Mars Sample Return Mission:
Mars Ascent Vehicle Propulsion Design

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Abstract— **The aim of this research is to analyze a potential Mars Sample Return (MSR) mission through the study of an optimized design of the Mars Ascent Vehicle (MAV) propulsion system. The main goal of the MSR mission is to return to Earth samples of rocks and dust collected by a rover operating on the surface of Mars, and conveyed to the MAV into an Orbit Sample (OS) canister.**

The MAV must accomplish an initial ascent phase from the Mars surface to a circular Low Mars Orbit (LMO) with a radius of 500 Km and 30° inclination, and then with its second stage it must circularize into the target LMO where it releases the OS payload. A combination of the MAV and a second vehicle, the Mars Earth Return Vehicle (MERV) orbiter, is required to fulfill the final return phase from Mars to the Earth. After completing three different phases of rendezvous operations, with a final Hohmann Transfer the MERV is able to bring the OS to Earth with its payload.

A spreadsheet model enables the evaluation of two different MAV architecture: a two-stage solid rocket, and a two-stage hybrid rocket. The study is based on the main rocket science equations, including the Tsiolkovsky Rocket Equation that calculates the change in velocity ΔV for the two stages of the MAV and the amount of propellant needed for both stages.

From the analysis it can be noted that the two-stage hybrid design has significant advantages, firstly in terms of Gross Lift Off Mass GLOM (270 Kg) when compared to the solid solution (355 Kg). The hybrid rocket also has lower mass by up to 60 Kg since it does not require a thermal igloo. Finally, the mass fractions for both stages are comparable, and the required ΔV for the hybrid stages are less than those needed for the solid, allowing considerable fuel savings. The hybrid solution is ultimately preferred, considering the best performance related to the thermal fuel properties enabling the MAV to safely operated in the harsh Martian environment.

Keywords— Mars, MSR mission, MAV, MERV, NASA, space propulsion system.

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1. INTRODUCTION

A Mars Sample Return mission presents a massive scientific value within the space exploration context. It would be one of the most important robotic space missions because of the nature of Mars, the target planet that presents relevant elemental and isotropic composition, identified in 2006 by MEPAG, the Mars Exploration Program Analysis Group by NASA.

This study investigates the challenge of returning to Earth a certain amount of Martian samples collected on the surface of Mars. This process will allow future analysis of rocks and dust at terrestrial facilities, that would give more information about the composition of the Martian planet; additionally, the related accomplishment of the return phase from Mars to the Earth would represents a milestone in space exploration.

The core of this research is the analysis of the Mars Ascent Vehicle, a rocket with the main task of returning samples collected on the Mars surface to Earth. The study concerns a first analysis of different architectures for the MAV proposed in the recent years, and the research focuses on two potential designs: a two-stage solid MAV, that represents a baseline architecture for the comparison of a second design, a two-stage hybrid MAV.

The sizing of the MAV has been done through a solver model in Excel, that shows the main features for both stages

considering the masses related to the main structure of the rocket and the orbital parameters required to reach the target Low Mars Orbit in which the second upper stage must be inserted with its payload, the OS canister.
Finally, an overview of the return phases related to the MSR mission would give information about the main maneuvers that the orbiter must accomplish to catch the OS into the LMO and then inserted into a final Hohmann transfer to return to Earth.

2. LITERATURE SURVEY

In the past years, several studies have been conducted for a MSR mission. Some projects like the most recent study of a MSR initially planned in 2005 stopped due to budget cuts (Ferreira, Augros, Ortega, 2006), and the critical structure of the entire mission require to follow the launch windows because of the relative alignment between Mars and Earth in the heliocentric reference system. The right position between the planets allows a great fuel savings, reducing the time of flight required to reach Mars. The whole MSR mission is articulated along three different launch phases.

