High Altitude Student Platform
(HASP)

University of Alabama in Huntsville

Thermal Imaging Balloon Experiment (TIBE)

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Project Abstract

The purpose of the University of Alabama in Huntsville (UAH) HASP infrared project was to gain a better understanding of the thermal effects that a high-altitude balloon experiences during flight. Thermal effects change the flight duration, altitude changes and ballast requirements. Successful acquisition of the thermal data could help improve future balloon endeavors and possibly span into other applications. Our project was built upon the past experiments of NASA's Deep Space Test Bed (DSTB) and HASP 2006, and introduced newer, refined, techniques to acquire more meaningful and accurate data. Our previous infrared experiment, Infrared Thermal Balloon Experiment (ITBE), flown on HASP in 2006 utilized three infrared temperature sensors. For the 2007 experiment the main focus of the study centered around an array of thermopiles that map thermal signatures starting from the Earth and continuing vertically to the balloon above. Originally, for Thermal Imaging Balloon Experiment (TIBE), the use of a thermal imaging camera was proposed, but the design changed to accommodate different equipment, thus the initial need for the large payload seat. The students involved with the project have managed mechanical, thermal, and instrument components for the duration of the project and throughout the data analysis. Previous balloon testing experience coupled with the information gathered from previous models, add to the understanding of high altitude balloon dynamics and ultimately towards achieving longer duration balloon flights. This project was supported by the Alabama Space Grant Consortium. This report will outline the TIBE instrument and HASP flight results. It will show that the experiment performed well; however, the results were different than originally expected. The sensors expected to replace the thermal imaging camera were unavailable within the allotted time for development and were replaced in the design by sensors with slightly different parameters.

Background

Previous Experiments

Previous high altitude experience for this team included infrared payloads developed and flown on DSTB and HASP 2006. UAH developed an infrared experiment using off the shelf commercial sensors that was flown as one of the student payloads on DSTB. In fall of 2006, UAH flew a more refined and technically specific version of their DSTB payload on the inaugural HASP flight. The DSTB experiment laid the foundation for the HASP/ITBE experiment flown in 2006 and contributed one of it's sensors in an effort to have control data. The DSTB payloads contained three infrared pyrometers similar to the HASP/ITBE experiment except that DSTB's sensors were not modular and were housed within a single payload. Only one of the prior sensors was used in the HASP/ITBE experiment, however the overall goal of the two flights was the same. ITBE was designed to be modular and utilized three small payload seats fixed to outstretched arms attached to the balloon gondola. The unique design parameter of ITBE was to use these outstretched positions and angle the pyrometers so that their field of view (FOV) would be filled with the balloon. Each of the three payloads contained Omega pyrometer sensors. Instrument decision criteria focused on small dimensions, lightweight, relatively focused field of view and a wide spectral response. The chosen instruments included one of the DSTB sensors, the Omega OS550 Series Infrared Industrial Pyrometer with a spectral response of 8 to 14 microns. The new sensors chosen to replace the OS533 Omegascopes used on DSTB were two Omega OS101 Series Industrial Infrared Temperature Transmitters with a spectral response of 5 to 14 microns. All sensors utilized a K type thermocouple which added more comparability to the final results.

Figure 1. Two Omega OS101 units were used.

Figure 2. Omega OS550 unit from DSTB

The DSTB experiment provided adequate data in large amounts due to small sampling rates, a parameter that would be specifically addressed for ITBE. Aside from the OS550 instrument providing control data for DSTB, the spectral response of the OS101 units were used because their spectral response are lower than the Omegascopes. However, the low end of the spectral response (5 µm), was not as low as the desired 3.4 µm. The technical goals for the UAH experiments focus on a thermal experiment performed by Henry Cathey of the Field Office of the Physical Science Laboratory located at NASA Wallops Flight Facility. His research included analytical models and various physical properties of balloon materials.[1] Cathey also provided a span of wavelengths at which typical high altitude balloon materials respond on the infrared spectrum. Cathey's research provided the foundation that UAH infrared research projects are based from. This provided the key goal and focus of the UAH Thermal Imaging Balloon Experiment (TIBE).

[1] Cathey, Henry M., "Advances in the Thermal Analysis of Scientific Balloons.", PSL, NMSU, January, 1996.

Procedure & Construction

Background and Theory

The conceptual design for TIBE planned for a modified ATX100 thermal imaging camera from Ann Arbor Sensor Systems. This did not fit within milestone deadlines, thus the research shifted to recreating a simpler concept of the ATX100 technology. The base technology behind many more modern thermal imaging devices is thermopile arrays. Thermopiles are comparable to thermocouples in their operation; however thermopiles essentially utilize a matrix of thermocouples housed in configurations that provide more optimal conditions for non-contact infrared temperature measurement. Like thermocouples, thermopiles also require a reference temperature to generate meaningful temperature data. These reference temperatures can be taken from the non-exposed ends of the thermopile matrix or from temperature sensors integrated in the thermopile circuitry. Included in the design were two single pin thermistors for measurement of ambient temperature both inside the payload and outside the payload.

Goals of the TIBE payload included measurement of the balloon material temperature and Earth's infrared radiation. The purpose of this is to examine the temperatures exhibited from Earth continuing upwards to the balloon. By measuring these temperatures it can be possible to relate the reflected radiation from the balloon to that of the Earth's radiation. The UAH payload utilized an array of four thermopile sensors placed at equal distances across a 90° arc. Again, the sensors originally planned to replace the ATX100 were unavailable during the timeline of this project so a fewer number of different replacement sensors were used. The replacement sensors were purchased from Devantech. Each individual sensor consists of an 8x1 array of thermopiles that produced a viewing angle of 41° in the long (8 pixel) dimension and 6° in the short (1 pixel) dimension. The sensors have a 4°C to 100°C manually calibrated operational range and 4°C to 100°C for the measurable range, yet our data shows lower temperatures. An anti reflective coating was applied to the lens covering the pixels which provided a visible IR range for the sensors of 2µm-22µm. Also, each sensor contained an on-board temperature sensor which provided a reference temperature that the thermopiles used.

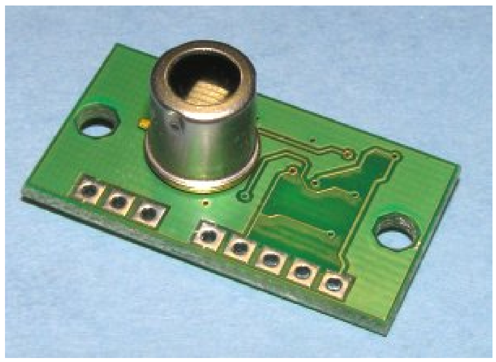

Figure 3. Devantech 8x1 thermopile array.

