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# Energy Optimization Analysis

# Overview

1. Test Plan
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3. Copter Energy With Time
4. Copter Force, Time, and Energy Plot
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# 1. Test Plan

| Run Data File Name | Force time (s) | Force Amplitude (N) | Coast Time (s) | Copter Weight (N) |
|---|---|---|---|---|
| BCB_1.txt | 0.5 | 5.94 | 0 | 12.8 |
| BCB_2.txt | 0.5 | 5.5 | 0 | 12.8 |
| BCB_3.txt | 0.45 | 5.7 | 0.15 | 12.8 |
| BCB_4.txt | 0.5 | 4.7 | 0.15 | 12.8 |
| BCB_5.txt | 0.4 | 5.4 | 0.25 | 12.8 |
| BCB_6.txt | 0.4 | 4 | 0.4 | 12.8 |
| BCB_7.txt | 0.4 | 4 | 0.55 | 12.8 |
| BCB_8.txt | 0.35 | 4.9 | 0.55 | 12.8 |

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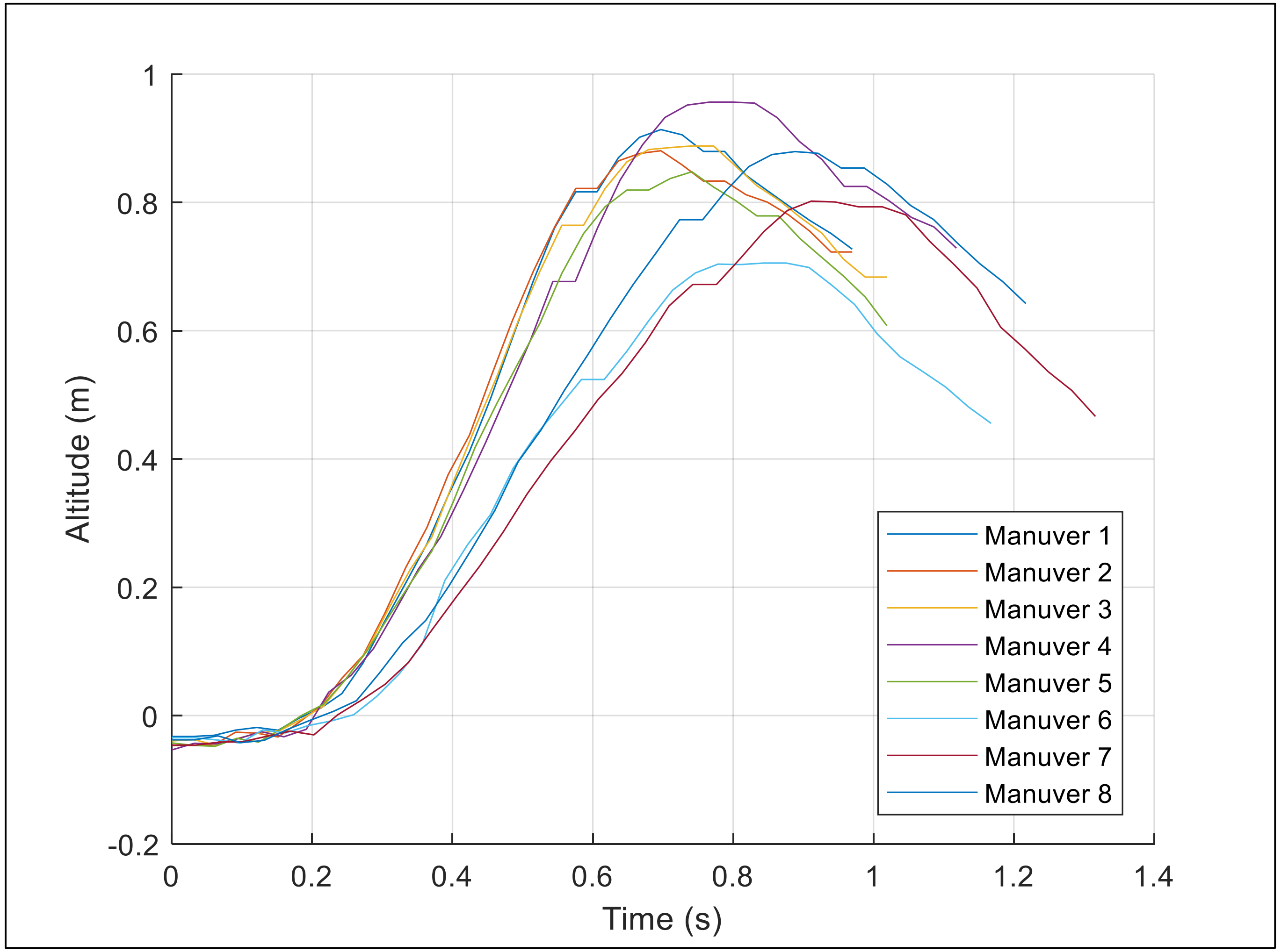
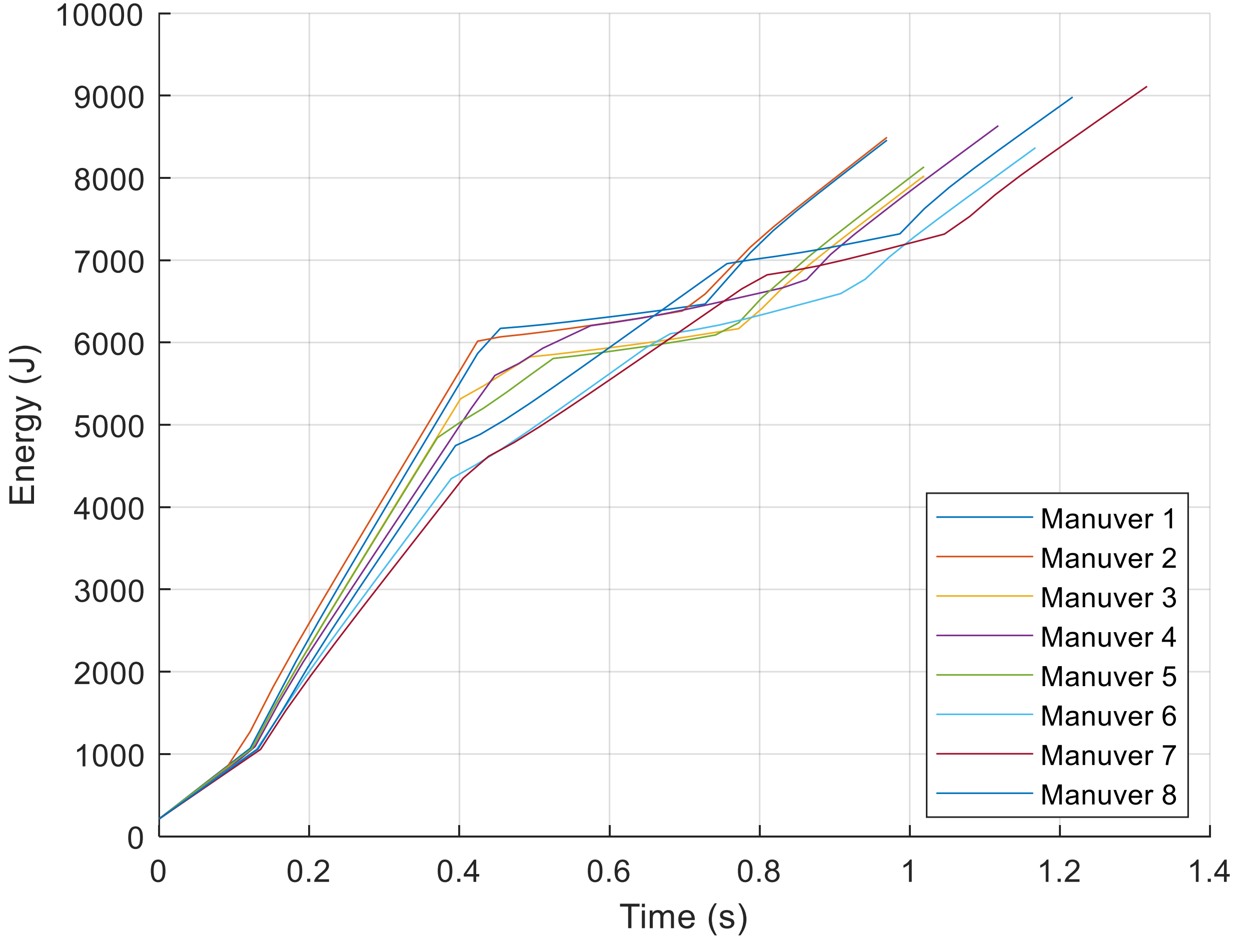
# 2. Copter Altitude During Test Runs