A new potential scenario for a MSR mission would begin in 2020 with the Mars 2020 mission, placing on the Mars surface a rover that will collect samples into a OS container along its route for a potential future return to Earth of the OS. The success of the entire mission is dictated by the MAV, a two-stage rocket that must follow a specific trajectory ranging from the Martian ground to the LMO: with its first stage the MAV would reach the target LMO, and release its payload into the orbit with its upper second stage dedicated to the orbital circularization. The comparison of two categories of propulsion design has important once into techniques within the MSR context, highlighting both MAV designs and justifying the choice of the hybrid approach instead of the solid one. After the insertion of the OS into orbit, the MERV coasts in the vicinity of Mars and after a sequence of three rendezvous maneuvers between the OS and the MERV, with a final Hohmann transfer, the MERV is able to bring the OS and fulfill the two final Transfer Earth Injection maneuvers (TEI) to return to Earth with its payload.

The spreadsheet model for a two-stage MAV was developed along with the analytic equations and parametric relationship that estimate the total mass of the rocket and its performance (Wooley, 2004). Both stages of the MAV consist of a fixed mass, such as avionics devices, and a variable mass which is a function of the total propellant mass carried by the entire rocket according to the Tsiolkovsky equation. The aim of this research is to determine the right values of the MAV main parameters through an iterative model, comparing the output data with the standard ranges published by the NASA official analysis (Cathey, Dux, Smith, 2011).

3. MISSION ARCHITECTURE

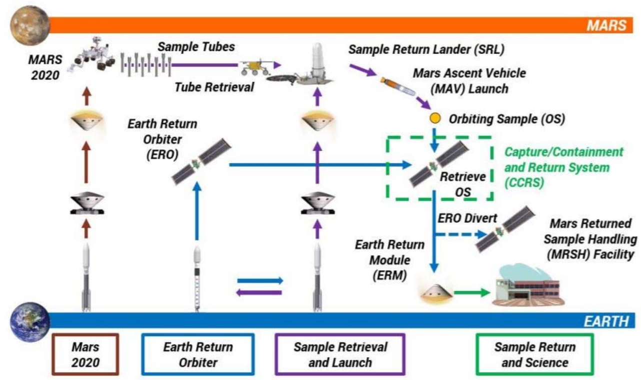

Figure 1: MSR mission architecture (from Figure 1 in [8])

The purpose of this research is to study the MSR mission jointly managed by NASA and ESA [1] and splits into three main launches as shown in Figure 1 for a total of five phases for the complete round-trip. In this scenario, the rover and the lander carrying the MAV would be launched from Earth in 2020 and 2022 respectively by two Atlas launchers; in 2024 a third Ariane launcher would bring the MERV, whose goal is to catch the OS in a circular, 500 Km radius and 30° inclination LMO.
The second stage of the MAV carrying the OS must be put into orbit prior to the arrival of the MERV, which is inserted in a final 36-hr elliptical orbit with two distinct Mars Orbit Injection maneuvers (MOI).
After entering the Mars vicinity in 2024, the MERV would use solar electric propulsion (SEP) to spiral down to the LMO for almost 6 months [2]. Then the MERV has 3 months to accomplish the rendezvous maneuvers including the final capture of the OS in the LMO, and finally starting the spiral out of Mars expected on April 5, 2024 and return on Earth through the solar electric thrusters following a final Hohmann transfer.
A summary of the five main phases of the MSR mission is listed below:

Phases	Launch year	MSR Objectives
1st phase	2020	rover carried to Mars surface by Atlas V 451
2nd phase	2022	Mars lander with the MAV carried to Mars surface by Atlas V 551
3rd phase	2024	MERV carried by Ariane V is inserted in the LMO
4th phase	2024	OS recovered in the LMO by the MERV
5th phase	2025	MERV returns to Earth with the OS

Figure 2: MSR Mission Architecture

The time of flight from Earth to Mars following the Hohmann transfer is determined considering the third

