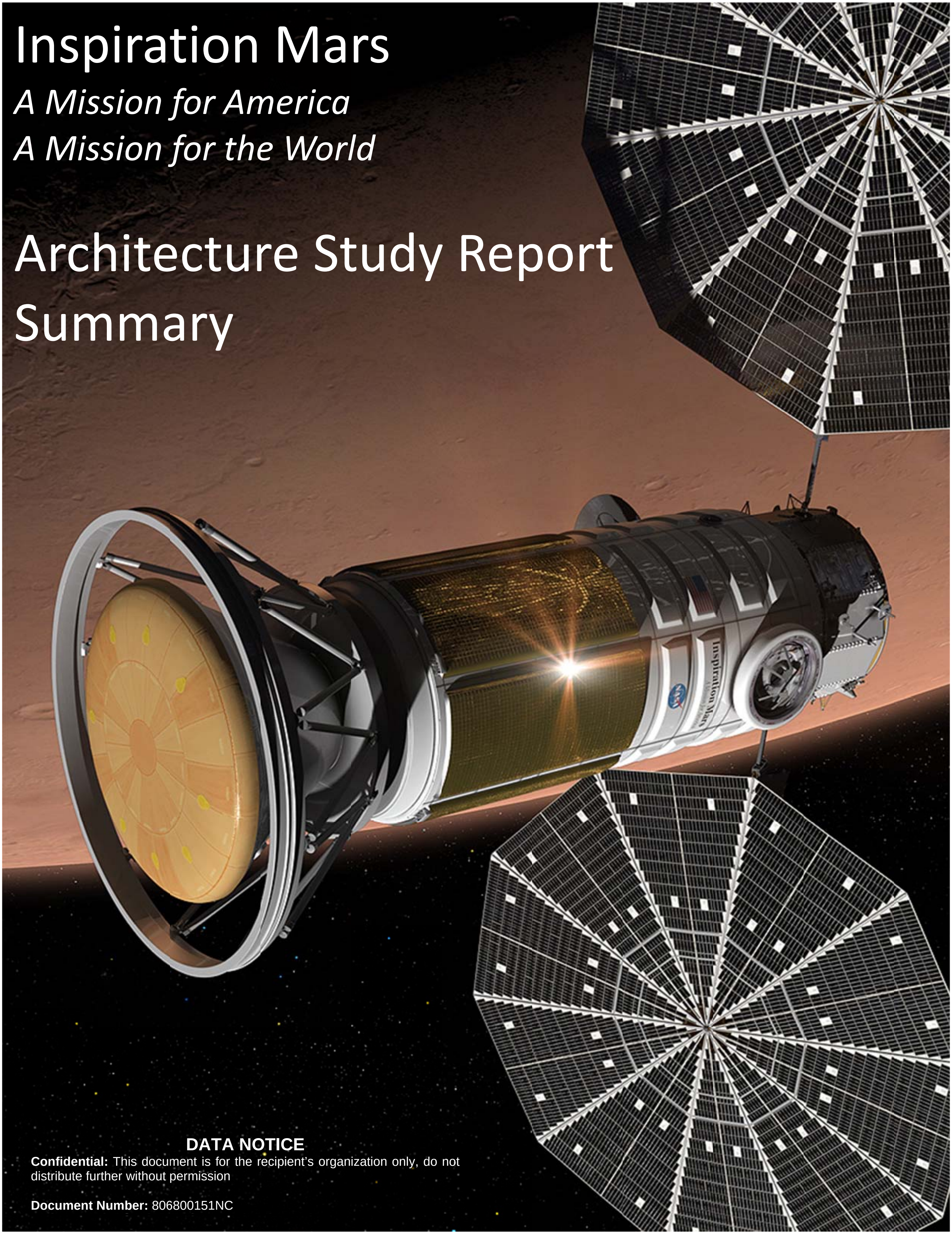
Inspiration Mars

A Mission for America
A Mission for the World

Architecture Study Report Summary



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1. EXECUTIVE SUMMARY

In the summer of 2013, word came from NASA that Voyager 1, a spacecraft in flight since 1977 and nearly forgotten by the world, had passed the outermost limits of the solar system, a threshold on its journey into the infinite. More than three decades after Voyager's flyby of Jupiter and Saturn, this work of human hands is 11.6 billion miles from Earth, and adding 38,000 miles to that distance every hour. The craft is now free of the Sun's realm and on to other stars, carrying into the darkness a camera, a 23-watt transmitter, and a plaque bearing our planet's cosmic address and the image of a man and a woman.

Voyager's crossing was accomplished in our time because it was envisioned in another – and not only envisioned, but approved, designed, built, tested, and sent on its way. This is the manner of all progress in space exploration, carried forward with the audacity of rocket science and the patience of cathedral building. And that latest signal from Voyager leaves us to ask what feats of skill and daring will one day be traced to the beginnings we have made. What great things have we, in our time, set in motion? What leaps have we made for mankind in the 41 years since the last footprint was left in lunar dust? And what of human space travel? Are we content to send forth only the etched likeness of men and women, but not men and women, to see and experience what lies beyond?

With this report, we at the Inspiration Mars Foundation, a private, philanthropic enterprise, offer our best answer to these questions. We submit for the consideration of the American people, the President, Congress, and NASA a new mission. We propose to send a spacecraft bearing two astronauts, a man and woman, to the far side of Mars and return them to Earth, a voyage of 314 million miles in 501 days, in collaboration with NASA, in the name of America, and for the good of humanity.

This first manned mission beyond the Moon, detailed in the pages that follow, would begin in early January of 2018 and end in the spring of 2019. The objective is to place the crew within a hundred miles of Mars. In August of 2018, on the 226th day of flight, the astronauts will enter the gravitational sphere of another world. This will be a momentous achievement in human experience, and also preparation for a landing one day on the second most habitable planet in our solar system.

Expected for decades, envisioned by presidents, and imagined for centuries even before the age of space travel, a landing on the Red Planet is within America's reach. The flyby of 2018 will bring that day closer. It will show what can be done, test what must be tested, measure what must be endured, and reveal what must be known before more manned spacecraft can launch from Cape Canaveral into the cosmic depths – to asteroids and to the Martian moon Phobos, as under current directives, and onward to the surface of Mars itself.

To wait more decades for a Mars flyby is to forfeit an opportunity that will not wait on American initiative. Other nations have designs and aspirations to make this achievement their own. For America, this is our last chance to be first, and even the very movement of planets seems to be saying *"Go"*: The flight to Mars would have to begin between Christmas Day 2017 and January 5, 2018, for a simple reason – speed. A planet's orbital speed around the Sun changes, accelerating as it comes close to the Sun and slowing down as it moves away. This planetary alignment is so rare because it requires Earth to be moving at its maximum speed when the spacecraft departs, essentially giving it a boost, and likewise for Mars to be as close to the Sun as possible when the spacecraft flies by. Alignments like this occur just once every 15 years, and some are better than others. The next one happens to be the best that this century will offer.

The trajectory we have plotted will require propulsion only to leave Earth and get on course to Mars. The rest of the journey will be propelled by, in turn, the gravitational forces of Mars, the Sun, and Earth. This free-return trajectory is possible only rarely, and the chance will not come again until 2033. The Inspiration Mars spacecraft has to be on its way to Mars in the first days of 2018, if this mission is to happen at all. And if it does not happen, then where does that leave human space exploration by the United States?

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In recent years, the most notable movements of American spacecraft have been powered by trucks and barges in the direction of museums, as if all we can afford and aspire to is a careful preservation of past glories. And for all the considerable feats of NASA in 130 flights by five shuttle orbiters, far-flung robotic missions, cosmic imaging with the Hubble Space Telescope, and an International Space Station now in its second decade of service, we are left with this fact: Since Apollo 17, no human has ventured more than 386 miles from Earth – a distance from Cape Canaveral, if traveled by car, that would not reach Pensacola.

The 18,000 men and women who work at NASA accomplish many things that go unheralded in the press, advances followed and appreciated mostly by academics and space enthusiasts. Each one of these endeavors shows the genius of NASA, its capacity and desire to extend the frontiers of human exploration. There are other spacefaring nations, but there is no other NASA. It has many counterparts, but no equal. Among the agency’s partners in the aerospace industry and in American universities, we can see as well a mastery of space science still without rival in any country.

