HASP Student Payload Application for 2019

Payload Title:

HAAT (High Altitude Atmospheric Turbulence)

Institution: University of Maryland

Payload Class (Enter SMALL, or LARGE): SMALL	Submit Date: 12/14/2018

Project Abstract:

The University of Maryland HASP team proposes to upgrade the capability and fidelity of the HAAT payload that was flown on the 2017 and 2018 HASP flights. The objective of HAAT is to develop the capability of characterizing/profiling stratospheric turbulence; data which represents a fundamental gap in knowledge which is necessary to aid in the prediction of boundary layer transition for hypersonic vehicles. HASP 2019 will combine the capabilities of previous HAAT designs. It will be equipped with two fine-wire probes for unsteady velocity and temperature measurements and a suite of various sensitivity PCB microphones for measuring acoustic pressure fluctuations into the tens of kilohertz. The fine-wire probes will enable the investigation of frequency ranges relevant to hypersonic boundary layer instabilities of the order of tens to hundreds of kilohertz; i.e. disturbance wavelengths of the order of millimeters to centimeters which are relevant to flight speeds of 2km/s to 5km/s.

The UMD HASP team includes one graduate student, eight undergraduate students, and will be project managed by a Post-Doctoral Associate working with Dr. Stuart Laurence. The team also includes two faculty advisers, Dr. Stuart Laurence and Dr. Mary Bowden. Dr. Mary Bowden has directed the Maryland Space Grant Balloon Payload Program for 15 years, launching over 80 payloads, a sounding rocket, and supporting seven previous HASP payloads.

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High Altitude Atmospheric Turbulence

UMD HASP 2019 Flight Proposal

December 14th, 2019

UMD Nearspace Program
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Department of Aerospace Engineering
Space Systems Laboratory
Hypersonic Aerodynamics and Propulsion Lab

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Contents

1 Abstract

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2 Terminology

UMD: University of Maryland (College Park)
BPP: Balloon Payload Program
CAT: Clear Air Turbulence
CVA: Constant Voltage Anemometer
CCA: Constant Current Anemometer
CTA: Constant Temperature Anemometer
CVT: Continuously Variable Temperature
DRS: Data Relay System
HAB: High Altitude Balloon
HAPL: High-speed Aerodynamics and Propulsion Lab
HASP: High Altitude Student Platform
HAAT: High Altitude Atmospheric Turbulence
FiSH: Fluctuations In Stratosphere by Hot-film
MARS: Mechanically Actuated Release System
MCU: Microcontroller Unit
ADC: Analog Digital Converter

3 Project Overview

3.1 Background and Scientific Objectives

Transition to turbulence of the boundary layers on the surface of a hypersonic flight vehicle brings with it a number of detrimental effects: a marked increase in surface heating levels (see Figure 1), elevated frictional drag, and large-amplitude pressure fluctuations that can couple with the structure of the vehicle and produce undesired oscillations. The prediction of transition in flight is thus of crucial importance in the vehicle design process. Transition is a highly complicated phenomenon and can follow several paths, depending on the intensity of the disturbance environment [1]. The conventional sequence for low-disturbance environments has free-stream disturbances (vorticity, sound, and/or entropy spots) exciting normal modes

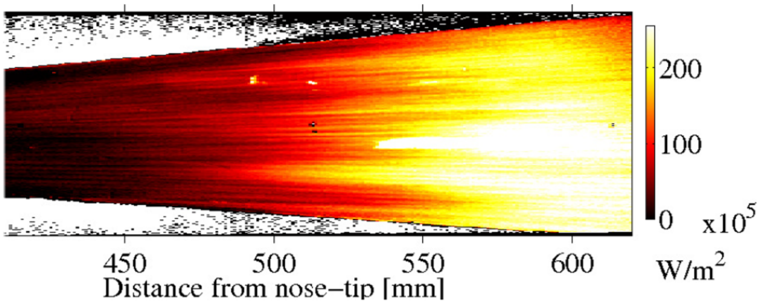


Figure 1: Heat-flux distribution measured on the surface of a slender cone at Mach 7.5 [2]. The marked increase in heat flux is caused by transition to turbulence of the boundary layer.

