http://dx.doi.org/10.21611/qirt.1992.055

Surface temperature measurements of thin films in the range -100°C to 100°C using infrared thermography

by Yves DELCLAUD

Observation and Remote Sensing Department, Aerospatiale, Space and Defense Division, Cannes Center, France.

Abstract

The temperature of thin films (of thickness around 10 μm) placed inside a vacuum chamber can be provided by thermography in the range -100°C to +100°C.
Following a description of the device and the experimental setup, method of temperature conversion, and associated sequence of calibration is described. The choice of suitable samples and structural supports influences the characterization of the method and its performance. Tests results corresponding to two samples representatives for typical applications (black paint and a thin film) are described.

1. Introduction to thermography

An infrared spectral radiometric device suitable for operation in space simulated conditions, over a wide range of wavelength (3 to 18 μm) has been developed. The specimen dimension is required , for reason of calibration validity, to fit within a (imaginary) 220 mm diameter sphere, where earth and sun radiations are simulated. The chamber housing of this complete device is a 10 m^3 test facility providing a 10^{-3} Pa pressure and a 90K level of internal temperature using cold shrouds.
In order to validate the computation of specimen equilibrium temperature, our efforts have been concentrated on the development of a facility capable of providing, by direct or indirect means, the temperature of any tested specimens.
It is important to note that performances evaluation tests were performed on solid specimens equipped either with film samples, characterised by their thin section (around 10μm) and strong spectral emissivity roughness, or black paints for calibration sequences.
These test conditions lead to the following considerations:

- determinations of sample surface temperature are needed;
- traditional temperature measurement procedures based on contact, such that of a thermocouple, are inappropriate because of their own physical influence on the quantity to be measured (the fragility of the films would in any case involve a high risk of breakage with such an approach).

For these two reasons, a system trade-off leads to the preference of a thermographic temperature measurement technique despite the various difficulties with their implicit risks, of such a method. Of the difficulties involved, the following four considered to be the most significant.

- The conversion of thermographic information into temperature involves the emissivity parameter of the sample (because thermography is an indirect method). The spectral emissivity is measured on elementary samples, representative of our samples, at the *Central Laboratory of Aerospatiale (Paris-Suresnes).*

- The roughness (rapid spectral variations) of the emissivity in the domain of the long wavelength camera (6-12 μm) required the development of a specific image processing software capable of taking this dependance into account, thus providing a true spectral integration, rather than using an often erroneously assumed constant (mean) value of emissivity.

http://dx.doi.org/10.21611/qirt.1992.055

- The problem of straylight, encountered in any Infrared device, particularly when operating at very low temperature (-100°C), has been notably reduced. The presence of black cold shrouds eliminate internal reflections, and several precautions -enumerated in chapter 2- reduce effect of external reflections. By conducting a calibration test, using a specific specimen, repeated straylight measurements could be avoided.

- Drifts in the acquisition chain occurring either during a test, which can last up to five days, or between two consecutives tests. The reference body used for calibration tests is no longer present during the actual measurement (the reference is sustituted by specimen). In order to make the link between calibration and measurement tests, drift trends were monitored by systematic measurements of a secondary reference black body maintained at 50°C, retractable and permanently present in the chamber.

2. Description of the device

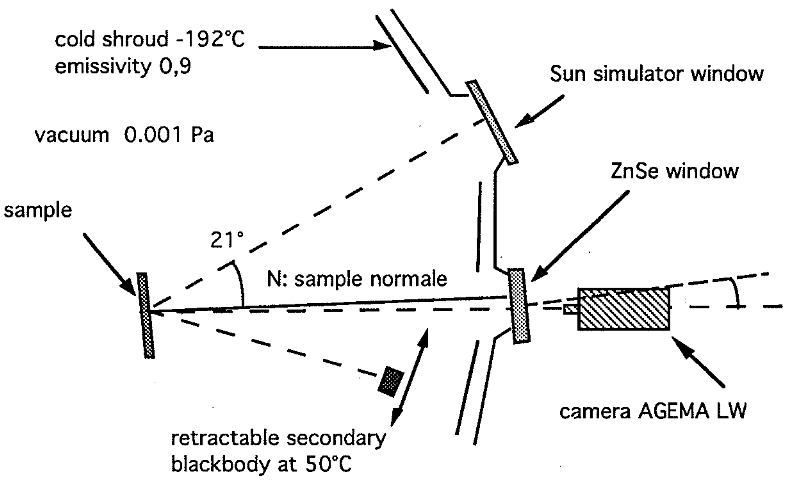

figure 1 **Device description**

The camera used was a basic 780 LW (7-12 μm) from Agema, part of a Thermovision 780 system. It was set up in room temperature conditions, adjacent to the vacuum chamber and aligned so as to view the sample through a ZnSe window.
The sample is positioned at the middle of chamber, 2 m from the cold shrouds, and can be rotated.

