Time Capsule to Mars Overview

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ABSTRACT

Time Capsule to Mars aims to land a globally-populated digital time capsule on the surface of Mars in the next five years. Sponsored by Explore Mars this entirely student led mission spans across the nation utilizing the diverse talents of multiple universities including Duke University, Stanford University, Florida Institute of Technology, Embry Riddle Aeronautical University, Georgia Institute of Technology, University of Colorado at Boulder, and Massachusetts Institute of Technology. Each university is responsible for a specific subsystem of the project. These subsystems span over categories including propulsion, structures, communications, avionics, guidance, navigation, control, and entry-descent and landing. The management structure of this program revolves around weekly correspondence with professional advisors and representatives from Boeing and national aerospace industry leaders which creates a technologically sound feedback loop that our team can learn from and use to achieve success. The mission plans to launch in the next four years, with a price tag of several million dollars. This paper details the technologies and systems mentioned above, but more importantly how they could be conscientiously integrated into the efficient, low cost, high reliability Time Capsule to Mars CubeSat.

INTRODUCTION

Time Capsule to Mars is an entirely student-led mission to land a globally-populated digital time capsule on the surface of Mars in the next five years that is sponsored by Explore Mars. The payload will be transported by CubeSat architecture, while simultaneously affording a test-bed of novel technologies seeking to enable more efficient and safe interplanetary travel. Each subsystem is owned by a university team of undergraduate/graduate students with faculty advisement. The result is a compilation of some of the most cutting-edge technology nationwide. The MIT Space Propulsion Lab is developing ion-electrospray propulsion for low weight, cost, and energy space travel. Aerogel is being explored as a method of extending the lifetime of the micro-thrusters on the order of the thousands of hours needed for interplanetary travel. The Duke University structures team is developing a combined thermal control-radiation shielding system through primarily unique layering of thermal Multi Layer Insulation (MLI), selectively emissive material, and aluminum. Auxiliary research is being explored regarding the potential of running the accelerated ions of the propulsion system through a solenoid network (directed by superconducting magnets) before kicking them out the back for the required momentum boosts. Such could create a magnetosphere capable of deflecting the deleterious charged particles that frequent interplanetary space. Further, the excess heat from avionics in the system could be applied toward accelerating the ions. The possibility of synthesizing the propulsion, thermal, and radiation shielding systems to create one mega-system that makes the best use of energy is the primary goal of the magnetosphere research. Toward the Entry-Descent and Landing end, Georgia Institute of Technology and the University of Connecticut are working together towards designing a passive and self-aerobraking payload to safely transport the time capsule to the Martian surface, where it must remain intact on the order of thousands of years. Within the next few years, our newly developing subsystems including unique trajectory design and communications (University of Colorado at Boulder), power and avionics (Embry Riddle Aeronautical University) and the systems engineering to bring everything together (Florida Institute of Technology). A highly desired objective of the mission will be to gather valuable scientific data regarding the space environment and how it could affect human travel to Mars, which is being led by the Space Environment and Satellite Systems (SESS) lab at Stanford. The program management structure affords weekly correspondence with Boeing representatives and other industry advisors, creating a strongly educational and technologically sound feedback loop for this unprecedented CubeSat mission. In addition to the college students leading the way, there is continual outreach to K-12 to foster excitement about science, technology, engineering, and mathematics (STEM).

PURPOSE & TEAM SUMMARY

The purpose of this project is to be able to integrate many low level technologies and bring together a multi-university team to be able to design, build, and launch a CubeSat to Mars containing a time capsule. This effort is being spearheaded by leading space universities in the nation in order to break down the project into more manageable portions so that the rigorous timeline can be met. The Massachusetts Institute of Technology is working on the Guidance, Navigation, and Control (GNC) scheme as well as the propulsion subsystem. The University of Connecticut at Storrs is working on the descent stage into Mars. Duke University is working on the spacecraft mechanical, thermal management systems, and radiation protection systems. Georgia Institute of Technology is working on the entry, descent, and landing phase and designing the outer mold line to ensure that the payload remains intact. Embry Riddle Aeronautical University is working on the avionics and descent stage of the spacecraft. The Florida Institute of Technology is working on systems engineering, assembly, test, and launch operations. The University of Colorado at Boulder is working on trajectory design, communications, and the mission operations. Stanford University is working on the scientific payload of the mission.

