UAH Propulsion Research Center

Final Report

Measurement of Injector Face Temperature Using Optical Diagnostic Techniques

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Prepared by

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Submitted to:

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1. Summary

A CCD camera was previously set up to record infrared images of the injector face of a small rocket combustor. Good semi-quantitative results were obtained but it was found that non-linearities in the camera system made accurate determinations of temperature difficult. A Pulnix CCD camera was purchased and calibrated. The system was calibrated for temperatures between 500 and 850°C. The best filter to use was found to be a BG850 glass filter. The actual calibrations are presented in the report. The system was to be used on a hydrogen oxygen system but the tests did not take place as scheduled. Attempts were made with a methane oxygen system but the carbon in the system interfered with the viewing of the injector face.

2. Results

A Pulnix CCD camera was setup and calibrated to detect near IR radiation in order to determine if an injector developed any hot spots during the firing. The system was calibrated to yield temperature in the range of 500-850°C. The calibration setup is shown in Fig. 1. The camera had a 10mm extension tube between the lens and the camera. Several filters were used including a BG750, BG850 and a BG900. Video images were recorded on a JVC 1 inch video recorder. The recorder was set to that the gain was constant. For much of the calibration process the camera was connected directly to the image processor on the computer to simplify the process. It was verified that the recorder made no difference in the intensity of the images.

The Pulnix CCD camera was chosen because it gives the user control over the gamma, gain and has a wide range for the electronic shutter. Most cameras have a gamma of 0.45 which is a non-linear gain to compensate for typical monitors non-linear intensity and the non-linear response of the human eye. Good for viewing but makes measurements more difficult.

Figure 2 shows a comparison of the camera output for gamma of 1.0 (linear) and 0.45. The intensity was change by opening the aperture of the camera. The x-axis is normalized by the intensity at $f^{\#}$ of 22. The gamma 0.45 curve looks qualitatively as expected. The gamma 1.0 curve is linear initially but then rolls over at higher intensities. It was determined that the camera has self-preserving circuitry which reduces the gain based on the overall intensity of the image. A correction for this was determined and will be discussed later.

The relationship between image intensity and temperature is shown in Fig. 3. A power function was fit to the data and is shown on the plot. The intensity has been normalized to account for the different intensities as a function of $f^{\#}$. The factors used are in Table I.

Table I Aperture correction

$f^{\#}$	C_f
22	1
16	2
11	4
8	8
5.6	16
4	32
2.8	64
1.8	128

The data shown in Fig. 3 is for a blackbody source. Data for the copper sample in the oven showed a similar trend but reduced by the emissivity, ε, of the copper albeit with more scatter. The emissivity of the copper sample was found to be approximately 0.7 for these temperatures. Some of the scatter was a result of the copper oxidizing during the tests. Injecting nitrogen into the oven reduced the scatter some but did not eliminate it.

As mentioned earlier there was an additional correction needed to account for the attenuation of the signal by the camera, which was proportional to the average intensity over the entire image. This correlation was obtained by recording images of the copper sample in the furnace looking through a field stop of various diameters. The peak intensity of the copper sample and the average intensity of the entire image was measured. The results are shown if Fig. 4 shows normalized intensity vs. average image intensity. It shows that up to an average intensity of 30 the image is not attenuated. After that the attenuation is nearly linear. Therefore if the average intensity is less than 30 no action is required. If the average intensity is greater than thirty then a correction factor can be obtain from the following relation ship.

$$C_I = 1 - \frac{I_{ave} - 30}{150}$$

I_{ave} is the average image intensity. This is combined with the emissivity ε and the correction for $f^{\#}$ C_f using the following equation.

$$I_{corr} = \frac{I}{C_f \cdot \varepsilon \cdot C_I}$$

The corrected intensity can then be used to obtain temperature from

$$T = 805.9 \cdot I_{corr}^{0.0655}$$

The temperature thus obtained will be in Kelvin.

