HASP Student Payload Application for 2009

Payload Title:	**Detection of ozone and nitrogen oxides in the stratosphere using nanocrystalline sensor arrays on a high altitude balloon flight**.

Payload Class: (circle one)	Institution:	Submit Date:
Small* Large	University of North Dakota (UND) and University of North Florida (UNF)	12-18-2008

Project Abstract: The UND and UNF team had a successful HASP 2008 balloon flight for the measurement of the ozone gas profile in the stratosphere. The nanocrystalline ITO thin film gas sensor array developed by UNF was used for the detection of the ozone gas profile, while the signal conditioning and microcontroller circuits developed by UND team were used in the ozone sensors payload. The profile was nearly matched with the expected theoretical profile, but the maximum magnitude of the measured value of ozone was smaller by a few ppm than that of expected value because of effects from hurricane Ike during the flight period. Based on this fruitful experimental work, UND-UNF team is proposing for a HASP2009 flight for the reconfirmation of sensors data using improved versions of the sensors and payload. Three different types of ozone sensors: nanocrystalline ITO sensors on rigid substrates of glass and ceramic and on flexible substrate of polyimide will be added for the comparison of sensitivity and speed of response of sensors. Recently, the UNF team invented ITO flexible gas sensor arrays, which show better sensitivity than that of sensors on glass and ceramic. In addition, sensors for detection of nitrogen oxides (NOx) in the top of stratosphere will also be added. The stratosphere may heat up by absorbing UV radiation due to the destruction of ozone in the presence of NOx, which could trigger unanticipated climate changes. Sensors for ozone and NOx will operate at room temperature with no need of an external heater, which may diminish power consumption. In addition, higher bit microcontrollers will be used in the payload for the improvement of A/D conversion. The surface topography of sensors before and after flight will be studied using a scanning electron microscope, while chemical composition of the surface of sensors will be investigated by energy dispersive analysis of x-rays. This project continues through the Dakota Space Society student-led consortium.

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Detection of ozone and nitrogen oxides in the stratosphere using nanocrystalline sensor arrays on a high altitude balloon flight

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Abstract & Background Information

During the summer of 2007, indium tin oxide (ITO) thin film gas sensor arrays fabricated over alumina and glass substrates were successfully tested and calibrated with different concentrations of ozone (0.5 ppm to 14 ppm) under varying pressures using the Low-pressure Test Bed at the Space Life Science Lab (SLSL), Kennedy Space Center (KSC-XA), as a student project through Space Florida with the support of NASA. Afterward, the University of North Dakota (UND) and the University of North Florida (UNF) team made a joint effort to measure the ozone gas profile in the stratosphere through HASP 2008. A nanocrystalline ITO thin film gas sensors array developed by UNF was used for the detection of the ozone gas profile, while the signal conditioning and microcontroller circuits developed by the UND team were used in the ozone sensor's payload. UNF Sensors arrays (patent pending) were developed and fabricated at UNF with support of the Edgewood Chemical Biological Center, US Army lab, and the U.S. Department of Defense. The earlier reported tungsten oxide sensors for the detection of ozone gases (Hansford *et al*., 2005) required higher operating temperature of about 450^{o}C to detect ozone, whilst the UNF developed nanocrystalline ITO sensors arrays operates at room temperature and requires no high demand heater. This limited requirement ultimately helps satisfy the power requirement and space limitations. The measured ozone profile was nearly matched with the expected theoretical, but the maximum magnitude of measured value of ozone was smaller by a few ppm than that of the expected value because of the effect of hurricane Ike during the flight period. Based on this fruitful experimental work, the UND-UNF team proposes to participate in the HASP2009 flight to reconfirm the earlier obtained data using an improved version of the sensors and payload. This flight will also help to serve to validate data to be collected aboard a space borne payload with RockSat. In the proposed payload plan, three different types of ozone sensors: nanocrystalline ITO sensors on rigid substrates of glass and ceramic and on flexible substrate of polyimide will be added to allow the comparison of sensitivity and speed of response of sensors. Recently, the UNF team invented ITO flexible gas sensor arrays, which show better sensitivity than that of sensors on glass and ceramic for the detection of gases. ITO sensors on flexible substrates may offer new opportunities to widen the field applications of gas sensors. With reduced cost and no power consumption, it may now be possible to fix these sensors on surfaces payload, satellites, or space vehicles.

