HASP Student Payload Application for 2016

Payload Title: The Acoustic Background of the Stratosphere		
Payload Class: (check one) X Small Large	Institution: UNC Chapel Hill	Submit Date: 12-18-2015

Project Abstract

Over the last two years, infrasound microphone arrays flown on the HASP have revealed a remarkably complex acoustic wave field in the stratosphere. While some of these signals are analogues for those seen on ground based arrays, others appear to be new to science. During the previous two HASP flights, however, the infrasound microphones have had inconsistent amplitude responses. Furthermore, interference from the HASP telemetry system or other payloads has created spurious signals in the infrasound data. During the HASP 2016, we seek to quantify the presence of spurious signals on stratospheric infrasound arrays, identify and mitigate the source of amplitude discrepancies during flight, and acquire additional observations of low frequency sounds. Results from this experiment will shed further light on the nature and variability of infrasound in the stratosphere as well as permit confident interpretation of the approximately 30 hours of acoustic data we have already collected.

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The Acoustic Background of the Stratosphere

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Abstract

Over the last two years, infrasound microphone arrays flown on the HASP have revealed a remarkably complex acoustic wave field in the stratosphere. While some of these signals are analogues for those seen on ground based arrays, others appear to be new to science. During the previous two HASP flights, however, the infrasound microphones have had inconsistent amplitude responses. Furthermore, interference from the HASP telemetry system or other payloads has created spurious signals in the infrasound data. During the HASP 2016, we seek to quantify the presence of spurious signals on stratospheric infrasound arrays, identify and mitigate the source of amplitude discrepancies during flight, and acquire additional observations of low frequency sounds. Results from this experiment will shed further light on the nature and variability of infrasound in the stratosphere as well as permit confident interpretation of the approximately 30 hours of acoustic data we have already collected.

Contents

1 Experiment

Acoustic waves are generated in the atmosphere via changes in mass flux, motion of embedded objects, or variations in flow fields. As they propagate from source to sensor, they also encode information about temperature and wind variations they encounter. Thus, sound can be used to remotely detect both natural phenomena (i. .e volcanic eruptions) and human activity (i. e. clandestine nuclear blasts) as well as sample regions of the atmosphere that are difficult to characterize by other means. Below-audible frequency sound, or "infrasound" (< 20 Hz) is particularly valuable as it can travel for thousands of kilometers without significant attenuation.

While acoustic waves propagate in three dimensions, the vast majority of sensor arrays are located on the Earth' surface. Prior to the HASP 2014 flight, in fact, there were apparently no attempts to detect infrasound at altitudes above 8 km for over half a century (Bowman and Lees, 2015). The HASP project thus provided an unparalleled opportunity to fill this 50 year measurement gap. Acoustic arrays flown on the HASP 2014 and 2015 recorded infrasound from the "ocean microbarom," pressure fluctuations from atmospheric gravity waves, hydrodynamic noise during ascent and descent, and a variety of other signals of unknown origin. Indeed, the flying sensors recorded a fundamentally different wave field compared to ground infrasound sensors in the same region (Bowman and Lees, 2015, 2016).

The HASP 2014 flight was primarily a proof of concept, showing that acoustic signals could be recorded on arrays lifted by stratospheric balloons. The HASP 2015 improved the fidelity of the acoustic sensors by keeping them in linear amplitude range and reducing temperature variations. Data from this flight indicated that vortex shedding and cable vibrations likely do not affect the infrasound microphones once the array reaches the stratosphere. However, signal amplitudes continued to vary between different microphones, and several sensors had clear evidence of electronic interference from an unknown source. Until the characteristics of this interference are fully known, and ideally its source identified, many of the more unusual signals recorded over the last two years must be treated with suspicion.

