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AERODYNAMIC DECELERATOR ATMOSPHERIC-ENTRY MODULE (ADAM) FOR MARS

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ABSTRACT

Mars has been a planet of interest to astronomers since time immemorial and even the ancient Indian writing 'Hora Sastra of Brihat Parasara' depicts Mars as 'Bhumiputra' meaning son of Earth. Since the time of Mariner.4, man-made machines pass the atmosphere of Mars to get a glance of the hidden science, and currently Curiosity surveys the surface and subsurface in search of cause of disappearance/future possibility of life.

ADAM is an atmospheric entry module that safely delivers micro/mini probes/payloads to Martian surface, weighing from minimum 5 kg to 15 kg net weight relevant for small scale researchers and explorers. The module is conceptualized in the configuration of a stretched sphere (tear drop shape during its atmospheric entry) and the rear cone separates out during the parachute deployment transforming the module to a sphere. This sphere drops down decelerating, aided with three thrusters to bring down the velocity to near zero value for a safer touchdown. Visco-elastic materials serves as shock absorbers to prevent impact load transfer to the payload inside.

The concept can be analogous to the advent of mini-satellites orbiting planet earth for short term studies and owned by knowledge enthusiasts. Thus vide this paper authors are trying to open new horizons for such aficionados to Martian surface.

INTRODUCTION

Since early 1960's a series of probes were launched to understand the red planet, both as fly-by or atmospheric entry modules. Of the pioneering efforts, Mariner-4 from NASA has been the first successful fly-by. The information about the mystery red planet started refined through Mariner-9 of NASA, Mars-2 and Phobos of USSR. Mars-3 and Viking have provided the edge of soft landing on martian surface.

A series of missions flew towards mars since then and few successful (both fully and partial success) such as Mariner, Vikings and Mars express have increased the quest of explorers around the world to accept the challenges of the mysteries of the journey to the planet. This has resulted in bold attempt of lander missions like Mars pathfinder, Mars Exploration Rovers spirit and opportunity, Mars Science Laboratory curiosity, and orbiters like Mangalyaan, MAVEN, ExoMars TGO etc.

Mars has been a planet of interest to space enthusiasts since time immemorial and even the ancient Indian writing 'Hora Sastra of Brihat Parasara' depicts Mars as 'Bhumiputra' which means 'son of Earth'. As explorations mentioned above proves with surprising results everyday that Mars was once similar to Earth with flowing water and was rich with life forms. More expeditions and once human landing can be justified on the urge to know the fate of the planet to the current state. Since the time of Mariner.4, man-made machines pass the atmosphere of Mars to get a glance of the hidden stories about Mars. Currently, curiosity surveys the surface and subsurface in search of cause of disappearance/future possibility of life, which can be a forerunner for upcoming human touchdowns on the red planet.

When the world is looking up for carrying heavier payloads that equates massive laboratories and robotic systems for explorations, this paper aims at providing a career platform for small scale concept evaluation probes of scientists. Authors are trying to present a small payload delivery system which is capable of delivering safely and accurately on to mars surface. The concept can be analogous to the advent of mini-satellites orbiting planet earth for short term studies and owned by knowledge enthusiasts. Thus new horizons for such aficionados, to Martian surface is opened vide the concept presented in this work.

CONFIGURATION

As the title suggests, this paper aims primarily of an atmospheric entry probe undocked from the mother spacecraft orbiting the planet and that enters the Martian atmosphere decelerating itself to a near zero touchdown velocity on the surface of the planet. A spherical configuration is proposed for the probe having an overall weight of 15 kg with the payload inside.

