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Analyzing Whether a Space Shuttle Can Withstand a Perpendicular Launch from Mars

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ABSTRACT

In the near future, humans will go to Mars. During these interplanetary journeys, astronaut safety will be paramount. This study aims to determine whether the astronauts will be able to launch safely from Mars in a space shuttle taking off perpendicularly. This study used kinematics along with equations for calculating atmospheric density and total force on the spacecraft to evaluate these values for each atmospheric layer. Approximations were made for the spacecraft's dimensions to find the cross-sectional front-view area of the spacecraft and the drag coefficient where verifiable data was unavailable. Although there is data for the dimensions of the spacecraft's front view, there isn't any on its area. The total force was found to be significantly lower than 3Gs which ensures a safe take-off for the astronauts and reduces manufacturing costs for assembling new rockets.

1. INTRODUCTION

It is imperative for the human race to colonize Mars as Earth will soon be overpopulated. A given shuttle needs to be able to launch from both Earth and Mars safely. Astronauts inside of the shuttle must not be crushed due to the external forces applied against them. A space shuttle can withstand an amount of force equal to at most three times the gravitational force on Earth (3Gs) [1]. By accounting for forces like gravitation, air resistance, and thrust, our main objective is to determine whether the space shuttle will be able to endure the total force applied against it during a perpendicular launch from the Martian surface [2]. This will determine if we have to build space shuttles differently or if we can still reuse the space shuttle models we have assembled so far. Factors like radiation protection and the ability to survive in space aren't taken into consideration since we are only analyzing if astronauts can survive the launch (which is for a relatively short duration) making them unaffected by those factors. If the space shuttle is able to tolerate the launch, it will have the potential to save billions of dollars when it comes to constructing new rockets.

2. METHODS

As the spacecraft embarks on its journey from the Martian surface to space, it must navigate a complex interplay of forces that could impact its trajectory, safety, and efficiency. These forces include the gravitational pull of Mars on the spacecraft, the aerodynamic drag force exerted by the atmospheric layers, and the opposing thrust force generated by the shuttle's propulsion systems.

The critical question here is whether the spacecraft, with its human crew aboard, can endure the cumulative impact of these forces which should not exceed 3Gs. This is essential to safeguard the astronauts during the launch phase.

To tackle this challenge, a meticulous calculation of all these forces is necessary. Determining the thrust force involves a comprehensive understanding of how the spacecraft's acceleration evolves during different stages of launch. In the transition from Stage 1 to Stage 2 of launch, the solid rocket boosters (SRBs) are jettisoned during Stage 2, resulting in an alteration of the shuttle's acceleration profile.

Stage 1 is characterized by a fixed duration of 120 seconds, a crucial parameter to consider in the calculations [3]. The exhaust velocity of the space shuttle and the SRBs combined plays a pivotal role in these calculations. Using the acceleration and the exhaust velocity of the space shuttle & the SRBs combined, the acceleration of the rocket is calculated through Equation (1):

$$a = \frac{v_f - v_i}{t} \tag{1}$$

where a is the acceleration, v_i is the initial velocity, v_f is the final velocity, and t is time. Using the acceleration of the vehicle, we can solve for the distance traversed during launch:

$$s = v_i t + \frac{1}{2} \cdot a \cdot t^2 \tag{2}$$

where s represents the distance covered during the spacecraft's ascent. Using Equation (2), we get to know that the spacecraft exits the atmosphere in stage 1 of launch. During this phase, the thrust force remains a constant factor and is the cumulative effect of the main engines and the solid rocket boosters (SRBs) operating simultaneously [3-5]. The vehicle's final mass and the gravitational acceleration it experiences are needed to calculate the gravitational force on the spacecraft in each atmospheric layer. Calculating the amount of fuel mass lost during the requires understanding the duration of the booster's burn in each atmospheric layer. By using the acceleration calculated in Equation (1), the amount of time taken is determined by solving for time in Equation (2). After that, the values for the mass flow rate of the SRBs and the ET(External Tanks) should be multiplied by the time taken to exit the current atmospheric layer in Equation (3) [4, 6].

$$m_l = m_1 \cdot t + m_2 \cdot t \tag{3}$$

where m_l is the combined fuel mass lost and m_1 and m_2 are the mass flow rates of the SRBs and the ET respectively. The output of the resultant mass is to be subtracted from the total mass of the spacecraft using Equation (4).

$$m_f = m_t - m_l \tag{4}$$

where m_t is the total mass of the spacecraft and m_f is the final mass.