Kepler equation [3]

$$t_2 - t_1 = \pi \sqrt{\frac{a_t^3}{\mu}} = \pi \sqrt{\frac{(R_{S-M}+R_{S-E})^3}{8\mu}} = 259\ days \qquad (1)$$

where

$$R_{S-E} = 149597870.700 \text{ Km} = 1.0 \text{ AU} \qquad (2)$$

$$R_{S-M} = 227940000 \text{ Km} = 1.524 \text{ AU} \qquad (3)$$

$$\mu = 3.986 * 10^5\ Km^3/s^2 \qquad (4)$$

are the radius to Earth from the Sun and to Mars from the Sun respectively, and μ is the gravitational parameter for the Earth.
To correctly execute the maneuver, the Spacecraft (S/C) must encounter Mars exactly at the time it crosses the planet's orbit; this means that the Earth and Mars must have the right angular relationship at departure given by a phasing angle of φ= 44°. To make the S/C goes from the Low Earth Orbit (LEO) to the transfer ellipse of the Hohmann transfer, the speed required must be increased from the LEO circular velocity v_{cs} to the heliocentric velocity v_1= 32.73 Km/s related to the Hohmann; so the change in velocity ΔV required by the maneuver to reach Mars planet starting from the LEO is given by

$$\Delta V = v_1 - v_{cs} = 32.73 - 29.78 = 2.95 \text{ Km/s} \qquad (5)$$

with

$$v_{cs} = \sqrt{\frac{\mu_S}{r}} = \sqrt{\frac{1.327*10^{11}}{R_{S-E}}} = 29.78\ {}^{Km}/_{sec} \qquad (6)$$

Each S/C follows a Hohmann Transfer in order to carry to Mars three payloads: the rover, the lander with the MAV and the MERV respectively, following the steps of the timeline presented in Figure 2. After the first three phases a second trip including the two return steps (4^{th} phase and 5^{th} phase) that compete to the MSR mission allows the OS to come back on Earth with the MERV, after a series of rendezvous maneuvers in the LMO.

4. Rendezvous Maneuvers

The second upper stage of the MAV carrying the OS must insert in the LMO prior of the MERV, this last one in the same orbit. So the orbiter searches for the OS payload catching it with a mechanical arm through three rendezvous maneuvers [4]. Rendezvous operations last for approximately one year, consisting of three main phases:

- Preliminary phase: the MERV coasts in the vicinity of Mars in a 36-hr elliptic orbit searching for the OS. The onboard identification of the LMO orbital parameters is required by the MERV for a correct insertion in the target orbit detecting the OS using its orbiter's Radio Direction Finder (RDF) listening for a solar-powered beacon signal.

- Intermediate phase*:* orbital matching between MERV and the OS following a small Hohmann maneuver from the 36-hr elliptical orbit to the final LMO.

- Terminal phase: final capture operations and starts of the two Transfer Earth Injection (TEI) maneuvers.

Focusing on these three steps, important aspects describe the dynamics between the MERV and the OS. Meanwhile the OS awaits retrieval by the MERV, which approaches the first MOI maneuver nearby Mars at the arrival date. Considering the launch window in Figure 2, the arrive in the vicinity of Mars is expected for August 28, 2024. Through aerocapture and several small orbit trim maneuvers, the MERV inserts in the 96-hr elliptical orbit, and then with a second MOI shunting it, changes the inclination and lowers the orbit apogee, reaching a final orbit shape consisting of a 36hr elliptical orbit, 45° inclination. Here, the *preliminary* rendezvous phase starts after the MOI maneuvers are completed: in order to maintain knowledge of its orbit at a high accuracy, the MERV periodically updates data acquisition with RDF from the OS beacon signal. Then, with a series of propulsive maneuvers, the MERV changes its orbital parameters such as the inclination, node, semi-major axis, eccentricity and line of apsides. In this way the MERV would be closer to the OS in an external almost co-circular orbit, eliminating any possibility of collision as shown in Figure 3, before the realization of the final rendezvous maneuver.