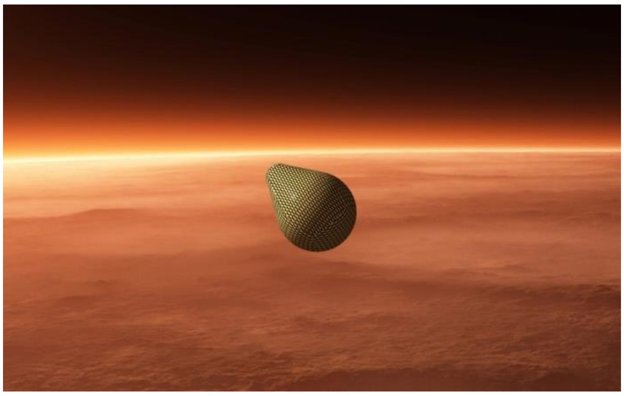

Figure 1. AERODYNAMIC DECELERATOR ATMOSPHERIC ENTRY MODULE (ADAM) ENTERING MARTIAN ATMOSPHERE

The Aerodynamic Decelerator Atmospheric entry Module, abbreviated as ADAM (refer Figure 1) consists of an outer aeroshell in the shape of a stretched sphere (tear drop shape) which is capable of resisting the entry and descent and landing loads in the form of pressure and temperature. A multiple layer of Thermal Protection System (TPS), insulating interlayer which prevents heat transfer to inner shell, a visco-elastic shock absorbing layer and the payload are the various parts of the probe. A decelerator system consisting of parachute and thrusters is also housed inside the Aero Thermo Structure (ATS).

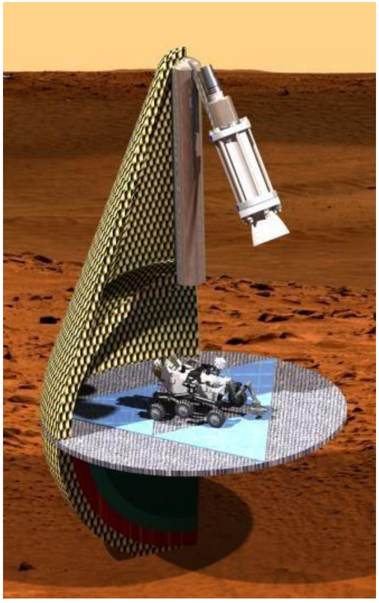

Figure 2. CONFIGURATION OF ADAM: VIEW DEPICTING VARIOUS COMPONENTS

The ballistic advantage of spherical shape is being utilized while configuring the ATS.

Spherical portion diameter: 0.50 m

Parachute diameter: 1.50m

Projected area of probe: 0.20 sqm

Projected area of probe-parachute: 1.77 sqm

Drag coefficient of probe alone: 0.50

Drag coefficient of probe-parachute system: 1.40

Ballistic coefficient of probe: 152.79 kg/sqm

Ballistic coefficient of probe-parachute system: 6.06 kg/sqm

Scientists across the world are on a constant pursuit to optimize the journey from earth to mars for an expedition probe. As known, the synodic period of mars has been found as 780 days, which is the duration of minimum-energy launch windows for a Martian expedition. Any trajectory to another planet involves three phases: Escape from the Earth’s gravity well, a transfer orbit, and arrival at the other planet orbit. India’s Mars Orbiter Mission-1 (MOM-1) adopted a Hohmann transfer orbiter which is a highly efficient transfer as it travels through 180° of true anomaly that allows the satellite to achieve maximum ΔV for minimum fuel consumption. When transfer variables like launch window or transfer time are significant over ΔV in some missions, type I trajectory (travels through less than 180° of true anomaly) or type II trajectory (travels through greater than 180°). On completing transfer orbit, it can execute flyby, orbit or land.

Eventhough the transit velocity approaches 10.00 km/s, the orbital velocity of martian spacecrafts for an average perigee of 500 km, after proper thruster breaking arrives as 3.50 km/s. Firing liquid apogee motor / thrusters continuously can impart minus ΔV, further reducing the velocity to the order of 2.0 km/s.

Considering a scale height of 11.1 for mars, and an angle of attack of minus 3° at altitude of 200 km as entry height, the following parameters are calculated.

