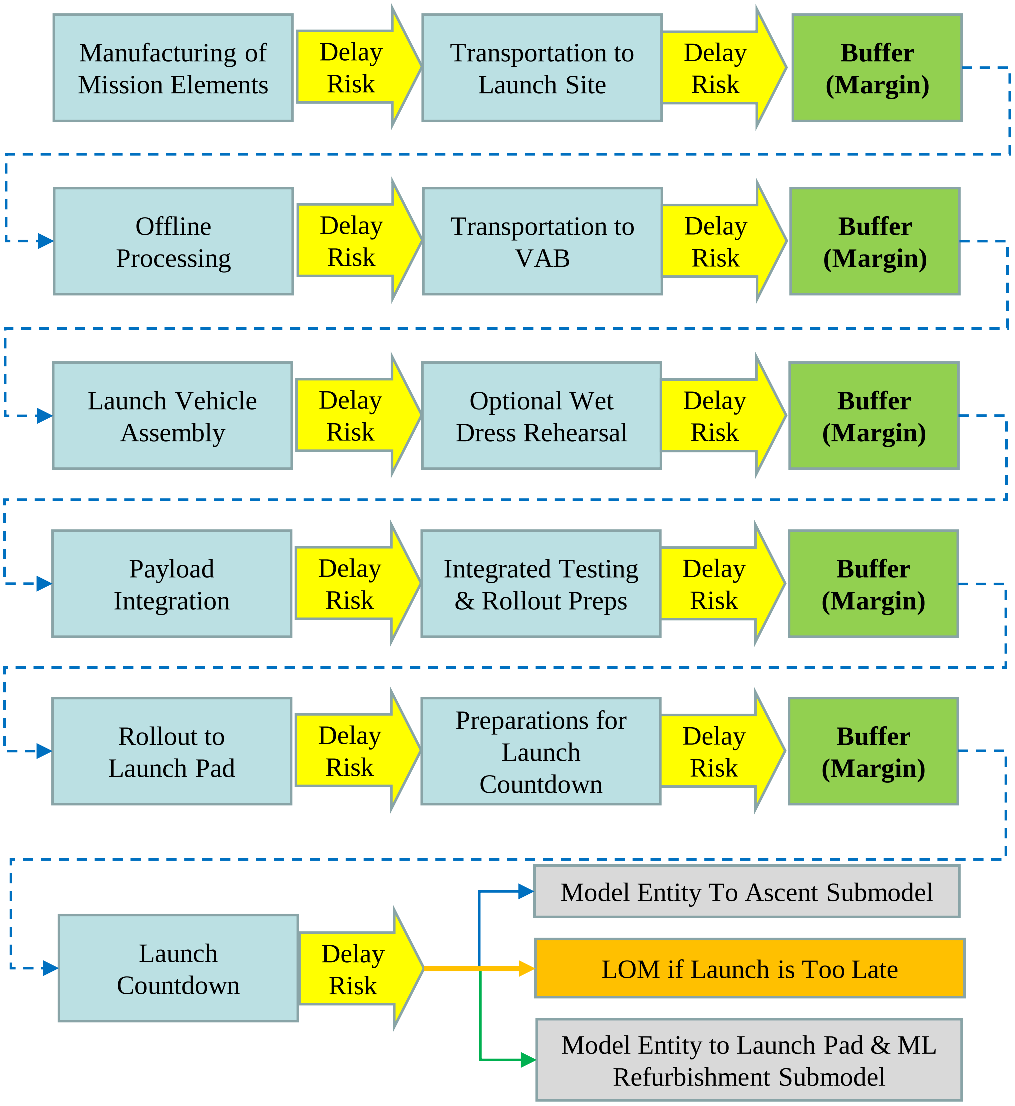


Figure 4: Flight Hardware Elements Entity Routing Within Model

5. QUANTITATIVE RESULTS

The simulation for the notional Split EMC manifest was completed, initially using a baseline set of assumptions and then simulating various what-if scenarios to see if the overall success probabilities for each of the three missions could be improved upon. The baseline set of assumptions included: (1) the launch schedule as originally given; (2) a constraint that the crew could not be launched any earlier than 30 days prior to when the TMI window closed; (3) the single string ground processing architecture; and (4) no spares (launch vehicles or spacecraft).

