2018 Red Eagle International Design Competition

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ABSTRACT

The human race has not ventured back to the Moon or beyond in nearly the last forty years. Thus, Team Icarus-consisting of students from both California State University Long Beach and Cerritos High School-decided to partake in the Red Eagle Competition. Red Eagle is a design competition that was created by the Mars Society to solve the issue of designing a craft to be able to land human crew and a 10,000 kg payload onto Mars. Our presentation will cover the process of how our team was able to develop the craft. We gave each person in our team roles of what to research on. Some topics that were researched are radiation protection, cost, time schedule, and landing procedure. Our team focused on researching any current or future technology that would be made by the year 2026. That year is when the whole craft will be built and launched for use. Our solution to the issue is our own custom designed lander which is also named *Icarus.* This craft has both a crew module and cargo bay to hold the required 10,000 kg. Parts used to construct the *Icarus* are from private aerospace companies and NASA. This mixture of government and private companies is to ensure the lowest price for construction possible. Private companies like SpaceX have managed to manufacture nearly 80% of their parts in house, thus making engines or the hull of the craft inexpensive. This is due to the fact that there would be less cost into shipping the parts across the country.

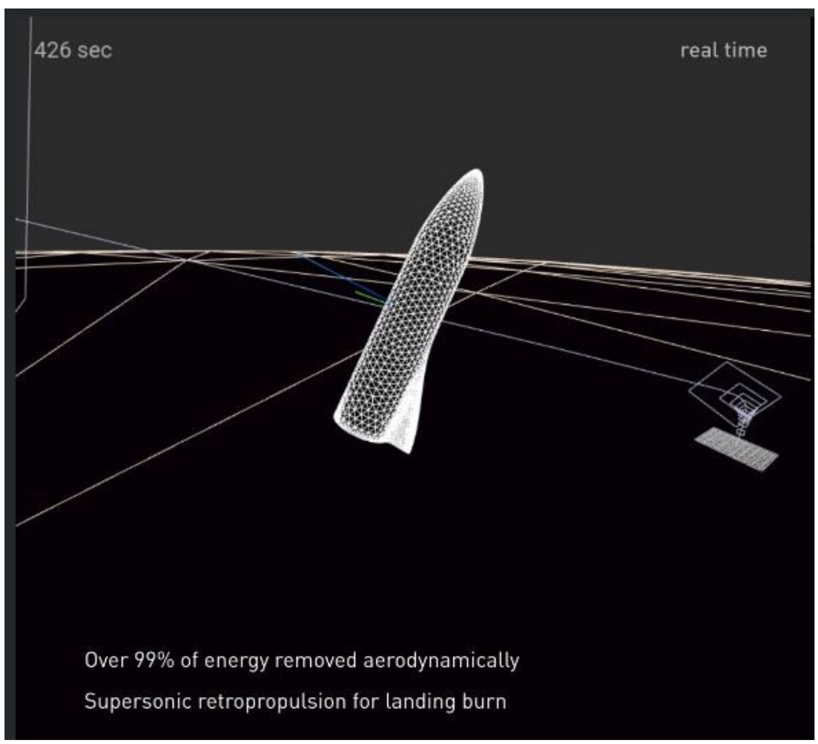
This research was a way for students to demonstrate their knowledge and understanding of the engineering process. Out team was able to understand the issue at hand, research, and develop a solution, and present it to the public.

CONTENTS

1. BACKGROUND

For the record, we are aware that there have only been seven successful Mars landings. Those missions were the Viking 1 Lander, Viking 2 Lander, Mars Pathfinder & Sojourner Rover, Spirit Rover, Opportunity Rover, Phoenix Mars Lander, and the Curiosity Rover. That being mentioned, all of these missions were unmanned. Companies like SpaceX and NASA are working to bring human payload onto Mars, but they still have a long way to go.

One famous example which is still a work in progress would be SpaceX's optimistic proposal to use their BFR, the Big Falcon Rocket. This rocket would be introduced into their fleet of highly successful Falcon rockets. The BFR would use four Raptor vacuum engines to maneuver the rocket in a trajectory which would allow for a hypersonic retropropulsion after entering Mars atmosphere. The rocket would have to perform a series of maneuvers that is able to remove 99% of energy aerodynamically. Then to conclude the landing, the BFR will ignite its two sea level Raptor engines to slow the craft down to land.



Pictured above is from a SpaceX simulation of the BFR maneuvering into hypersonic retropropulsion

1.1 Design Summary

In order to ensure our passengers and ten metric ton payload will land safely on the surface of Mars, we are referencing the stages used by NASA to land its Curiosity rover. In short, our lander will perform a series of de-orbits, orientate itself so that its bottom faces perpendicular to the surface, slow down using its heat shield, then perform a powered descent onto the surface. After completing a 6G[1] burn for one minute, the engines will lower in thrust to land the lander safely on the surface.

Once the rocket has decelerated to a speed of around 20 m/s, the landing legs will deploy and remain extended until landing. This whole process will take just over 4 minutes to occur. NASA's Curiosity Mars rover was able to land from the edge of Mars's atmosphere to the surface of Mars in only a matter of 7 minutes. However, NASA used a large supersonic parachute which decelerated the rover with a neck-snapping 9 G's. Our aim is to ensure that the crew and payload will not be harmed in this mission.

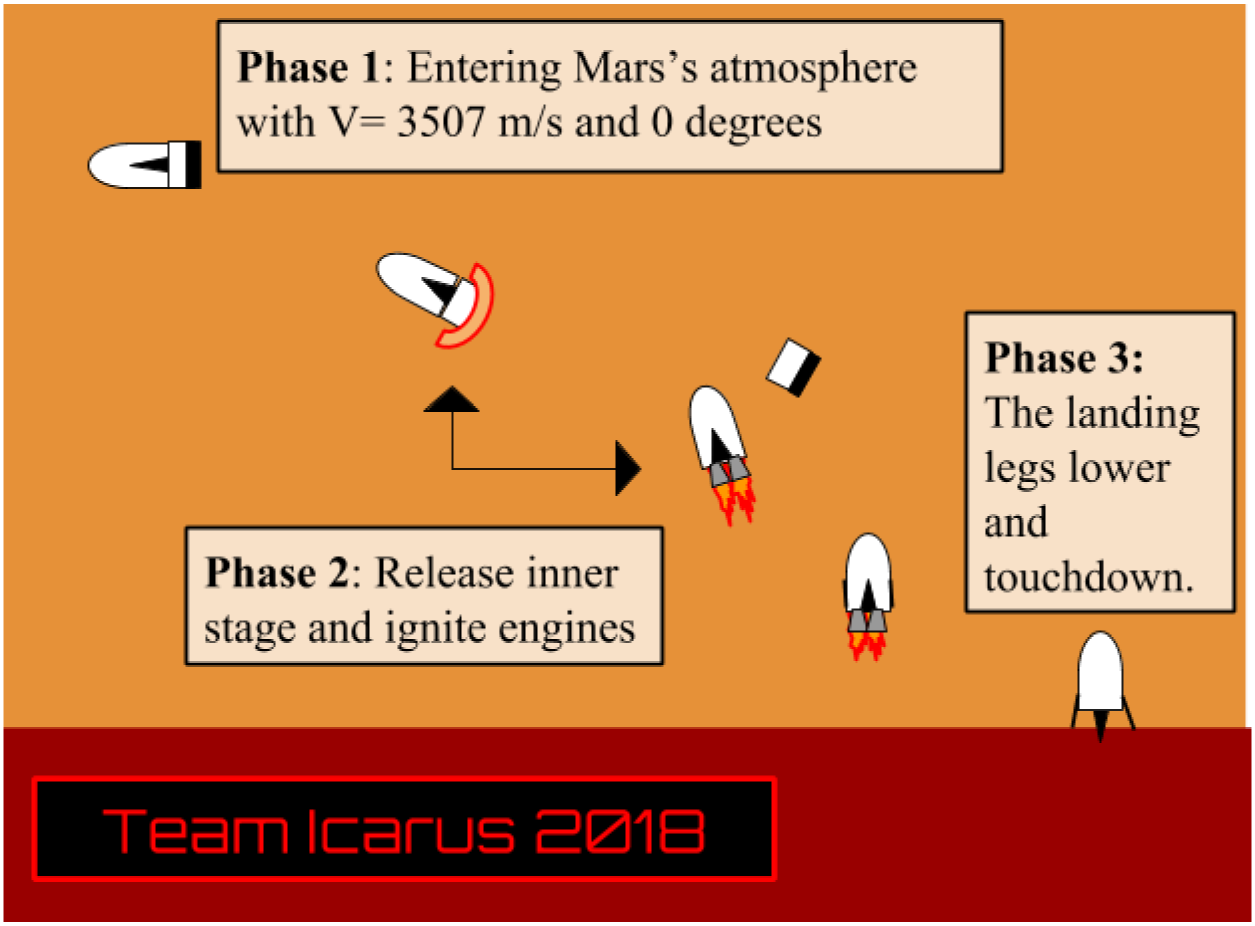
1.2 Design Restrictions

The list of constraints for the proposed lander include:

- The proposed lander must be able to land a 10,000 kg payload and a human crew onto the surface of Mars.
- The lander must be designed, built, and launched by no later than 2026
- The craft must be affordable
- The assumed initial condition of the craft approaching Mars's atmosphere is at the hyperbolic velocity of 3,000 meters per second.
- Lander can do either a propulsive capture or aero-capture to get into Mars orbit and land.
- Rockets, aero-shells, wings, rotors, balloons, and/or airbags may be used to deceleration and landing.
- The payload must not encounter excessive g loads at any time.
- Alternatively, the lander can enter the atmosphere and land immediately.
- Craft needs to be able to communicate with the Deep Space Network
- The craft must have technology that is available by 2026

[1] G = 1 Earth Gravity

1.3 Design Timeline



A more in-depth and further explanation of the powered deceleration can be found in section 12. Propulsive Landing.

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2. AEROBRAKING

2.1 Overview

In order to reduce mass and save costs, we have chosen to utilize aerobraking as part of the process to land safely. We have calculated that aerobraking could save as much as 28,332 kg in fuel mass from the entire lander and shed off 2,289 m/s of Delta-V for free. Once the spacecraft enters the sphere of influence of Mars, it will alter its course such that the periapsis is at an altitude of 83.767 km. We chose this number after conducting a series of guess and check calculations using a program written after the "Forget Aerobraking" Equation, which calculates the change in velocity of a spacecraft after one pass through the atmosphere. According to our calculations, if the spacecraft alters its periapsis to this number, and coasts through the atmosphere one full time, then the drag force will make it enter a stable Martian orbit at around the same altitude. From that orbit, it can deorbit immediately or choose to linger over the planet and deorbit elsewhere. We used this strategy because we kept in mind that the purpose of the challenge is to design a lander that can be used for almost any Mars mission that wishes to deposit 10,000 kg, so we want to have the flexibility to land anywhere on the surface of Mars.

