HASP Student Payload Application for 2015

Payload Title:
Quantifying Stratospheric Infrasound with a Free Flying Acoustic Network

Payload Class: (check one)	Institution:	Submit Date:
Small ✠ Large	UNC Chapel Hill	12-19-2014

Project Abstract

The flight of the UNC payload on HASP 2014 demonstrated the successful operation of a free flying acoustic sensor array in the stratosphere. A wide variety of pressure fluctuations spanning five orders of magnitude in frequency were recorded. However, the provenance of these signals was difficult to ascertain, raising the possibility that some of them may have been due to vibrations on the HASP gondola or other non-acoustic sources. The joint UNC/NC State experiment proposed here will address this issue by using a suite of temperature, vibration, and wind sensors in addition to an expanded acoustic array. We will improve the design of our acoustic sensors to keep them in linear amplitude range throughout the duration of the ascent and float portions of the flight. In addition, we will develop instrumentation and measurement techniques for future independent (non-HASP) airborne acoustic arrays by lowering an independent data logger/microphone package beneath the gondola. We expect the array to verify detection of ocean wave infrasound observed in HASP 2014, determine whether episodes of broadband pressure fluctuations are due to wind noise or clear air turbulence in the troposphere, and evaluate the source of numerous narrowband signals observed during float.

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Quantifying Stratospheric Infrasound with a Free Flying Acoustic Network

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Abstract

The flight of the UNC payload on HASP 2014 demonstrated the successful operation of a free flying acoustic sensor array in the stratosphere. A wide variety of pressure fluctuations spanning five orders of magnitude in frequency were recorded. However, the provenance of these signals was difficult to ascertain, raising the possibility that some of them may have been due to vibrations on the HASP gondola or other non-acoustic sources. The joint UNC/NC State experiment proposed here will address this issue by using a suite of temperature, vibration, and wind sensors in addition to an expanded acoustic array. We will improve the design of our acoustic sensors to keep them in linear amplitude range throughout the duration of the ascent and float portions of the flight. In addition, we will develop instrumentation and measurement techniques for future independent (non-HASP) airborne acoustic arrays by lowering an independent data logger/microphone package beneath the gondola. We expect the array to verify detection of ocean wave infrasound observed in HASP 2014, determine whether episodes of broadband pressure fluctuations are due to wind noise or clear air turbulence in the troposphere, and evaluate the source of numerous narrowband signals observed during float.

Contents

1 Experiment

Acoustic signals in the atmosphere contain valuable information on natural and anthropogenic activity both on and above the surface of the Earth. In addition, sound waves can be used to infer atmospheric structure between the emitter and the detector. Several key advantages can be realized by placing instruments in the free atmosphere rather than in a more traditional ground deployment. These include

- Quantification of the three dimensional wave field of directional acoustic sources
- Near complete reduction of wind noise on free floating sensors, particularly at higher altitudes
- Greatly increased detection range
- Lack of a turbulent boundary layer directly above sensor
- Distance from undesirable noise sources
- Potential for detection of novel acoustic signals that do not reach the Earth's surface

Despite this, few studies have investigated the potential for free flying acoustic networks. Project Mogul searched for Soviet atomic bomb tests using balloon-mounted pressure sensors in the 1940s (Weaver and McAndrew, 1995). Several studies used balloon-mounted microphones to investigate infrasound generated by clear air turbulence in the 1960s (Wescott, 1961a,b, 1964) and blast waves from underground nuclear tests were studied using pressure sensors on dropsondes (Banister and Hereford, 1991). The successful flight of our team's infrasound network during HASP 2014 thus represents one of the few (and certainly most recent) attempts to measure infrasound in the stratosphere. Through continued proposals to fly on HASP and pursuit of funding for independent campaigns from the National Science Foundation and elsewhere, we intend to open the lower fifty kilometers of the atmosphere to routine acoustic observation.

Signals recorded during the HASP 2014 flight were surprisingly complex (Figure 1). With such a diversity of waveforms in a relatively unexplored environment, it is imperative to distinguish between true acoustic signals and noise. Known or suspected noise sources include

- Bobbing or penduluming of network at neutral buoyancy

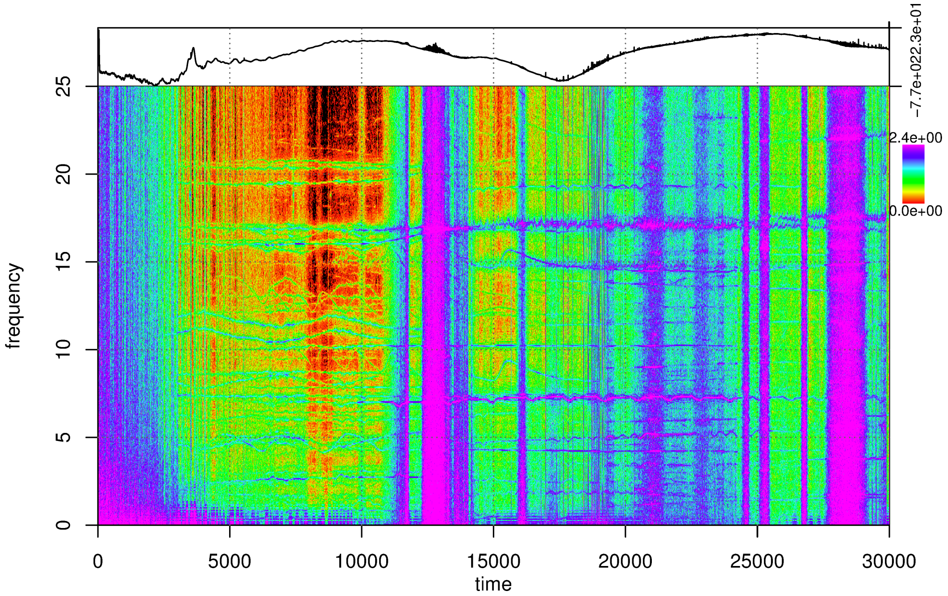

Figure 1: Fourier spectrogram of signals recorded by an infrasound microphone on board the HASP 2014 balloon. The spectrogram covers the ascent and float phase of flight.

