LRE Combustion Instability

Some Basics

Combustion Instability in F-1 Engine

- Typical combustion instabilities observed in early F-1 engines

from V. Yang
Acoustic Pressure Oscillations

- Can approach them from point-of-view of dynamic system modeling

\[
\frac{d^2 p'}{dt^2} + 2\alpha \frac{dp'}{dt} + \omega_\alpha^2 p' = F(t)
\]

Resonant Frequency

Forcing Function

Gain/Damping

after Culick and Yang, Overview of Combustion Instabilities in Liquid Propellant Rocket Engines

Feedback Loops in Combustion Instability

- Gas that burns (heat release) expands, and generates compression waves

Rayleigh’s Criterion

\[ p'q' dt > 0 \]

for amplification of oscillations

from T. Lieuwen
Combustion Driving

- Ways that heat release can be made to fluctuate and lock-in to pressure oscillations
  - bulk reactant flowrates respond to $\Delta p_{\text{injection}}$
    - can also impact atomization
    - interact with pump cavitation
  - acoustic pressure fluctuations correlate to acoustic velocity fluctuations
    - can impact flow within injectors and downstream of injectors
    - alters atomization, mixing, flame stabilization

Acoustic Resonances

- C.C. Longitudinal modes
  - $f \propto a/L$
- C.C. Transverse modes
  - radial and azimuthal/tangential
    - $f \propto a/R$
- Injector and manifold resonances
Frequency Based Nomenclature

- Chugging
  - low freq: $f \sim 10-400$ Hz
  - often related to propellant feed system oscillations
- Screeching (screaming)
  - high freq: $f > 1$ kHz
  - typically contains highest energy, most damaging
- Buzzing
  - intermediate frequencies

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Suppression
Main Combustion Chamber Dynamics

\[ \nabla^2 p' - \frac{1}{a^2} \frac{\partial^2 p'}{\partial t^2} = h \equiv \text{linear + nonlinear sources} \]
\[ \mathbf{n} \cdot \nabla p' = -f \quad \text{along boundaries} \]

RD-170 Main Chamber Assembly

Combustion Instability Prevention

RD-170 Main Chamber Assembly

- Perforated plate reduces feedback to supply system
- Baffles suppress transverse modes

Line 1 – Stable Combustion
Line 2 – Injector/Baffle Damping
Line 3 – Distributor Damping
Line 4 – Acoustic Cavities

from V. Yang
Acoustic Cavities - Helmholtz Resonators

- Cavity acts to absorb pressure fluctuations from high p part of cycle and return it during low p
  - also produces jet leaving orifice that provides viscous damping
- Often placed
  - near injectors
    - important to suppress oscillations there
  - in corners
    - near pressure anti-node (spatial location with large p')

\[
f \cong \frac{1}{2\pi} \frac{a}{\sqrt{VL/A}}
\]