Thrust and Flight Modeling
Static Motor Tests and Flight Modeling Lab

http://twistedsifter.com/2012/10/red-bull-stratos-space-jump-photos/
Outline

• Static Motor Tests and Flight Modeling Lab Overview

• Flight Modeling:
  • 1 Degree of Freedom (DOF) Model
  • 3 DOF Model
Static Motor Rotation Lab Objectives

- Measure the thrust curves, mass flow rate of combustion gases and specific impulse for two rocket motors.

- Construct analytical and 1-D (1 DOF) and 2-D (3 DOF) numerical models of rocket flight.

- Compare the analytical and numerical models with the output of RockSim or OpenRocket.
Where will the rocket go?
Flight modeling

- What key forces dictate the flight trajectory?
Reminder: Lift and Drag

The sum of pressure and shear stress is the resultant force. It is split into two components:

1. **Lift**: The component of resultant force that is \textit{perpendicular} to the \textit{incoming net velocity vector} (effective flow direction).

2. **Drag**: The component of resultant force that is \textit{parallel} to the \textit{incoming net velocity vector} (effective flow direction).
One DOF Model: Free Body Diagram
One DOF Model: Governing Equation
Modeling Thrust

- Is thrust constant during flight?
Static Motor Rotation Lab

- Reloadable Hardware
  - Aft Closure
  - Case
  - Forward Closure

- O-rings
- Propellant grains
- Nozzle
- Delay grain
Static Motor Thrust Curve

http://www.eng.hmc.edu/NewE80/StaticTestVideos.html
Static Motor Lab, Section 2:

- Calculate the total impulse.
- Calculate the average thrust and average mass flow rate.
- Calculate the exit velocity of the combustion gases from the nozzle. What assumptions did you have to make?
- Calculate the specific impulse, $I_{sp}$. 
Drag Force
Analytical One DOF Model

- GE:
  
  \[ m\ddot{z} = T - mg - F_D \]

- Assumptions:
Numerical One DOF Model

- GE:

- Many options for numerical solution methods, e.g.
  - OpenRocket uses Runge-Kutta (RK4)
  - One option is Explicit Euler ignoring high order terms...
Explicit Euler
One DOF Model

for t = 0 to maxTime
{
    T = ...
m = ...
Fd = ...

    z_dd(t) = 1/m*(T-m*g-Fd);
z_d(t) = z_d + z_dd*Δt
    z(t) = z + z_d*Δt
}

z(t) = z + z_d*Δt
Three DOF Model

• What are the 3DOF?
Why does the rocket rotate?

- Initial direction of motion
- Wind
- New direction of motion
- Direction of flow from rocket motion
Reminder: Angle of Attack
Angle of Attack
Three DOF Free Body Diagram
Non-Rotational Forces

- z-direction

- x-direction
Torque Balance
Rotational Damping

- The *rotational damping* can be modeled as
Rocket Stability

- Is this stable?
  - Depends on location of $C_P$ versus $C_G$
Reminder: Complication #3 Angle of Attack

\[ C_L, C_D = f(\alpha, Re) \]
Drag and Lift direction

- Drag and lift can be defined w.r.t.

Rocket axis

Effective flow direction
Three DOF Model

for t = 0 to maxTime
{
    T = ...
    m = ...
    Fd = ...
    L = ...
    Td = ...
    alpha = ...

    z_dd(t) = ...
    x_dd(t) = ...
    θ_dd(t) = ...
    ...
}

To Linde Field

- Good luck!