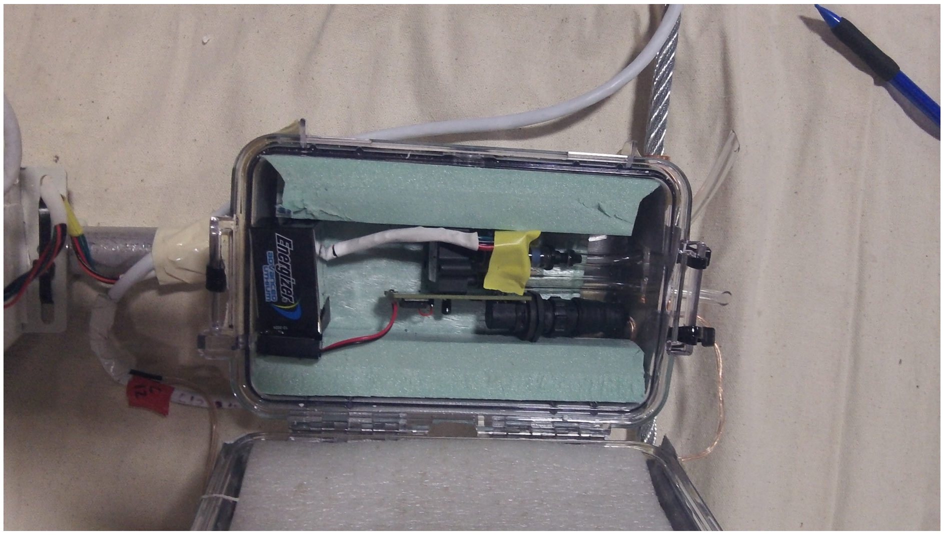


Figure 1: Infrasound microphone attached to the HASP 2015 flight ladder. The casing has been opened to reveal the instrumentation inside.

To address this issue, we propose to do the following:

1. **Quantify the nature and source of non acoustic signals related to electromagnetic interference**
2. **Determine which signals are localized to the HASP by deploying an independent stratospheric infrasound network**
3. **Collect acceleration and temperature data at high sample rates**
4. **Operate a robust ground infrasound network with attention to wind mitigation**

We will accomplish the first goal by co-locating three sensors at two different locations on the HASP flight ladder, for a total of two infrasound stations. One station will be at the top of the flight ladder and one will be on the bottom. Each station will consist of an InfraBSU infrasound microphone with a mechanical filter configured for stratospheric observations per the design used in the HASP 2015 (see Figure 1).

The second sensor at each station will be an InfraBSU microphone with the mechanical filter removed, creating a differential pressure transducer with two open ports. In theory, this should result in no pressure signals being recorded for the entire flight; if signals are recorded, they will indicate interference from another source. In practice, such bare microphones do tend to record high frequency waves and wind noise due to the spatial separation of the two ports, but the signals are attenuated by over an order of magnitude (Figure 2). The third sensor will simply measure the voltage drop across a bare resistor; this will quantify interference from poor cable shielding or issues with the data logger.

We will address the second goal by launching an independent infrasound network via a Mylar sounding balloon. This network will consist of two infrasound microphones carried by the Boomerang balloon flight control system. The Boomerang unit permits the altitude of a Mylar sounding balloon to be controlled via gas venting and ballast dropping. The planned float altitude and flight duration of this second station will depend on the timing of the HASP flight campaign. If HASP is launched prior to the stratospheric turn around, the Boomerang target altitude will be the wind minimum at approximately 20 km. Otherwise, the Boomerang will be inserted at approximately 30 km. Launch timing and flight path will be discussed with CSBF. The balloon and payload will be in compliance with FAR 101.1(4).

The third goal is to verify the lack of significant vibrations during flight as suggested by results from the HASP 2014. However, the HASP 2014 accelerometer operated at 1 sample per second, which is too low to capture vibrations that may occur from "violin string" oscillations of the flight ladder. We propose to install an accelerometer operating at 400 Hz, which is our standard sampling rate for infrasound on previous HASP

