The Effects of Pressure and an Acoustic Field on a Cryogenic Coaxial Jet

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Effects of Pressure and Acoustic Field on a Cryogenic Coaxial Jet

- **Objectives:**
  - Document the nature of the acoustic wave/coaxial-jet injector interaction
  - Map a range of input variables
  - Explore application of the data and the findings for rocket combustion instability
- **Motivation:**
  - Combustion instability has always been one of the most complex phenomena in liquid rocket engines
  - High amplitude and high frequency acoustic instabilities (screaming), can lead to local burnout of the combustion chamber walls and injector plates
- **Approach:**
  - Using the AFRL supercritical facility
    - Span sub and supercritical pressures
    - Cryogenic temperatures
    - Acoustic Field
  - A coaxial injector design based on the single-jet cryogenic injector used in all previous studies (well characterized)
  - A specially-designed acoustic driver
  - Single-shot shadowgraph

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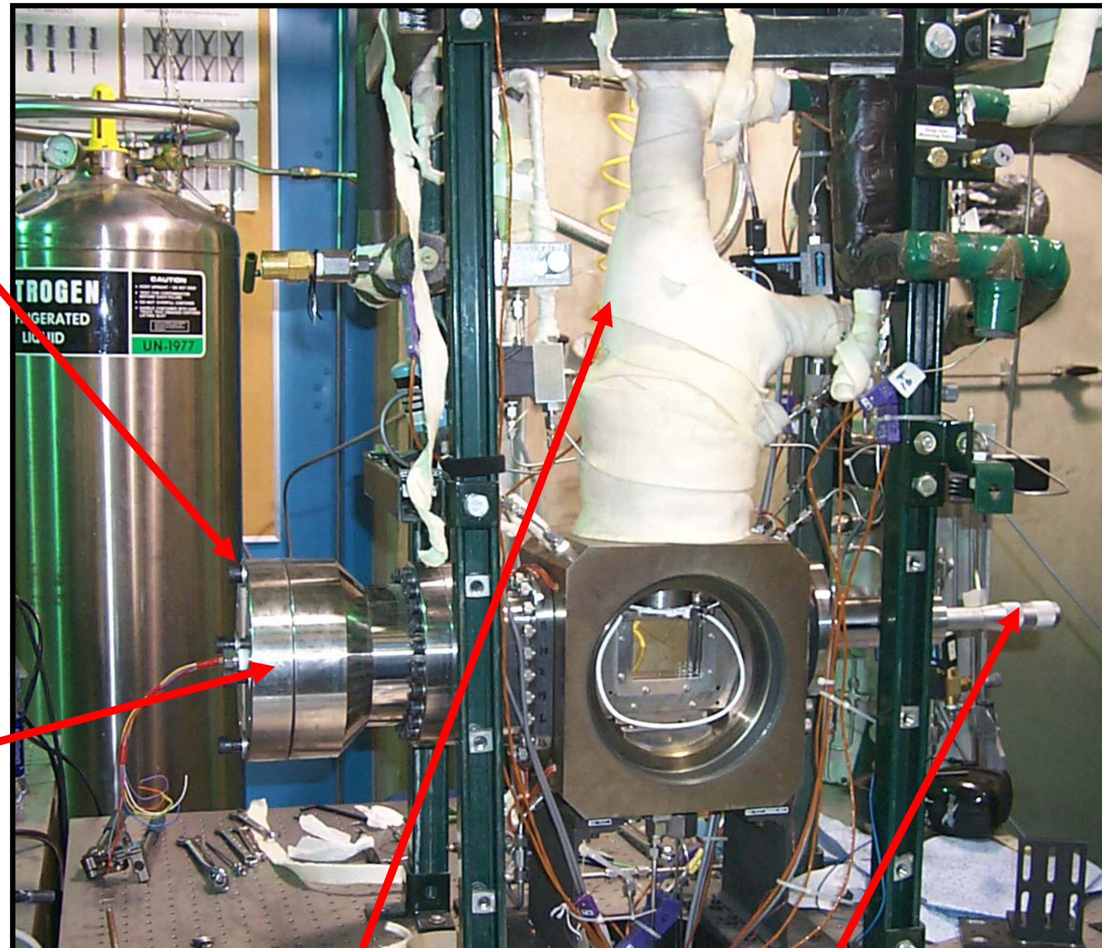
High-Pressure Test Rig

Housing for the PiezoSiren and the Waveguide flanged to the high-pressure chamber