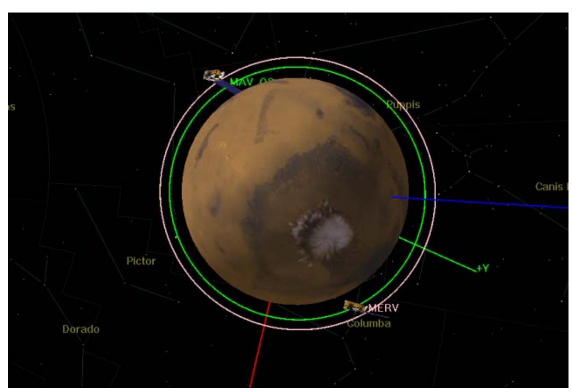

Figure 3: Co-circular orbits between the MERV (outer orbit) and the OS (inner orbit) around Mars

Two important factors regarding the shunting are considered: the total time available for the intermediate rendezvous maneuvers of 36 weeks, that represents an important constraint for the whole operations, and the errors related to the MAV orbit injection causing significant orbit

dispersion of the OS. The lack of the following requirements results in a significant effect on the total ΔV needed for rendezvous operations, and implies as a consequence a greater amount of propellant for each orbital parameter that needs to be changed.
Finally, the terminal rendezvous phase has the main task to capture the OS in the basket onboard the MERV accomplished by an autonomous onboard system with high level of accuracy called LIDAR (Light Detection and Ranging System). As well as the MOI maneuvers required by the MERV to insert it in the 36-hr elliptic orbit around Mars, also the TEI insertions are splitted into two burn sequences.

At the end of the terminal rendezvous phase, the two TEI maneuvers are performed in order to allow the orbit insertion of the MERV that must depart from the circular LMO of 500 Km radius and 30° inclination in a final 96-hr elliptical orbit. With a final Hohmann Transfer the MERV carrying the OS comes back to Earth.

5. MAV MODEL DESIGN

In order to develop a functional design for a potential MAV rocket that must fulfill the ascent phase from Mars ground to the target LMO, different functional aspects related to the MAV structure have been taken into consideration during the entire process of analysis. A two-stage architecture is considered. The MAV must have a compact shape balanced in length and height along both stages, and all systems related to its main structure such as the avionics devices, the propellant and oxidizer tanks, the thrusters and the main engine must match correctly in the entire design. Previous studies included all types of propulsion systems, including solid, liquid, hybrid and gelled propellants.

The initial analysis for this research started with referring to the JPL 2015 study [5] by evaluating the Two Stage To Orbit (TSTO) liquid and hybrid options with the goal of correctly fitting within a mobile MAV configuration. To accomplish the study, the analysis refers to three main parameters describing important characteristics for each categories of rockets:

- GLOM: Gross Lift Of Mass
- Length: outlines the dimensions for the two-stage MAV
- AFT: Allowable Flight Temperature: it represents the minimum temperature value tolerated by the whole MAV system

The first comparison between 10 categories of potential MAV design showed properties varying with the propellant considered for each model. Notably, the MAV solid case required at least two stages, because it cannot be restarted multiple times, its first stage is needed to reach the target LMO and the upper stage is needed for circularization. This crucial point for the solid propellant excluded the mono-propellant solution involving massive structure and weight of the rocket without a proper guidance control. Another possible solution is represented by the MAV solid-liquid architecture: unlike the solid propulsion, a liquid booster can be started more than once allowing for better control and a more precise insertion in the LMO with the MAV upper stage. On the other hand, the AFT value for the liquid solution is +17°C and cannot guarantee efficient operation on Mars, that has cold and cyclical range of temperatures. Similar to the liquid propellant, a pressure-regulated system shows low performance in terms of AFT and GLOM, because of the heavy pressurized tanks carried on the MAV. These aspects require a greater length of the entire structure, lowering the balance of the rocket. Finally, the two-stage hybrid rocket represents an important solution, because of the high properties of the mixtures of oxidizer combining nitrous oxide (N_2O) and oxygen (O_2).

