Understanding the Non-Contact Temperature Measurement Technology

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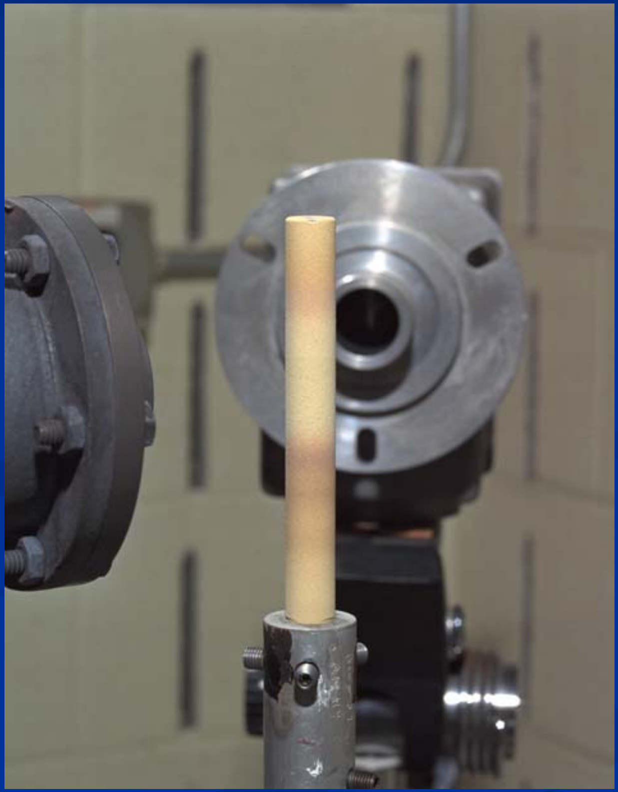
Introduction

- The ability to accurately measure the temperature of different materials has always been a challenge for the Instrumentation Engineer.



Optical Pyrometer. Courtesy of NASA.

Introduction

- When not used carefully in closed environments, Thermocouples and RTD’s could report the environmental temperature rather than the temperature from the product under examination.
- They are also temperature limited and when needed for applications above those limits, very expensive and low reliable materials are necessary to do the job.

Radiation Basics

- A moving particle is a source of an electromagnetic field that propagates at the speed of light. The resulting radiation energy is a stream of photons that travel at light speed.
- This radiation can be reflected or focus by the use of lenses and mirrors, and it can be used to measure the temperature of the object that emits it.

Radiation Basics

- This photon emission is inversely proportional to its wavelength. As we look at higher wavelength values in order to realize the measurement, the infrared energy available to do the measurement will be less.

- The higher the temperature the body is experiencing, the shorter the wavelength of the energy it produces.

Radiation Basics

- Objects at temperature of about 700° C and above radiate electromagnetic energy in the visible portion of the electromagnetic spectrum. Moreover at temperatures below the 700° C the infrared energy continues even though it is invisible to the human eye.

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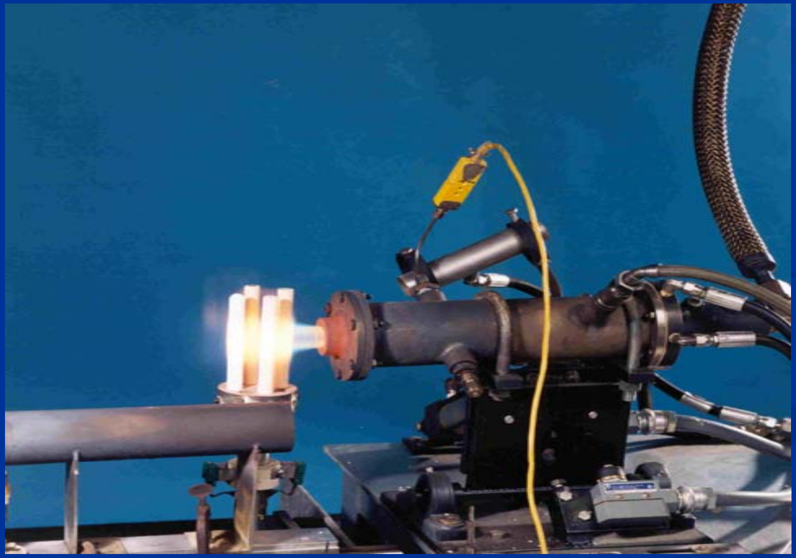
IR Temperature

- Temperature is a measure of the collision of internal atoms in a body. This temperature can be known by measuring the correct intensity of the emanated electromagnetic radiation also known as *Thermal Radiation*.



Burner Rig. Courtesy of NASA.

What is a Blackbody?

- The blackbody is the ideal radiator of infrared energy. It emits the maximum amount of infrared energy at a given temperature and wavelength.