- Wind noise and pressure changes throughout ascent and descent as well as from wind shear across the array
- Electronic interference from other instrumentation
- Undesirable anthropogenic sources, such as aircraft, that obscure signals of interest

Noise from other sources likely exists as well, but has not been quantified so far. With this in mind, we have identified three key objectives for HASP 2015:

1. **Distinguish between “real” acoustic signals and noise**
2. **Increase the robustness of the acoustic network to rapid pressure fluctuations, temperature extremes, and wind**
3. **Decouple one microphone/data logger system from the flight line to simulate a second free-flying balloon station**

We will address the first goal by logging **vibration, temperature, fluid flow**, and **electronic noise** in addition to pressure fluctuations during flight. Vibrations will be quantified using a 3 component geophone installed on the gondola. Thermocouples will be attached to the microphone transducers to examine the effects of temperature changes on differential pressure measurements. An anemometer will be located on the gondola to measure fluid flow and turbulence during flight. One channel on each of the two data loggers on the gondola will be left open to capture electronic noise.

We will satisfy the second goal by **decreasing the corner frequency of the mechanical filters** on each microphone, allowing them to equilibrate faster during ascent. The **network aperture will be increased** from 12 m (as it was during the HASP 2014 flight) to 50 m, resulting in a reduction in incoherent wind noise and an increased ability to determine the arrival angle of acoustic signals. **Four microphones** will fly on the balloon as opposed to three, further reducing the effects of incoherent noise. Microphones will be installed in **rigid boxes with foam insulation**, rather than in lunch coolers. This should reduce interior temperature fluctuations while crossing the tropopause and from insolation at float.

We will accomplish the third goal by **lowering a self-contained sensor/logger box below the gondola** via a braked mechanical reel. Since the box will have its own data logger, powering system, and microphone, it will provide **an independent measure of the acoustic wavefield** during the flight.

1.1 Scientific Objectives

- Constrain the source of narrow band stratospheric acoustic signals like those observed in 2014 (see Figure 1).
- Determine whether the "stripes" of broadband pressure fluctuations (i.e. between 10000 and 15000 seconds on Figure 1) are from sources proximal to the balloon
- Verify the suspected signature of ocean wave infrasound recorded in 2014
- Search for impulsive signals from mine blasts or bolides

We are planning a ground campaign to deploy stations in the balloon flight path to increase the probability of recording the same infrasonic signals on the ground and in the air. In addition, our team is in discussions with Los Alamos National Laboratories about setting off a large ground explosion during flight. Such an explosion would be recorded simultaneously on ground stations, the HASP balloon, and possibly by GPS stations measuring electron density in the ionosphere.

1.2 Engineering Objectives

- Increase the length of the sensor string to to match standard ground network apertures
- Keep sensors in nominal linear amplitude range during ascent and float
- Transmit at least one acoustic channel to the ground via HASP telemetry
- Quantify electronic noise and vibrations on the flight system
- Lower a sensor/logger package below the gondola to simulate a stand-alone balloon payload
- Measure the impulse response of the balloon by requesting a ballast drop

2 Payload Design

Our payload consists of four systems: a microphone array located on the flight ladder, a payload box located on a large payload slot or alternatively "piggybacked" beneath the flight deck, a reel beneath the flight deck, and a reeldown box hung off the side of the gondola. Four infrasound microphones will be used in the experiment: two on the flight ladder, one in the payload box on the HASP gondola, and one on the package at the end of the reel (Figure A-1).

2.1 Flight Ladder Array

Two infrasound microphone packages will be located on the flight ladder, one on the top rung and one on the bottom rung. Each package will contain an infrasound sensor, a 9 volt lithium battery, and a thermocouple. Foam insulation will surround the infrasound sensor, and the package housing will consist of an impact-resistant plastic project box painted white to reflect solar radiation. The package will attach to the ladder rung via two U-bolts, similar to how the microphone packages were attached in 2014 (Figure A-2). However, we expect the foam insulation to provide better thermal control than the lunch coolers we used last year, and a rigid project box should afford more protection to the sensors. Sensor outputs will be conveyed to data loggers on the gondola via two CAT-6 Ethernet cables. Each cable will have two data channels, one channel left open and logged to characterize electronic noise, and one spare channel. This design greatly reduces the number of wires that must be threaded along the flight ladder compared to last year.