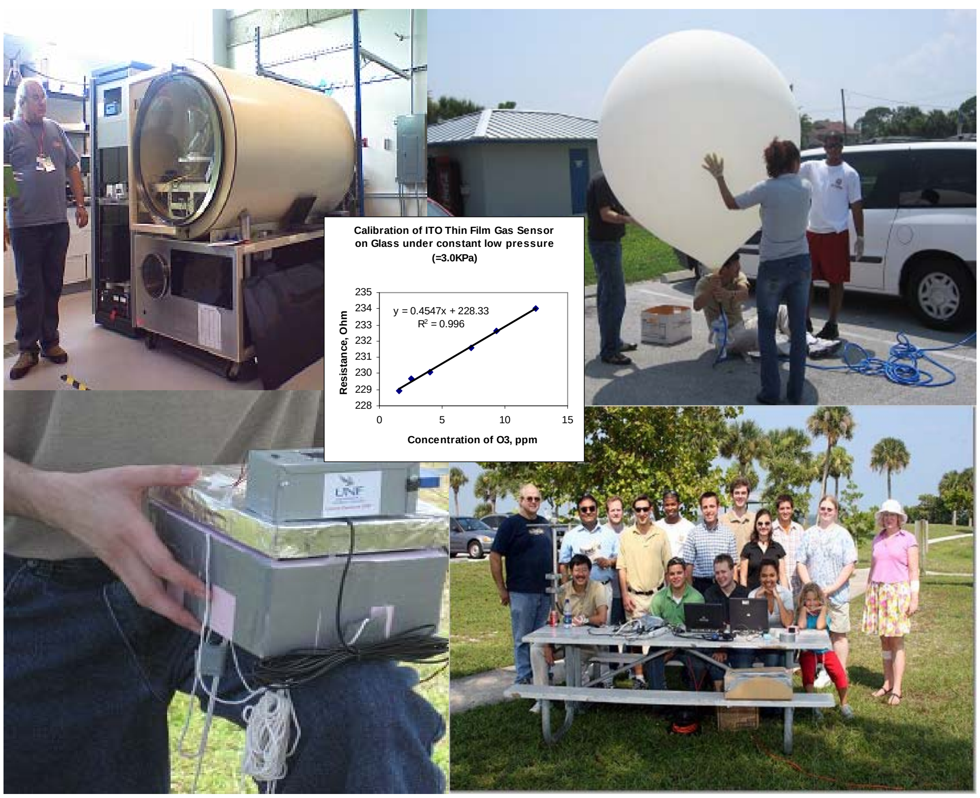
In addition, sensors for the detection of nitrogen oxides (NOx) in the top of the stratosphere will also be added to gain new scientific understanding. NOx contains varying amount of nitric oxide and nitrogen dioxide. Winds circulating high above the Arctic have impact on the upper stratospheric ozone level. The NOx extends from about 30 miles from the mesosphere to the top of Earth's stratosphere and destroys this ozone. The stratosphere may in turn heat up by absorbing UV radiation due to destruction of ozone in the presence of NOx, which could trigger

unanticipated climatic changes that are currently poorly modeled. Therefore, it is equally important to detect NOx when detecting ozone in the stratosphere. Sensors for ozone and NOx will operate at room temperature and demonstrate no need of an external heater, which will save the power consumption during flight. In addition, the use of a higher bit microcontroller in the payload will improve the resolution of the data, from the A/D conversion, and hence will increase the accuracy of measurements. The surface topography of sensors before and after flight will be studied using a scanning electron microscope, while the chemical composition of the surface of sensors will be investigated by energy dispersive analysis of x-rays.