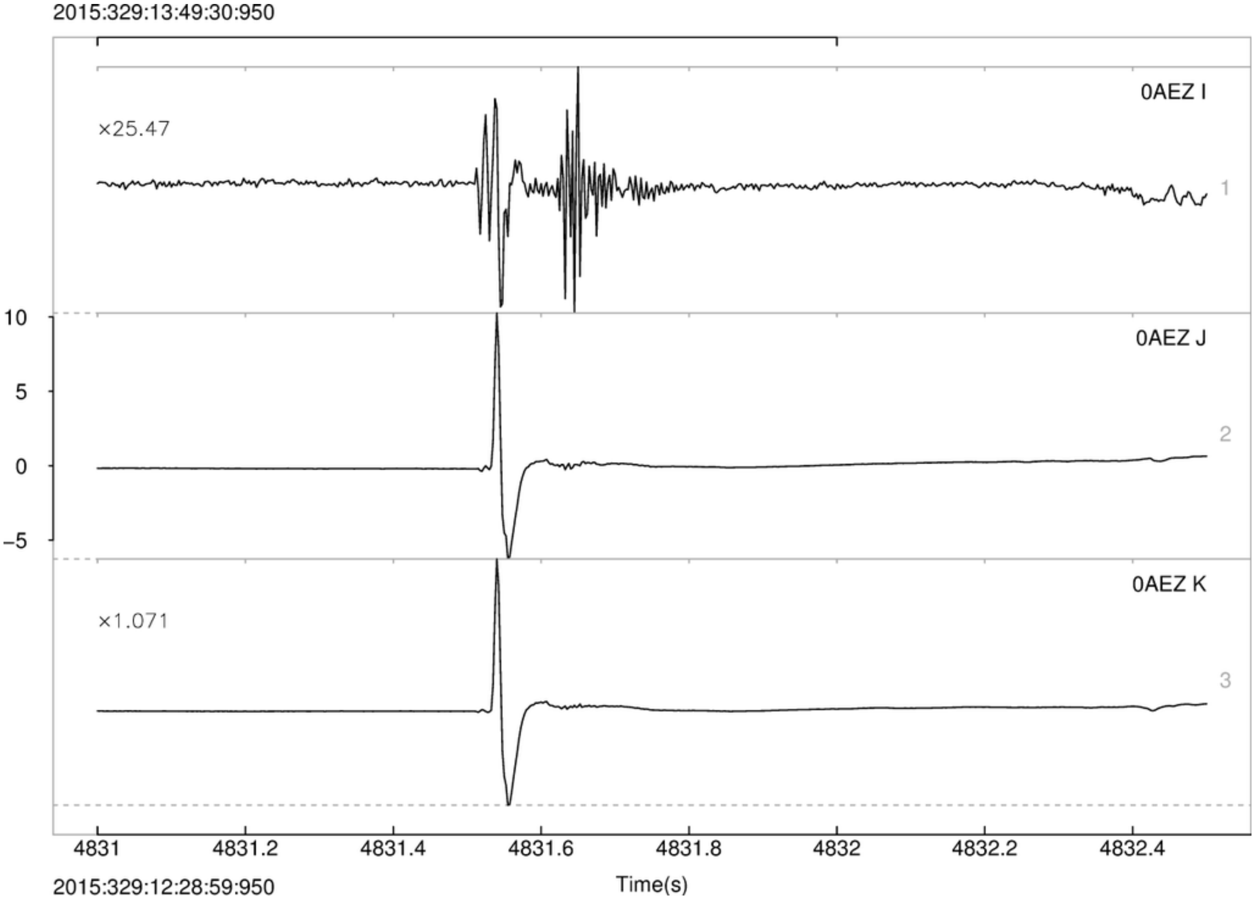


Figure 2: A weather balloon burst recorded on a differential pressure transducer (top) and two infrasound microphones (bottom). The bare transducer is attenuated 25 fold compared to the complete microphones. Y-axis is in Pascals.

flights. Also, HASP 2015 had temperature sensors on only two of the nine infrasound microphones; it would be instructive to collect further data on temperature variations between all microphones during flight. This is a possible, though unlikely, explanation for some of the amplitude variations experienced over the last two years.

The fourth objective is to operate three very low noise infrasound arrays near the launch site in Ft. Sumner. Two arrays were deployed in the region during the 2015 campaign, but the signal to noise ratio was poor due to wind effects. This has made it difficult to search for common signals detected on the ground and HASP during flight.

1.1 Scientific Objectives

- Compare the nature of the ocean microbarom peak to the one detected during past HASP flights
- Ascertain the time scale of different acoustic phenomena in the stratosphere
- Record signals from thunderstorms or mine blasts if the opportunity arises
- Robustly quantify the infrasound environment (amplitudes, frequencies, and direction of arrival) in the Ft. Sumner area

1.2 Engineering Objectives

- Separate acoustic and non acoustic signals recorded on the infrasound sensor array through all portions of the flight
- Characterize high frequency motion of the flight ladder in three dimensions
- Keep microphones in operational temperature range (-25 to 50 Celsius) at all times
- Improve payload box design to minimize temperature fluctuations

2 Payload Design

Our payload consists of four systems: infrasound sensing/noise characterization packages on the flight ladder, an accelerometer package on the flight ladder, a flight imaging and temperature logging system on the payload plate, and Gem infrasound loggers on the flight ladder and the gondola.