The results from the discrete event simulation for the baseline set of assumptions (Scenario A) and a limited exploration of the trade space (Scenarios B through G) are shown in Figure 5. The trade space included changing the launch schedule, allowing the crew to be launched earlier relative to the closing of the TMI window, adding ground processing infrastructure, and providing spares.

The Mars 2039 mission had a very low probability of successfully launching all elements to meet the departure window in the baseline Scenario A. The launch reliability for both the Phobos 2033 and Mars 2043 missions are approximately 0.65. However, the reliability for the Mars 2039 mission is only 0.07. The differential between missions is due to the greater number of launches required for the first surface mission and the fact that the 2039 mission overlaps significantly with both the previous and subsequent missions.

In Scenario B, the duration of the crew launch opportunity was increased to 60 days. This change, however, did not significantly improve the launch reliability. This result was due to the lack of schedule margin available in the overall launch campaign. The cascading delays from previous launches did not allow for significant improvement from increased margin on the final launch.

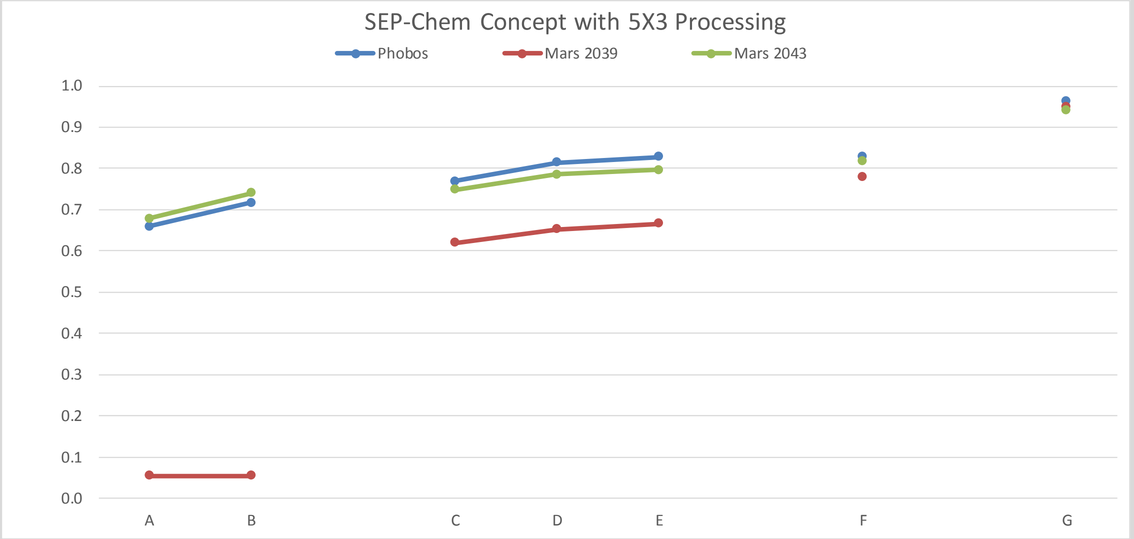
For Scenarios C, D, and E, the available margin was increased by “optimizing” the planned launch dates as shown in Figure 6. The optimization process included universally shifting planned launch dates earlier, adding more margin across the campaign, including the final launch. Note that the launch of the Phobos 2033 crew return mission is fixed based upon when the crew returns in 2035, so that launch could not be shifted. The optimization process was also performed for the Phobos 2033 and Mars 2043 launch campaigns.

Scenario C, which adds the optimized launch campaigns, provided significant improvement for Mars 2039 and modest improvement for both Phobos 2033 and Mars 2043. The added margin in the 2039 mission reduced the risk of cascading delays impacting the crew launch.

Scenarios D and E progressively increased the crew launch window by another 30 days in each case. This provided a modest increase in success probability with each step, though with a declining effectiveness with increased window length.

For the next case, Scenario F, a mobile launcher and an integration high bay were added to the available ground infrastructure. This change resulted in a fairly significant improvement to the Mars 2039 campaign, modest improvement to the Mars 2043 campaign, but essentially no improvement to the initial Phobos campaign. The additional ground infrastructure allowed the 107 days launch timeline to somewhat overlap for different launches since processing for the next mission could be done in parallel with the current mission. This effectively added additional margin to the launch campaign.