$$a_g = G \cdot \frac{m_m}{r^2} \tag{5}$$

In Equation (5) where a_g is the gravitational force, G is the gravitational constant, m_m is the mass of Mars and r is the radius, the gravitational acceleration at the top of the current atmospheric layer is to be calculated by making use of the Mars' mass and Mars' radius added with the distance the spacecraft has travelled [7]. Utilizing m_f and a_g at the top of the atmospheric layer, the gravitational force of Mars applied on the space shuttle is calculated using Equation (6):

$$F_g = m_f \cdot a_g \tag{6}$$

where F_g is the gravitational force to assess the aerodynamic drag force exerted on the spacecraft during its ascent, two essential factors come into play: the velocity of the spacecraft and the density of the prevailing atmospheric layer. To tackle the velocity component, we kickstart our analysis by determining the spacecraft's velocity at the upper boundary of the specific atmospheric layer. Equation (1) plays a pivotal role here as it allows us to calculate the velocity (v) when we solve for it. The Martian atmosphere is significantly thinner than Earth's, primarily composed of carbon dioxide (around 95.3%). Close to the planet's surface, the atmosphere is relatively denser compared to higher altitudes. As you ascend from the surface, the density gradually decreases, resulting in a significantly thinner atmosphere at higher elevations [8]. This drop in atmospheric density is a crucial factor as it impacts the aerodynamic drag. When the spacecraft is in flight, the density of the current atmospheric layer is to be calculated through 7:

$$\rho = \frac{0.699^{-0.00009s}}{0.1921 \cdot T} \tag{7}$$

where ρ is the density and T is the temperature in Kelvin. Due to the lack of verifiable data, the drag coefficient of the average rocket was used in order to find out the drag force [9]. Utilizing the velocity and density calculated, the drag force can be measured through Equation (8):

$$F_D = \frac{1}{2}\rho v^2 C_D A \tag{8}$$

where F_D is the drag force, A is the area of the spacecraft's front view as calculated from **Figure 1**, and C_D is the drag coefficient. A convenient way to express the total force applied on the spacecraft at the top of the atmospheric layer is through Equation (9):

$$F_f = F_T - F_g - F_D \tag{9}$$

where F_f is the total force at the top of the layer and F_T is the thrust force. 3Gs of force that the space shuttle should withstand is calculated through Equation (10):

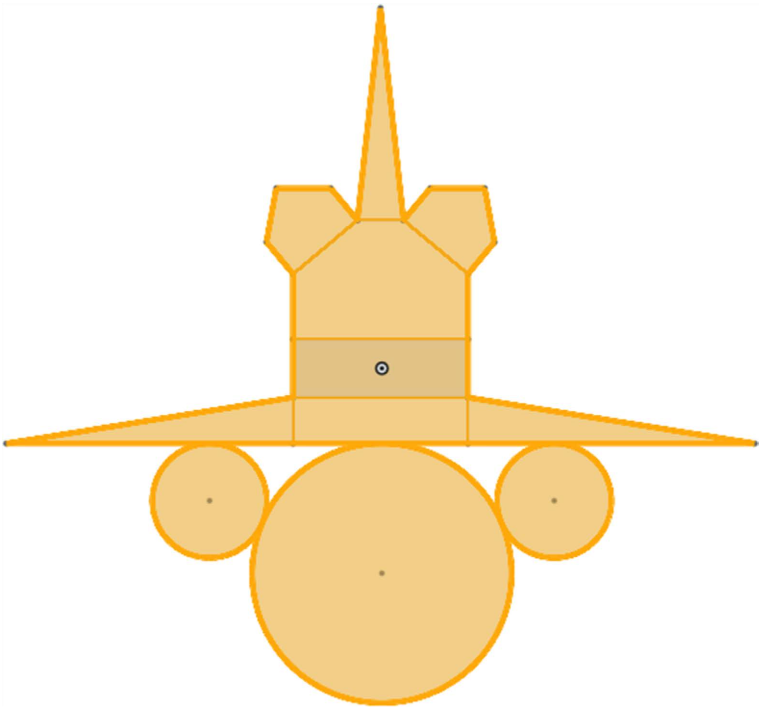

Figure 1. Models the area of the front view of the spacecraft.

$$3G = 3 \cdot m_f \cdot 9.807 \qquad (10)$$

where G is 3 times the force of gravity on Earth. If the final force being applied on the space shuttle is less than or equal to 3Gs of force, the spacecraft will be able to endure its launch in the atmospheric layer.

3. RESULTS AND DISCUSSION

Through our analysis, we have demonstrated that the space shuttle possesses the structural resilience to withstand the cumulative force acting upon it throughout its ascent within the Martian atmosphere. Our methodology involved a systematic comparison of the final forces experienced at the end of each atmospheric layer as shown in **Figure 2** along with a comparison with the shuttle's designed tolerance of 3Gs as shown in **Figure 3**.

At each stage of ascent, we tracked key parameters listed in **Table 1** such as the final mass, final velocity, gravitational acceleration, temperature, and the air density, all of which exhibited variations as the spacecraft moved upwards.

