The Mechanics of a Rocket

James Saslow
San Jose State University

Abstract

The purpose of this research is to investigate the liftoff of a rocket into Low Earth Orbit (LEO). The rocket experiences 3 forces while in this trajectory: Propulsion, gravity, and drag. Propulsion occurs when mass is ejected from the exhaust of a rocket. Air resistance occurs when an the rocket moves through a fluid, this case being air. The rocket needs to reach fast velocities to escape Earth's gravitational pull, but if it moves too fast, the air resistance could cause catastrophic pressures on the rocket. The maximum pressure the rocket reaches is called Max Q. Max Q is the most dangerous moment during the rocket's trajectory. Max Q occurs at the peak of the pressure vs time graph

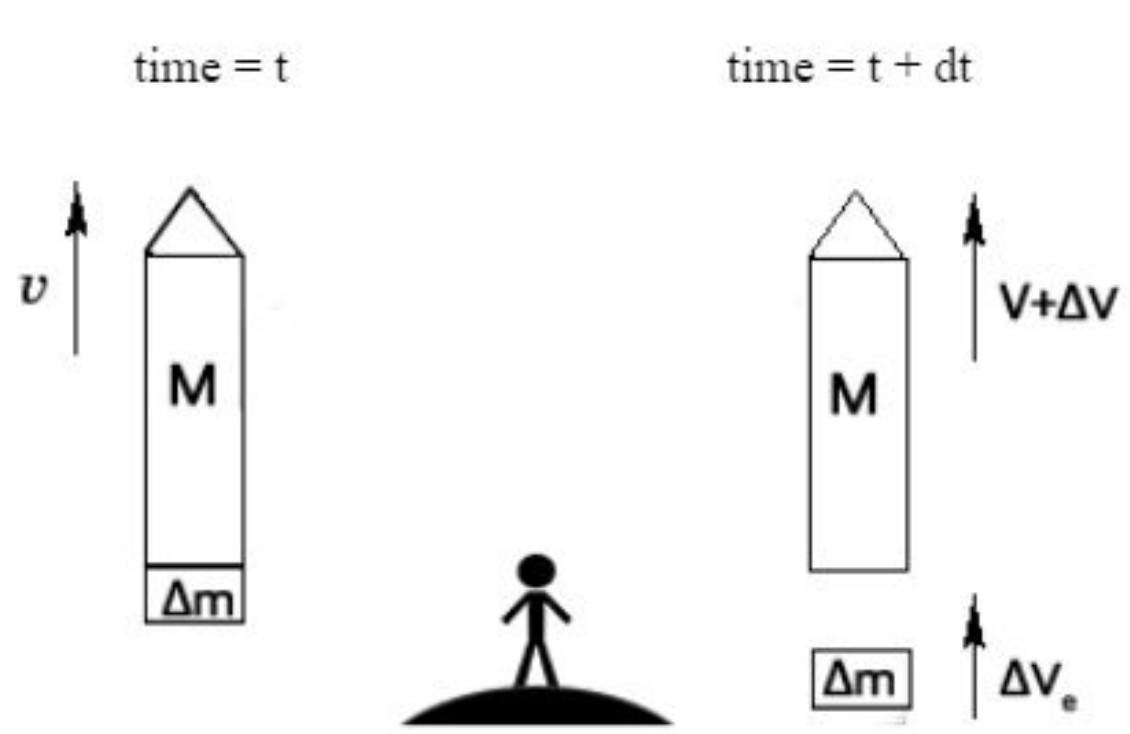
Introduction

Objectives -

- How does a rocket move in empty space?
- Simulate a realistic rocket launch by including external forces
- Determine and discuss MAX Q

The conservation of momentum is responsible for rocket motion.

The rocket must generate thrust to conserve momentum with the propellant sent out of the exhaust of the rocket



Building the Model

To simulate a realistic launch, we must consider

- Propulsion
- Gravity
- Quadratic Drag

The Propulsion Force

Tsiolkovsky Rocket Equation

$$\Delta v = v_e \ln \frac{m_0}{m_f}$$

where v is the rocket velocity
v_e is the fuel exhaust
m_0 and m_f are the initial and final mass of the rocket respectively

The Gravitational Force

$$F_g = m_f g$$

This is a valid approximation since g doesn't vary significantly between sea level and LEO

The Drag Force

$$D = Cd \, \frac{\rho V^2 A}{2}$$

Drag = coefficient x density x $\frac{\text{velocity squared}}{\text{two}}$ x reference area

Coefficient Cd contains all the complex dependencies and is usually determined experimentally.