2.2 Calculations

Figure 2.2.1

This equation gives the change in velocity over one orbit period given a ballistic coefficient, density at periapsis, relative velocity at periapsis, distance at periapsis, central attractive constant of the planet, eccentricity of the entry orbit, as well as the scale height of the Martian atmosphere.

$$\Delta v = k \; \rho_0 \; v'^2_0 \; r_p \sqrt{\frac{2\pi}{\mu}} \; \frac{1}{\sqrt{e}} \; \sqrt{H}$$

k = ballistic coefficient

ρ_0 = Density at periapsis

v = Relative velocity a periapsis

r_p = distance periapsis - center of the planet, [km]

μ = central attractive constance, [$m^3.s^{-2}$]

e = eccentricity

H = Scale height ar periapsis [RT/g]

Mass = 30,000 kg

$C_d = 0.47$

r = 177.166 in = 4.500 m

$A = \pi r^2 = \pi(4.5\ m)^2 = 63.617\ m^2$

$k = \frac{mass}{Cd\,(A)} = \frac{43{,}478\ kg}{0.47(63.617 m^2)} = 1{,}003.345\ kg/m^2$

$\mu = 4.269x10^{13}\ m^3.s^{-2}$
H = 11,100m
*Mars atmosphere surface density = 0.020 kg/m^3

Density = $\rho_0 = (\frac{1}{e^x})0.020$ kg/m3 h = periapsis height
x = h/H H = 11.1km

Trial #1 - 100 km
h = 100. km
$\rho_0 = (\frac{1}{e^{9.009}})0.020$ kg/m3 = 2.446x10-6 kg/m^3
Δv_{retro} = 446.295 m/s

Trial #2 - 50 km (is peri and parking orbit altitude)
h = 50. km ρ_0 = 2.212x10-4 kg/m^3
R = 3,390 km r = 3,440 km
v_{park} = 3,522.737 m/s v_{hyper} = 5,815.683 m/s
$\Delta v_{retro} = \left|v_{park} - v_{hyper}\right|$ = 2,292.746 m/s

Δv_{break} = 14,129.899 m/s

After trials #1 and #2, we concluded that the periapsis height must be between 50 km and 100 km because Δv_{retro} was too small at 100 km, and too large at 50 km

Trial #3 - 75 km
h = 75 km
ρ_0 = 2.326x10-5 kg/m^3 r = 3,465 km
v_{hyper} = 5,815.683 m/s v_{park} = 3,510.205 m/s
Δv_{retro} = 2,305.478 m/s

Δv_{break} = 4,078.497 m/s

This allowed us to narrow the approximations to 75 km < h < 100. Km

Trial #4 - 80. km
h = 80. km
ρ = 1.482x10-5 kg/m^3 r = 3,470 km
v_{park} = 3,507.675 m/s v_{hyper} = 5,815.683 m/s
Δv_{retro} = 2,308.208 m/s

Initially, we started with the mass of 30,000kg; however, after updating the project, the new mass was 114,000 kg, which changed the ballistic coefficient to 1,454.123. Using these values and the program we found the best periapsis altitude to be **98.686 km** high.

3. ATTITUDE CONTROL

Attitude is the angular orientation of the spacecraft with respect to an external frame reference(earth, nearby objects, celestial spheres, etc.), which is an important part of space traveling and navigation.

For the main part of the attitude control system, we will be using Mariner Mars spacecraft as our model. The subsystem in the Mariner Mars spacecraft includes celestial sensors, inertial measuring system, a reaction control assembly, a thrust vector control system and associated attitude control electronics. Celestial sensors include cruise and acquisition sun sensors and a Canopus tracker[2]. Inertial reference unit contains three single-axis, rate-integrating, strap-down gyros; a. pendulous, digitally rebalanced accelerometer, and their electronics. A reaction control assembly consists of two independent assemblies. Each assembly contains a gas storage tank, a pressure reduction valve, and six solenoid operated valves with exhaust nozzles. A thrust vector control system includes autopilot electronics and a two-axis rocket engine gimbal actuator assembly. Associated attitude control electronics contains the implementation of the control laws, and all mode selection and power switching concept.

In total, there will be twelve 110 Newton thrusters, oriented around the module(All the thrusters will be placed relative to the center of gravity of the spacecraft, attitude control is achieved by operating different combinations of thrusters to generate the 3-axis torque). Four will be situated at both the top and bottom of the module, four at the base by the landing gear and four near the top by the command module. The four thrusters will be equidistant to control the pitch and the yaw. Two additional thrusters will be added at the two sections. These four additional thrusters will face towards the back of the rocket, and only one top and bottom thruster will ignite depending on how the rocket needs to roll. These four engines are going to be used to control the roll of the rocket should it move during descent. The total mass of this system is expected to be around 2000 Kg.

4. COMMUNICATIONS

To communicate with earth, the lander would utilize an X-band radio. The benefits with X-band radio is that they have high bandwidth and do not require a lot of power to operate. In addition,

[2] Canopus tracker is an optical device that measures the position of the stars using photocells or a camera.

X-band radio is reserved for mostly deep space-related systems, meaning that it won't be hard to find a suitable frequency. In this scenario, two high-gain 1.5-meter antennas would be present on the lander, with each antenna having its own rubidium ultra-stable oscillator (USO). This would provide redundancy, as there would be a backup antenna and oscillator in case one doesn't fully extend or is damaged. Furthermore, the rubidium USO would be more robust than regular USOs are more suited for atmospheric descent than other types.
The type of transmitter that would be present on the lander is an HRT440 X-Band High Rate transmitter, developed by General Dynamics. The equipment is able to transmit up to 440 MBPS of data at a frequency of 8200.5 MHz. The mass of this transmitter is about 2.6 Kilograms. For the power amplifier, we will use a TESAT Solid State Power Amplifier.

As the lander begins reentry into the martian atmosphere, each antenna would eject from the lander. In addition, another antenna would be tucked away inside the lander, and would only extend once the lander has made a touchdown with the martian surface. This antenna would communicate with the Mars Reconnaissance Orbiter, which would act as a relay to earth. However, should the MRO's mission end before 2026, the lander should still be able to communicate with earth, albeit with a lower data transmission speed. The system would have a total mass of about 130 Kg, including communication subsystems, and the total power input would be around.

5. LANDING LEGS

5.1 Configuration

During the final stages of landing, the spacecraft will require a stable position that can be safe from other hazards such as rocks on the landing zone. Therefore, our team decided to use landing legs which will give the best stability and hazard avoidance.

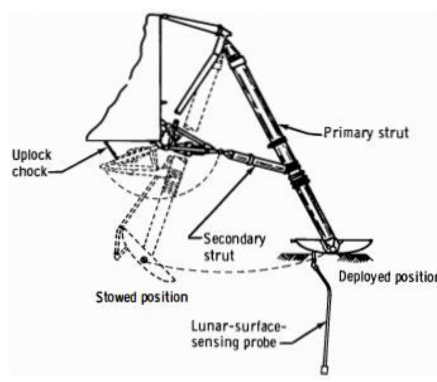


Figure 2. - Stowed and deployed positions of the landing gear.

The landing gear is cantilever legs, which has more advantages - such as ground clearance - over the inverted tripods. These legs will be bonded and coated with Aluminum, which was used during the Apollo missions. This aluminum alloy will be about 7x stronger than pure aluminum and will have a mass of less than a third. While it is currently hard to mass produce graphene, there has been considerable progress in the field, with expected mass producing techniques to be achieved in the early 2020s. This will allow us to meet our deadline for 2026. Through NASA's landing analysis, aluminum cantilever legs have been shown to have better stability when landing due to the center of gravity being located lower on the spacecraft. The addition of the secondary strut also distributes the large force from the payload which will reduce the total weight of the payload.

The main parts of the landing legs include the primary strut(telescopic), secondary strut, uplock chick(locking), and the foot pad. Unlike the inverted tripod that is fixed to one area, the cantilever gears can be opened or closed depending on the situation, reducing volume needed for the initial state during launch. The primary strut is connected to a secondary strut which can fold under the payload, locking on to the payload through the uplock chick.

During contact of the landing, the primary struts absorb the greatest amount of force, which is directed to the secondary struts. The secondary struts support the primary struts by connecting to the base's corner of the payload and the side of the landing legs. This allows the force to be distributed to the base of the landing module which reduces the stress from the landing legs.

5.2 Foot Pad

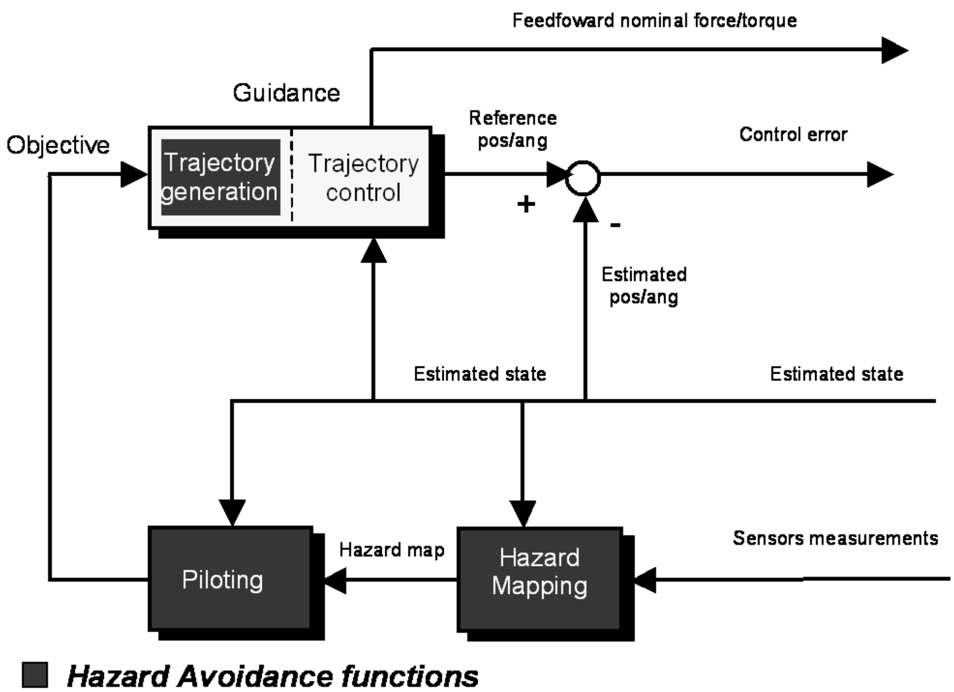
The foot pad is a disk-like structure that rests at the end of the primary strut to ensure the stability of the payload on Mars. These pads will consist of primary shock absorbers which are deformable aluminum alloy 7178 honeycomb cylinders that reduce the total force and weight applied to the legs. The same absorbers were used during the Surveyor soft-landing spacecraft, which successfully landed on the Moon with less force onto the legs.

