Part 3: QUESTIONS AND INTERPRETATION

6.1 Coding

Question 1:

There is an advantage to how we had to code in the gravity because this method involves accessing a dictionary that contains this information and is further utilized in different functions and different contexts as a parameter that can be changed. This method allows for code reuse and minimizes redundancy. Additionally, by passing acceleration due to gravity as a parameter, it makes the code more flexible and easier to change in the future. For future uses, if the environment is different and there is another acceleration, it can be easily changed. However, if the acceleration value was hard-coded into the program, it would make it very difficult to change values. Furthermore, hardcoding the acceleration into the program can lead to a risk of error and lead to inconsistencies in the program. I would not have done it differently because this structured approach has multiple benefits including flexibility and maintainability. If I were designing a system, I would take on an approach with this technique as it keeps the variables managed in a central location and utilized in various environments. It is essentially easier to implement.

Question 2:

If I try to call F_gravity using a terrain slope of 110 degrees, the function will run and calculate the force of gravity. The first check examines if the parameter is a scalar or an array. If not, the function will raise an exception. The second check examines if the parameter is an array and has values between -75 and +75. If the check fails, the function will raise an exception. Given these two checks, a terrain slope degree of 110 does not pass. 110 degrees is not a valid angle considering it's taken from the positive x-axis since it indicates that the slope is behind the motion of the rover as long as the rover is traveling in the positive x-axis direction. The way the angles are currently input can easily tell us whether the rover is going down (negative angle) or up (positive angle). By including degrees over 110 we introduce ambiguity in our motion which may require extra preparation and coding to make sure these scenarios are handled correctly.

6.2 Motor and Speed Reducer Behavior

Question 3:

The maximum power output by a single rover motor is 161.483 Nm. The speed at which this Power output occurs is 1.881 radians per second. This can be seen graphically in **Figure 1** below. Furthermore, looking at the values in **Table 1**, the maximum value is 161.483 watts at 1.881rad/s

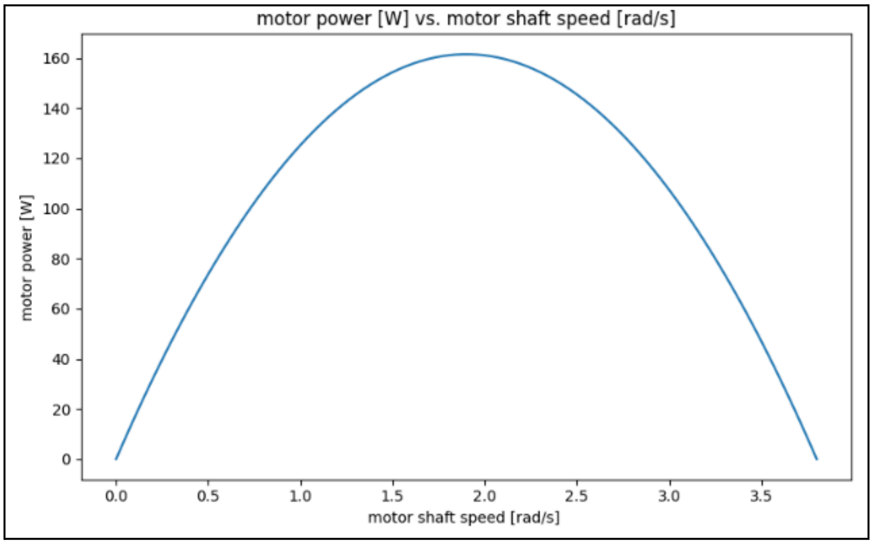

Figure 1: Motor shaft speed(rad/s) vs Motor Power(W)

Table 1 : Motor shaft speed(rad/s) vs Motor Power(W)

Motor Shaft Speed (rad/s)	Motor Power(W)
1.688888889	159.5061728
1.727272727	160.1652893
1.765656566	160.6925824
1.804040404	161.0880522
1.842424242	161.3516988
1.880808081	161.4835221
1.919191919	161.4835221
1.957575758	161.3516988
1.995959596	161.0880522

Question 4:

The speed reducer contributes to the behavior of the power output of the drive system. Given that as motor shaft torque increases, the motor shaft speed decreases, creating an inverse relationship between the two. The speed reducer is a gear ratio of two gears, the larger gear and the pinion. If the larger gear diameter has a bigger diameter than the pinion, then it creates a positive gear ratio leading to a larger torque. If the pinion has a bigger diameter than the gear ratio, then it creates a fractional gear ratio, leading to a smaller torque. This relation between the gear ratio from the speed reducer and power output can be explained through the equations that are shown in **Figure 3**. The result of the speed reducer is to keep the power output constant but to decrease the speed of each wheel and increase the torque of the wheel. **Figure 2** shows this since power is the same as in **Figure 1,** but the speed is reduced.