2.2 Payload Box on Gondola

We propose to place our main data logging system on a large payload slot (Figures A-3 and A-4), though we prefer a piggyback arrangement if it would permit us to have a larger footprint. We will construct an acrylic box painted white to reflect solar radiation and mounted to the HASP gondola with four hex bolts (Figure A-3). The box will contain a Refraction Technologies RT-130 6 channel data logger, a GPS, an Arduino Uno with data logging shield, a 3-component geophone, an infrasound microphone, and a thermocouple. A hot wire anemometer will be mounted above the box if it is located on a large payload slot, **exceeding the height allowance of the payload** (see Figure A-4). If this interferes with HASP operations or other payloads, the anemometer can be mounted somewhere else on the gondola, so long as it is several centimeters above the top platform for optimum wind measurement. If our payload is piggybacked beneath the flight deck, we must place the anemometer elsewhere as well as locate a GPS antenna somewhere with a clear view of the sky.

The RT-130 data logger will digitize signals from infrasound sensors on the flight ladder array and the infrasound sensor in the payload box. It will also digitize the vertical channel and summed horizontal channels from the geophone and one of the open channels on the flight ladder array. The GPS will provide time synchronization for the RT-130. The Arduino will digitize records from the thermocouples, the anemometer, and the other open channel on the flight ladder. The RT-130 and Arduino will be powered via HASP, and the infrasound microphone will be powered via a 9 volt lithium battery.

2.3 Reeldown System

The reeldown system is designed to slowly and safely lower a data logger and microphone 30 m beneath the gondola (Figure A-5). A heavy duty braked kite reel rated to a minimum of 100 lb tensile strength will control the descent rate and support the logger/microphone package during flight. These reels have a governing mechanism that allows operators to safely control the ascent rate of large kites in strong winds. We will use a string with a minimum of 100 lb tensile strength to prevent the package from falling off the gondola in case the reel fails. Finally, we will attach a 2 m parachute to the instrument package to ensure a safe descent in the unlikely event of a detachment.

The reeldown will be started via an analogue command from HASP, triggering a reed relay that will initiate a nichrome wire cut down of a string holding the reel handle in place. The nichrome cut down will be fused to prevent the circuit from drawing too much current and jeopardizing the operation of the data loggers in our main payload box.

2.4 Reeldown Instrumentation Package

The package at the end of the reel will consist of an aluminum box painted white to reflect solar radiation. It will contain an Omnirecs Data Cube data logger (the same one used during the 2014 flight), an Arduino Uno and high altitude GPS logger shield, an infrasound microphone, a triaxial accelerometer, a thermocouple, a 9 volt lithium battery, and a pack of two D-cell lithium batteries. The Data Cube will digitize the infrasound microphone, the vertical channel of the accelerometer, and the summed horizontal channels of the accelerometer. The Arduino will record GPS positions and temperature. The Data Cube, accelerometer, and Arduino system will draw power from the D-cells, and the infrasound microphone will use the 9 volt battery.

2.5 Thermal Management

We will ensure that all equipment enclosures are white to keep them cool during float. Based on the performance of our payload in 2014, we do not see the need for additional thermal management for the reeldown package or the microphones. However, the RT-130 data logger has a lower nominal temperature limit of -20 C, which may be breached during the thermal/vacuum test and while crossing the tropopause. We will insulate the logger using foam to prevent cold temperatures from penetrating the device. Based on our previous work with Arduino boards, we do not anticipate needing special thermal management considerations for them beyond those already mentioned.

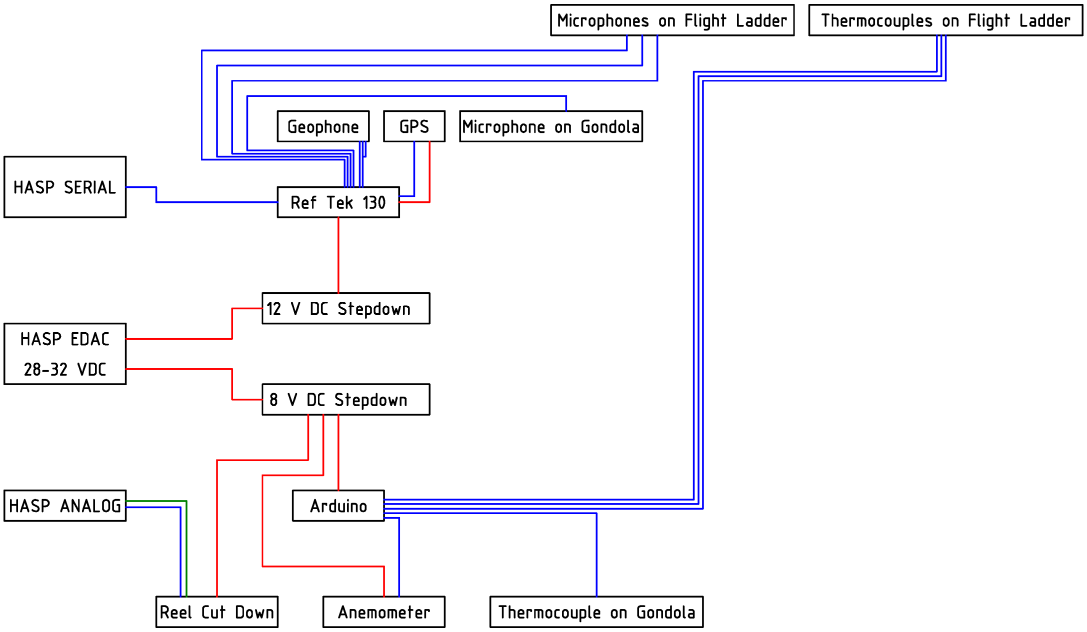

Figure 2: Power and communications between HASP and the proposed payload. Power supply is in red, data channels are in blue, and communication lines are in green.