5.3 Hazard Avoidance

Hazard Avoidance is a method of using different systems to help the payload land in a safer area. By landing in a safer area, the landing legs are more efficient and safer to use. When hazard avoidance is not used, landing legs require a design that withstands a slope of 22.5^{o} and rocks of 60cm high. These designs will greatly increase the mass of the landing gear.

Hazard Avoidance includes stages of Hazard Mapping, Piloting, and Guidance. Hazard Mapping utilizes cameras to detect hazards by looking for shadows, high slopes, and large boulders. These informations are transferred to the piloting stage. Piloting uses the data collected by other systems to combine and plan and decide where the safest landing area within the predicted zone would be. Guidance is the stage of landing the payload by steering the payload to the desired landing zone.

Deimos Engenharia Hazard Avoidance Concept Flow Chart



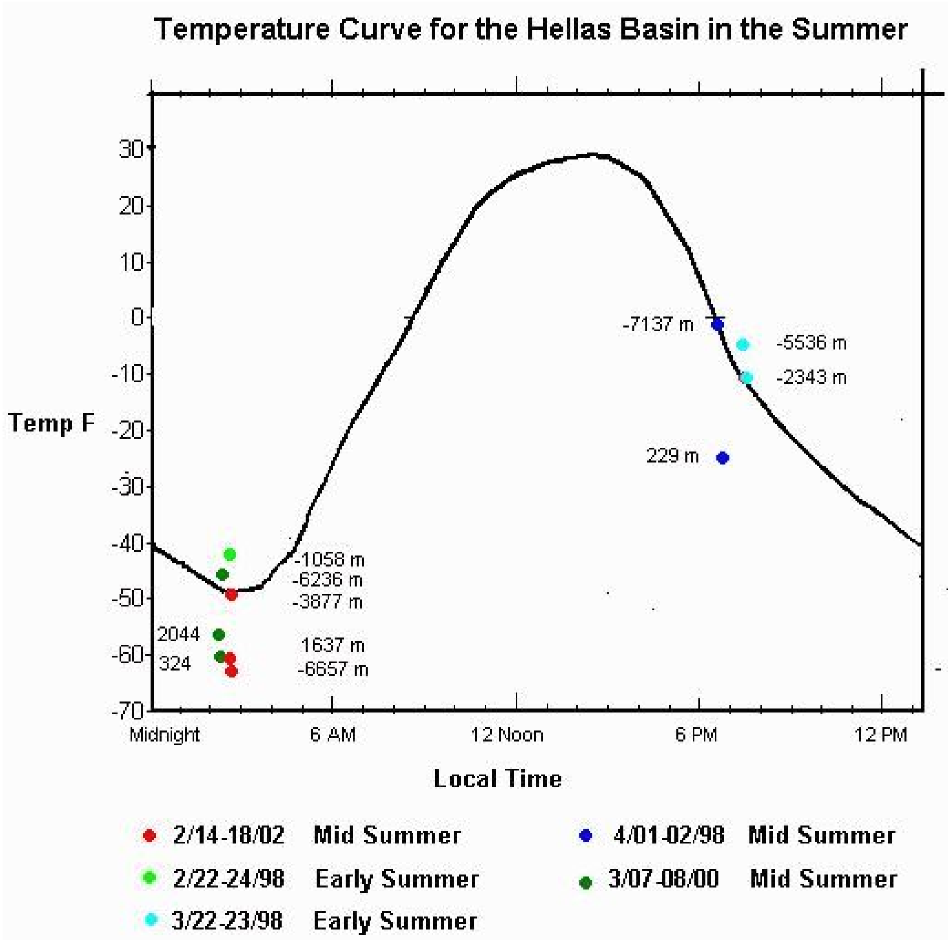
6. LANDING ZONE

Due to the rocky terrain of Mars, a suitable landing zone is needed to ensure stability while landing as well as to provide the best possible scientific experiments. The northern plains of the Hellas Planitia region of Mars will provide the best place to land the payload, taking into account the safety and scientific factors needed to launch an expedition to Mars.

The region is relatively flat and large with little impact craters, providing a safe place to land the payload. In addition, with an average depth of 9000 meters, the payload will have more time to slow down as well as have the benefit of coming into contact with high air pressure, thereby helping to decelerate the spacecraft. This location would also be friendly to human exploration, as the average surface pressure is 12.4mBar, 103% higher than the average surface pressure at the topographical datum.

The temperature in the region is comparably warmer than the rest of Mars, with the average temperature varying between -54 to -29 degrees Celsius in the summer, and -70 to -40 degrees Celsius in the winter. However, in the summer, the temperature sometimes can get as high as 1 degrees Celsius. In addition to the eccentricity of the Martian orbit, winters in the northern hemisphere of the region are slightly warmer than the southern regions. This temperature would guarantee the feasibility of meeting the heating requirements for a human exploratory mission to Mars, at least for the short term.

This level of temperature and air pressure often times passes above the triple point of water, meaning that liquid water could exist under the surface, at least for some parts of the year. In fact, it is theorized that glaciers exist under the martian surface, a theory supported by the discovery of Lobate Debris Aprons on the martian surface. This geological feature suggests that there is a layer of ice about 100-1000 meters thick under the surface, responsible for the honeycomb terrain and other physical abnormalities frequently found in the region. If these sub-surface glaciers exist, they may be able to provide a unique place for astronauts to live, not to mention the scientific value of such glaciers to the international community.



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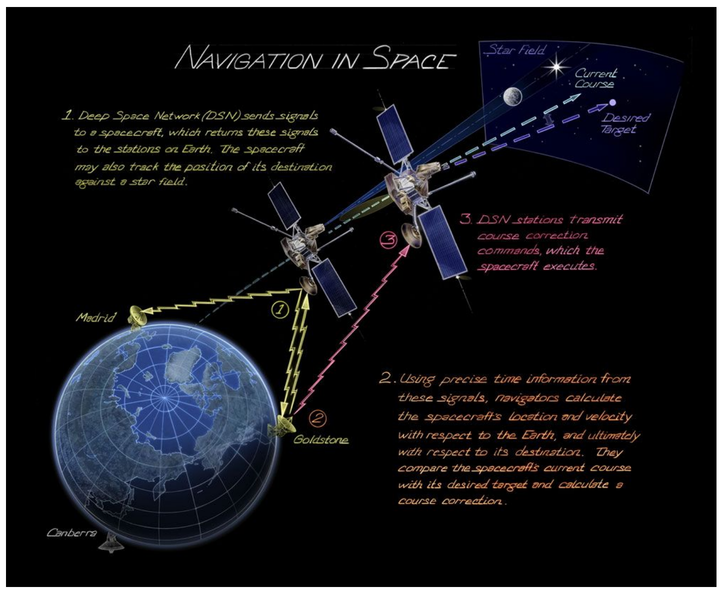
7. NAVIGATION

The Spacecraft will be approximately 54.6 million kilometers from earth and to successfully communicate to the spacecraft and the crews onboard, a powerful network called the Deep Space Navigation(DSN) is used. Currently employed and continually developed by JPL, the DSN receives precise position and velocity through radio signals.

Due to the Earth orbiting and rotating, the Earth is unable to track the spacecraft from one part of the world. Therefore, the DSN works by constantly facing the spacecraft through the use of large antennas located in different areas around the world. These locations include Goldstone in California's Mojave Desert; near Madrid, Spain; and near Canberra, Australia.

One part of the DSN uses the Spacecraft-Quasar Delta Differential One-way Range(DDOR or Delta Door) to correctly approximate the motions of the spacecraft using the locations of the quasars[3] at a few billions of a degree.

Two key components of the DSN are the transponder and amplifier. The two instruments utilize the *parachute low-gain antenna*(on aeroshell parachute cone) and *medium gain antenna*(on cruise stage) during the descent stage, which assists the Telecommunications System. The Telecommunications System receives ultra-high frequency(UHF) of 400MHz in the parachute UHF antenna and descent UHF antenna. The parachute UHF antenna is used during the travel to Mars, but once the descent stage is detached, the decent UHF antenna begins to work.



National Air and Space Museum, Smithsonian Institution DSN Illustration

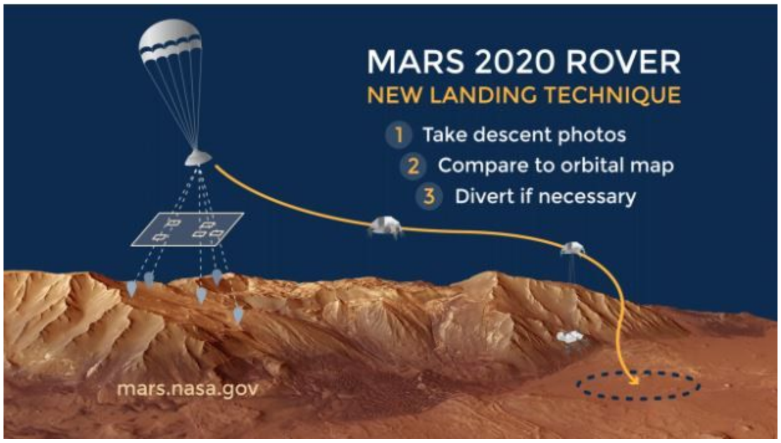
[3] "[A] massive and extremely remote celestial object, emitting exceptionally large amounts of energy, and typically having a starlike image in a telescope. It has been suggested that quasars contain massive black holes and may represent a stage in the evolution of some galaxies."

7.1 Terrain-Relative Navigation

The Terrain-Relative Navigation(TRN) is used together with Hazard Avoidance which uses a camera on the spacecraft and payload to autonomously find the best landing location, avoiding any damages on the payload. This system allows the payload to descend 100m within the original landing location by utilizing the positions and measurements compared to existing data. This technology will be used on Mars 2020, which focuses on the rover; however, this technology can be used to land our payload safely onto the Mars surface.

The TRN works with an existing map of the landing zone, which considers all the hazards within the area. This map is stored by the spacecraft, which will descend on a parachute and propulsion system. During its descent stage, the payload will take pictures of the surface directly beneath the spacecraft; these pictures are then compared to the saved maps by the computers within the spacecraft. This comparison allows the spacecraft to avoid hazardous areas up to 300 meters in diameter by directing itself to a secure location.

The TRN will improve the landing stage due to its accurate estimates by using pictures during the descent stages. In the past, many rovers had a hard time avoiding the hazardous areas during its Entry, Descent, and Landing(EDL) stages because the estimation of the landing zone happened during the spacecraft's orbiting stages or entry. These methods used estimations from radiometric data given by the DSN, which was not precise enough when the EDL was at about 1-2 kilometers, which went up to 2-3 kilometers during entry. However, the TRN will make estimations during its last stages of EDL, allowing the payload to calculate its position from the landing zone with an accuracy of about 60 meters. The TRN system will accurately calculate the heading of the spacecraft and safely direct the spacecraft to a better landing site.