LN2 Cooling Tower

Pressure transducer traversing micrometer

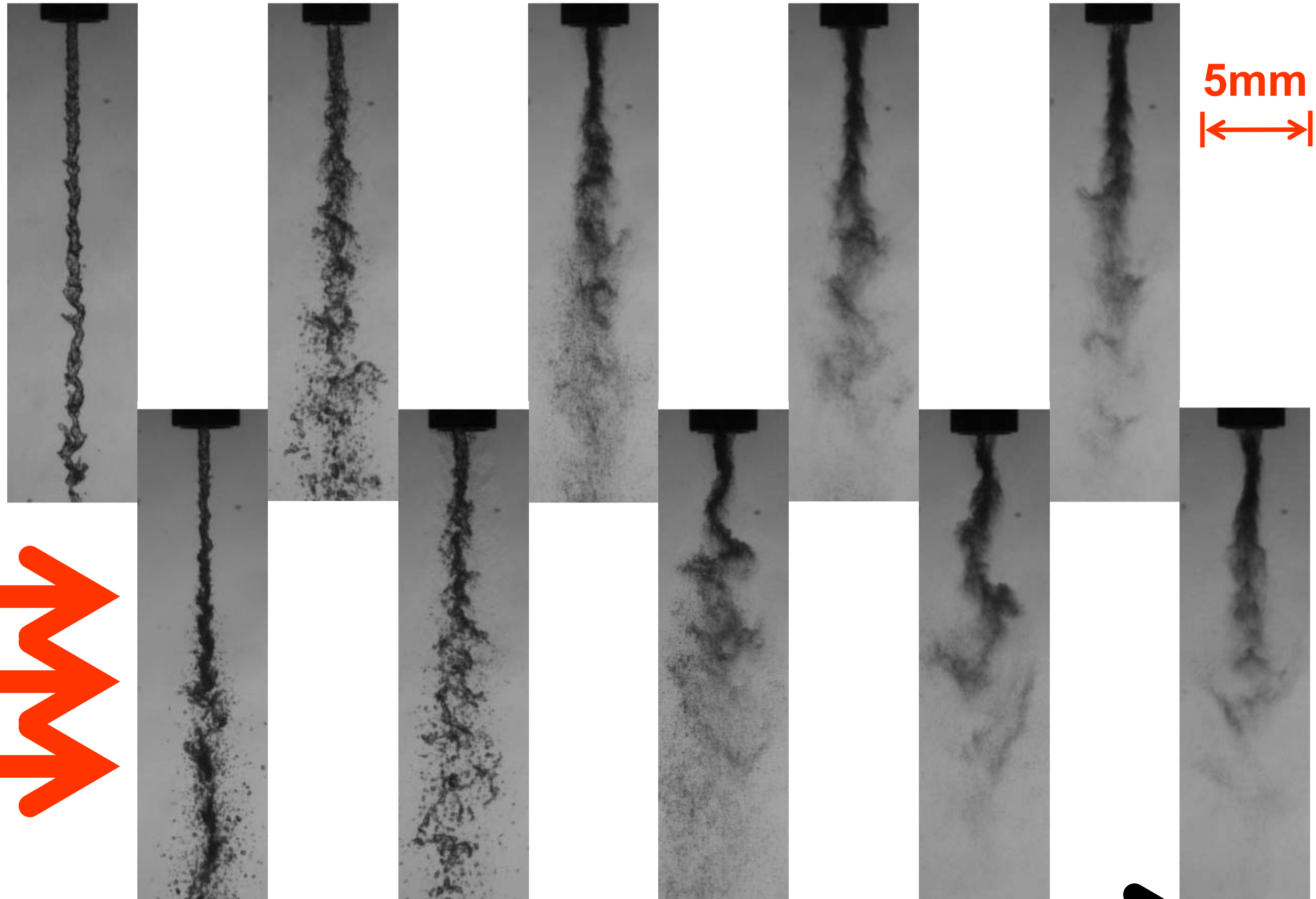
Available Data

- **Fluids:**
  - Warm Gas-Like N_2 flow in the annulus of coaxial injector
  - Cold Liquid-Like N_2 flow in the center post of coaxial injector
  - Ambient temperature Gas-Like N_2 pressurizing the chamber
- **Operational Conditions:**
  - 4 Chamber Pressure 1.4, 2.4, 3.5, 4.8 MPa
  - 3 Central jet ("oxidizer") flow rates ~275, 450, 625 mg/s
  - 5 Annular jet ("fuel") flow rates 0, 480, 1300, 2200, 2800 mg/s
  - Acoustic field off and on at 2700 Hz
- **Data:**
  - 10 Backlit images at each flow rate and pressure
  - More than 1400 images total
  - Exit plane temperature measurements