By placing the IR sensors in an arc formation, the UAH team wanted to measure the spectrum of infrared the balloon material is exposed to. Knowing infrared energies consist of three major components, absorption, transmission and reflection. Additional information comes from Cathey's research that the thin film plastic, or balloon material, remain transparent at most wavelengths except for the vicinity of 3.4µm at which point the balloon material becomes opaque. At this wavelength, the balloon should be measurable using non-contact temperature sensors. The Devantech sensors are capable of detecting infrared energies from these wavelengths. The TIBE payload was positioned on the top corner of the HASP gondola, thus the UAH payload should have "seen" from Earth's horizon all the way to completely vertical, the balloon. By measuring this 90° spectrum, infrared energies from both Earth and deep space can be compared to that of the balloon. This should allow the transmission and reflective radiation to be subtracted from the balloon measurements thus leaving the absorption radiation and thus, the balloon temperature.

<u>Payload Construction.</u>

The payload construction began with the mounting plate supplied by Louisiana State University (LSU). The base frame attached to the plate consisted of 1/8”x 1” aluminum angle. Overall, the payload took on a rectangular box construction with the short side corners cut off at 45°. The corner overlooking the edge of the gondola is where the arc of sensors was installed. A 90° quarter piece of 8” poly-vinyl-chloride (PVC) piping was mounted in the corner and holes were drilled in equal distances to mount the sensors providing a full spectrum from Earth to the balloon.

Figure 4. TIBE payload looking from the outside corner of HASP gondola.

The actual walls of the payload consisted of ¾” hex-cell honeycomb with a bilateral carbon fiber weave baked on both the inner and outer surfaces. A ½” hex-cell panel was used for the top of the payload that also had carbon fiber weave baked on the inner and outer surfaces.

All the sides were then connected using a bilateral fiberglass weave and epoxy resin. The outer most corner relative to the positioning on the gondola had a missing section where the sensors were mounted via the PVC.

Circuitry

The circuitry for the payload remained relatively light and the data output was configured to downlink upon gondola power up at a rate of 4800 baud. The data logger was built around a Vinculum VDIP1 USB mass storage interface that allowed the data being recorded from the sensors for downlink, to also be interfaced to a USB peripheral without implementing the USB protocol stack. The central microcontroller that ran the system was an Atmel ATmega8 which interfaced with the various sensors, wrote data to a USB flash drive, and recorded and stored data from Dallas DS1722 temperature sensor peripherals. The ATmega8 also generated data via RS232 which interfaces with the HASP telemetry system. A circuit diagram of the payload system can be seen in the appendix, A2.

Integration

Payload integration at LSU took place at the end of July 2007 in Palestine, TX at the Columbia Scientific Ballooning Facility. The week of integration proved more difficult than originally expected with a voltage regulator failing and rendering the IR sensors useless. The HASP gondola supplies 28 VDC at 2.5 Amps, so a voltage regulator was needed to decrease the DC voltage to a lower voltage for the circuitry. During testing, the solid state voltage regulator failed in a mode that allowed a voltage much higher than the tolerances of many downstream components, and in turn damaged them. Among the destroyed components were, most importantly, the four Devantech IR sensors. Rush shipping was able to deliver replacements before the week of integration was over, and the TIBE payload was hand delivered by the UAH team. Upon integrating the TIBE payload it was found that, even at an increased baud rate, the sampling rate of data took a noticeable amount of time to fill a data packet for transmission. Data was sampled around every 45 seconds or so and recorded in almost as much time. No preflight integration was needed after integration in late July. Flight occurred in early September 2007 with a scheduled launch window centered on Labor Day weekend. All systems integrated smoothly and grounded data was transferred with little, if any, interruption. Launch time was September 2nd, 2007 at 7:12 am local mountain time (13:12 UTC). Data acquisition was based on Line-of-Site (LOS) communication and the gondola telemetry systems were shut down approximately 16 hours later at 2:00 am on September 3rd, 2007 (07:52 UTC). Data was collected and downloaded to the LSU HASP server in packets containing nearly 9 minutes of data acquisition.

Discussion of Results

Upon receiving all of the data from the LSU servers, the data files were combined into a one large file. Very little data was corrupted and all bad data was discarded from further evaluation. Upon first glance at the graphs, it appeared as if the sampling rate for the infrared instruments was sufficient, determined by the number of data points. There were twenty-nine strings of data from the TIBE payload, containing a numerical counter, internal/external temperature, and infrared readouts for each sensor beginning with onboard temp and then reading from each pixel top to bottom. Each sensor was numbered according to its placement on the arc mounting, beginning with 1 for the horizontal sensor and ending with 4 for the vertical sensor. Similarly, the pixels were numbered reading from top to bottom, with pixel 1 starting lower on the arc than pixel 8. Each of these data strings were initially plotted against one another with temperature acting as a function of time.

	A	B	C	D	E	F	G	H	I	J	K	L	M
1		Sequence Number	Internal Temp	External Temp	Sensor 1 Onboard Temp	Sensor 1 Pixel 1	Sensor 1 Pixel 2	Sensor 1 Pixel 3	Sensor 1 Pixel 4	Sensor 1 Pixel 5	Sensor 1 Pixel 6	Sensor 1 Pixel 7	Sensor 1 Pixel 8
2	0:00:00	0	15	15	13	17	17	15	16	13	11	8	7
3	0:00:45	1	15	15	14	17	16	17	16	14	13	10	8
4	0:01:30	2	15	15	14	18	17	17	16	14	12	10	7
5	0:02:15	3	15	15	14	19	16	16	16	14	13	9	8
6	0:03:00	4	15	15	14	18	17	17	16	14	12	9	7

Figure 5. Data Sample (left to right): Counter, internal temp., external temp., IR Sensor (onboard temp., individual pixel temp. (1-8)).

The components used for internal/external temperature measurements were Dallas DS1722 temperature sensors. +/- 2C accuracy, 12 bit (0.0625C) resolutions that were fully integrated devices with a digital interface. These sensors proved fairly sensitive to environmental changes. The IR sensors also proved sensitive to the environment as readings fluctuated steadily within a given standard deviation until temperatures dropped. The sensor specifications and raw data can be seen in the appendix.

The low operating temperatures of the sensors proved to adversely effect the experiment by keeping most of the data at 0° C for the majority of the flight. This conflicts with the manufacturer specifications of 4° C, the exception to this was pixel 1 on the first sensor. Sensor 1 was pointed directly horizontal with respect to the gondola and pixel 1 for sensor one was the lowest most pixel in the array, placing it closest to the gondola. This pixel registered a temperature for the entire duration of flight. The other pixels in the other sensors mainly stayed at 0° C with minimal outlying anomalies. Later testing will be performed on these sensors to try and recreate this behavior.