8. HEAT SHIELD

8.1 Physical Description

In short, our heat shield would be a lining of PICA-X tiles on the bottom of the removable inner stage. PICA-X tiles were created by SpaceX while closely collaborating with NASA. The NASA Ames Research Center originally created Phenolic Impregnated Carbon Ablator (PICA). The material that makes up PICA and PICA-X is low in density and were successful at withstanding high amounts of heat. PICA was used in the Stardust mission where a spacecraft was responsible for returning a comet sample successfully for the first time in January 2006. The mission was recorded to be one of the fastest reentry speed for an aircraft into Earth's atmosphere-clocking in speeds of 28,900 mph. While the capsule to return the rocket was only a single piece, SpaceX's variant was able to have its PICA-X tiles in a tiled configuration. A tile configuration allowed for SpaceX to have a more "cost-effective" approach.

Pictured above is the NASA Stardust capsule with reentry burn marks

SpaceX's efforts on making a cheaper PICA tile was a great success. Because they were able to produce tiles on their own, SpaceX was able to design a 3.6-meter diameter heat shield that took less than 4 years to create. If we decide to reach out to SpaceX to use their heat-resistant tiles, we would be able to reduce the cost of our lander to a large amount. The Dragon 1 and Stardust missions can affirm this.

SpaceX's Dragon 1 capsule heat shield-holes indicated to take sample core testing

8.2 Heat Resistance

NASA's Curiosity rover aeroshell experienced temperatures up to 1,600 degrees F. We expect that our craft would experience similar or higher temperatures, considering that our payload is 10,000 kg. The craft could experience a higher velocity when descending into Mars's atmosphere because of the heavy payload to increase its acceleration. Although the craft may not experience such high temperatures like what the Stardust had to face, the air density is much thinner and won't face as much friction in the atmosphere.

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9. PARACHUTE

9.1 Options for Deceleration Phases

Mars's atmosphere is considered to be the perfect mix for a disaster when it comes to landing on its surface. Below is a graph showing the success rate and methods to decelerate a craft.

Celestial Bodies	Landing Success Rate	Deceleration Methods
Earth	76.9%[4]	• No Heat Shield • Powered Descent
Moon	76%	• Heat Shield • Parachutes needed • No rockets needed to land
Mars	53%	• Heat Shield needed • Powered Descent needed

Some deceleration methods not mentioned above are using airbags or a "sky crane." The skycrane was used to lower the Curiosity Rover onto the Martian surface. After the heat shield and back shield were released, a skycrane holding the rover would use retro thrusters to allow the machine to gently land on the surface. However, the skycrane would only be used once, because the thrusters aren't able to turn off once it is fired.

Airbags much stress on the human payload were also a solution to bring a heavy payload onto the surface of Mars without damaging it. However, the concept of involving multiple airbags is that it would cause our lander to bounce around without any control. Once everything has come to a stop, then it's safe for people to start coming out. We don't want to put our passengers onto more stress right after they land. In addition, we would need to have more circuitry to wire up to the airbags so they deploy at the right time. This added circuitry and power sources would have added weight onto the craft.

[4] This number is based upon the amounts of Falcon 9 boosters recovered as of January 31, 2018, not from all missions in the past that have occured.

9.2 Physical Description

The parachutes would be the most crucial part of the deceleration of our craft. If the deceleration causes too much impact in a short period of time, then the crew members will experience serious injuries or even death. According to a textbook that was written by the Federal Aviation Administration, it is possible for a human to experience up to 12 G's for a few minutes at a time. The disadvantage to this is that not an average person would be able to handle up to 5 G's without going into Gravity-Induced Loss of Consciousness (commonly known as G-LOC).

NASA's Curiosity rover slowed down by 9G's, that is enough to snap a person's Neck-if the person is orientated in a position for that to be possible. Because our design's safety calls for utmost importance, we are delaying the parachute so that it won't deploy the very second it reaches Mars's atmosphere. We would deploy it at an altitude where there is enough density for the parachute to inflate, but also low enough so that it doesn't instantaneously open up.

We considered using a parachute that is currently under development by NASA through its ASPIRE experiments. Because the lander must be built by the year 2026, we decided to choose a parachute that would be developed for the near future. Plans for using the parachute are stated to be in the year 2020, when NASA plans to use it for future rover exploration mission. The materials that create the parachute are nylon, Technora, and Kevlar. Technora is known for having strong material properties and is one of the few materials used to make previous parachutes NASA Mars rovers missions. The trial parachute is designed so that it is able to take up high amounts of stress but still be light enough to not be a burden for packing and folding.

Based on videos of the parachute used in the test trials, the parachute seemed to be a streamline parachute. It does appear to be a dome, so we will be assuming that the parachute will be a true dome shape size for further calculations.

The recent test determines that the parachute can take up to 35,000 lbs of force-drag. We will be using that to scale down the parachute to be safe and useful in our module.

9.3 Deployment

Again, our main point of deploying is to not decelerate so much to the point where it may cause fatalities onboard. An equation that we used to figure out how much the maximum deceleration the lander would face by itself would be around 86.072 m/s^2. (We emphasize that this number doesn't involve the parachute.) That would mean at the point where the most deceleration would occur would happen, the astronauts would face up to 8.738 G's-we based this value using the gravitation on Earth which is 9.8 m/s^2. Instead of using the gravitation on Mars, it seemed more logical to include the G-load according to Earth's gravitation. That way, for individuals who have trained in a centrifuge would have already experienced weight based on something that they already have experienced. In comparison, the g-load based on Mars's gravitation would have been 23.194 m/s^2. We used the following equation to find out when maximum declaration would occur.

$$a_{max} = \frac{V^2 \beta sin(\gamma)}{2e}$$

Variable:	V-for lander's entry velocity	β-atmospheric scale height for Mars	sin(γ)-lander's flight path angle (in degrees)	e - base of the natural logarithm
Values:	3505.743 m/s	$\frac{1}{11,100\ m} \cong$ 9.009 x 10^{-5} m^{-1}	25	2.7182...

However, the craft wouldn't have decelerated enough. When trying to find the altitude when the craft experiences the maximum amount would mean that the craft would have already crash landed before reaching the point where the reduction in speed tapers off.

On October 4, 2017, NASA carried out ASPIRE by deploying the parachute on a craft that went up to an altitude of over 50 kilometers above Earth's surface. Once the second stage burned out, the payload detached and continued to execute the experiments. The payload then started to descends towards the Earth. Computers that were on the payload calculated the proper conditions to deploy the parachutes, and the parachute went out of the back of the vehicle at about 100 mph. That provided a point where the parachute was able to deploy instantaneously.

Rather, we would like to deploy the parachute roughly 13 km in altitude. That way, we can program a hatch release to where the parachutes are stored and it can inflate slowly, allowing for the parachute canopy to fully inflate, but not as quickly when ejected like during the ASPIRE test trials.

9.4 Drag Force

For our calculations, the drag coefficient is 1.5, since our parachute is in the shape of a dome.

$$F_D = \frac{1}{2}\rho C_d A v^2$$

The equation is to calculate the force of drag

We know that for a parachute to work properly for our craft, it needs to exert the same amount of force drag to equal the craft's weight, which would be roughly 161, 347 m/s^2. That is a huge number, the ASPIRE parachute under trial would over straining the parachute. 35,000 lbf can be converted 155,688 N.

$$A = \frac{2mg}{\rho C_D v^2}$$

Chute area

$$D_V = \sqrt{\frac{8mg}{\pi \rho C_d D^2}}$$

This is the equation to find the descent velocity

9.5 Final Calculations

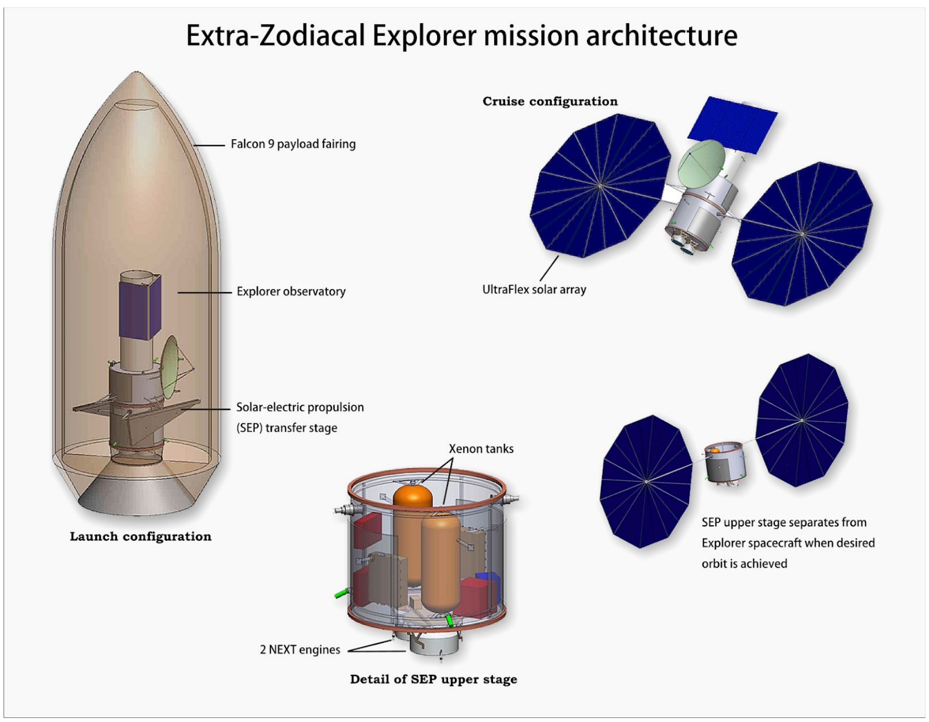
If our team decided to use a parachute, it would have been a large parachute that would have done very little to slow the craft significantly. Again, the air density is too low to slow our payload down enough. The parachute may only work for NASA's rovers because they won't be potentially having 10 or 20 rovers in their cargo hold. But in our case, using a parachute won't be feasible, and a powered descent with 3 Vikas-4B rockets would prove to be sufficient. A more in depth explanation for the powered descent can be found out in section 12.

