

A New Probe For The Measurement of High-Temperature Gases

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Outline

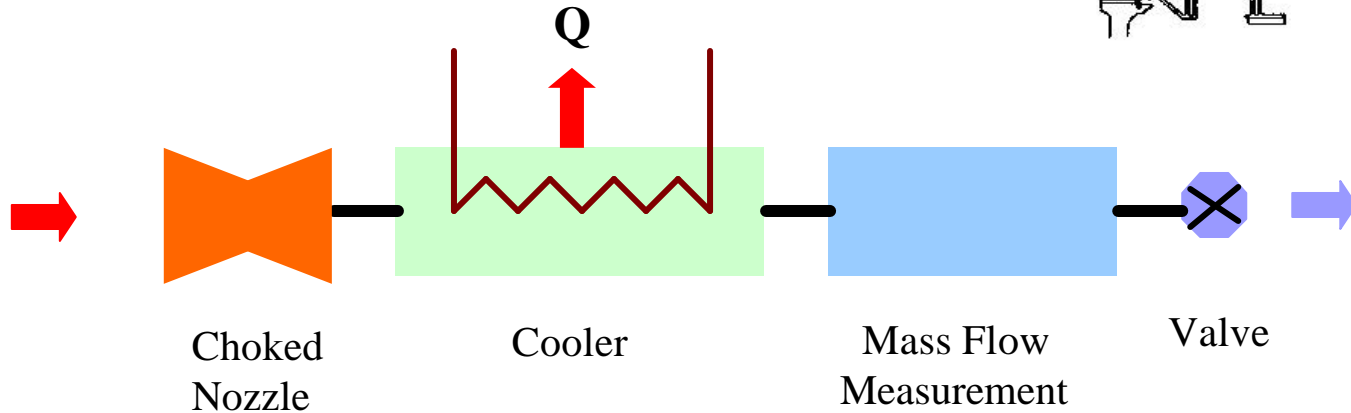
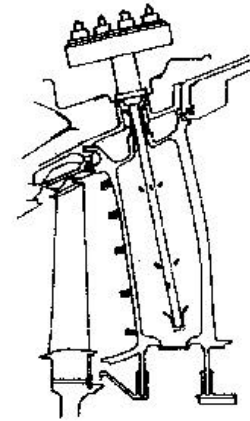
- Introduction
- Theoretical operation of probe
- Experimental testing
- Calibration results and error analysis
- Conclusion

Introduction

- Importance of accurate measurement of high temperature
 - Efficiency
 - Engine monitoring
 - Fault diagnosis
- Current temperature measurement techniques
 - Thermocouples
 - Infrared Thermometry
- Aim of project: The development of a new temperature measurement technique

Theoretical Operation of Probe

- Fundamental principles
- Probe design and structure



$$\dot{m} = f(P_0, M, T_0) \xrightarrow{\text{Choked Nozzle}} T_0 = f(P_0, \dot{m})$$

Theoretical Operation of Probe

Fundamental Principles

- Flow through choked nozzle
- Mass flow through orifice plate

$$C_1 \times A^2 \times P_0^2 \times \frac{g^2}{g-1} \times \left(\frac{g+1}{2} \right)^{-\frac{1}{2} \left(\frac{g+1}{g-1} \right)} \times (C_p \times T_0)^{-\frac{1}{2}} = \dot{m} = C_2 \times A_2 \times \sqrt{2 \times \Delta P \times r}$$

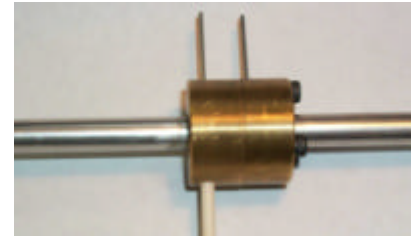
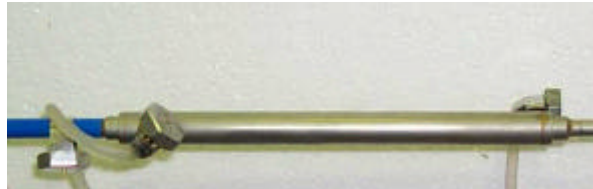
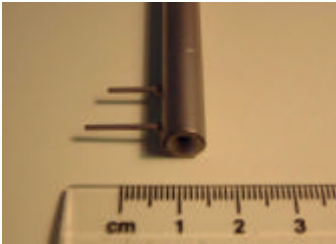


$$T_0 = C \times \frac{A_1^2}{2A_2^2} \times \frac{P_0^2}{\Delta PP} \times \frac{\left\{ \frac{g}{\sqrt{g-1}} \left(\frac{g+1}{2} \right)^{-\frac{1}{2} \left(\frac{g+1}{g-1} \right)} \right\}^2 R}{c_p} \times T_2$$