Before any of the conversion to temperature care must be taken to ensure that the background is reduced to zero. If there is significant background then the intensity correction needs to be taken first.

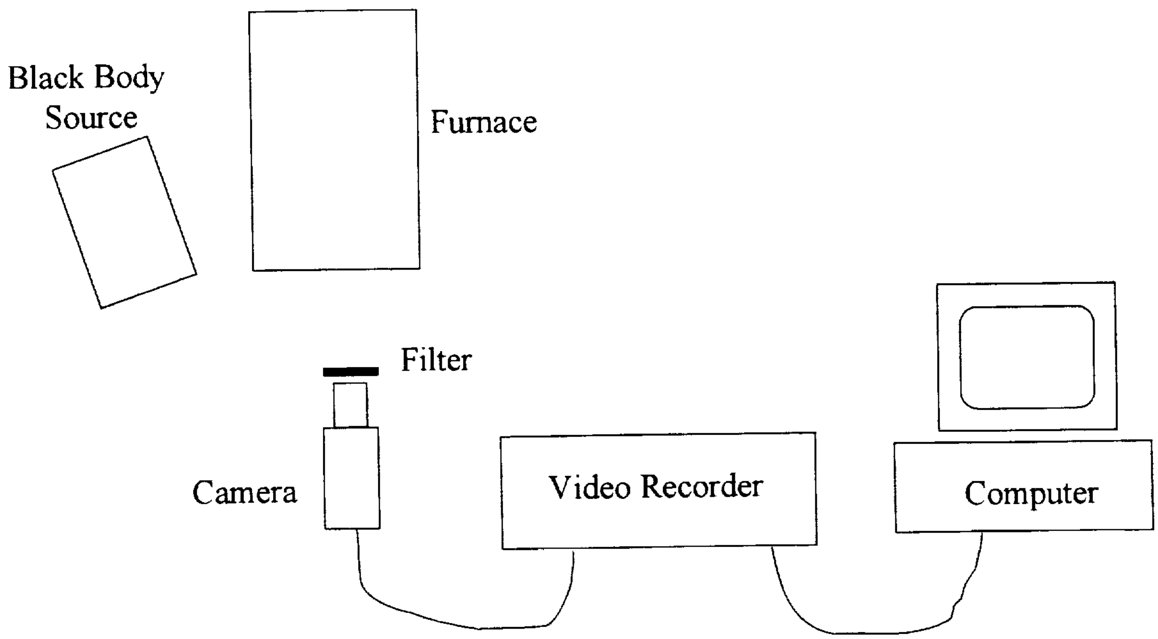

Figure 1. IR imaging calibration setup.