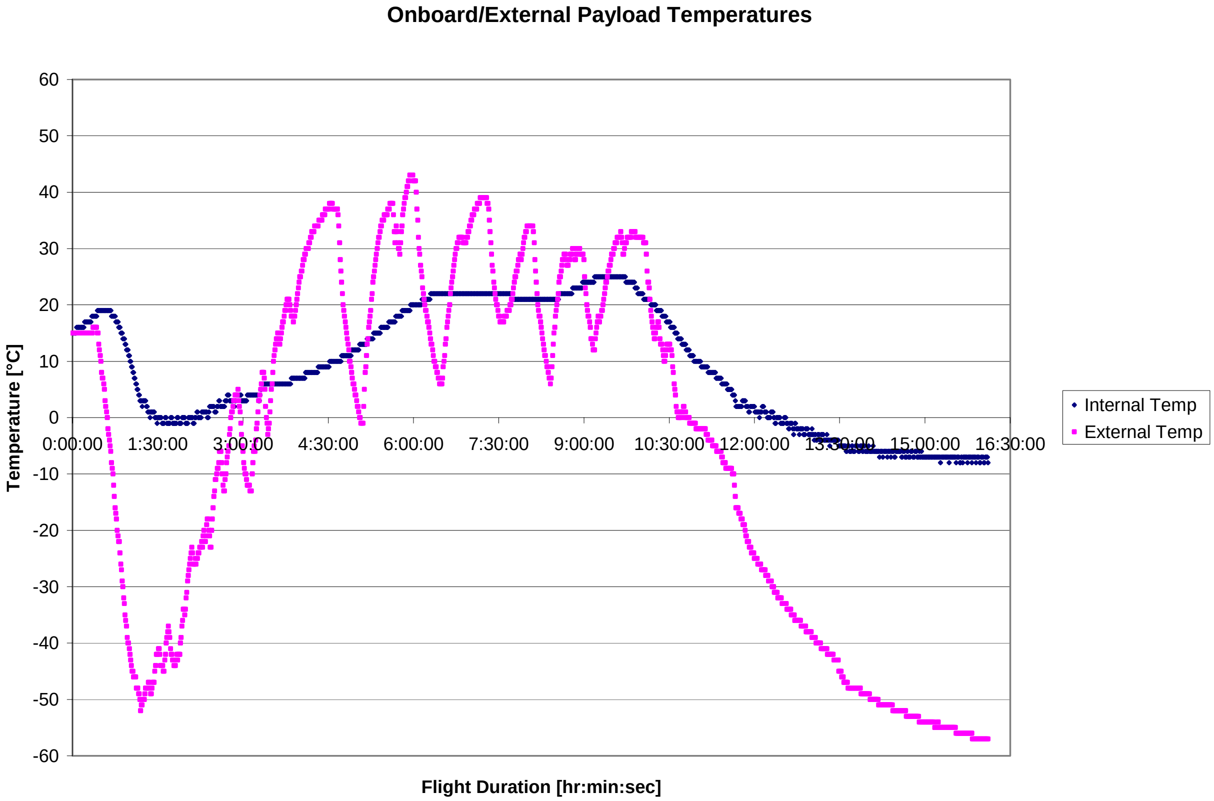

Figure 6. Internal and external temperatures for TIBE payload.

Shown above are the internal and external temperature data for the TIBE payload. The internal active thermal control system worked flawlessly, providing an internal thermal environment well within an acceptable range. The external temperatures matched up well to the gondola readings provided by LSU. The hex-cell honeycomb panels, carbon fiber, and fiberglass/epoxy resin insulated superbly when compared to the internal temperatures of the HASP 06 payloads.

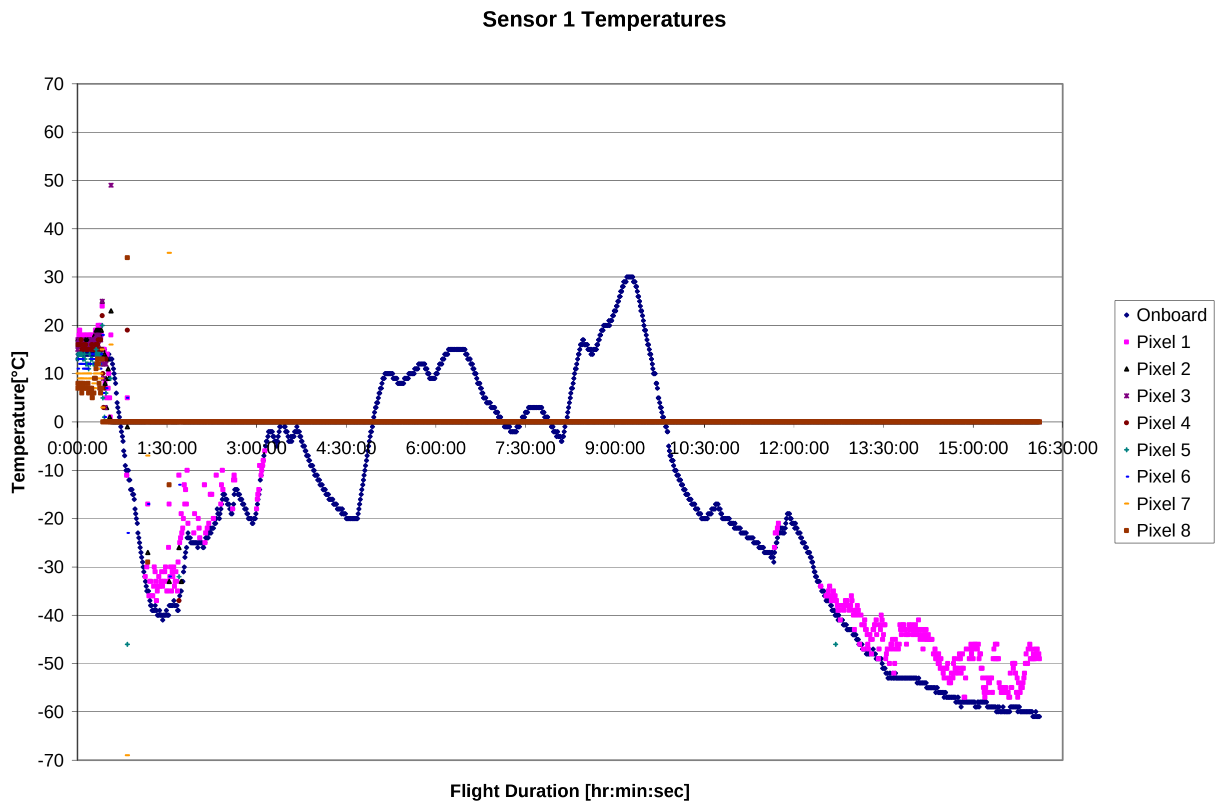

Figure 7. Sensor 1 (0° arc position) temperature data.