10. POWER SYSTEMS

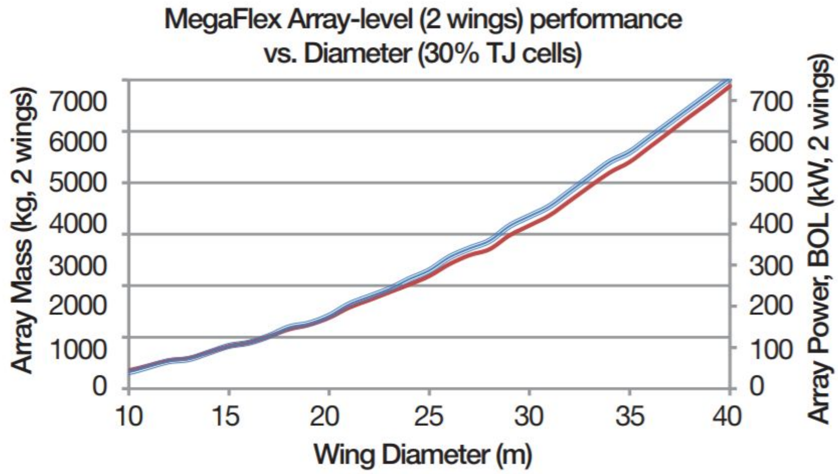
Due to the long duration of time between reaching the SOI and touchdown, batteries cannot solely be relied upon to power the lander. For this proposal, both batteries and solar arrays will be present on the lander.

Up until entry into the atmosphere, power will be provided with 2 Next Generation Ultra-flex Solar Arrays (NGUs), consisting of Multi-Junction Inverted Metamorphic Solar Cells, which offers higher energy conversion efficiency and lighter mass. The two arrays will have a diameter of 3.75 meters, with each having a mass of 330.88 Kg. Each solar array would have its orientation controlled using the two-axis Solar Array Drive Mechanisms provided by Orbital ATK, which would each have a mass of 6 kg. In addition, a Power Condition and Distribution

Unit will be present to regulate power, which would be approximately 5 Kg . There will also be an Onboard Data Network, accessible from both earth and the Lander. The network would be configured to be a three-plane Time-Triggered Gigabit Ethernet. This is a similar setup to that in NASA's Deep Space Habitat, which also utilizes solar arrays arranged in this fashion. One benefit of using these arrays is the low cost of around $1500 per Kg. Another added benefit to using these types of arrays is their high efficiency, which will be able to generate between 175 -220 Watts per Kg at 1 AU. At the lowest estimate, this should provide a peak power of over 20 Kw, and a low of 15. In addition, if the solar arrays should ever become temporarily un-operational, power could be derived from the batteries. The batteries could then be recharged using the arrays. Before the lander begins entry into the martian atmosphere, the solar panels will be ejected, and power will be derived from the batteries.



The system depicted here is similar to the one that shall be used on the lander



Inside the lander would be a series of five 120V DC Lithium sulfur batteries, which would be precharged. Each battery would have a mass of 25 Kg, bringing the total mass of the batteries to 125 Kg. The benefit of lithium Sulfur batteries is that they have a higher energy to mass ratio, and so can store more energy. If fact, lithium sulfur batteries can store almost double the energy as a lithium ion battery. In addition, due to the high voltage, wire gauges would decrease in size due to the lowered current, further reducing weight and cost.

Currently, the best batteries can store 200Wh per Kg. However, by 2026, it is theorized that this can be improved to 500Wh per Kg. This would bring the maximum power storage to 62.5 Kwh of energy, which is more than enough to power all vehicle systems and subsystems.

However, there are a few problems with these types of batteries. Over a few charge and discharge cycles, the batteries become unstable due to lithium ions reacting with sulfur, clogging the surfaces and reducing the amount of lithium getting inside the cathode. To fix this, a thin film of graphene, 90 nanometers thick, could be used to prevent the two particles from mixing. This has been achieved in the small scale, and by 2026, there is not doubt that this can be done in the larger scale. In addition, because of the high potential energy density and the nonlinear discharge and charging response of the cell, a microcontroller and voltage regulator would have be present on the lander to ensure that there is no rapid discharge of the batteries. The battery management system would have a mass of no more than one Kg.

11. PROPULSIVE LANDING

11.1 Engine Type

*All these specifications were done at Sea-level

Engine Type:	Thrust (N):	Mass (kg):	Fuel:	Specific Impulse (sec):	Length (m):
RL10A-4-2	99,195	198	Liquid Hydrogen & Liquid Oxygen	451	2.286
RL10B-2	110,093	301	Liquid Hydrogen & Liquid Oxygen	465.5	2.197 (stowed) 4.153 (deployed)
Vikas-4B[5]	101,820	900	UH25 & N_2O_4	296.2	1.99
Merlin 1D[6]	845,000	5,633[7]	Liquid Oxygen & Rocket-Grade Kerosene	275	2.92
Raptor	3,050,000	N/A	Subcooled Liquid Methane	334	N/A

[5] "India's VIKAS engines." http://www.b14643.de/Spacerockets/Specials/VIKAS_engines/Vikas.htm. Accessed 15 Aug. 2018.
[6] Merlin 1D engines are used for current missions that use the Falcon 9 first stage booster.
[7] This was taken from the fact that SpaceX's Merlin engine's thrust ratio that exceeds 150. We used 150 to calculate the weight of the engine instead.

Initially, we were considering on using SpaceX's engine that is currently under testing; we thought we would be using the vacuum Raptor engine. These engines as mentioned earlier are considered to be the 42 engines that make up the booster portion of the BFR. Although there have been tests performed by SpaceX, not too many specifications about the engine's performance have been released yet.

Our team also considered the engines that have been created by the company Rocket Aerodyne because they were the suppliers for the Space Shuttle's engines. However, their thrust is not as powerful as the Merlin of the Raptors. In addition, the potential cost would also be beneficial, because SpaceX can create their Falcon 9 boosters every 21 days[8]. Because the company can create the rockets at such a small amount of time, Merlin engines would be a better choice.

However, we decided to go with the Vikas-4B engines. The Merlin engines were our second best option because of its thrust to mass ratio. We prefered the Vikas because its fuel didn't required to be "super-chilled" (the Liquid Oxygen is kept at -340 degrees Celsius throughout the whole 6 month journey to Mars. The chemical fuel wouldn't degrade before the time of landing.

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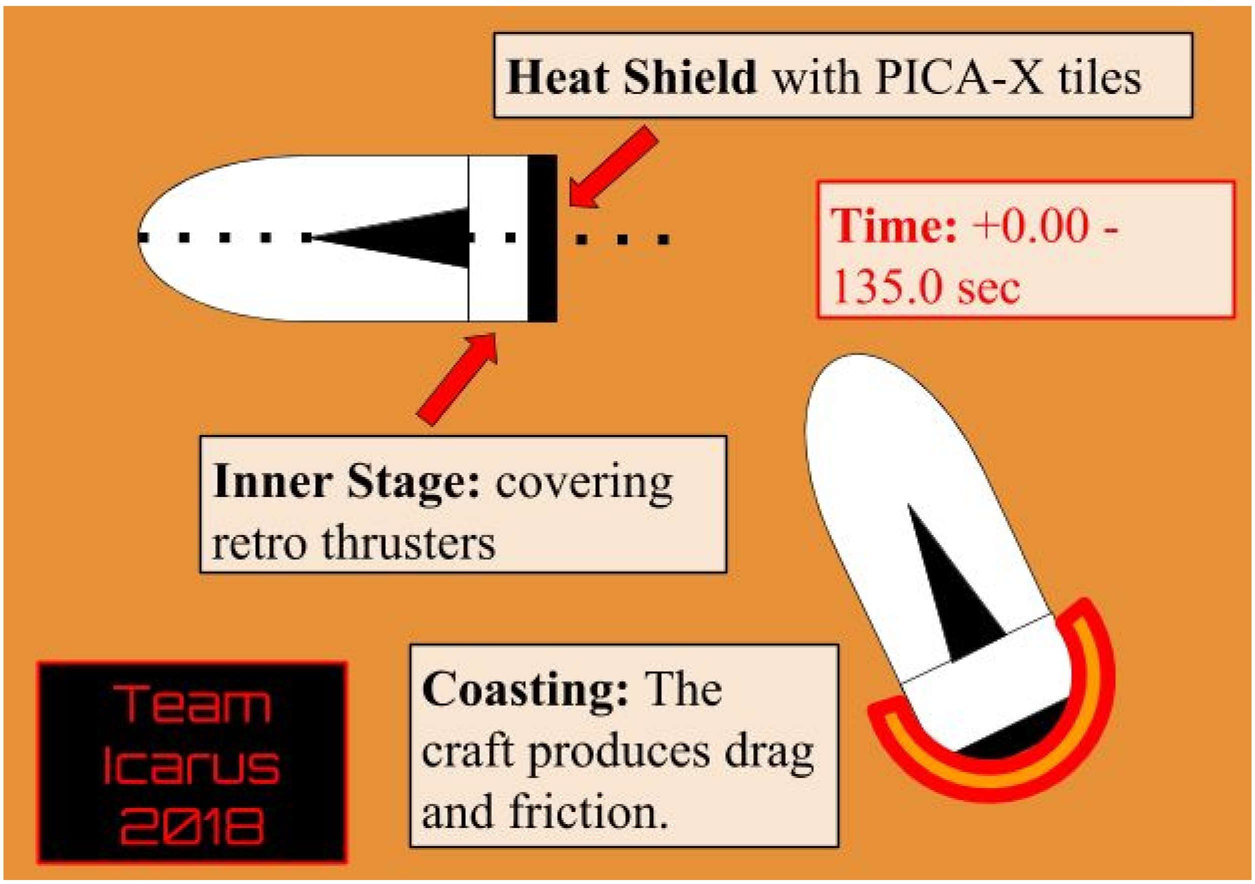
[8] Our team consists of students that are veterans of the Project Lead the Way (PLTW) Aerospace Engineering course. Students were given the opportunity to tour the SpaceX Headquarters in Hawthorne, California (January 2017) and were informed by a Quality Engineering Manager (Ryan Quinnan) that each rocket was made every 21 days.

