Original

Thermal Lag of Hercules' Pyranometers

FOOT J S

Meteorological Research Flight
RAE Farnborough Hants

MRF Internal Note No 13

March 1982

1. Introduction

This brief note describes results from a flight conducted to investigate the thermal lag of the pyranometers mounted on the Hercules. It was initiated from two observations. Firstly, Cluley (MRF Note No 4) attempted to derive the temperature coefficient of the pyranometer by observing the change of output voltage when viewing a constant source on a level run immediately after a rapid ascent or descent when the temperature of the sink, which is monitored, is changing. His results gave much higher values of the temperature coefficient than laboratory tests and he concluded that "the thermistor monitoring the body temperature has a different relaxation time than the cold junction of the thermopile so misleading results are obtained in non-equilibrium condition." The second observation is that the instruments occasionally show negative readings. This is not uncommon for the downward facing instrument, particularly if the sun is low, the sky overcast or the underlying surface is dark. But on occasion it has also occurred for the upward facing instrument. In all cases (to my knowledge) it was preceded by aircraft ascents or descents, ie non equilibrium temperatures. This experiment attempts to identify the causes more clearly and to measure the time constant involved.

2. Experiment

The downward facing pyrgeometer was replaced by the spare pyranometer with the inner glass dome removed. The two downward facing instruments could then be compared, one with a single glass dome the other with the standard double glass domes. The flight, H503 (22/3/82), was principally for Met O 15 trials, but included two rapid profiles (2/3000'/min) to 300 ft asl with straight and level runs at that level and a landing at dusk.

The purpose of the double dome is mainly associated with ground use where the outerdome will heat up in direct sunlight and radiate in the infrared; the inner dome will then reduce the transfer of heat to the thermopile. The behaviour of a pyranometer with a single dome is similar to the behaviour of the pyrgeometer (Foot and Squires, MRF Note No 12) which have a single silicon dome. It is necessary during calibration of a pyrgeometer to take account of the dome temperature, but on aircraft with the dome well ventilated, the errors arising from the dome being at a different temperature are usually small.

3. Results and Discussion

The results are presented in the form of the raw data plots with scales of DRS bits for selected parts of the flight. (The new SEL transcription enabling a paper to be drafted the day after a flight!) Ch3 is the normal pyranometer, Ch4 is the pyranometer with a single dome. Approximate scales in physical units have been added to the raw plots. Also shown is the static pressure and the multiplexed thermistor signals from the 2 lower pyranometers and the upper pyranometer and pyrgeometer. All quantities increase positively vertically upwards in the plots. The purpose of showing the upward facing pyranometer and pyrgeometer thermistor outputs is because the pyrgeometer has one thermistor on the silicon dome. This gives some indication of how the temperature of outer glass domes of the pyranometers (which are not measured) are changing. The two sink (or body) temperatures of the two downward facing pyranometers cannot be distinguished in the raw plots but, as expected, show very similar trends. Figure 1(a) and (b) show output from the transit at a constant height. The variation with time in Ch3 and 4 being due principally to changes in the underlying cloud cover; there was no cloud above the aircraft. Under constant temperature conditions the two instruments showed the same variation. Reference to the calibration of the instruments - Ch4's calibration being appropriate to the unaltered instrument - indicates that the inner dome reduces the sensitivity (bits/Wm^{-2}) of that instrument by 6%, a figure which seems totally plausible. The times when the variations from the two instruments are dissimilar correspond to periods during or just after an ascent or descent. The best period to study was the landing as the sun had set and the upward signal was <$5Wm^{-2}$. Figure 2 shows the period up to landing. The offset on both Ch3 and 4 means that the data recording system will record down to $-14Wm^{-2}$. The modified instrument shows more rapid variations in signal than the unmodified and in particular after the descents at 184040 and 184730 the modified instrument's signal recover to a near constant and positive signal after about 1 minute whereas the unmodified instrument recovers to a near zero value after about 5 minutes. Referring to the sink temperatures for the lower pyranometers it is clear that they stabilise after about 1 minute. It therefore is not surprising that Cluley was unable to derive sensible temperature coefficients as the response of the pyranometer after profiling is greatly influenced by the thermal inertia of the inner glass dome which of course is not forcibly ventilated like the outer dome. The sign and magnitude of the changes are also of interest, particularly in comparing the performance of a pyranometer with the single glass dome to a pyrgeometer with a single silicon dome (see MRF Note No 12). At first sight we might expect that on descent the dome would warm more rapidly than the bulk of the instrument and give rise to a positive offset on the instrument. This may be the explanation of the slight increase in signal at 184520 before giving negative offset >14Wm^{-2}. This feature was observed on one of the other profiles - but it does not occur at 183300 possibly because the descent was not as rapid. The reason for the negative offset with a glass dome is probably because glass has a thermal conductivity approx $^1/200$ the value of aluminium which forms the bulk of the body of the instrument and therefore in rapid descents the sink of the instrument warms more rapidly than the inner surface of the glass; the net flow of heat in thermopile is therefore from the sink to the blackened surface and thus the signal is negative. Work on the pyrgeometer (MRF Note No 12) suggest that in rapid profiles the error due to rapidly changing temperatures was <10Wm^{-2}. Silicon has a thermal conductivity close to aluminium therefore these competing processes are likely to be very different in the two instruments.