- It is also a perfect absorber as it completely absorbs all infrared energy that impacts its surface.

- It is considered the ideal standard. Used for calibration purposes.

Emissivity

- Emissivity is defined as the ratio of electromagnetic flux that is emitted from a surface compared to the flux that would be emanated from a blackbody at the same temperature.
- This property is measured on a scale from 0 to 1. The emissivity of one (1) is an ideal condition that is attributed to an ideal emitter of electromagnetic radiation, a *Blackbody*. In reality a blackbody does not exist and objects emissivity will fall somewhere within the scale.

Emissivity vs. Reflectivity

- The ability to successfully measure the sample temperature using non-contact temperature detectors depends on the object's capacity to absorb, reflect, transmit and emit infrared energy. The quantity of absorbed (A), transmitted (T) or reflected (R) energy varies with the wavelength of the infrared energy. These three properties relate themselves on the following equation.

$$A+R+T=1$$

Emissivity vs. Reflectivity

- Gustav Kirchoff discovered that the emissivity of a material is identical to its absortivity or E=A. This means that the emissivity of a material will be dependant on the reflectivity and the transmission of the material at a specific wavelength (λ).

$$E_\lambda = 1 - R_\lambda - T_\lambda$$

Emissivity vs. Reflectivity

- In order to simplify this equation we must carefully select a wavelength for which the sample is opaque (T=0).
- Finding a wavelength at which the material is opaque in respect to the incident infrared energy will avoid the energy wave to be transmitted through the material. By following this procedure we make emissivity only a function of the reflectivity of the material.

$$E_\lambda = 1 - R_\lambda$$

Emissivity Correction

- Today most instruments will offer an external emissivity adjustment that the user can set with the correct emissivity value.
- The fact that the values for the emissivities of many substances have been found and are published in many reference literatures can be very deceiving.
- A sample's emissivity can change with surface changes such as corrosion as well as with temperature changes. As the temperature increases some materials experience a change in color that will include a change in emissivity value.

Which wavelength should I use to perform the measurement?

- There are many materials that require a specific wavelength in order to measure temperature correctly.

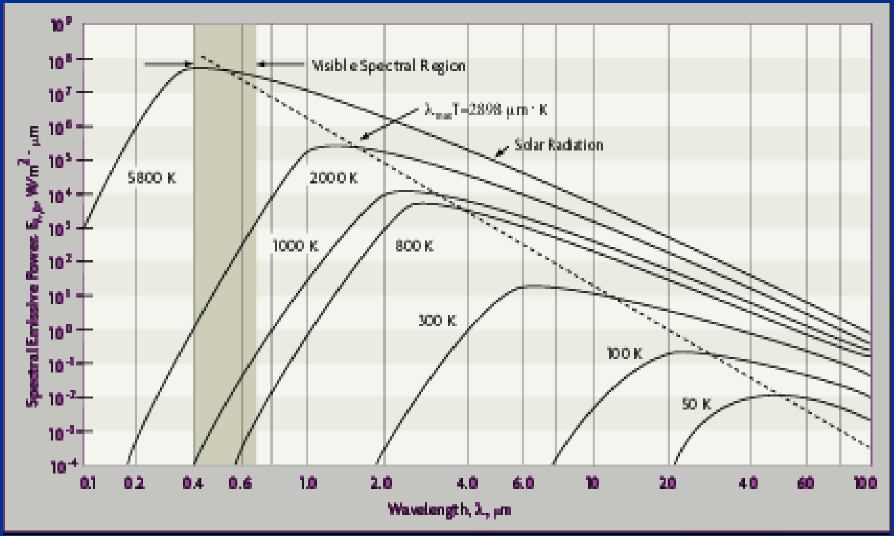
- Materials like oxidized steel will offer roughly the same emissivity value for all wavelengths. This materials are known as Graybodys. In this case there is no problem; a variety of instruments with different types of lenses will do the job.

Which wavelength should I use to perform the measurement?

- The measurement of an unoxidized metal is a very different case. At short wavelengths the unoxidized metal may have an emissivity of 0.3 to 0.4. When observed at longer wavelengths the emissivity value will be lower and lower. At 8.0 to 14.0 microns the emissivity can be as low as 0.02 and the metal virtually behaves like a mirror.

Which wavelength should I use to perform the measurement?