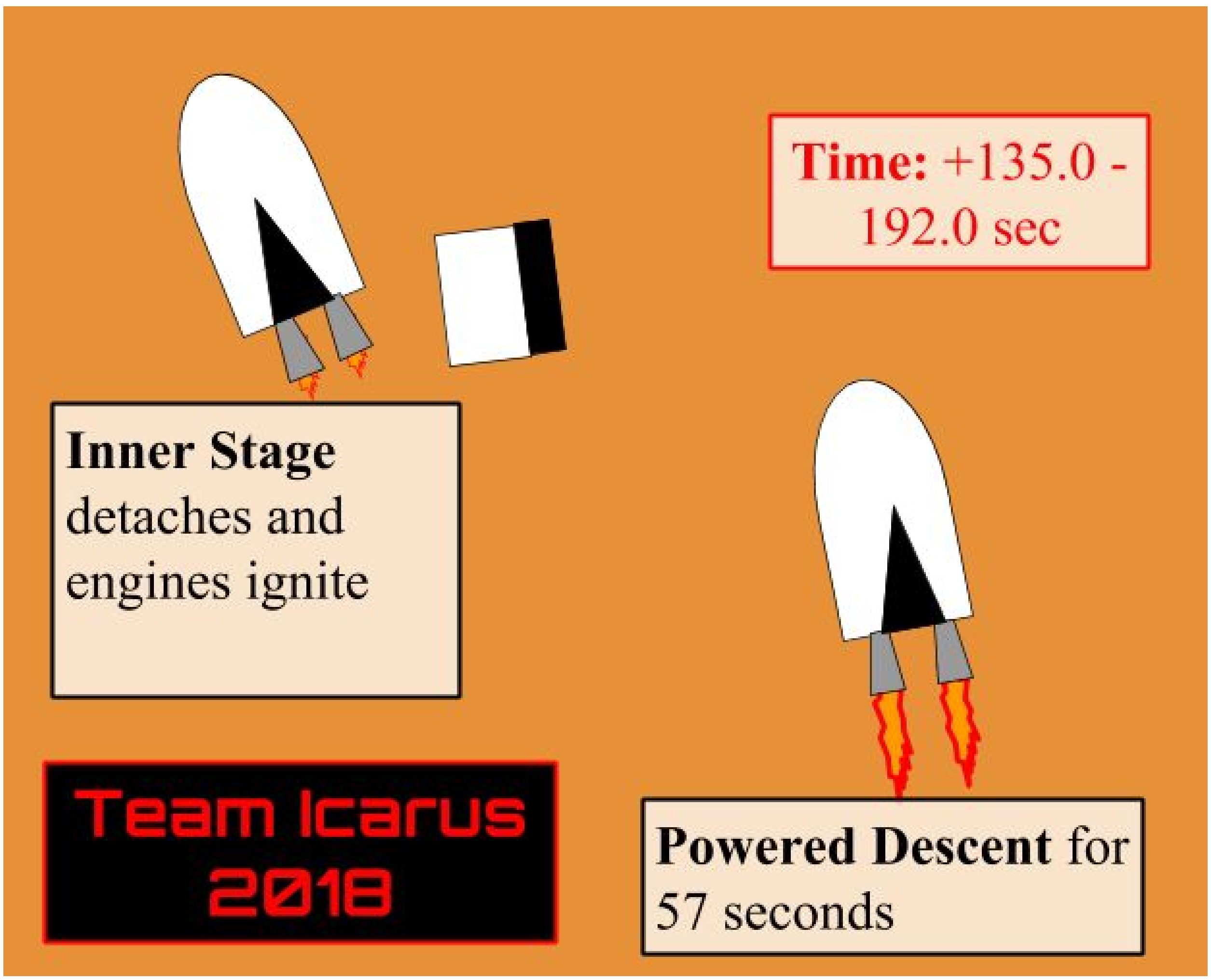
11.2 Phase One: Coasting

After the aerobraking, our rocket would be entering the atmosphere at a speed of 3507.773 m/s. The rocket's initial orientation would be at 0 degrees. As it falls towards the surface of Mars's its bottom would slowly pitch its bottom (where the retro thrusters are) so that it's almost perpendicular to the ground. This gentle coasting will last for about 135 seconds or approximately for 2.4 minutes.



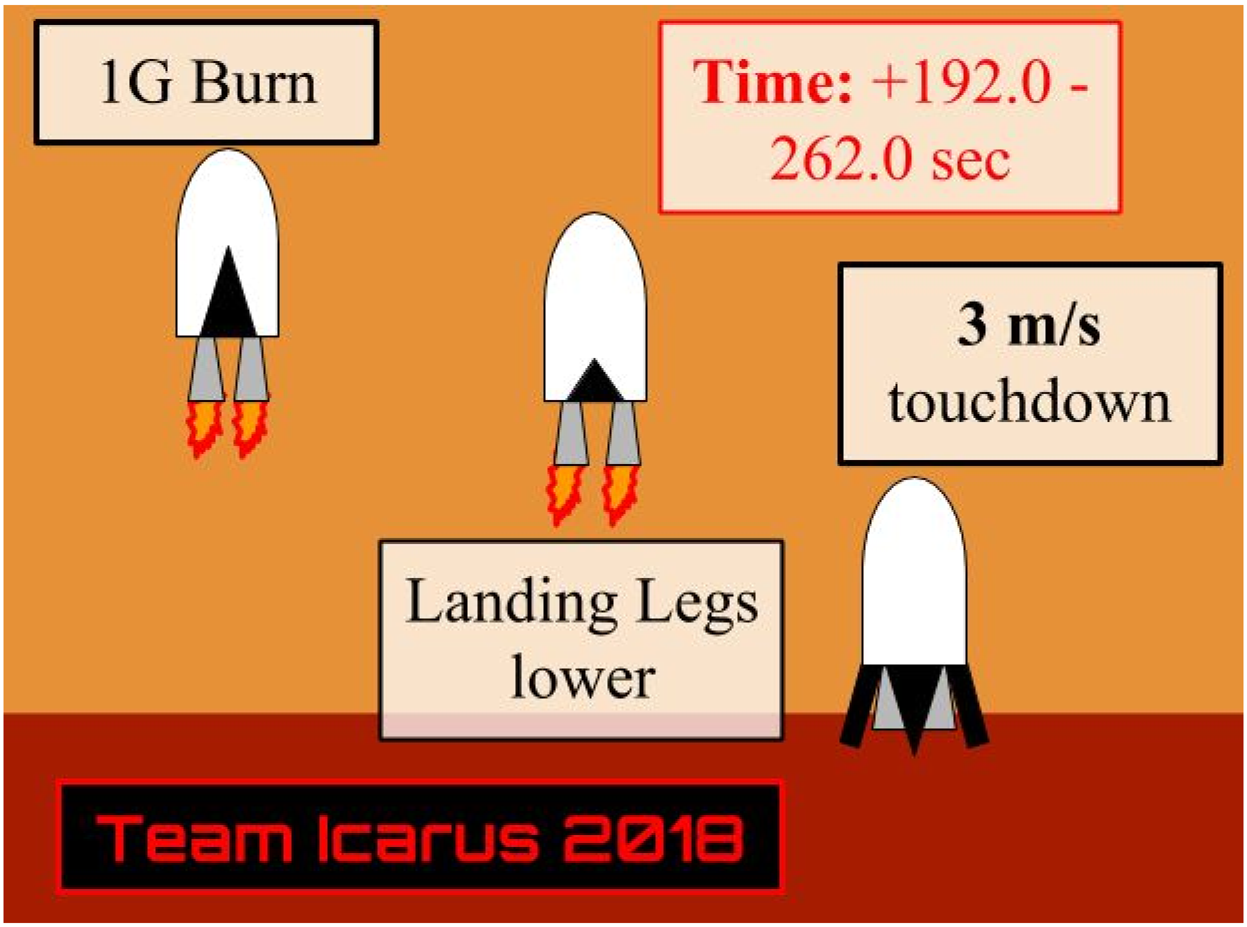
11.3 Phase Two: 5 G's of Deceleration

Next, after the craft has coasted for a little bit, the inner stage then falls off and reveal the Vikas thrusters. The Vikas thrusters would ignite and and produce a thirst that would be equivalent to 6 G's on Earth. This period would last for 57 seconds. The crew on board will be wearing military grade G-force suits to bring down the 6 G's down to a more tolerable 5 to 4 G's. During this burn, all horizontal and vertical velocity components would have been eliminated and it would be easier to maneuver the craft to its preferable landing zone below.



11.3 Phase Three: Landing

After the astronauts have braved a strong descent, the second burn of the Vikas engines would occur. Instead of a 5 G burn, the thrusters would provide a 1.35 G burn for about 70 sec. In the last 20 seconds of the landing, the legs will deploy and help keep the lander upright after the descent with a speed of 3 m/s.



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12. FEASIBILITY

One of the major concerns for this proposal is feasibility, since any mission to mars must be able to be accomplished by 2026. One of the main focuses of this proposal was that every technology that was included was either developed or well into development to ensure that the 2026 deadline was reached. In addition, previous moon and mars missions were consulted in order to see what technologies had been used in what way to ensure that this mission was a success.

In order to ensure the feasibility of communications with the lander, the Ka radio was decided upon as the best way to communicate with earth. Not only has the Ka-band system been tested and used before, but it is expected to become more advanced by the year 2026. In addition, previous mars missions such as the MRO have utilized experimental ka band radios, and have proven that they work.

Power requirements for the modules were able to be met through a series of prototype batteries. While this does not gives us an extremely accurate statistic on the amount of power it will provide, these batteries still meet the power requirements of the lander. Furthermore, given that the power requirements could be met with technology from 2018, it can be assured that energy to mass ratios will only improve as the years add up, greatly increasing the feasibility of meeting the power requirements.

The rocket engine we will be using, the Vikas-4B, is being produced and has been tested in spaceflight. The engine meets and exceeds the requirements for the Martian landing, making it perfect for the mission. SpaceX has demonstrated that their launches have greatly improved their performance after landing each of their Falcon boosters by proving that their thrusters have the ability to reignite again. In addition, improvements to fuel mixtures would increase the maximum thrust that the engine could produce, thereby helping to slow down our lander into the Hellas Planitia crater.

Heat shielding requirements for the entry into the Martian atmosphere is less than that on reentry to earth, due to Mar’s thin atmosphere. This means that heat shields can be reliably built and used. Furthermore, the heat shield proposed in our design has already been tested and used, further making this proposal feasible.

13. SOLAR FLARE/RADIATION PROTECTION

There is a danger that comes to mind when discussing entry into the martian atmosphere and landing on the surface, the radiation involved to get there in the first place. There are different types of radiation, three of which we have to worry about, the first is the radiation trapped in the earth's magnetic field, which we don't have to worry about, the two types of radiation that require necessary protection are solar flares, and Galactic Cosmic Radiation(GCR). A Solar Flare is a celestial event that occurs once or twice every eleven years, the total energy in a solar flare is about 10^21 to 10^25 joules; this event occurs only in the magnetosphere, and since the red planet has a weak magnetic field, the astronauts don't need as much protection from solar flares as they do GCR, GCR is Radiation that distant stars and galaxies emitted, in all directions.

However damaging the radiation is, there are a set of materials that have properties that protect against the damaging properties of radiation. For example, aluminum could provide protection against solar flares, however it can't provide anything against Galactic Cosmic Radiation, lead composite glass is typically used to protect against radiation, however lead itself is extremely heavy, so the typical radiation protection is a material that consists of hydrogen, specifically water.

Water has an interesting property 7cm of water can cut down the radiation by half, using the data found in Peter Echart's *Spaceflight Life Support and Biospherics,* it would take about .32 Sv from earth to the martian atmosphere, with the design incorporated into the lander, the shielding on board consists of 5 cm thick walls, using that thickness in proportions with the 7cm:50% ratio, the water in the walls will cut down radiation by 17.9%, making the .32 Sv to 0.24 sv which makes the effects of radiation on the human body negligible.

Electromagnetism and State physics can tell us how the physical structures for aluminum shielding and the water contained within can reduce radiation. From the sun, we know that a massive amount of radiation (around 99% or so) is given off as ultraviolet or infrared. Electromagnetic waves entering the radiation shielding will have a certain skin depth, a length factor attributed to how quickly the waves would be shrunk after entering the lattice structure of aluminum. With shrunk waves, we have a reduction in amplitude resulting in a reduction in energy seeping through.