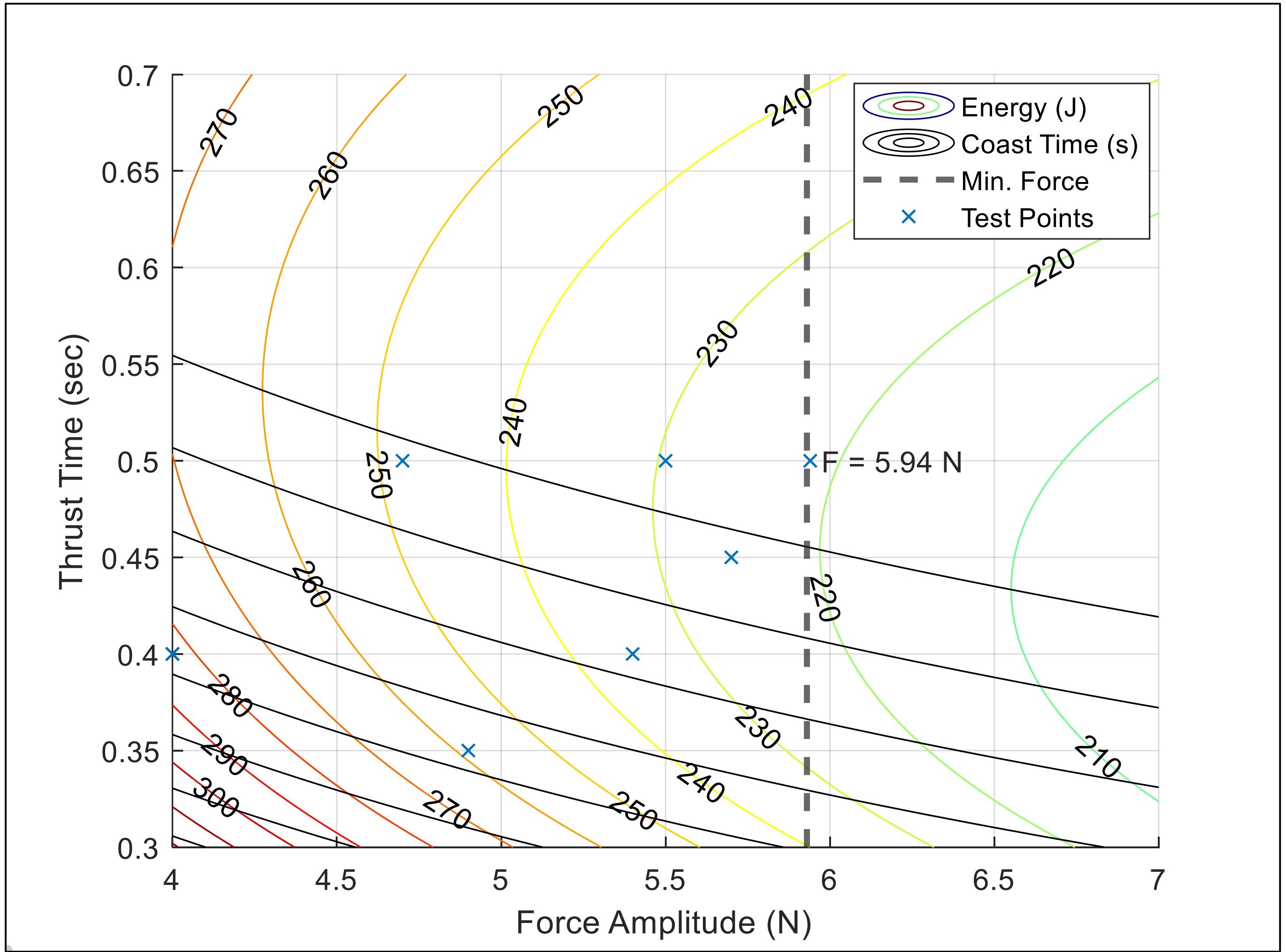

The copter didn't quite reach the 1 meter mark in most of the tests as seen to the left. This is due to the force time not being changed between most of the test, leading to the total impulse from the propellers to be less, while the impulse from gravity remains the same leading to a low altitude being reached.

# 3. Copter Energy With Time




To the left the energy with time that the copter has consumed is shown. All of these values were calculated by measuring the voltage and current supplied, multiplying to get the power and then integrating over the run time. They are all in the 8000 to just above 9000 Joule range, meaning low variation between the different force amplitudes.

# 4. Copter Force, Time, and Energy Plot




A contour plot was made that has the force amplitude on the x-axis, thrust time on the y-axis, and energy consumed during the maneuver on the contour. This was calculated using mechanical energy as a basis and then derived based upon the equation:

$$E = C\,W\left(\frac{x_d\,m}{F\,t_f} + t_f\right)$$

The test points are plotted with blue “x” marks but are not contoured, to see the measured energies during the test runs compared with the calculated results see the next slide.

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# 5. Copter Force, Time, and Energy Comparison

| Calculated (J) | Measured (J) | % Error |
|---|---|---|
| 221.5 | 8245 | 97.31 |
| 229.5 | 8273 | 97.23 |
| 225.2 | 7810 | 97.12 |
| 248.0 | 8420 | 97.05 |
| 234.9 | 7920 | 97.03 |
| 283.2 | 8153 | 96.53 |
| 283.2 | 8899 | 96.82 |
| 258.6 | 8769 | 97.05 |

