Health and Safety Laboratory

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International Fire & Cabin Safety Research Conference

Atlanta, October 2007

Measurement of flame breakout conditions

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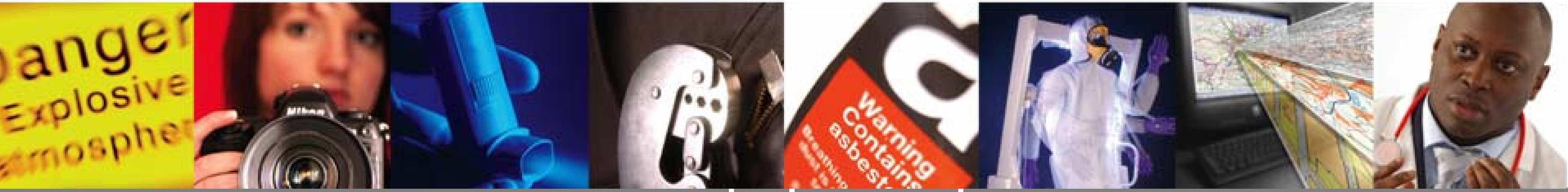

Combustor burn through

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FAR § 25.903(d)(l) requires that the hazard from a combustor case burn through must be minimized.

Combustor burn through

- **Traditionally flame breakout shields have been fabricated from tantalum rich materials.**
- **Develop a realistic small scale test for assessing performance of new materials alongside traditional methods**
- **Stages in test development**

  Decide design fire

  Design and assemble suitable test rig

  Validate test rig conditions

  Test materials and shield configurations

Combustor burn through 'design fire'

FAA – AC 20 -135 powerplant installations provides guidance

Special fireproof requirements for engine case burn through

Location of protection same as in real installation

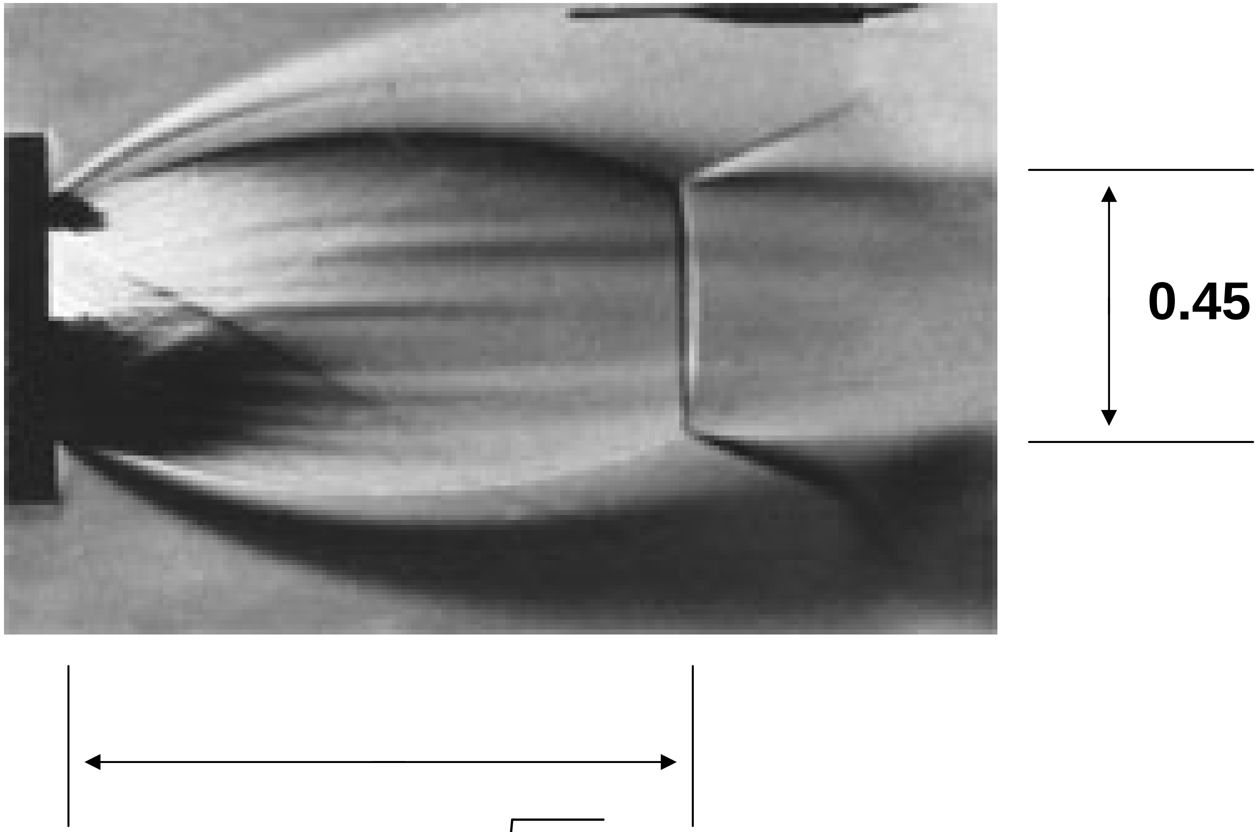
Minimum flame temperature 1920 K

Flame emerging through 1'' orifice

Source conditions same as real combustor chamber

Test duration – 3 minutes

High pressure jet structure (1)



$$X_m = 0.67\,D\sqrt{\frac{P_o}{P_b}}$$

P_o - reservoir pressure

P_b - back pressure

High pressure jet structure (2)

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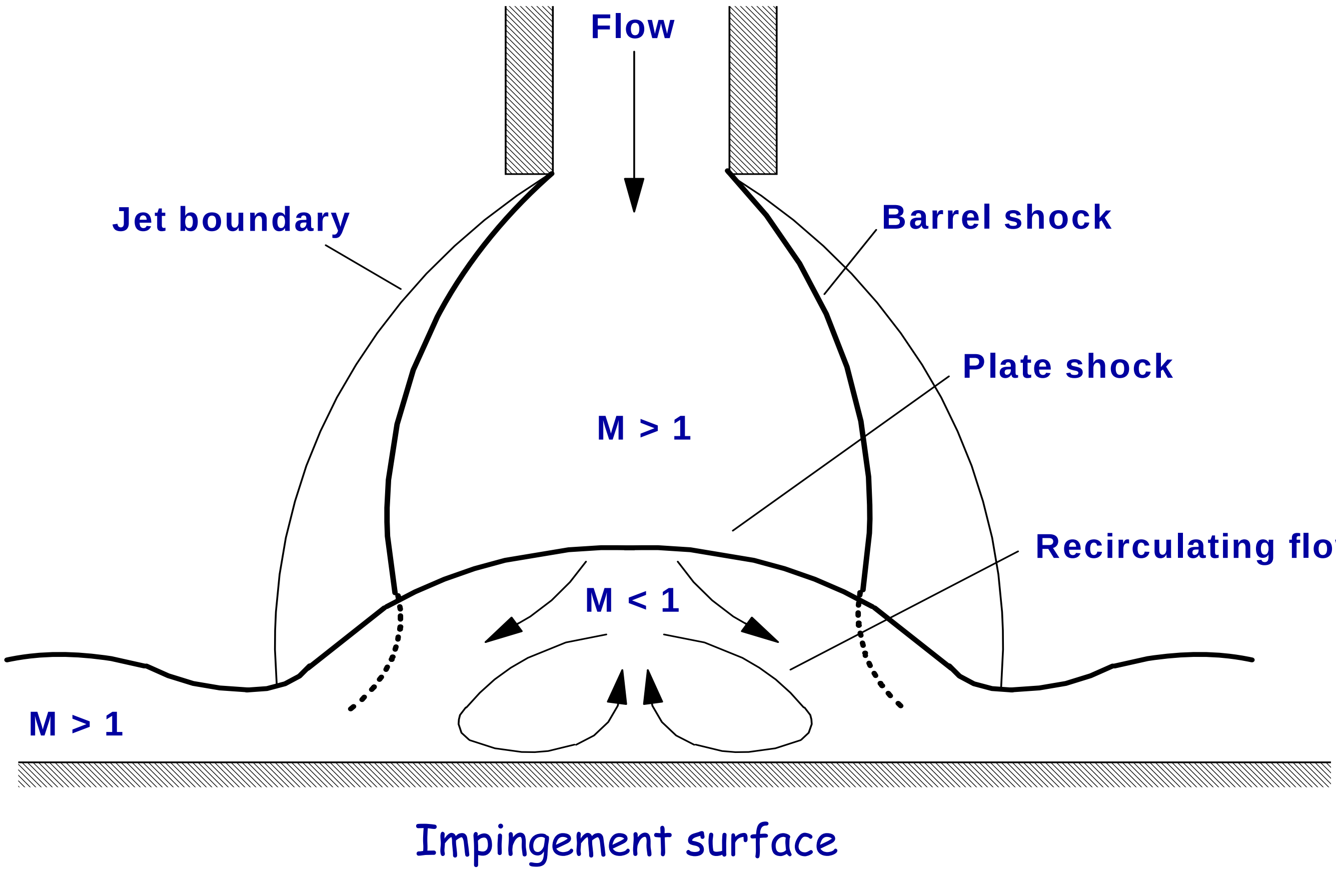

Proposed jet structures
(from N L Messersmith and S N B Murthy, Purdue Univ.)