Entry velocity at 200 km altitude: 2000 m/s

Maximum deceleration: 11.5 m/s (3.28 ‘g’)

Altitude of maximum deceleration: 20.40 km from surface

Velocity at maximum deceleration: 491.93 m/s

Maximum dynamic pressure: 880 Pa

Drag force at maximum deceleration: 180 N

Altitude of maximum heating: 8.20 km fromsurface

Maximum heating rate: 3033 Watt/sqm (lesser than the space capsule recovery experiment heating rate as achieved by ISRO in earth atmosphere)

On decelerating to terminal velocity calculated as 272.02 m/s using parachute, rest of the kinetic energy is dissipated using the 22 N single seat valve bi-propellant retro thrusters oriented at 120° angle in the horizontal plane and 62.9° to vertical, as shown in Figure 3.

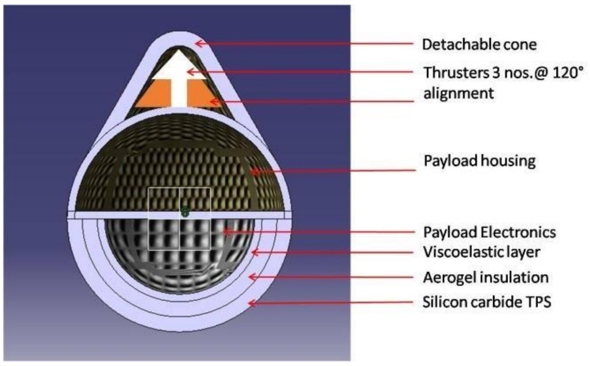

Figure 3. CROSS SECTION OF ADAM DEPICTING DECELERATING SYSTEM OF ADAM, AS PROPOSED

Drag force calculated at terminal velocity is 52.77 N and the firing of thrusters further reduce the velocity from height of maximum heating (8.20 km). Thus, firing thrusters produce a net upward thrust of 30.07 N which need to oppose the weight of the probe in gravity acceleration; i.e 39.24 N (for weight of 12 kg after parachute and thruster burn). Thus a near zero velocity is achieved at touchdown height. On sensing an altitude of less than a meter from surface, the parachute-thruster system detaches and flies off from the probe dropping it to survive on the viscoelastic shock absorber.

The materials of the module and parachute holds very high significance as the heat of 3033 W/sqm need to be survived during the hypersonic flight regime. Following materials are proposed considering the thermal protection needs.

Spherical ATS of probe: Carbon infiltrated Silicon-carbide tile TPS outer layer (20mm thick).

Immediate inside layer to the TPS layer: Aerogel insulation to prevent heat transfer to inside (10mm thick).

Innermost layer: Viscoelastic membrane to absorb shock of any possible impact and protect the payloads (20mm thick).

Inner frame and other rigid structures can be made by using duralumin or similar lightweight aluminum alloys.

Parachute is proposed as a braided porous fabric made of Kevlar 49 fibers which can survive the 880 Pa pressure on deceleration.

ENTRY DESCENT LANDING

The entry probe, ADAM will be a piggyback to the main orbiter, which on reaching the perigee point of 500 Km around the planet will get separated using a pyro- system separation mechanism or a shape memory hinge operated separation system. This shall enter at a predetermined angle of attack of 10° from local horizontal for a low ballistic entry.

The following plots shows the atmospheric air density variation plot for mars from an entry height of 200 km (Figure 4), the velocity change since entry till touchdown (Figure 5) and the heat flux variation of the probe (Figure 6).