Shown above is the IR data from sensor 1, which is at the 0° arc position or horizontal with respect to the gondola. This sensor was the closest to the gondola compared to the other three. Also, the positioning of the pixels travel upwards on the arc according to the number, pixel one being the lowest, then two and so on with eight being the highest on the arc. Pixel one on this sensor was the only thermopile that did not zero out for the duration of the flight. Upon closer inspection it can be seen that it follows the onboard temperature profile for the sensor very closely with the exception of times between the first and third hour and again from approximately the twelfth hour until power down. The deviation between temperatures during these times are overall slight, but can register up to 15 degrees warmer at times. This can be caused by a possible obstruction by the corner of the gondola.

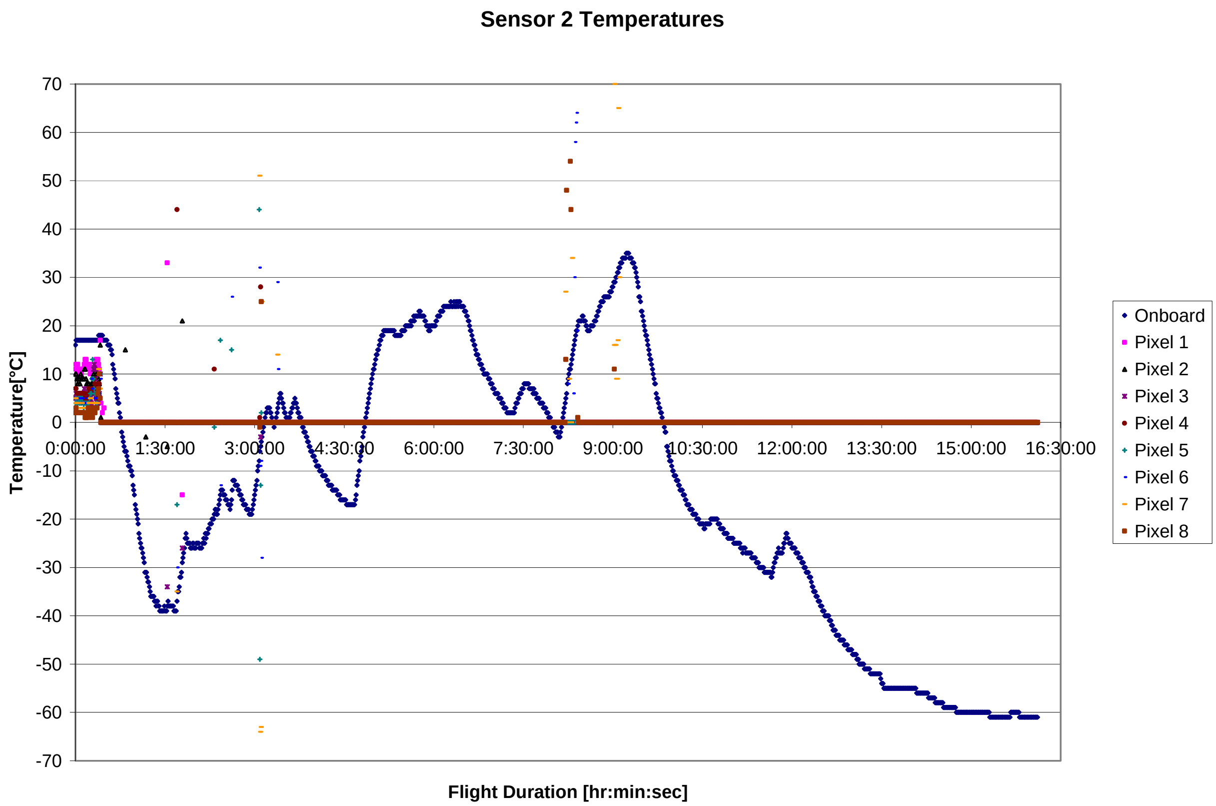

Figure 8. Sensor 2 (~30° arc position) temperature data.

The IR data from sensor 2 showed much activity during pre-launch but showed very little afterward, which suggests that the sensors were not sensitive to the balloon's radiation. However, the onboard temperature sensor data follows the onboard temperature profile from sensor 1 very closely. Periodically, aberrations of both high and low temperature data can be exhibited by the pixels. These data points could normally be dismissed as outliers, but they occur in more instances than normal bad data packets which suggested that perhaps the rotation of the balloon exposed the sensor to saturation via sunlight.