High pressure jet structure (3)

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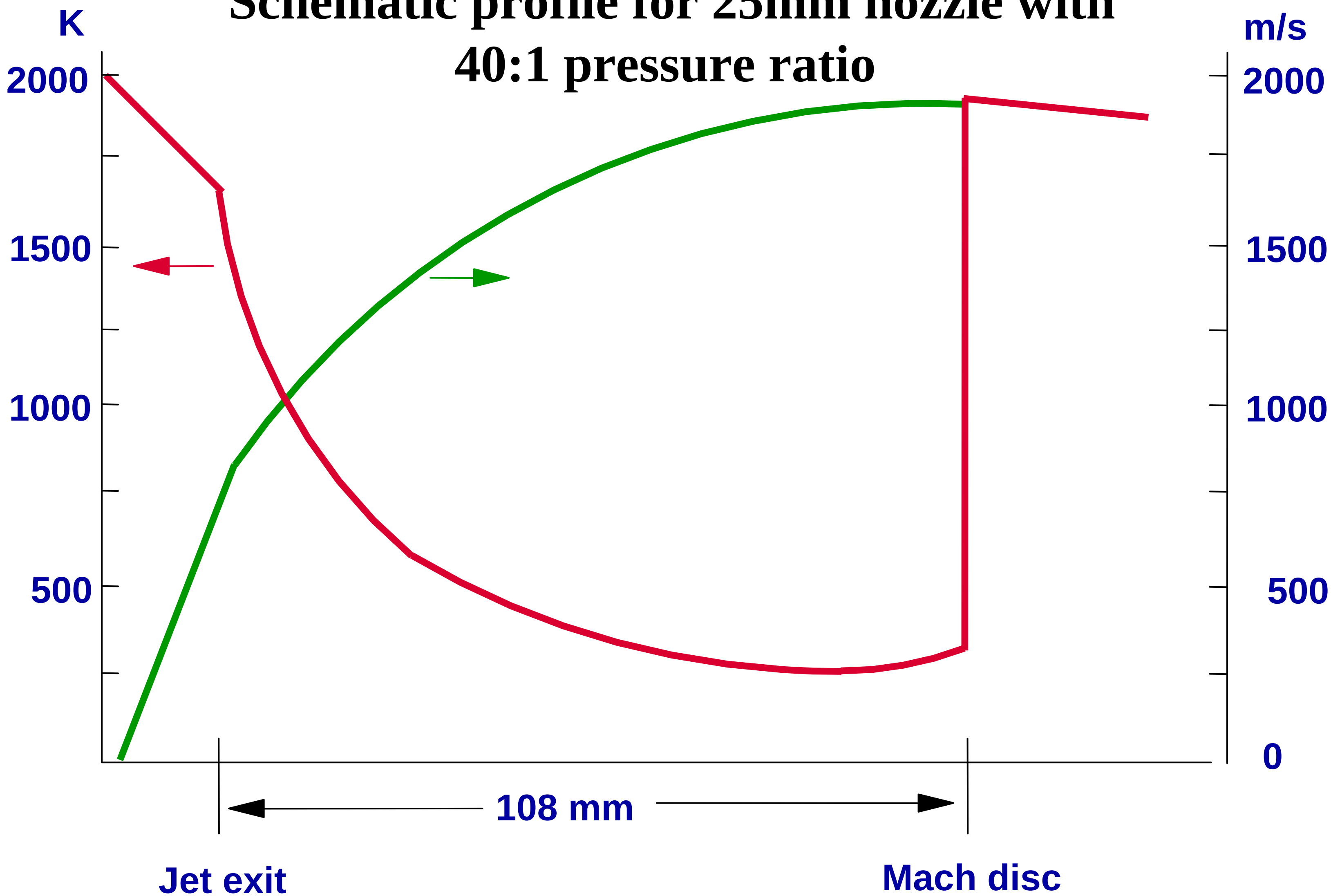
Schematic profile for 25mm nozzle with 40:1 pressure ratio



Jet operating conditions

Nozzle diameter	**25.4 mm**
Chamber stagnation pressure	**Up to 70 bar**
Air mass flow rate	**2 kg/s**
Fuel (stoichiometric)	**Methane or kerosene**
Running time	**> 3 minutes**

Rig implementation (1)

- **1 Te air - 4 m^3 air storage at 207 bar**
- **Air delivery up to 2 kgs^{-1}**
- **Dual fuel – methane or kerosene**
- **Rolls-Royce Tay can modified to allow for reduced flow rates**
- **Standard ignition system**
- **Software control of combustion conditions**
- **Mass flow controlled operation**

Specification of test conditions

- **Direct measurement of pressure in combustor**
- **Compute stagnation temperature**

1. Compute total mass flow from choked flow at nozzle and defined conditions

2. Measured heat loss to water-cooled nozzle (60kW) factored in

3. Fuel flow computed on basis of heat required to achieve target stagnation temperature assuming stoichiometric exhaust composition

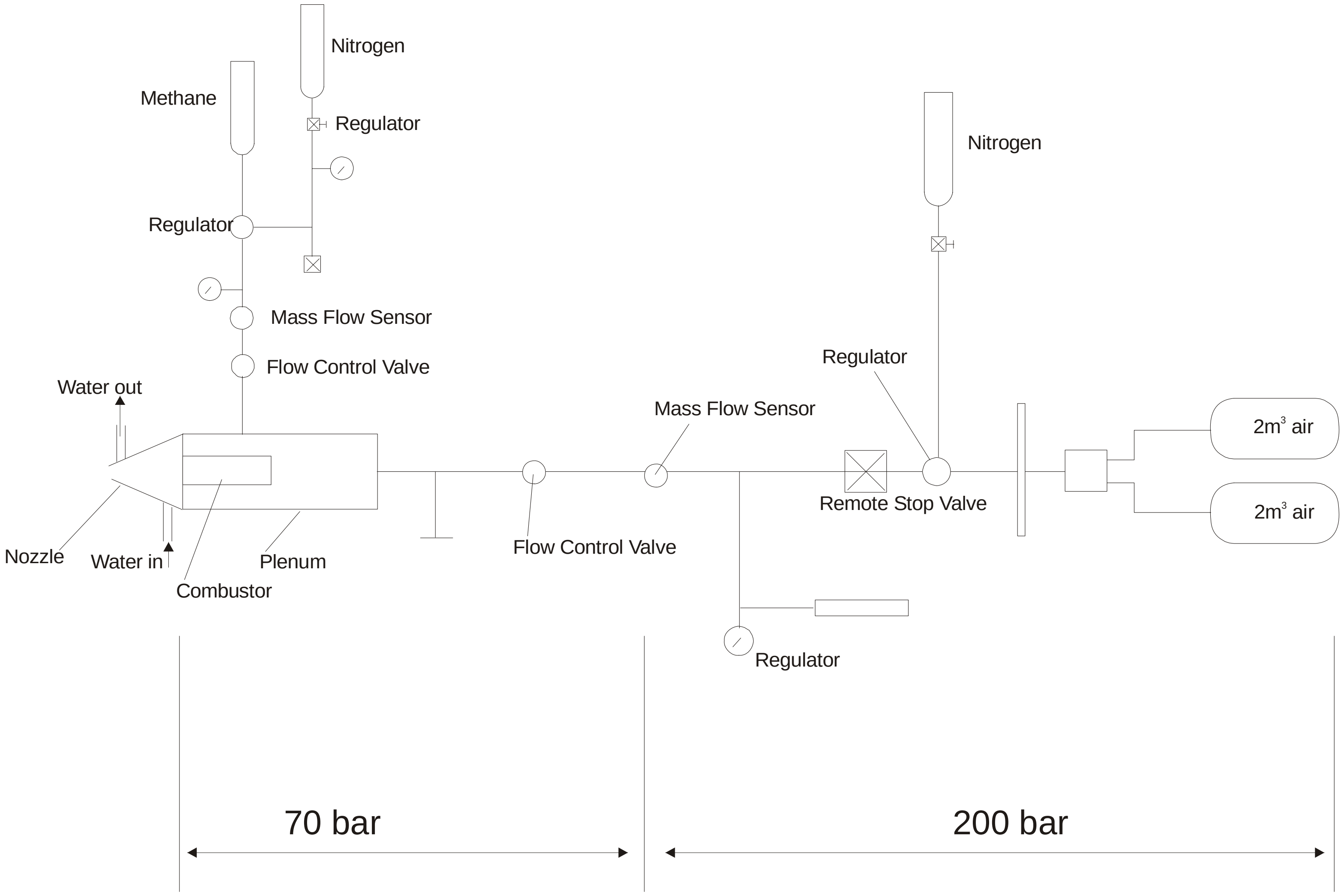
4. Compute specific heat of exhaust using fuel flow rate from (3)