2.6 Communications

We will command the cut down circuit to activate and release the reel using analog pin F. We will monitor the voltage drop across the cut down circuit using analog pins K and L. After five minutes of confirmed voltage readings across K and L, we will command the cut down circuit to turn off using analog pin N. We intend to transmit data at a bit rate of 9600 from the RT 130 serial interface to HASP. This data stream will monitor the microphone on the gondola.

2.7 Power and Mass Budget

Three power systems will operate on the proposed payload: two using batteries, and one from HASP. Microphones will utilize 9 volt lithium batteries as they did in 2014. The reeldown package data logger, accelerometer, and thermocouple will draw power from two lithium D cell batteries. The data logger and other sensors on the HASP gondola will use the provided power supply (see Table 4 for maximum anticipated power draw and Figure 2 for the power circuit schematic).

The microphone packages and cabling on the flight ladder will total about 1.9 kg (see Table 1). This weight may vary by ± 0.1 kg depending on the final attachment system and enclosure material. The large payload plate will support 7 kg, with an uncertainty of ± 1 kg depending on the geophone model, the number and length of cables needed, and the construction of the payload box (Table 2). The reel and cut down will weigh 2 kg, with an uncertainty of ± 1 kg depending on the reel model. The instrumentation and suspension system supported by the reel will weigh 2.2 kg, with an uncertainty of ± 0.1 kg depending on the parachute and enclosure design. Specifications for the reel and suspension system weight are described in Table 3.

2.8 Flight Event Sequence

When the decision to show is issued the day before launch, all microphones will be powered on. The reeldown instrumentation package will be powered on as well. This will avoid having to start external power during launch day as we did in 2014. We will discuss with the RT-130 data logger manufacturer to determine if we can remotely command data acquisition start, or configure the data logger to start automatically on power up. Otherwise, a team member with appropriate Personal Protective Equipment must be on hand to start acquisition on the RT-130 after the final power up before launch.

Once float is achieved and data downlink has begun, we will request the release of several kilograms of ballast so we can calculate the impulse response of the balloon. When the gondola is over a safe area and gravity waves are not present, we will issue an analog command to release the reel. The reel will slowly extend to its maximum length and remain there for the duration of flight and descent. We would like our payload to remain continuously powered through descent and landing as it was in 2014.

2.9 Hazards

The reel may present a tangling hazard during deployment and while at full extent as well as a slight risk of detachment. Waiting to deploy the reel until the balloon reaches float will greatly reduce the possibility of the reeldown package swinging back and forth. Also, we have provided three mechanisms to mitigate the risk of the reeldown package detaching from HASP. First, the braked reel will ensure a slow and steady descent to full length, preventing force transients that could snap the string. Second, the suspension string will be rated to 100 lbs test, insuring that it will hold the package even if it descends too fast. Finally, a 6' parachute above the package will slow its descent to approximately 10 mph at impact if it does come free from HASP. No other hazards are anticipated from this project.

3 Project Management

The team consists of five graduate students and one undergraduate. Daniel Bowman and Patrick Gouge (UNC Chapel Hill) will oversee the scientific objectives, construct the microphone array on the flight ladder, set up sensors and data loggers on the large payload plate, and develop instrumentation for the reeldown package. Jacob Anderson (Boise State University) will assist with microphone design and data logging. C. Scott Johnson, Tristan Novak, and Joshua Stevens (North Carolina State University) will develop systems to characterize electronic noise on the microphones, create a robust and calibrated hot wire anemometer, and construct the reel. Daniel Bowman (daniel.bowman@unc.edu) will serve as team leader. Dr. Jonathan M. Lees (UNC Chapel Hill; jonathan.lees@unc.edu) will advise the science team, and Dr. Rachana Gupta (NC State; ragupta@ncsu.edu) will advise the engineering team. We anticipate bringing up to 5 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* Consult with the Columbia Scientific Balloon facility regarding anemometer mast, reel system, and flight ladder array
- *February/March* Assemble instrumentation and loggers; verify correct functionality in the lab
- *April* Construct instrument enclosures
- *May-June* Complete and demonstrate reel system
- *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
Microphone box and attachment system	2	0.20	0.40
Microphone	2	0.060	0.12
Microphone Battery	2	0.004	0.008
Thermocouple	2	0.007	0.014
Array Signal Cabling (150’)	1	1.4	1.4
Total			1.9

Table 2: Estimated Mass on Large Payload Plate

Item	Quantity	Item Mass kg	Total Mass kg
Instrument Enclosure and Attachment	1	2.0	2.0
DC Voltage Stepdown	2	0.011	0.022
Ref Tek 130	1	2.5	2.5
GPS	1	0.39	0.39
Geophone	1	1.7	1.7
Arduino Uno	1	0.028	0.028
Arduino Logger Shield	1	0.022	0.022
Micro SD Card	1	0.009	0.009
Microphone	1	0.060	0.060
Microphone Battery	1	0.004	0.004
Thermocouple	1	0.007	0.007
Anemometer	1	0.010	0.010
Cabling	1	0.20	0.20
Total			7.0