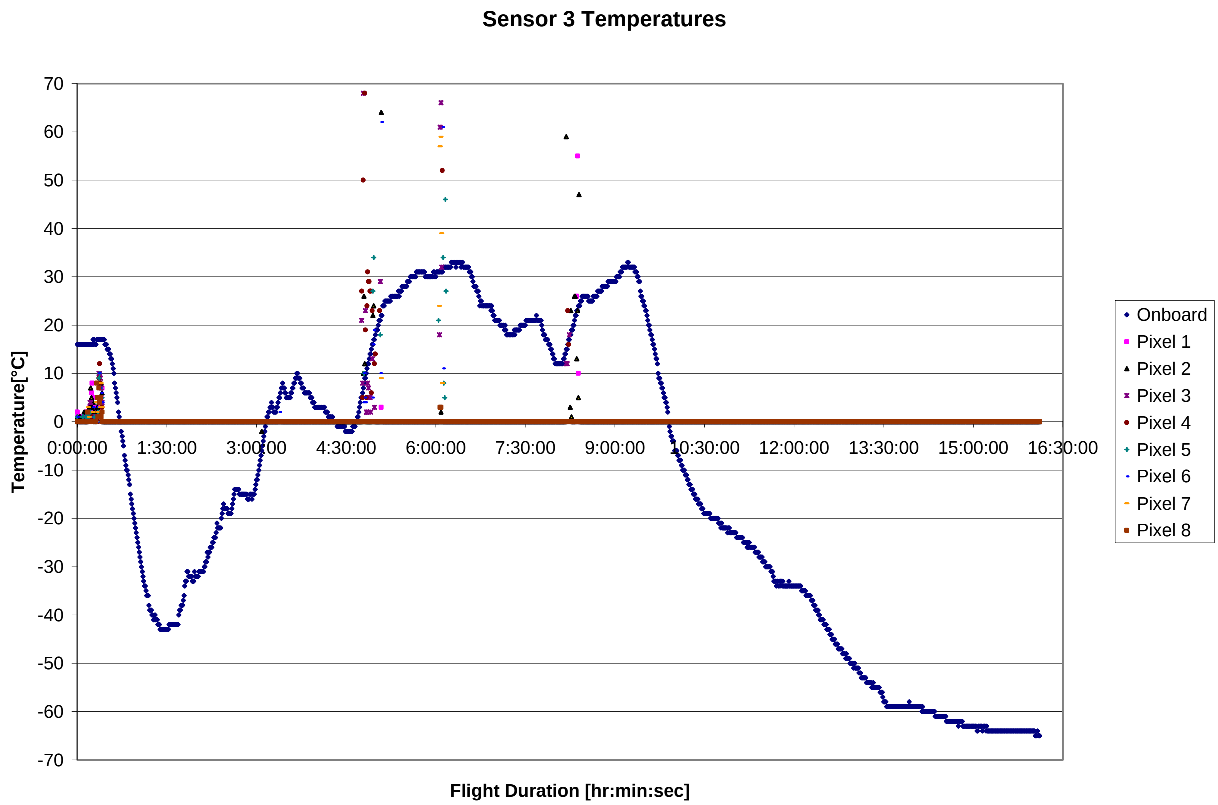

Figure 9. Sensor 3 (~60° arc position) temperature data.

Sensor 3 exhibits very similar behavior as sensor 2. A noticeable amount of aberrations occurred frequently yet at different time placements than that of sensor 2. The onboard temperature data seemingly followed the same profile as the first two sensors, but a noticeable increase in overall temperature became prevalent.

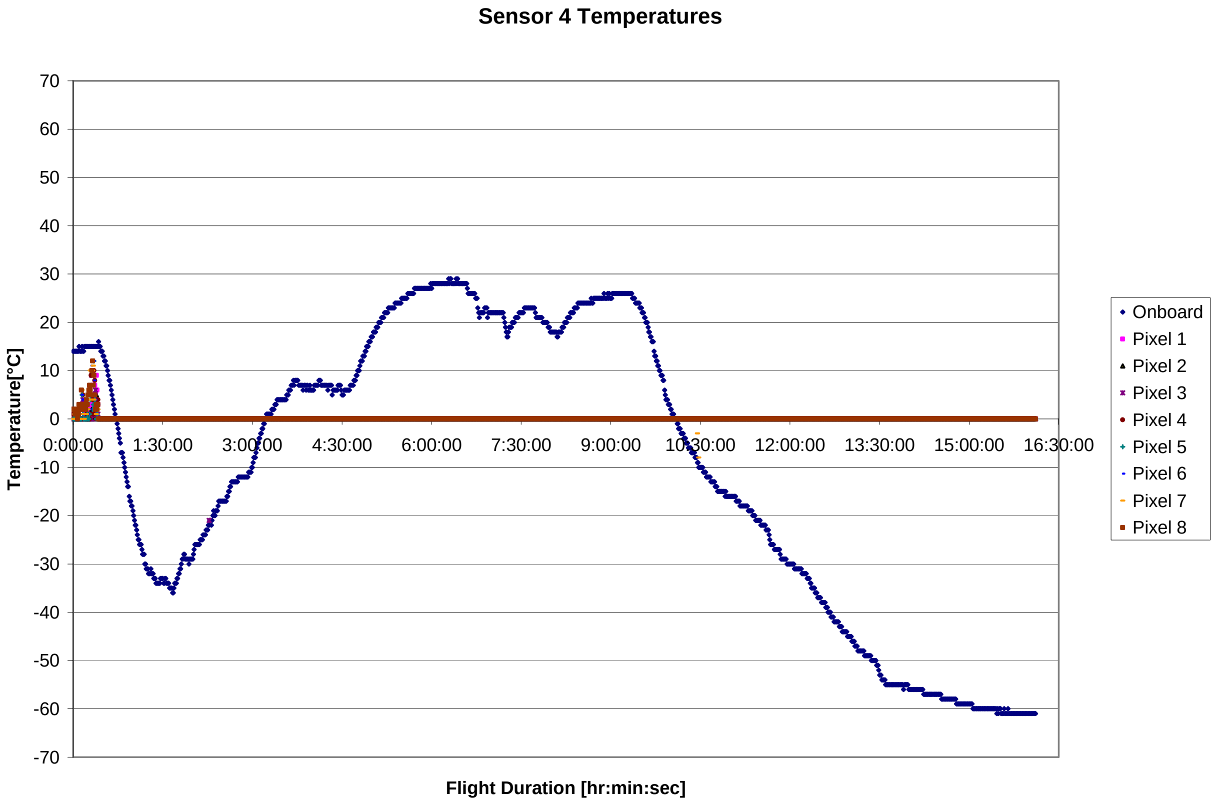

Figure 10. Sensor 4 (~90° arc position) temperature data.

No aberrations were present for the fourth sensor that was aimed directly upwards, which supports the speculation of possible glimpses of sunlight for the other sensors since viewable sunlight from overhead would not have been possible given the gondolas position in the sky. Also, while the onboard temperature followed a similar profile to the other sensors, when directly compared to the others it can be seen a steady rise in overall temperature occurs from sensor 1 to sensor 4. More notable is the smoother trends exhibited by the onboard temperature sensor when compared to sensor 1. It should also be noted that these onboard temperature sensors were not in proximity of the electronics bay of the payload.

Larger views of the preceding figures can be found in the appendices.

Conclusions & Future Plans

In conclusion, the TIBE project showed unforeseen results and also showed progress in technology over the previous two experiments. While the data was not as useful as originally anticipated it can be learned that stronger efforts must be taken when trying to overcome designed hardware limitations. Since the flight of HASP 2007 the sensors from the original design, which are believed to be optimal sensors if detection is possible, have been obtained and testing will begin shortly. The overall concept and goal of the TIBE experiment will remain the same, though the design will change slightly with the acquisition of the superior equipment. Much ground testing will take place over the coming months over a wide array of operation temperatures and conditions. UAH wishes to continue researching the thermal effects imposed on the high altitude balloons and plan to propose for the 2008 HASP program. The results from the 2006 and 2007 flights will continue to be studied, and will be used. Possible future experiments still include the possibility of a thermal imager with optics. This is ultimately the direction the team wants to take and through thermopile arrays virtual infrared images can be constructed. Thermal imaging will provide the ability to see real time temperature changes as a field of infrared signatures.