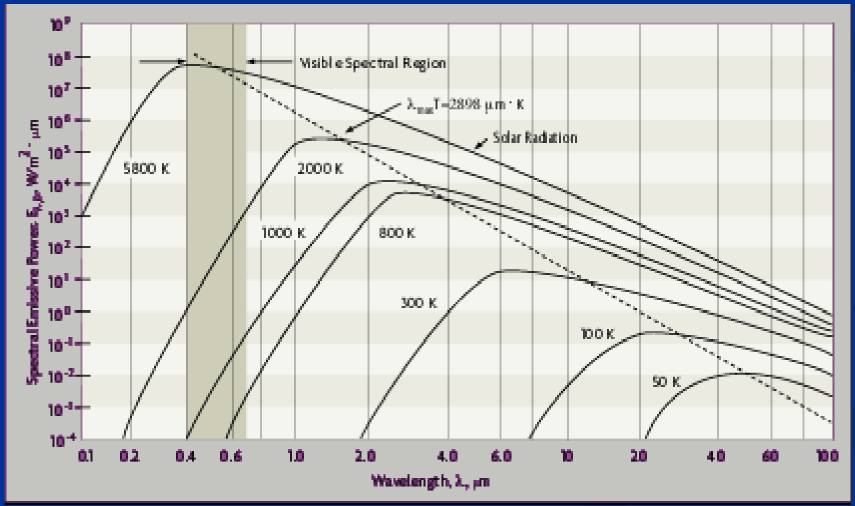
- At very low values of wavelength there is a rapid increase in radiant energy with a temperature increase.



Infrared Radiation vs Wavelength variation. It is clear that there is more energy difference per degree at shorter wavelengths. Reprinted from Omega Transactions, *IR Theoretical Development*.

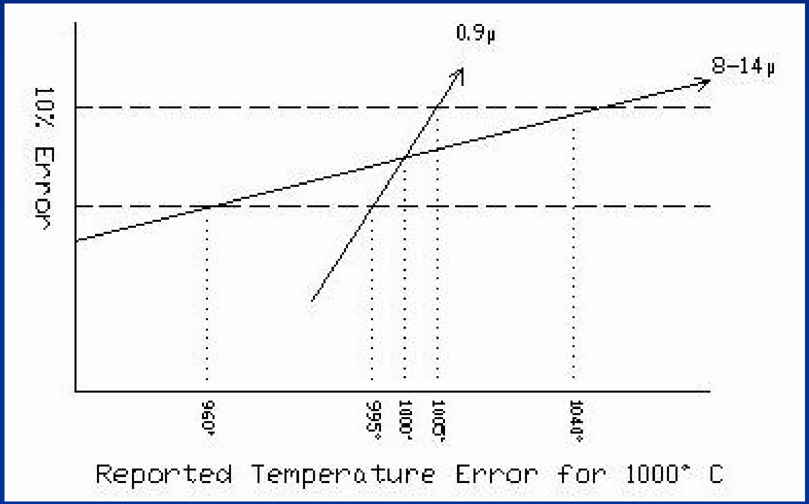
Which wavelength should I use to perform the measurement?

- At longer wavelengths this rate is much lower resulting in a less accurate region.



Infrared Radiation vs Wavelength variation. It is clear that there is more energy difference per degree at shorter wavelengths. Reprinted from Omega Transactions, *IR Theoretical Development*.

Which wavelength should I use to perform the measurement?



Temperature error due to a 10% signal change. Partially reprinted from IRCON *Non-Contact Temperature Measurement*, Vern Lappe.

Temperature error is greater for a higher wavelength value since the slope of a blackbody curve for a specific wavelength becomes flatter as the wavelength is increased.

- If there is a change in signal value due to a change in emissivity, dust, dirt or smoke; temperature errors are greater when a longer wavelength instrument is used.

Which wavelength should I use to perform the measurement?

- The temperature measurement should be made at the shortest possible wavelength that will correctly measure the process temperature.
- Changes on the sample's emissivity with respect to changes in the color of the sample will be minimum on instruments with wavelength of more than 3µm.