SUBcritical Chamber Pressure

Acoustic

OFF



Acoustic

ON

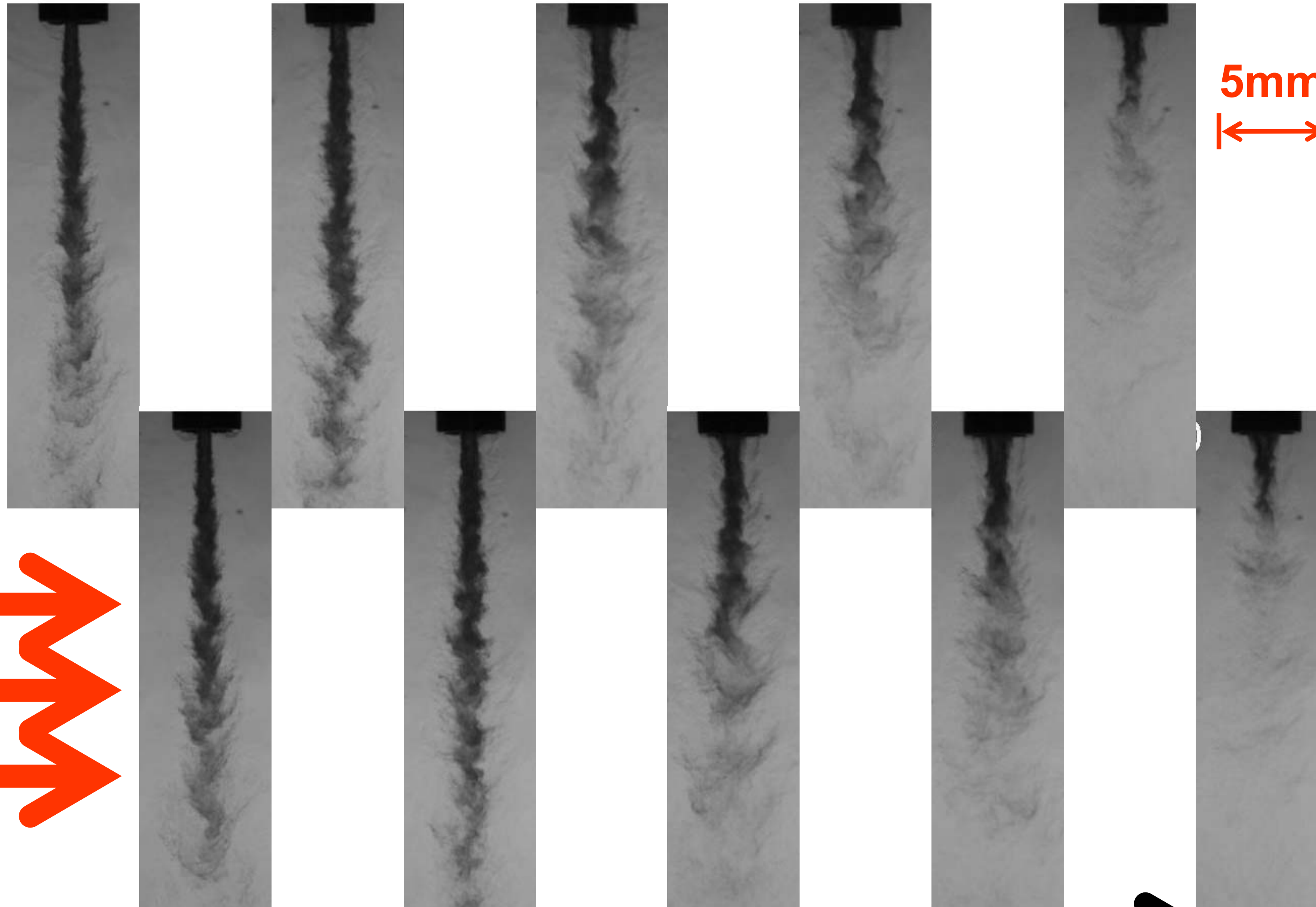
Increasing Annular Flow Rate

Center flow ~ 275mg/s; Chamber Pressure 1.4 MPa

NEAR-Critical Chamber Pressure

Acoustic

OFF



Acoustic

ON

Increasing
Annular
Flow Rate

Center flow ~ 275mg/s; Chamber Pressure 3.5 MPa

SUPERcritical Chamber Pressure

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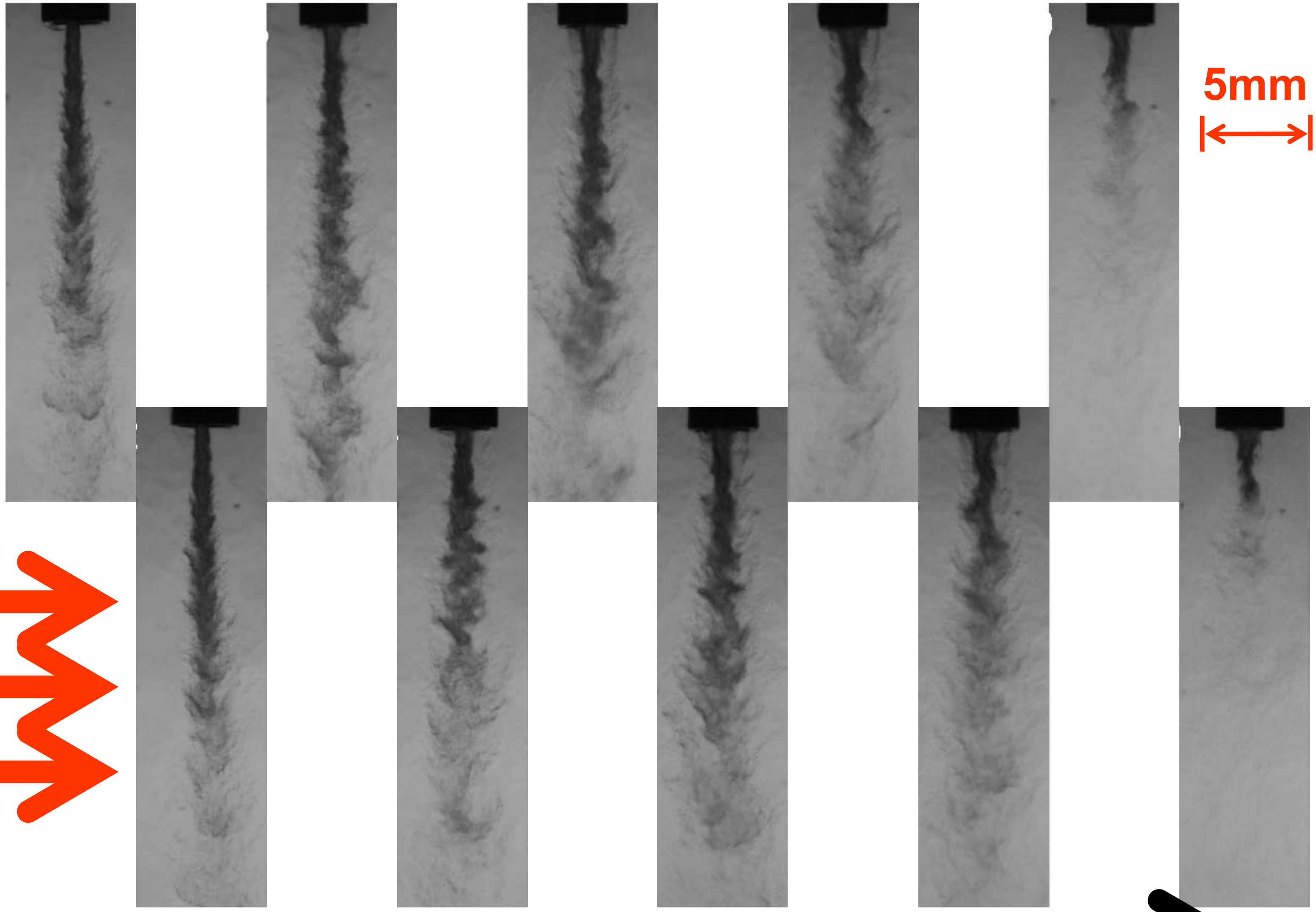
Acoustic

OFF

Acoustic

ON



Increasing Annular Flow Rate

Center flow ~ 275mg/s; Chamber Pressure 4.8 MPa

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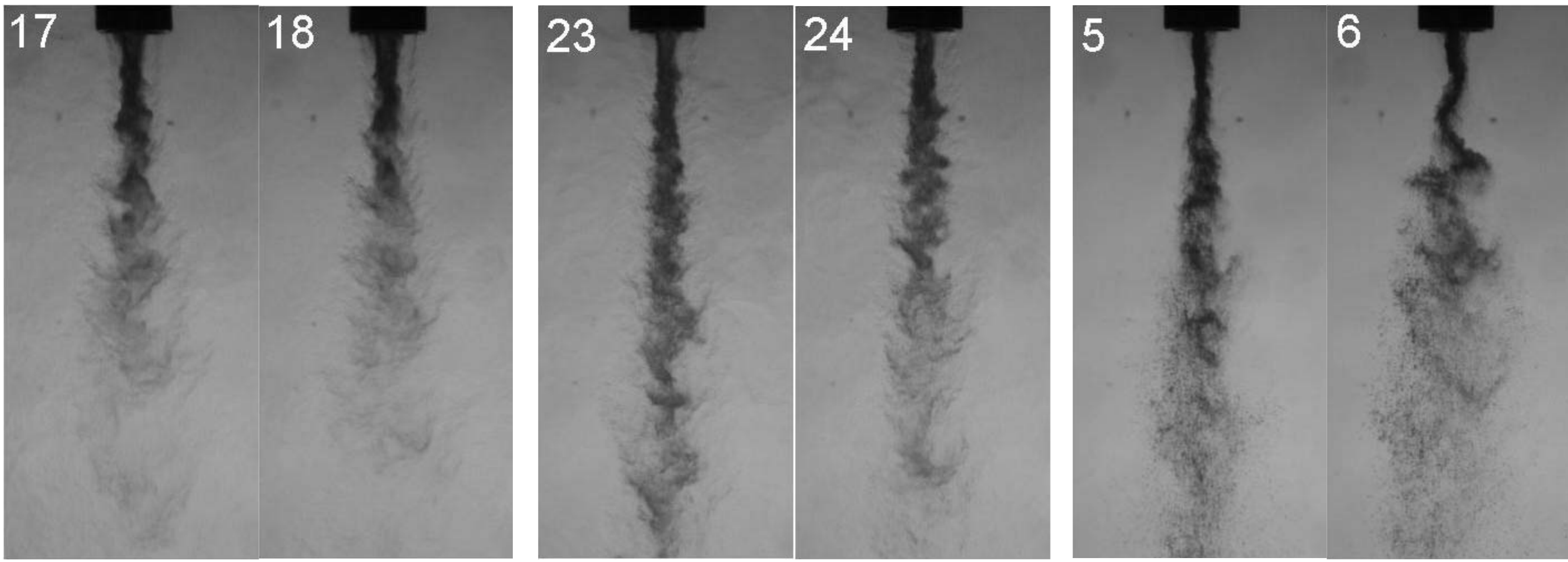
Acoustic Effect Rating