5. Recompute fuel flow

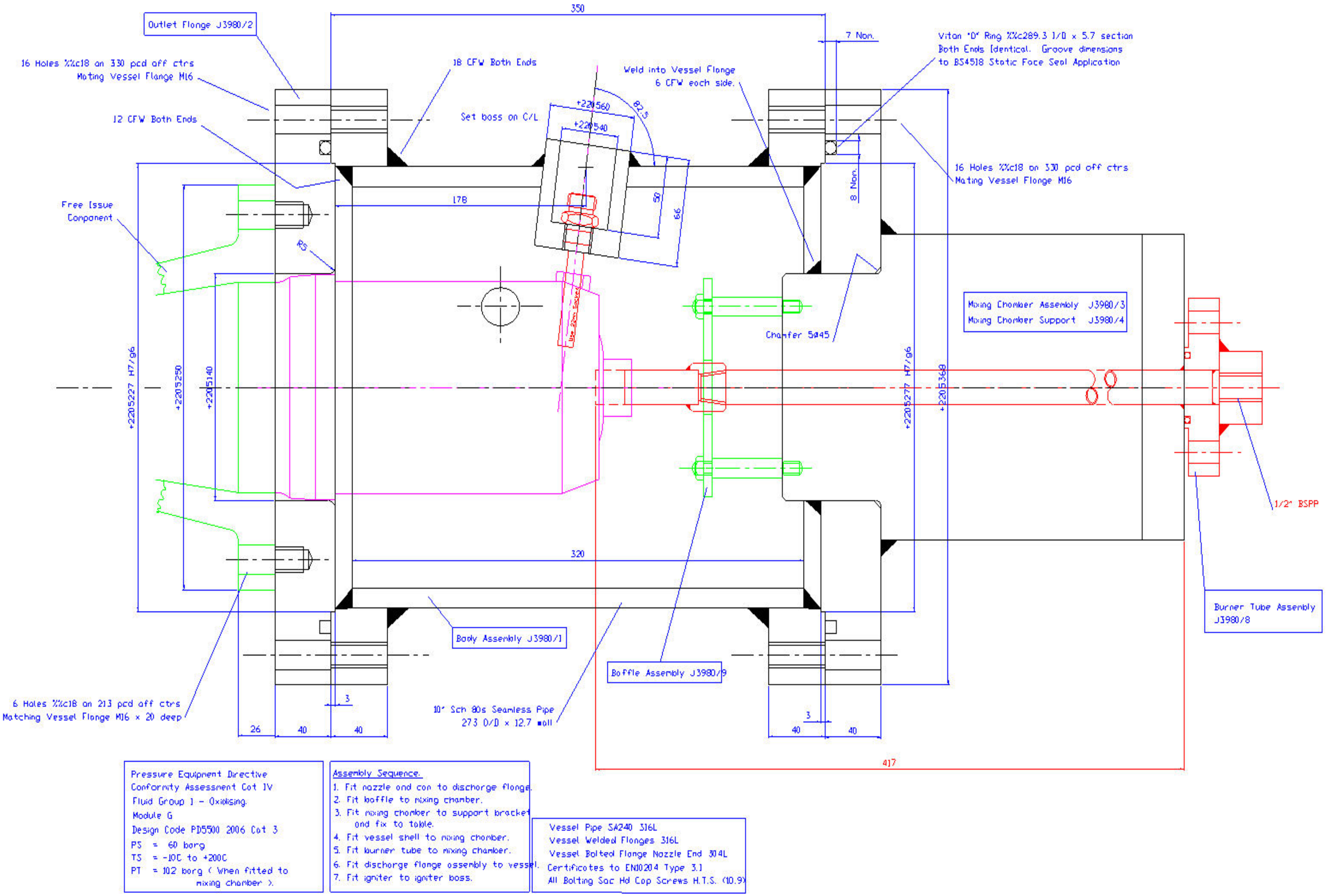
6. Estimate exhaust stagnation temperature from energy balance:

$$\sum_{i}^{exhaust} \dot{m}_i \int_{Tref}^{T} Cp_i \, dT + \text{Heat loss rate} = \dot{m}_{fuel} \, \Delta H_{fuel}$$

Burn through rig -shematic



Combustor unit



Rig implementation (1)

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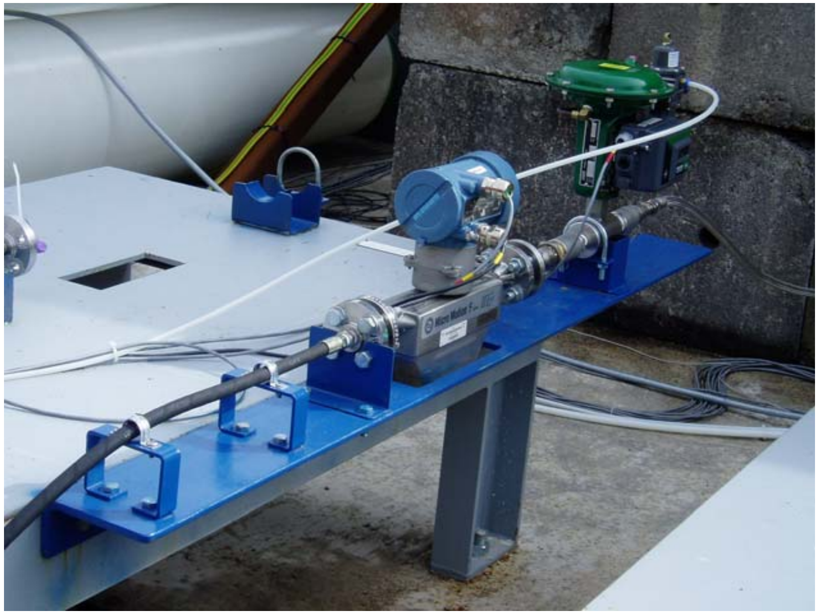
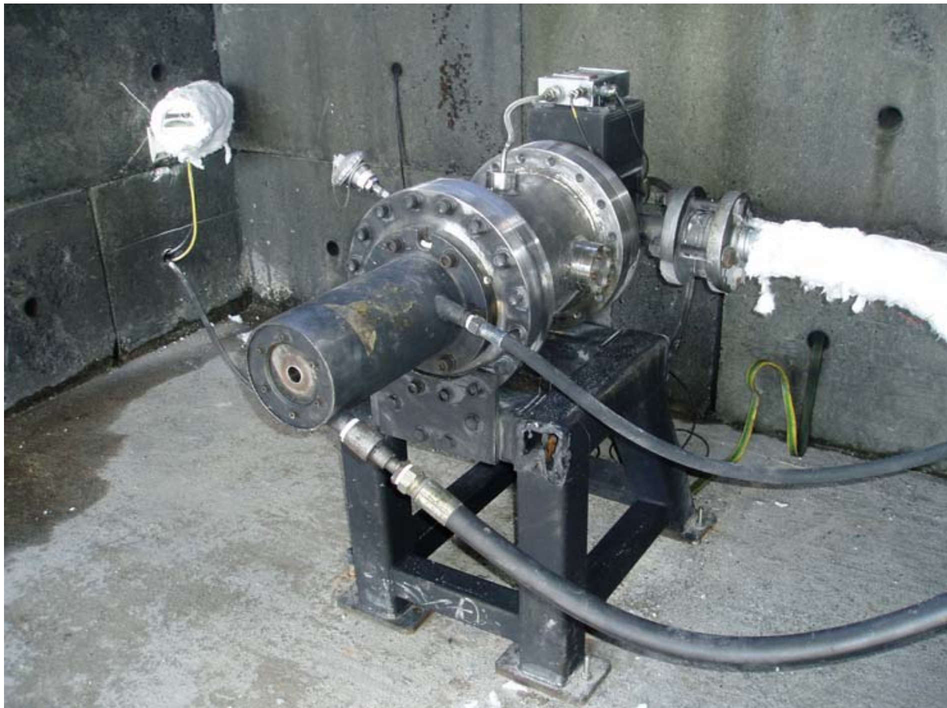
Rig implementation (2)