In Scenario G, the capability to launch a replacement mission was added with the optimistic assumption that the grounding duration after an accident would be minimal. This scenario significantly improved the results for all three missions, raising the success likelihood for all three missions to approximately 95 percent.



Scenario	A	B		C	D	E		F		G
Optimized	No	No		Yes	Yes	Yes		Yes		Yes
Spares	No	No		No	No	No		No		Yes
ML	1	1		1	1	1		2		2
HB	1	1		1	1	1		2		2
Crew Launch Window	30	60		60	90	120		120		120
Excel File:	**EvolvableMarsInputFile_SEP-CHEM_2015_09_22.xlsx**						Worksheet	**Sheet7**		

Figure 5: Quantitative Results and Trade Space

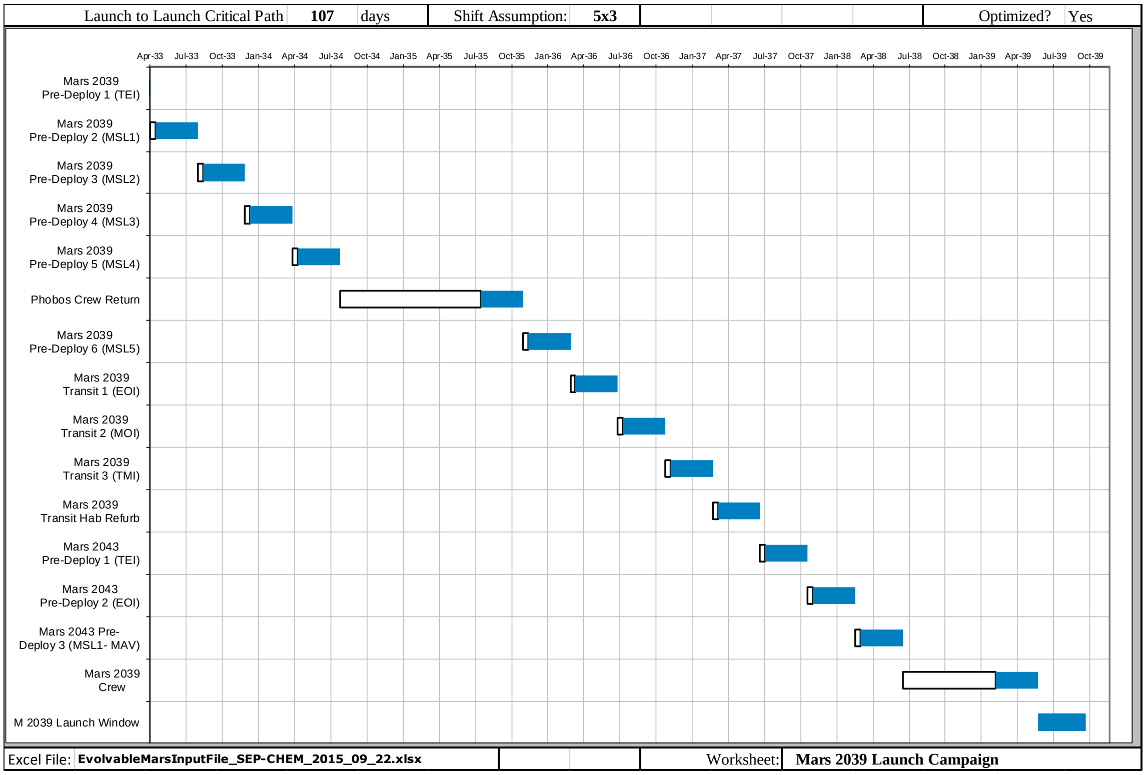


Figure 6: Optimized Mars 2033 Launch Campaign

6. ANIMATION FEATURE

The orchestration required for human exploration of Mars is difficult to portray adequately with Gantt charts or even more visually rich charts that have gotten the nick name of "Bat Charts."[1] Figure 7 is a Bat chart showing a conceptual Mars exploration mission from DRA 5.0. It is an invaluable resource and, when coupled with a dynamic presenter, explains how one goes about getting people to Mars.