Theoretical Operation of Probe

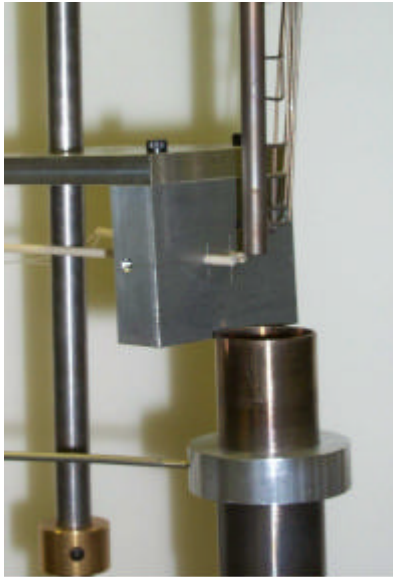
Probe design and structure

- Upstream flow nozzle
- Cooler
- Downstream mass flow measurement



Experimental Testing

Two types of probe temperature calibration

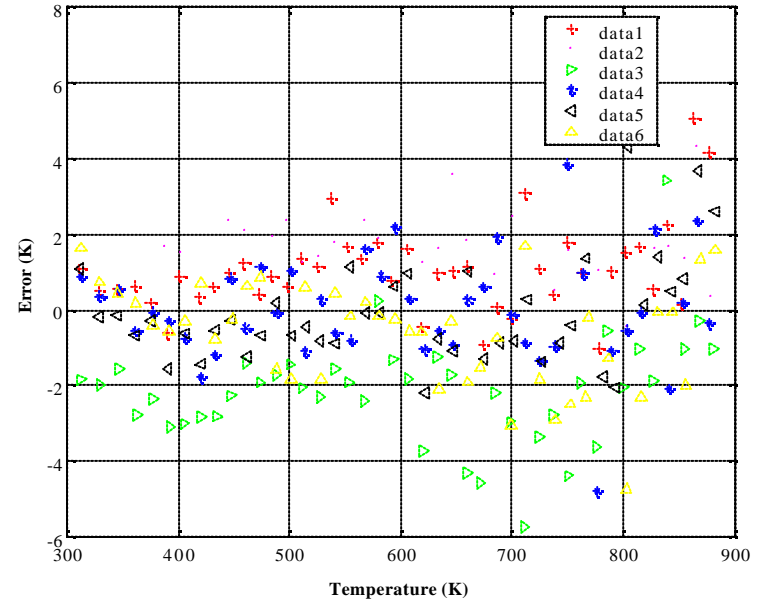
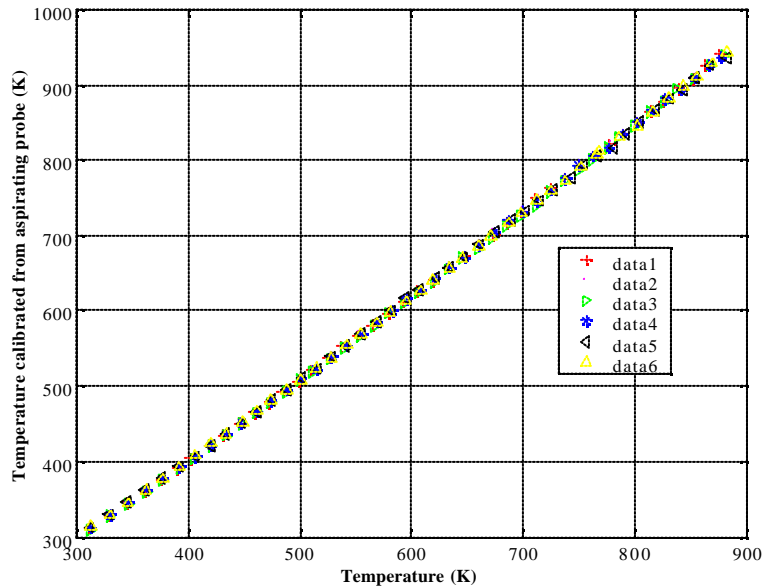


Calibration Result and Error Analysis

- Probe calibration curves and measurement uncertainty
- Analysis of factors affecting probe calibration
 - Inlet area change due to thermal expansion
 - Gas property