4. Conclusions

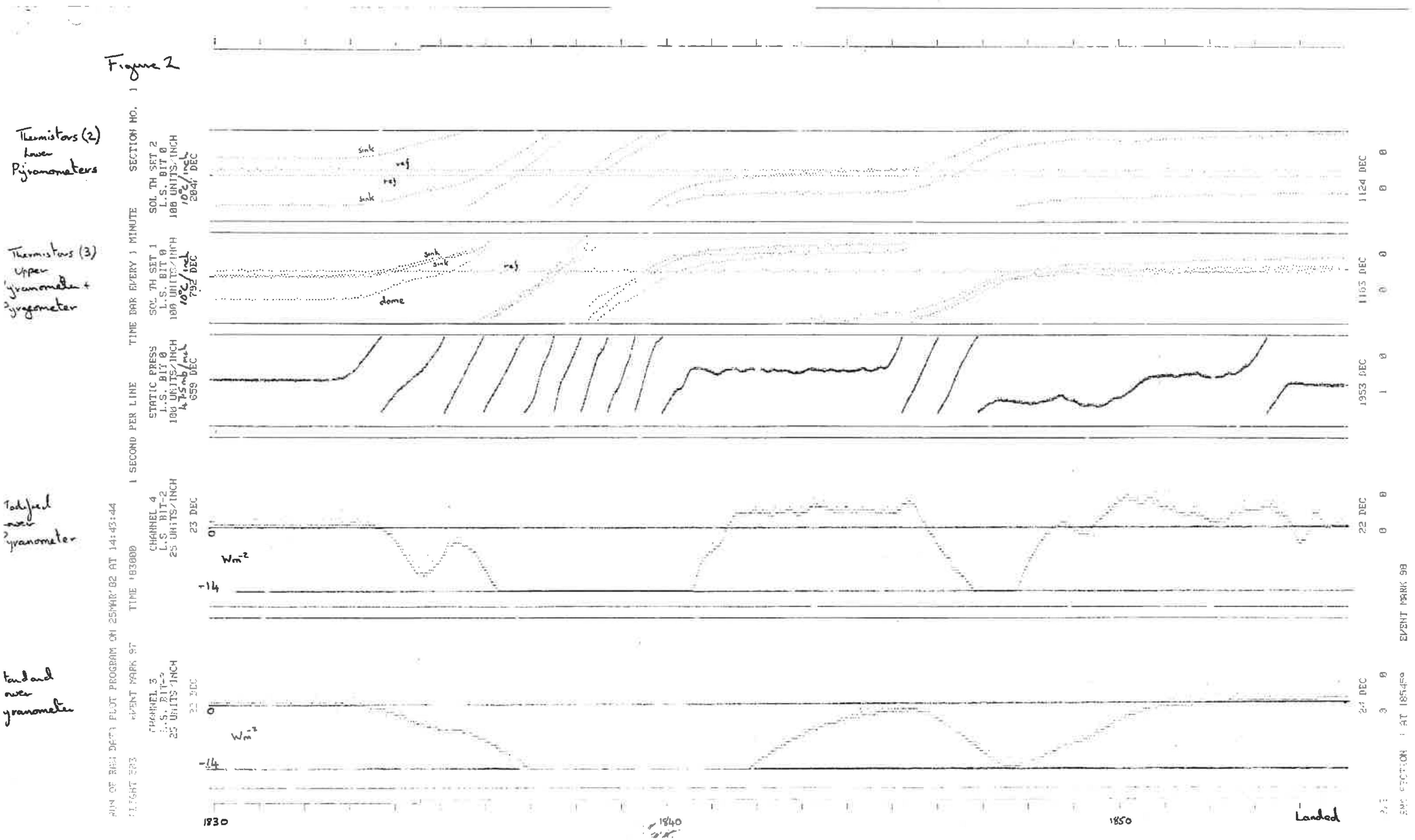
a. During rapid profiles when the pyranometers are not in thermal equilibrium large errors (>14Wm^{-2}) are to be expected from both upper and lower instruments. These errors are larger than are experienced with the pyrgeometers because glass is a much poorer conductor of heat than silicon.

b. After profiles at least 5 minutes should be allowed for the temperature of the inner glass dome to stabilise. It is not sufficient to note when the sink temperature stabilises.

c. Removal of the inner dome reduces the time lag of the instrument but during profiles large errors will still occur.

d. A possible solution to these problems would be to replace the Eppley precision pyranometers with Eppley black and white pyranometers. In these instruments the cold junction of the thermopile rather than being in contact with the sink is adjacent to the hot junction, the cold junction being painted white, the hot one painted black. For every form of heat exchange, except short-wave radiation, the two junctions perform identically. Such instruments would be expected to measure accurately even during rapid profiles. The thermopile area of these pyranometers seems, unfortunately, to be larger than at present and therefore larger obscurers would be needed to shield them from views of the aircraft. Replacement therefore may not be considered to be very practical.

Figure 2


RUN OF RAW DATA PLOT PROGRAM ON 25MAR'82 AT 14:43:44
FLIGHT 593
EVENT MARK 97
TIME 183000
1 SECOND PER LINE
TIME BAR EVERY 1 MINUTE
SECTION NO. 1
Thermistors (2) lower Pyranometers
SOL TH SET 2
L.S. BIT 0
100 UNITS/INCH
10°C/inch
2047 DEC
sink
ref
ref
sink
1124 DEC
Thermistors (3) upper pyranometer + pyrgeometer
SOL TH SET 1
L.S. BIT 0
100 UNITS/INCH
10°C/inch
792 DEC
sink
sink
ref
dome
1163 DEC
STATIC PRESS
L.S. BIT 0
100 UNITS/INCH
4.75mb/inch
659 DEC
1953 DEC
Tadjeed over pyranometer
CHANNEL 4
L.S. BIT-2
25 UNITS/INCH
23 DEC
0
Wm⁻²
-14
22 DEC
EVENT MARK 98
tandard over pyranometer
CHANNEL 3
L.S. BIT-2
25 UNITS/INCH
23 DEC
0
Wm⁻²
-14
24 DEC
1830
1840
1850
Landed