Rig implementation (3)



Rig implementation(4)



Rig calibration

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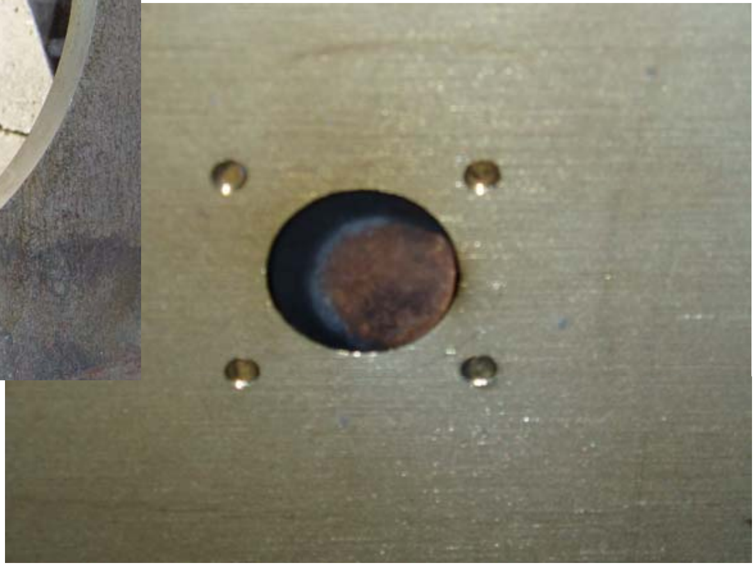
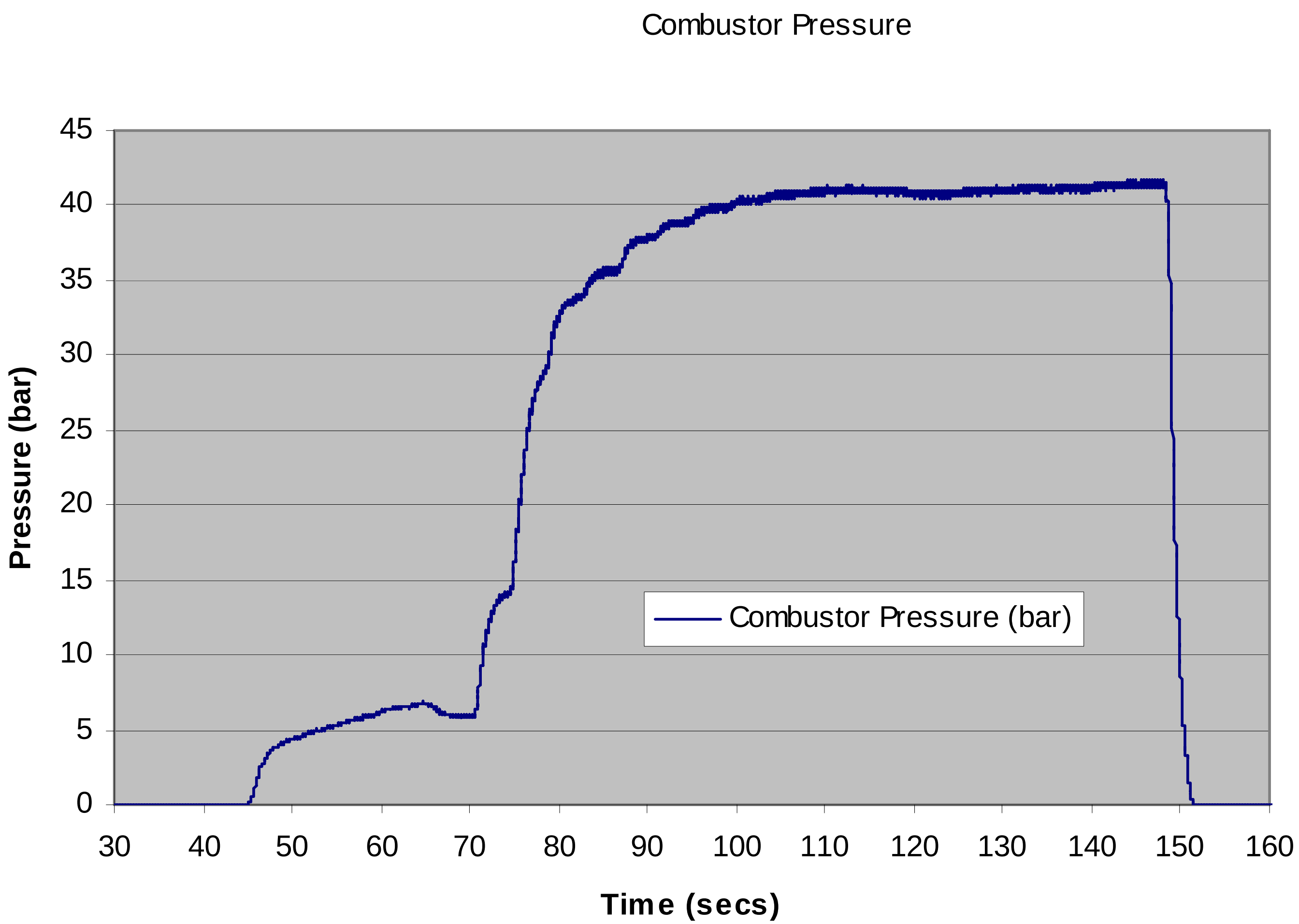
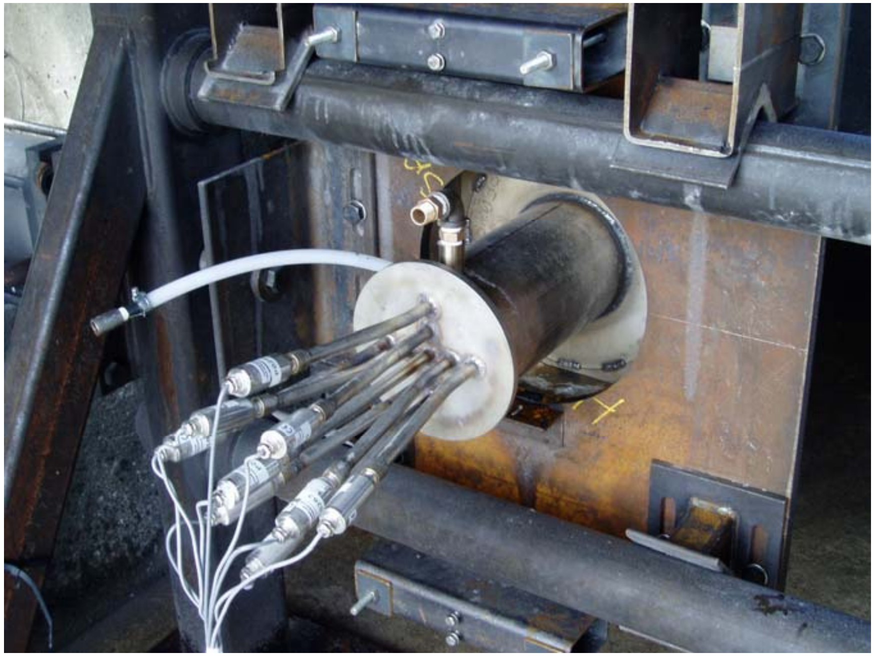
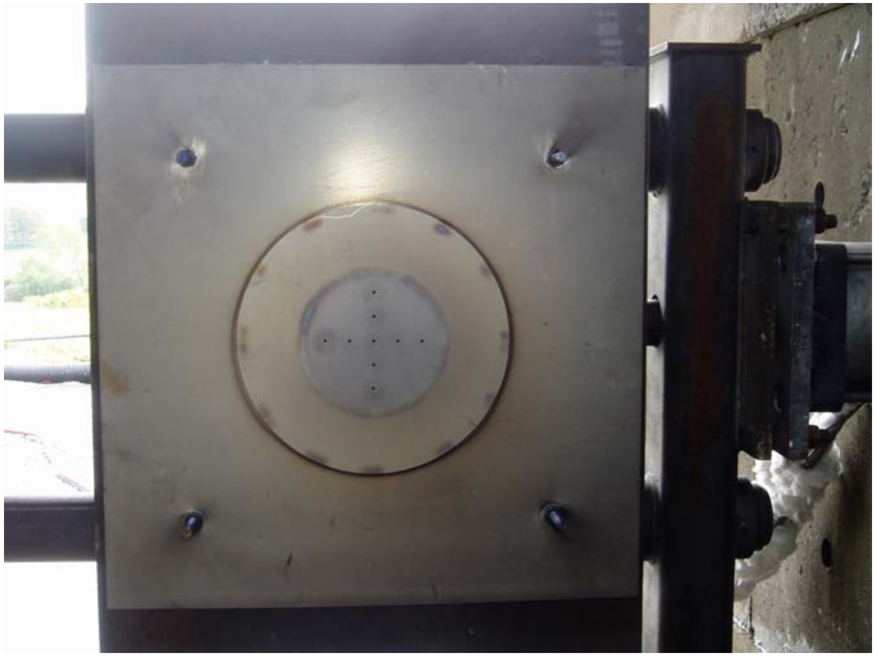