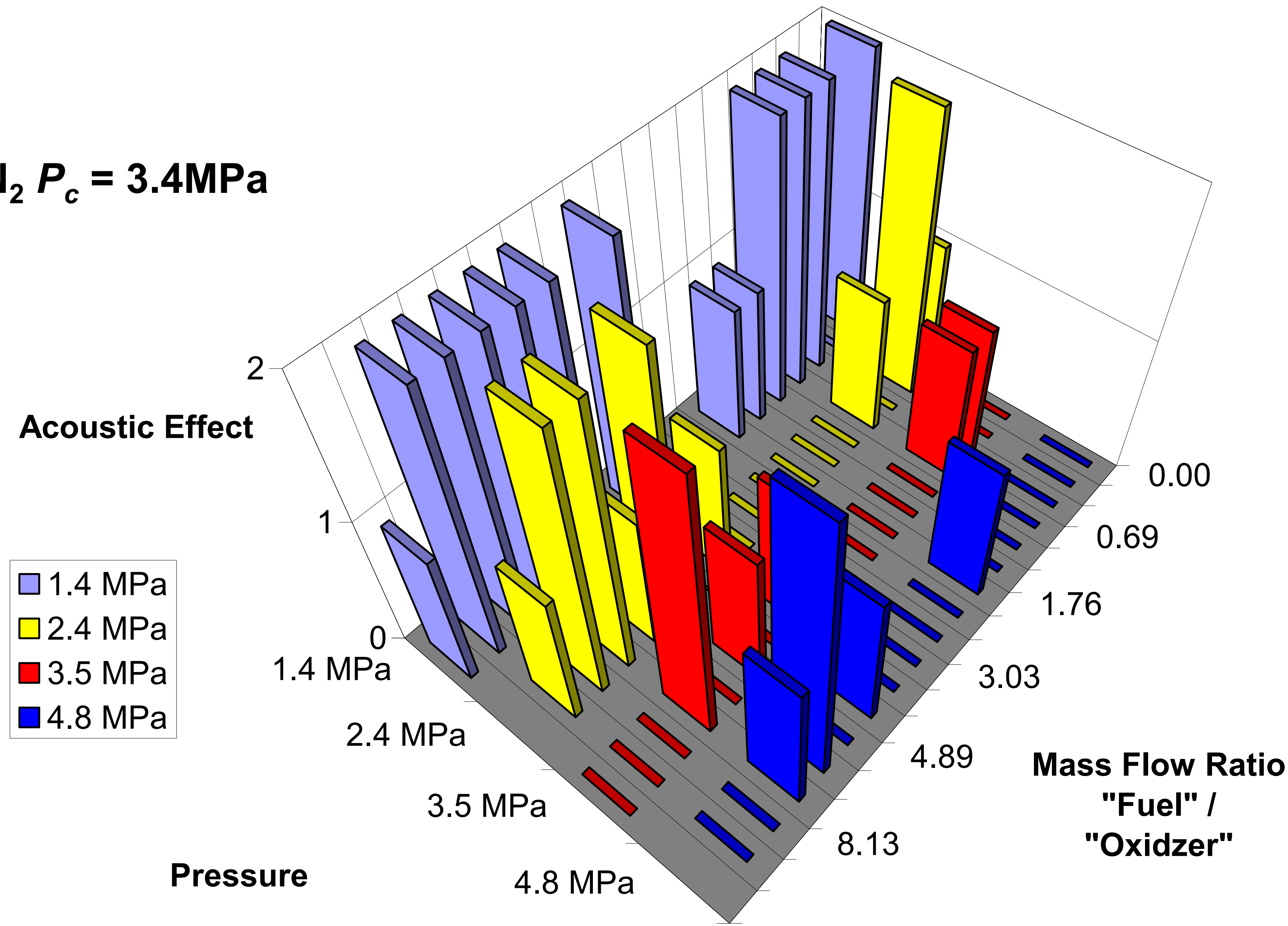


OFF	ON	OFF	ON	OFF	ON

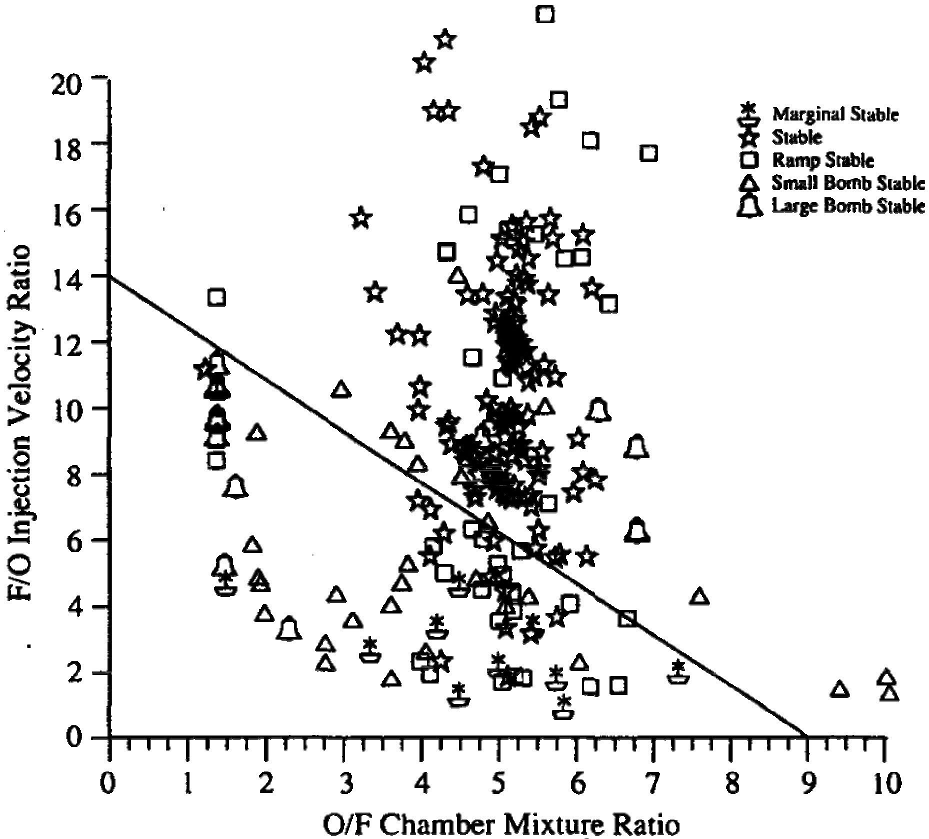
Acoustic Rating "0"	Acoustic Rating "1"	Acoustic Rating "2"
Pch ~ 3.5MPa	Pch ~ 4.8MPa	Pch ~ 1.4MPa
$\dot{m}_{fuel}$ = 2255 mg/s	$\dot{m}_{fuel}$ = 486 mg/s	$\dot{m}_{fuel}$ = 1355 mg/s

