Solid Propellant Combustion and Its Stability

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Breaking News: NASA building a restaurant on the moon

Great food...but no atmosphere

Design Process

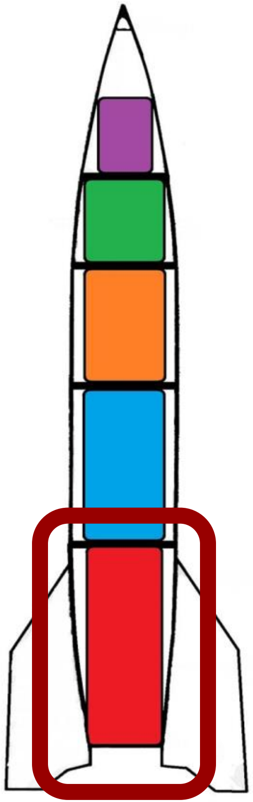
Payload

Drogue Chute

Payload/Avionics

Main Chute

Motor and Casing



Quick Recap

Motor and Propellant Selection

Aerotech L2200G-P Mojave Green (HTPB/AP/AL)

Motor Case

2024 Aluminum Alloy

Nozzle

Built into Motor

Igniter

Bridgewire explosive

Today's Overview

WASHINGTON STATE UNIVERSITY

- Propellant Combustion
    - ~~Burn rate~~
    - Flame Pattern
    - Ignition Characteristics
- Propellant Stability
    - Acoustic Resonance
    - Ignition Wire Configurations
    - Combustion Stability

Physical and Chemical Processes

Experimental Observations

- Three dimensional microstructures
- Three dimensional flame structures
- Intermediate products in the liquid and gaseous phase
- Spatially and temporally variant processes
- Aluminum agglomeration
- Non linear response behavior
- Formation of carbon particles

Double-Base Flame Pattern

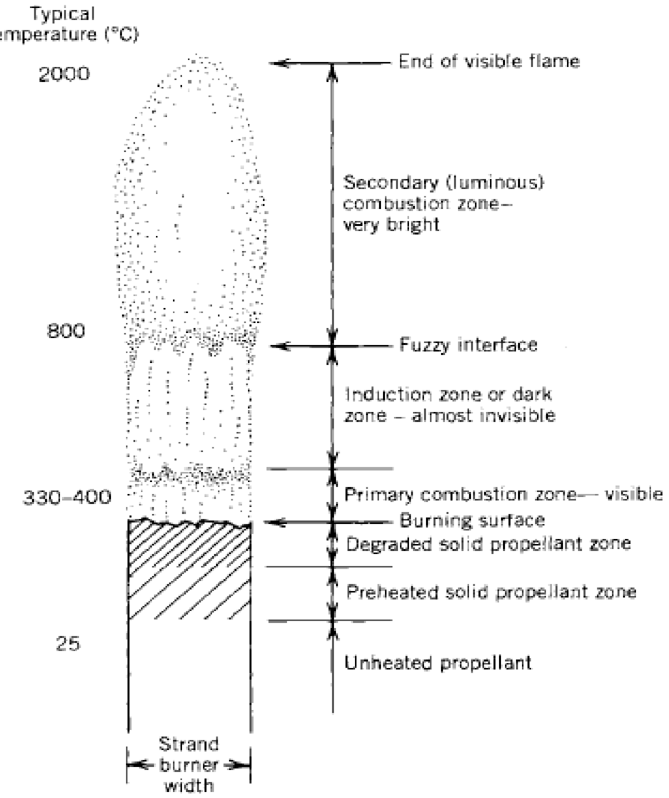


FIGURE 13–1. Schematic diagram of the combustion flame structure of a double-base propellant as seen with a strand burner in an inert atmosphere. (Adapted from Chapter 1 of Ref. 13–1 with permission of the American Institute of Aeronautics and Astronautics, AIAA.)