Calibration Result and Error Analysis

Probe calibration curves and measurement uncertainty



Calibration Result and Error Analysis

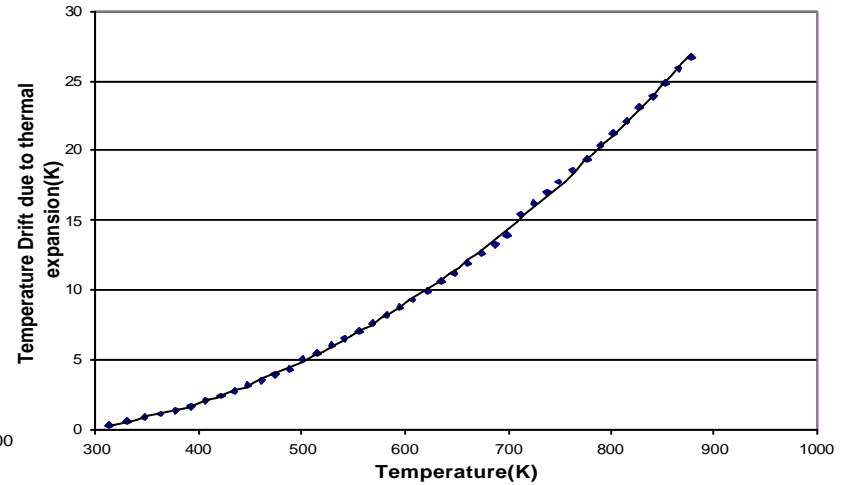
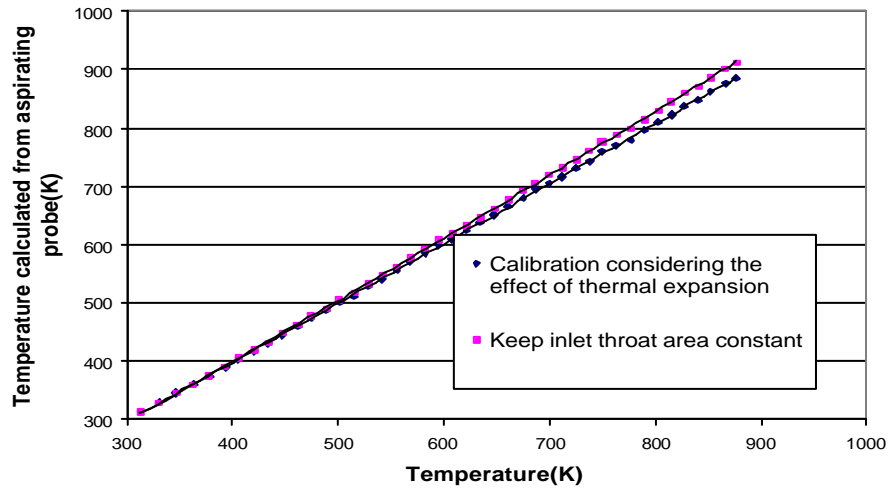
Analysis of factors affecting probe calibration

$$T_0 = C \times \frac{A_1^2}{2A_2^2} \times \frac{P_0^2}{\Delta PP} \times \frac{\left[\frac{g}{\sqrt{g-1}} \left(\frac{g+1}{2} \right)^{-\frac{1}{2} \left(\frac{g+1}{g-1} \right)} \right]^2}{c_p} R \times T_2$$

The diagram illustrates the calibration equation with highlighted factors. A blue box labeled "Area factor" points to the term $\frac{A_1^2}{2A_2^2}$. Another blue box labeled "Gas Property factor" points to the term $\frac{\left[\frac{g}{\sqrt{g-1}} \left(\frac{g+1}{2} \right)^{-\frac{1}{2} \left(\frac{g+1}{g-1} \right)} \right]^2}{c_p}$.