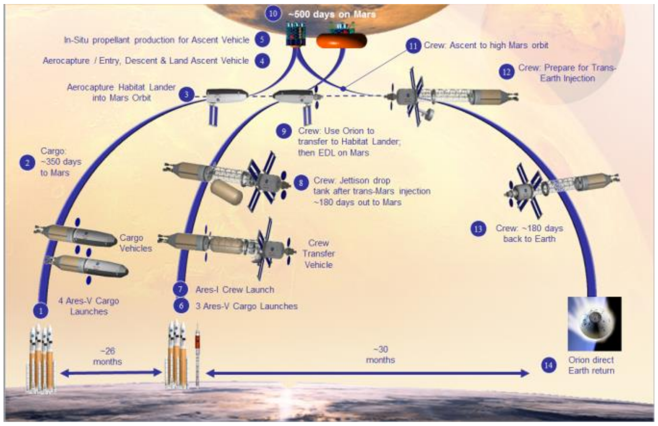


Figure 7. Mars DRA 5.0 – "Pre-deployed" & NTR [1]

Combining the information contained in the campaign manifest chart (Figure 1) along with the associated Gantt charts, a dynamic visualization or animation can be created that goes a step further in demonstrating time-based operations and the interaction between elements. The beauty of the animation is that it combines the type of information found in Gantt charts, manifest charts, and Bat charts, along with details provided by presenters, into a short video that can tell the whole story into and of itself. Displaying the video has more clearly conveyed the complexities involved with a human Mars campaign, evoking responses such as, "it looks like we are invading Mars!"

The animation feature added to the simulation provides additional benefit from a modeling perspective. Simulation animation is a valuable tool for model verification and validation. It allows viewers to see that entities are tracking through the correct routing in the model. When the model is run in a deterministic model viewers can determine if launches are being produced per the planned schedule.

The simulation tool used, Rockwell Automation's Arena, has an embedded animation feature for the entity routing through the model code. It also allows the user to create custom animations using imported icons and graphics that are more familiar to the non-modeling community. Creating these custom animations takes additional time and effort, but the resulting visual display can tell a compelling story in just a few minutes. Unfortunately, given the static nature of this paper, the animation is limited to a screen capture, shown in Figure 8.