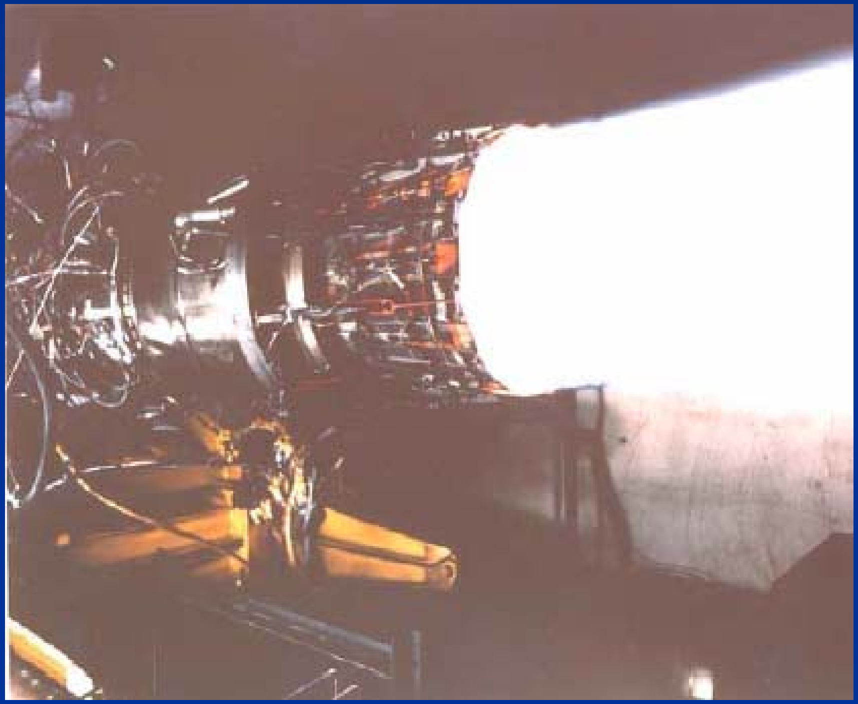
CMC test background

- Ceramic Matrix Composites (CMC's) are articles of interest for multiple Naval Aviation applications. Their ability to handle high temperature and their low weight, low density characteristics make them the preferred choice for engine exhaust applications.

Existing Component Status

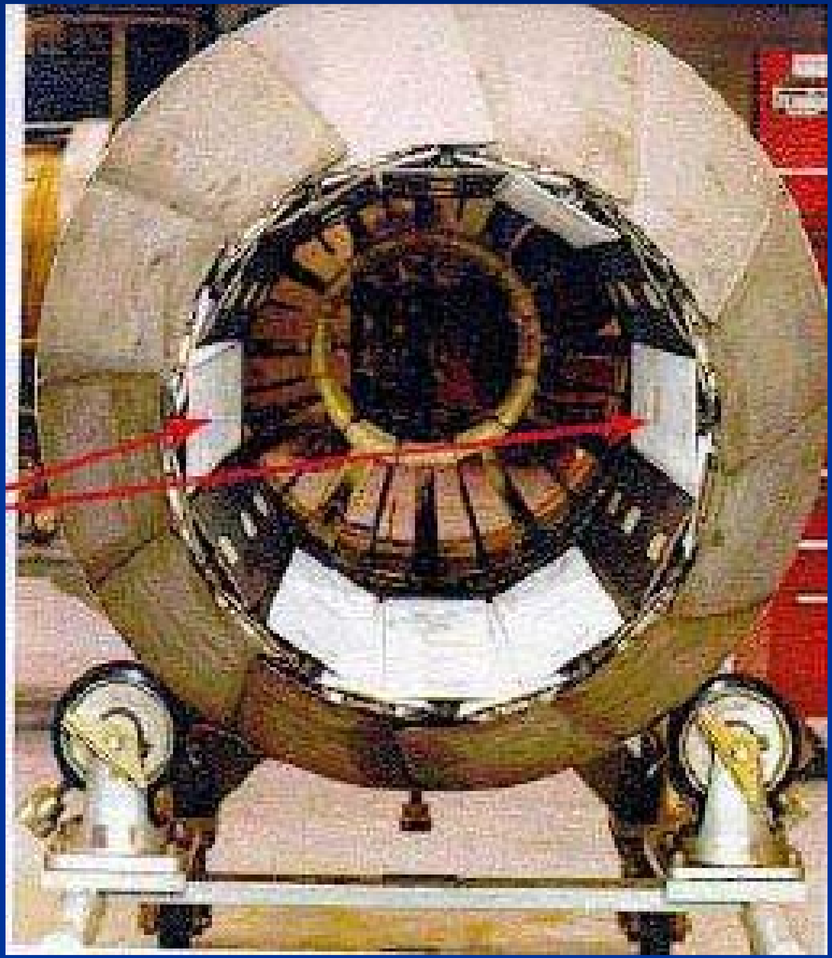
- Many components have experienced over 800 hours of flight including a significant amount of A/B.
- Component affordability and Life Cycle being addressed.

Test objective



- To test and evaluate several improved CMC's designs under simulated jet engine conditions.
- Obtain data indicating the proposed materials are capable to extend life and reduce costs over existing CMC components.

Test Procedure



- Expose material coupons to jet engine simulated thermal transients including intermittent salt fog and measure retained mechanical properties.