PREVIOUS WORK AND ACKNOWLEDGEMENT

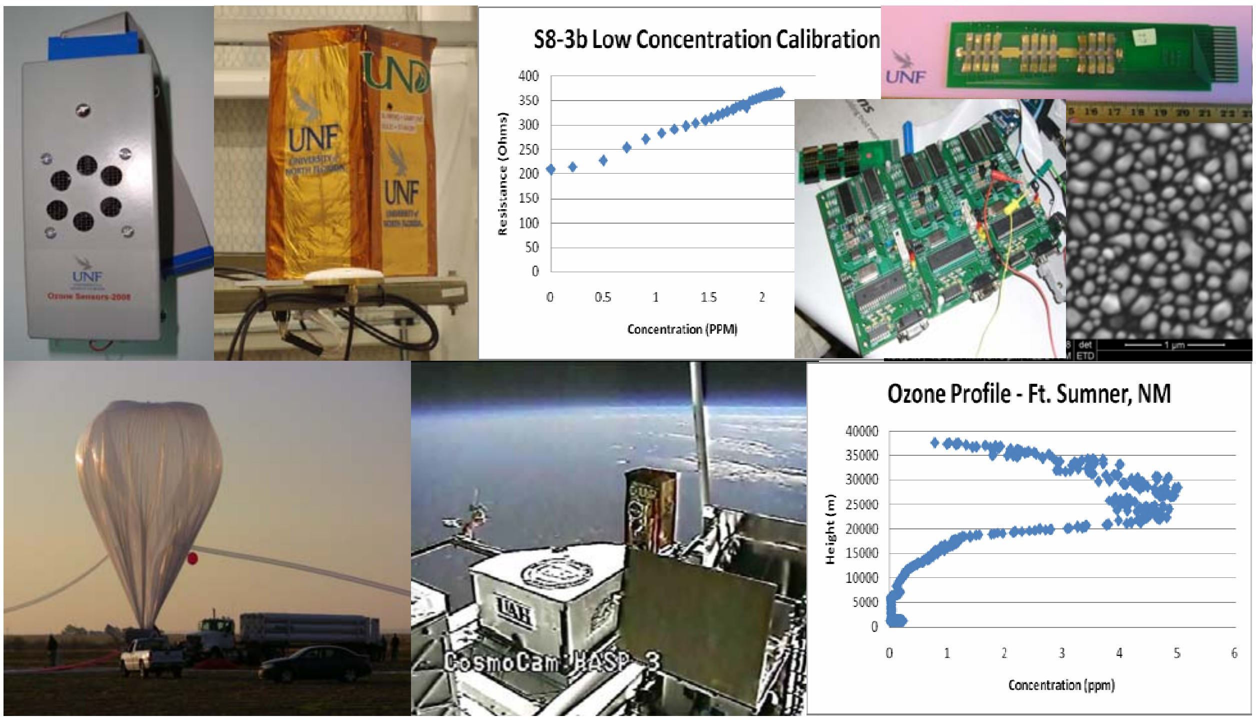
Year 2007

With the support of Space Florida and its summer students, UNF ozone sensors were tested and calibrated under low pressure at the SLSL, KSC-XA. The small payload was integrated and launched by balloon from Kelly Park - Port Canaveral, Florida. These images show the student directed research project mentored by NASA personnel, academic researchers, and Space Florida representatives. The payload and data was not recovered because of a failure in telemetry and GPS ground tracking.



Year 2008

With the support of HASP and the North Dakota Space Grant Consortium, UND and UNF made a joint effort to develop and integrate an ozone sensor payload. The payload was launched by on a HASP balloon flight for 32 hours. The payload worked successfully to measure the profile of ozone. The payload and data were recovered. Post-flight analysis of the payload noted very little change to the functionality of the sensors response and properties compared to a control sensor array.



