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ASE 376D Rocket Engineering Practicum
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Monte Carlo Vehicle Modeling

Link to code repository

The purpose of this project is to determine the mass-to-orbit achievable by a launch vehicle, given uncertainty in inputs. To this end, a Monte Carlo model was created to accept various dispersions and determine the associated payload mass. Table 1 lists the input distributions accepted by the model, and Figure 1 depicts the inputs as histograms.

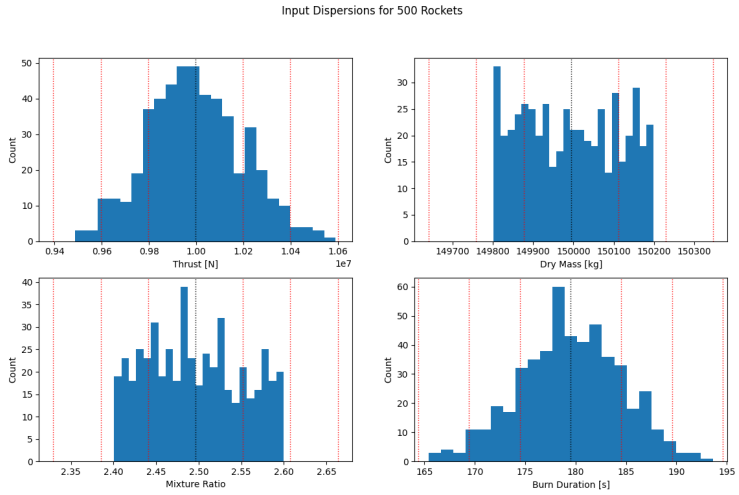


Figure 1: Histograms of Input Parameters

Input	Nominal Value	Tolerance (±)	Distribution Type
Thrust	10,000 kN	200 kN	Normal
Dry Mass	150,000 kg	200 kg	Uniform
Wet Mass	500,000 kg	500 kg	Normal
Mixture Ratio	2.5	0.1	Uniform
Burn Duration	180 s	5 s	Normal

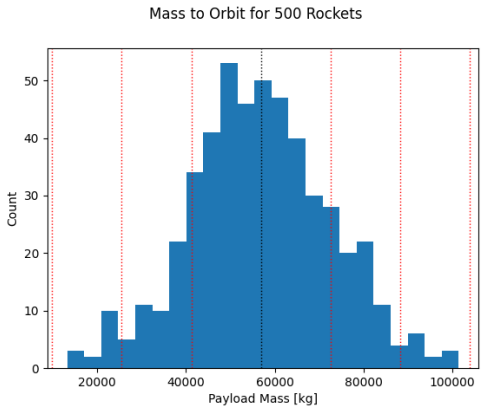
Table 1: Input Parameter Dispersions

Using this data and some simplifying assumptions, a mass-to-orbit value was calculated for each Monte Carlo test case. The total number of Monte Carlo cases N was determined via the Z-score, which gives insight into the distance (in terms of standard deviation) of each payload mass from the mean value:

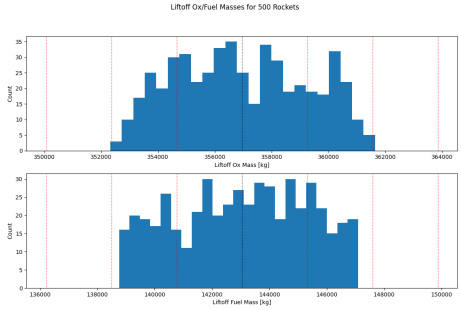
$$Z = \frac{x - \mu}{\sigma} \tag{1}$$

where x is a particular payload mass, μ is the mean of all payload masses, and σ is the standard deviation. After some iteration, a value of $N = 500$ was selected in an effort to ensure that all mass-to-orbit values lie within three standard deviations of the mean.

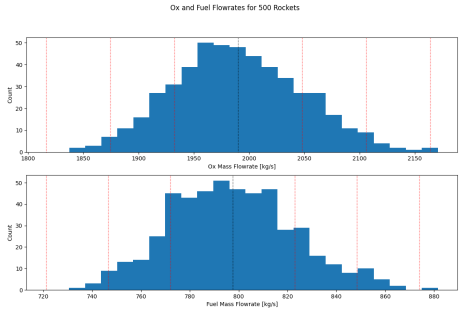
The distribution of calculated payload masses, along with mass flow rates and liftoff masses of oxidizer and fuel, is visualized in Figure 2. The mean and 1/2/3 standard deviations are marked on the histograms in black and red dotted lines, respectively. Table 2 provides a summary of the numerical mean and standard deviation of each calculated parameter.



((a)) Payload Mass Histogram



((b)) Liftoff Masses Histogram



((c)) Flowrates Histogram

Figure 2: Histograms of Calculated Parameters

Parameter	Mean	Standard Deviation
Mass to Orbit	55,678 kg	15,696 kg
Liftoff Oxidizer Mass	357, 210 kg	2400 kg
Liftoff Fuel Mass	142, 910 kg	2306 kg
Oxidizer Mass Flow Rate	1988 kg/s	55 kg/s
Fuel Mass Flow Rate	795 kg/s	26 kg/s

Table 2: Calculated Parameter Distributions

In addition, propellant depletion was tracked throughout the vehicle's burn duration was quantified, assuming constant flow rates. Figure 3 shows a yarnball plot of oxidizer and fuel masses with respect to burn time.

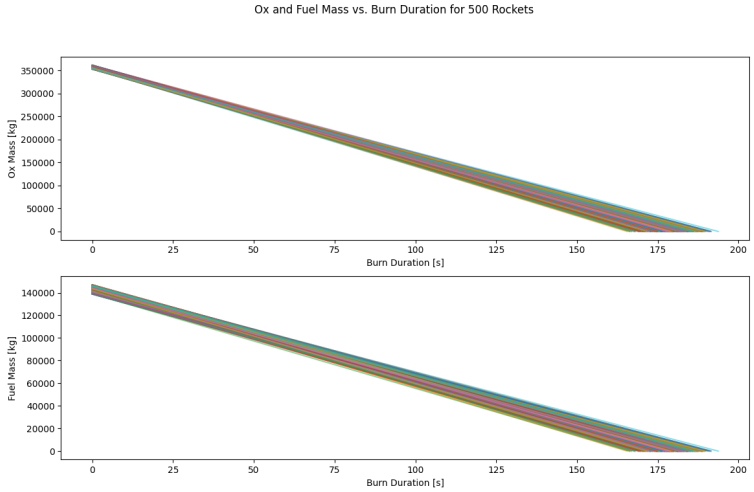


Figure 3: Yarnball Plot of Propellant Mass

The sensitivity of payload mass to individual variables was also determined by iteratively varying input tolerances and observing the resulting mean payload mass and its standard deviation. It was found that tightening the bounds on thrust, wet mass, and burn time particularly impacted the mass-to-orbit delivered by the rocket. Since these values follow a normal distribution, they shift closer to the mean and result in a higher payload mass with smaller standard deviation. From a more physical perspective, these parameters are an indicator to engine performance, a significant factor in optimization of payload mass delivery.