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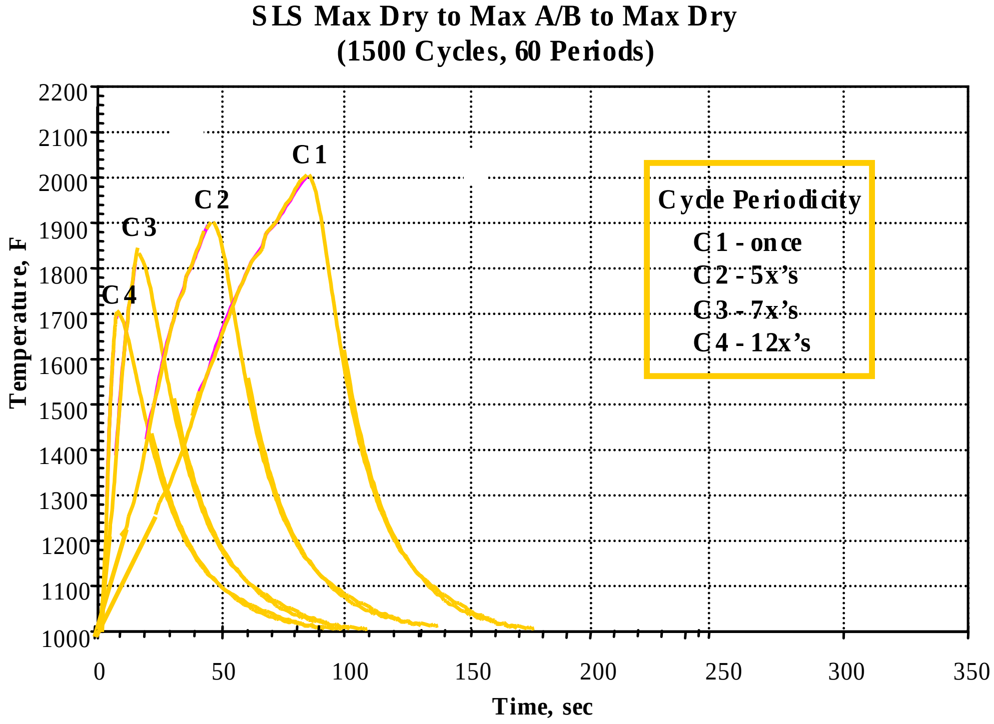
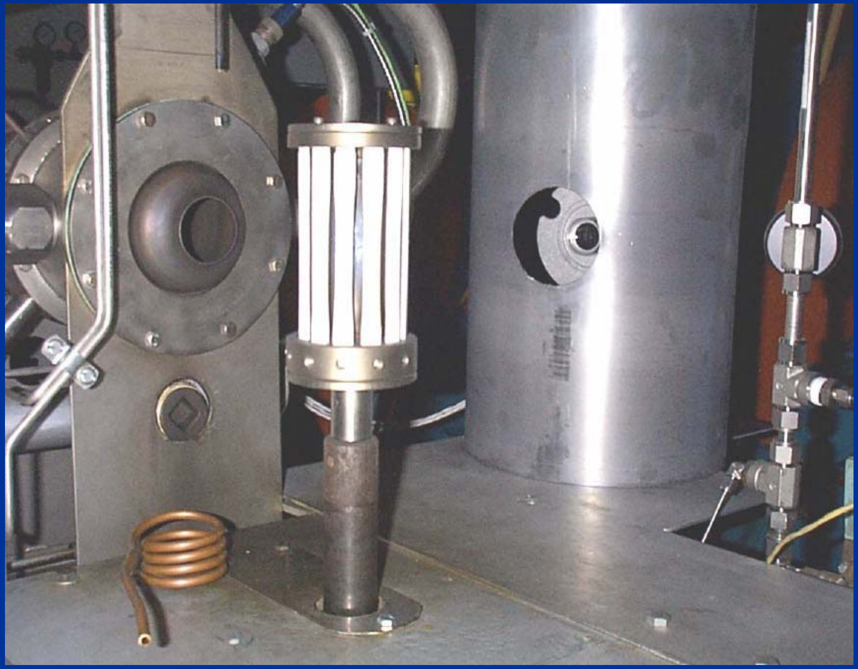
Jet Engine Field Usage
and corresponding CMC Temp

AB time	Frequency	Tmax (F) Back, Front
10	47%	1450, 1700
20	29%	1650, 1850
45	20%	1750, 1900
85	4%	1850, 2000