Table 3: Estimated Mass of Reel System

Item	Quantity	Item Mass kg	Total Mass kg
Nichrome Cut Down Mechanism	1	0.020	0.020
Reel Mounting System	1	1.0	1.0
Braked Kite Reel	1	1.0	1.0
Total Reeldown System Mass			2.0
Payload Box	1	0.25	0.25
Power Supply	1	0.30	0.30
Data Cube	1	0.71	0.71
Data Cube GPS	1	0.073	0.073
Arduino Uno	1	0.028	0.028
Arduino GPS Shield	1	0.047	0.047
Micro SD Card	1	0.009	0.009
Microphone	1	0.060	0.060
Microphone Battery	1	0.004	0.004
Thermocouple	1	0.007	0.007
Accelerometer	1	0.001	0.001
Cabling	1	0.050	0.050
Suspension Line	1	0.50	0.50
Parachute	1	0.20	0.20
Swivel	1	0.002	0.002
Total Hanging Mass			2.2

Table 4: Estimated Maximum Power Draw

Item	Power Draw mA
Ref Tek 130 Data Logger w/GPS	142
Arduino Uno and Logger Shield	200
Hot Wire Anemometer	40
Nichrome Cut Down	1000
Grand Total	1382

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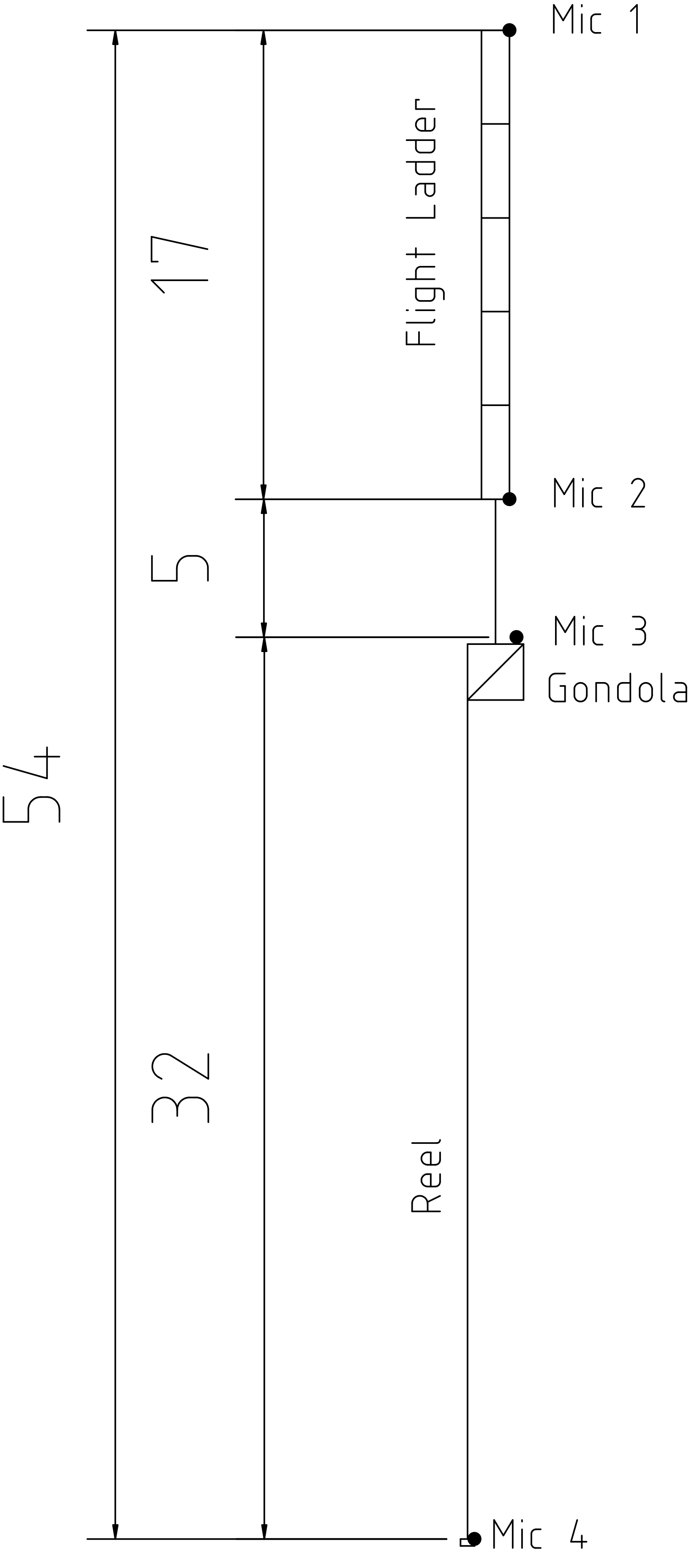
Wescott, J. W. (1964). Acoustic detection of high-altitude turbulence. Technical report, The University of Michigan.