Combustor conditions

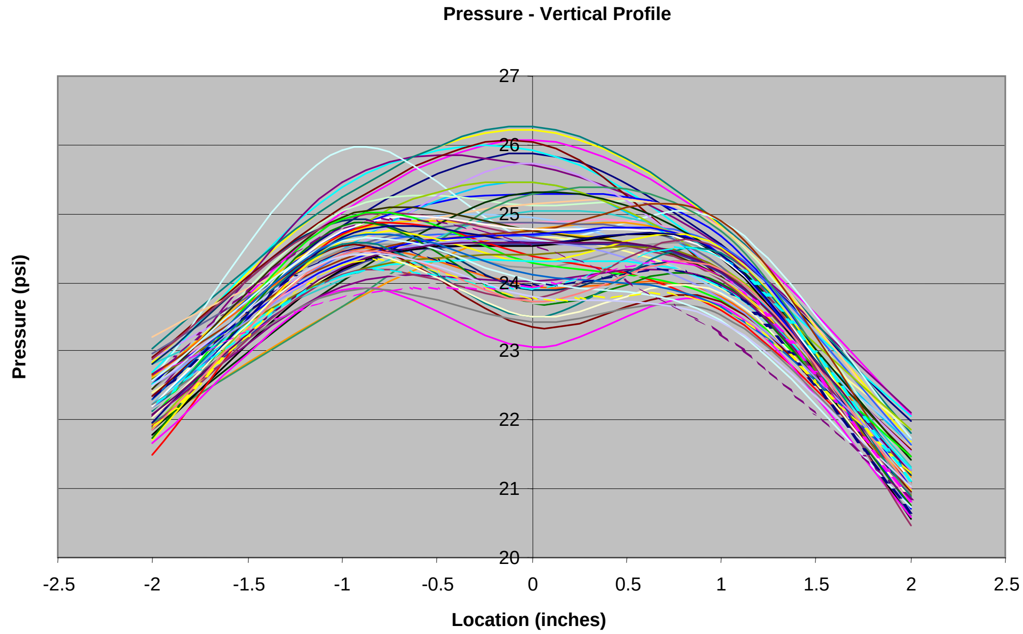


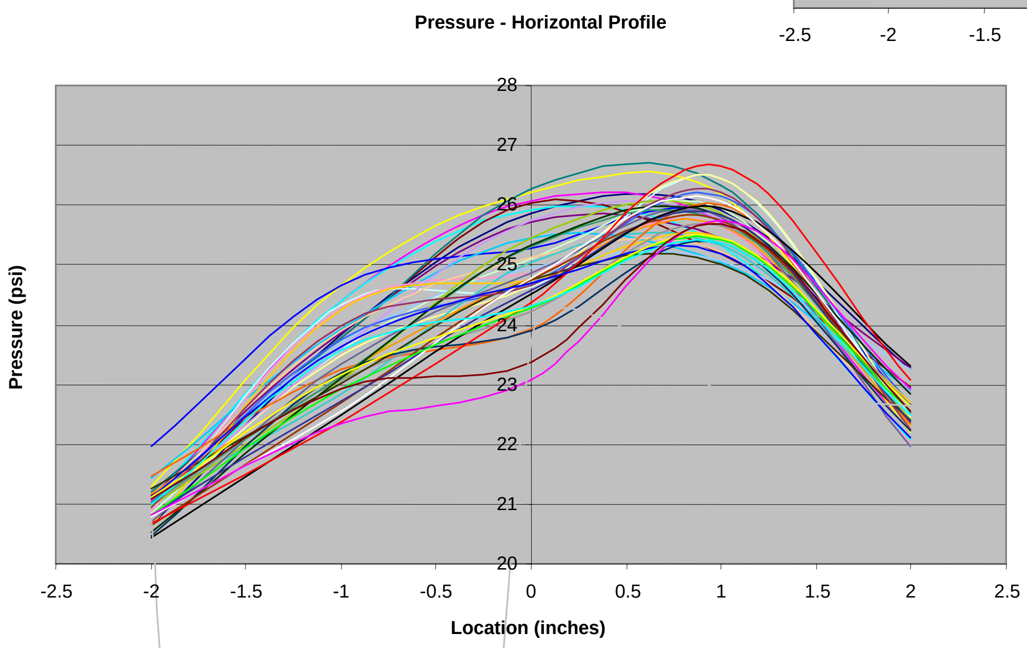
Far-field impingement(1)