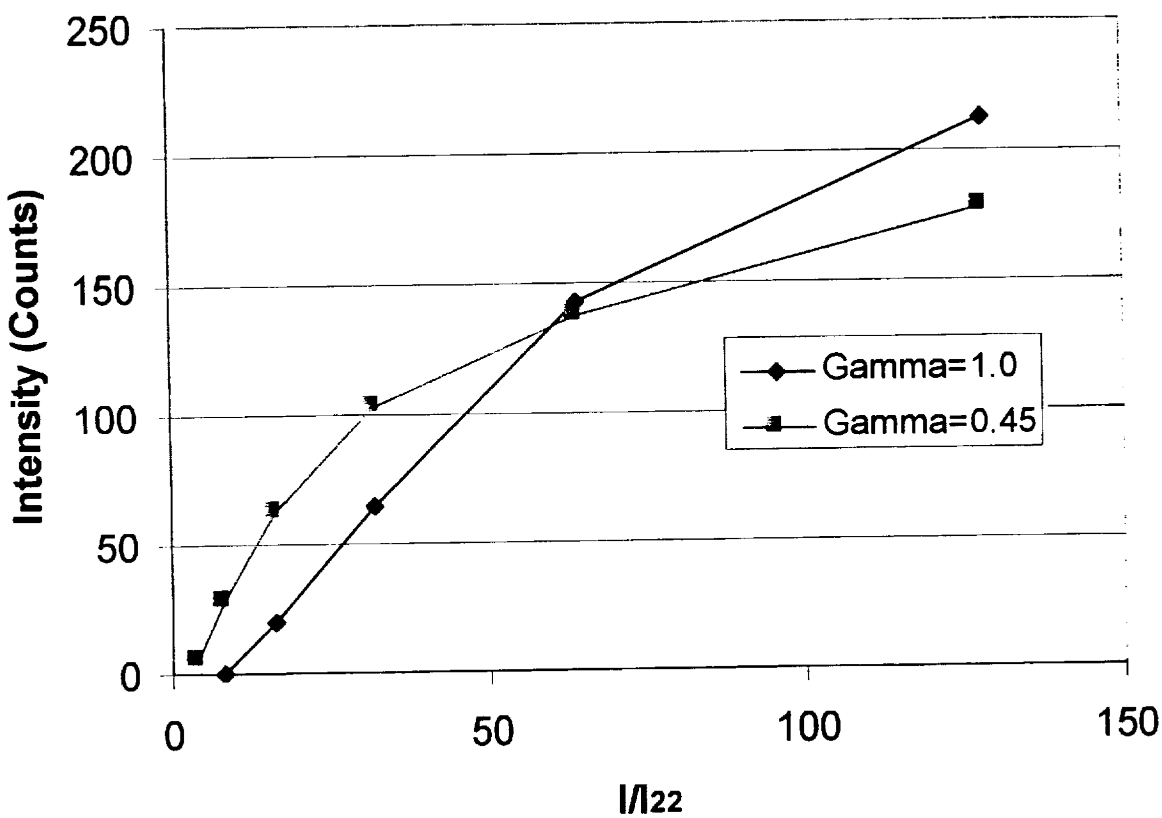

Figure 2. Intensity output of camera vs. normalize intensity input for gamma = 1.0 and 0.45. The intensity input was changed by changing the lens aperture. The intensities are all normalized by the intensity with an $f^{\#}$ of 22.

