Nov. 18, 1967

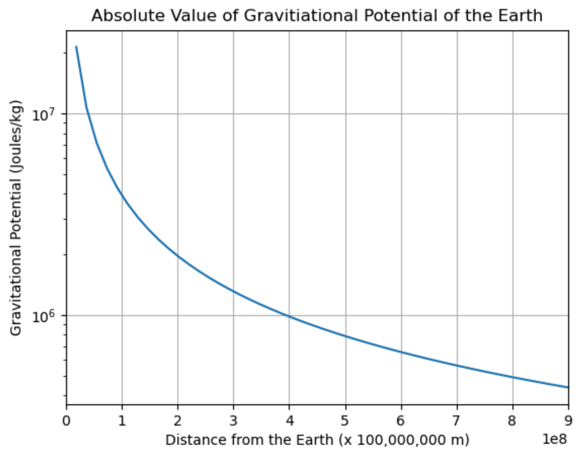
BASIC GEOLUNAR PHYSICS AND S-IC PERFORMANCE EXPECTATIONS

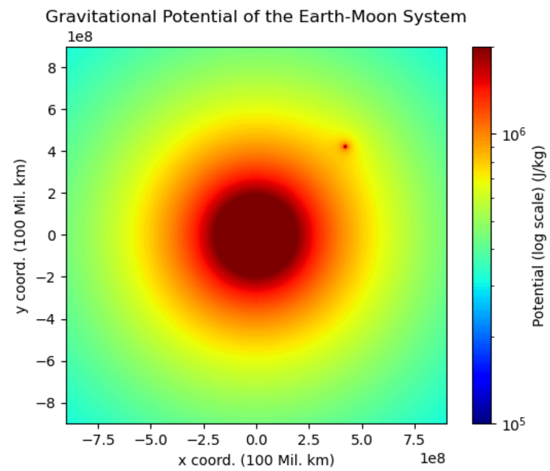
I. Introduction

In order to undertake an expedition to the moon, one must study and understand the physics of the journey in the same way one would study a topographical map before a trail hike. In our geolunar journey, the contours of our map are not hills but rather gravitational forces. The same gravity that Sir Isaac Newton discovered on Earth affects objects floating through space, and the same universal laws apply. In this report, we will walk through calculations and visualisations of the basic forces at play in our navigation to and from the moon. We will also briefly explain the physics of rocketry and run preliminary calculations on the expected performance of the first stage of the Saturn V (S-IC).

II. The Gravitational Potential of the Earth-Moon System

Every object, no matter its size, has an aspect called the "gravitational potential." This represents the potential for a gravitational force to pull other objects inwards, and it gets smaller as one gets farther from an object. Within the geolunar system, this potential varies as the Moon and Earth interact with each other. The graphs below illustrate both the way that the gravitational potential of Earth drops off on a logarithmic scale (meaning the space between values on the vertical scale gets smaller as they increase) and the gravitational potential of the geolunar system as a whole.

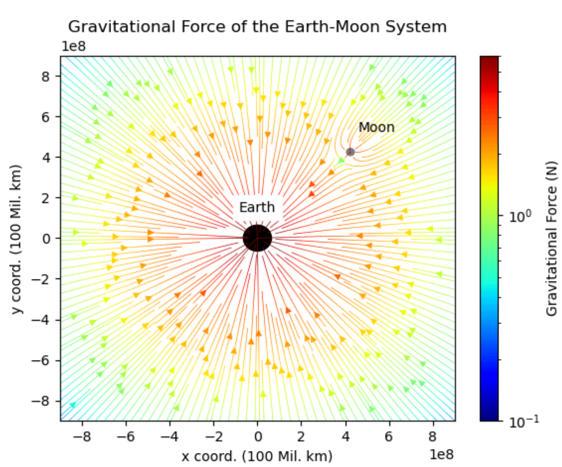




These graphs - and all others in this report - were created using the coding software Python by inputting the applicable equations, evaluating them for the area around the geolunar system, and plotting the results. Quite usefully, the program also retains all of the values calculated by the formula at every location. This means that, at any given point, one could access the exact potential at that location with one command.

III. <u>The Gravitational Force of the Earth-Moon System</u>

A more familiar force that we will have to contend with on the journey to the moon is gravity. The same force that affects everything on Earth acts in the same way in space. Python was used once again to produce the following graph showing arrows known as "streams" indicating the direction and strength of the gravitational force imparted by the Earth and Moon on the Apollo Command Module as it travels through space. The Earth and Moon have been labeled, and their sizes have been increased by a factor of 10,000 to make them visible.



IV. <u>Projected Performance of the Saturn V Stage 1 (S-IC)</u>

For the gravitational potential and force to be of any consequence, the Apollo Command Module must be lifted into space and propelled there by rockets. Physics has provided us with numerous equations to apply to this, the most prominent being the "Rocket Equation."

$$\Delta V(t) = v_e ln(\frac{m_0}{m(t)}) - gt$$

The specific notation of the equation is not important, but the rocket equation governs the principles of propulsion and, along with other mathematical concepts, can be used to estimate the performance of rockets before they are ever tested. Taking in certain specifics of the S-IC, we calculated that the stage will burn for a total of 157.7 seconds and lift the rocket to an altitude of 74.2 km (~ 46.1 miles).

V. Discussion and Future Work

During the recent launch of the Apollo 4 mission, the first use of the S-IC, data indicated that the stage burned for 160 seconds and burned out at an altitude of about 70km. Our engineers' predictions of burn time and burnout altitude proved to be fairly accurate, however, they were more accurate on the burn time than burnout height. The burn lasted only about 1.5% longer than predicted, but the altitude estimate was 6% higher than the test stage made it. This overprediction likely stems from a few sources. First, the rocket equation is "one dimensional," meaning it only evaluates the change in velocity in a vertical straight line. In reality, the Saturn V executes a roll program shortly after liftoff, so its trajectory is not entirely linear. The calculations also did not take into account the drag force provided by Earth's atmosphere, which would slow down the rocket slightly and lower the burnout altitude.

Going forward, NASA will make calculations that better reflect the actual forces and dynamics at work and compare them to test results to confirm their accuracy.