Calibration Result and Error Analysis

Area ratio factor-thermal expansion effect

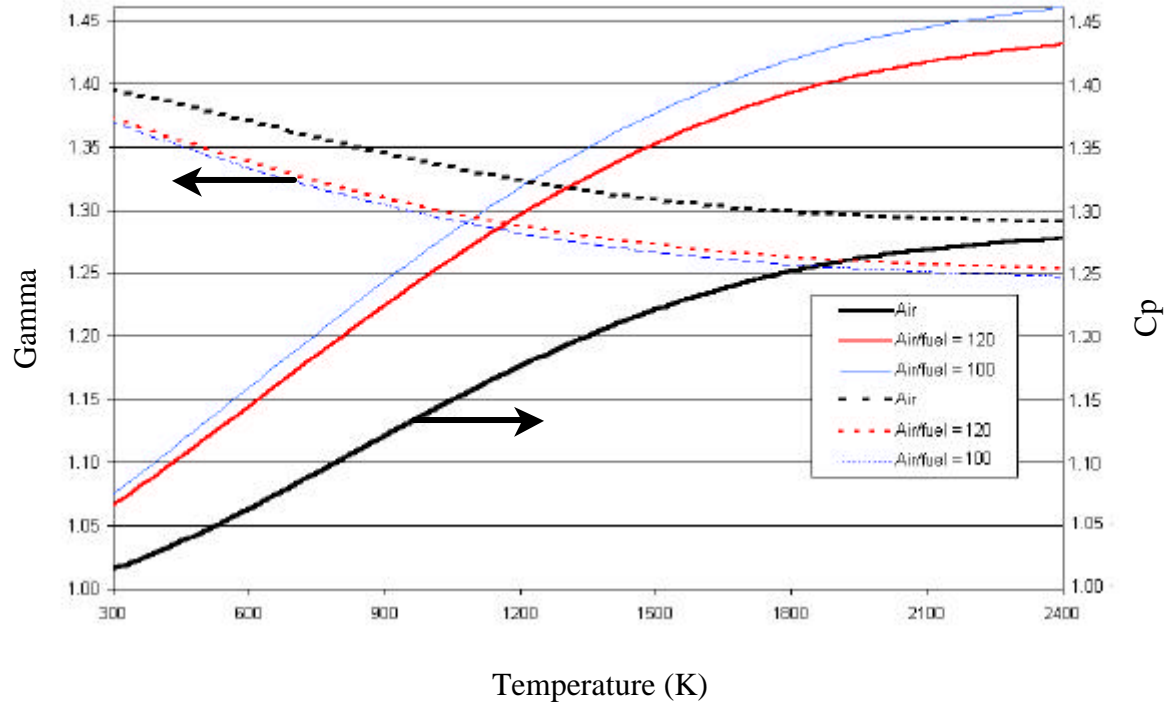


This effect can be calibrated for and does not cause error

Calibration Result and Error Analysis

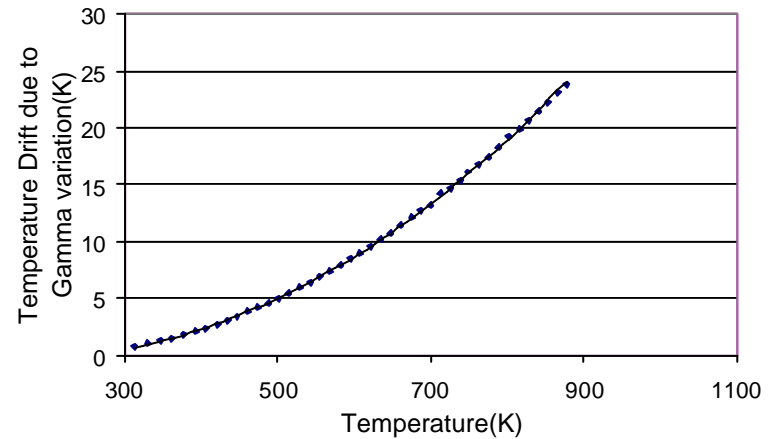
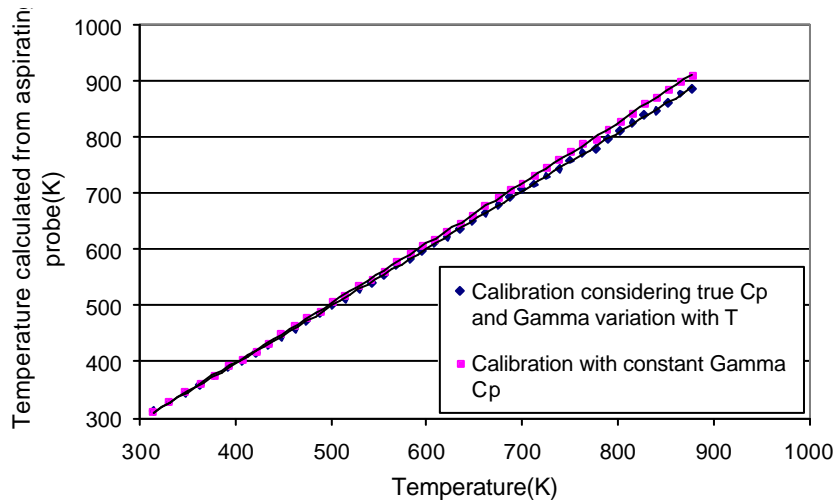
Gas Property factor