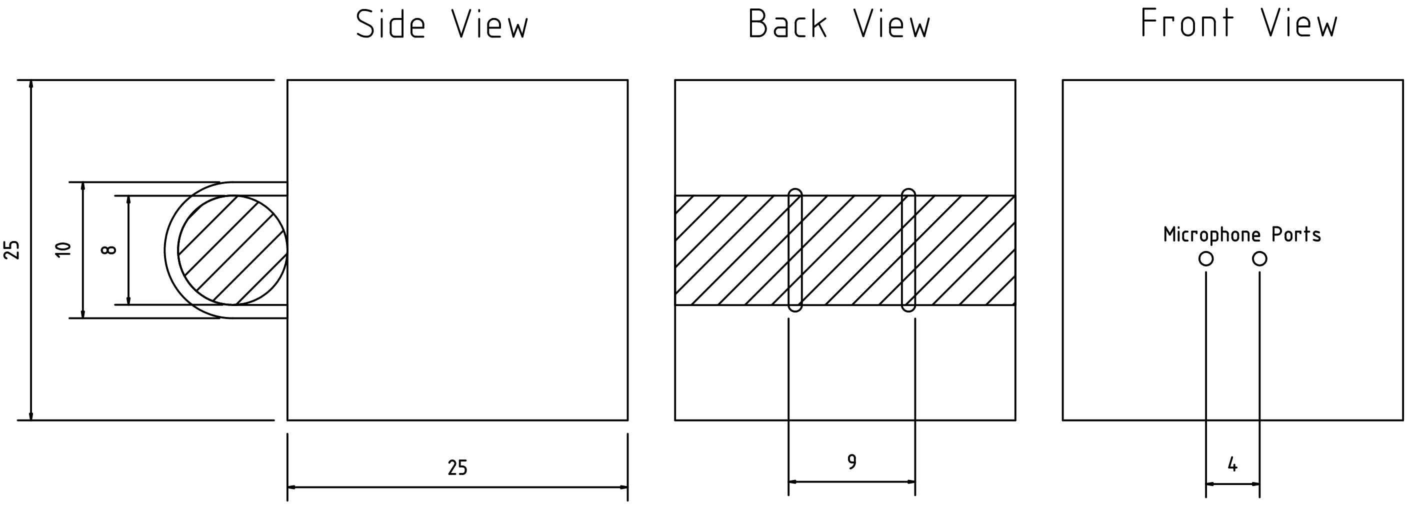
A Technical Drawings

Units of A-1 are meters. Units of A-2 through A-6 are centimeters.

