PRELIMINARY THERMAL SCIENCE RESULTS OF THE IONSPHERIC SCIENCE AND INERTIAL SENSING (ISIS) SOUNDING ROCKET PAYLOAD. T. E. Caswell[1], D. L. Thorsen[2], and J. G. Hawkins[3], [1]Project Manager, Alaska Student Rocket Project (tess.e.caswell@nasa.gov), [2]Principal Investigator, Alaska Student Rocket Project (dlthorsen@alaska.edu), [3]Faculty Advisor, Alaska Student Rocket Project (jghawkins@alaska.edu)

Introduction: The fifth mission of the Alaska Space Grant Program's Student Rocket Project (ASRP) launched on January 10th, 2009. The Ionospheric Science and Inertial Sensing (ISIS) payload had a two-fold mission: mapping the plasma density profile of the D-region of the ionosphere at high latitudes and proving a student-built attitude determination package. A secondary objective of the mission created a thermal profile of the payload's nose cone and skin during flight.

The ISIS vehicle consisted of two primary segments: the payload, which contained the majority of scientific instruments and avionics within an aluminum skin, and the nose cone. The nose cone was constructed by Jim Rasmusen, a former engineering student at the University of Alaska Fairbanks (UAF). The unique design of layered fiberglass and epoxy provided an RF-transparent structure to support the mission's science objectives. [1]

These two segments were mated to an Improved Orion sounding rocket provided by NASA Wallops Flight Facility. Vehicle test, integration, and launch operations were supported by the NASA Sounding Rocket Operations Contract (NSROC). The vehicle is designated 30.073UO/Thorsen in NSROC documentation.

To develop a thermal profile of the vehicle in-flight, ISIS supported a suite of thermocouples along the length of the payload. The Thermal Science Instrument collected data from these sensors throughout launch, exoatmospheric flight, and reentry into the Earth's atmosphere. Total time of flight was 311 seconds. Data returned to the ground real-time via the ISIS telemetry system.

The thermal profile developed by the ISIS payload can be used to predict thermal loading on future sounding rocket payloads, thereby improving the efficacy of that payload's design process. Mechanical design may take this thermal prediction into account during materials selection and component design. Temperatures within the spacecraft, modeled using known vehicle skin temperatures, allow more effective design of payload hardware and avionics.

ISIS flight data was compared to a SIMULINK prediction created by UAF graduate student Venkata Mudunuri. [2] This model, which is in turn compared to thermal predictions created by the NASA Sounding Rocket Operations Contract (NSROC), is validated by ISIS flight data. [3]

Discussion: Students at the University of Alaska Fairbanks designed and built the ISIS payload under the guidance and sponsorship of the Alaska Space Grant Program. The payload's primary mission was the study of the geophysical properties of the D-Region ionosphere; to this end the payload supported a variety of instruments built at UAF as well as four instruments built by students in Japan. The payload also supported several engineering objectives including a student-designed attitude determination package, thermal science instrument, non-pyrotechnic door, and telemetry system [4].

The payload structure consisted of two major sections: the main body of the payload and a nose cone constructed of layered fiberglass and epoxy.

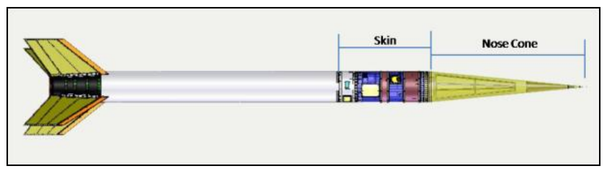

Figure 1: ISIS Vehicle

The main body of the payload consisted of an internal frame supporting six deck plates upon which the majority of vehicle systems were mounted. The internal structure was surrounded by a 1/8-inch aluminum skin of 13.75-inch internal diameter.

The ISIS nose cone, also built at UAF, was a straight-sided, 11° tapered cone constructed of layered fiberglass and epoxy. The design was an improvement on a similar nose cone flown on the fourth ASRP mission (SRP-4 or 30.047/Hawkins) in March 2002. The nose cone was 69.8 inches in length and attached to the skin via an adapter ring with a smooth transition of outer surfaces. The nose cone was topped by a 3-inch steel tip attached to a 5/8-11 threaded rod, which extended into the open volume of the nose cone and supported a 25-lb brass ballast. [5]

Overall payload weight including instruments, avionics, internal structure, skin, nose cone, and vehicle mounting structure was 145 pounds. Ballast weight contributed an additional 25 lbs. The payload was mounted to an Improved Orion vehicle for flight and launched on January 10, 2009.