Table III.5: Probable Radiation Dose Prompt Effects[27]

Dose(Sv)	Probable effects
0-0.5	No obvious effects; possibly minor blood changes
.5-1.0	Radiation sickness in 5-10% of exposed personnel; no serious disability
1-1.5	Radiation sickness in 25% of exposed personnel
1.5-2	Radiation sickness in about 50% of exposed personnel; no deaths anticipated
2-3.5	Radiation sickness in nearly 100% of personnel; about 20% deaths
3.5-5	Radiation sickness; about 50% deaths
10	Probably no survivors

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14. SAFETY

The astronauts onboard our spacecraft need to be in good condition. In other words, astronauts need to maintain normal body weight and BMI and meet the amount of nutrition and calories the human body requires. So we recommend, eating healthy, sleeping enough, and exercising, prior to our launch. Not only do we need astronauts to be in the best shape they can be, we also recommend only drinking water and nothing else. We only recommend water for liquids because, water is the most effective drink for tearing down fat and it maintains a balanced ratio between testosterone and estrogen. Maintaining a balanced ratio between testosterone and estrogen would benefit an astronaut by keeping their mind clear and their body functioning properly and not fatigued. As a result, we would recommend starting a healthy lifestyle as soon as possible.

On the spacecraft it's of utmost importance for your body to function properly because, especially in space where the air is so thin. We need astronauts to be able to prevent being diagnosed with psychological diseases. Psychological diseases include PTSD, OCD, etc.

As for the G's experienced during the landing, at a max of around 6 Gees, the maximum g force experience by the astronauts is less that that experienced by the Apollo 16 crew, as they experienced 7 Gs of force. In addition, special G suits currently manufactured can increase human tolerance by one. By 2026, it is believed that this tolerance will be increased to two Gs, making the net G force experienced by the astronauts to around four Gs. This is about the same as that on a rollercoaster, and is highly manageable.

Considering the fact that should the power on the lander run out, the astronauts will be stranded, a large amount of power will be created and stored by the lander. The lander by our estimations requires about 12Kwh minimum to operate, and by including larger than needed batteries and solar arrays, we can ensure that the lander will always have more power than it needs.

15. SCHEDULE

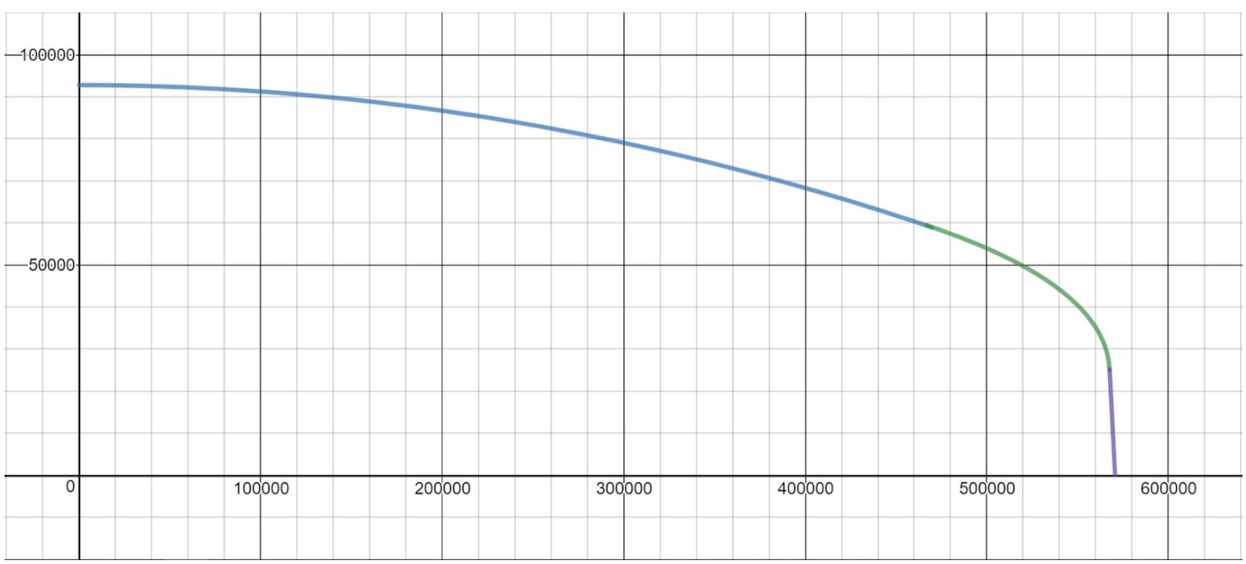
15.1 Entering Atmosphere

After completing the aerobraking maneuver completing one orbit of the parking orbit, it is time to begin the final approach. Prior to final descent, the rocket make make a small burn which puts it into a sub orbital trajectory. This new trajectory will have the craft experience enough atmospheric drag to put it into a ballistic trajectory into Hellas Planitia.

15.2 Attitude Control

During the final descent, altitude will be controlled by 18 cold gas thrusters situated on the outside of the lander that will permanently calculate and adjust the amount of thrust needed to maintain the desired altitude. Each four will be able to control pitch, roll, and yaw. The lander should be able to orientate itself in a matter of seconds or minutes while the craft is in transition from the deorbit to entering Mars' atmosphere.

15.3 Deceleration and Powered Descent



Pictured above is a 2D position-time graph showing the path that our lander will take in order to land.

Position-time Graphs

$$\left(-0.185t^2 + 3505.773t,\ -1.856t^2 + 83767 + 9000\right)$$

$0 \le t \le 135$

$$\left(-29.583t^2 + 3456.193t + 466756.974, -1.829t^2 - 497.274t + 50440.664 + 9000\right)$$

$0 \le t \le 57$

$$\left(-0.022t^2 + 83.731t + 567644.808 - \frac{1.12}{2}t^2, -1.672t^2 + \frac{13.2455}{2}t^2 - 705.78t + 25153.625\right)$$

$0 \le t \le 71$

These are the equations used to represent the 3 stages that our lander will execute.

As shown above, the graph represents the 2D path in which our lander would take from Martian space to the Martian soil. After the deorbit burn, the rocket will be coasting (the blue line) for 135 seconds. After the 135 seconds, the rocket fires its engines at max thrust, producing up to 6 G's of deceleration, with the intention to remove all velocity in the x-direction. Once this 57 second engine burn is complete, the rockets reduce their thrust to create 1.3 G's of deceleration (the orange line). This 70 second phase would cancel out what remains of the x-direction velocity and all the y-direction velocity. At the end of the burn, the rocket will have touched down.

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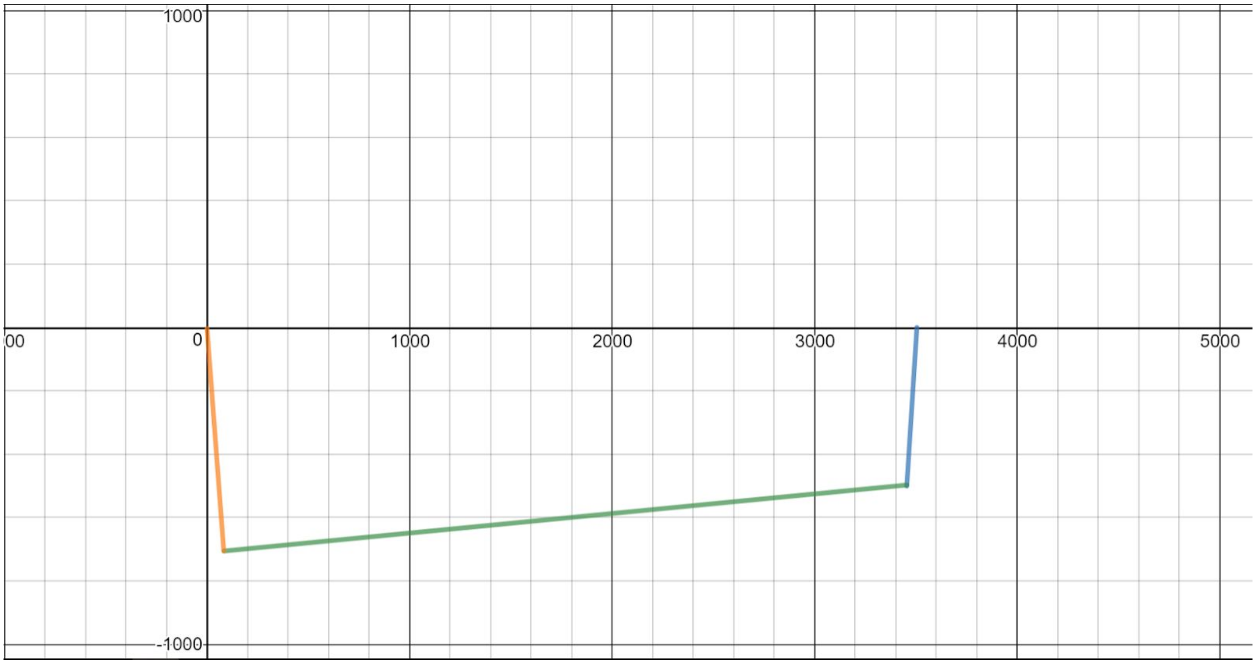

The graph above shows the velocities during decent in both the x and y direction (Velocity-time graph)

5 Velocity-Time Graphs

6

$$((-0.37t + 3505.773),(-3.712t))$$

$0 \leq t \leq 135$

7

$$(-59.166t + 3456.193, -3.658t - 497.274)$$

$0 \leq t \leq 57$

8

$$(-0.044t + 83.731 - 1.12t,\ - 3.344t + 13.2455t - 705.78)$$

$0 \leq t \leq 71$

Above are the vectors for velocity during the time of descent

The blue line is the speed in both the x and y directions. So during the first part of decent, the craft picks up negative velocity in the y-direction, but loses some speed in the x-directions due to atmospheric drag. That particular part of descent is about 135 seconds. Then after that 135 seconds, the green line shows the massive loss in x-direction velocity for 57 seconds. During this first burn the rocket experiences up to 6 G's worth of deceleration with the task of cancelling out most of the velocity in the x-direction. Then during the final burn, the orange line, the lander performs a burn which would put the laner at approximately 2.926 m/s as the lander touches the Martian soil.

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16. VISUALIZATION

At the start of this project, we had several ideas about how to best design a vehicle capable of landing on Mars with its payload of 10 metric tons. We had two similar designs, but varied slightly on the final descent and landing. One used parachutes a retropropulsion landing, while the other planned on using large lifting gas (ie. Helium) balloons and an airbag for landing. After several days of debate and suggestions, we created out final design based on parachutes and a retropropulsion landing. Many members of our team felt the lifting gas balloons and large inflatable airbags for landing we not as reliable as they were intended to be.