A-1
Acoustic Array



A-2: Microphone Packages on Flight Ladder

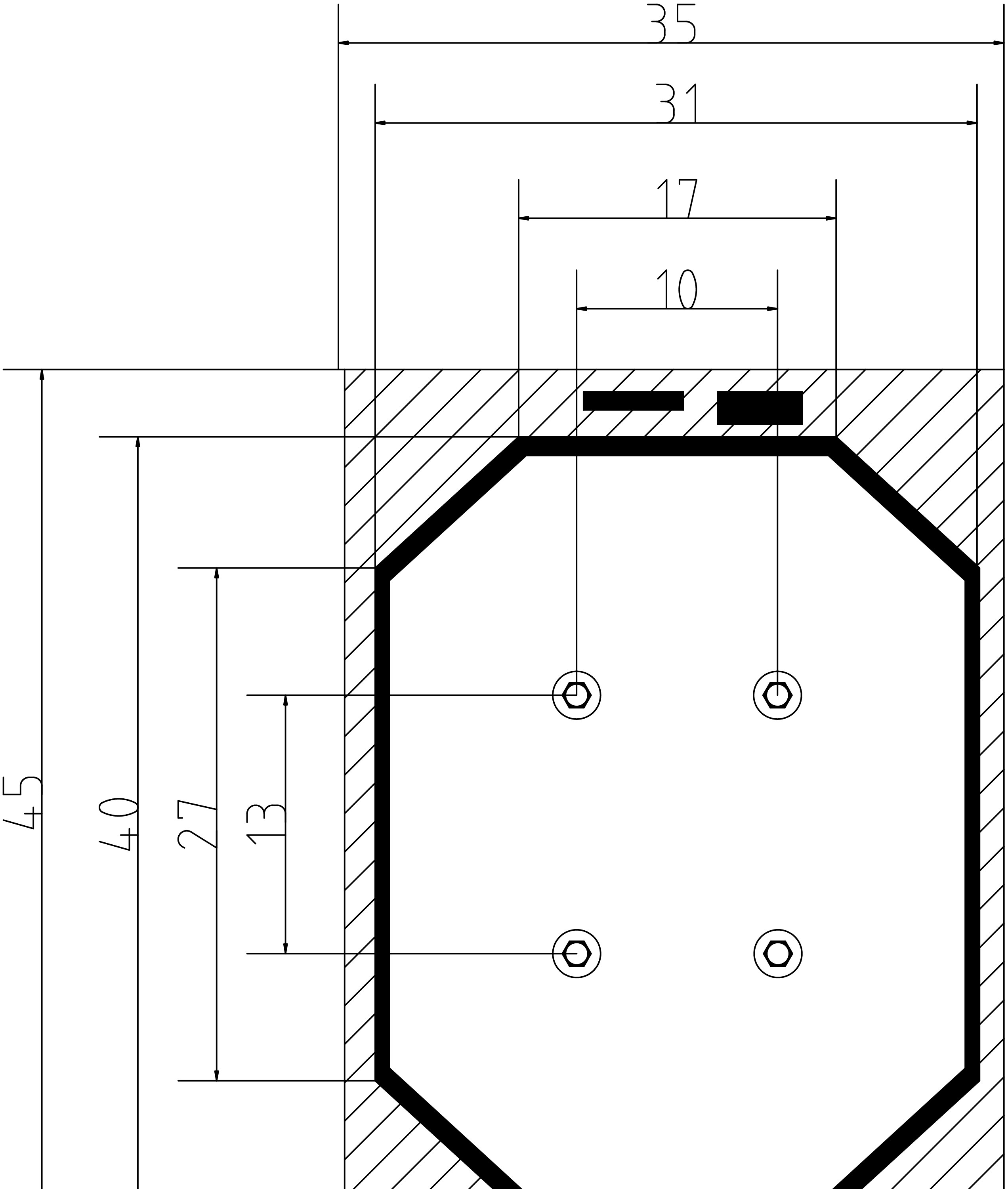


Side View

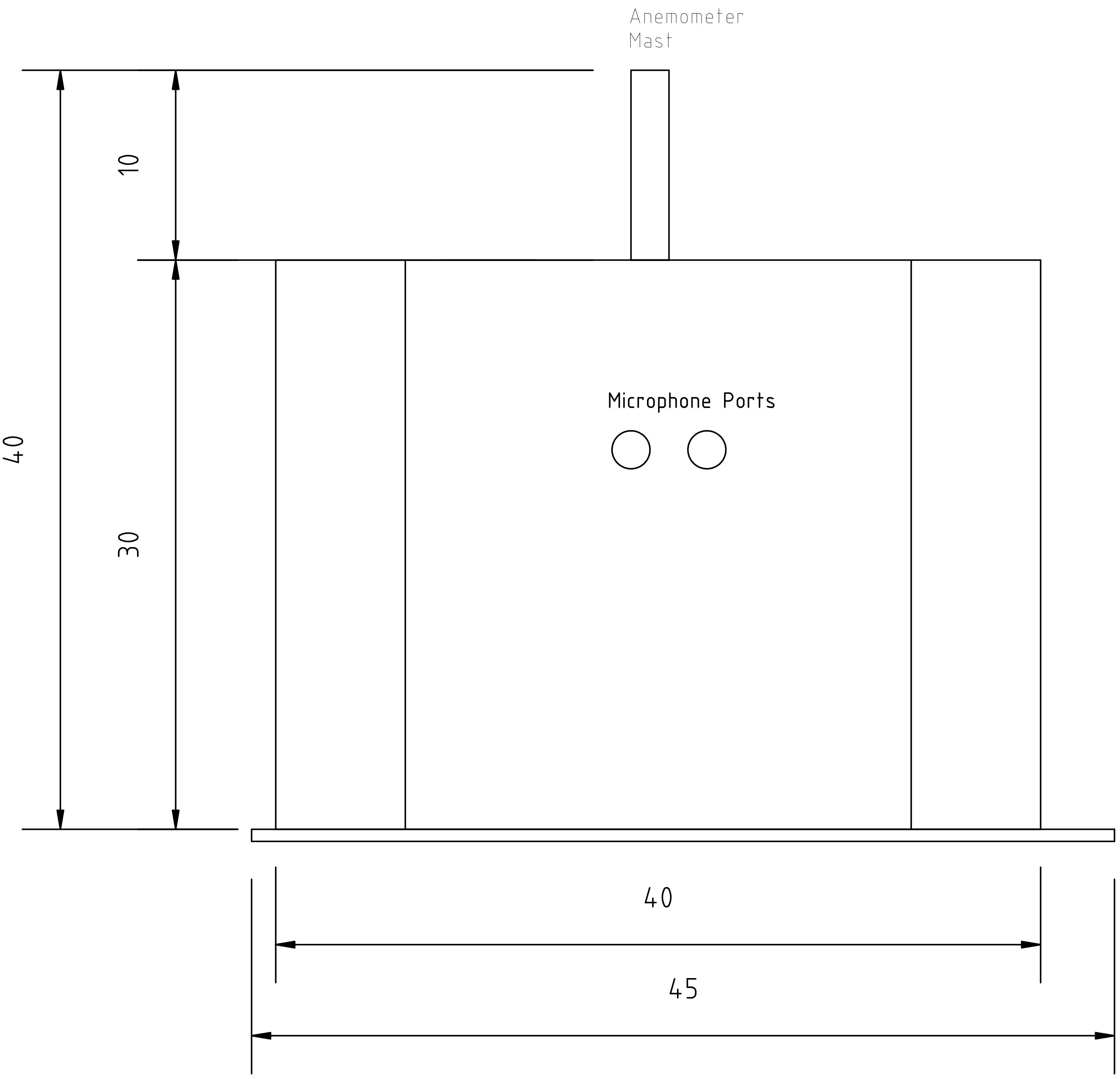
Back View

Front View

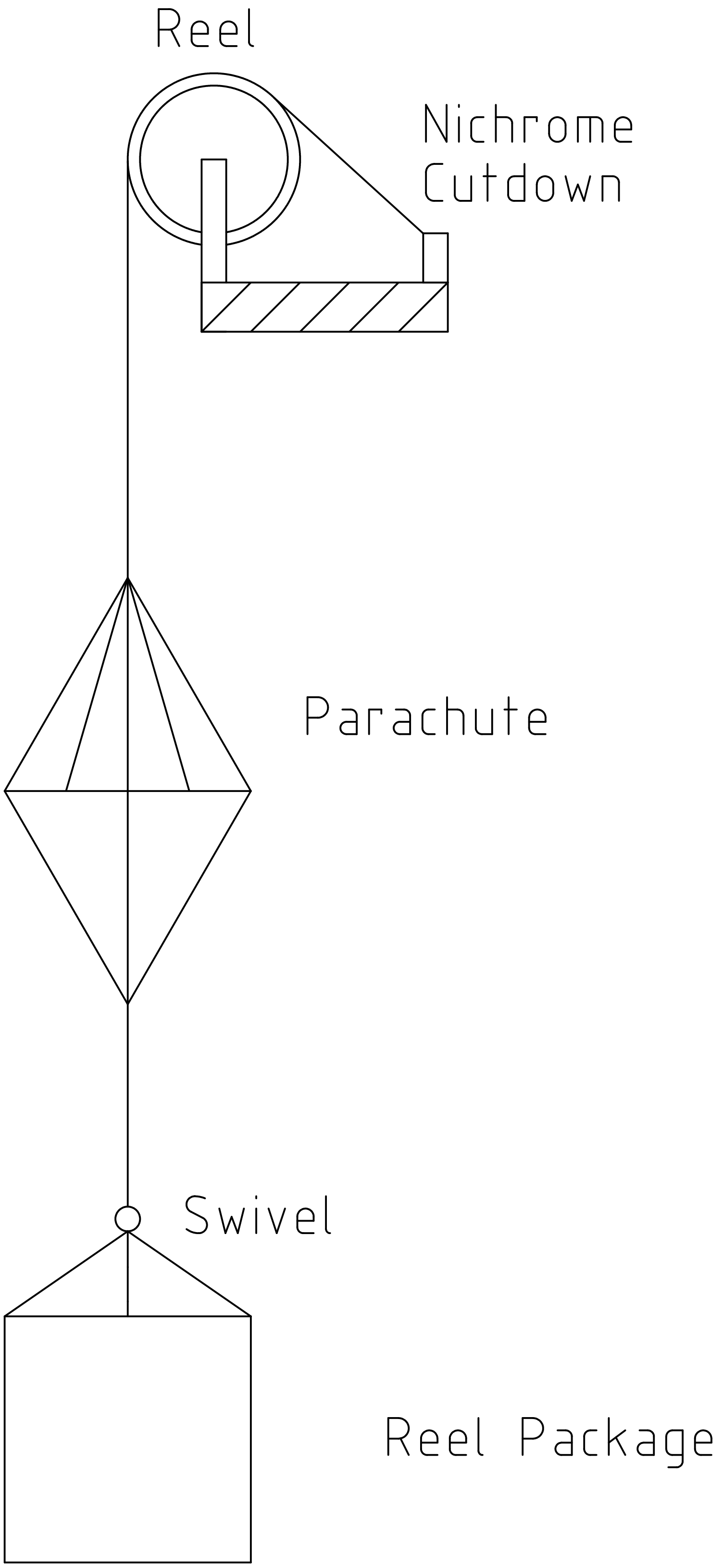