Total time of flight was 311 seconds. 24.4 seconds were powered flight, after which the vehicle coasted to an apogee of 98.7 km. The vehicle impacted approximately 57.6 miles downrange of Poker Flat Research Range and was not recovered.

The ISIS payload supported twelve type-K thermocouples mounted along the nose cone and skin in support of the Thermal Science engineering objective. Sensors 0-7 were affixed to the inside of the payload skin by high-temperature thermal epoxy and therefore were affected by conductivity through the skin (1/8” T-6061 aluminum). Sensors 8-10 were embedded in the fiberglass nosecone with their tips at the outer surface of the vehicle and measured surface temperature directly. Sensor 11 was embedded in an aluminum washer between the fiberglass nose cone and steel nose tip.

Thermocouple distances from the nose tip are given in **Error! Reference source not found.** and shown in Figure 2. Order of the thermocouples down the rocket is, from tip to motor: 11 (nose tip washer), 10, 9, 8, 0 (top of payload skin), 1, 2, 3, 4, 5, 6, 7 (bottom of skin).

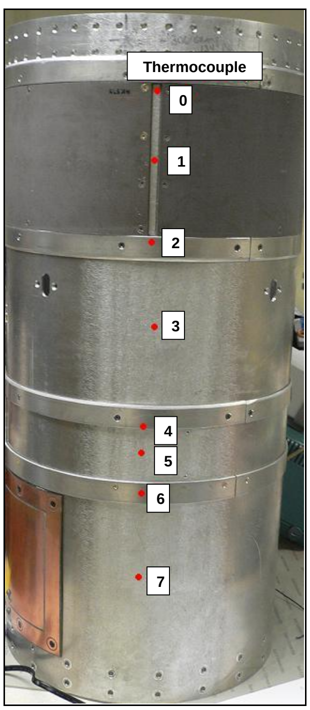

Figure 2: Thermocouple locations on the skin of the ISIS payload.

Table 1: ISIS thermocouple placement.

Thermocouple	Distance from nose tip [in]
11	3.10
10	20.64
9	38.09
8	55.54
0	76.00
1	78.63
2	81.88
3	85.38
4	89.63
5	90.75
6	92.63
7	96.63

The ISIS payload was subjected to vibration testing along multiple axes during Test and Integration at Wallops Flight Facility in June 2008. This testing revealed weak connections between the thermocouple wires and the Thermal Science board mounted to the internal structure of the vehicle, which resulted in thermocouples failing to transmit during testing. The connection between the thermocouple wires and their motherboard was replaced and fortified once the payload was returned to UAF.

Three thermocouples attached to the skin, however, reported only intermittent data during the flight: TC7 transmitted only at the end of the flight, TC1 failed to report for approximately 50 seconds in middle of the flight, and TC4 failed to transmit during a brief period immediately after launch. The values plotted in Figure 3 have been averaged to remove noise.

Analysis of flight data. The data from the ISIS Thermal Science instrument displays two major subsets: thermocouples in the nose cone which registered sharp, intense peaks of heating during powered flight and exhibited purely radiative cooling during exoatmospheric flight, and thermocouples on the payload skin which exhibited gradual heating and less pronounced cooling.

Thermocouples on the nose cone of the vehicle experienced rapid aerodynamic heating during the first 22 seconds of flight. TCs within this subset are sensors 8-11. With the exception of TC 11 (discussed below), thermocouples nearer the tip of the vehicle (stagnation point) experienced greater heating.

The sensors which experienced the most extreme heating also experienced the most pronounced cooling. In this case TCs 8-10 displayed idyllic radiative cooling profiles, with temperatures dropping asymptotically towards ~63 C.

Thermocouples mounted to the skin of the rocket exhibited more gradual heating during powered flight. These sensors evince a lag behind the thermocouples mounted in the nose cone due to the time required for heat to conduct through the aluminum skin. These sensors also reported the temperature of the cylindrical portion of the vehicle, where aerodynamic heating was less intense.

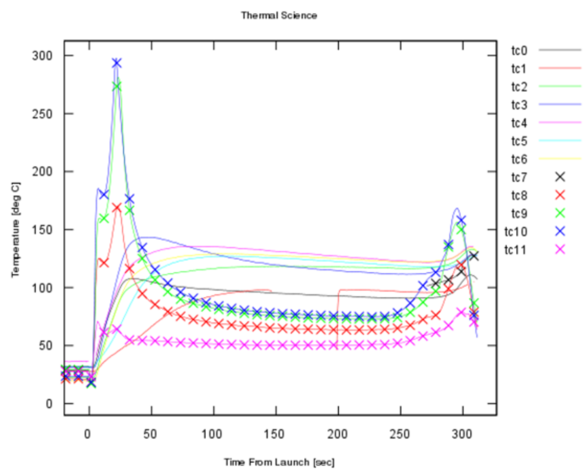

Figure 3: ISIS thermocouple outputs.