All of these strengths are never more impressive and inspiring than when they are directed toward a great American objective in space. In the space program’s defining moments, the various attainments and capacities take on a cumulative force, bringing unity and clarity to all that NASA is doing. Needed in our time is a grand and worthy goal, enlisting all in common effort, marked in bold on every calendar, winning back the world’s attention. The Mars mission of 2018-2019 is the kind of hard, daring, and high-yield quest for which NASA was made.

It would complement many other projects of NASA today – in aeronautics, exploration, science, and space technology. No project would be supplanted or interrupted. Indeed, even the spacecraft and crew lift would take place on launches currently scheduled. Far from hindering any undertaking at the agency, the mission will leverage much of this work, give it new focus, reward years of effort, and put to use all that we have learned.

A prime example of assets and knowhow to be leveraged is Orion, the modern successor to the Apollo Command Module. NASA’s progress on Orion, critical to any further American exploration of space, can only be accelerated by directing it toward a Mars flyby, a project that would instantly become the agency’s marquee mission. The Asteroid Initiative announced in 2010 by President Obama will likewise gain the momentum and public attention that it deserves if it is preceded by a dramatic, high-profile success – especially by one that will help to enable human flight to asteroids. To make more progress on every front, NASA must first make more history, and what better chance than a manned flyby of Mars?

The Inspiration Mars Foundation, as a nonprofit founded to organize the effort and provide a large share of the funding, seeks to broaden a partnership with NASA that we have already begun. At NASA centers including Johnson, Kennedy, Stennis, Langley, Ames, the Jet Propulsion Laboratory, the NASA Engineering and Safety Center and elsewhere, we have consulted closely on such challenges as thermal protection and the ultimate design of the crew capsule. With this venture, we ask Congress and the President to grant an American mission to Mars a place within a launch schedule already set, using rockets and systems already in testing, to meet an objective already set forth.

At the President's direction, current NASA plans aim for a manned mission to circle Mars sometime in the 2030's. The flight we propose will seize an opportunity to conduct the logical precursor mission in the next five years. The first step in a mission to Mars, after all, is to conquer the distance there and back, and a flyby mission will accomplish this. By putting a sprint mission to Mars in the here and now, Congress and the President can prepare the way for the manned orbital mission on NASA's agenda. The first flight to Mars can be an achievement of *this* decade. And by that leadership, the United States can fill the next decade with new attainments that might surprise even the space scientists of today.

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No impediment of engineering or astrophysics compels a delay of 15 years or more in this first human encounter with Mars. And such technical challenges as remain are far likelier to be met in the pressure and creative drive that a target date will inspire. Long, open-ended timetables are not always an ally of great endeavor. Sometimes, before the final hurdles are overcome, and the final problems solved, it takes a decision and a date certain, backed by Congress and the executive. It will not be any easier, or any cheaper, to do in 20 years what can be done in five.

By doing it now, moreover, we expand the range of what can be achieved and learned in the 2020's and 2030's. We will be able to combine the capabilities demonstrated on this mission with those of the coming asteroid missions, in ways that multiply the scientific gains. Robotic missions, for example, could in the 2020's collect large and varied samples of Martian soil and transfer them to Phobos. When the mission sequence turns to Phobos, most likely in 2033 when the next favorable trajectory occurs, that manned journey would be able to retrieve the samples. The soil would give us answers to some basic questions about life in our Solar System – and, with that, one of the monumental benefits of a Mars landing before that landing even takes place.

More than any new federal funding for this mission – some might be needed, but not much – what NASA would require to carry out its part of the work is the freedom to direct existing funds to the enterprise. This is a freedom that Congress can grant and the President can assure, as John F. Kennedy did to clear the bureaucratic path for Apollo. The Inspiration Mars Foundation, for our part, has begun funding development work rallying industry and academia to the cause. The foundation will bring as many resources to bear as private financing can yield, leveraging to maximum effect our government's commitment to this mission.

At a time when many purely commercial space ventures are already well underway, the partnership we propose will keep the United States government as the unquestioned leader in space, even as private support helps to ease stresses on our federal budget. Cooperation of this kind might even show the way for a new model of joint effort and funding, allowing NASA to do what it does best aided by private wealth, the imagination of its scientists and engineers unconstrained by hard lines in a budget.

Perhaps several hundred million dollars in new federal spending can make this mission happen. And that sum is best viewed in this context: The public and private expense of shipping off America's shuttle fleet to museums can be counted in the hundreds of millions of dollars. Moving just the Endeavor from a hangar in Florida to a pedestal in Southern California cost in the range of $40 million. At an additional expense comparable to what we have collectively spent to retire our old spacecraft, America can send a new spacecraft on a single flight that will log close to the miles of all the shuttle missions added together.

For the most part, a Mars flyby would use hardware and systems already developed, proven, and paid for. Going to Mars is a chance for our country to finally claim a clear and compelling return on decades of investment. This mission would gather up the hard-gained knowledge and technical skill of two generations in space science and channel it to great purposes. The history of aviation and space travel has always turned on *firsts*, those breakthrough moments that redefine the possible. Our American astronauts, when they have returned from the realm of another planet, will be witnesses to what this country can do, and where we can go, when we have determined to do so.

So many of the necessary technologies are ready, or almost ready, for that breakthrough moment. NASA in recent years has been perfecting a heavy-lift Space Launch System, more powerful than anything that ever carried an Apollo module. With its intended Dual Use Upper Stage, an SLS vehicle – already scheduled for a late-2017 launch – is all that is needed to carry a Mars-mission payload. With their design of Orion spacecraft, NASA engineers have been thinking hard about the challenges of safe reentry into the Earth's atmosphere at ever-high speeds. The technologies at work there can help with the architecture, heat shield, and trajectory design of a manned vehicle returning from Mars at a rate of nearly nine miles per second. The agency also has the systems and materials nearly in place to support life in a small cabin on a long mission, and we at Inspiration Mars have and are developing innovations of our own to contribute. In partnership with NASA, we can apply all of this knowledge to the longest journey ever made.

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This report describes, in every detail, a mission involving all of the complexity one would expect. As our NASA partners will attest, however, we have worked with them (providing funds through Reimbursable Space Act Agreements) to achieve as spare a primary architecture as possible, relying in nearly every case on technology that America already has, and on things that our space scientists and engineers either know how to do already, or else are now striving to master. Daring greatly is not the same as risking greatly, and at every stage, starting with launch, we have drawn upon the known and familiar – assets in current use or in planning to carry out an established mission sequence.

The SLS, as currently designed, carries either crew in the Orion capsule or an unmanned payload such as a spacecraft. The safety inherent in separating crew and cargo is a fundamental tenet of the architecture. So the plan calls for two launches. In the days before crew departure, an SLS rocket would launch from the Kennedy Space Center, placing into low Earth orbit the full spacecraft for the flyby mission. That payload will consist of four parts: an SLS upper-stage rocket that will propel the spacecraft from Earth's orbit to Mars; a service module containing electrical power, propulsion, and communication systems; a Cygnus-derived habitat module where the astronauts will live for 501 days; and, for the last hours of the mission, an Earth

Reentry Pod. This pod is derived from the work to date on Orion, but will greatly increase the entry speed for this new vehicle to be known as Orion Pathfinder.

In the second launch, a commercial transportation vehicle (to be selected from among competing designs) and crew will carry the astronauts into orbit for rendezvous with the IM Vehicle Stack. The two craft will meet using docking procedures and systems that have been perfected in 136 spaceflights, by 209 astronauts, to the International Space Station. After the crew transfer and detachment of the commercial vehicle, the SLS upper-stage will ignite a Trans-Mars Injection burn to escape Earth's orbit and begin the journey.

Thirteen years' continuous operation of the Space Station has also taught us a great deal about human survival under the pressures of prolonged space travel. On a Mars-bound flight, shielding our astronauts from exposure to cosmic rays and solar particle events is only part of the challenge. There are also the imperatives of basic life support for more than a year and a half; of creating room for backup systems in case any primary units should fail; and of countering the sheer stresses to body and mind for two people alone in a small compartment who, at their highest altitude from Earth, will be looking homeward from a distance of 89,599,814 miles.