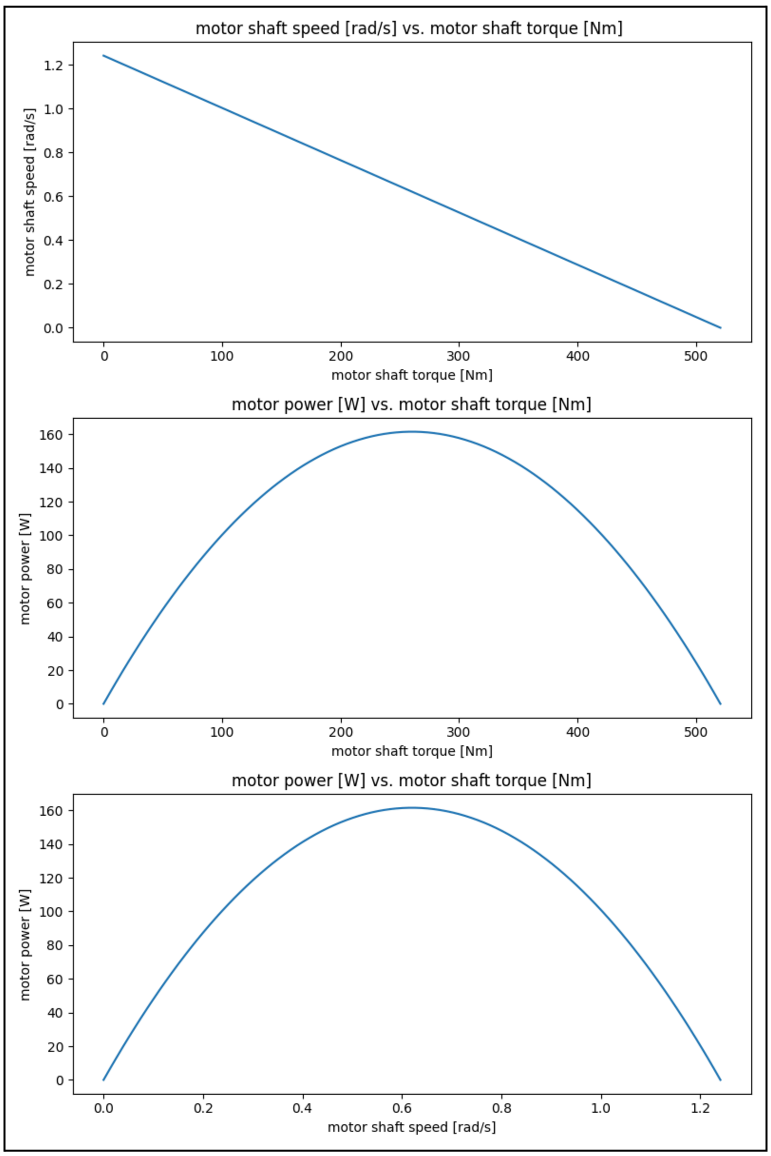

Figure 2: Graphs for speed, torque, and power using gear ratio

```
for i in range(len(tau)):
    tau_out.append(Ng * tau[i])
    omega_out.append(omega[i]/Ng)
    power_out.append(tau_out[i] * omega_out[i])
```

Figure 3: Coded equations for output speed, torque, and power

6.3 Rover Behavior

Question 5:
There is an inverse and almost linear relationship between the terrain slope and the maximum velocity of the rover as seen in **Figure 4**. As the slope of the terrain increases, there is more gravitational force acting to oppose the rover, which leads to more torque and force required to move the rover. Therefore, the velocity of the rover decreases with an increase in slope. The velocity is highest at negative slopes as gravity assists in moving the rover at higher speeds. In this scenario gravity reduces net resistance forces, so the rover can move faster with less energy. The explanation of the slight deviation from linearity is a result of multiple factors that complicate the interaction between velocity and the slope of the terrain. Here, velocity does not decrease at a constant rate as the slopes increase. This makes sense because forces like gravity and rolling resistance contribute to this velocity. Additionally, the steeper the slope, the more pronounced effect gravity has on maximum velocity.