within the boundary layer through receptivity; these modes initially undergo linear amplification until their amplitudes are sufficiently large that nonlinear effects take over, eventually resulting in breakdown and the formation of turbulent spots, which then merge to produce a fully turbulent boundary layer. This process can be influenced by a number of operational modifiers, for example, surface roughness. While a substantial amount of progress has been made in understanding various parts of this sequence using theory and numerical simulations, it is too complicated to simulate completely given current computational capabilities (and even then would still require a knowledge of the disturbance environment to provide appropriate boundary conditions); this points to the need for ground and flight testing.

Unfortunately, while hypersonic ground testing is orders of magnitude less expensive than flight testing, experiments in traditional ground-test facilities are compromised by the presence of much higher freestream disturbance levels than in flight, which can strongly affect the location of the onset of turbulence [3]. This has led to the development of quiet tunnels [4], which are believed to have similar disturbance levels to those found in flight (though in the absence of detailed atmospheric measurements, this remains an assumption); however, the current generation of quiet tunnels is unable to achieve sufficiently high Reynolds numbers to produce natural transition on geometries of interest. The extrapolation of transition locations from ground testing to flight thus must be performed through some kind of prediction methodology. Basic amplitude ratio (or e^N) methods have found extensive use due to their simplicity, but, as pointed out by Reshotko [1], are 'defective in principle and perhaps also in practice,' as they do not accommodate the disturbance environment (the importance of which should be clear from the description in the previous paragraph).

In 1976, Reshotko's [1] review article on boundary-layer stability and transition expressed pessimism regarding the prediction of transition in flight due to the lack of information of the disturbance environment at relevant altitudes. Hypersonic flight will typically take place in the range 100 kft to 200 kft, i.e., in the upper stratosphere and lower mesosphere. Such altitudes are well beyond the limits accessible by aircraft-based measurement; for example, the U2-based HICAT program [5] was restricted to $70kft$, and the Perlan-Airbus high altitude glider which reached $76kft$ in September 2018 [6, 7]. In the years since Reshotko [1], however, a number of balloon- and sounding-rocket-based measurements have probed the upper atmosphere: balloons are able to achieve altitudes of up to approximately $150kft$ [8, 9, 10, 11, 12], while sounding rockets are used for higher altitudes, **e.g., [13]**, among many. Previous measurements have primarily been carried out by atmospheric physicists, with the intent of obtaining information regarding clear air turbulence (CAT) at these altitudes to improve our knowledge of atmospheric processes. Nevertheless, CAT in the mid and upper stratosphere remains inadequately characterized. Hence, a clear gap remains in knowledge/literature of the Stratospheric turbulent environment to inform hypersonic boundary layer transition predictions. Misinterpreted freestream disturbances can markedly enhanced thermal and mechanical loads if not appropriately understood and taken into consideration for robust vehicle design.

UMD NearSpace's 2017 HAAT campaign successfully incorporated both hot-/cold-film instrumentation, and associated equipment, into a designated space on the HASP gondola. This flight was primarily used to validate the measurement system for high altitudes (up to $109kft$) and extended duration; data was recorded at a sampling rate of $30kHz$ over a duration of 7 hours. Investigation of the turbulent spectra indicated decays of $-5/3$ (inertial sub-range) and -7 (viscous sub-range) in regions of high disturbance. Furthermore, during the HASP flight is was found that external structural components of the payload, made from $3D$ printed plastic, deformed. The payload did remain intact and data was not corrupted, however no future outside structural body panels made from $3D$ printed plastic will be used in future UMD flights.

UMD NearSpace's 2018 HAAT campaign utilized three PCB microphones. All three of these microphones are rated down to $-40°$, have successfully flown on FiSH sounding balloon payload several times, have been tested in UMD's thermal chamber, and have been thermal-vacuum tested at the Columbia Scientific Balloon Facility (CSBF), at HASP 2018 integration with success. Despite rigorous testing no data was recorded on the data acquisition system (DTS Slice Micro). The data acquisition system used in the HASP 2018 payload was the same as that used in the HASP 2017 payload and all FiSH sounding flights. Inspection of the data acquisition system after the HASP 2018 flight indicated loose connections. The TRIC deploy-able data module operated as intended.