Ultimately, success will come down to a combination of the right craft and the right people. Applying the best ideas of both the Space Station and of the new Cygnus multi-purpose vehicle – a spacecraft just launched this September on its maiden flight to service the Station – the Inspiration Mars team is at this moment designing a full, Cygnus-based habitat module to be tested on the Station. With a view to maximum utility at minimum mass, keeping things as simple as possible, the crew's habitat will have 600 cubic feet of living space. The cabin and service module will include such features as advanced shielding against radiation during solar particle events, personalized medical technologies for each astronaut, and proven systems to manage air, water, and all else that is necessary for life on board.

All of this presupposes, of course, a man and a woman capable of persevering in circumstances that will be difficult, sustained, and inalterable. If any organization knows the qualities to look for – courage, fortitude, and inner discipline, just to start with – it is NASA. And with NASA's aid, we are confident that we can find and prepare a married couple for the millions of miles they will traverse together.

Assuming a Trans-Mars Injection burn on January 5, 2018, the craft's nearest approach to the Red Planet will occur on August 20 of that year. At that moment, the crew will be closer to Mars than the Space Station is to Earth. As they pass by the planet, on the dark side, Mars will pass by them, catching the spacecraft with its gravitational pull. This will slow the craft relative to the Sun and reorient it toward Earth. Some 30 hours after the crew's closest encounter with Mars, the planet's gravitational influence will give way to the force of the Sun, effecting what astrophysics terms a hyperbolic trajectory, and averting the need for an all-or-nothing propulsion burn to direct the craft homeward. From then on, the celestial mechanics will govern, and indeed the plan employs the same "slingshot" force that propelled Apollo 13 back to Earth after it lost power.

The 274-day journey home will, at one point, carry the astronauts through the solar orbit path of Venus. They will thus become the closest humans ever to the Sun, having already been the farthest humans ever from the Sun. Able at any point to make corrective maneuvers, they will approach Earth's atmosphere on May 21, 2019, for reentry and splashdown. And, of course, these last moments of the 501-day mission will require some of the hardest and most intricate feats of engineering.

The craft, just before reentry, will still consist of the crew cabin, the service module, and the Orion Pathfinder Earth Reentry Pod. On final approach, the crew will transfer into the Pod, which will then separate from the jettisoned modules and take our astronauts the rest of the way. They will return at a velocity never before attempted, an unavoidable challenge for reentry in the mission. *Any* deep-space mission, undertaken by any country, will have to overcome the final technical problems entailed in high-speed reentry. The first nation into deep space will be the first to master safe reentry at unprecedented speed.

As we know from the success of Curiosity, which landed on Mars despite tremendous heat and velocity by use of similar thermal-protection technologies, NASA is very close to engineering a capsule capable of withstanding all the stresses of a high-speed return to Earth. We have the heat-shield technology. We have, in Orion, the basis for a reentry craft that can in every other crucial respect soon be mission-ready. Eventually, these existing assets and capabilities will have to be integrated anyway to meet NASA's current presidential mandates for deep space. The concentrated creative energy of a Mars mission will complete it in a matter of a few years.

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Picturing that day when two of our own have just splashed down in the South Pacific – two who have seen Earthrise from our planetary neighbor – we might consider as well the creative energies awakened in the lives of young Americans. Perhaps more than to anyone else in a watching world, this mission will speak to them – about their country's potential, and also their own. In the years after Apollo, twice as many high-school students pursued the sciences than before, and twice as many earned science and engineering degrees in college and graduate school. We can hardly calculate all of the good that followed from that single national objective declared and reached. As President Obama observed at NASA in 2010, Apollo "inspired a generation of scientists and innovators. . . . It's contributed to immeasurable technological advances that have improved our health and well-being, from satellite navigation to water purification, from aerospace manufacturing to medical imaging. . . . And leading the world to space helped America achieve new heights of prosperity here on Earth, while demonstrating the power of a free and open society to harness the ingenuity of its people."

All of this can happen again, yielding new discoveries beyond anything we can predict – decades of technological dividends from a new national endeavor in space. No lesson plan, or aggregate goal of educational attainment, can call forth talent and enthusiasm in the life of a child like the sight of thrilling enterprises they want to understand and be a part of. How do we encourage more boys and girls to study the sciences? Show them what science can do. How do we multiply the ranks of engineers, physicists, mathematicians, and doctors in less than a generation? Show American children all that these disciplines are capable of doing – and doing for peaceful and worthy ends, with the mix of daring and humility that guides human pursuits at their best.

There is no rival power, at least right now, for America to catch up with in any space race. Whatever other governments might seek with their own space technology, there is nothing in the heavens that the United States aspires to seize or dominate. American space exploration has never proceeded at the level of pure self-interest, national vanity, or cheap propaganda, which is surely one reason why no one has done it better. We do it well because we do it for the right purposes. When one of our own first descended that ladder, it was the achievement of a nation but a leap for all mankind, and felt as such by every soul who shared in the moment. The desire to peer beyond our appointed place in the vastness of Creation is in us all, and the greatest journeys are made on behalf of all.

It is true that from far enough away, where the Sun becomes just another star, our galaxy a faint scattering of light, and finally even all of that vanishes into an eternity of thousands of light years – each a distance of 5.87 trillion miles – the flyby of Mars can seem insignificant, a jump from one speck to another. A fair measure, however, looks not at endless space but at finite man and where we began. To say of Mars one day – and of other points beyond in moments that none of us will see – "*We were there,*" is to say much more than that in the story of the cave-dweller who became the spacefarer in an instant of geologic time. As in the journey to a satellite of our planet just 240,000 miles away, an encounter with another planet, and one day a landing there, is not nothing for creatures formed of the dust of this Earth.

Though such missions are not undertaken with a view to sheer drama, it is worth imagining how the flyby might unfold, those 60 hours in the proximity of Mars that justify the 501 days, and how it might feel to the explorers and to us. It is said that in all of science there is no finer instrument than a person with eyes to see, present to tell in words what telescopes, pictures, and robots cannot convey. Looking out through the window of their capsule, this woman and man will see another world, and across the void that little light in the darkness with a touch of blue. And all of humanity can see it with them, in the moment, hearing the voices of two people upon the face of the deep, transmitted back in the universal language of awe. When Apollo 8 made its initial pass by the Moon on the night of December 24, 1968, that was the most widely seen event ever on television. A year of violence and sorrow ended with the shared experience of a lunar sunrise, and three astronauts reading the opening verses of Genesis, Chapter One. Such moments do not fade quickly from memory, and perhaps the much greater distance from Mars to Earth will give new power to the lesson. How small so many human strifes and hatreds can seem, how ungrateful the desire to destroy, when we see from afar from this refuge we share.

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All of this can come about within the next six years, a little less than the time between a ringing presidential vow of a Moon landing and the event itself in the summer of 1969. By chance, the completion of a Mars mission would occur just before the 50th anniversary of Apollo 11. And if America takes on this challenge, and all of the opportunities that come with it, we can then greet the Apollo anniversary with more than nostalgia. Commemorations, apart from giving past attainments their due, are also moments of accounting, and sometimes can carry a hint of rebuke. We will have to ask in July of 2019 how we have used the time, where we have journeyed since, what followed in what President Kennedy called "the greatest adventure on which man has ever embarked."

One of two answers will be open to us. We can reply that in this half-century human space flight never went farther than where the Eagle landed; that we had plans and ideas to make longer missions, but we never did and we never tried. Or, just weeks before the anniversary of America's arrival at Tranquility Base, we will be able to answer that two of our countrymen have just traveled the distance of Mars and back – and that they were the first.

For all of these reasons, and for its own sake, the 2018 Inspiration Mars mission is worth doing. We submit this report with unreserved faith in the men and women of NASA, with a single-minded commitment to surmounting every obstacle, and with complete confidence that this mission can be done.