SENSOR FABRICATION PLAN

Nanocrystalline ITO thin film gas sensors arrays for the detection of ozone gas and NOx gas will be fabricated at UNF. The undergraduate student team at UNF will be involved in the fabrication work under the supervision of Dr. Nirmal Patel. The UNF team will be in touch with their UND counterparts for the testing of sensors and for the interfacing of these sensors with the designed electronics.

STUDENT WORK PLAN

Student Work plan at the UNF

(1) Nanocrystalline Indium tin oxide (ITO) thin film gas sensors array will be fabricated over glass and alumina substrates for the detection of ozone gas as well as NOx gas.

(2) Nanocrystalline Indium tin oxide (ITO) thin film gas sensors array will be fabricated over flexible polyimide substrates for the detection of ozone gas

(3) The surface morphology of sensors before and after recovery of the payload will be examined using a Scanning Electron Microscope (SEM), and chemical composition of sensors will be determined using an Energy Dispersive Analysis of X-rays (EDAX) in order to check any possible damages on the surface of sensors.

(4) Sensors will be tested and calibrated with NOx at UNF, while with ozone gas at UND. Sensors parameters will be determined.

(5) The sensors' array will be interfaced with the printed circuit board (patent pending) and its 26-pin connector and cable.

(6) A miniature, flexible, and low power heater (Minco make) will be integrated on the backside of the sensor arrays. The purpose of the heater is to combat the low temperatures at troposphere and to keep sensors at nearly constant temperature around 25^{o}C. A miniature RTD will also be mounted to monitor and control the temperature using electronics circuit.

(7) Sensors' array with heater and printed circuit board will be mounted in the low weight aluminum box.

(8) A miniature low power fan will be mounted on the box so that fan can push the gas molecules over the surface of the sensors at the prescribed CFM. This will not affect the balloon's state. A wire mesh will be fixed over the fan in order to filter out dust particles as well as protect the surface of the sensors.

(9) The box containing the sensors, the heater, and the fan system will be delivered to UND for further interfacing with the microcontroller circuit and payload. The payload will be tested as per the guidelines of HASP on the ground before launch.

(10) If required, the necessary modification of sensors and/or circuitry will be performed after testing the electronic communication circuits at UND on a test flight.

Student Work plan at the UND

(1) Will improve the existing electronics design by the following steps:
  a. Add a greater bit rate for improved data resolution
  b. Add an internal clock to the program to time stamp measurements in synch with the HASP telemetry data
  c. Modify the mechanical design slightly to allow easier integration and deconstruction post-flight

(2) Test UNF sensors for compatibility with electronics.

(3) Test UNF sensors under O_3 with a low-pressure test chamber, internal generator, and secondary calibrated sensor source for reference.

(4) Perform whatever necessary steps to ensure a safe data recovery from flight, and successful mission.