Composite Flame Pattern

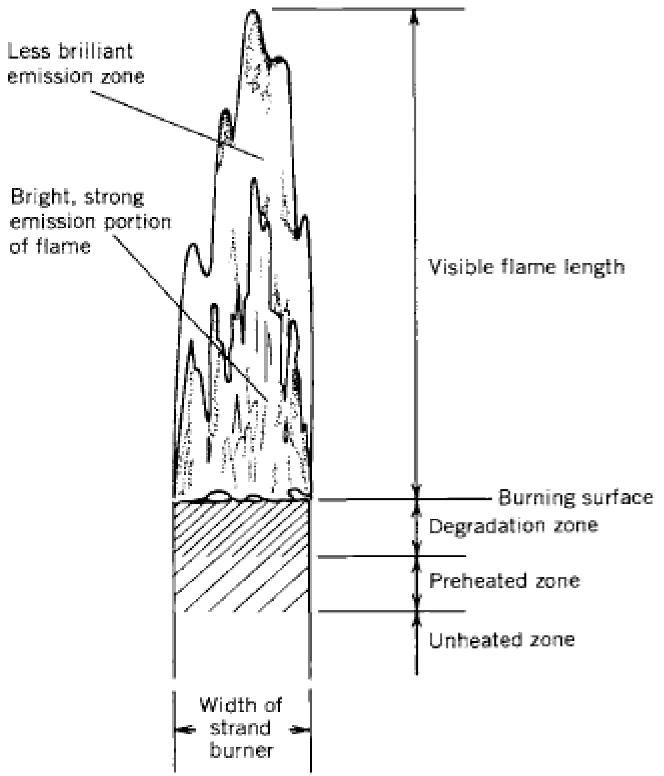


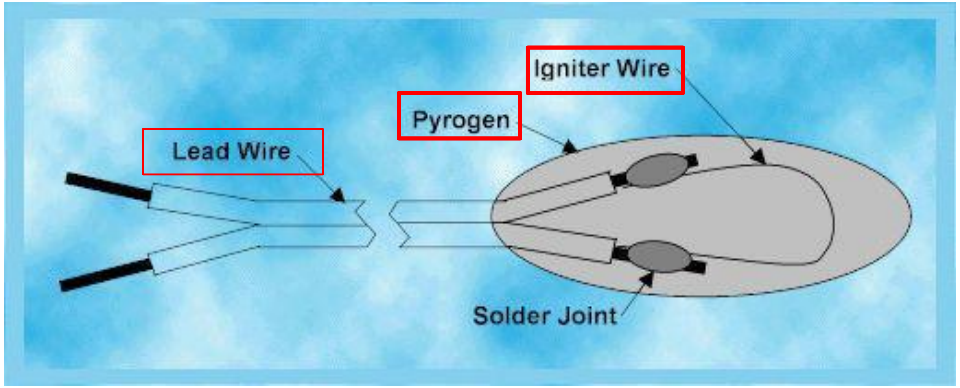
FIGURE 13–2. Diagram of the flickering, irregular combustion flame of a composite propellant (69% AP, 19% Al, plus binder and additives) in a strand burner with a neutral atmosphere. (Adapted from Chapter 1 of Ref. 13–1 with permission of AIAA.)

Bridgewire Igniters

Competition Rules (page 4)

https://www.youtube.com/watch?v=VT6v6UkJE5Q

Igniters - How They Work



http://www.jacobsrocketry.com/aer/ignition_and_igniters.htm

- 2 Conductor Lead Wire
- Igniter (Bridge) Wire
- Pyrogen
- Launch System with Alligator Clips