2. TECHNICAL SUMMARY

2.1 GOALS AND REQUIREMENTS

As stated above, the Inspiration Mars project aims to execute a human flyby mission to Mars in late 2017. In pursuing the mission described in this Study Report, the Inspiration Mars Foundation started by establishing a set of top level goals for the project:

- **Demonstrate the feasibility of human missions to Mars**
- **Foster knowledge, experience and momentum for space exploration**
- **Address technical risks in human deep space exploration**
- **Conduct research on the human physiology of deep space travel**
- **Inspire a sea-change in the American Space Program**
- **Cement the U.S. position as the world leader in space exploration**
- **Inspire youth through science, technology, engineering and math (STEM) education and motivation**
- **Enable in-depth public participation**

From the Inspiration Mars goals, four top level requirements emerged that became principal drivers of the mission architecture:

- **Implement the earliest practical Inspiration Mars fast free return trajectory**
- **Two crew members, one man and one woman**
- **Return the crew safely to Earth**
- **An American lead mission principally employing US intellectual property, manufacturing capability and facilities.**

2.2 TRAJECTORY AND LAUNCH WINDOW

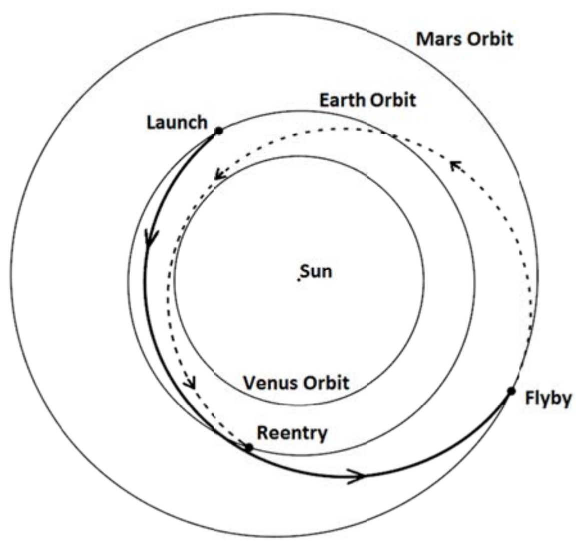

Figure 2-1. Inspiration Mars Trajectory

The goal of the Inspiration Mars project is to send two humans in a specially designed spacecraft on a deep space mission that would fly by Mars and return to Earth. To properly represent humanity and inspire the youth of both genders equally, the two person crew will consist of a man and woman, with the best team being a couple with a longstanding bond.

This mission utilizes what is known as a “fast, free return trajectory.” This particular trajectory, shown in Figure 2-1, occurs only once every 15 years with the next opportunity arising in late 2017. The total travel time is 501 days during which the crew will become the first people to leave the Earth-Moon system, to travel furthest from the Sun and to travel closest to the Sun. While this is still a long time compared to our spaceflight experience to date, it is quite fast compared to standard Mars mission concepts with durations of two to three years. The faster mission and small crew size reduces the amount of food, water and living space that will be required, allowing for the use of a smaller spaceship. The faster mission also reduces the radiation exposure to the crew. The smaller spaceship means that the rockets needed to carry out this mission are within the realm of today's technology. The two person crew requires a relatively small re-entry capsule, which can be made using state-of-the-art technology.

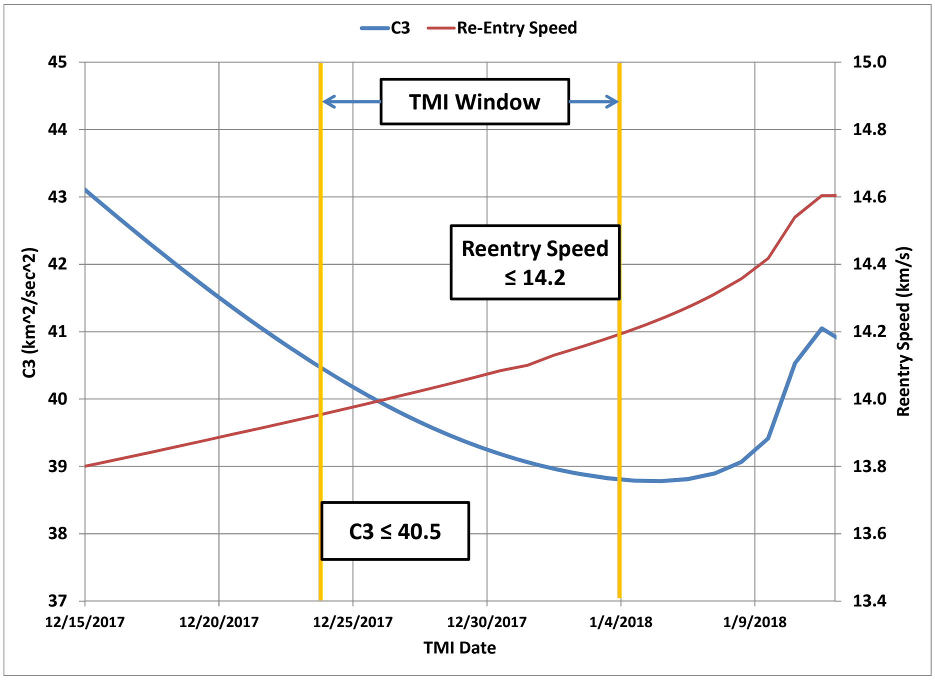

Figure 2-2. Constraints on Mission TMI Burn Date.

As shown in Figure 2-2, there is a fixed and finite window of time in which to execute the trans-Mars injection (TMI) burn for the Inspiration Mars trajectory. Due to the available rocket capabilities, the TMI window opens when the "C3" drops below 40.5 km^2/s^2 (C3 represents the minimum energy requirement to accomplish the mission for a given payload mass). Due to the limitations of the current heat shield materials, the window closes when the expected Earth re-entry speed at the end of the mission exceeds 14.2 km/second. This results in a TMI window from December 24, 2017, to January 4, 2018. Another similar opportunity does not arise for 15 years. The short time period between today and the launch window is both an opportunity to show the world what America can do as well as a challenging constraint that touches every aspect of the mission.

2.3 INSPIRATION MARS MISSION ARCHITECTURE AND SPACECRAFT DEFINITION STUDY

The Inspiration Mars Foundation commissioned a 60 Day Study to evaluate potential mission approaches and spacecraft design concepts that could be used to perform the mission. The challenges included launching the crew and all of the required spacecraft hardware into orbit and headed towards Mars, keeping the crew alive and healthy for the entire 501 day mission, and returning the crew safely from space to the surface of the Earth.

For the launch segment, the study looked at virtually every US launch vehicle available or in development, including the SLS and commercial launch vehicles. Operational scenarios included single and multiple launches, on-orbit rendezvous, docking and refueling, development of higher performing upper stages, as well as three and four stage launch vehicles.

In order to keep the crew alive and healthy, the study team considered the Orion spacecraft, Commercial Crew options, rigid cargo vessels and inflatable modules as options for living space. An environmental control and life support system (ECLSS) design concept was developed to identify the amount of water and food that would be needed as well as technologies to maintain a breathable atmosphere inside the living space.

The IM spacecraft will reenter the Earth's atmosphere at speeds up to 14.2 km/sec, much higher than any other manmade object. To safely carry out this critical phase of the mission we considered various options such as the Orion crew module, different commercial crew vehicles, a refurbished Apollo capsule and a new design optimized for the IM mission.

Two teams were established to work options leading to the best solution. The Primary Architecture Team was tasked with evaluating the potential to use the SLS rocket and Orion spacecraft to carry out the entire mission. A Backup Architecture Design Team looked at using existing and planned rockets, spacecraft and re-entry vehicles. Both teams leveraged the knowledge and experience of various NASA centers and organizations through the use of Reimbursable Space Act Agreements (RSAA) as well as resources from a wide range of industry partners.

The use of SLS and Orion was attractive for many reasons. First, these vehicles are part of the NASA Program of Record and are already progressing on their established development schedules. Second the Orion crew module could serve as both a reentry vehicle and the primary habitable living space (the use of an inflatable module for additional volume was also required). Lastly, the SLS-Orion offered the possibility that the entire mission could be done with a single launch which greatly reduced the overall mission complexity.

