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SENSITIVITY OF BLACKBODY REFERENCE PANELS TO WIND BLAST

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As part of the effort at Stennis and JPL to discover the root causes of TIMS' temperature calibration errors, we undertook a series of experiments to measure the sensitivity of a heated plate to cooling by wind blast.

We set up a powerful blower which was capable of generating a jet of wind in excess of 200 miles per hour. In the jet we mounted an electrically heated copper plate, one quarter of an inch thick and six inches square. The electrical heaters were capable of delivering a total power of 800 watts. The power to the heaters was feedback controlled with reference to a thermistor mounted on the back of the copper plate. The plate was mounted about 2.5 feet from the blower nozzle, at about 45 degrees to the direction of the jet. The jet was wide enough to wash the whole surface and its temperature at the plate was about 28 C.

In order to simulate temperature differences which approximated flight conditions, we ran the plate at about 65 C, for a delta T of 37 C.

The plate was instrumented with thermocouples in an attempt to measure the strength of temperature gradients within the plate. We placed thermocouples in holes drilled into the edge of the plate, in holes drilled from face to face, and surface mounted with a clamp. We found it quite difficult to measure the plate temperature in a way that we felt was insensitive to errors caused by the wind. For instance, merely clamping the thermocouple junction bead onto the surface with a small fiberglass tab led to errors of over five degrees due to heat flowing into the wind-cooled thermocouple leads.

We observed apparent lateral gradients as well as depth gradients, but in the most extreme cases, the temperature differences within the copper metal amounted to no more than 1.0 C.

If one considers the area covered by one of the 100 watt heater elements, one can easily calculate the maximum gradient that can be sustained with the heater at maximum output power. The power density was 5.2 watts per square centimeter. The handbook value for the conductivity of copper was 3.8 watts/cm*degree(C). After some calculating, I arrive at the maximum delta T of 0.82 C.

1) delta T = Power*thickness/(area*conductivity)

Since full output power was not required to maintain the 37 C temperature difference, the maximum delta T inside the plate must be less than this estimate, maybe even as low as 0.1 or 0.2 C.

The next step was to measure the gradient across the paint layer. Since paint has a much lower conductivity than copper, maybe it could sustain a gradient large enough to account for the errors. Two techniques were attempted.

Method 1

Method 1 required the comparison of the radiance of the wind blown target to a reference target unaffected by the wind. For this second target we used a sheet metal horn immersed in a stirred hot water bath. The temperature of the water was adjusted to approximate the anticipated temperature of the interior of the plate by reference to thermocouples fixed to the immersed horn and imbedded in the plate. The blower and plate heater were then turned on and the plate was allowed to reach a steady state.

At this point, brightness temperatures were measured for the target and the comparison horn with a Barnes PRT5 Precision Radiation Thermometer and with an Omega radiation thermometer.

As confirmation of the accuracy of the comparison, measurements were made of the two targets after the blower had been turned off and the plate had reached its new steady state. Under these conditions, the gradients through the plate and paint are minimized. The difference in brightness temperature between the plate and the immersed horn under these conditions are entirely due to the actual plate-horn difference and to the possible non-unity of the plate emissivity.

Method 2

The paint used on the heated copper plate was presumed to account for the greater part of the temperature drop during the operation of the blower. It is relatively easy to calculate the expected effect from increasing the thickness of the paint and to argue backwards to derive a conductivity for the paint from a comparison of the brightness temperature of two patches of different thickness.

Thickened paint patches two centimeters square were applied with multiple coats to areas of the plate which had been nearly isothermal in prior observations. The thicknesses were measured with a depth micrometer.

The plate and the blower were then turned on and allowed to reach a steady state. The brightness temperature across the plates was observed using an Inframetrics Model 520 Thermal Camera and images were recorded on video tape. The Inframetrics camera is equipped with the ability to display the temperature profile generated by a single scan line. The sweep across the unequal patches of paint showed the brightness temperature differences clearly and this information permitted the temperature drop across the paint layer.

Once the conductivity was known, we were able to calculate the temperature drop to be expected across a single thin layer of paint. This value could then be compared with the temperature drop from method 1.

One thing we discovered in the course of our experiments was that the single thickness coat of paint that appeared to eye to be solid black, fell short of being a perfect blackbody. The emissivity was estimated by a a number of methods, as follows:

Under conditions of no wind, with the plate heated to a steady state, the brightness temperature of the surface was compared to the temperature of the interior of the plate. The gradient across the paint was assumed to be zero, attributing the whole drop observed to the departure of the plate from blackness. The radiance observed under these conditions is the sum of the thermally emitted radiation and the reflected radiation from the surroundings where the experiment was being conducted. We took this latter temperature to be the ambient air temperature.

2) Total Radiance = emissivity * BB(T plate)
                    + (1 - emissivity) * BB(T air)

$$\text{2a) emissivity} = \frac{(\text{total rad.} - \text{BB(T air)}}{(\text{BB(T plate)} - \text{BB(T air)})}$$

In these formulas, the simplified form for the reflected term which derives partially from Kirchhoff's Law was adopted in the absence of detailed knowledge of the angular dependence of the incident radiation and the reflectivity of the plate.