The percent error is extremely high when comparing the two results. This can most likely be explained by the fact it is was derived with mechanical energy in mind, which when used carelessly can lead to extremely erroneous results as it is assumed to be able to be recovered, which in this case would happen when the copter would move down. In real life this doesn't happen as the propellers are always expending energy to spin and never recover anything.

# 6. Numerical Energy Optimization

Using MATLAB, a non-linear numerical optimization of the mechanical energy was carried out before the extreme error was found later. This still may be useful as it could indicate where to start at least. Using the "fmincon" function in MATLAB a minimum mechanical energy needed is 220.5 Joules at a thrust force of 5.96 Newtons and a thrust time of 0.455 seconds.

The contour plot on slide 6 was analyzed and an optimum of approximately that was expected where the zero coast time contour crosses the minimum thrust force line. This lines up with the optimization, and verifies that the optimizer is at least close to being correct. The MATLAB code used is shown in Appendix A (Slide 9).

# 7. Appendix A

Optimizing line in main script file

```
[op_force, op_energy, exit_flag] = fmincon(@energy_fun, [5.94, 0.45], [], [], [], [], [0, 0], [5.94, inf], @coast_time)
```

energy_fun function file

```
function [out] = energy_fun(x)
% Energy function being optimized
f = x(1);
t = x(2);
out = 20.093 * 12.06 * (1 * 1.23 / f / t + t);
end
```

coast_time function file

```
function [c, ceq] = coast_time(x)
% Non-linear inequality function
% for optimizing energy
f = x(1);
t = x(2);

c(1) = t - 1 * 1.23 / f / t;
c(2) = 0;
ceq  = double([]);
end
```