Burner Rig Profile for CMC/VEN APPLICATION



Experimental Procedures

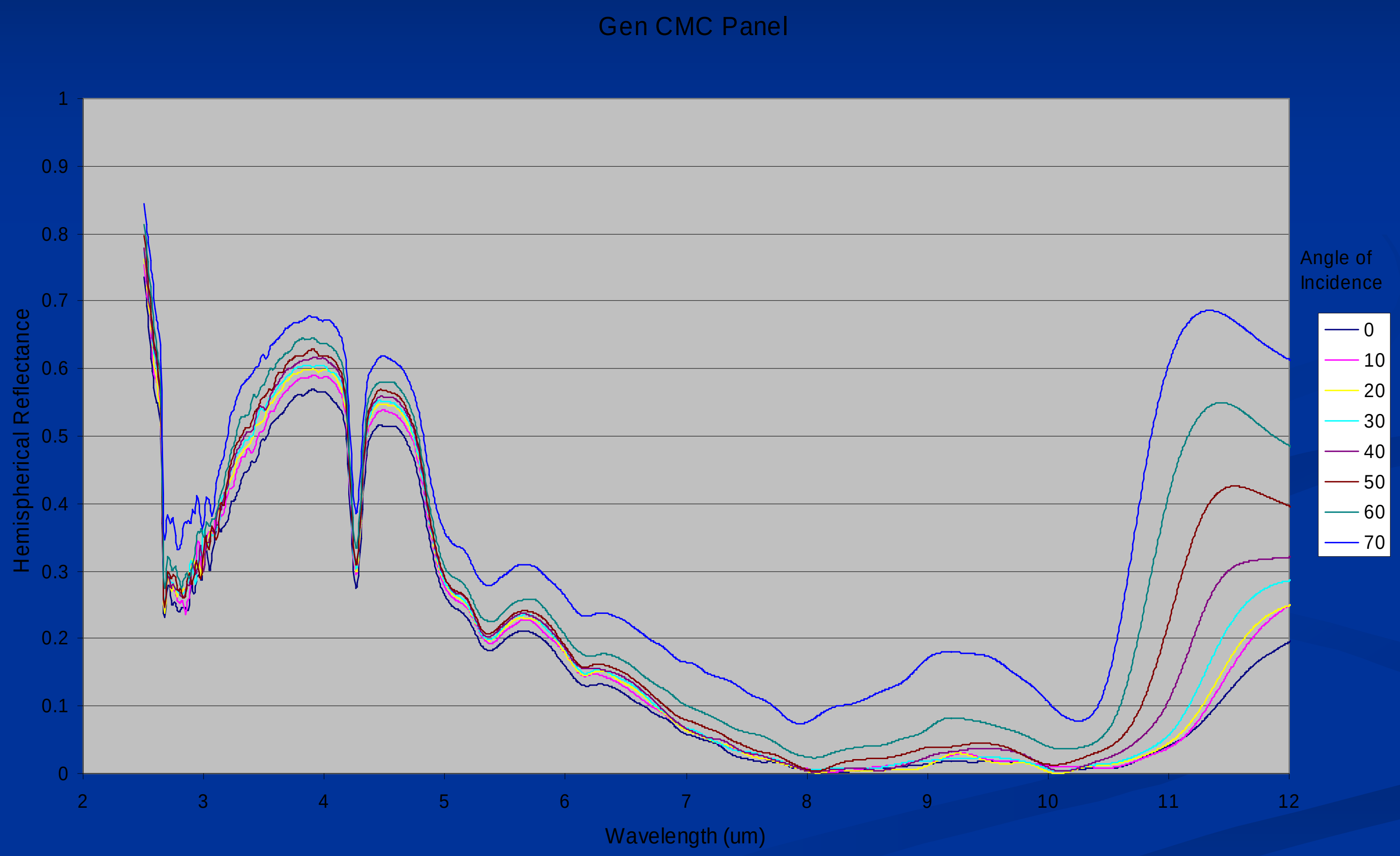


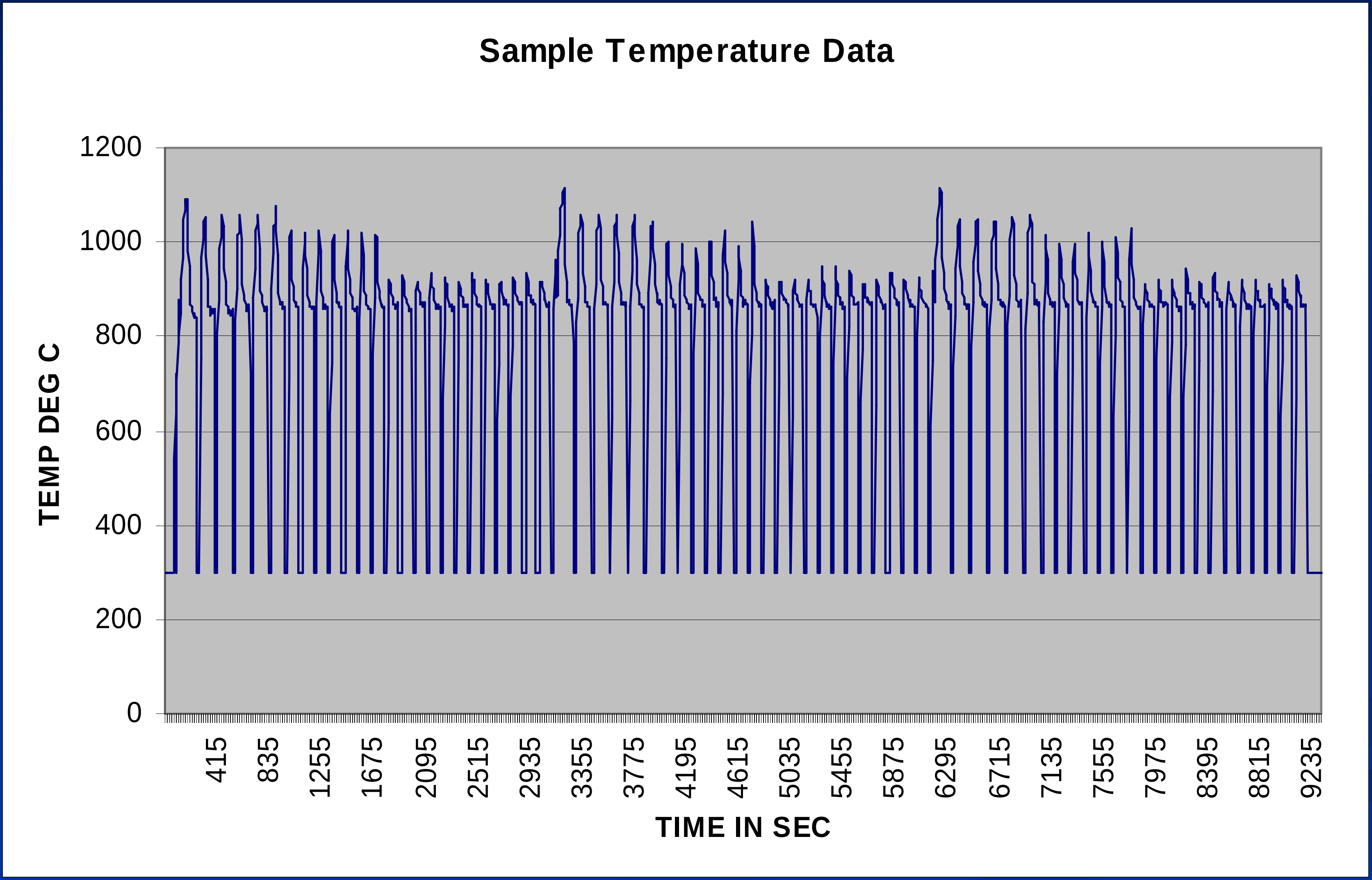
- Use of Low Pressure Beacon Burner Rig Facility, v=Mach 0.3
- Environment includes thermal gradients and combustion by products.
- Process controlled by the temperature on the sample's surface.