6. TWO-STAGE HYBRID MAV

The hybrid solution for the potential MAV has multiple benefits. First, the propellant combination allows the best AFT value (-72°C) within the other MAV categories, and presents many advantages in terms of I_{sp} performance compared to a general pure N_2O system. The combination with the oxygen produces a self-pressurizing oxidizer with high density and performance. The hybrid propulsion is investigated as an enhancing technology for a potential concept of the MAV, this because the hybrid solution allows higher I_{sp} (298 s) than the solid propulsion (287 s), restartability and the ability to safely operate at extremely low temperatures [6]. All of these properties enable the two-stage hybrid MAV to withstand the harsh conditions on Mars, without requiring a thermal igloo unlike the two-stage solid rocket. It also shows a better performance in terms of GLOM, and other important benefits considering the mass a primary design driver for the whole architecture of the rocket. Moreover, in the way the hybrid solution enables operation at low and cyclical temperatures it is possible to minimize the power requirements of the entire MAV system. Another key aspect is that in a hybrid rocket, the regression rate $\dot{r}$ is not a function of the chamber pressure as it is with the solid one, and it only depends on the oxidizer mass so it does not have to operate at high pressure, allowing the entire system to minimize the mass the rocket has to carry and affords flexibility to optimize the chamber pressure. Titanium is used in the combustion chamber of the two-stage hybrid MAV to support at least 400 psi of chamber pressure.

Hybrid motor combustion stability depends on oxidizer mass flux, and generally the thrust of the hybrid MAV is setting about 5700 N to optimize the GLOM and trajectory parameters. Complete optimization of thrust/trajectory, nozzle expansion ratio, chamber pressure and stack height would be performed high levels of precision. Relative to a NASA preliminary study case, the current MAV design employs eight thrusters, four at 22N and four at 5N mainly driven by dynamic pressure loading at the end of the first burn and coast period to maintain attitude control. The thruster would be located at the aft end of the combustion chamber, maximizing the moment arm and utilize empty space around the motor.
Focusing on a second subgroup derived from the first selection of the initial MAV design options, the baseline solid rocket and the hybrid case represent favorite design with higher performance than the other possible propulsion cases cited.

7. METHODOLOGY

The research focus on the design of a two-stage MAV, considering a baseline two-stage solid rocket, favored because its architecture reduces both the complexity of the whole system and the related masses [7]. Then, a comparison between the baseline solid MAV and a two-stage hybrid MAV is presented to show the higher performance of the hybrid than the solid rocket.

A spreadsheet model implementation in Excel gives the two highlights for the MAV design: the change in velocity ΔV for both stages and the related total ΔV required to accomplish the ascent trajectory from Mars to the target LMO, and the GLOM value that competes to the rocket structure, involving the masses of the two stages and the OS payload fraction of 5 Kg. A South-East-Zenith (SEZ) inertial reference frame (Figure 4) is considered to obtain the idealistic velocity ΔV^* on the Mars surface to loft the MAV to the required orbit's apex of 500 Km.

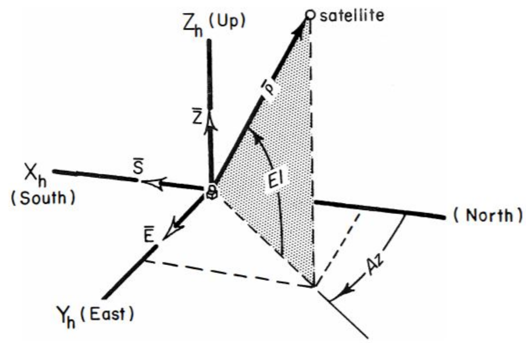

Figure 4: SEZ reference system with origin in the Mars ground site, 15°S-25°N latitude (from Figure 2.7-1, pag. 84 in [3])