Acoustic Effect

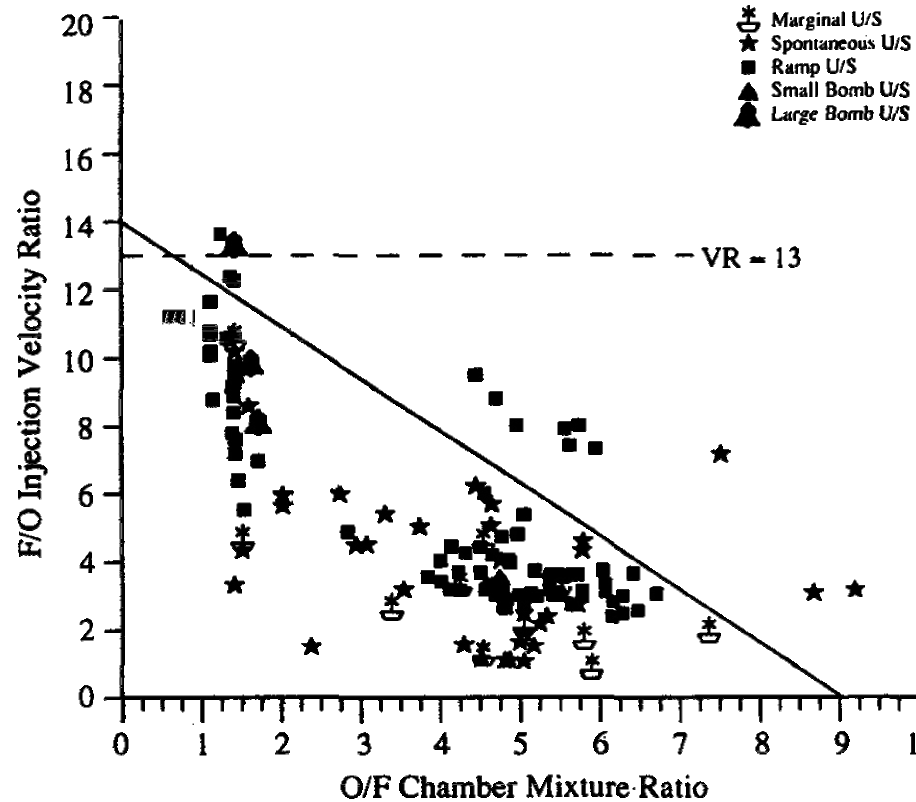
N_2 P_c = 3.4MPa



Rocket Combustion Stability Data



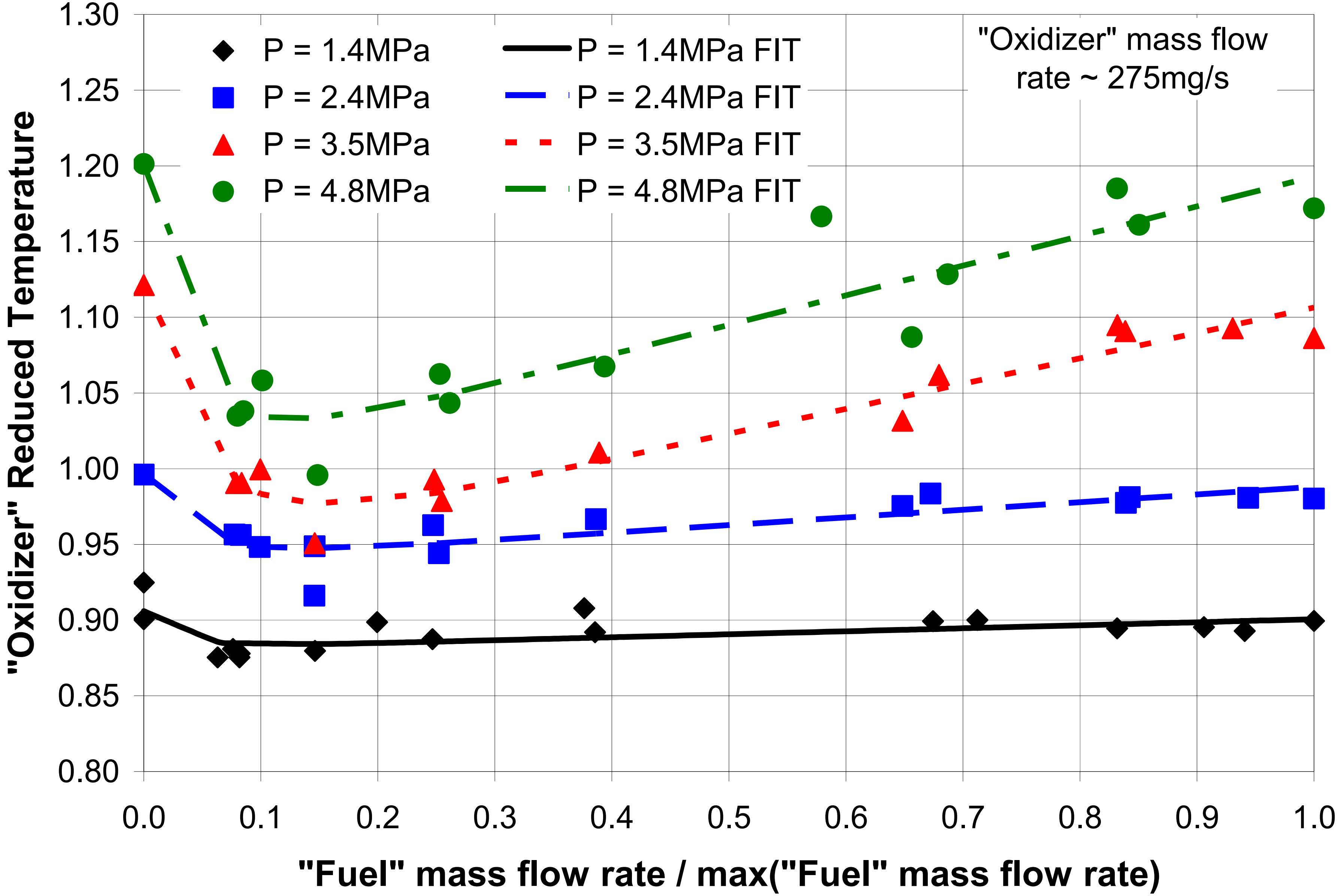
Stable



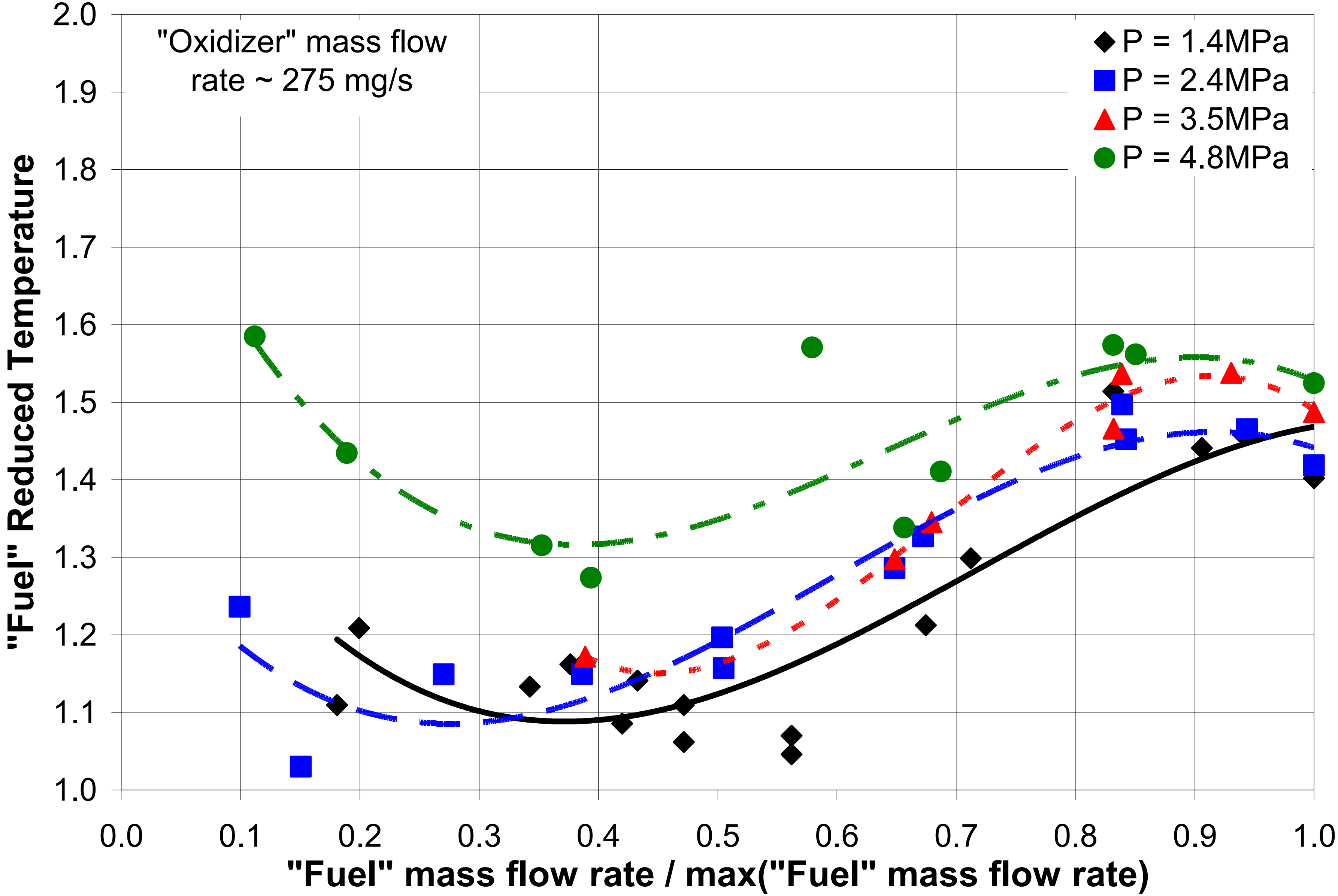
Unstable

Taken from Hulka, J. and Hutt, J.J. *Instability Phenomena in Liquid Oxygen/Hydrogen Propellant Rocket Engines,* 1994.