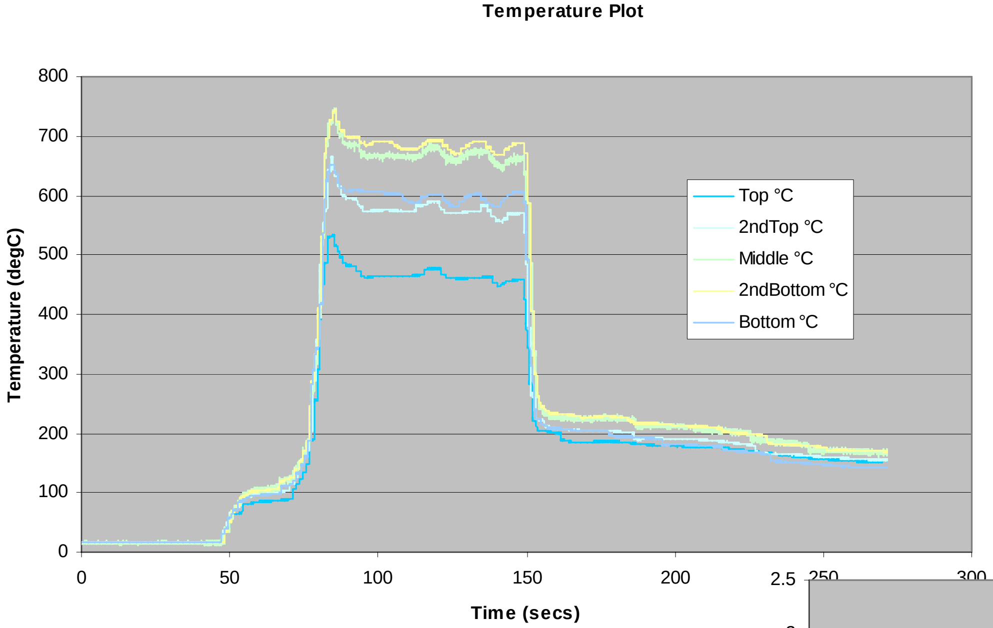


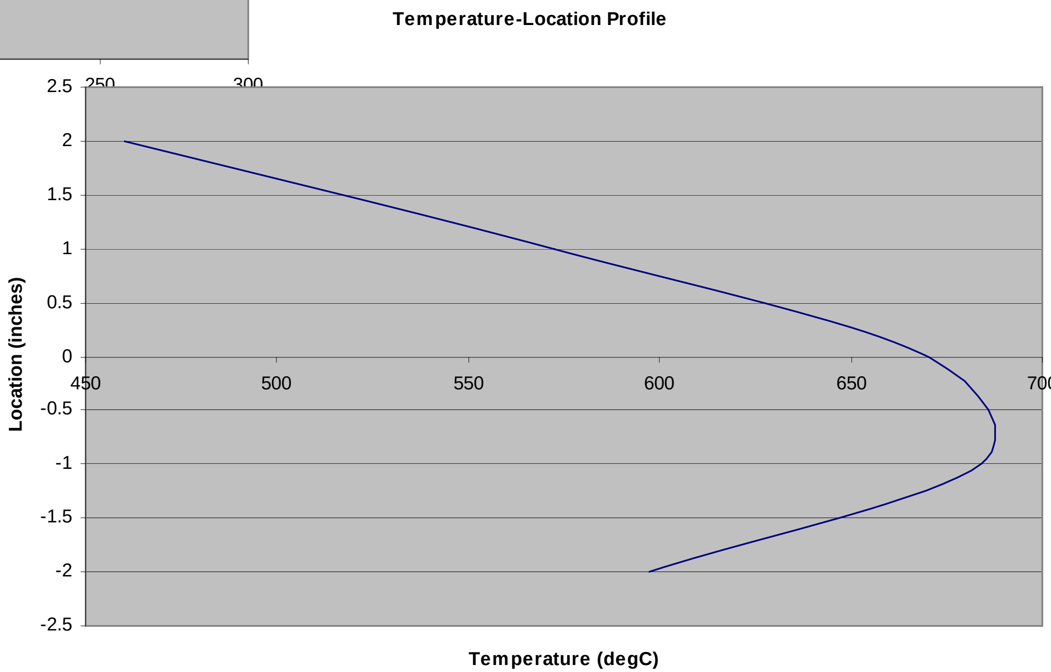
Far-field impingement(2)



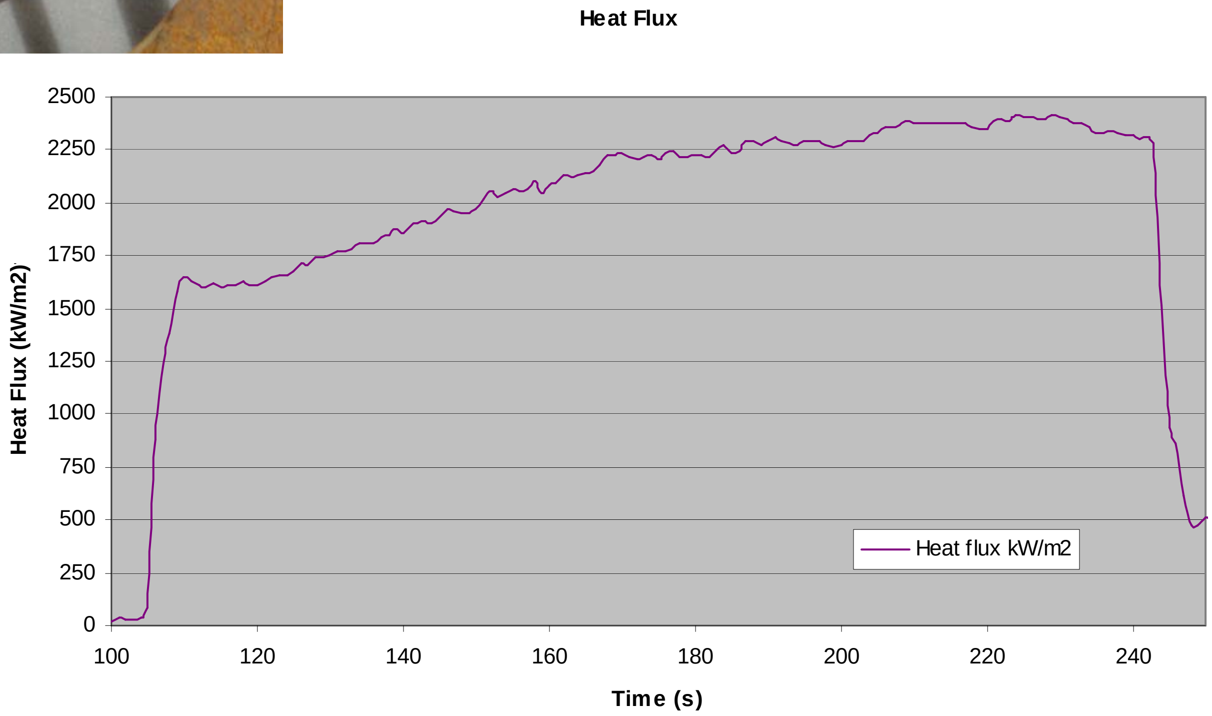


Far-field impingement(3)

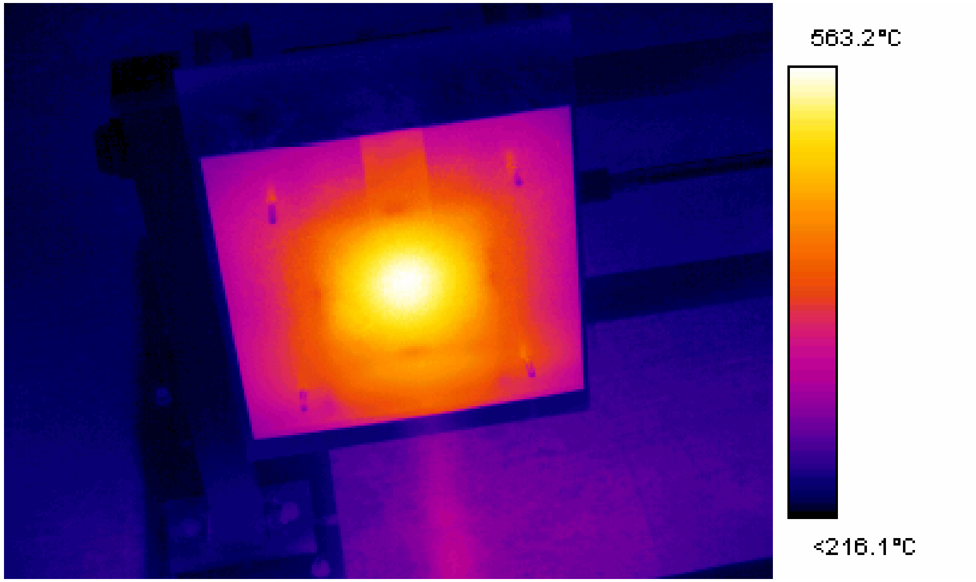




Far-field impingement(4)



Far-field impingement(5)



- **IR Imaging for temperature measurement**
- **Difficulty is fixing emissivity**
- **Here paint of known emissivity is used**

Near-field impingement(1)

75 mm impingement

42 s burn through

Near-field impingement(2)

Video Deleted

Near-field impingement (3)