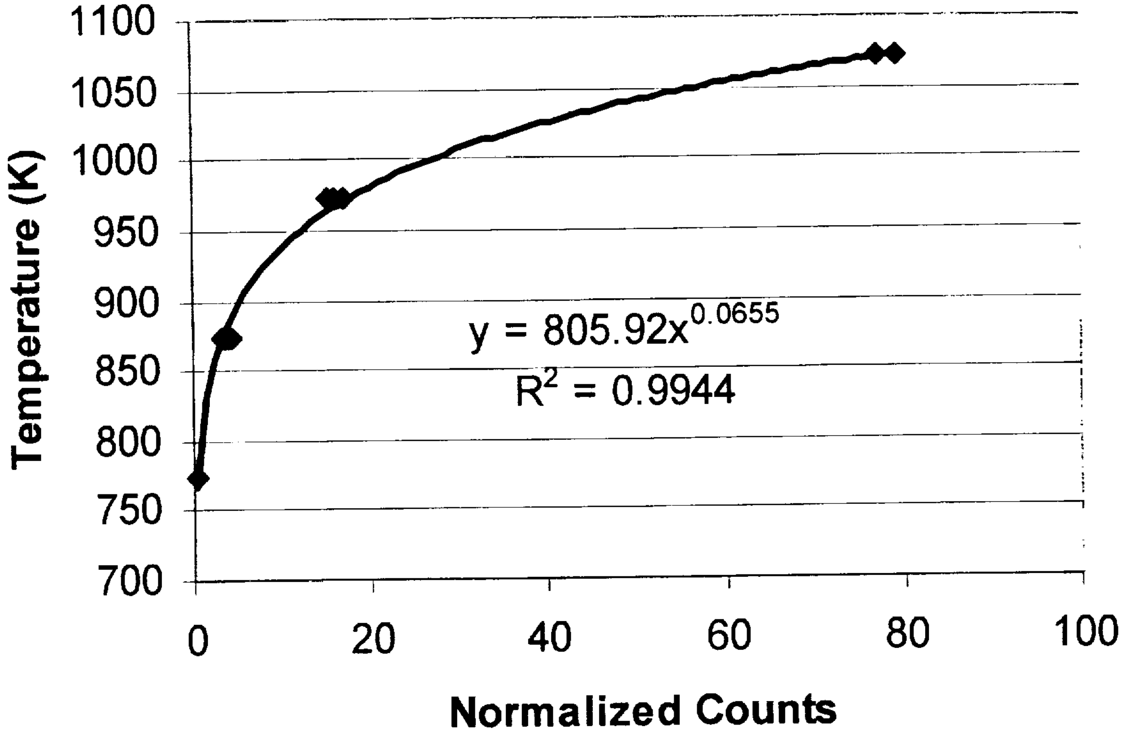

Figure 3 Relationship between image intensity and temperature for the blackbody source. Intensity is normalized to an aperture of $f^{\#}$ 22.

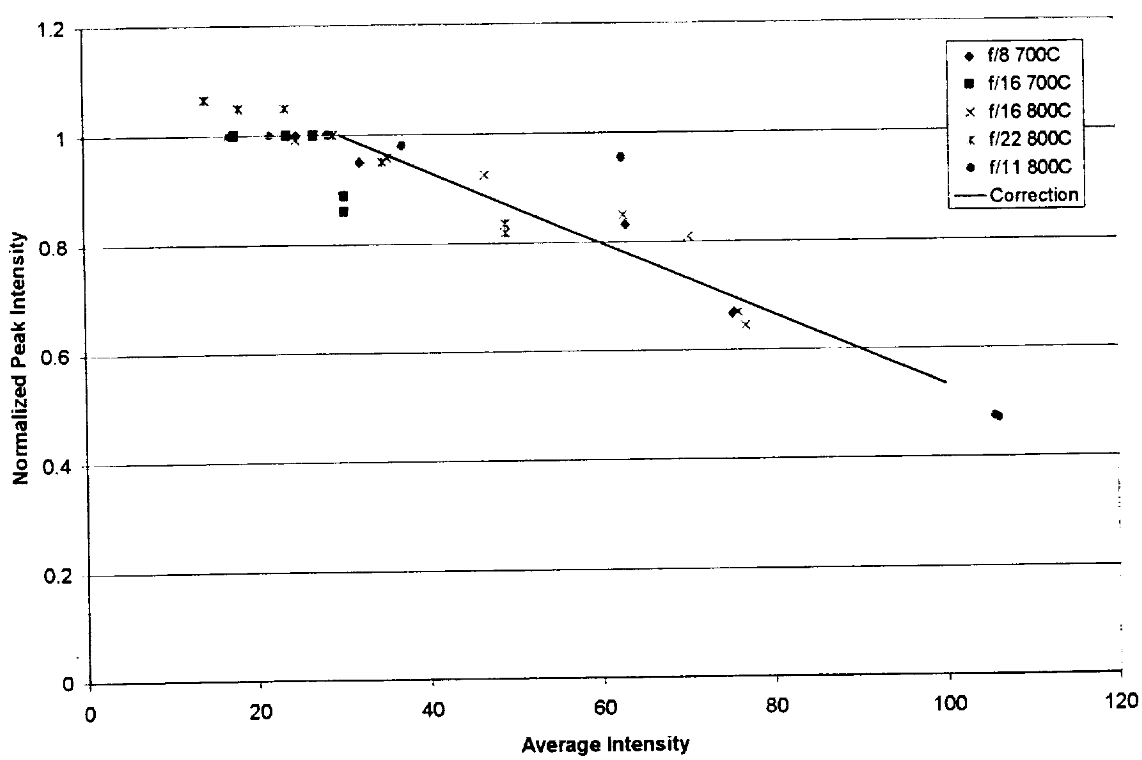

Figure 4. Response of camera to average image intensity.

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