By the orbital mechanics equations the ideal velocity ΔV^* is obtained by the SEZ velocity vector components

$$\Delta V^* = \sqrt{{V_S}^2 + (V_E - V_M)^2 + {V_Z}^2} \tag{7}$$

with

$$V_S = -\dot{\rho}\cos(El)\cos(Az) \tag{8}$$

$$V_E = \dot{\rho}\cos(El)\sin(Az) + V_M \tag{9}$$

$$V_Z = \dot{\rho}\sin(El) \tag{10}$$

$$\rho = \rho_S\bar{S} + \rho_E\bar{E} + \rho_Z\bar{Z} \tag{11}$$

where *El* is the Elevation angle, *Az* is the Azimuth angle, V_M= 218.15 m/s is the rotational velocity on the Mars surface and ρ is the SEZ position vector. The related values for each component are shown in Table 1.

Components	Value [m/s]
V_S	-1288.8
V_E	1679.6
V_Z	1125.0
ΔV^*	2398

Table 1: SEZ vector velocity components

From the general formulation of the velocity components in the SEZ topocentric reference frame it is now possible to determine the values for velocity and then estimate the masses for each stages of the two-stage MAV model.

Table 2 shows a summary of the main orbital parameters required to insert the OS in the LMO

LMO parameters	Value
Apex [Km]	500 ± 100
Inclination [°]	30 ± 0.2
Eccentricity	0
Gravitational constant [m/s^2]	9.81
Mars surface velocity [m/s]	218.15

Table 2: LMO parameters

The real ΔV_1 for the MAV 1st stage is obtained by adding to the SEZ ideal velocity value ΔV^* the losses expressed in term of ΔV and categorized into gravity, drag and steering losses. The fly-path angle ϕ_{bo} between the direction of the velocity vector of the 1st stage and the horizontal local is 45°, and the non zero inclination allows to reduce the amount of leaks that would affect the total ΔV_1, considering each losses component a function of the ϕ_{bo}. The total ΔV_1 for the MAV 1st stage is then given by

$$\Delta V_1 = \Delta V^* + \Delta V_{losses} \quad (12)$$

The ΔV_2 required by the MAV 2nd stage to circularize once the MAV 1st stage has coasted to the LMO apex h is given by the horizontal component of its velocity and the circular velocity of the LMO. The direction of the velocity vector is aligned with the horizontal local, thus φ_{bo}=0° and its burn occurs above the atmosphere unlike the MAV 1st stage ; this avoids any additional losses that would reduce the total ΔV. The ΔV_2 required to circularize in the LMO is given by the orbital mechanical equation

$$\Delta V_2 = V_c - \Delta V_1 \frac{r_M}{r_M + h} \cos(\phi_{bo}) \quad (13)$$

with V_c the circular velocity at the given LMO and r_M the radius of Mars.

By summing these two velocity values obtained by the orbital parameters it is possible to estimate the MAV total ΔV required to put the OS into orbit starting by the Mars launch site

$$\Delta V = \Delta V_1 + \Delta V_2 \quad (14)$$

In order to estimate the total GLOM of the MAV, a two-stage architecture and a payload fraction of 5 Kg OS is considered. Both stages consist of a dry mass M_{dry} given by a fixed mass M_{fix} related to the avionic systems, thermal igloo and tanks, and a variable mass that is a function of a fraction of the total mass of propellant M_{prop} carried by each stage. The Structural Mass Fraction (SMF) is a value that ranges between 8-20%, and represents the percentage of the propellant mass involved in the amount of the variable mass. For this study, the SMF is of 9%. The payload mass fraction for the MAV 1st stage is given by the entire wet mass of the MAV 2nd stage, and for the second one is the mass of the OS main payload M_{OS}. The implementation of an iterative model allows to express the output values considering that the propellant mass is a function of the variable mass which in turn is a function of the propellant mass, this last one expressed by the Tsiolkovsky Rocket Equation

$$M_{prop} = \left(M_{dry} + M_{OS}\right) * (e^{\Delta V / I_{sp} g} - 1) \quad (15)$$

where

$$M_{dry} = M_{fix} + SMF * M_{prop} \quad (16)$$

Figure 5 shows the trend of the Tsiolkovsky Equation for a two-stage solid MAV, relating the ΔV values to the propellant mass fractions for the two stages and the mass ratio.