The HASP 2019 flight will focus on furthering the capability of the HAAT payload by combining lessons learned from HASP 2017 and 2018 with new equipment and developments at UMD. HAAT will encompass a greater suite of sensors capable of monitoring acoustic frequency ranges in the order of tens to hundreds of kilohertz, and disturbance wavelengths on the order of a few millimeters up to a few tens of centimeters (of interest in flight speeds of $2km/s$ to $5km/s$). Specifically the payload will be equipped with three PCB microphones of varying sensitivity and hot/cold fine-wire sensors fully calibrated for Stratospheric flight conditions. The equipment planned for this HASP flight is also incorporated into UMD's FiSH sounding balloon payload.

3.2 HAAT

3.2.1 Sensors

The goals for the HAAT HASP 2019 payload differ from those of our 2017 and 2018 campaigns through combining and improving capabilities. The 2017 version of HAAT yielded uncalibrated hot/cold thin-film probe instrumentation, while the 2018 version utilized a suite of high-sensitivity microphones. HASP 2019 will combine this instrumentation to simultaneously measure unsteady pressure, temperature and velocity fluctuations while also monitoring mean ambient temperature and pressure.

HAAT is designed to make velocity and temperature measurements through a constant voltage anemometer (CVA) supplied by Tao Systems (Model 4-100 MiniCVA). The operating principles behind CVAs allow for extremely fast-response measurements ($> 450kHz$), which make this type of probe particularly well-suited for measuring turbulent fluctuations. The MiniCVA enables the operation of a single hot-wire (CVA) probe and a single cold-wire (CVT) probe on a printed circuit board with dimensions of $2.0 \times 4.0 \times 1.75$ inches (width x length x height). Historically, the constant-current anemometer (CCA), with full thermal lag compensation, has been used for turbulence measurements. Developments led to the constant-temperature anemometer (CTA) probe which is most widely used in wind tunnels today for turbulent velocity measurements. With the CTA probe, a feedback loop is used to maintain the wire at a constant temperature with a narrow bandwidth of operation. A high bandwidth can, however, only be achieved after very careful tuning of the CTA's circuit parameters. The CVA probe does not share the CTA's rigid bandwidth limitations. Furthermore, sensitivity will be increased by using fine-wire probes (thin-film probes were used in HASP 2017) in on the HASP 2019 flight. Specifically, the probes are TSI model $1201 - T1.5$ (typical wire diameter: $> 6\mu m$, typical length: $\approx 1.2mm$). This will provide a measurement resolution of at least $2.5mm$ over the entire turbulence spectrum down to the viscous sub-range in the stratosphere.

Three PCB microphones will be implemented with varying levels of sensitivity: one 378A06 microphone (sensitivity $12.6mV/Pa$; frequency range, $+/-2dB$, 3 to $32,000Hz$), one 378B02 microphone (sensitivity

$50mV/Pa$; frequency range, $+/-2dB$, 4 to $20,000Hz$) and one 378A04 (sensitivity $450mV/Pa$; frequency range, $+/-2dB$, 10 to $16,000Hz$). Based on these specifications, the 378A04 is the most sensitive of these microphones and should capable of measuring much weaker pressure fluctuations that the other two microphones. It is useful to incorporate have all three microphones so that signals can be compared and offer confidence in the fidelity of the measurements. All three of these microphones are rated to operate down to $-40°C$ and have been flight proven several times with FiSH, and survived the HASP 2018 flight (although no data was recorded).

In addition, the HASP 2019 payload will house two K-type thermocouples (0.010" diameter × 6" long) and a pressure transducer (Kulite CTL-312 (M) series). One thermocouple and the pressure transducer will be mounted in the base of the payload to monitor the ambient conditions so that appropriate calibrations can be applied upon data retrieval. The other thermocouple will be mounted internally to monitor the in-house payload temperature with time.