Unfortunately, the Primary team's evaluation of the SLS-Orion option uncovered many technical challenges. First, while the Orion spacecraft is being designed to perform a wide variety of mission scenarios, many aspects of the IM mission fall outside of that design envelope. One of these critical areas was the reentry speed. Orion's missions only require reentry into the Earth's atmosphere at speeds up to 11.2 km/sec, whereas the special IM trajectory would have the spacecraft reentering at speeds near 14.2 km/sec. While this is only a 27% increase in reentry speed, the physics of atmospheric heating produce heat loads that are several times greater. To survive the Orion spacecraft would need a new, thicker, heavier heat shield along with a strict mass limit that is difficult to achieve given the fixed geometry of the Orion crew module. Additionally, the specialized ECLSS needed for the 501 day mission and the amount of food and water required for the crew increases the launch mass of the Orion capsule to the point where a safe launch abort is perhaps no longer possible. With respect to SLS, the current program plan calls for the near-term development of an upper stage that is not capable of the producing the throw mass required for Inspiration Mars. However, the program plan does call for the development of the Dual Use Upper Stage (DUUS) in the early 2020's. This version of the SLS will have the required capability. Lastly, using SLS and Orion for IM would mean that people would be on board for the very first launch of the SLS rocket. The Inspiration Mars Advisory Board determined that this brought risks that were inconsistent with the safety goals established for the project. As a result, the combined use of SLS and Orion to perform Inspiration Mars mission was dropped from further consideration.

The Backup Team also faced challenges. Analysis of the existing fleet of launch vehicles (aside from SLS) showed that the mission would require three or more launches to get all of the hardware into orbit. This would involve launching multiple rockets within very tight launch windows and subsequent multiple rendezvous operations. Additionally, in order for the existing upper stages to have enough propellant to achieve the necessary spacecraft velocity for the required trajectory, on-orbit refueling would be required. This technology has not yet been demonstrated on the scale required. The team also found that the planned Commercial Crew spacecraft are not being designed for any missions beyond low earth orbit (LEO). Hence, while they could be used to get the crew to orbit, they could not be used as living space or reentry vehicles. The Backup team did have success in identifying a suitable spacecraft for living space. The Cygnus pressurized cargo module (PCM) developed by Orbital Sciences has the size and design flexibility to be configured into a spacecraft large enough to provide the living space required per NASA standards and still store all of the required food and water. The Cygnus service module can also provide the power, propulsion and electronics needed for mission. Finally efforts undertaken by the NASA Engineering and Safety Center (NESC) and the Jet Propulsion Lab (JPL) under RSAAs showed the benefits of separating the systems needed to keep the crew alive for 501 days from the systems needed for the crew to survive the hours required for reentry. Therefore it made sense to utilize a small capsule that would only be used for the two crew members to safely reenter the Earth's atmosphere.

By comparing the findings of the two teams charged with developing the architecture needed to carry out the Inspiration Mars mission, a hybrid solution was developed. The IM Vehicle Stack, shown in Figure 2-3 would consist of a Habitat Module made from a modified Cygnus PCM and a Service Module that together would provide everything needed to keep the crew alive during the 501 day mission. Attached to the Cygnus would be a specially designed Orion Pathfinder Earth Reentry Pod (ERP) that would separate prior to reentry and return the crew to Earth. A Spacecraft Adapter would be used to attach the IM Vehicle Stack to the launch vehicle.

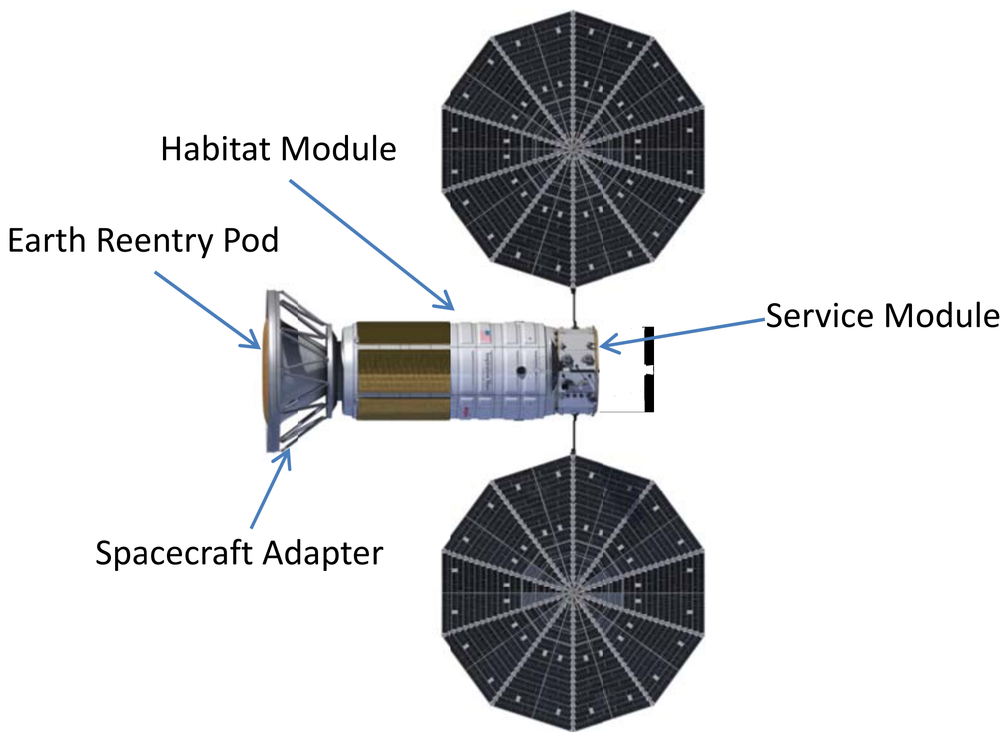

Figure 2-3. The Inspiration Mars IM Vehicle Stack.

2.4 MISSION OPERATIONS

Figure 2-4 shows the Concept of Operations (ConOps) resulting from the hybrid architecture solution. The IM Vehicle Stack would be lifted into LEO by the SLS rocket with the DUUS, the only launch vehicle with enough throw mass for the job. Then the crew would rocket into orbit using the services of a Commercial Crew provider. Once on orbit the Commercial Crew vehicle would dock with the IM Vehicle Stack, transfer the crew and depart. Afterwards, the DUUS would perform the trans-Mars injection burn to send the spacecraft and crew on their way to Mars.

The Martian flyby alters the trajectory of the IM Vehicle Stack sending it on a path to intercept Earth. Just prior to entry interface the crew would transfer over to the ERP and separate from the Habitat Module. The ERP would then carry out the Entry, Descent and Landing portion of the mission ending with a splashdown in the Pacific Ocean.

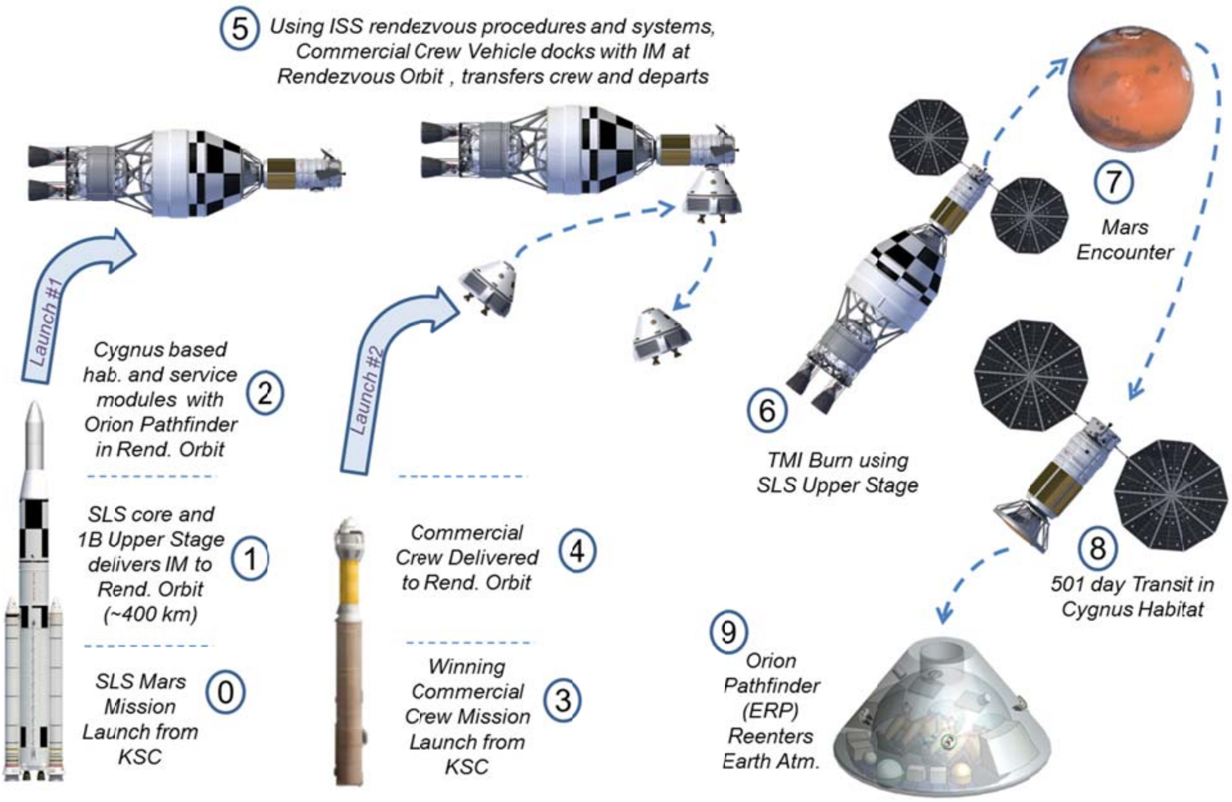

Figure 2-4. Inspiration Mars Concept of Operations.