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-Michael Stewart

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-Brian Decker

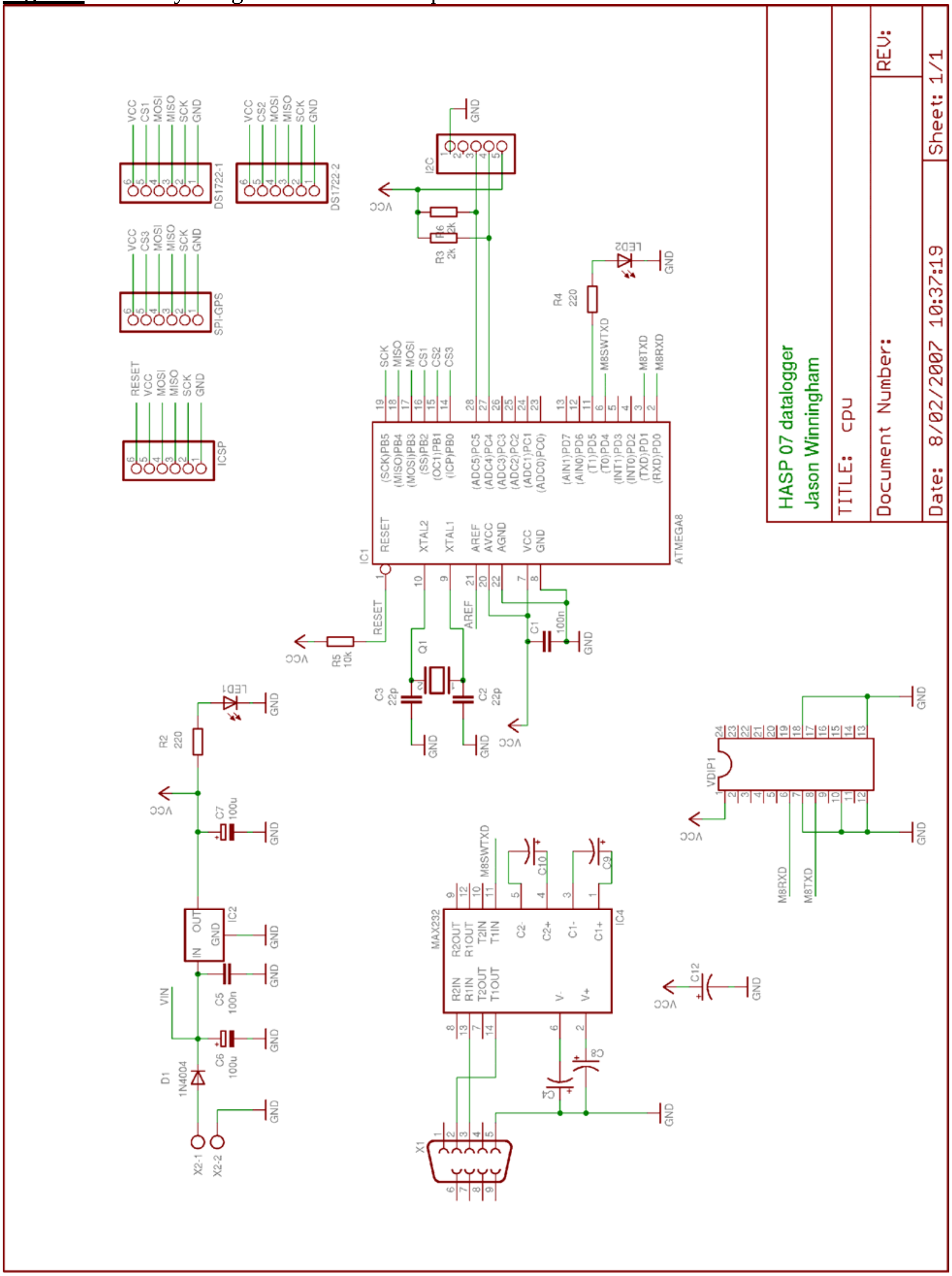
Appendix

Fig. A.1- Technical specifications for the Devantech sensor.

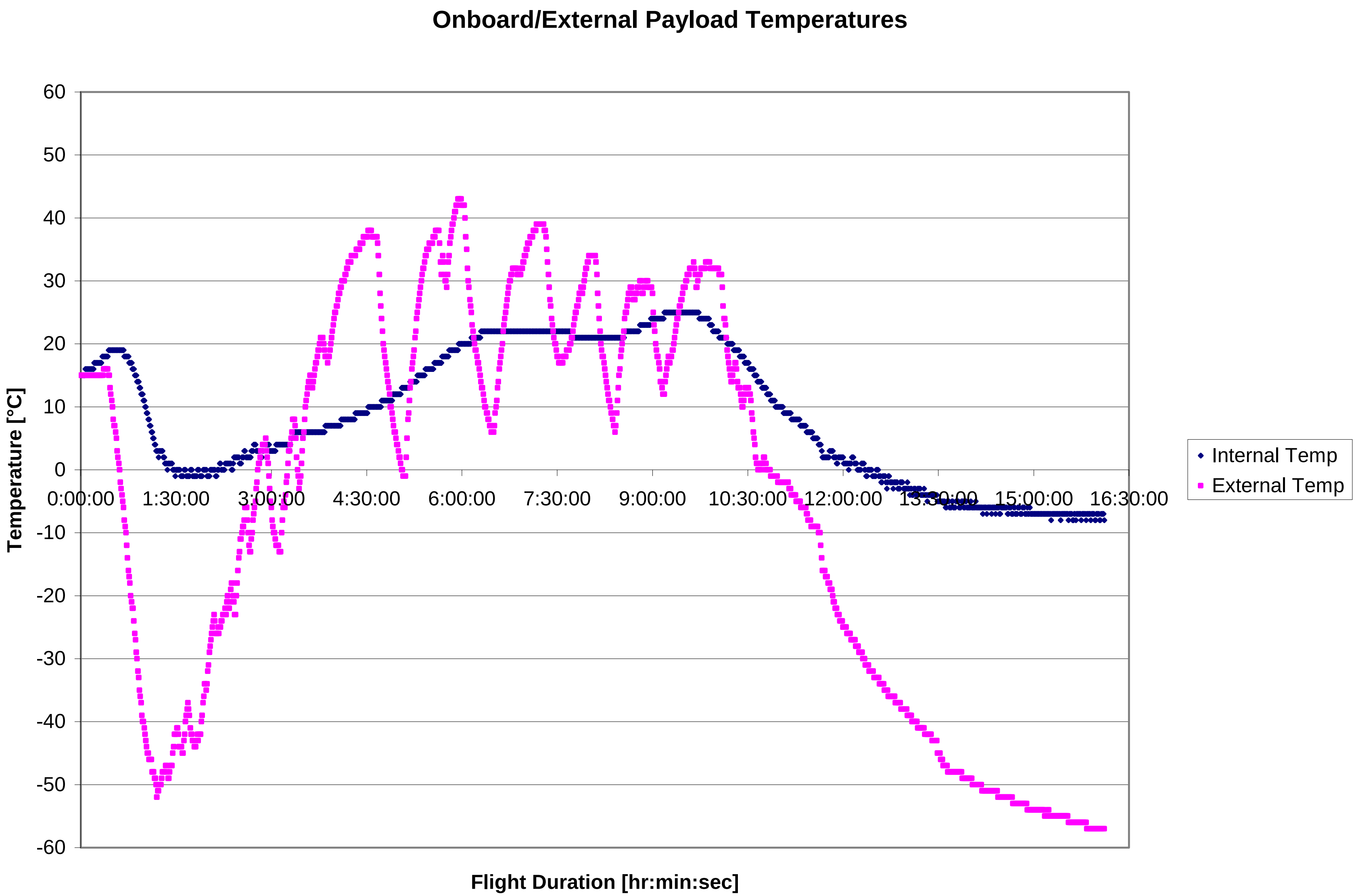
TPA81 8x1 Thermopile array.