Ignitability Factors

1. Propellant Formulation

1. Initial Temperature

1. Surrounding Pressure

1. Mode of Heat Transfer

1. Grain Surface Roughness

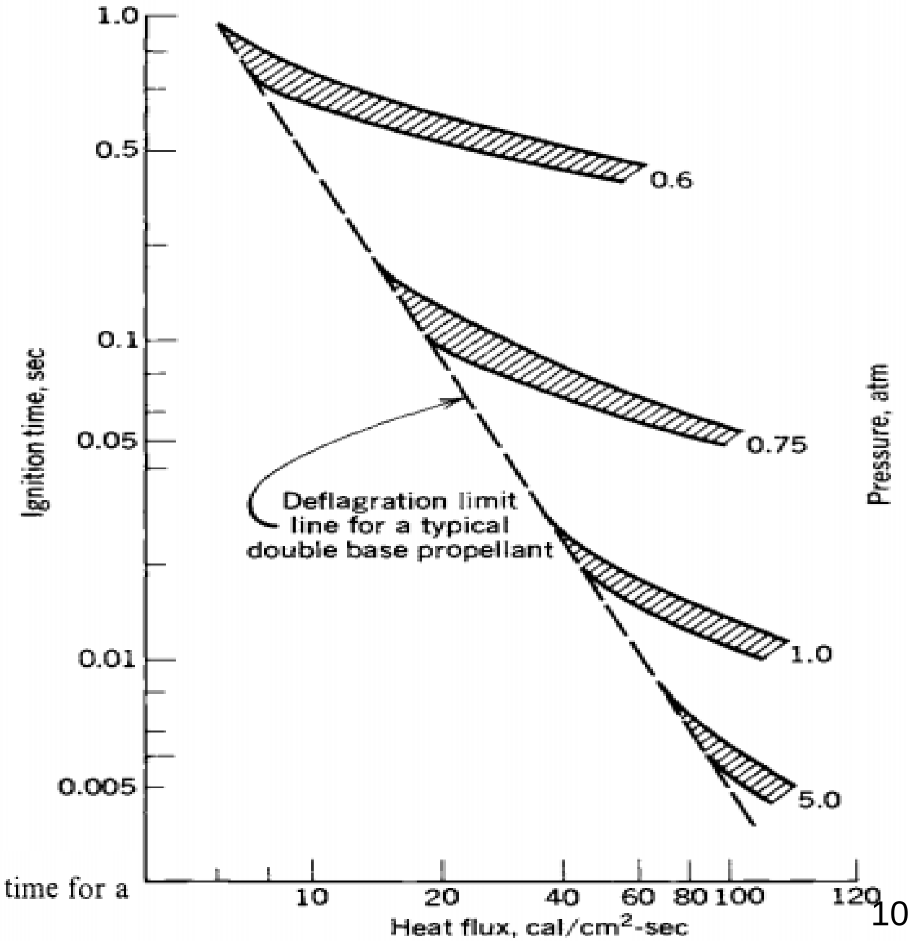


FIGURE 13–4. Propellant ignitability curves: effect of heat flux on ignition time for a specific motor.

Ignitability Factors Cont.

6. Propellant Age

7. Composition & Hot Solid Particle Content

8. Igniter Propellant

9. Velocity of Hot Igniter Gases

10. Cavity Volume & Configuration

Ignition Phases

- Phase I: Ignition Time Lag
- Phase II: Flame-Spreading Interval
- Phase III: Chamber-Filling Interval

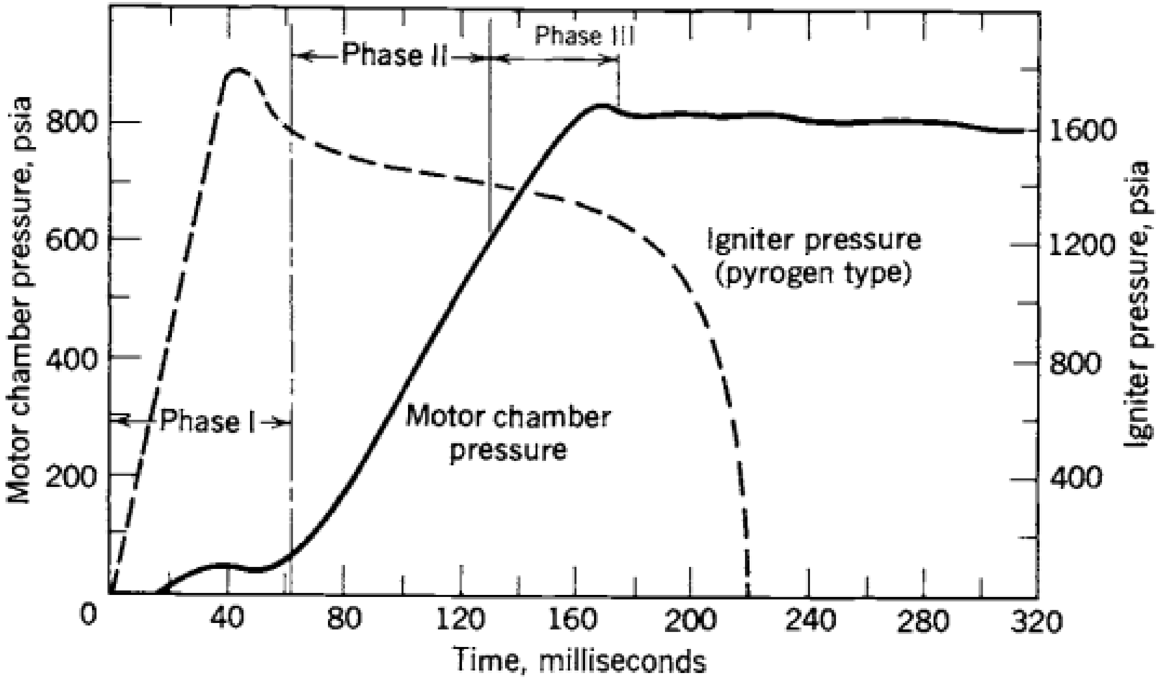
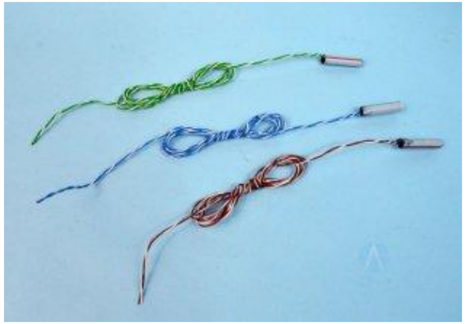