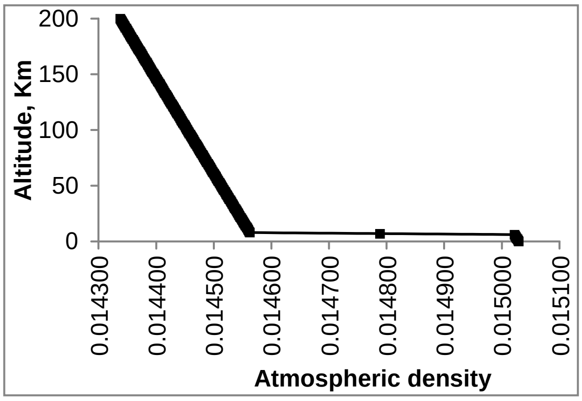

Figure 4. VARIATION OF MARS ATMOSPHERIC DENSITY WITH RESPECT TO ALTITUDE

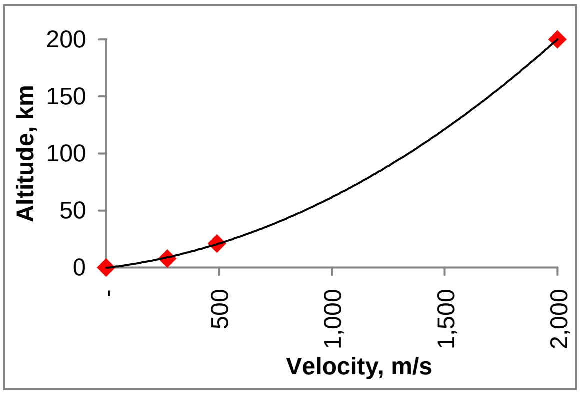

Figure 5. VELOCITY VARIATION WITH RESPECT TO ALTITUDE

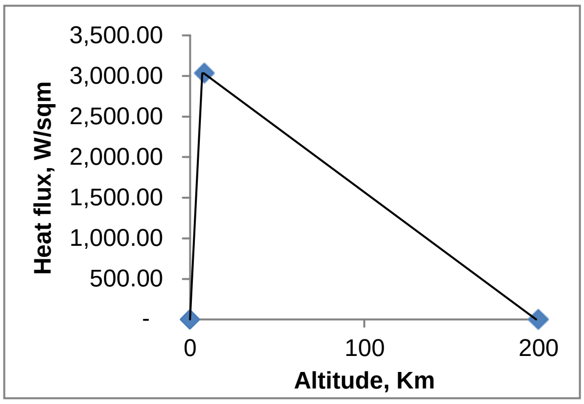

Figure 6. HEAT FLUX OF HYPERSONIC FLIGHT REGIME WITH RESPECT TO ALTITUDE

Based on the payloads and the studies proposed, a suitable landing site shall be specified based on which the spacecraft – probe separation shall take place for a precise landing. Aram chaos, Chasma boreale, Chryse planitia, Eastern Olympus Mons, Elysium planitia, Gusev crater & columbia hills, Huygens ridge, Kasei valles, Lyot crater, Milankovik crater, Newton crater gullies, Nili Fossae region, North polar cap, Olympus Mons caldera, Peak Magnetic anomalies, Slope streaks, Syria Planum, Terra Cimmeria, Utopia basin floor and Valles Marineris are the major landing sites of interest to the mars enthusiasts for the various significance of these places. Of these, the plains of Chasma boreale (Figure 7) beholds olivine deposits which points towards the once existed water in liquid form, as per NASA studies.

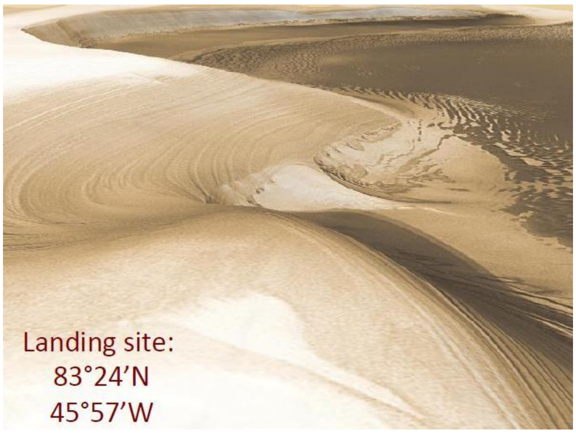

Figure 7. CHASMA BOREALE, 83°24'N 45°57'W; SOFT SAND BEDS THAT FAVOURS IMPACT LESS SOFT LANDING, PRESENCE OF POLAR LAYERED DEPOSITS AND WATER EQUIVALENT HYDROGEN (WEH) AT WEIGHT PERCENTAGE LEVEL AT 41.45% MAKES THIS AREA A SUITABLE LANDING SITE FOR MOST OF THE SMALL SCALE EXPLORATIONS.