Voltage	-	*5v only required*
Current	-	*5mA Typ. excluding servo*
Temperature Range	-	*4°C - 100°C*
Accuracy (Full FOV)	-	*+/-3°C from 4°C to 10°C* *+/-2°C +/-2% from 10°C to 100°C,*
Field of View	-	*41° x 6° (8 pixels of approx. 5° x 6°)*
Outputs	-	*1 ambient + 8 pixel temperatures*
Communication	-	*I2C Interface*
Servo	-	*Controls servo in 32 steps to 180° rotation*
Small Size	-	*31mm x 18mm*

Fig. A.2- Circuitry design for TIBE data acquisition.



<u>Fig. A.3</u>- Internal/External Temperature data from TIBE.



<u>Fig. A.4</u>- IR data for Sensor 1 (~0° arc position).

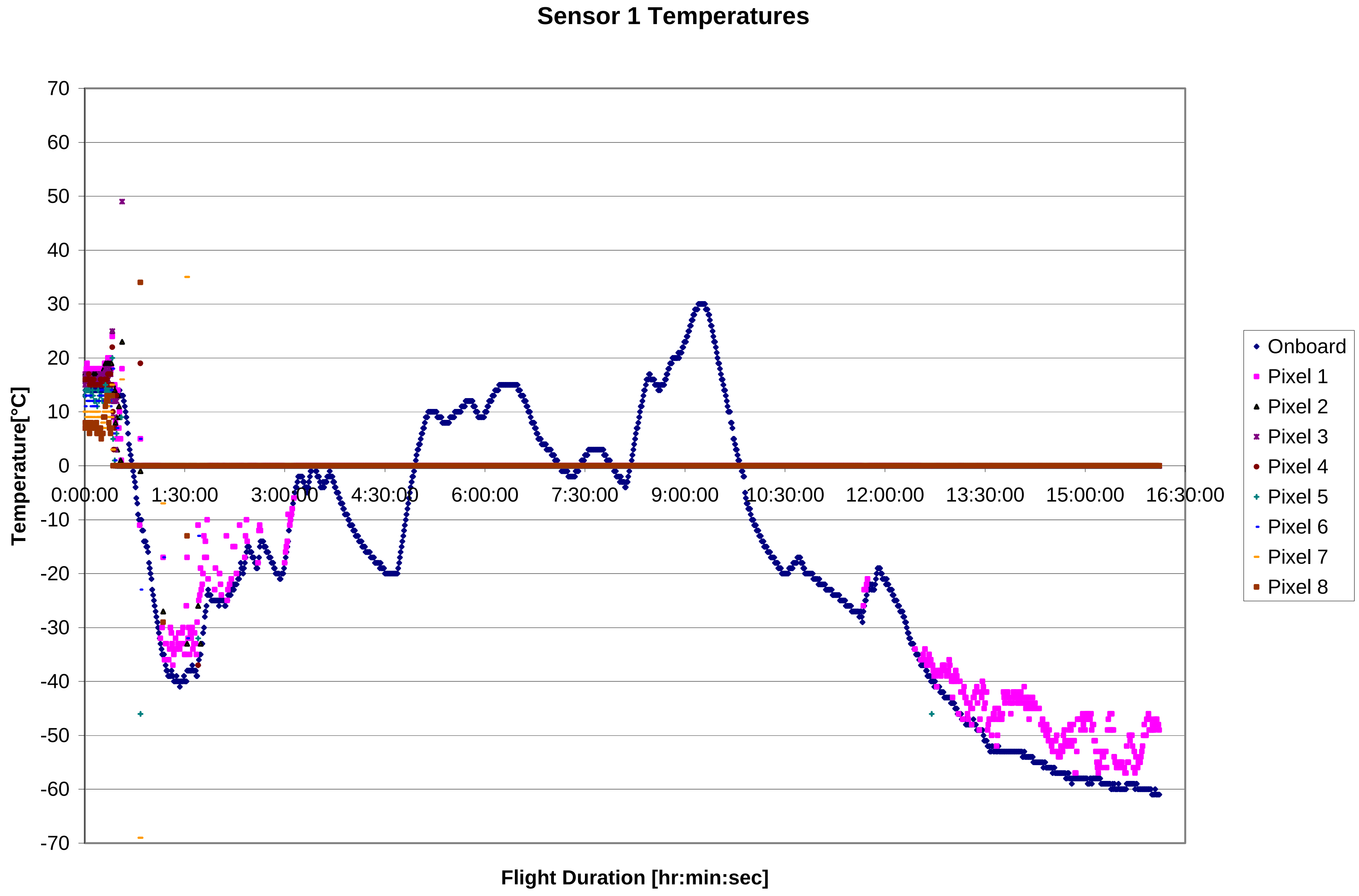


Fig. A.5- IR data for Sensor 2 (~30° arc position).