2.1 Infrasound Sensing/Noise Characterization Packages

Two infrasound/noise packages will be located on the flight ladder, one at the top rung (towards the balloon) and the other on the bottom rung (towards the gondola). Each package will consist of one infrasound microphone with a mechanical filter. This microphone will record infrasound signals. Another infrasound microphone will not have a mechanical filter attached, and should not record any pressure fluctuation signals during flight. A third sensor will consist of a bare resistor attached to the same type of battery as the microphones use; this will measure cable inductance and battery voltage fluctuations. Finally, a digital temperature sensor will record the internal temperature of the package and convey it to the payload plate via a white shielded Cat 6 Ethernet cable. Signals from the two microphones and the resistor will be digitized inside the package on an Omnirecs DataCube3. Power for the DataCube will be drawn from the HASP gondola and conveyed to the flight ladder on one channel of the Cat 6 cable described previously. Note that placing the loggers on the flight ladder departs from HASP 2014 and HASP 2015; in this case we are trying to avoid sending analog signals down long lengths of cabling. The package will be constructed of shatterproof clear Acrylic covered on the outside with white duct tape to reflect sunlight and aluminized Mylar on the inside to trap heat. It will be attached to the flight ladder rung with 3 metal U-bolts. The microphones and resistor will be powered using 9 volt lithium batteries.

2.2 Acceleration Package

The acceleration sensing package will be attached to the middle rung of the flight ladder. It will consist of an ADXL 345 accelerometer with a range of ± 2 g. The signals will be digitized on a DataCube at the same sample rate as the infrasound microphones (400 Hz). Power for the DataCube and accelerometer will be drawn from HASP via the CAT 6 cable.

2.3 Cameras and Telemetry

Two prototype Raspberry Pi video acquisition systems were flown on HASP 2015, one looking down (to monitor phenomena beneath the balloon) and one looking up (to monitor sensors on the flight ladder). Both of these failed during the ascent from a suspected GPS glitch. We will design new versions of these loggers that are more error tolerant. The downward facing camera will monitor aircraft and thunderstorms beneath the balloon as well as permit quantification of the rotation and side to side motion of the gondola. The upward facing camera will monitor the balloon's shadow, observe any motion of the flight ladder, and look for evidence of wind gusts. An Arduino Uno on the small payload plate will record temperature signals from the flight ladder and transmit them to the HASP telemetry system.

2.4 Gem Loggers

Two prototype Gem infrasound microphone/logger combinations were flown on HASP 2015, both of which operated nominally throughout the day and into the night. These devices are very low weight and draw very little power, making them ideal for future balloon flights where mass and power minimization may be critical. However, they suffered from high levels of electronic noise and eventually failed due to low temperatures during HASP 2015. We propose to test the new generation of Gems by mounting them on two rungs of the flight ladder and one on the payload plate. Gems on the flight ladder will be independently powered via a 9 volt lithium battery, while the Gem on the payload plate will draw power from HASP. The Gems will augment the infrasound detection capability of our network and contribute to our ability to conduct infrasound balloon flights independent of HASP.

2.5 Thermal Management

During the HASP 2015, we covered our microphone packages with white tape and our payload plate with an aluminized Mylar sheet to reflect sunlight. This system worked well during the day, keeping temperatures between 5 and 25 C during float. However, the microphone packages dropped to -50 C and instrumentation on the payload plate approached -40 during the night. Temperatures were also very low while crossing the tropopause. Therefore, we plan to keep our outer reflective coatings, but thermally insulate the interior of our instrumentation packages to prevent extreme temperature drops at night. This insulation will consist of foam padding and an inner layer of aluminized Mylar to reflect infrared radiation back into the package.

2.6 Communications

Temperature data from the three instrumentation packages on the flight ladder will be transmitted to the ground via the HASP telemetry system. Each packet will consist of a GPS time stamp, 3 16 bit temperature records, and a checksum. The POWER ON command will be issued just prior to launch, and we request that power be maintained to our payload as long as possible. Continued payload power after impact is desired.

2.7 Power and Mass Budget

The DataCube3 acoustic data loggers, Arduino temperature logging system, cameras, and one gem logger will utilize HASP power (Table 3). The total power draw will be 5.9 W, well beneath the maximum allowed draw of 15 W. The microphones, bare resistor, and gem loggers on the flight ladder will be powered using 9 volt lithium batteries.