FIGURE 13–3. Typical ignition pressure transient portion of motor chamber pressure–time trace with igniter pressure trace and ignition process phases shown. Electric signal is received a few milliseconds before time zero.

Igniter Selection

- Fat Boy Starters
  - Manufactured by QuickBurst
  - Used for J-size motors and larger
  - Requires 12 volts
  - Moisture and shock resistant
  - $13.44 for 3 pack
- First Fire Starter
  - Manufactured by AeroTech
  - Used for H-size motors and larger
  - Requires 12 volts
  - $12.83 for 3 pack



http://www.apogeerockets.com/Rocket_Motors/Motor_Starters/Fat_Boy_Starters

http://www.apogeerockets.com/Rocket_Motors/AeroTech_Accessories/First_Fire_Igniter

Launch Controller

- Go Box Launch Controller
  - Manufactured by Pratt Hobbies
  - Connected to 12 volt system
    - Car battery
    - 8 pack of AA batteries
    - Jump start battery
  - Will set off all types of igniters
  - $39.99

http://www.apogeerockets.com/Launch_Accessories/Launch_Controllers/Go_Box_Launch_Controller

Combustion Instabilities

- ~~Vortex shedding~~
  - ~~Applies to large rockets~~
- Acoustic/pressure resonance
  - Random
  - Changes with cavity geometry
  - Impossible to characterize analytically
  - Repeatable with identical motors

