Phase 4: Design of the EDL and Rover System

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MEEN 357-505

Team 14: Very Fast, Kinda Furious

"On my honor, as an Aggie, I have neither given nor received unauthorized aid on this academic work."

"None of the members of the team communicated in any way with other teams with regards to specific coding issues with this project."

Overall performance was our main focus when beginning the testing process. While keeping costs to a minimum is incredibly important in the real world, we wanted to primarily divert our attention to three core aspects of the rover performance before looking at minimizing costs. These three aspects were achieving a consistently fast speed, energy efficiency and extending the rover's lifetime, and being able to safely overcome steep terrain angles – while of course, not crashing. However, with a constraint of $7.6 million as the maximum cost, we made sure to stay within the budget. The final parameters that were chosen were a magnesium chassis, the base_he motor, and the Pb_acid-1 battery with 4 battery packs. This combination of parameters yielded the most ideal rover system to proceed with speed but be able to move through steep terrain while staying under budget.

We tried dozens of combinations, initially using randomized guesses and recording the outputs for comparison. Our first decision was using magnesium as the chassis type because it had a higher strength than steel but wouldn't weigh down the rover like carbon would. Having the chassis type set in stone, we moved on to testing different battery types and motors. The _he motors all offered better results than the basic motors so they were all discarded when determining the parameters. Our initial solution to solving the motor problem was to implement a for loop that changed the motor based on the terrain angle. However, as this is not a feasible solution for an actual rover, we had to scrap this idea. For a while, we thought we would use speed_he as our motor to ensure a fast velocity, but as we began changing the terrain angles and running more iterations, we realized that speed_he may not be the safest option to cross steep inclines. Therefore, the motor was changed to base_he thinking that it would allow the rover to maneuver better on steeper or more varied terrains. The battery type and amount of modules turned out to be one of the hardest decisions. After doing preliminary research, we found that NiMH seemed to be the battery with the longest life and could outperform the PbAcid batteries. However, when running tests with NiMH, it seemed to weigh the rover down significantly and increased the overall time to complete the mission by over 100 seconds more than some of the previous tests. Therefore, we decided to use the PbAcid-1 battery with 4 modules, a minimum of 3 to ensure that the rover would perform with a backup fourth pack, which kept the rover fairly lightweight and was far cheaper than the NiMH battery by about $1 million. After deciding on our motor, chassis, and battery, each optimizer was tested, but all optimizers except COBYLA resulted in a failed run or unfavorable results.

Our final rover design contained the following optimized parameters:

Optimized parachute diameter = 17.925208 [m]
Optimized rocket fuel mass = 287.713446 [kg]
Time to complete EDL mission = 65.117790 [s]
Rover velocity at landing = -0.957719 [m/s]
Optimized wheel radius = 0.700000 [m]
Optimized d2 = 0.050000 [m]

Optimized chassis mass = 455.022744 [kg]
Time to complete rover mission = 733.611966 [s]
Time to complete mission = 798.729756 [s]
Average velocity = 1.338668 [m/s]
Distance traveled = 1000.000000 [m]
Battery energy per meter = 529.669462 [J/m]
Total cost = 5992821.025332 [$]

From the final operational parameters, it can be concluded that although the mission took longer to complete, it was more energy efficient and cheaper while still ensuring that the rover could traverse steep terrain. The choice to use base_he as opposed to speed_he was made with the actual application of the rover in mind and not the rover race. In terms of the race, speed_he would beat out base_he any time, with a time to complete mission of 470.894671 s as seen in *Figure* 1. However in actual rover application, the speed_he would not offer much to the rover, and the likelihood of failure at steeper terrains would be increased significantly. While aiming to keep costs low and make the rover as efficient as possible, the parameters that were chosen seemed to be the most ideal. In order to improve our rover from here, we would have done better to take full advantage of the budget given. With over a million dollars unused, the rover could have become quite formidable for the race. In the race, our rover did not quite live up to its name as it lost in the first round. The decision to choose base_he while logical for practical rover use was not the correct decision in terms of the race.

APPENDIX

Magnesium', torque_he', PbAcid-1', 4	Magnesium', base_he', PbAcid-1', 4	Magnesium', speed_he', PbAcid-1', 4
Optimized parachute diameter = 17.925043 [m]	Optimized parachute diameter = 17.925208 [m]	Optimized parachute diameter = 17.838691 [m]
Optimized rocket fuel mass = 287.683945 [kg]	Optimized rocket fuel mass = 287.713446 [kg]	Optimized rocket fuel mass = 285.895109 [kg]
Time to complete EDL mission = 140.060189 [s]	Time to complete EDL mission = 65.117790 [s]	Time to complete EDL mission = 64.943540 [s]
Rover velocity at landing = -0.001350 [m/s]	Rover velocity at landing = -0.957719 [m/s]	Rover velocity at landing = -0.547112 [m/s]
Optimized wheel radius = 0.700000 [m]	Optimized wheel radius = 0.700000 [m]	Optimized wheel radius = 0.700000 [m]
Optimized d2 = 0.050000 [m]	Optimized d2 = 0.050000 [m]	Optimized d2 = 0.050000 [m]
Optimized chassis mass = 455.066938 [kg]	Optimized chassis mass = 455.022744 [kg]	Optimized chassis mass = 453.648284 [kg]
Time to complete rover mission = 695.573660 [s]	Time to complete rover mission = 733.611966 [s]	Time to complete rover mission = 405.951130 [s]
Time to complete mission = 835.633850 [s]	Time to complete mission = 798.729756 [s]	Time to complete mission = 470.894671 [s]
Average velocity = 1.410299 [m/s]	Average velocity = 1.338668 [m/s]	Average velocity = 2.376602 [m/s]
Distance traveled = 1000.000000 [m]	Distance traveled = 1000.000000 [m]	Distance traveled = 1000.000000 [m]
Battery energy per meter = 530.331835 [J/m]	Battery energy per meter = 529.669462 [J/m]	Battery energy per meter = 590.770690 [J/m]
Total cost = 6329048.322612 [$]	Total cost = 5992821.025332 [$]	Total cost = 6315072.972449 [$]

Figure 1: Comparison of Motors

```python
# The following calls instantiate the needed structs and also make some of
# our design selections (battery type, etc.)
planet = define_planet()
edl_system = define_edl_system()
mission_events = define_mission_events()
edl_system = define_chassis(edl_system,'magnesium')
edl_system = define_motor(edl_system,'base_he')
edl_system = define_batt_pack(edl_system,'PbAcid-1', 4)
tmax = 5000
```

Figure 2: Altered Code

```python
################################################################################
# call the COBYLA optimizer -------------------------------------------------------#
cobyla_bounds = [[14, 19], [0.2, 0.7], [250, 800], [0.05, 0.12], [100, 290]]
#construct the bounds in the form of constraints
cons_cobyla = []
for factor in range(len(cobyla_bounds)):
    lower, upper = cobyla_bounds[factor]
    l = {'type': 'ineq',
         'fun': lambda x, lb=lower, i=factor: x[i] - lb}
    u = {'type': 'ineq',
         'fun': lambda x, ub=upper, i=factor: ub - x[i]}
    cons_cobyla.append(l)
    cons_cobyla.append(u)
    cons_cobyla.append(ineq_cons)  # the rest of the constraints
options = {'maxiter':50,
           'disp' : True}
res = minimize(obj_f, x0, method='COBYLA', constraints=cons_cobyla, options=options)
# end call to the COBYLA optimizer -----------------------------------------------#
################################################################################
```

Figure 3: Chosen Optimizer