Application of IR thermography for quantitative temperature measurements in a Thermal-Vacuum Space Simulator.

by M. Broussely[1], G. Machin[1], R. Simpson[1], A. Cozzani[2], C. Gomez Hernandez[2]

[1] *National Physical Laboratory, Teddington, Middlesex, TW11 0LW, UK*
[2] *Test Centre Division of European Space Technology Centre (ESTEC), Noordwijk, NL*

Abstract

This paper will present the work and progress made through the introduction of infrared thermography to determine surface temperature during thermal-vacuum tests on spacecraft. Such tests cover a wide range of temperature (even down to –100°C) and concern materials with low emissivity. The difficulties encountered when undertaking these measurements are assessed through two series of tests, from which recommendations in the experimental set-up to quantify the temperature measurement are given as well as an evaluation of the uncertainty.

The reported work is done under contract with the European Space Agency.

1. Introduction

Spacecraft design requires increasingly precise modelling of the heat transfer that takes place between the active elements on-board and free space. The extreme conditions of space where both very high and very low temperatures coexist mean that materials of very well known emissive properties are used to help regulate the overall temperature of the vehicle. Prior to launch the operation of the spacecraft is tested in a space simulator and 2D information of the surface temperature is extremely valuable during such experiments because it demonstrates the efficient (or otherwise) operation of the spacecraft thermo-regulation system.

These measurements are currently performed by extensive instrumentation of the spacecraft with thermocouples. However infrared thermography potentially has a strong advantage over this method because it covers a large range of temperature while giving a complete non-invasive 2D map of radiance. However, the quantitative interpretation of IR measurements presents a number of rather severe difficulties that need to be assessed.

The purpose of this paper is to describe the tests performed with a MW (3-5µm) and a LW (7-9.5µm) infrared imager on reference and test targets placed in a small vacuum chamber, report the results and discuss the procedure recommended to make the best use of thermal imaging for this exacting measurement.

2. Experimental set-up

Samples of low emissivity (multi-layer insulation) MLI materials, including a specular reflector, were affixed to the surface of a target block, which also incorporated a blackbody cavity, spatial resolution targets and reference surfaces of known total emissivity. The block was instrumented with type-T calibrated thermocouples, to measure the temperature of the blackbody and the reference surfaces. The block was placed in a small space simulator chamber whose temperature could be varied from –140 °C up to +80°C. Temperature gradients could be induced in the chamber as the block holder and the shrouds could be set at different temperatures (Figure 1).

Figure 1 IR image - Block at -20°C, walls at 22°C

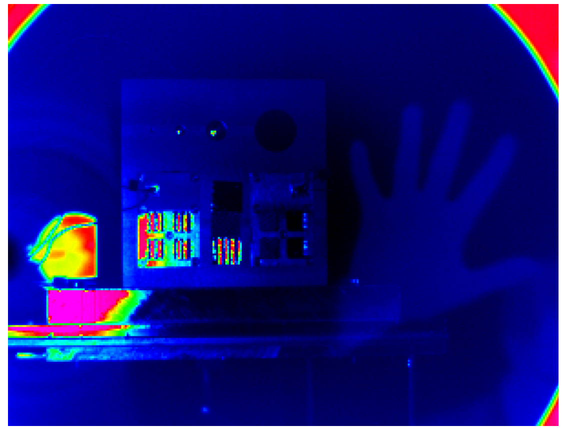

Figure 2 Target at -100, reflections

A viewing window in the chamber was selected to be mechanically robust and have a good transmission spectrum at the working waveband of the imager.

The imager, viewing window and target were then aligned in order to have a good knowledge of all parameters of the radiance transfer equation. This includes a) avoiding a direct reflection of the imager off the window surface and back into the imager and b) knowing the radiation parameters of the objects reflected onto the window or onto the target itself in order to perform an accurate correction. Figure 2 gives an illustration of this, with the test object at -100°C inside the chamber. We can see reflections of the camera (left blue circles), the operator's hand (right) as well as contrasts on the target due to background reflections within the chamber and samples with different emissivities.

3. Exploitation

To utilise thermal imaging quantitatively in this (or any) application a careful calibration of the imager is first required. Then through viewing the targets blackbody reference a correction for window transmission can be made on all subsequent measurements. Then measurements of the reference targets of known emissivity allow the identification of the background radiation reflected from non-black targets. Finally a configuration allowing a high contrast between self-emitted radiation and reflected contribution (e.g. the test object at low temperature and the shrouds at high temperature; figure 1) allow the validation of the emissive properties of all the samples.

The purpose of these different tests is to evaluate the uncertainties caused by the correction by means of the radiance transfer equation, over the whole range of temperatures measured. This will help determine the limits of the use of the IR imager in such applications, especially when trying to measure low temperature targets. Figure 3 shows the level of the MW thermal imager digital output level as a function of the temperature of the target and of the integration time (IT). This shows that below a target temperature of about -50°C, the level recorded is mainly due to the reflected radiation on the viewing window and an internal electronic offset, i.e. this particular imager cannot be used easily for the determination of temperatures below that temperature.

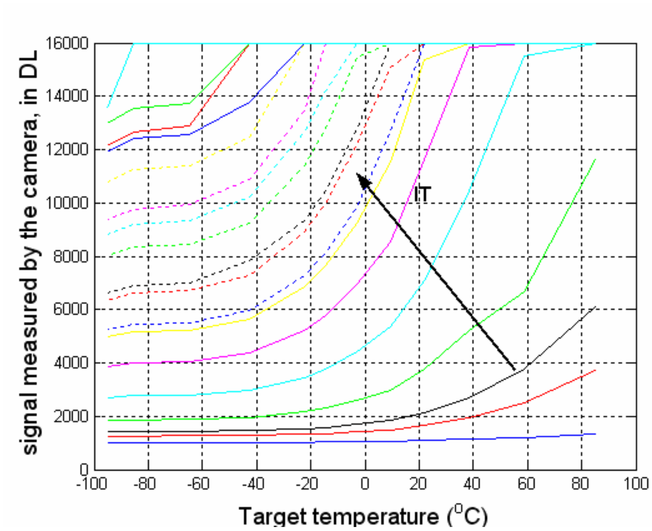

Figure 3: Camera output level vs target temperature

3. Conclusion and further works

The results reported in this abstract currently focus on a MW imager. Forthcoming tests will exploit both a MW and LW imager. The results of those tests will be reported in this paper as will recommendations on how best to exploit thermal imaging for space simulation testing.

The overall aim of this work is the routine application of an infrared imager for the thermal-vacuum testing of spacecrafts at the ESA Large Space Simulator facility. One specific upcoming use will be the testing of the Mercury transfer module and Mercury planetary orbiter of ESA's Bepi Colombo Mercury Mission.