Calibration of instrumentation over a range of velocity (0–$20m/s$) temperature (220–$300K$), and pressure (10^3–$10^5 Pa$) with fluctuation sensitivity of at least 1% sensitivity of mean values, using UMD's custom calibration facility currently under development with Aerolab (a wind tunnel manufacturing company based in Maryland). UMD's low pressure wind tunnel for calibrating sensors to Stratospheric conditions is modeled after the Aarhus Wind Tunnel Simulator II (AWTSII) [14]. Additionally, with completion of the HASP 2019 payload the UMD thermal chamber with be used to verify payload operation down to $-60°C$ for a period of 6-7 hours. This will test ability of the thermal management of the system, the data acquisition system, and sensors to function under conditions typical HASP temperature environment.

3.2.2 Data Acquisition System (DAS)

HAAT will incorporate two independent SLICE Micro DTS data acquisition systems; a SLICE Micro DTS is shown shown in Figure 2. Two data acquisition systems will be used so that: 1) the amount of on-board memory is doubled; 2) accommodation of more sensor channels; 3) two simultaneous sample frequencies; and, 4) extended sample time. One DAS will power and record the three PCB microphones at $50kHz$, and the other DAS will record the CVA and CVT probes, the Kulite, and the thermocouples at $10kHz$. This arrangement will provide ≈ 14 hours maximum record time.

The SLICE Micro DTS data acquisition system is small and lightweight, with the heat sink footprint measuring 3 × 3 inches and a system mass of $187g$. The SLICE system is extremely rugged, having been engineered to military standard MIL-STD-810E. Hence, it is capable of withstanding temperatures ranging from $-40°C$ to $60°C$ and shock loading up to $500g$. The DAS will be powered through HASP,

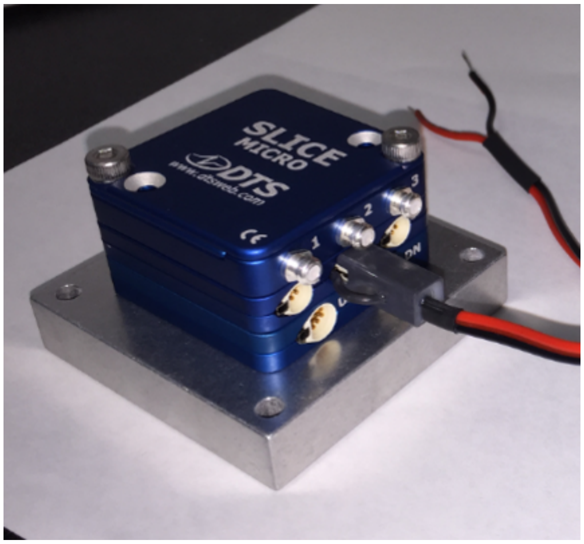


Figure 2: SLICE Micro DTS data acquisition system.

with a current draw of $60mA$ at $30V$. The system has $16GB$ ($32GB$ total) of non-volatile flash memory for storage purposes and can sample up to $200kHz$. Serial commands will be implemented to trigger data acquisition in order to maximize the amount of data collected at float.

Due to the nature of the volume of data being recorded, the data will not be downlinked via HASP. The high rate of 16-bits at kHz makes the link impractical to use. Instead, the Arduino unit in HAAT will be downlinking a status indication via the serial link. The DAS downlink will tell whether or not data is being recorded.