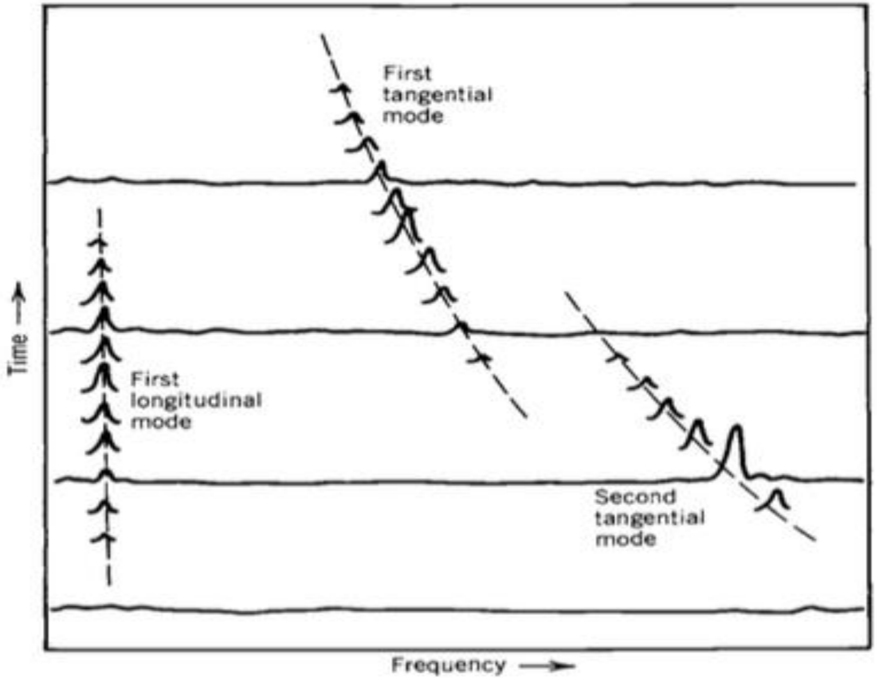
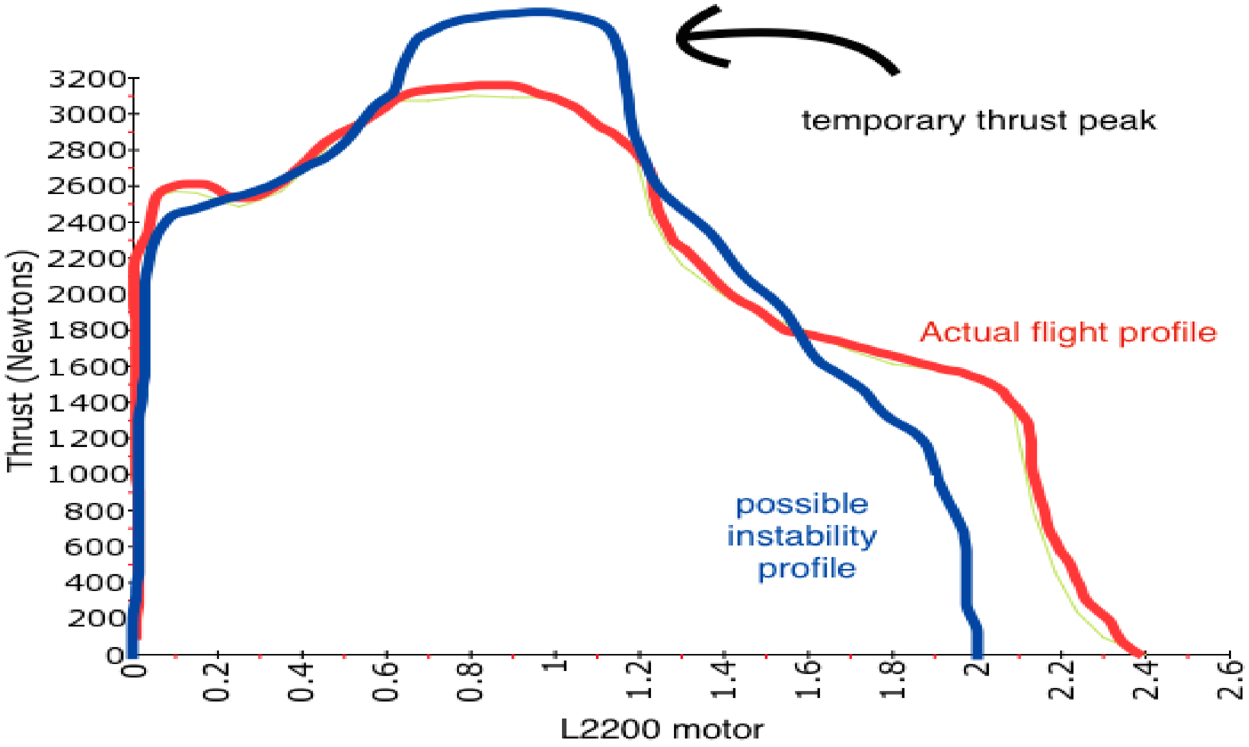


FIGURE 13–6. Example of mode frequency display; also called a "waterfall" diagram of a motor firing. Only four complete time–frequency curves are shown; for easy visualization the other time lines are partly omitted except near the resonating frequencies. The height of the wave is proportional to pressure. As the cavity volume increases, the frequencies of the transverse modes decrease. (Adapted from E. W. Price, Chapter 13 of Ref. 13–1, with permission of AIAA.)

Acoustic

- Due to unstable combustion
- Pressure oscillates at least 5%, usually greater 30%
- heat transfer increase, create temporary thrust
- Decrease burning duration

In our case,


temporary thrust peak
Actual flight profile
possible instability profile
Thrust (Newtons)
3200
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6
L2200 motor