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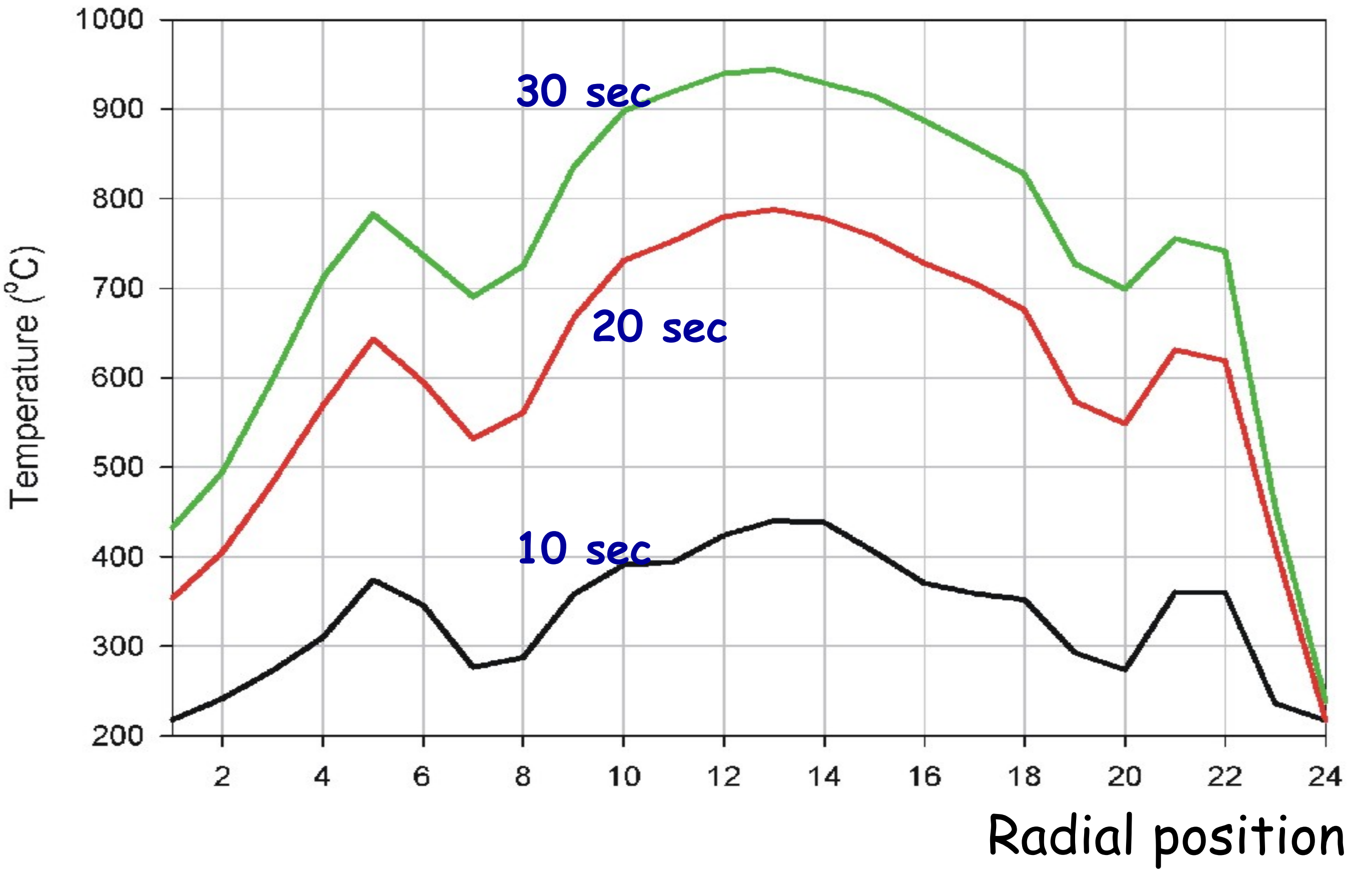

IR imager rear plate temperatures

Measurement difficulties in high pressure, hot jets:

- **Intrusive devices**

  shock structures

  unrepresentative conditions
- **Radiation losses**
- **Protection of probes**
- **Introduction of seeding**
- **Wide range of temperature, velocity, density**

Non-intrusive measurement techniques

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• **Laser Doppler**	**V**	**systems available** **any CW laser** **strong signal**	**frequency limits** **seeding** **particle following** **multiple beam**
• **PIV**	**V**	**“**	**“**
• **Spontaneous Raman**	**T**	**any pulsed laser** **single beam** **well documented**	**weak signals** **temperature limit**
• **CARS**	**T**	**improved signal strength**	**multiple beam** **temperature limits**
• **Rayleigh**	**V, T, ρ**	**single beam** **strong signal** **wide limits**	**narrow line-widths**

Rayleigh scattering features

- **Molecular scattering**

  accurate flow following

- **Narrow band scattering centred on probe laser wavelength**

  probe laser is single axial mode

- **Velocity information contained within band position**

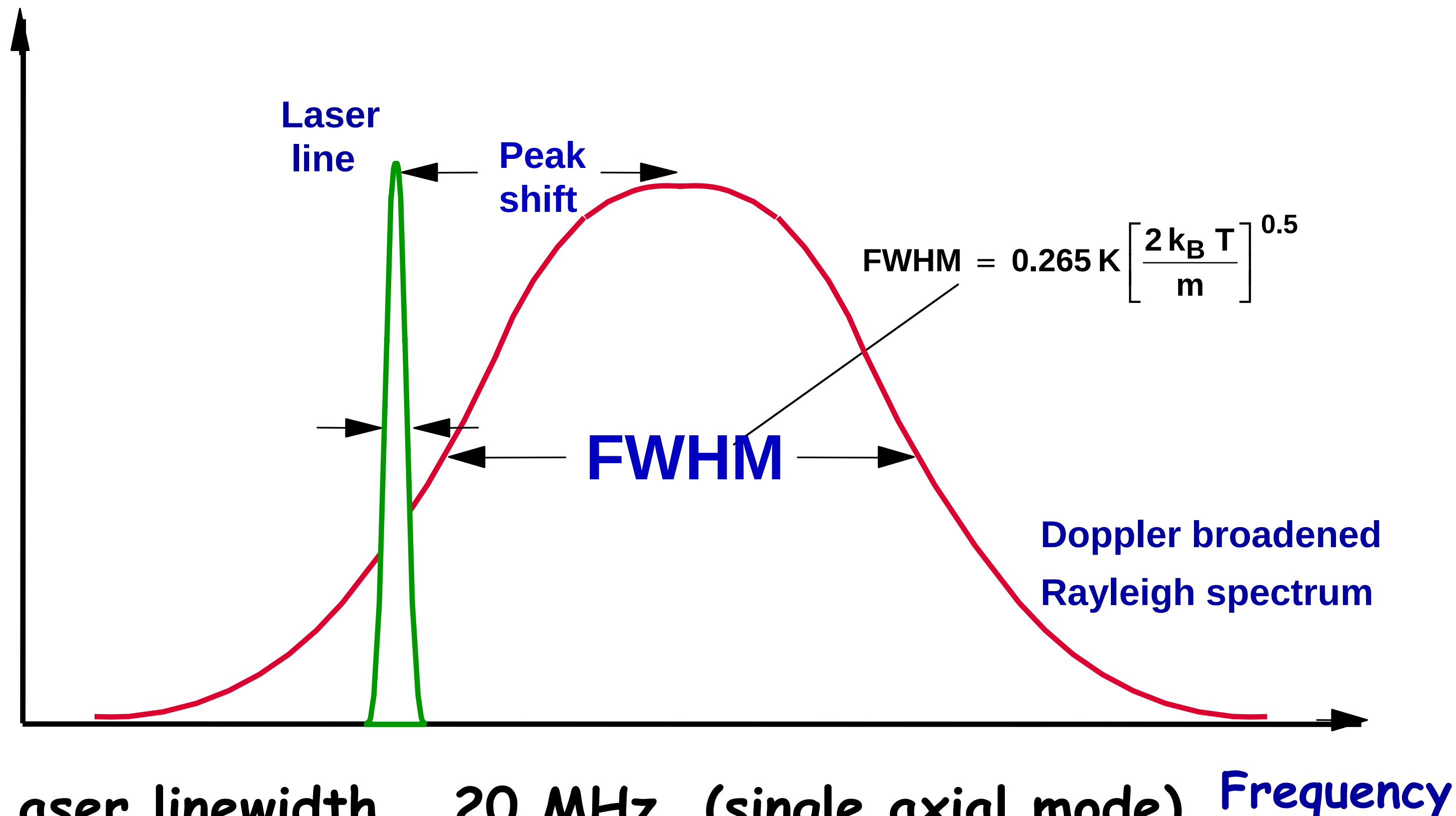
  doppler shift

- **Temperature information contained within band shape**

  doppler broadening

- **Scattered signal strength related to molecular density**

Rayleigh scattering details (1)