2.5 CAPABILITY AND TECHNOLOGY DEVELOPMENT

While the Inspiration Mars program utilizes many existing and planned technologies, there is still much work to be done. Three of the key areas of focus for IM are the DUUS, outfitting the crew in-space HAB to maintain crew health and well-being, and the design of the crew entry pod and heat shield for reentry. The main requirements for the upper stage are as follows:

- **Deliver the IM Vehicle Stack to low earth orbit**
- **Loiter on orbit until the Commercial Crew vehicle can dock and transfer crew**
- **Propel the IM Vehicle Stack into the required free return trajectory**

Though SLS is scheduled to be ready for its first flight in time for the IM mission, the slated upper stage (known as the Interim Cryogenic Propulsion Stage, or iCPS) lacks the performance required for the IM mission. While other combinations of upper stages were studied, the planned DUUS is the most expedient and practical solution for the SLS upper stage. Boeing and the SLS program conducted a mission study which indicated that the DUUS should have sufficient performance for the IM mission. Completing the development of this upper stage in time for the mission will require a focused and dedicated effort. However, this development will markedly increase the initial payload capacity of the SLS for all future missions, providing benefits to our nation for future human exploration missions, but also for potential scientific and national security missions as well.

The fundamental driving requirements for crew health and safety are life support, environmental control and free habitable volume. These are summarized below:

- **Life support and environment control shall support the crew for a minimum of 501 Earth days**
- **There shall be a minimum habitable free volume of 5.7 m^3 per crew member, or a total of 11.4 m^3**

The above requirements and the fact that there are no identified mission abort scenarios after TMI drive the need for a high reliability ECLSS design based on the tested systems presently in use on the ISS. ECLSS development has already commenced through ongoing systems engineering and the development of an ECLSS Test and Development Unit (ETDU) scheduled for completion in December 2013. The ETDU will be used to test major life support functions in the baseline design.

The mission trajectory presents additional challenges for life support and human health. Though the mission will fly during a solar minimum, deep space radiation is still a significant concern, one that the IM study team has been studying for almost a year. A medical team, led by Dr. Jonathan Clark, has addressed the radiation exposure and a range of other medical issues associated with the IM mission. This team has determined that the risks are manageable with the relatively short duration of the mission. The human physiology research from the IM mission will certainly lay the medical groundwork for all future deep space missions

While “crew safety” is a mission requirement, a quantitative measure is needed to evaluate the overall mission design. To that end a crew safety risk the goal of 0.99 probability of safe crew return was established, which is consistent with other human spaceflight programs.

The third major area of continued study is the reentry speed and associated heating. As stated above the reentry speed of the ERP will be greater than any other man-made object. Given the significance of the reentry concern an RSAA was put in place with Ames Research Center (ARC) early in the study to address the vehicle shapes, entry trajectories and thermal protection system (TPS) materials that would be required to safely bring the crew back to Earth.

ARC recommended the use of phenolic impregnated carbon ablator (PICA) as the TPS material for the IM ERP heat shield. PICA has been used for multiple heat shield designs and has been successfully tested to heating rates of 1400 W/cm^2, higher than any other existing heat shield material. However, the reentry analyses done to date have shown that the ERP will be exposed to even higher heating rates. The PICA will have to be tested to these rates before the mission can be performed, but the plans for test facility upgrades only expand the limits to 2000 W/cm^2.

Hence this becomes both a restriction on the reentry trajectory and a critical test to be completed before 2017. Hence, the key requirements for reentry are:

- **The entry vehicle shall provide for safe recovery of the crew based on an Earth closing speed of at least 14.2 km/sec.**
- **During reentry the TPS materials shall not be exposed to heating exceeding 2000 W/cm^2**

2.6 PROGRAM TIMELINE AND MANAGEMENT

Aside from the technical opportunities associated with the Inspiration Mars mission, there are programmatic challenges as well. The schedule is admittedly tight with the DUUS and entry pod development having the highest priority for initiation. Extensive discussions with Boeing and the SLS program indicate that the DUUS could be developed in time for the Inspiration Mars Mission. Many other schedule challenges exist, but none beyond America's reach. The top level schedule is provided in Figure 2-5, summarizing an extensive schedule planning effort at the subsystem level with hardware providers.

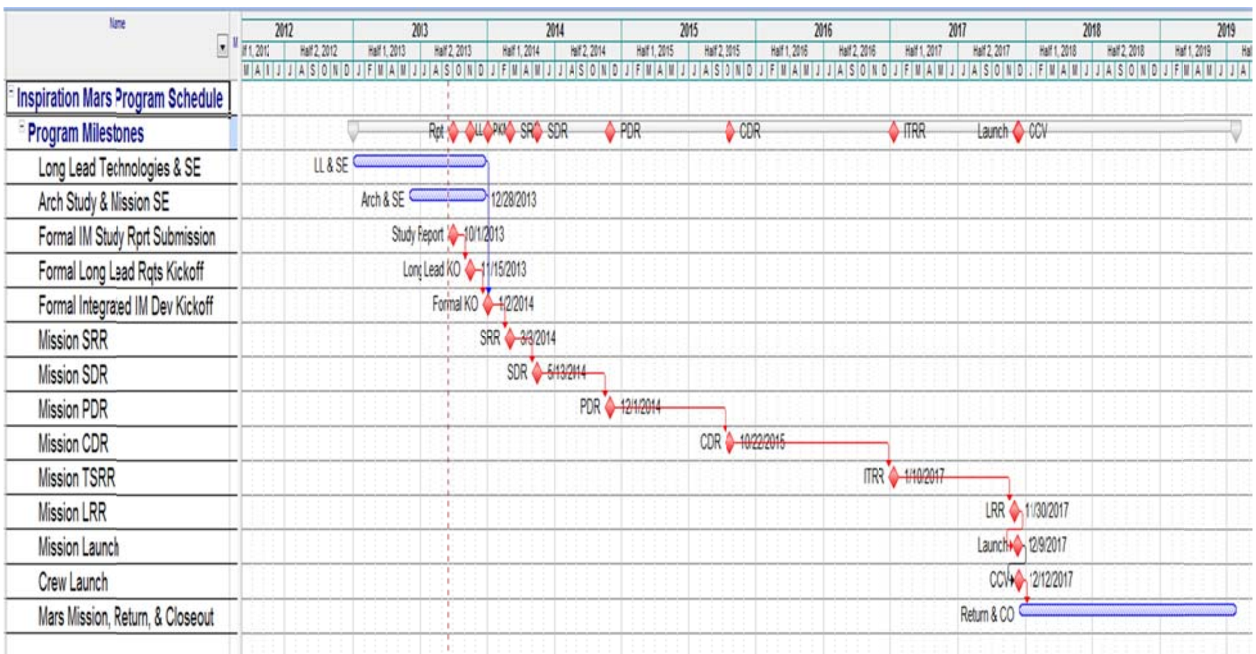

Figure 2-5. Top Level Schedule.

The Inspiration Mars mission is envisioned to be a private–public partnership between the Inspiration Mars Foundation (IMF) and NASA. This proposed partnership will enable the IM mission to benefit from the over five decades of human spaceflight experience by NASA as well the ongoing development of the NASA human spaceflight infrastructure. At the same time it also enables NASA to directly benefit both from the capabilities and technologies being developed by the IMF, the experience gained in the mission development, and the knowledge gained from having two humans in space for 501 days on this Mars flyby mission.