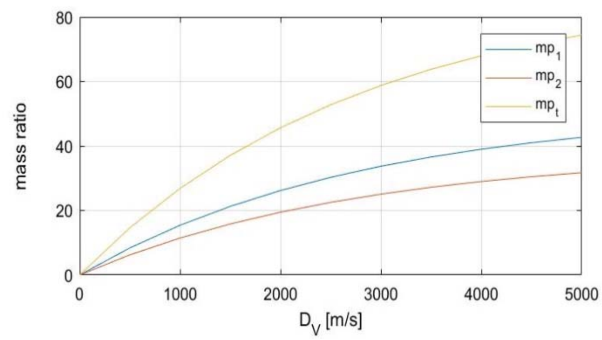

Figure 5: trends for the propellant mass fraction of both stages 1 and 2, and the total MAV propellant mass

Once estimate with the Tsiolkovsky equation the propellant masses for each stage, the final total mass of both stages is expressed by

$$M_{stage\ 1,2} = M_{dry\ 1,2} + M_{prop\ 1,2} \quad (17)$$

And the final GLOM mass is the sum of the payload fraction (M_{OS}) and the masses of the MAV 1st and 2nd stage

$$GLOM = M_{stage\ 1} + M_{stage\ 2} + M_{OS} \quad (18)$$

For a general analysis of a rocket sizing, the GLOM is one of the primary parameter considered to correctly optimize its structure, reducing costs and complexity of the entire system.

8. RESULTS

Table 3 shows a summary of the input and output values related to the design of the baseline two-stage solid MAV and a two-stage hybrid MAV obtained by the numerical analysis with the spreadsheet model implemented.

MAV parameters	Two-stage solid	Two-stage hybrid
Stage mass 1 [Kg]	221.85	150.32
Stage mass 2 [Kg]	80.58	114.59
Stages mass [Kg]	302.43	264.91
OS payload mass [Kg]	5	5
Thermal igloo mass [Kg]	50	0
GLOM [Kg]	357.43	269.91
ΔV_1 [m/s]	2554.44	1675
ΔV_2 [m/s]	1829.88	2700
ΔV [m/s]	4384.32	4375
I_{sp} [s]	285	298

Table 3: output values for the two-stage solid and hybrid MAV

Table 3 illustrates the comparison between the two MAV systems, showing better properties for the two-stage hybrid solution, firstly in terms of Specific Impulse that is higher than the solid because of the fuel mixture: the combination of Nitrous Oxide and Oxygen allows superior performance and a reduction of the costs in terms of propellant needed by the MAV. Another important aspect that leads to optimize the GLOM for the hybrid MAV is the thermal property that conducts to a reduction of the additional mass saving up to 60 Kg of thermal igloo. Figure 6 illustrates the trend of GLOM varying with the total dry mass M_{dry}. For both designs a 30 Kg mass related to the OS canister are considered in the M_{fix} of the MAV 2nd upper stage.

The total ΔV for the two-stage hybrid is finally comparable to the ΔV of the two-stage solid, this because for the hybrid a contribution of the I_{sp} makes a positive impact on the changes in velocity required.