Center Jet Exit Temperature

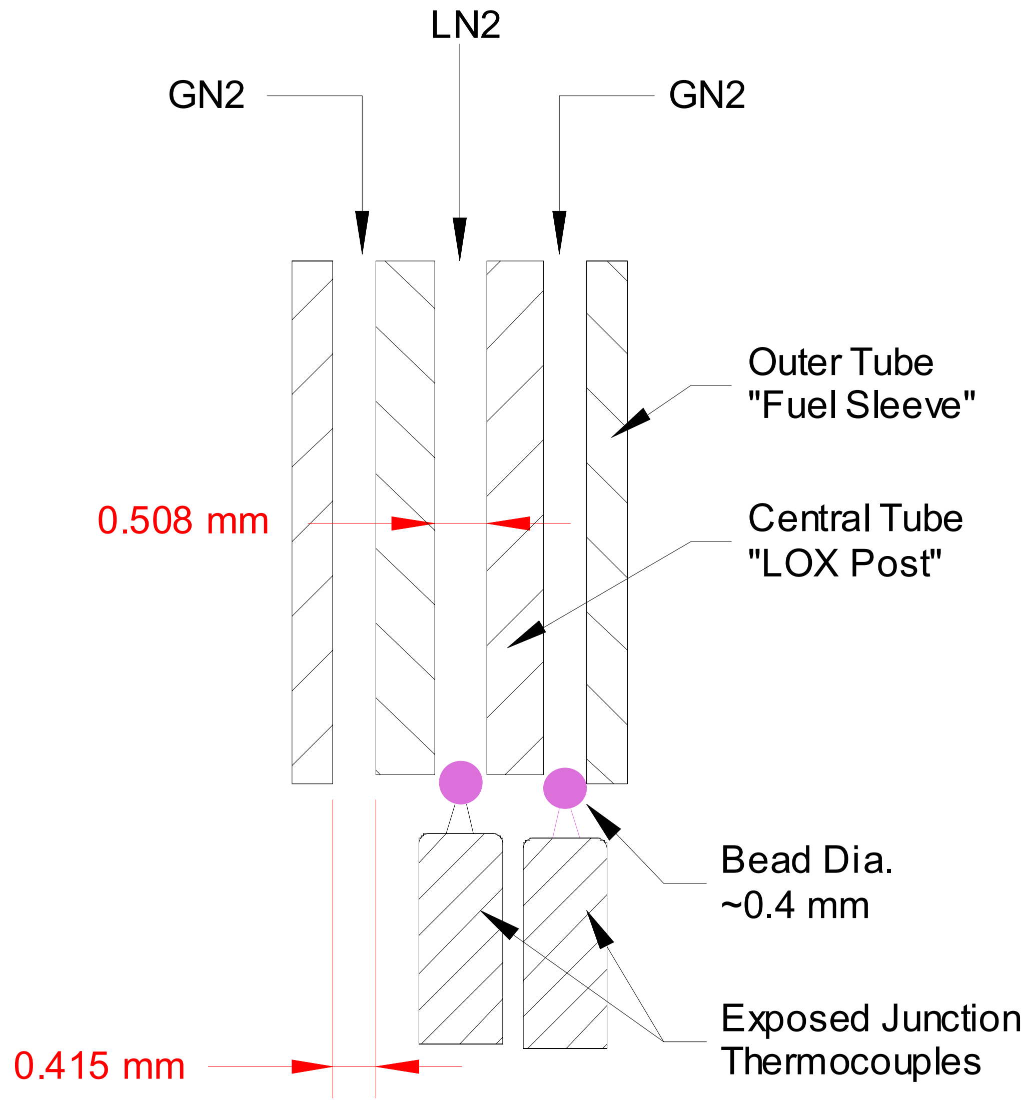


Annular Flow Temperature



Schematic of Temperature Measurements

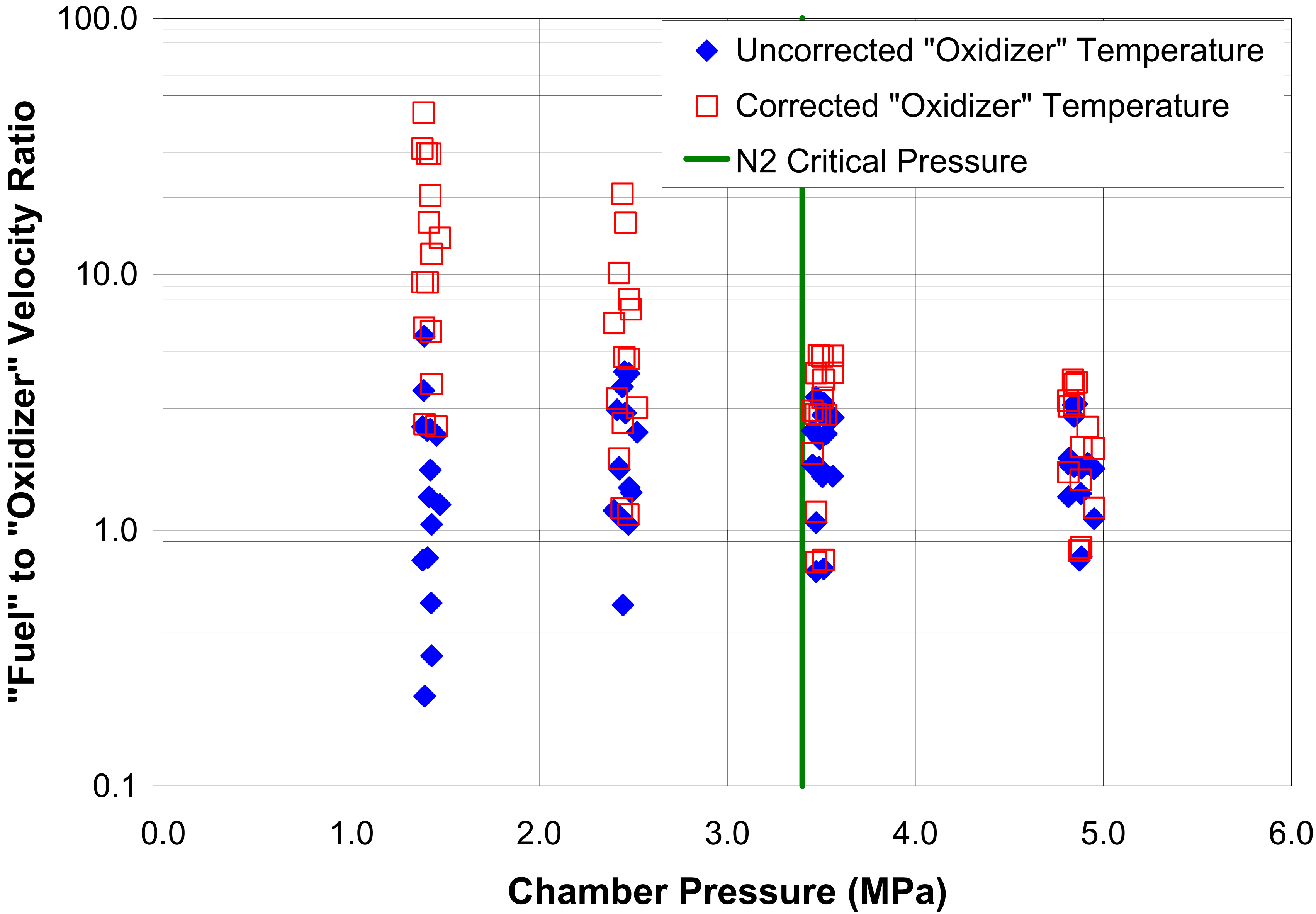
- **The size of the thermocouple bead is about the same size as the gap width and center jet diameter**
- **Thermocouple probably touching the wall of the injector tube**