Instrumentation and cabling on the flight ladder will total about 6.6 kg (see Table 1). This weight may vary by ± 1 kg depending on the final attachment system and enclosure material. The payload plate will

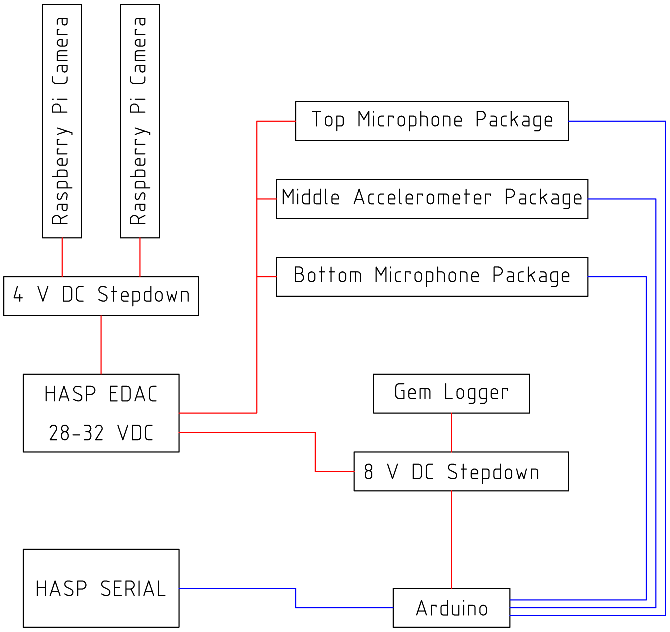


Figure 3: Power and communications between HASP and the proposed payload. Power supply is in red and data channels are in blue.

support 0.92 kg, with an uncertainty of ± 0.25 kg depending on the configuration of the cabling and the payload box (Table 2).

2.8 Flight Event Sequence

The infrasound microphone, bare differential pressure transducer, and voltage monitored resistor will be attached to independent 9 volt lithium batteries as close to launch as possible. The timing of this procedure will be negotiated with CSBF; it may be feasible to turn them on the morning of the launch (as we did in 2014) or the day before (as we did in 2015). After pickup but before roll out, the Cat 6 cable between the flight ladder and the gondola will be attached to the payload plate. We do not anticipate any further action after this cable has been attached.

2.9 Hazards

We do not anticipate any hazards during setup, launch, and flight. However, recovery personnel will need to use caution when recovering the flight ladder in case the lithium batteries in the microphone packages have burst during impact. Experience over the last two flights indicate that this is rather unlikely.

3 Project Management

The team consists of two graduate students and two undergraduates. Daniel Bowman (Graduate, UNC Chapel Hill) will initially serve as team leader. He will train Kayla Sieffert and Ethan Dinwiddie (Undergraduates, UNC Chapel Hill) as they take on engineering and leadership roles on the HASP project. They will also participate in at least one attempt to record infrasound via arrays on weather or solar balloons. As the project proceeds, Kayla will take on the position of Team Lead. Kayla and Ethan also will be responsible for the majority of the final scientific report in December 2016. Jacob Anderson (Graduate, Boise State University) will be responsible for preparation of the Gem loggers. Dennis Phillips (Graduate, Michigan State University) will be consulted during instrumentation development and may contribute additional logging systems. Dr. Jonathan M. Lees (UNC Chapel Hill; jonathan.lees@unc.edu) will serve as faculty advisor. We anticipate bringing 2-3 team members to testing in Palestine and launch at Fort Sumner. The team will prepare manuscripts for submission in peer-reviewed journals if sufficient scientific and engineering objectives are achieved.

3.1 Timeline

- *January* Begin training Kayla and Ethan in instrumentation and engineering
- *February/March* Assemble and test infrasound/noise sensing packages
- *April* Construct acceleration and camera systems, configure Gem loggers for flight
- *May-June* Test full HASP array
- *July* Thermal/vacuum test in Palestine, Texas
- *August/September* HASP flight
- *September-December* Analysis of flight results

4 Mass and Power Budget Tables

Table 1: Estimated Mass on Flight Ladder

Item	Quantity	Item Mass kg	Total Mass kg
Instrumentation box	3	1.0	3.0
Omnirecs DataCube3	3	0.71	2.1
Microphone	4	0.060	0.24
ADXL Accelerometer	1	0.002	0.002
9 Volt Lithium Battery	9	0.004	0.036
Gem Logger and Enclosure	2	0.25	0.50
Cabling (75’)	1	0.70	0.70
Total			6.6