SUBSYSTEMS FURTHER DEFINED

The Massachusetts Institute of Technology is working on the Guidance, Navigation, and Control scheme as well as the propulsion subsystem of the project. The GNC design is being worked on by a graduate student sponsored by Draper Laboratory. Different levels of autonomy for interplanetary travel will be examined, comparing combinations of optical, inertial, and ground support navigation updates. A Guidance Control scheme has been developed for trajectory maintenance to nearby waypoints. To increase autonomy, a Guidance Navigation scheme is under development to understand the accuracy profile of onboard navigation and the implementation of Trajectory Correction Maneuvers (TCM). Desired accuracy levels for specific regions of interest will be identified ahead of time as major waypoints and would be targeted. The use of these targeting sequences in conjunction will lower the dependence on ground support as well as serve as backup system for unexpected communication outages. During planned communication segments the trajectory may be revised as needed based on system performance. Integrating this system together with the avionics and the communications system is a challenge that is being addressed by systems engineering team at FIT who is currently examining this at the requirements level. The team is currently ensuring that all the channels of communication are open, and also ensuring that the avionics team is able to understand the full scope of the requirements and the necessary hardware requirements that are needed in order for the GNC team to be able to navigate. The integration and the requirements tracking is being handled very carefully to ensure the requirements are being communicated to each of the specific subsystems. For example, the placement and number of star trackers is being examined right now and the systems engineering team is making sure that the placement number is the exact amount necessary. The main performance metrics, volume, mass and power, are being examined for the placement of the star trackers. Other systems engineering responsibilities for the integration that are being looked t are the amount of code and the requirements for the code and logic.

The MIT team is developing the propulsion system. This system is an ion electrospray propulsion technology that uses an ionic liquid to provide the necessary change in velocity to reach Mars. This works by an electric field to extract and accelerate heavy ions from the ionic liquid. The efficiency and the specific impulse is being improved upon to provide the necessary thrust, duty cycle, and the velocity change that is needed in order to reach the final destination. The systems engineering team is working closely with the team at CU Boulder, the GNC team, the avionics team, and the thermal team to ensure that the propulsion system will have all the requirements that it needs to operate. The team is currently examining the placement and the thermal requirements needed to ensure that the propulsion unit is able to function throughout the mission. This includes working with the trajectory team to determine what they deem as the minimum specific impulse and duty cycle that the propulsion system must be able to meet to reach the final destination. The systems engineering team is working with these two teams to determine the optimum characteristics of the propulsion system that ensures a timely arrival while also maturing the technology to a reasonable level without an extreme cost. The systems engineering team is working with the mechanical structures team to ensure that the propulsion subsystem remains at the correct temperature and to determine ways of attaching the system to the structure without compromising any structural integrity and ensuring that the propellant does not leak into other areas of the spacecraft.

The University of Connecticut at Storrs team is currently working on designing the interior of the lander and the payload memory storage options. They are working in conjunction with the Georgia Institute of Technology who is developing the outer mold line and the decelerator for re-entry. The Georgia Institute of Technology is currently examining three specific options for this a spherical shell, a 45-degree sphere cone, and a hypersonic inflatable aerodynamic decelerator. These options are still being evaluated in conjunction with mass, volume, power, and current avionics requirements on the spacecraft to determine which would be the most feasible. The systems engineering team at FIT is working with both University of Connecticut, Georgia Tech, and Embry Riddle to determine the final masses and volumes. The current optimum is a 45-degree cone, which has a landing impact limit of 50g's and a 30% mass margin. However, efforts are being made to reduce the mass to allow for more mass of the other systems. The systems engineering team is approaching this currently from a requirements view point and also an overall system view of the mass and volume maximum allowable values. The systems engineering team is working with University of Connecticut to determine what memory storage options would be able to meet the planetary protection requirements on top of being able to meet the requirements for reentry and longevity requirements. The memory storage is the most complex part of the project and requires close attention. The systems engineering team is helping the payload subsystem by ensuring that the longevity, planetary protection, reentry, interplanetary travel, and memory density requirements are being properly communicated and documented so that the team is kept up to date.

The team at Embry Riddle team is currently examining different options for flight computers and the requirements necessary for deep space survivability. The requirements that must be met for the subsystem are complex and include many different subsystems that requires examining what are the best options. The team is examining using a COTS option and designing a custom flight computer. There are tradeoffs being conducted between the two and The systems engineering team is working with Embry riddle to determine the requirements that are being used for evaluation and the heritage of some of the systems being evaluated. The software and hardware requirements being put on the subsystem team is being fleshed out so that the exact requirements are known by subsystem team. The systems engineering team is working on integrating in the requirements and also determining the amount of cabling that would be needed in order to accomplish the goal. The systems engineering team is ensuring that there is room for cabling in the mass and volume budgets and that the computer and power supply are placed in the ideal locations for mass balancing and also for reducing the amount of cabling that is needed throughout the entire mission.

The FIT team is currently evaluating different options for the assembly, testing, and launch operations as well as the systems engineering roles. The team is currently designing and planning for multiple launch vehicles in case that the primary one is not available to be launched on. The team is getting ready to start validating and verifying of requirements that will be needed. Verification and validation methods are being evaluated and the team is working on consolidating the tests and simulations that will need to be run to the bare minimum to account for the shortened schedule. The team is also working with the Boeing Emerging Leaders Development Program that are assisting the team in the systems engineering and the scheduling of the program. The systems engineering team is starting to develop schedules for each individual subsystem that will help the subsystems see the overall picture as well as the timeline that the teams must be kept on in order for the project to be on time.

The systems engineering team is currently trying to integrate the requirements and help with selection choices so that the design options are known and the cascading effects of the design choices are known to the other subsystems. The different teams from leading space universities around the nation are collaborating together to design an interplanetary CubeSat.