The highest temperatures on the vehicle were registered by thermocouple (TC) 10 at 21.6 seconds into the flight, 2.8 seconds before motor burnout. The maximum temperature recorded by TC 10 was 297.8 °C (757.8 °R). It is interesting to note that TC 10 was not the closest to the tip of the vehicle, where the greatest temperatures would be expected. The closest sensor to the nose tip, TC 11, was embedded in an aluminum washer between the steel nose tip and the fiberglass cone. TC 11 registered a maximum temperature of only 79.2 °C (539.2 °R).

This phenomena in the flight data is thought to result from the thermal capacitance of the brass ballast in the nose cone. The ballast – 25 lbs of brass – was physically attached to the nose cone tip (and, hence, the washer containing TC 11) via the 5/8-11 threaded support rod. Given the large thermal mass of the ballast, nose tip, and threaded rod combined (5.55 kJ/K), it is reasonable to conclude that this mass served as a heat sink for the nose of the vehicle. [6]

Comparison of Simulink model to flight data. Data aquired by the ISIS Thermal Science instrument validates some aspects of the SIMULINK model developed by Mr. Mudunuri and contradicts others. Figure 4 compares SIMULINK predictions against NSROC predictions. Note that the NSROC model divided the skin into five equal layers, with the "Block 1" layer outermost. The temperature of all five layers were averaged to predict overall shell temperature. [3] Figure 4 displays temperature predictions based on the SIMULINK model (blue), NSROC average skin temperature (green), and Block 1 skin temperature (red). Note that Block 1 temperature follows a profile similar to the nose cone thermocouples (which were located at the outer surface of the vehicle), while the average skin temperature generated by NSROC follows a profile similar to the ISIS skin thermocouples.

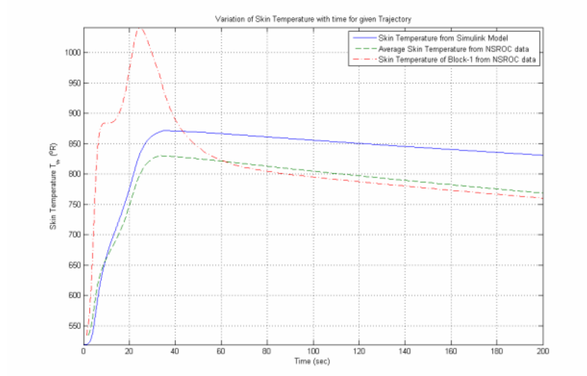

Figure 4: Predicted skin temperatures.

It is important to note that the SIMULINK model considered a point 66" from the nose tip, while the nearest thermocouples on the ISIS payload were located at 55" (sensor 8) and 76" (sensor 0). Sensor 8 read a maximum temperature of 170.8 °C (798.4 °R), while sensor 0 read a maximum of 111.17 °C (691 °R). Of further importance is the fact that sensor 8 was located on the nose cone of the vehicle, while sensor 0 was located on the aluminum skin - as stated previously, thermocouples in these two regions of the vehicle observed significantly different heating profiles. An interpolation between these two sensors, therefore, would be suspect. Further analysis is required to directly validate the SIMULINK model by interpolating ISIS skin temperatures at a point 66" from the nose tip. For the purpose of the below conclusions, Sensor 8 is assumed to have reported most closely the thermal conditions of the nose cone at 66".

In general, ISIS flight data shows lower temperatures than predicted by either SIMULINK or NSROC. Cooling during exoatmospheric flight reached much lower temperatures (605 °R actual vs. approximately 850 °R predict). Analysis is still underway to investigate the causes of these discrepancies.

Conclusion: The ISIS Thermal Science Instrument created a thermal profile of the ISIS sounding rocket payload in-flight. Data included two major subsets: thermocouples located at the outer surface of the vehicle, which experienced greater extremes of heating and cooling, and thermocouples mounted to the inner skin of the vehicle, which experienced more gradual effects.

Flight data verified aspects of the SIMULINK model developed by Mr. Venkata Mudunuri - however, the model could not be directly verified due to the physical location of thermocouples on the vehicle skin. Further work is required to directly validate the model via interpolation of flight data.

In general, ISIS flight data evinced lower temperatures than either NSROC or the SIMULINK model predicted.

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