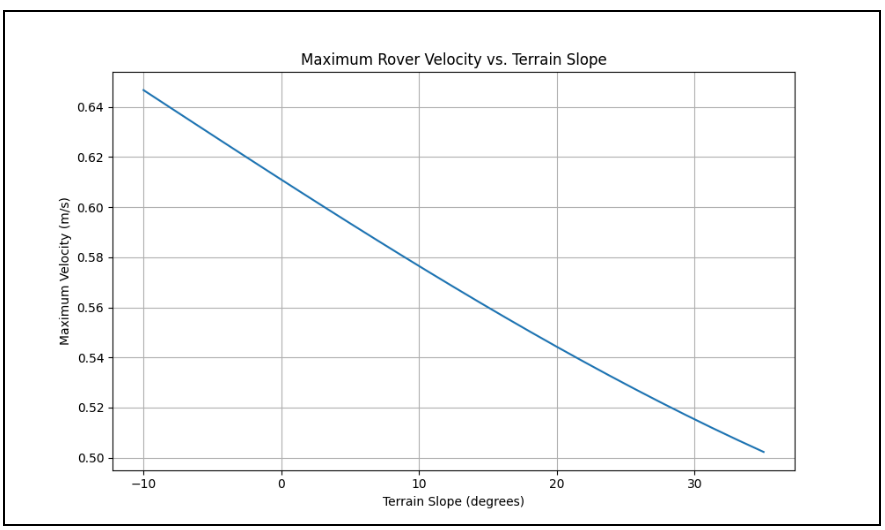

Figure 4: Maximum velocity vs Terrain slope

Question 6:

Figure 5 below exhibits a linear relationship between the rover's maximum velocity and the coefficient of rolling resistance. At low Cr values, the rover is at its highest maximum velocity at approximately .36 m/s. At high Cr values, the maximum velocity is at its lowest at approximately 0.1 m/s. The coefficient of rolling resistance depends on the properties of the rover wheels and the surface on which it is traveling and represents the resistance to the motion of the vehicle. A higher coefficient means that more energy is lost due to friction between the rover's wheels and the terrain surface, which limits the amount of power available to push the rover forward at high speed. A smaller coefficient indicates that the rover experiences a small amount of friction, allowing for more torque and power to mobilize the rover. As a result, the rover can reach higher speeds. The graph appears to be linear, which is reasonable as maximum velocity decreases at a constant rate as the coefficient increases. This relationship can be attributed to the resistive force being proportional to the coefficient of rolling resistance. The relationship between these resistive forces and velocity is linear when friction is prominent and other factors are negligible. The trend makes sense physically as the higher rolling resistance can cause more power to be lost due to friction and only affects the rolling resistance linearly by multiplying the resistive force by a scalar. In this situation, a constant decrease in velocity as Crr increases is expected from the rolling resistance.