Table 2: Estimated Mass on Payload Plate

Item	Quantity	Item Mass kg	Total Mass kg
Instrument Enclosure and Attachment	1	0.50	0.75
DC Voltage Stepdown	2	0.011	0.022
Arduino Logger	1	0.022	0.022
Gem Logger	1	0.10	0.10
Raspberry Pi Camera System	2	0.054	0.11
Cabling	1	0.20	0.20
Total			0.92

Table 3: Estimated Maximum Power Draw

Item	Quantity	Item Power Draw W	Total Power Draw W
Raspberry Pi Camera System	2	2	4.0
Arduino Logger	1	0.50	0.50
Gem Logger	1	0.20	0.20
DataCube3	3	0.38	1.2
Total			5.9

References

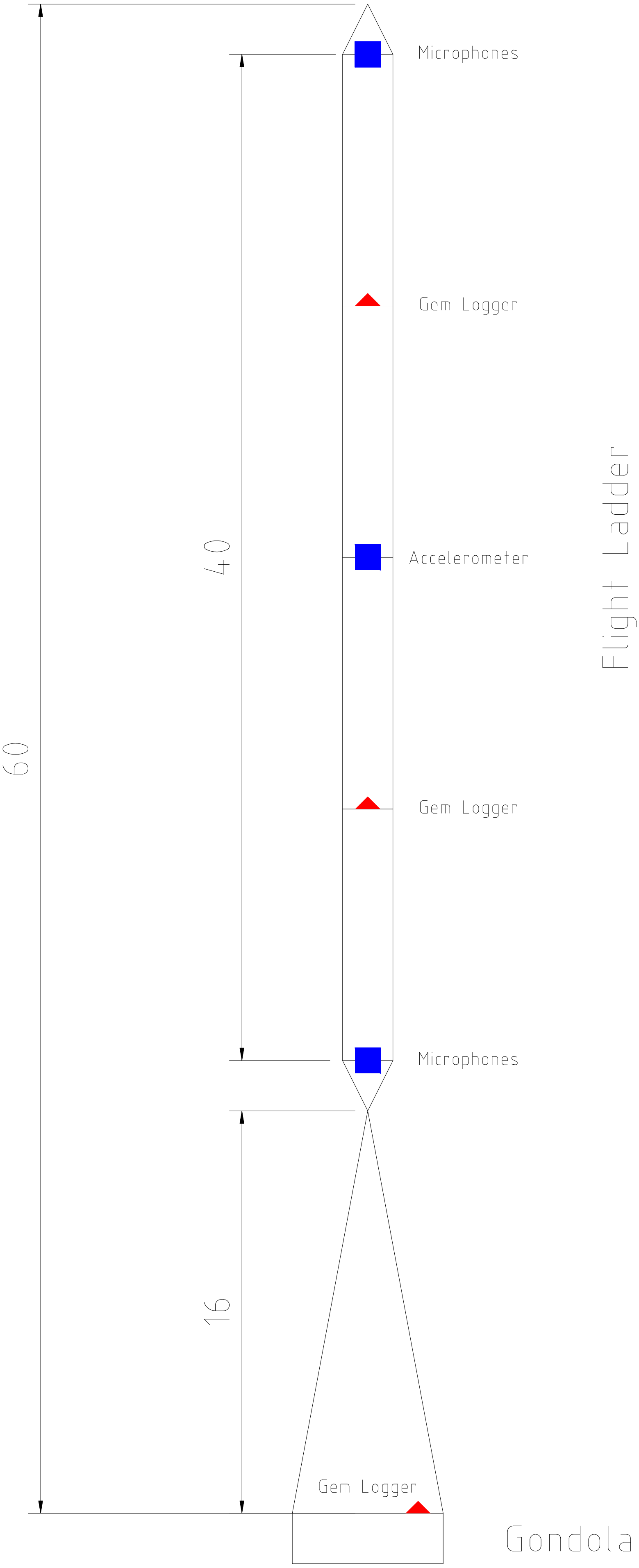
Bowman, D. C. and Lees, J. M. (2015). Infrasound in the middle stratosphere measured with a free flying acoustic array. *Geophysical Research Letters.*

Bowman, D. C. and Lees, J. M. (2016). Direct measurement of the acoustic wave field in the stratosphere. In *Proceedings of the 2016 IEEE Aerospace Conference.*

A Technical Drawings

Units of A-1 are feet. Units of A-2 are centimeters.

A-1: Location of Sensors



A-2: Microphone/Accelerometer Packages