Team Structure

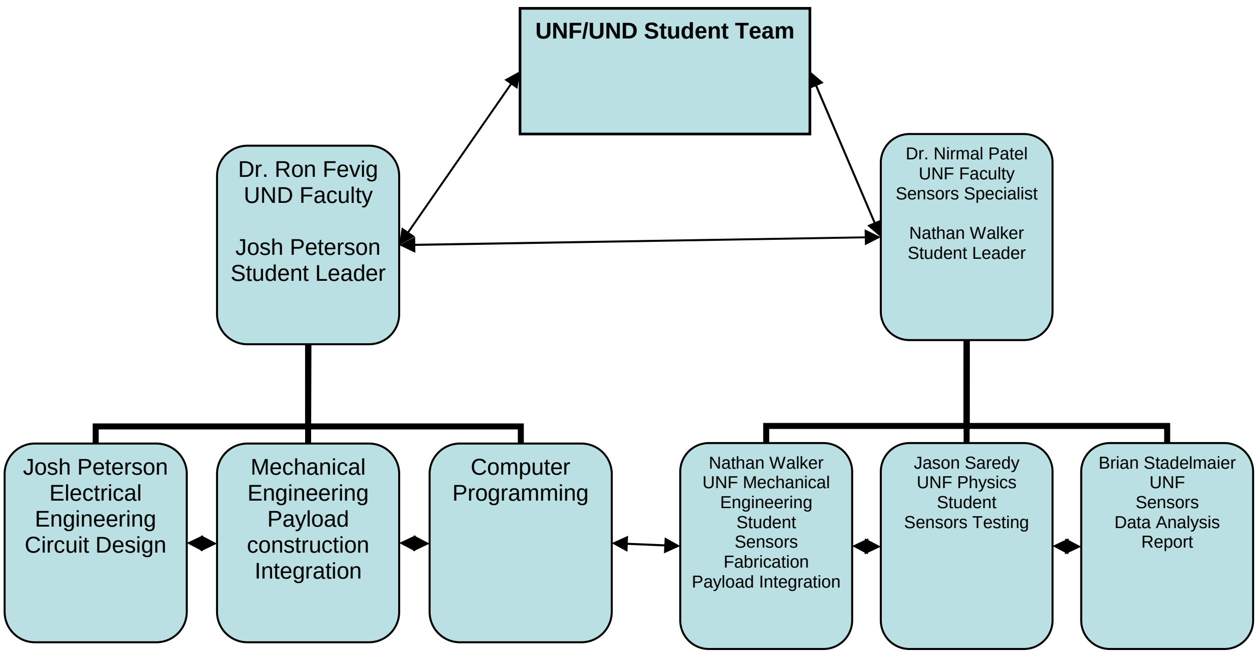


Fig.3 Team Management

UND and UNF Students Teams

The team structures and management methods will remain largely the same as the HASP 2008 effort.

UNF –

(1) Nathan Walker, active participant in the 2008 HASP effort

(2) Jason Saredy

UND-

(1) Nate Ambler (interim), will help establish the necessary framework garnered from the past flight to help support the 2009 HASP UND/UNF effort, and to assist in the RocketSat mission development. This position however, will be filled by a senior member of the Dakota Space Society (DSS) post graduation in the fall of 2008.

(2) Joshua Peterson, new member, who is also developing interchangeable electronics with the RocketSat will help incorporate these to the UND/UNF effort for 2009.

(3) Will Swearson, administratively handle many of the HASP matters for DSS.

(4) Additional, yet unidentified members will be added to the effort as the needs arise.

Task and Work Plan Path

The initial work break down schedule (WBS) includes the basic tasks required of the HASP project, which includes the Proposal, Integration Plan, Integration Certification, Operation Plan, and Science Report. However, this schedule also includes the strong intent to fly an identical payload locally through the High Altitude Ballooning group at the University of North Dakota (UND), this task includes creating an identical bus to that of HASP so that all anomalies can be detected in a true flight mode.

Month 09	UND	UNF
January	Payload Specification+Plan	Sensors Fabrication Plan+Desgin
Feb	Designing of circuit+Payload	Fabrication of Sensors
March	PCB Fabrication+Programming	Interface PCB+ Testing of Sensors
April	Testing of Circuit with Sensors	Sensors parameters +Calibration
May	Payload building+Sensors Testing	first deliver of sensors to UND for testing
June	Payload Testing at UND	Feedback from UND+Imrpovment
July	Sensors Calibration+Integration	Final fabrication+Intergration of sensors box
August	Testing of Payload at CSBF, TX	Integration of sensors with payload at CSBF
September	Launching Payload+Data+ Analysis	
October	Payload Recovering+Testing of sensors+SEM+EDAX analysis+Failure analysis, if any	
Navember	Data analysis+Report Writing	
December	Submission of Science Report	

Note: We can adjust our work plan if there will be early an launch schedule

Fig. 4 Work plan path

HASP Integration

It is expected that a minimum of three students from UND and UNF and one faculty member from UND/UNF will travel to CSBF, Palestine, Texas in late July/ Early August of 2009 (as per the date given by HASP) for the integration of the sensor payload onto HASP. It is expected that approximately four students from UND and UNF and two faculty members (UND and UNF) will travel to Ft. Sumner for launch of the HASP payload.