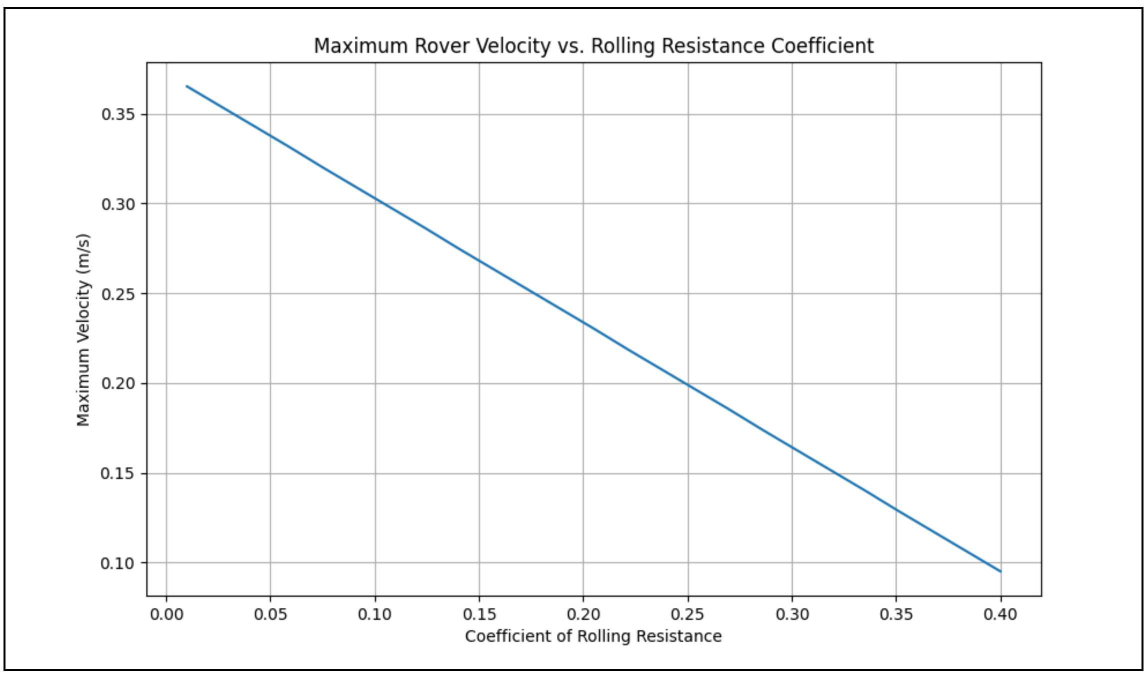

Figure 5: Maximum Rover Velocity vs Rolling Resistance Coefficient

Question 7:

Figure 6 shows the maximum speed of the rover over various terrain conditions. The x and y axis are represented as the rolling resistance and the terrain slope, respectively. The z-axis shows the max rover of the speed. An increase in the terrain slope and rolling resistance coefficient decreases the maximum speed of the rover, which is supported by the previous graphs. Higher speeds are observed at the lowest values of terrain slope and rolling resistance. This graph communicates that the rover is more viable on terrains with smaller slopes and smaller coefficient values; smoother terrains are appropriate for the rovers to become more mobile and operational. As the coefficient of rolling resistance increases, the rover's speed consistently decreases, which was also observed in the previous graph. As the terrain slope also increases, the maximum speed decreases as well. The more dominant consideration that affects how fast the rover can travel is the terrain slope. As the terrain slope increases, the maximum speed drops significantly as evidenced by how steep the slope is. The rolling resistance coefficient still plays a role in the maximum speed but the impact of the slope is not as extensive as increasing the terrain slope. Essentially, since the maximum velocity decreases faster over a wider range of terrain slope, the terrain slope has more impact on the velocity of the rover and is more sensitive to the slope that the rover is traversing through. Ultimately, the rover's maximum speed is heavily affected by the terrain slope. In terrains of high slope, the rover will have difficulty in maintaining speeds even when the rolling resistance coefficient is moderate. Minimizing the terrain slope is more crucial than managing the rolling resistance in terms of determining how fast the rover can move.

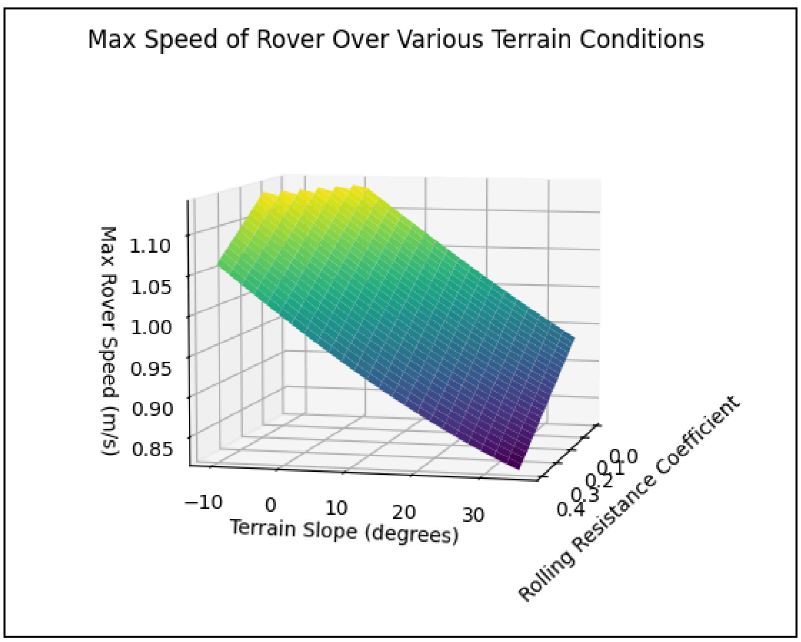

Figure 6: Max Rover Speed vs Terrain Conditions