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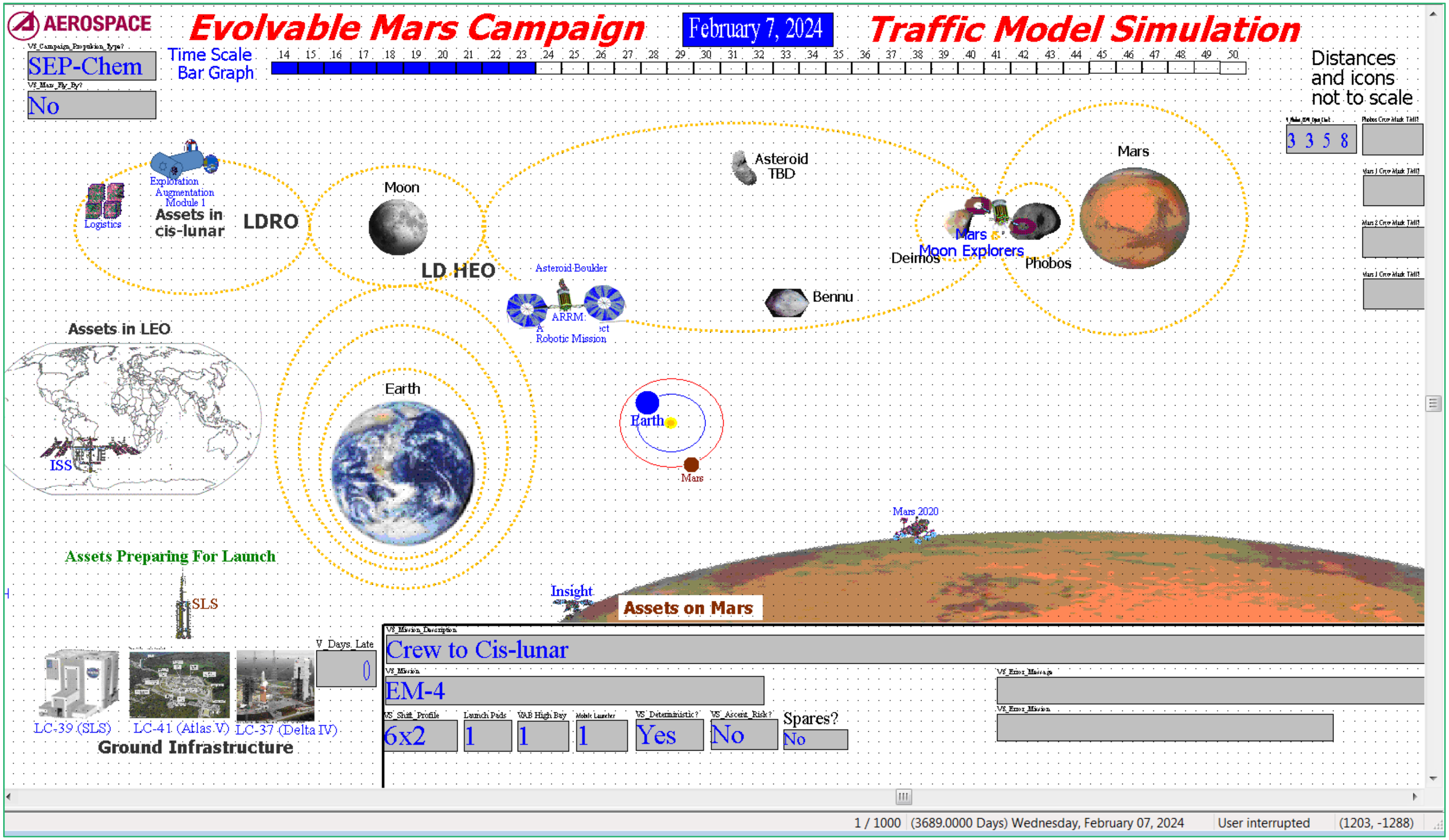
[1] Bat charts typically have the Earth on the bottom and the destination on top along with a lander hanging upside down like a sleeping bat.



VS_Campaign_Propulsion_Type? SEP-Chem

VS_Mars_Fly_By? No

V_Days_Late 0

VS_Mission_Description Crew to Cis-lunar

VS_Mission EM-4

VS_Shift_Profile 6x2

Launch Pads 1

VAB High Bay 1

Mobile Launcher 1

VS_Deterministic? Yes

VS_Ascent_Risk? No

Spares? No

VS_Error_Massage

VS_Error_Mission

1 / 1000 (3689.0000 Days) Wednesday, February 07, 2024 User interrupted (1203, -1288)

Figure 8: Animation Screen Shot

The screen shot from the animation shows that the captured date is February 27, 2024, as can be seen at the top or bottom right of the screen. The time scale bar graph provides a sense of the overall duration of the years being simulated. On this particular date, per the Evolvable Mars Campaign under study, the Asteroid Redirect Retrieval Mission (ARRM) will be on its way back from retrieving a boulder from Asteroid TBD (as labeled in Figure 8) and on its way to a lunar distant retrograde orbit (LDRO). At that LDRO is an Exploration Augmentation Module (pressurized volume to augment Orion, referred to as ICH in Figure 1) being supported by logistics and crew visit flights delivered by the SLS on an annual basis. There is also a satellite orbiting and exploring the moons of Mars, Phobos and Deimos. On the surface of Mars are the lander Insight and the rover Mars 2020. The International Space Station is in low Earth orbit. An SLS is being prepared for the next launch. The most recent launch was the EM-4 mission, which took a crew to cis-lunar i.e., LDRO.

When the animation is actively running, all of the launch vehicle and spacecraft icons move in accordance with the planned operational concept, subject to any delay risk. The yellow lines indicate the orbital paths that the spacecraft will follow. In the middle of the picture is a feature showing the Earth and Mars as they orbit the sun. These icons move in relation to one another consistent with how they do so in real life. This allows one to visually see when the planetary alignments are conducive to the Trans-Mars-Injection windows.

This particular screen shot shows in the information table at the bottom that it is running in the deterministic mode such that there are no delays or launch vehicle ascent failures. The table also indicates that the SLS ground processing assumptions reflect 6-day, 2-shift processing through 1 mobile launcher, 1 integration high bay, and 1 launch pad.