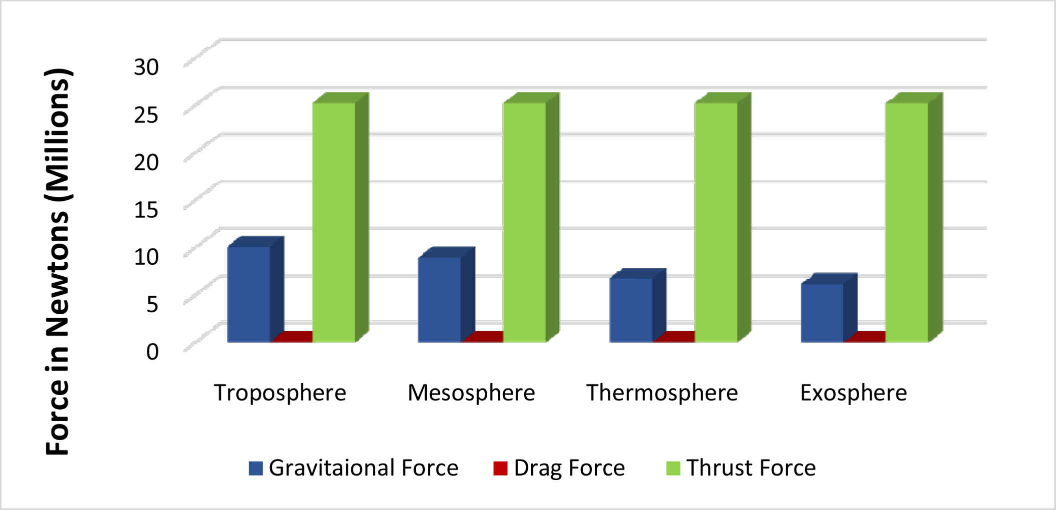

Figure 2. Compares the individual forces that are being factored during launch.

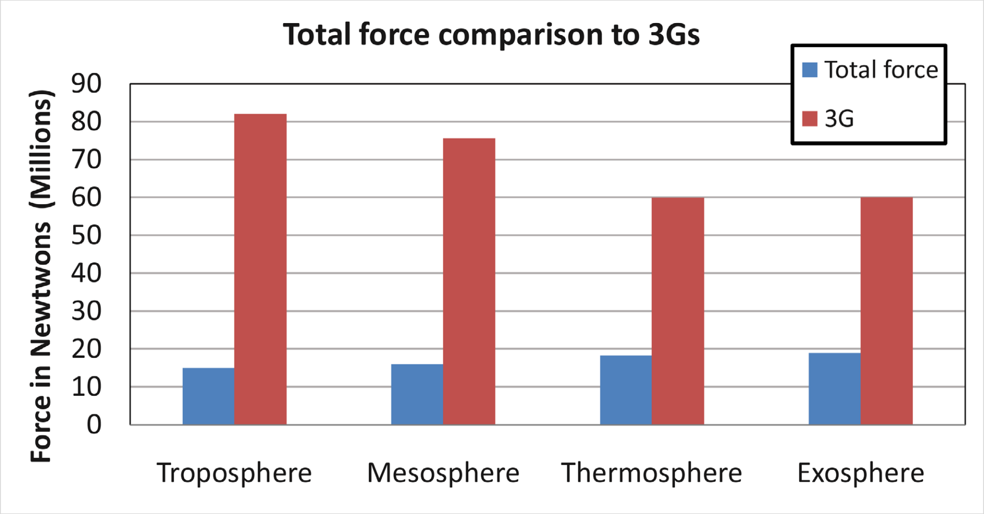

Figure 3. Illustrates the final force being applied on the space shuttle at the end of each layer being compared to 3Gs of force the spacecraft is meant to withstand.

Table 1. **Parameter table.**

Parameter	Troposphere	Mesosphere	Thermosphere	Exosphere
m_f (Kg)	2,788,230.4	2,571,150.22	2,189,592.9	2,030,302.9
V (m/s)	2351.16	3335.28	5065.6	5787.2
ρ (Kg/m^2)	0.0005	0.000003	0.00003	0.000002
T (Kelvin)	150	250	350	400
a_g (m/s^2)	3.614	3.511	3.26	3.141

The findings are reassuring; the total force exerted on the spacecraft decreased at each atmospheric boundary: 81% in the Troposphere, 78% in the Mesosphere, 69% in the Thermosphere, and 68% in the Exosphere. These observations have significant implications, particularly in terms of fuel conservation. Notably, the shuttle effortlessly exits the Martian atmosphere during Stage 1, signaling that a substantial portion of its fuel can be saved. Consequently, the dimensions of the fuel tanks may also be optimized, reducing the overall fuel requirement.

In practical terms, these conclusions bear the potential to yield substantial cost savings in the manufacturing and production of these rockets. As fuel consumption decreases, so do the demands on the size of the fuel tanks. Smaller tanks mean reduced material costs, less weight to launch into space, and more streamlined engineering, all of which contribute to considerable cost reductions. Engineers can now explore innovative designs that optimize the use of resources and minimize waste. This enhanced affordability can open up new opportunities for governments, organizations, and even commercial entities to participate in space exploration and research. Beyond the financial implications, these insights pave the way for more sustainable and efficient space exploration, as we work towards the realization of our interplanetary ambitions.

However, in order to achieve a more accurate conclusion, a detailed study must be conducted on Mars to get accurate densities instead of using an equation for air-density approximation. An accurate cross-sectional front view area of the system would also benefit in calculating the drag force applied (which would however be negligible due to the immensely thin atmosphere).

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CONFLICTS OF INTEREST

The author declares no conflicts of interest regarding the publication of this paper.

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