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A4 1 Could Apollo 11 Make It into Orbit from a Moon-Sized Earth

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Abstract

This paper explores the viability of the launch of the Apollo 11 Saturn V rocket from a "super-dense Moon" (SDM), a hypothetical celestial body which possesses the physical dimensions of Earth's moon, but with the mass of Earth itself. Using surface gravity, thrust/weight ratio, orbital velocity, and escape velocity, we are able to evaluate rocket performance within very high gravitational environments. The results show that the Surface Gravity for SDM is equal to 131.97 ms^{-2} which equates to 13.45g, hence lowering the thrust-to-weight ratio of the Saturn V rocket to 0.093. Furthermore, there is an increase of the required orbital escape velocities as they escalate to 15.14 kms^{-1} and 21.45 kms^{-1} respectively. As such, the Saturn V would be unable to achieve lift-off, demonstrating that planetary density limits the viability of human space travel greatly.

Introduction

Apollo 11 was the first space mission to land humans on the Earth's moon [1]. On the 16th of July 1969, a Saturn V rocket carried the Apollo 11 crew from the surface of the Earth into orbit, and onward to the Moon. This would be the rocket's only voyage however, as its spent stages were discarded into space and the astronauts on the lunar surface were instead carried back by the ascent stage of the lunar module. For that reason, the capabilities of the rocket as a return vehicle were never tested.

The difference in the masses of the Earth and the Moon makes the journeys between them asymmetrical; it would be trivially easy for a super heavy-lift rocket like the Saturn V to escape the much weaker gravity of the Moon. For a rigorous test of the rocket's capabilities, one must imagine a more challenging return journey. In the 1943 novella *Le Petit Prince* (*The Little Prince*)[2], the title character recounts his life living on an asteroid the size of a house, but with gravity like a planet. This provides a useful thought experiment: suppose the Moon was the same size but had the same mass as the Earth. How differently would a rocket perform launching from this hypothetical super-dense Moon (SDM) compared to the Earth?

Equations

The gravitational field strength of the SDM, g_{SDM}, is related to that of the Earth, and the radii of the Earth and the Moon by:

$$g_{SDM} = g_{earth}(R_{Earth}/R_{Moon})^2. \quad (1)$$

The escape velocity, v_{escape}, of a body is related to its mass and radius:

$$v_{Orbit} = \sqrt{GM/R}, \quad (2)$$

$$v_{escape} = \sqrt{2GM/R}. \quad (3)$$

Results

Equation (1) is first used to calculate the acceleration due to gravity on the SDM, using the known values for the Earth's gravitational acceleration, radius, and the radius of the Moon [3]. A value of 131.97 ms^{-2} is obtained, which is approximately 13.45 times greater than that of the Earth. The weight of the Saturn V rocket can then be found via the calculated gravitational acceleration. Using the known thrust of the Saturn V rocket [4], the thrust-to-weight ratio can be found, in this scenario the ratio was found to be 0.093.

The velocity required to achieve a circular orbit around the SDM is then calculated using Equation (2), with the values for the mass of Earth and the radius of the Moon. This was calculated to be 15.14 kms^{-1}. The escape velocity at the surface of the SDM is then calculated using Equation (3), with the same values used to calculate the orbital velocity, this produces a value of 21.45 kms^{-1}.

Discussion

This paper considered the scenario in which the Apollo 11 mission's launch stage (utilising a Saturn V rocket) instead took place from a hypothetical Super-Dense Moon (SDM) instead of the Earth, in order to assess the upper limits of its feasibility as a return vehicle which was untested in the original Apollo programme. In this alternate scenario, the SDM was modelled as having the same volume and dimensions as our Moon, but with a much greater mass equal to that of the Earth. This drastically altered initial launch conditions by raising the acceleration due to gravity at the lunar surface by a factor of approximately 13.45, while raising the global escape velocity to 21.45 kms^{-1}, far greater than that of the Saturn V's max velocity achieved, which NASA recorded at 10.42 kms^{-1}. Therefore, while this study shows that the Saturn V rocket would not be capable of escaping the gravitational pull of the SDM, it does offer better assessment of the vehicle's capabilities. Such data could prove useful in future assessments of how gravitational disparities between high-value locations in our Solar System could affect the feasibility of missions such as sample return from external Moons (for example, the icy, potentially life supporting moons such as Europa, Callisto and Enceladus), especially when considering much more powerful future vehicles such as SpaceX's reusable Starship, though further, targeted study is required.

Conclusion

These results demonstrate the difficulty of taking off from extremely dense celestial bodies. This is both because the weight of the rocket is increased when the body has higher mass and when the surface is closer to the body's center of mass. These two factors combined mean the Saturn V rocket could not provide enough thrust to overcome its weight and leave the ground.

This difficulty in escaping highly dense bodies may help explain the limited scope of current human space flight; Earth is the densest planet in the solar system [3]. Future papers could attempt to calculate the maximum mass the moon could have while still making take-off possible or what changes need to be made to the rocket to make take-off possible.

References

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