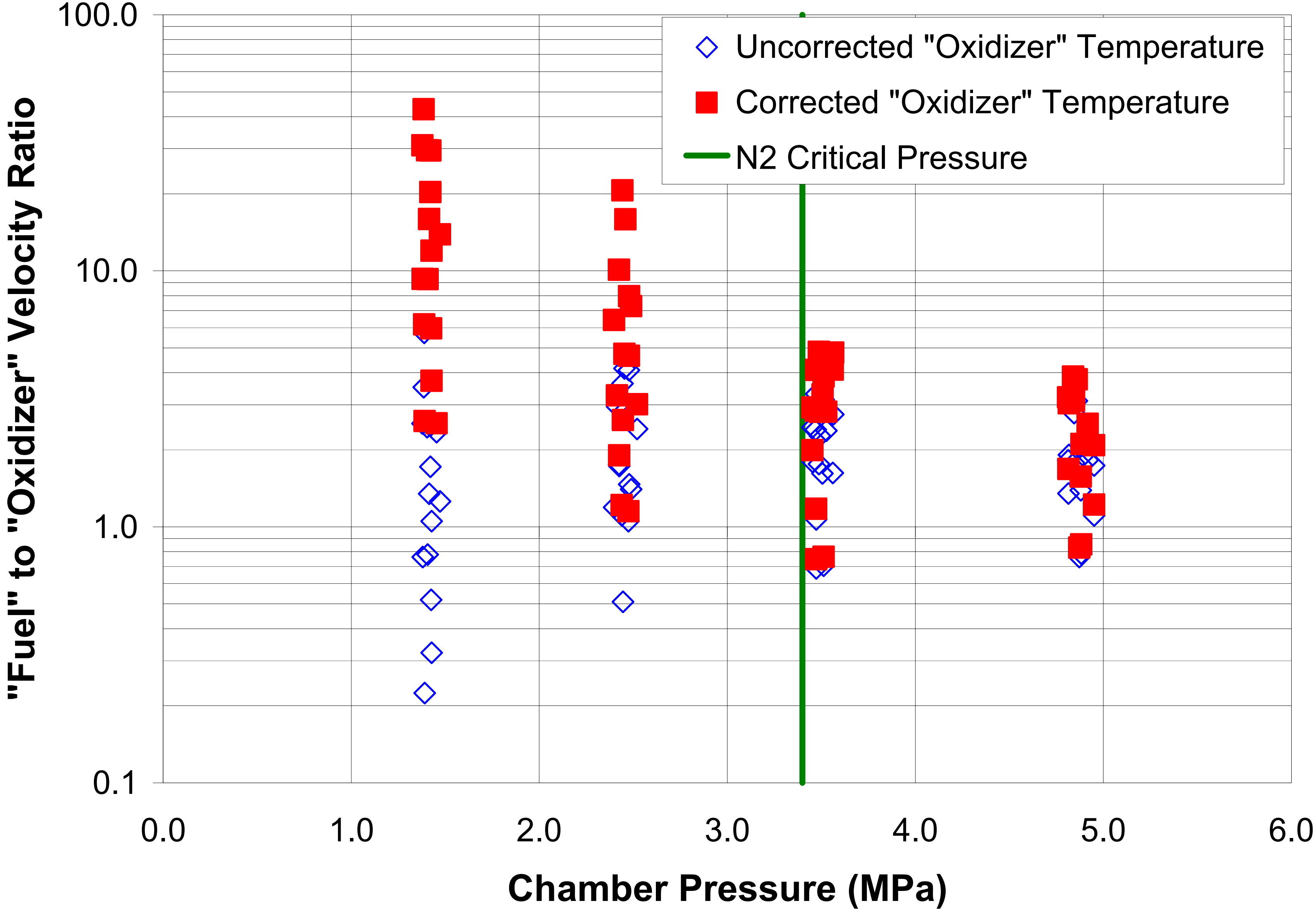
Center Jet Temperature Corrections

- **Corrections to the subcritical pressures necessary to make the results physical**
  - Given mass flow rates of fuel and oxidizer and chamber pressure the predicted center jet “oxidizer” temperature produced a vapor pressure that was greater than chamber pressure.
  - Implied a vapor phase condition of the center jet, image data showed liquid phase to be present.
- **Attempted corrections using a commercial CFD code**
  - Limited by equation of state and transport properties
- **Turbulent Pipe Flow**
  - Assumed TC measured bulk mix mean temperature and computed centerline temperature
  - Average correction about 7K lower
  - Gave physically meaningful densities to most subcritical conditions