Operating precautions and test facility performances:

- the ZnSe window is tilted to avoid detector ghosts in the final image;
- a sample, presenting specular reflectance, can also be tilted during measurements;
- straylight reduction was achieved by two means:
  . *internal* straylight was minimised with an appropriate black paint on the internal side of the 90K cold shrouds, thus leading to 90% emissivity,
  . *external* straylight was minimised by setting the camera as close as possible to the ZnSe window;

http://dx.doi.org/10.21611/qirt.1992.055

- each calibration or characterisation step uses a sample support presenting a high thermal surface homogeneity, permitting an average to be achieved over 40 image points;
- the monitor is well adjusted so that mean video signal level is set at center of the camera's dynamic range;
- the optical path is free of any bandpass filter, in order to increase the signal to noise ratio.

3. Definition of the method

The video signal of the camera is assumed to be proportional to the flux W entering its aperture. *In an ideal case, the signal is proportional to the radiance (* $W.m^{-2}.sr^{-1}$*) of the measured body.* This hypothesis nevertheless assumes negligible straylight and sample reflected radiance. Interim results related to the estimation and measurement of existing straylight show that, with the presently described device, this first approximation can be made to simplify the image processing. Final results have confirmed these assumptions. It should be noted that straylight problems have been considered as much in terms of specular as for diffuse reflectance).

The basic formula giving the integretad radiance at camera level is:

$$L(T)=\int_{\lambda 1}^{\lambda 2} th(\lambda).rc(\lambda).\varepsilon(\lambda,T).L_{bb}(\lambda,T).d\lambda$$

with:

$\lambda 1, \lambda 2$	spectral range (µm)
$\varepsilon(\lambda, T)$	spectral emissivity versus temperature
$rc(\lambda)$	camera spectral response
$th(\lambda)$	spectral transmission of ZnSe window
$L_{bb}(\lambda,T)$	black body radiance ($W.m^{-2}.sr^{-1}$)

Calibration sequence

Calibration of the whole device (total optical path and electronic chain) was performed by a calibration test. During this specific test, the reference body, described in chapter 4, was stabilized at different temperatures ranging from -120°C to 100°C. These measurements enabled a set of calibration characteristics to be established for the primary reference black body. In parallel, following each acquisition on primary reference, measurements on the secondary black body was performed.

Measurement sequence

The measurement is made using a thin film sample of 10 µm thickness, whose previously measured spectral emissivity is known to present strong emissivity roughness (see *figure 3*). Two or three thermograms are acquired on the sample and the secondary black body.

Processing sequence

This sequence is divided in two phases.

- Preparation: for each different sample (film or paint), a table is set up, providing the relationship between the temperature of the sample (range -150°C, +150°C) and the integrated emittance, according to the formula below:

$$T_{film} \longrightarrow L_{film}(T_{film})=\int_{\lambda 1}^{\lambda 2} th(\lambda).rc(\lambda).\varepsilon_{film}(\lambda,T_{film}).L_{bb}(\lambda,T_{film}).d\lambda$$

http://dx.doi.org/10.21611/qirt.1992.055

Processing: in this last step, the video signal of the thermographic image is c*onverted to integrated emittance* using the calibration characteristics and taking into account possible drift of the secondary black body acquisition value since calibration test has been performed. By equalization of the integrated emittance, and use of the hereabove table, the temperature of the sample can then be determined at any point of the image.

video signal -----------------> $L_{bb}(T_{bb})$

$L_{bb}(T_{bb}) = L_{film}(T_{film})$ -----------------> T_{film}

4. Description of the reference body

A specific specimen supporting different samples has been manufactured for calibration and characterisation of the method performance. This sample is a disc of 220mm diameter and 10mm thickness. It is thermally controlled and presents the following features:

- a 0.5 °K surface homogeneity on both sides;
- adjustable surface temperature between -150°C and 150°C, using an internal heater;
- temperature measurement with an accuracy of 0.5°C, using calibrated thermocouples distributed over the specimen;
- the specimen thinness is such that thermal gradients can be neglected and surface temperature can be directly related to the internal temperature provided by internal thermocouples;
- the internal heater allows both sides of the specimen to be controlled and used.