A Principal Investigator (PI) management model is well-suited to meet the IM mission management challenges. The head of IMF will be the PI with responsibilities including mission requirements, constituency development, crew life support systems/health/safety, and conducting payload mission operations. NASA and its industry partners' responsibilities will consist of providing mission infrastructure to include element launch, crew launch, crew transfer operations, the habitation module, trans-Mars injection, crew return, human spaceflight systems expertise, and crew training support. The IM organizational structure would provide NASA and the IMF with management roles consistent with their public-private fiduciary and legal responsibilities.

An IM Mission Development Management Team (MDMT) will be responsible for overall mission management, the payload and payload mission operations. The MDMT will be led by the IM mission Program Manager and comprised of empowered managers from the IMF, NASA and Industry. NASA and/or industry partners will be responsible for the mission infrastructure that supports the PI's payload including the spacecraft bus, system integration, launch and spacecraft mission operations.

2.7 RISK

The Inspiration Mars program leadership is intimately aware of the major challenges and risks this endeavor poses. Success of the mission is directly tied to the proactive mitigation of the risks. Together, the stakeholders and leadership of the Inspiration Mars mission have the capability to execute the necessary mitigation approaches while persistently identifying and mitigating risks as the program progresses. Table 2-1 provides the top 3 programmatic risks identified by the IM program leadership. While technical risks and associated mitigation approaches have been identified for the mission architecture, the programmatic risks in Table 2-1 are the most significant.

Table 2-1. Top 3 IM Risks

Risk Statement	Mitigation Approach
1. Schedule-Without establishing leadership commitments and organizational priorities that will promote the "can- do" environment needed to meet the January 2018 fixed launch date within expected budgets, the IM mission may not be executable.	Pro-active engagement of senior NASA and Industry Partner leadership to inspire their commitment.
2. IM needed elements (SLS, etc.) under development for the current Program of Record may be unavailable if their schedule is not maintained, thus jeopardizing the IM mission.	Ensure Stakeholders are aware of schedule criticality and responsible for maintaining schedule.
3. Development of the upper stage and a crew Earth Reentry Pod are susceptible to complications that can result in detrimental schedule delays.	IMF to work with NASA over the next 90 days to establish a development plan that takes advantage of a Skunk Works environment and puts under contract in a timely manner.

2.8 CONCLUSION

Inspiration Mars represents the next step in human exploration of our universe. The mission will be concurrent with the 500th anniversary of the first circumnavigation of Earth by Magellan and the 50th anniversary of the first circumnavigation of the Moon by Apollo 8. In May 2019, the

ERP will return the Inspiration Mars crew safely to Earth concluding the mission just prior to the 50th anniversary of Apollo 11.

There are definitely challenges in developing the flight hardware and accomplishing the Inspiration Mars mission within the time constraint. However, there is an overwhelming belief that this mission is not only technically feasible, but programmatically achievable in the short time frame remaining We believe it is well-worth the commitment, resources and hard work to take advantage of this truly unique opportunity.

The IM mission blazes the path towards human exploration of the surface of Mars. As the first step in the series of missions that includes visits to asteroids and the orbiting of Mars, the Inspiration Mars mission should not be seen as a change in direction for our nation, but rather an improvement in the tactical implementation of the current space policy. By taking advantage of virtually every major development in the current human spaceflight program (SLS, Orion, commercial cargo and crew, ISS testing, etc.), the IM mission creates synergy between the competing priorities of Commercial Crew and Human Exploration for the first time. The accelerated technology development will even provide benefits to national security.

We now call on our nation’s leaders to seize this singular opportunity to begin human exploration of the solar system and affirm America’s leadership throughout the world.

3. ACKNOWLEDGEMENTS

It is with upmost importance that we acknowledge those people and organizations that have thus far contributed to the Inspiration Mars mission and through their interest and belief in this mission have made this report and the future of the Inspiration Mars mission possible.

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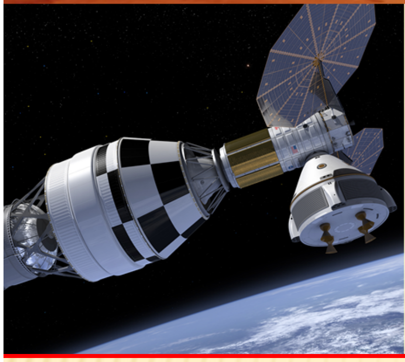
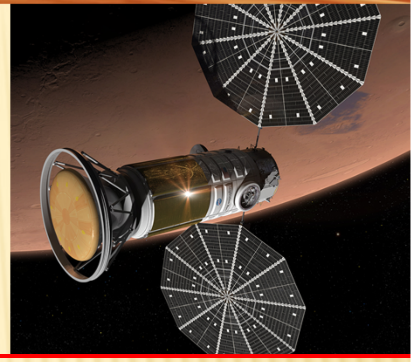


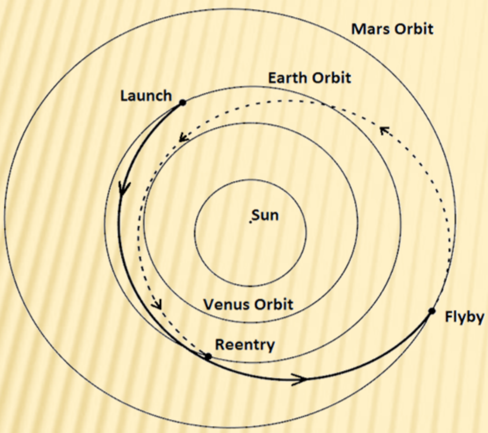
Inspiration Mars Goals

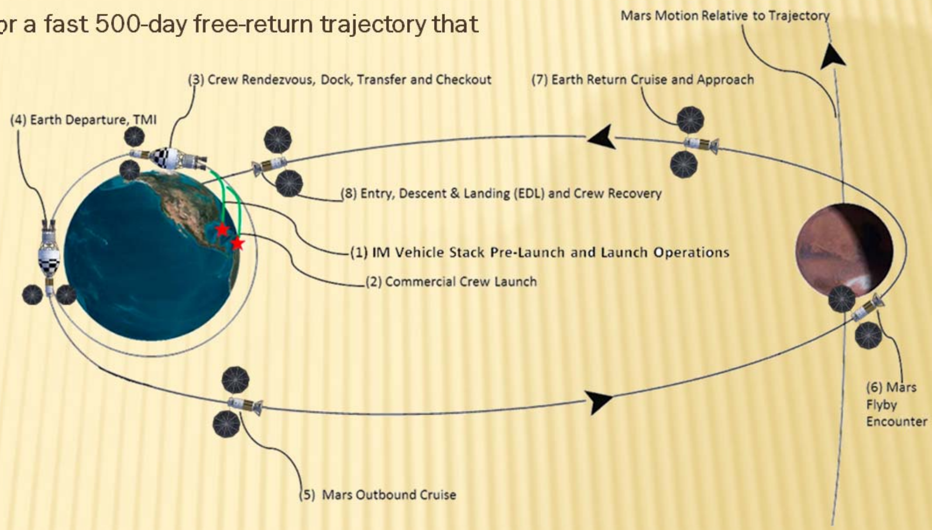
- An American crew – a man and a woman – on an historic journey to fly within 100 miles of the Red Planet and return safely to Earth
- Inspire a sea change in the U.S. Space Program and maintain leadership in space exploration
- Demonstrate feasibility of human missions to Mars and retire risks of human deep space exploration
- Foster knowledge, experience and momentum for space exploration



Mission Design

- An unique opportunity in Jan 2018 for a fast 500-day free-return trajectory that minimizes risk to the crew