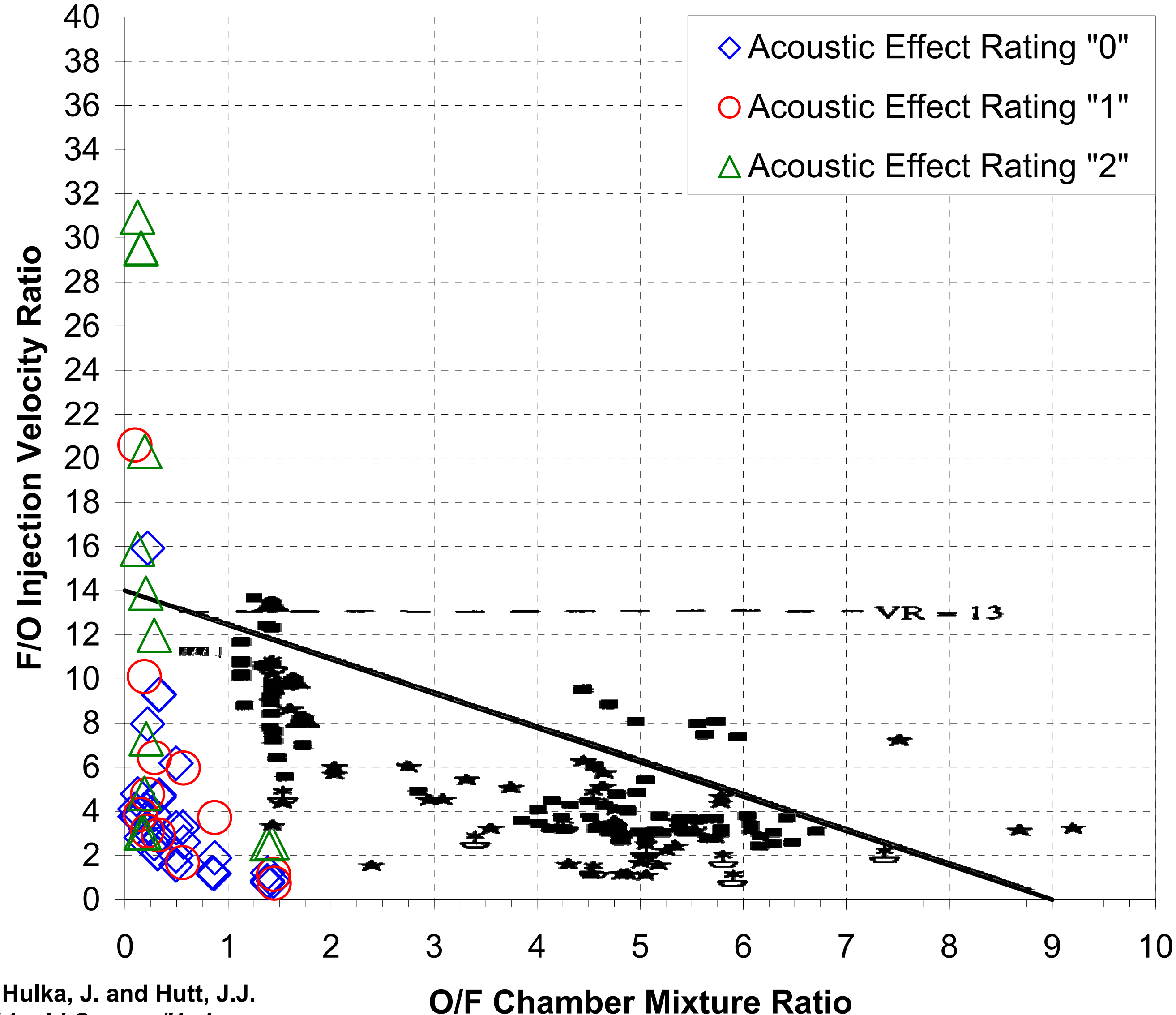
Velocity Ratio



Velocity Ratio

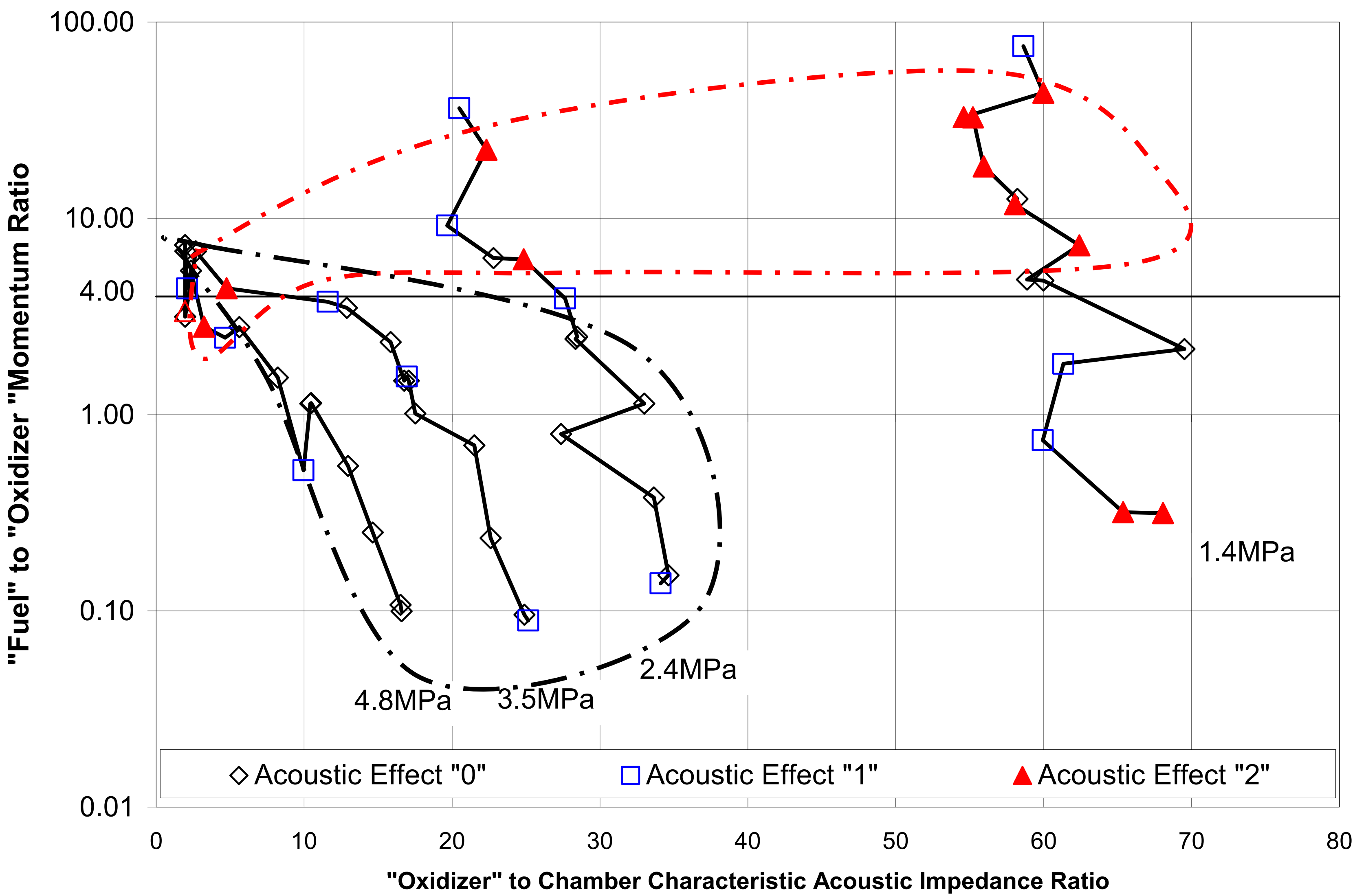


Comparison to Rocket Combustion Stability Data



Solid symbols taken from Hulka, J. and Hutt, J.J. ***Instability Phenomena in Liquid Oxygen/Hydrogen Propellant Rocket Engines*****, 1994.**

Momentum Ratio vs. Acoustic Impedance Ratio



Future and Ongoing Work

- Make improvements to the temperature measurements
  - Improved Correction
  - Different technique to make measurement
  - CFD
- Further analyze the available image data
  - Complete measurements
  - Further inspection of the images for effect of acoustic field interaction
- Conduct experiments using He as the fuel simulant
- Implicate findings to rocket combustion instability
- Collect data different frequencies of the acoustic field
- Make measurements with

  Laser Induced Thermo Acoustic (LITA)

Summary and Conclusions

- Unique setup enables conditions as close to the real rocket engine without combustion as possible

- Preliminary analysis of the data show global effects of acoustic field more noticeable at subcritical pressures compared to supercritical pressures
  – With exceptions

Summary and Conclusions (cont.)

- Absolute magnitude of temperature measurements at the exit of the injector are not known with great accuracy yet, but the trends can be considered valid
- Possibly a better way to separate the stability of real rocket engines is to plot the data with a fluid mechanics parameter and an acoustic parameter, which remains to be verified

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