Our final design for this project is quite similar to the SpaceX BFR. The similarities are of pure coincidence, but we felt that the design we have created is the best way to complete the mission at task. The current design has three parachutes built in towards the nose of the rocket. Three Vikas-4B engines are going to slow our craft down to land onto the surface. Those three engines are housed inside the interstage, as seen on the bottom of the craft.

17. COST BREAKDOWN

System Cost = αQβMΞδSε(1/(IOC-1900)) BΦγD   (John Space Center)

Variable:	Value Given:	Value
Q (Quantity)	Number if engineering development units, mock-ups, simulators, ground-test articles, flight test articles, and production vehicles	6
M (Mass)	Dry mass of vehicle in lbs	84,000 lb
S (Specification)	Constant for a planetary lander	2.46
IOC (Initial Operating Capability)	The system's first year of operation	2027
B (Block)	Level of design inheritance	1
D (Difficulty)	Between -2.5 to 2.5 on increments of 0.5 (-2.5 being easy and 2.5 being extremely difficult)	2.5

Cost Breakdown

Item	**Cost**
Lander	$127 B
Fuel	$1.3 M
Rocket Engines	$30 M

Potential Total: $127,000,000,000

The cost of 127 billion dollars seem very high because the cost is in terms of the John Space Center with consideration of inflation. The cost is reasonable once it is based upon federal money, not the NASA budget.

18. MASS BREAKDOWN

Item	Notes	Mass
Lander	Aluminum-Lithium Alloy	11, 680 kg
Fuel	UH-25 and N_2O_4	76,000 kg
Rocket Engines Reaction Control System	3 Vacuum Vikas-4B Engines 18 R-4D thrusters	2,700 kg 130 kg
Radiation Protection	Water	9, 700 kg
Heat Shielding	Heat blankets and PICA-X tiles	3,000 kg
Micrometeorite Protection	2 Aluminium Plates, Kevlar, Nextel, and MLI	110 kg
Communication Systems	Multiple antenna and systems	130 kg
Power	Solar arrays and batteries	450 kg
Payload	10 metric ton payload	10,000 kg
Terrain Navigation System	Multiple radar cameras and systems	200 kg

Total: 114,000 kg

19. CONCLUSION

As of today, trying to land a craft on Mars is challenging. The planet has atmosphere that is remarkably thin, just 1% of Earth's atmosphere. This highly thin atmosphere gives little in the help of deceleration by atmospheric drag or by parachutes. The most efficient way to possible land anything on Mars is through a powered descent and landing.

There are multiple solutions to the issue of landing a human rated payload, but it's currently not available because there hasn't been technology to handle that, yet. As mentioned before, only unmanned missions have been able to land successfully on the surface of the red planet. The atmosphere was the big factor to allow a design capable of landing a large payload while having enough safety to ensure that the human payload would survive. It seemed that a descent with parachutes and a heat shield would work, but the air density of Mars is about 100 times less than Earth's.

We had various design ideas. Initially we were thinking of using a sky crane to drop the payload after it had descended towards the surface. That idea was eventually thrown out because the sky crane couldn't be reused because it would crash at a distance away from the landing sight. Therefore, a different approach was necessary.

Also, the parachutes were later deemed unnecessary after some further final calculations. Our calculations showed that the whole lander would be slowing down, but its speed would remain closely to the same as its initial velocity when entering Mars atmosphere. In addition, the parachutes would have been cut off and flown away. Potentially, the diameter would have been around 20 m or more. That would have been a big waste of time and energy into making parachutes that would only be a one time use. Instead, we found out that a powered descent using our retro thrusters would be more efficient.

With attitude control, we can have our craft enter the atmosphere at a certain angle then fire our retro thrusters so that it can get rid of all vertical and horizontal velocities. That way, our lander can be facing vertically and land our cargo and crew safely into the crater, Hellas Planitia.

And lastly, we would like to extend a special thanks for Mr. Turek, Cerritos High School's PLTW Aerospace Engineering teacher and physics teacher for informing the members of Team Icarus for this design competition. In addition, we also really appreciated the work with our team member Kevin Tan, (our college mentor) in making sure that our group remained on task and offered tips to find out solutions to our proposal.

20. DESIGN OUTLINE

1. Engine Configuration
    a. 3 Vikas 4B Vacuum Engines
        i. Triangular Pattern with all engines capable of gimbaling
2. Power Breakdown
    a. Communication Systems (Radio receivers and transmitters) - 40 Watts
    b. Life Support Systems (Thermal protection, lighting, hygiene, etc) - 17 Kilowatts
    c. Spacecraft Control Systems (RCS thrusters, sensors) - 2 Kilowatts
    d. TRN Equipment (SAR cameras, sensors) - 1.5 Kilowatts
    e. Misc (Onboard computer systems)
3. Heat Protection
    a. Space Shuttle's Heat Blankets
        i. Advanced Flexible Reusable Surface Insulation Blanket lined inside craft
        ii. Absorbs heat and can endure 3000°F (1650°C)
4. Micrometeorite Protection
    a. Outside of the craft (on top of the heat shield)
    b. When entering the atmosphere of Mars, the micrometeorite protection would melt to expose the heat shielding to then further protect the payload and crew from burning up in entry.
5. Radiation Protection
    a. 4 cm of water around payload bay (28.5% decrease in radiation exposure)
    b. Reduces radiation exposure to 180 mSv for 6 month trip.
    c. Craft will rotate to facilitate temperature control
6. Mass Breakdown
    a. Mass Breakdown by Parts

Item	Notes	Mass
Lander	Aluminum-Lithium Alloy	11,680 kg
Fuel	UH-25 and N_2O_4	76,000 kg
Rocket Engines	3 Vacuum Vikas-4B Engines	2,700 kg
Payload	10 metric ton payload	10,000 kg
Power	Solar arrays and batteries	450 kg
Terrain Navigation	Multiple radar cameras and	200 kg

System	systems	
Communication Systems	Multiple antenna and systems	130 kg
Reaction Control System	18 R-4D Thrusters	130 kg
Radiation protection	Water	9,700 kg
Heat Shielding	Heat blankets and PICA-X tiles	3,000 kg
Micrometeorite Protection	2 Aluminium Plates, Kevlar, Nextel, and MLI	110 kg

b. Mass Breakdown by Systems

System	Mass
Primary Systems	100,380 kg
Sub-Systems	910 kg
Protection Systems	12,810 kg

c. Total Mass: 114,000 kg

7. Mission Debrief
    a. Aerobraking
    b. Re-entry
    c. Powered Descent
    d. Landing
8. Schedule (Aug 26, 2018 - Dec 31, 2026)
    a. Planning and Design(9/1/18-4/9/19)- From the time from the proposal to the presentation, we've noticed some issues with our initial design. There were some values that we didn't take into account. For example, our lander didn't include drag when descending Mars's atmosphere. Once we've finally had some affirmation that our plan is feasible, we would then have to do even further more research. It is possible that we may have overlooked some items that will help our lander operate with no error.
    b. Tech Development(12/5/18-1/17/24)- There are a lot of unknowns involved into making this lander. For one, there isn't a lander that is available in the

commercial market to use. Thus, there needs to be a way to figure what adjustments must be needed to ensure the lander will properly function and prevent casualties from happening. One example would be figuring out how to place the PICA-X tiles into a configuration that will cover the Icarus. In addition, there needs to be development of the terrain navigation system to ensure that our craft will be able to fire the right amount of thrust at a certain time. If too little is put at the wrong height, the lander will face certain trouble. As a result, the extensive amount of time is needed to develop the technology for Icarus.

c. Tech Testing(1/10/20-5/16/25)- Once the design is proved to be safe and passes all reviews, such as Critical Design Review, the systems including electronic, communications, navigation, engine, and landing systems can be tested to ensure that all software and hardware operates all processes and information correctly.
d. Spacecraft Production(2/21/23-4/10/25)- As the technology required for this lander are finishing their tests, the simulator, flight test article, and the production model are being produced. These three models begin production at the same time, but the emphasis is completing the version before it (in other words: the simulator is built first, then the flight article, and finally the production model). This allows for the engineers to overcome any challenges met during production of the simulator or the flight test article and apply the changes to the final production model.
e. Spacecraft Testing(3/26/24-6/15/26)- After the completed building of the simulator, flight test article, and the production model, the technology is being installed. After the installation is complete, the engineers move on to test the newly equipped models. Should any flaw occur, changes can be made prior to the fitting and testing of technology in the production model.
f. Final Preparations(7/15/26-12/30/26)- All equipment and systems are check for the last time. The payload is moved to check for its final pre-launch preparations before being moved. Once a successful conclusion for qualifications is made, the spacecraft is moved to launch site.

9. Aerobraking
    a. Periapsis velocity at 98.686 km is 5.786 km/s while the craft is still on its hyperbolic trajectory.
    b. Delta v brake from aerobraking is 2.288 km/s
    c. This brings the craft to an orbital velocity of 3.498 km/s.
    d. The extra 200 m/s of delta v gives us about 9% margin for error
    e. We also chose to put the Icarus in a 90 degree (polar) orbit. This means that the delta v calculations will be the most accurate.
    f. Also, this way the Icarus or any future craft will be able to choose any part of Mars to land on.

10. Cost of Lander

a. System Cost = αQβMΞδSε(1/(IOC-1900)) BΦγD   (John Space Center)

Variable:	Value Given:	Value
Q (Quantity)	Number if engineering development units, mock-ups, simulators, ground-test articles, flight test articles, and production vehicles	6
M (Mass)	Dry mass of vehicle in lbs	84,000 lb
S (Specification)	Constant for a planetary lander	2.46
IOC (Initial Operating Capability)	The system's first year of operation	2027
B (Block)	Level of design inheritance	1
D (Difficulty)	Between -2.5 to 2.5 on increments of 0.5 (-2.5 being easy and 2.5 being extremely difficult)	2.5

b. Cost Breakdown

Item	**Cost**
Lander	$127 B
Fuel	$1.3 M
Rocket Engines	$30 M

c. Total: $127 Billion[9]

i. This total is possible through federal funding

ii. The cost of 127 billion dollars seem very high because the cost is in terms of the John Space Center with consideration of inflation. The cost is reasonable once it is based upon federal money, not the NASA budget.

iii. If the cost is based off the Big Falcon Rocket by SpaceX, the approximation of the cost will be about 10 billion dollars.

[9] Based on the Johnson Space Center's Advanced Missions Cost Model. If the same craft were made in a private company, it would cost approximately $10 billion. This estimation is based on the SpaceX BFR which Musk claims can be with at most $5 billion. "SpaceX signs up Japanese billionaire for circumlunar BFR flight ...." 17 Sep. 2018, https://spacenews.com/spacex-signs-up-japanese-billionaire-for-circumlunar-bfr-flight/. Accessed 29 Oct. 2018.

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