Motor Selection Analysis

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Disclaimer: A lot of this is probably model-rocketry-101, and will not be 100% accurate. I've never launched a model rocket before, so if anything sounds completely off, please let me know.

Overview

The two main factors that we don't have control over are:

- The external environment (the structure of the atmosphere, weather conditions on launch day).
- The internals of the motor we choose to use (construction, behaviour), because of the category we are competing in (COTS).

We have design freedom over the remainder of the launch vehicle (LV). This is not complete because of the constraints set out by ESRA, but these are relatively high level. Once we've finalised a motor, the design space for the rest of the LV is opened up. It seems possible to derive almost all remaining design questions from the motor and the competition goal. Without providing links to all design decisions that will have to be made, the following lists a few examples. These allow cascading information to be determined. Further into design, sub-problems can be properly defined.

- Diameter gives us upper and lower bounds on the LV's total length (using stability, caliber, fineness ratio recommendations/constraints for target-apogee flight). This can in turn be used to make general statements about and define constraints for the air frame and then space we have to store avionics hardware, recovery hardware, payload etc...
- Mass and thrust data gives us a hard upper bound on the mass of the remainder of the LV if we're to reach 10'000ft, which all feeds into the paragraph above.
- Price gives us a rough estimate of remaining budget to work with (even if this is subject to change).
- $\cdots$

Motor Parameters

The following section outlines some motor parameters that should be used to inform our choice. Some of these are given on data sheets online, others need to be calculated.

Available with data sheets

- Type (single-use, reloadable, hybrid)
- Delay time(s)/whether it even has a delay charge or not (booster)
- Average thrust
- Maximum thrust
- Thrust-vs-time curve
- Total impulse and impulse class
- Burn time
- Diameter
- Length
- Total mass
- Propellant mass (and how this changes over the burn)
- Centre of gravity (and how this changes over the burn)

These parameters can easily be obtained from a .rse file.

Determined independently

- Allowable - does the SAC allow the use of this motor? Any motors with a total impulse greater than 40'960 Ns cannot be used. This will rule out higher-power motors.
- Sufficiency - in the best case, is it physically possible for this motor to reach 10'000ft with a 4kg payload? This will rule out lower-power motors.
- Overall consistency between units (focusing on but not limited to the thrust curve) - what uncertainty is there around the thrust curve provided in the data sheet? Are there multiple sets of test data for this motor that support each other? What is the source of the test data? Has the manufacturer supplied a measure of standard deviation for any parameters? How many tests have been carried out to determine values for the datasheet?
- Reliability - are there any instances where this motor has been known to CATO?
- Price - is this motor too expensive?

Selection Criteria

Given the complete set of parameters above and the competition goal, in what order should we consider the parameters when selecting the optimal motor? This list is ordered based on priority and describes the ideal value of each parameter, so the process of selecting a motor becomes an optimisation problem.

1. Allowable
   Must be allowed

2. Sufficiency
   Must be able to reach $\geq$ 10'000ft carrying $\geq$ 4kg of extra mass (at this stage, the required payload is the only mass information we have)

3. Reliability
   Maximise
   It's not obvious how this could be quantified. It could involve the number of reported failures online in blogs, videos, forums, papers. Is it correct to assume that modern motors are more reliable than older motors? Are certain internal propellant structures more prone to failure than others? When do the most failures occur?

4. Type
   Reloadable $\geq$ single-use $\geq$ hybrid
   Considering a measure of simplicity, hybrid motors take the lowest rank and having reload capability - provided it doesn't add any significant risks - is better than not having reload capability.

5. Uncertainty
   Minimise
   Because we don't have the ability to throttle the motor, our final apogee is coupled to the motors performance: once it's been ignited, we have no active control. Therefore I think consistency of motor performance should have the highest priority of all parameters. We'd have room to configure the mass of the LV to raise or lower it's apogee accurately if we had accurate information about the motors performance. But mass optimisation wouldn't matter if there was still a significant chance the motor might leave the LV too high or too low. Adding mass to the vehicle might even amplify uncertainty in the apogee. How a value for 'consistency' is determined for each motor requires discussion. Which parameters should be used in this calculation? I think burn time, average thrust and the *shape* of the thrust curve are priority (in that order). These would also be the most complex/expensive to test ourselves.

6. Delay time(s)/whether it even has a delay charge or not (booster)
   No delay charge > delay charge, minimise delay time
   A miscalculation here would still give us a good chance of hitting the target apogee if everything else was correct, hence the low priority. This becomes relevant after motor burnout as the LV approaches its' apogee. As soon as the delay charge fires and the vehicle splits, it becomes impossible to predict its aerodynamic behaviour. If this fired too early it would make it less likely that we could accurately hit the target altitude. Therefore ideally, chute-deploy should be triggered by our own software and a separate charge. We could combine IMU measurements with a moving average of altitude to guarantee that the LV had passed apogee before activating the 'initial recovery event' (explained by docs). If all motors have delay charges built-in, we should choose the smallest value that gives us high confidence it will **not** activate before apogee. It would be possible to determine an optimum delay time if we had to choose one, by comparing the number of points gained for hitting the target altitude vs performing the initial recovery event successfully (without leaving it too late during descent and zippering the LV), but this shouldn't be necessary.

complete these

7. Average thrust
8. Maximum thrust
9. Thrust-vs-time curve
10. Total impulse and impulse class
11. Burn time
    Maximise
    Long burn time + low average thrust → minimised average veloctiy → minimised drag.
12. Diameter
    Minimise
13. Length
    Minimise
14. Total mass
    Minimise
    Although overall, the LV should be relatively heavy for momentum and resistance to wind disturbance, we want to have maximum control over the placement of mass. Also, when considering stability, the CoG of the LV should be as high up as possible and it's safe to say the motor will attached as low as possible, therefore the mass of the motor should be minimised.
15. Propellant mass (and how this changes over the burn)
16. Centre of gravity (and how this changes over the burn)
17. Price
    Minimise