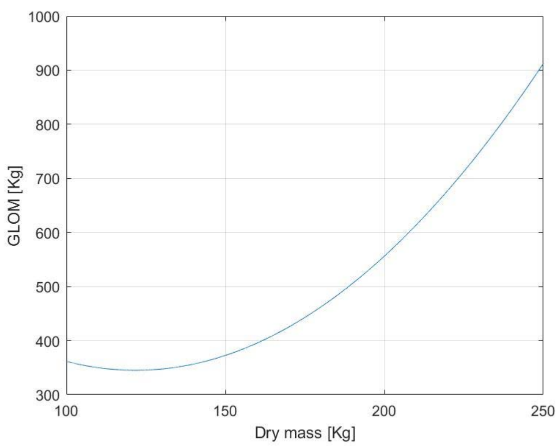

Figure 6: The effects of dry mass M_{dry} on GLOM for a two-stage MAV

9. CONCLUSION

The MAV design represents a challenging problem faced in the past years, considering multiple concepts with the common aim of developing a rocket able to lift off from another planet in different, harsh conditions and without the possibility to have a crew acting on the rocket system in case of failure. The MAV is the key of a potential unmanned MSR mission presented here and the complexity of the return phase required a vehicle able to fulfill each steps of the mission in a linear timeline. The two-stage solid design allows a massive and common architecture for a MAV but presents important crucial points that affects its performance lowering the functional ability in the Martian operative context. On the other hand, the two-stage hybrid MAV overcomes the critical issues of the solid, increasing safety, mission flexibility since it can be started multiple time by a valve action, and reducing costs and complexity when compared to its superior performance in terms of Gross Lift Off Mass and Specific Impulse. Further development of the hybrid MAV would focus on the kind of propellant and mixture oxidizer with the main task of improving thermal performance and guarantee a high level of control over the entire system. Finally, the fulfillment of the MSR mission would represent an important step in the future space exploration giving a solid contribution to the planetary missions.

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Biography

Laura Sopegno *received a M.S in Aerospace Engineering, Space and Propulsion Systems specialization, from Polytechnic of Turin, Turin in 2019. She worked for the two years of her Master in a student team, DIANA, as a project engineer, focusing on the Cad design and FEM analysis of a Martian rover prototype that competed in the European Rover Challenge (ERC) in Starachowice, Poland, in 2018 and 2019. She spent a six months period abroad at University of Denver developing her Master's Thesis on the study of the Mars Ascent Vehicle, that represents the key aspect in the Mars Sample Return (MSR) mission, in agreement with the European Space Agency (ESA) standards. Her interests span numerous areas, firstly from the scientific and technical field in the aerospace sector, to the construction field for buildings and civil applications which she studied for five years at the High School.*

Kimon P. Valavanis *is a John Evans Professor and Director of Research and Innovation in the Department of Electrical and Computer Engineering, with a joint appointment in the Department of Computer Science at the University of Denver. He is also Director of the DU Unmanned Systems Research Institute (DU2SRI). He holds a Guest Professor appointment in the Department of Telecommunications, Faculty of Electrical Engineering and Computing at the University of Zagreb, Croatia. His research interests span the areas of intelligent systems, focusing on: integrated control and diagnostics of unmanned systems; modeling and formation control of cooperative robot teams; navigation/control of unmanned aerial vehicles; modeling, design and development of complex mechatronic systems; design of the next generation of unmanned systems; mathematical theories for intelligent machines. He is Fellow of the American Association for the Advancement of Science (AAAS), Senior Member of IEEE, Editor-in-Chief of the Journal of Intelligent and Robotic Systems (Springer), and Fulbright Scholar.*

Matthew J. Rutherford *is an Associate Professor in the Department of Computer Science with a joint appointment in the Department of Electrical and Computer Engineering at the University of Denver. He is also Deputy Director of the DU Unmanned Systems Research Institute (DU2SRI). His research portfolio includes: the development of advanced controls and communication mechanisms for autonomous aerial and ground robots; applications of real-time computer vision to robotics problems using GPU-based parallel processing; testing and dynamic evaluation of embedded, real-time systems; development of complex mechatronic systems (mechanical, electrical, and software); the development of software techniques to reduce the amount of energy being consumed by hardware; development of a high-precision propulsion system for underwater robots.*

Lorenzo Casalino *is an Associate Professor in the Department of Mechanical and Aerospace Engineering at the Polytechnic of Turin. He is also a member of the Engineering College of Polytechnic of Turin. He is the author of important publications, both nationally and internationally, with high experiences in the space field.*