- Temperature
- Gas composition



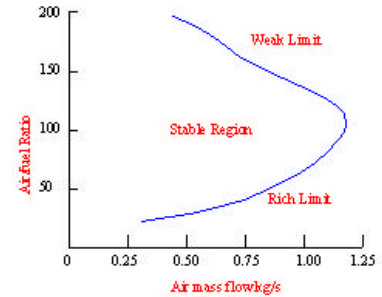
Calibration Result and Error Analysis

Gas Property Effect ---Temperature

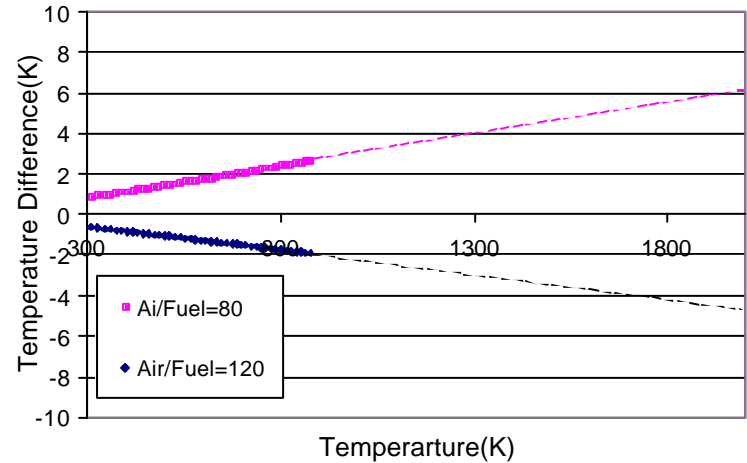
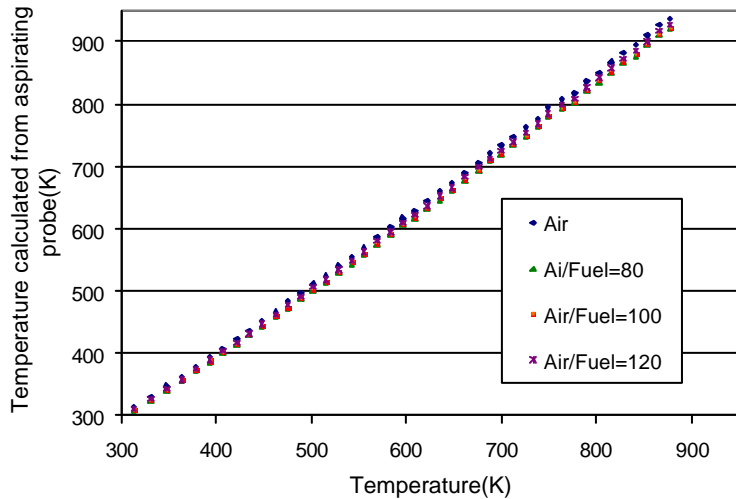


This effect can be calibrated for and does not cause error

Calibration Result and Error Analysis



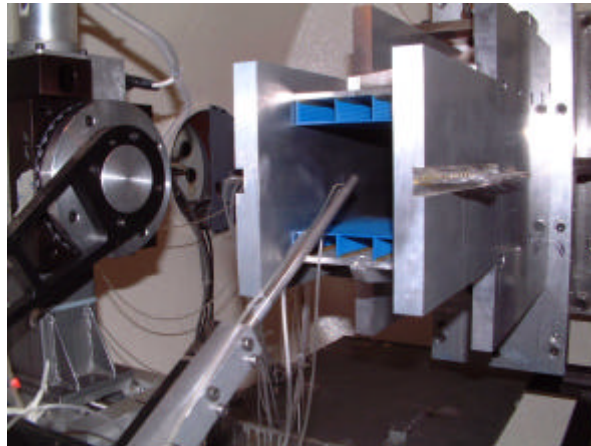
Gas Property Effect --- Gas Composition



- This effect can not be calibrated for and estimated uncertainty is ± 6 K at 2000K
- Gamma probe is developed to measure gas composition and remove the error

Conclusion

- Theory tested and the new probe improved to work
- Probe measurement error is $\pm 2.89\text{K}$ within 900K
- Effect of no consideration for air/fuel ratio results in uncertainty of $\pm 6\text{K}$ at 2000K in engine environment
- Additional testing
 - Mach number
 - Re number
 - Angle



Thank You