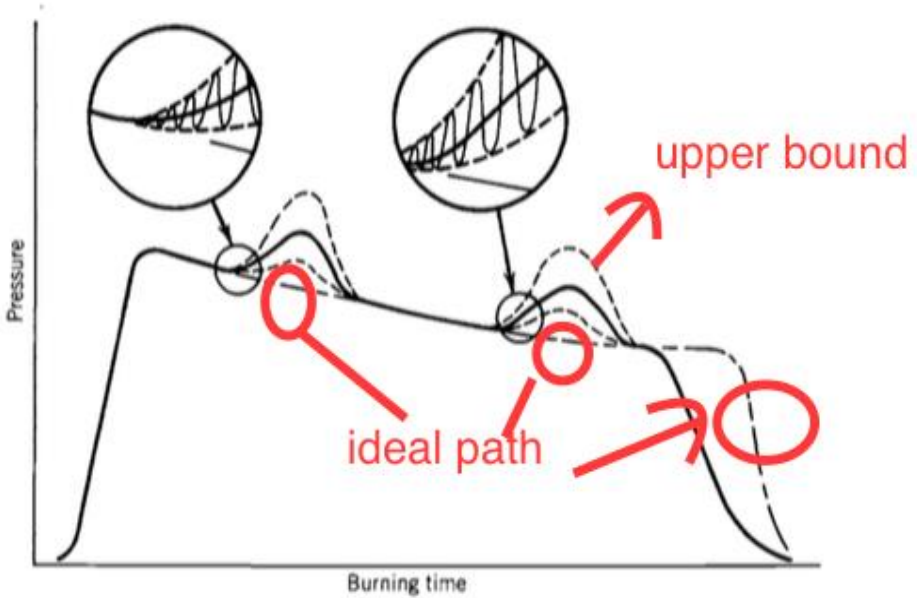


FIGURE 13–5. Simplified diagram showing two periods of combustion instability in the pressure–time history, with enlargements of two sections of this curve. The dashed lines show the upper and lower boundaries of the high-frequency pressure oscillations, and the dot-dash curve is the behavior without instability after a slight change in propellant formulation. The vibration period shows a rise in the mean pressure. With vibration, the effective burning time is reduced and the average thrust is higher. The total impulse is essentially unchanged.

Combustion Stability Assessment

- Accepted combustion stability rating procedure does not exist
- Most common: T-burner
  - Process
  - Results
  - Limited method

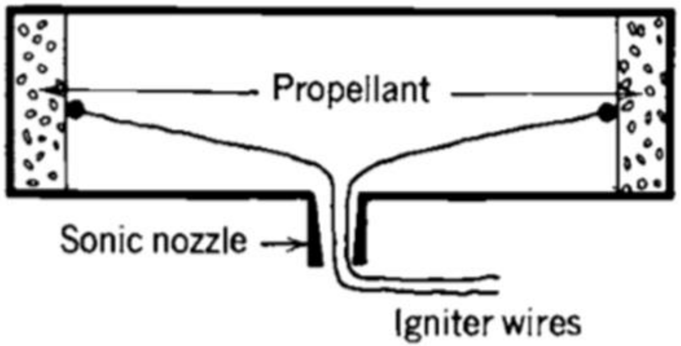
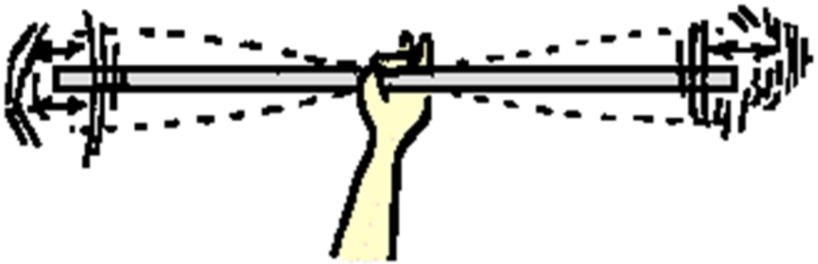


Figure 13-7: Standard T-burner

Addressing Combustion Instability

- Changing grain geometry
  - Shifts frequencies away from undesirable values
- Changing propellant composition
  - Adding aluminum, changing the binder
- Adding mechanical device
  - Reduces unsteady gas motion
  - Changes natural frequency of cavities
  - Cons: extra inert mass, additional problems with heat transfer or erosion



A vibrating metal rod forces the air column inside into vibrations at the same frequency - resonance occurs.

http://www.physicsclassroom.com/class/sound/Lesson-5/Resonance

How does it apply to our design?

- Chosen motor: Aerotech L2200G-P Mojave Green
- Aerotech does not provide combustion stability information
- Possible to test the stability ourselves
- Addition of mechanical device

Summary

- Flame pattern predetermined for our design
- Fat boy or First Flame Igniter with Go Box Launcher
- The combustion stability of propellant will be observed during testing of the full scale motor.

Next Steps

- Work on solid motor design review
- Finalize purchase orders
- Continue RockSim designs and simulations
- Begin electrical and recovery considerations

THANK YOU!

Questions?