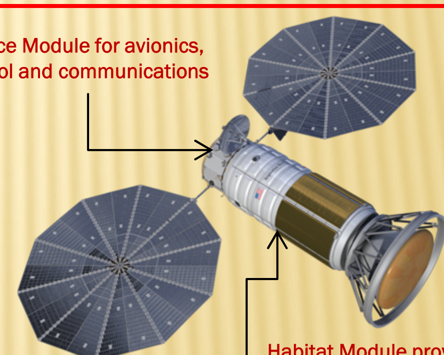
Vehicle Systems

- Leverage existing systems combined with custom new developments

Mass Margin Approach			
SLS TMI limit with performance margin reductions	19,000	kg	
SLS Performance over Margined Estimated Value	469	kg	3%
Margined Estimated Value	18,531	kg	
Average Contingency Margin	2,764	kg	17.5%
Current Best Estimate	15,767	kg	
Estimated Average Mass Growth Allowance	2,628	kg	20%
Base Mass Estimate	13,139	kg	
Total of Margin over Base Estimate	**5,861**	**kg**	**45%**

45% Cumulative mass margin

Service Module for avionics, control and communications

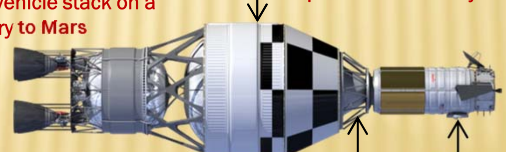


Habitat Module provides pressurized volume for crew

Solar Arrays provide primary power to vehicle systems

Cross section showing crew volume

Advanced Upper Stage to deliver vehicle stack on a trajectory to Mars



Payload Faring Adaptor

Docking portal for crew embarkation and Mars viewing

Earth Reentry Pod for high-velocity (14.2 km/sec) Earth reentry

Inspiration Mars Foundation
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A Mission for America
A Mission for the World

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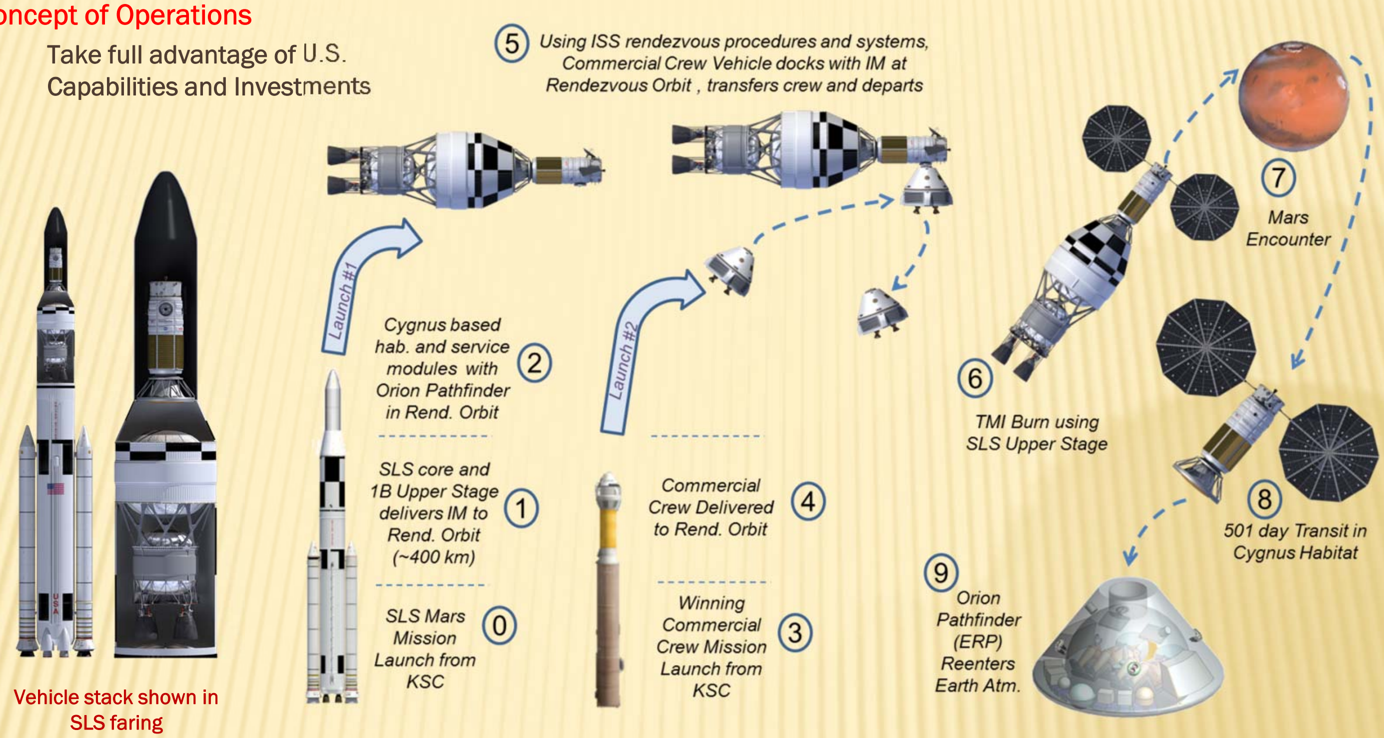
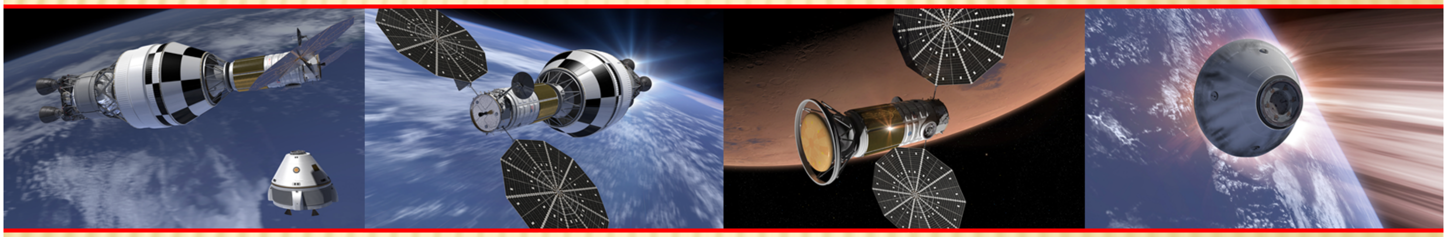
Concept of Operations

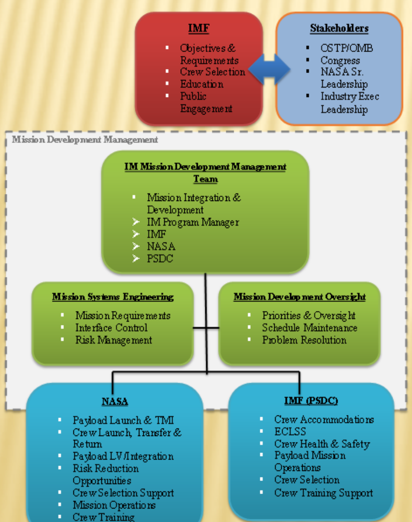
- Take full advantage of U.S. Capabilities and Investments





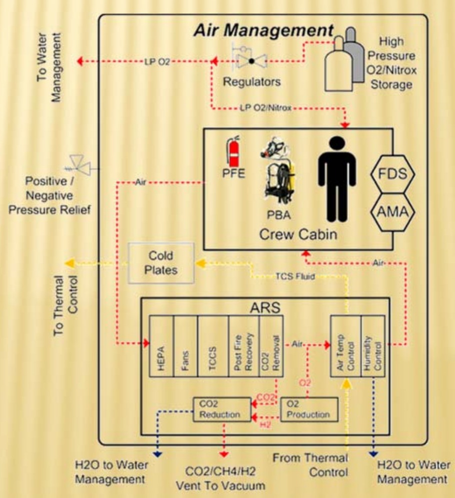
Management

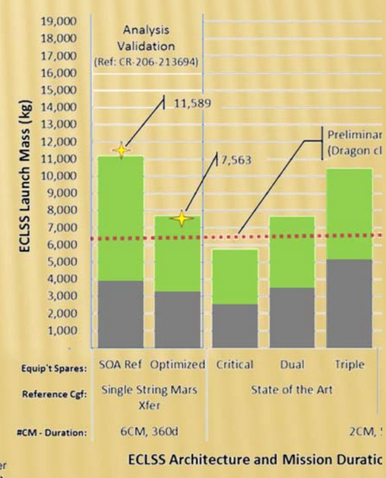
- An Innovative Public-Private Partnership with Philanthropic Catalyst



Crew Systems

- State of the Art Systems for Life Support, Thermal Control and Crew Health





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