Payload Specification

The sensor operates and ozone gas measurements are processed according to the electronics block diagram shown in Fig. 5. Resistance values from the ozone sensor are converted to voltages by the conditioning circuitry, which are then read by an LTC1298-based A/D converter. These values are processed by a BS2-IC microcontroller which interfaces with the HASP data handling system. Temperature and pressure sensor readings are processed in a similar manner and are folded into the data stream by the microcontroller. Power from HASP is conditioned by circuitry based on LM78LXX voltage regulators and is provided to each payload electrical subsystem in Figure 5.

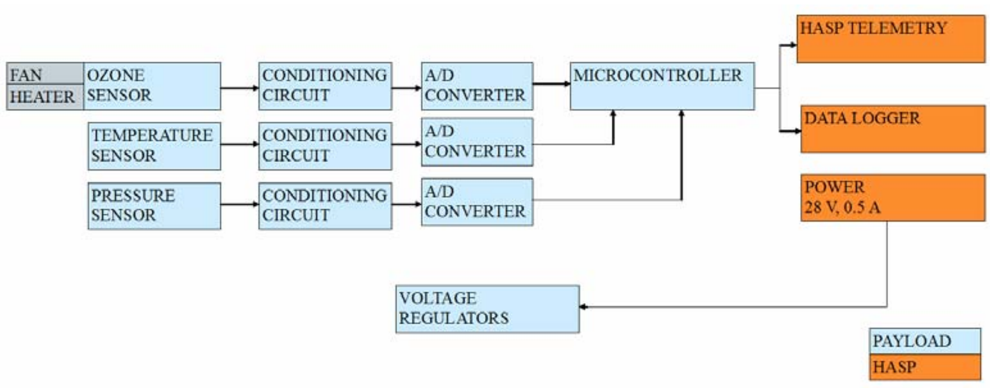


Fig. 1 Electronics Block Diagram

Mounting Footprint

Selection of the small payload dictates the mounting plate that interfaces with the payload. This mounting plate design is provided in the HASP Student Payload Interface Manual (Version 02.08.08) and is shown below in Fig.6. This mounting plate design will not require modification.

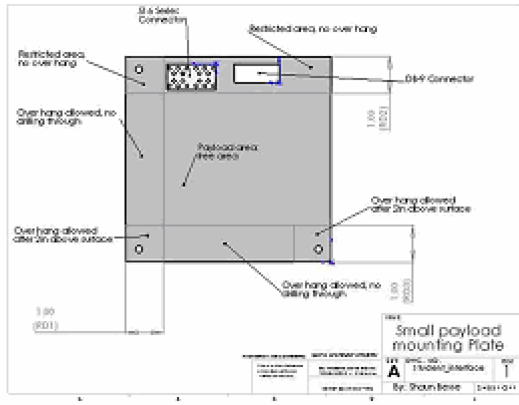


Fig 2 – Mounting Plate (Besse, 2007 and HASP Version 02.08.08)