A-3: Payload Box Attachment



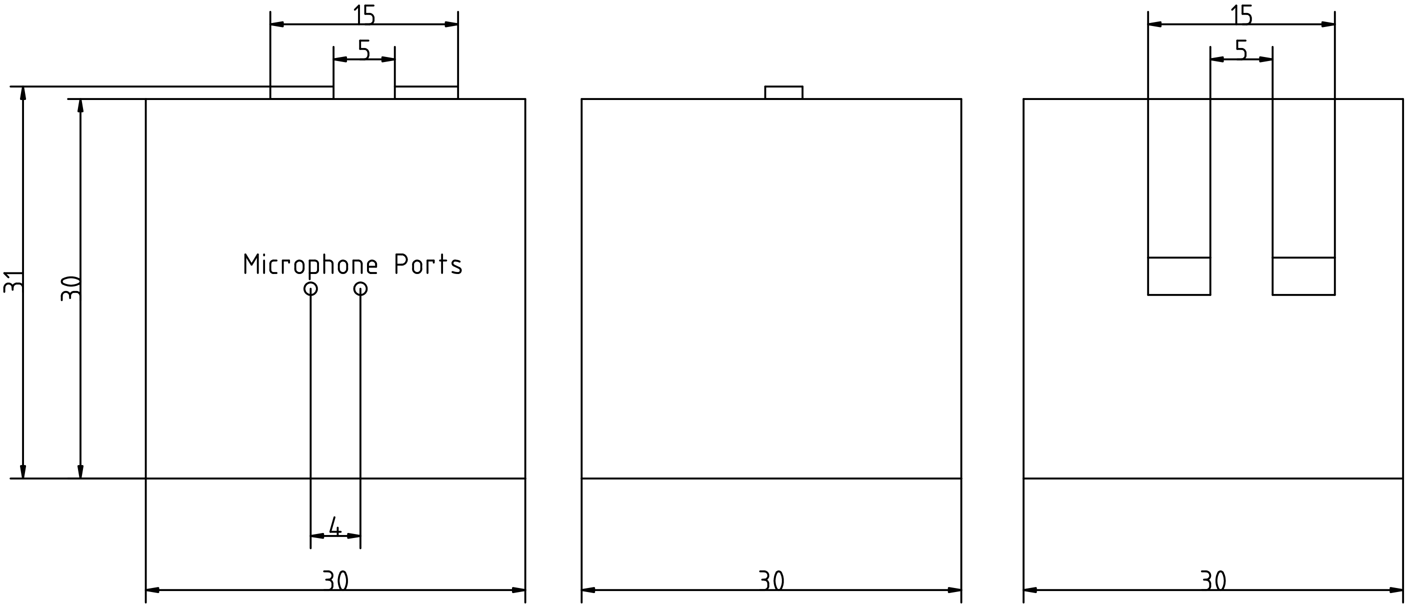
A-4: Large Payload, Side View



A-5: Schematic Diagram of Reel System



A-6: Reeldown Package



Front

Side

Top