3.3 Payload Systems

3.3.1 System Overview

The schematic for the circuitry for HAAT payload is presented in figure 3. HASP power will be used only to operate the DAS due to the maximum current requirements imposed on the system. The power is first fed through a $10V$ regulator to power the End-of-Chain (EOC) terminals, which is used to power and trigger the DAS. $15V$ batteries are used to power the mini-CVA and the fine-wire probes. Discrete pins F and N will be used to trigger the mini-CVA once float altitude is reached. This saves on battery life during the ascent phase. An Arduino Mega (powered internally by a 3 cell Li-Po battery) will be used to facilitate interfacing with the HASP gondola. The Arduino Mega will take in status signal lines from the DAS trigger switch. These lines will tell the Arduino whether data has started to be recorded on the DAS. These signals will be transmitted down to the ground via HASP serial capabilities. The Arduino will also be responsible for acting upon the commands sent up to the payload through the serial connection. The list of these commands have been summarized in table 4. The relay switches will be triggered by the Arduino to connect 'STRT' to 'GND' on the end-of-chain terminals, thus triggering the DAS systems. The relays will be connected so that their resting position connects 'STRT' to 'GND' automatically. Hence, the trigger to start the DAS systems will be to turn the relays off. This also means that if the Arduino should fail, data acquisition will begin. This design is simpler (in terms of triggering the DAS systems) and more robust than the 2018 design which failed.

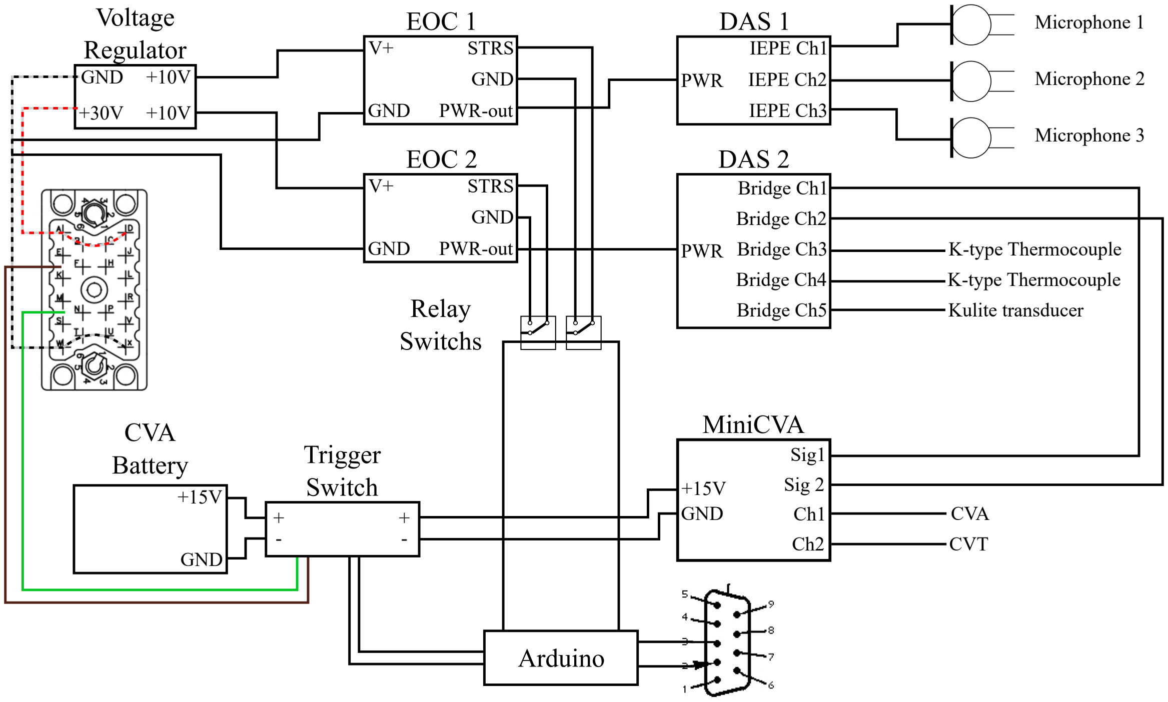


Figure 3: Schematic diagram of HAAT systems.

3.3.2 EDAC Interface

HAAT will utilize the power and discrete lines of the provided EDAC connector, as seen in Figure 3. Power will be routed through a voltage regulator board that will regulate the $30V$ from HASP down to $10V$ lines to be used in the payload. The $10V$ lines will power the two DAS (and thus the microphones through an excitation voltage). It should be noted that in the power budget (see Table 2), the peak current draw of the HAAT payload is $455mA$ from HASP at $30V$. This is the worst case current draw during payload operation. The actual current draw is much closer in value to the average current draw which, during normal operation, is $124mA$.