Laser linewidth	20 MHz	(single axial mode)
FWHM	1.93 GHz	(T = 300 K)
	4.32 GHz	(T = 1500 K)
Peak shift	2.75 GHz	(U = 1000 m/s)

(FWHM and peak shift values:) at 514 nm

Rayleigh scattering details (2)

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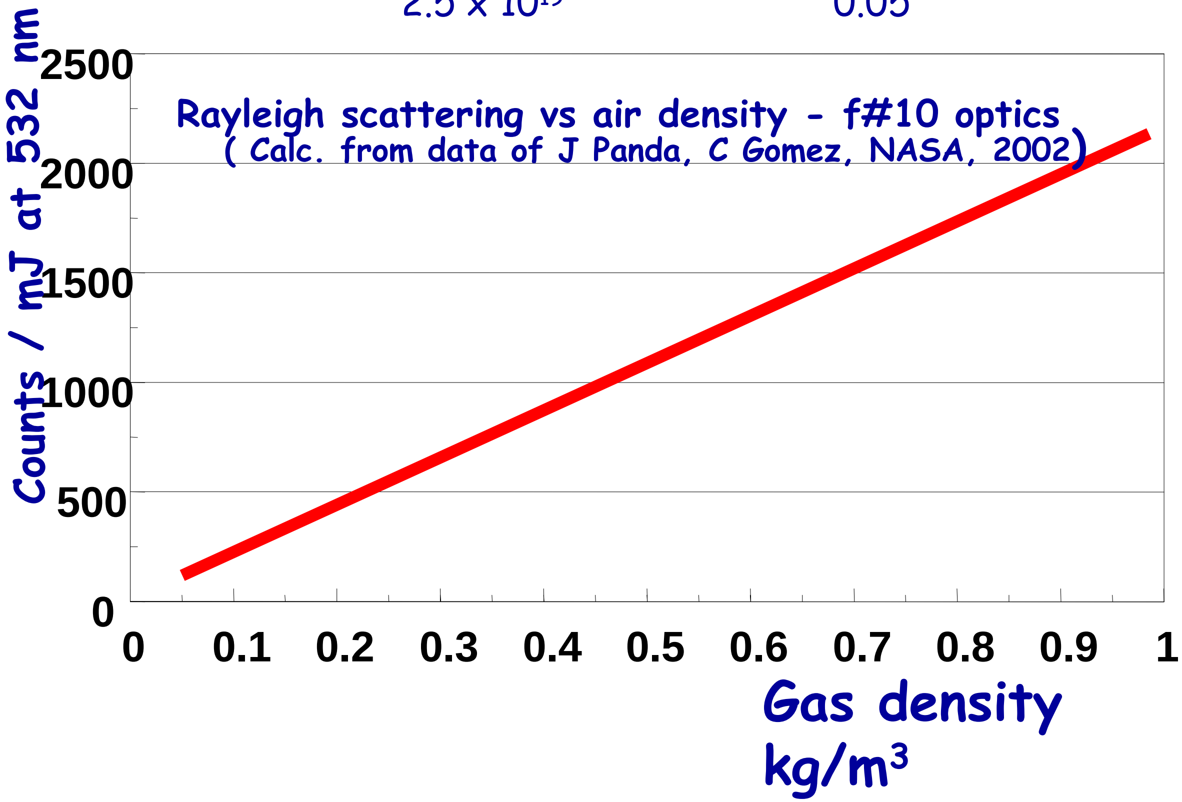
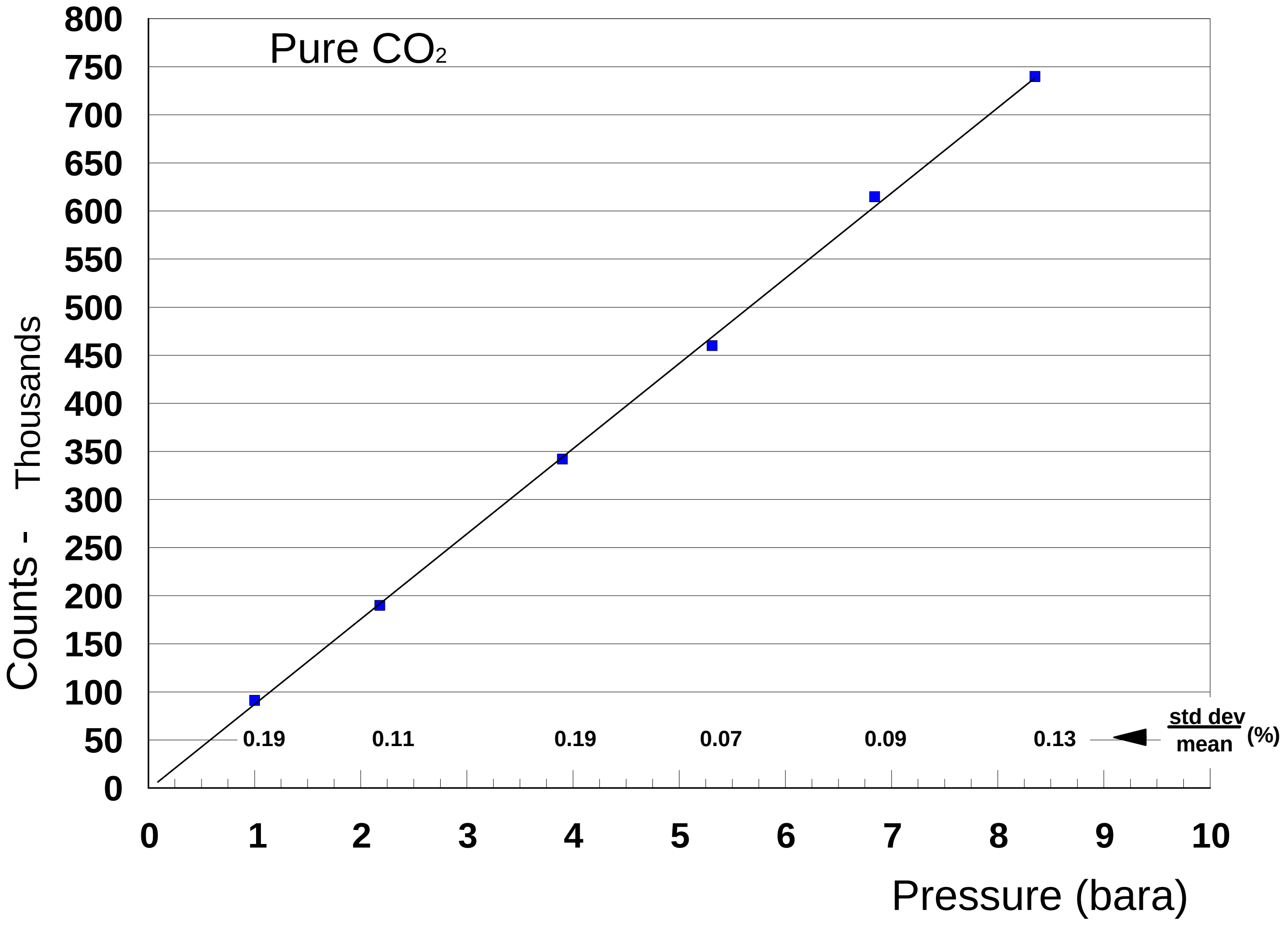
$$P = I \; N \; V \; \eta \int \frac{d\sigma}{d\Omega} \, d\Omega$$

2.5×10^{20} 10^{-3} 5×10^{-28}

2.5×10^{19} 0.05



Rayleigh scattering tests



Next steps

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- Rig gives reliable and steady simulation of burn through conditions at pressures up to 60-70 bar. Run times > 3 minutes @40 bar.
- Now concentrate on near-field < 250mm.
- Impingement plates show evidence of hot and cool rings.
- Main problem is measurement and validation of test conditions.
- Non-intrusive laser measurements are the best way forward.
- Rayleigh scattering offers possibility of good signal levels in hostile jet environment.
- Temperature, velocity and density available from single measurement. Sheet illumination a possibility