Desired location and orientation

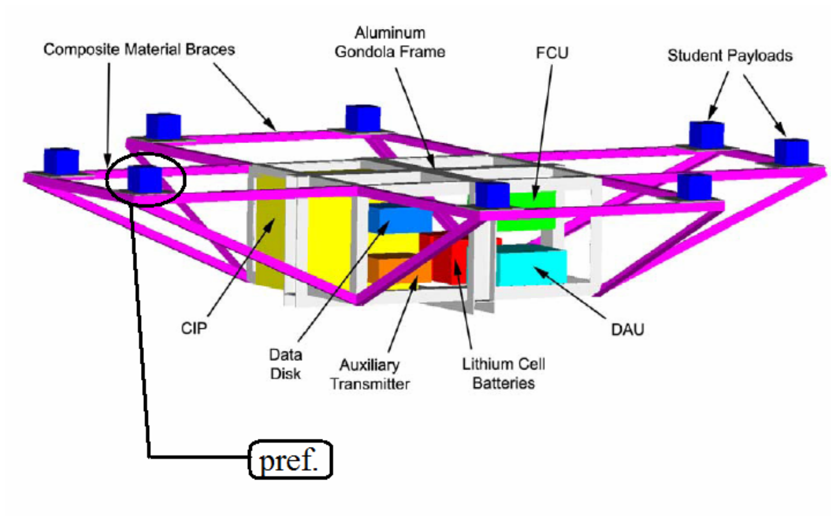


Fig. 3 – Proposed HASP Configuration (Guzik and Wefel, 2004)

The requested smaller payload should be oriented on the side away from any solar cells to avoid disparate solar thermal radiation. There should not be any obstacle for air circulation into payload. We also prefer that CosmoCam camera should focus our payload, particularly at the night time to watch the blinking of LED for data collection.

Payload Dimension

This payload requested is the small payload; its height will be 30 cm, and the sides will be 15 cm x 15 cm.

Payload Mass Budget

The mass budget is itemized below in Table 1.

Table 1 – Itemized Mass Budget

Item:	Mass:
Sensors (including RTD, fan, heater, box)	500g
SS Data Recorder	250g
Temperature Regulator	300g
Connections	400g
Structure	550g
Total	**2000g**

This is less than the 3 kg limit for the smaller payloads.

Payload Power Budget

The 0.5 Amps at 30 VDC power supplied by HASP adequately accommodates the power requirements for the payload electronics, as well as the heater and fan for the sensor. Table 2 details the preliminary estimate for our power budget

Table 2 – Itemized Power Budget

Item:	Power requirement:
Payload Electronics	1 W
Sensor Heater	8 W (max.)
Sensor Fan	2 W
Total	**11 W**

This is less than the 15 W limits for the smaller payloads.

Preliminary heat transfer calculations, utilizing such equations as shown in equation 1, heat transfer, showed the onboard sensor heater is adequate to keep the sensor at nominal conditions. An additional exploration of the effects of temperature on component integrity is ongoing, and part of the investigation. These initial estimations utilized the proposed materials for the walls, and a minimum temperature of -60^{o}C and a general operating temperature of 15^{o}C (found from altitude variation from 0 km to 36 km shown in the modified Fig. 8, altitude profile).

Equation 1 – Heat Transfer

$$q = m(\Delta T)C_p$$

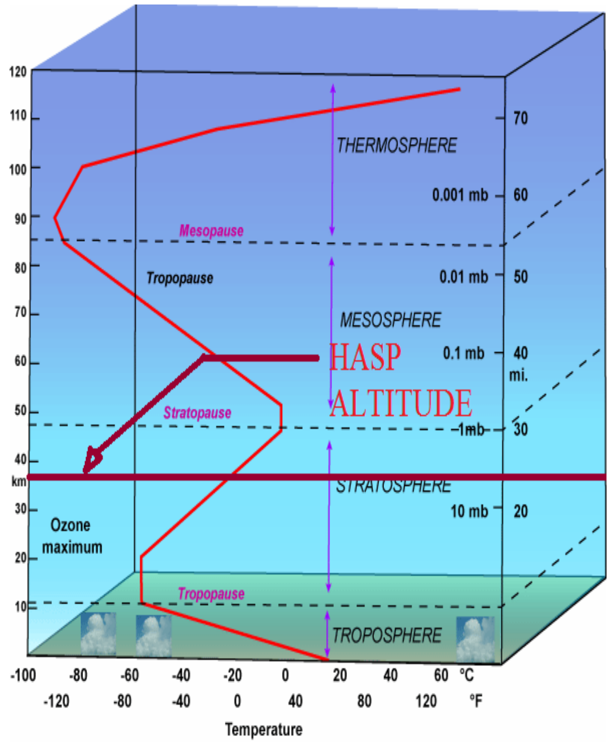


Fig. 4 – Modified Altitude Profile (Atkins, 2007)