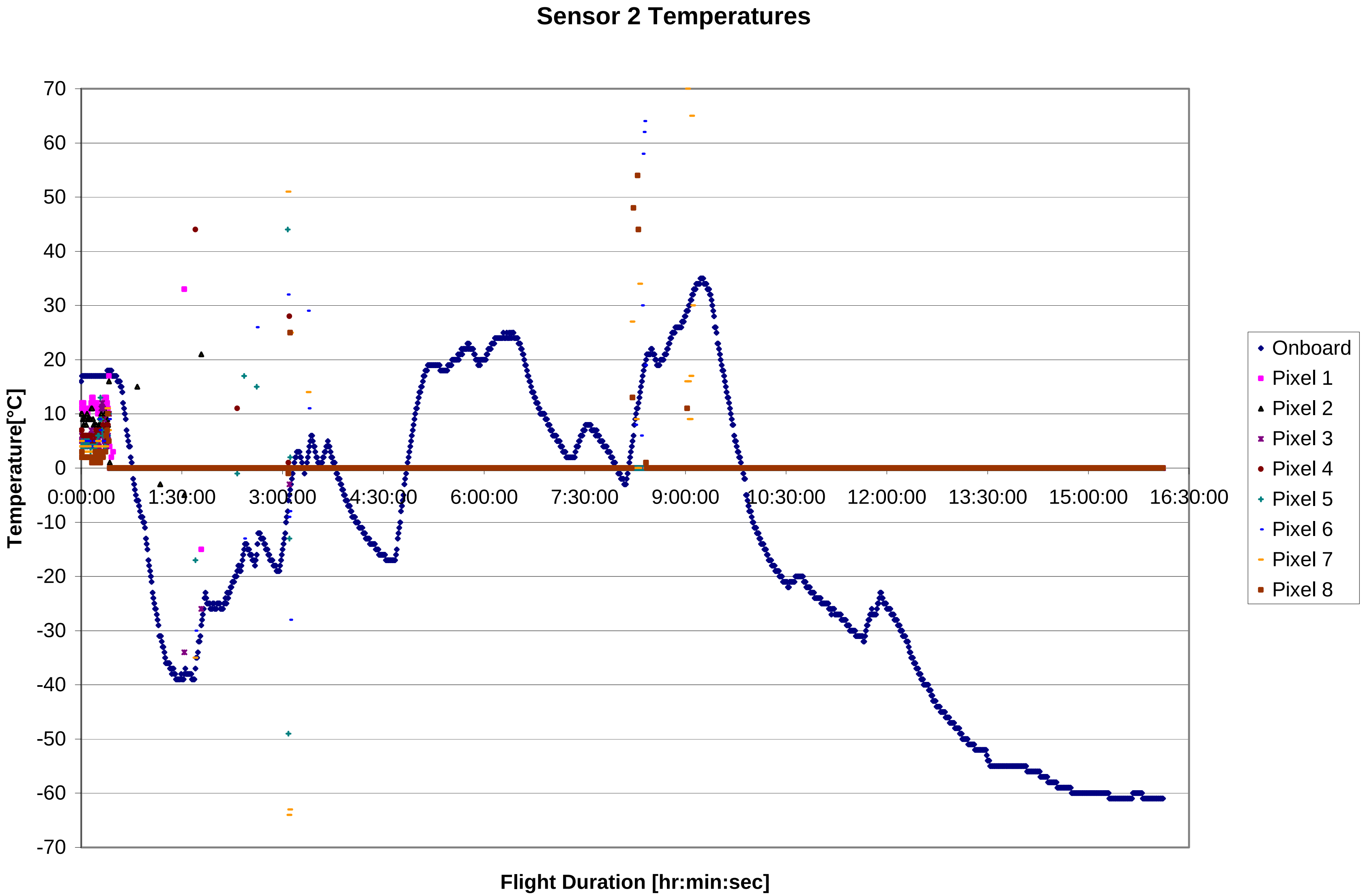


Fig. A.6- IR data for Sensor 3 (~60° arc position).

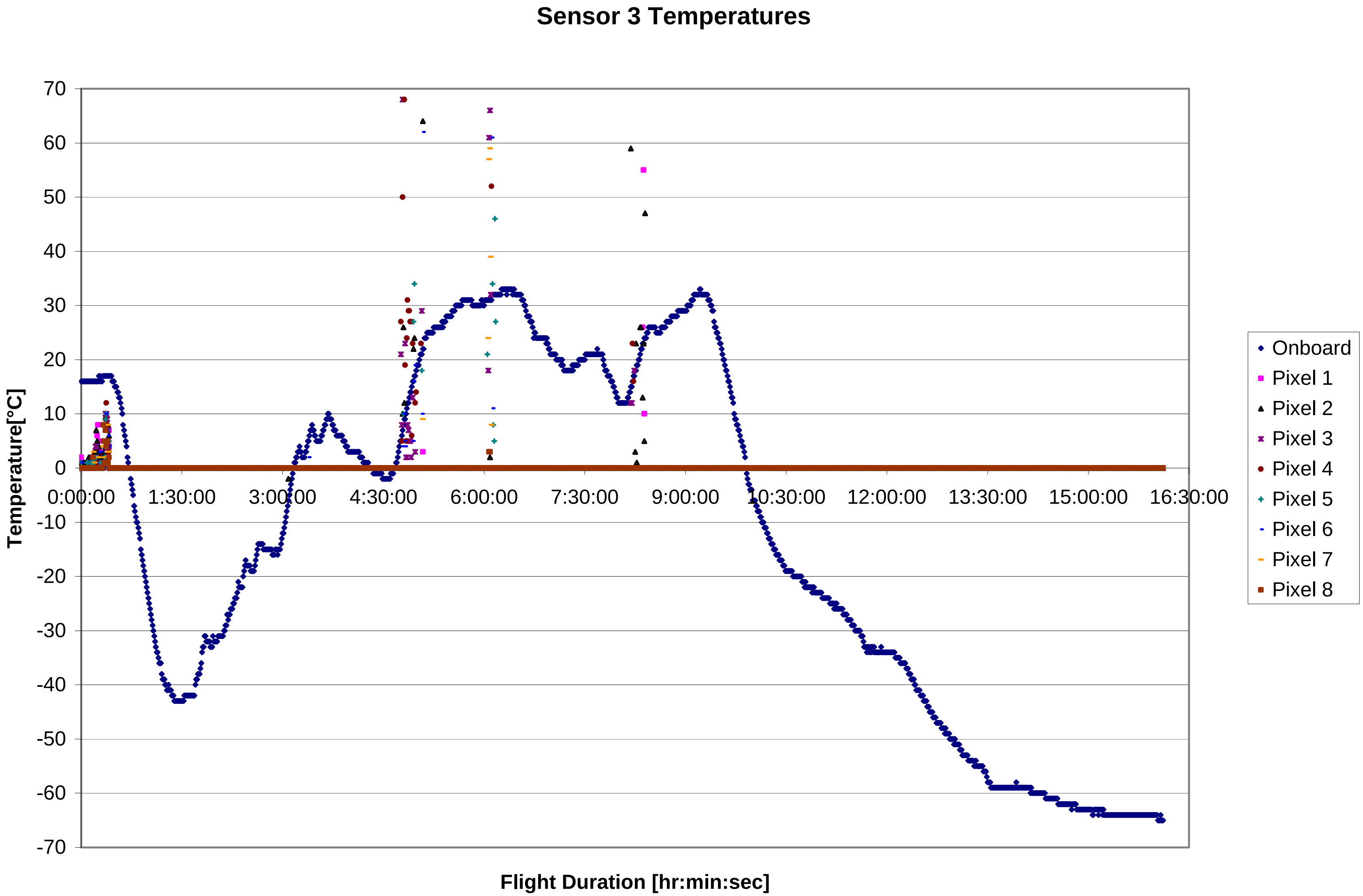


Fig. A.7- IR data for Sensor 4 (~90° arc position).