For the purposes of calibration and the characterisation test, the sample was equipped (as shown on *figure 2)* on one side with two different types of black paint and the other with two cemented thin films (see spectral emissivity of film n°2 on *figure 3*)

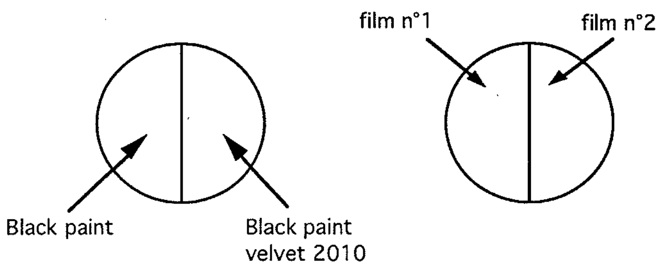

figure 2 - Specimen configuration

http://dx.doi.org/10.21611/qirt.1992.055

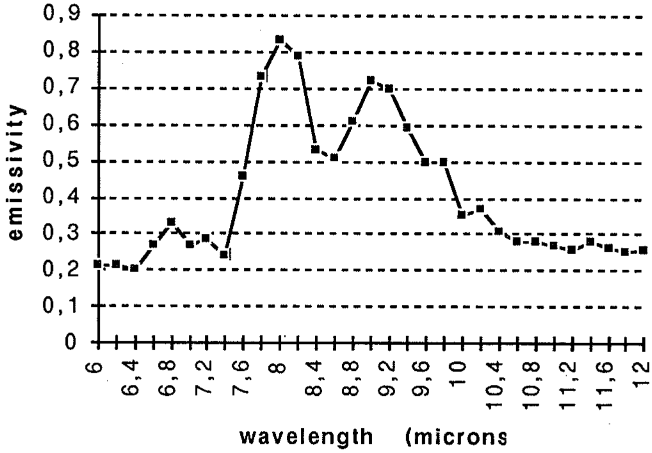

figure 3 - Example of thin film emissivity (n°2)

5. Results

The results presented in *table 1* provide a comparison between the controlled temperature given by the thermocouples and the temperatures derived from radiometric analysis of the video image. The accuracy of the method depends on many parameters including ,for example, the spectral emissivity of samples, *the least significant bit of the analogic-numeric-converter* and the detector sensibility. This article does not provide a detailed analysis of these noise sources, the sum total effect of which is nevertheless given in the table below.

Interpetation:
All of the converted temperatures are inside the corresponding domain of accuracy.
The accuracy of the measurement of film n°2 at -100°C is 20°C because its averaged emissivity is low (around 0.4). The radiometric limit of the device was reached in interpreting this thermogram.

Table 1

	Sample Controlled temperature				
	-100	-50	0	50	100
velvet 2010	-100.1	-52.1	1.8	51.6°	100.9
(accuracy)	(+/- 11)	(+/-6)	(+/-2)	(+/-1)	(+/-1)
film n°2	-87	-56	-0.1	48.6	98
(accuracy)	(+/-20)	(+/-10)	(+/-4)	(+/-2)	(+/-1)

Temperature derived from radiometric analysis (and corresponding accuracy) compared to temperature measured by thermocouples (in degrees Celsius).

http://dx.doi.org/10.21611/qirt.1992.055

6. Conclusion

This article proves that low temperatures can be accurately determined by thermographic techniques, if sufficient precautions related to the experimental setup are followed.
The interest of such a technique *is not only an enrichment of the test facility,* now capable of temperature and temperature gradients measurement by the thermographic method coupled to spectral radiometric measurements on the same specimen (sample) at the same time in the range -100°C to +100°C, *but also a potentially autonomous device* capable of providing low temperature measurements on different kinds of samples, such as satellite parts and components in space simulated conditions, and of monitoring the temperature behaviour of any specimen exposed to simulated sun and earth radiations and a cold environment.