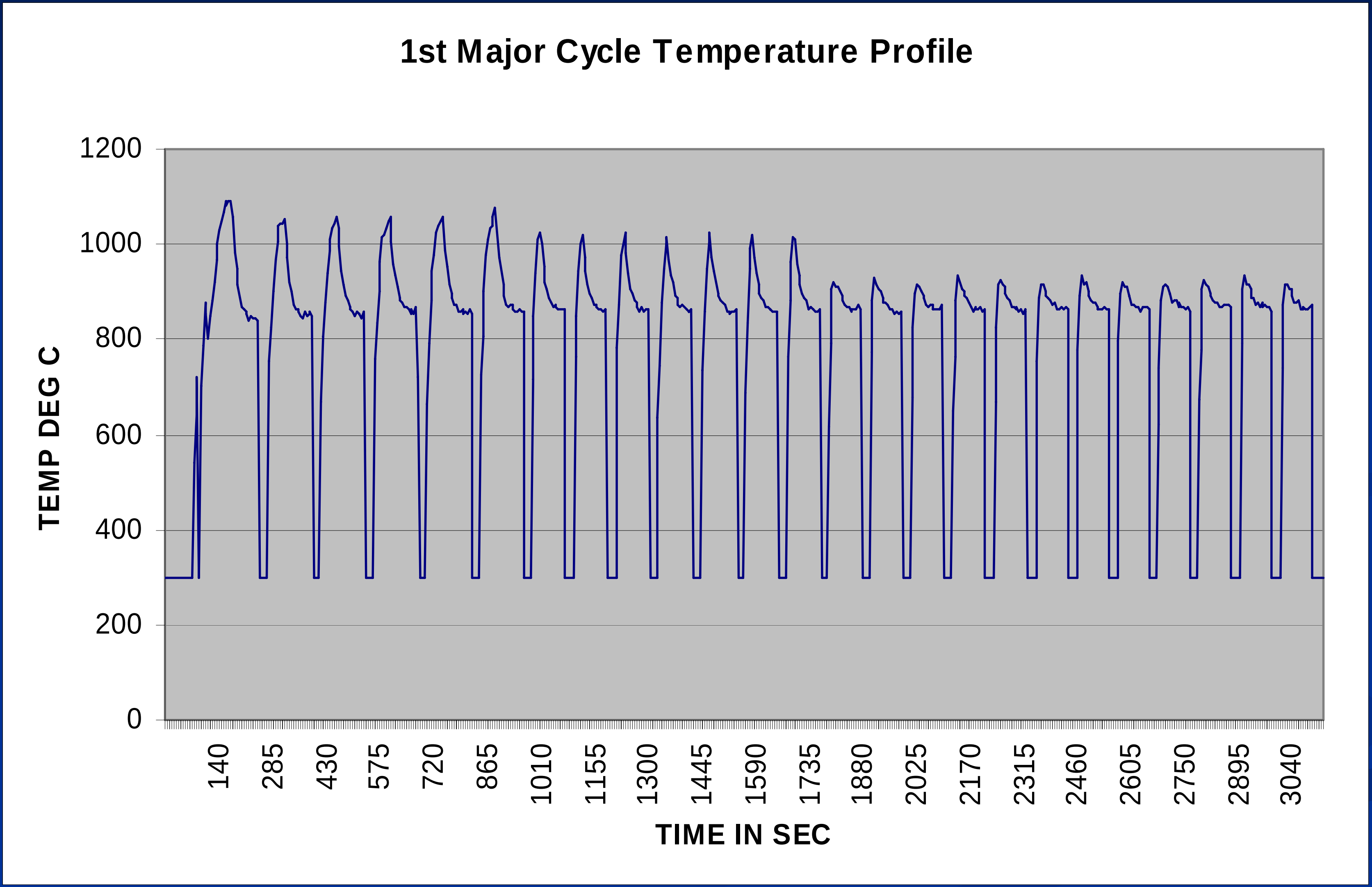
Experimental Procedures

- Ceramic Matrix Composites (CMC's) will be exposed to four (4) types of time/temp profiles for the determined number of cycles.

Sample's Radiance vs. Wavelength




Sample Temperature Data
TEMP DEG C
1200
1000
800
600
400
200
0
415
835
1255
1675
2095
2515
2935
3355
3775
4195
4615
5035
5455
5875
6295
6715
7135
7555
7975
8395
8815
9235
TIME IN SEC


1st Major Cycle Temperature Profile
TEMP DEG C
1200
1000
800
600
400
200
0
140
285
430
575
720
865
1010
1155
1300
1445
1590
1735
1880
2025
2170
2315
2460
2605
2750
2895
3040
TIME IN SEC

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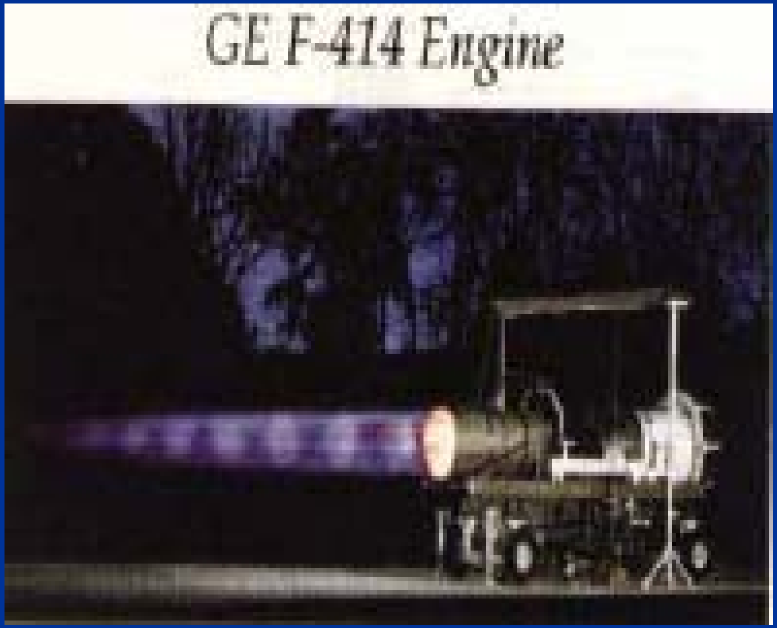
Point of interest

- Temperature profile so aggressive that sample holder had to be redesigned. Stronger material used and cool air was injected through center pole.

Conclusion



- The burner rig system controlled by the Optical Pyrometer successfully simulated realistic thermal transients of CMC components.
- Optical Pyrometer made possible the use of the sample temperature (not the flame temperature) to control the process.

Questions?