On soft landing, the module stabilizes itself using a roly-poly stabilization based on centre of gravity of ADAM. The top pyramidal portion of the module opens up as petals on a shape memory electro activated hinge / tension wire activated hinge mechanism. The inner side of the petals are equipped with solar panel power generators (in-case an RTG power plant is not availed).

For any mini-rovers to roll down, as by pathfinder 'SOJONER', the petals can act as a ramp to the surface. On complete deployment of the solar panels, a shape memory rod can be deployed for hoisting the flag which is a relay antenna to the orbiter too (refer Figure 9). Rest of the payloads can start operating on receiving signals / feedbacks as equipped.

MISSION PROFILE

The module delivers safely micro/mini probes/payloads to Martian surface, weighing from minimum 5 kg to 15 kg net weight relevant for small scale researchers and explorers, where as the current entry probes concentrates on huge robotic on surface laboratories.

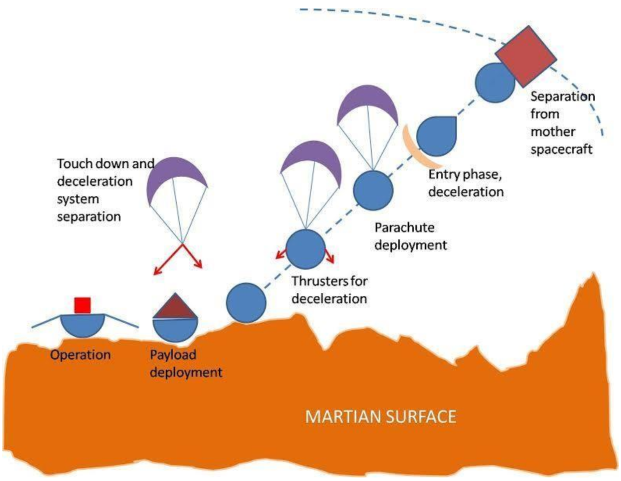

Figure 8. MISSION PROFILE

The module is conceptualized in the configuration of a tear drop (Figure 8) during its atmospheric entry and the rear cone separates out during the parachute deployment transforming the module to a sphere. This sphere drops down decelerating, aided with three thrusters to bring down the velocity to near zero value for a safer touchdown. Visco-elastic materials serves as shock absorbers to prevent impact load transfer to the payload inside.

CONCLUSION AND FUTURE SCOPE

As discussed, the major challenges are the fabrication of the module release system from the spacecraft (specific to probe-payload size), thermal protection system as discussed in previous section, the decelerating systems of the probe (parachute and thruster system), shock absorbing viscoelastic system for the payload passengers, on-surface deployment systems of module, on-surface stabilization of module, power source and extraction, module-payload separation/deployment.

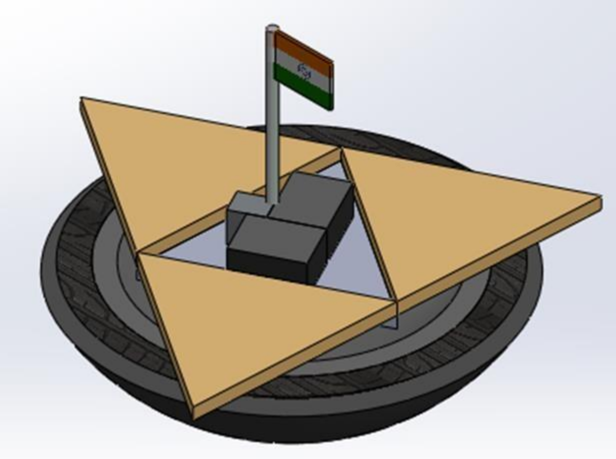

Figure 9. DEPLOYED CONFIGURATION OF ADAM AT MARS SURFACE

The concept is analogous to advent of mini-satellites when larger spacecrafts of agencies reign the space arena. Hence small scale space enthusiasts can enter planetary exploration via such small payload delivery systems which can be a prospect to future.

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