As per the instructions, on the EDAC 516 power connector only pins A,B,C,D are wired to the payload as +30 VDC power supply and pins W,T,U,X are wired to your payload as power ground to avoid failure to the power circuit or loss of payload. A voltage regulator is not necessary according to initial tests despite the slightly higher +33 VDC at launch for the sensor; however, a voltage regulator and divider will be used for peripherals.

Downlink Serial Telemetry Rate

The payload module requires the RS232 HASP telemetry to send the state of resistance to the ground. A data-recording unit will be included with master controller in the event that the telemetry link fails. The DB9 connecter is required to the HASP system's telemetry system so that the data can be sent to the base station via the RS232 link. The RS232 link will operate at 2400 baud, with the standard RS232 protocol with eight data bits, no parity, one stop bit, and no flow control. A standard packet will contain the information-formatted vis-à-vis the Student Payload Serial Connection section of the HASP-Student Interface Document.

Uplink Serial Command Rate

No uplink commands are anticipated.

Anticipated Use of analog Downlinks

No additional analog downlinks are anticipated.

Anticipated Additional Discrete Commands

No additional active discrete commands are anticipated.

Anticipated Procedures

Prior to Integration:

- Calibration / Testing of sensors
- Set initial values for data recorder
- Place sensors in appropriate payload slots
- Check program and LED for status

Integration:

- Mount payload module to HASP
- Connect HASP Power Connector
- Connect HASP Serial Connection
- Test system by recording initial readings and making sure all data is nominal
- Troubleshoot

Pre-Flight Operations and testing:

- Set initial values for data recorder
- Place sensors in appropriate payload slots
- Check all batteries
- Connect HASP Power Connector
- Connect HASP Serial Connection
- Check mass and size pf payload
- Test thermal-low temperature and high temperature test
- Test pressure and vacuum test
- Test 10g vertical and 3 g horizontal test

Flight Operations:

- Record values for resistance across the sensors

Post-Flight Operations:

- Examine all parts of payload
- Remove all PCB and sensors box, test PCB with power
- Send sensors box to UNF for electrical testing, SEM+EDAX analysis, failure analysis.

Financial Considerations

The majority of developmental costs will be incurred under the currently funded RockSat effort; however, incidental expenses will require additional funding sources to be identified in the upcoming future. UNF will now seek funding for its expenses through Space Florida and UND will continue to rely on the NDSGC and additional funding sources (*e.g.* DSS, Student Senate, University Research).

Additional Questions and Considerations

At the request of another student and faculty member at UND, we have considered incorporating a biological payload into our own. This secondary payload would test lettuce sprouts against the effects of the low pressure and high UV conditions in the stratosphere. This secondary payload would require additional payload volume in excess of the dimensions allotted by the small payload limits. We would be interested in obtaining a large payload slot is one is available.

References

(1) Guzik, T. Gregory and John P. Wefel. "The High Altitude Student Platform (HASP) for Student-Built Payloads." 35th COSPAR Scientific Assembly. Houston, Texas, 2004. 1-8.

(2) Hansford, Graeme M., et al. "A low cost instrument based on a solid state sensor for balloon-borne atmospheric O3 profile sounding." Journal Environmental Monitoring (2005): 158-162.

(3) HASP – Student Payload Interface Manual, Version 02.08.08
http://laspace.lsu.edu/hasp/documents/public/HASP_Interface_Manual_v20808.pdf

(4) Atkins, Noel. Survey of Meterology. 10 November 2007
<http://apollo.lsc.vsc.edu/classes/met130/notes/chapter1/vert_temp_all.html>.