The speed of the animation can be adjusted with a slide bar, not shown, such that 40+ years of exploration can be shown in a few minutes or several hours. For an audience already familiar with the subject matter a few minutes is typically all that is needed to convey the information. If briefing people that are new to the subject, the model is run at a slower pace, with stops occasionally at key points, to explain what is going on and why.

7. CONCLUSIONS AND FORWARD WORK

The capability to perform integrated launch and assembly campaign reliability risk analysis and visualization using discrete event simulation for human exploration of space including Mars continues to evolve to meet the demands. As NASA and other stakeholders propose new strategies or mature existing ones, the models are able to keep pace in order to support analysis requirements. New features have been added to enhance the value of the tools.

The quantitative findings for launch campaigns supporting discrete Trans-Mars-Injection windows of limited duration are consistent with previous analyses [9] [10] [14]. The launch and assembly campaign reliability will likely be one of the top overall risk drivers. Keys to providing high launch and assembly campaign reliability include timely availability of launch vehicles and spacecraft, adequate margin in ground processing schedules, availability of ground processing infrastructure, the ability to launch the crew early relative to the closing of the TMI window, the availability of spare launch vehicles and spacecraft, and the wherewithal to return to flight quickly after a failure.

Forward work includes modeling additional risk factors that are in play relative to achieving TMI windows as well as the post TMI risks. The time and effort to produce the animation feature, which can be invaluable, needs be reduced. Developing additional animation features that drill down into key areas, such as launch processing or critical flight operations will be considered.

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[15] Rockwell Automation’s Arena: http://www.arenasimulation.com/

BIOGRAPHIES

Grant Cates *is a Senior Project Leader at The Aerospace Corporation since February 2014. Prior to that he was a Chief Scientist at SAIC. He retired from NASA in 2006 after 25 combined years in federal service, including 7 years on active duty in the Air Force. At NASA he served in varying capacities on the Space Shuttle Program, including Space Shuttle Columbia Vehicle Manager and Flow Director. He received a Ph.D. in Industrial Engineering from the University of Central Florida in 2004.*

Chel Stromgren *currently serves as the Chief Scientist of Binera, Inc. Risk Analytics Division. In this role, Mr. Stromgren leads the development of probability and risk-based strategic models and strategic analysis of complex system development. Mr. Stromgren has supported NASA in the analysis of Space Shuttle and International Space Station operations in the post-Columbia environment and has led the development of strategic campaign models for the lunar exploration initiatives. He holds a Bachelor of Science degree in Marine Engineering and Naval Architecture from the Webb Institute and a Master of Science degree in Systems Management from the Massachusetts Institute of Technology.*

Bryan Mattfeld *received bachelor's degrees both in Aerospace Engineering and Mathematics from Virginia Polytechnic and State University in Blacksburg, Virginia in 2013. He has 4 years experience in space systems engineering and risk analysis. His work includes the development and analysis of space systems and mission design models. He currently works for Binera, Inc. in Silver Spring, Maryland and is an AIAA member.*

William Cirillo *currently serves as a Senior Researcher at NASA Langley Research Center in Hampton, Virginia, where he has worked for the past 20 years in the area of Human Space Flight Systems Analysis. This has included studies of Space Shuttle, International Space Station, and Human Exploration beyond low Earth orbit. In 2005, Mr. Cirillo served at NASA Headquarters as a core member of the Exploration Systems Architecture Study (ESAS) team, where he was responsible for studying the use of Ares I/Orion in meeting future ISS crew and logistics transportation needs. Mr. Cirillo currently leads a team of analysts in assessing at a strategic and tactical level the manifesting of assembly and logistics flights human exploration beyond low Earth orbit.*

Kandyce Goodliff *is an aerospace engineer at NASA Langley Research Center in Hampton, VA, with the Space Mission Analysis Branch (SMAB). Her primary roles as a systems analyst for SMAB are conceptual design and sizing of human and robotic spacecraft, mission and spacecraft analysis, and campaign analysis for human exploration. She has a Bachelor of Science in Aerospace Engineering from Embry-Riddle Aeronautical University and a Master of Science in Mechanical Engineering from the George Washington University.*

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