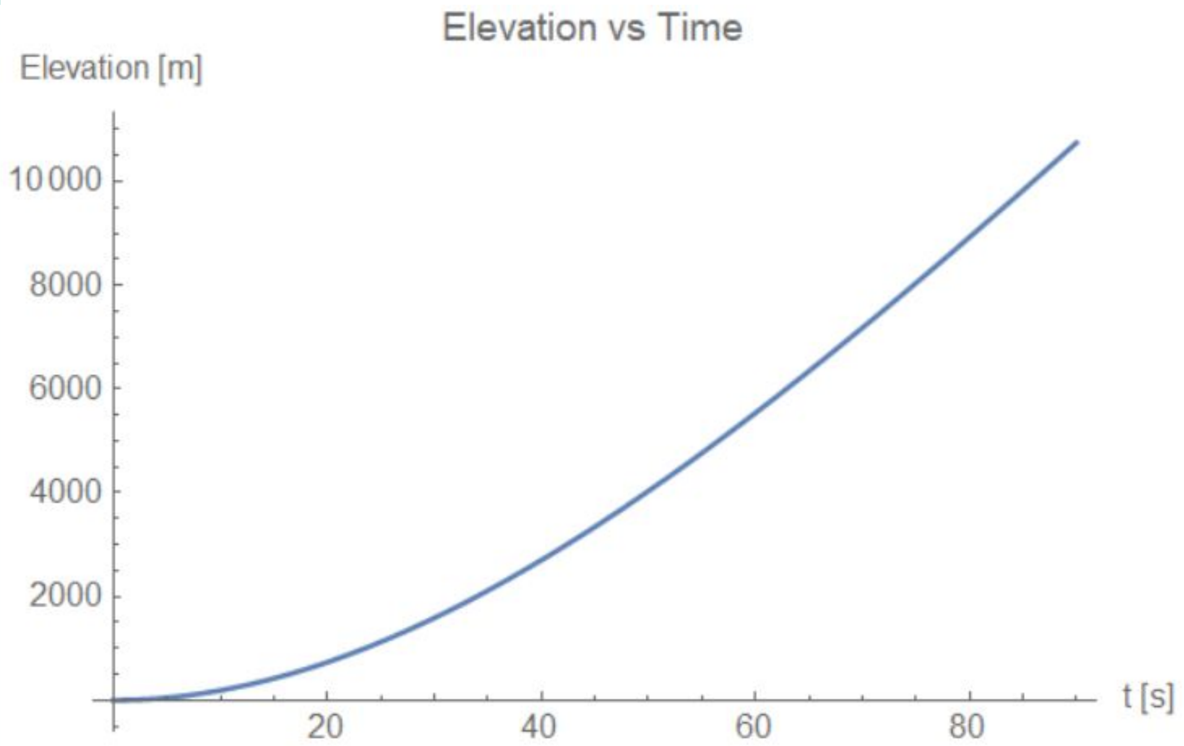
Choice of reference area A affects the value of Cd.

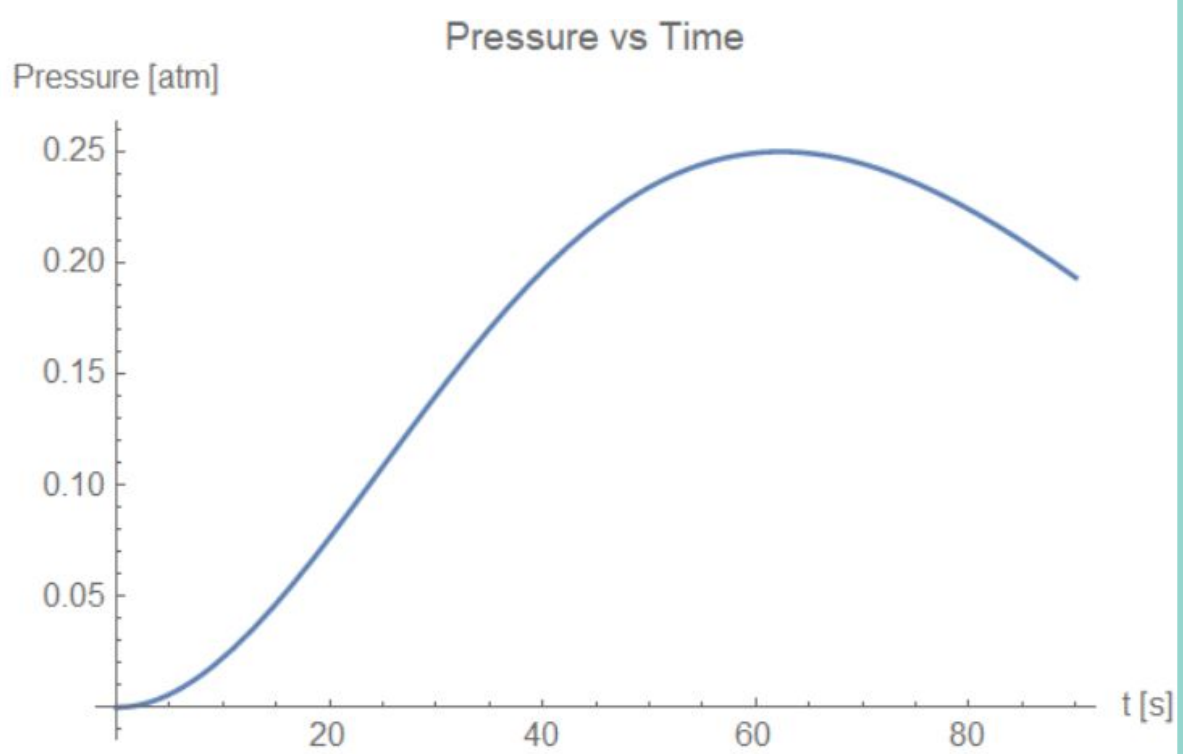
Results

We can numerically solve the equation of motion with the included external forces using specs similar to the Falcon 9 rocket

$$F_g + D + F_{prop} = m_f \ddot{y}(t)$$

where F_g = gravitational force
D = drag force
F_{prop} = propulsion force





MAX Q occurs at the peak of the pressure vs time graph at t = 60s

t = 60s is approximately the same time where MAX Q occurs in reality, which suggests validity in our model.

Conclusion

Final Remarks

1) **MAX Q is moment of highest stress on the rocket.**
2) **Initial Conditions determine if a rocket survives MAX Q**

Correct Initial Conditions

➡ **The Rocket Survives Max Q**

Incorrect Initial Conditions

➡ **Catastrophe**

Further Information

https://www.grc.nasa.gov/www/k-12/rocket/drageq.html

https://courses.lumenlearning.com/suny-osuniversityphysics/chapter/9-7-rocket-propulsion/#:~:text=mim