4 Design Specifications

4.1 Structural Layout

The main housing of HAAT payload structure will be will be a two-piece CNC'd expanded polypropylene (EPP) box with a minimum wall thickness of $10mm$. The back wall of the payload will separate to allow access inside the main housing; M4 bolts and wing nuts will fix the payload door closed as shown in figure 4. EPP is a highly versatile closed-cell bead foam that provides a unique range of properties, including outstanding energy absorption, multiple impact resistance, non-conductive, thermal insulation, and vibration damping. It is commonly used in the manufacture of seating, car bumpers, stowage systems, door panels, pillars, and bicycle/motorcycle helmets.

All electronics will be mounted to EPP housing via easily removable plates secured within the payload. As shown in figure 4, the main body of the payload will be within the allowed payload space but the microphone, fine-wire probes, and thermocouple will stick out of the payload area by $50mm$, $190mm$, and $53mm$, respectively, on the side of the payload facing away from the HASP gondola. The sensors must be pointed away from the main HASP gondola and positioned as far from the payload box as possible. The arrangement of the sensors are that same as that used in the HASP 2017 and 2018 flights. The total height of the system will be $300mm$ above the main mounting plate. Figure 5 illustrates the proposed internal layout of the HAAT payload; refer to figure 3 for the system overview. HAAT will be rigidly attached

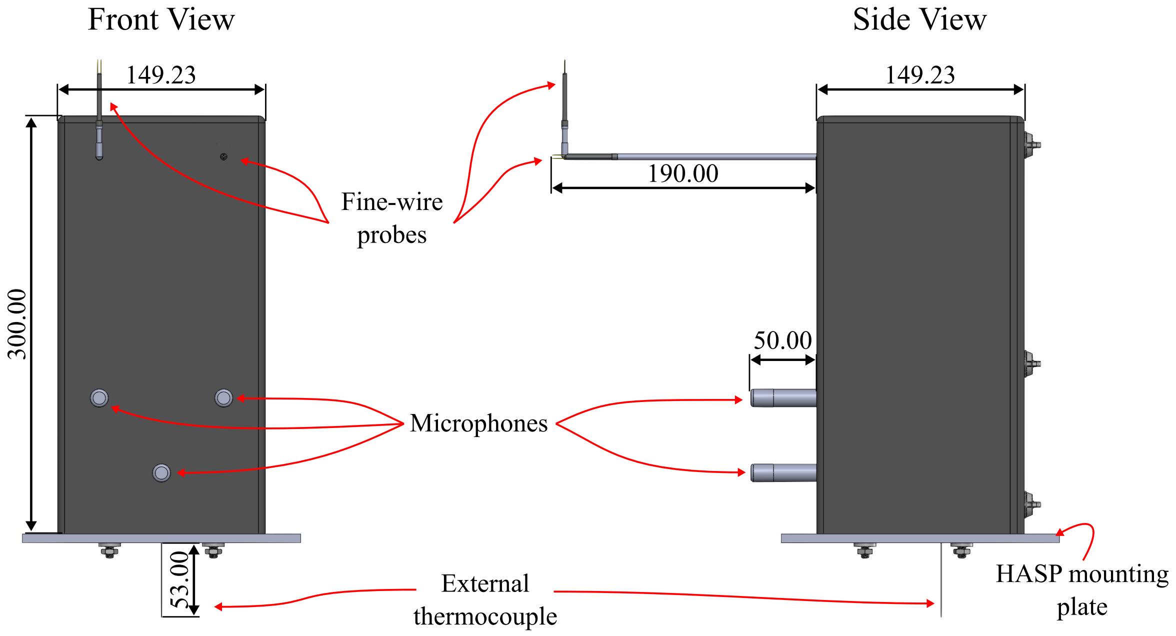


Figure 4: Schematic of HAAT payload; dimensions in mm.

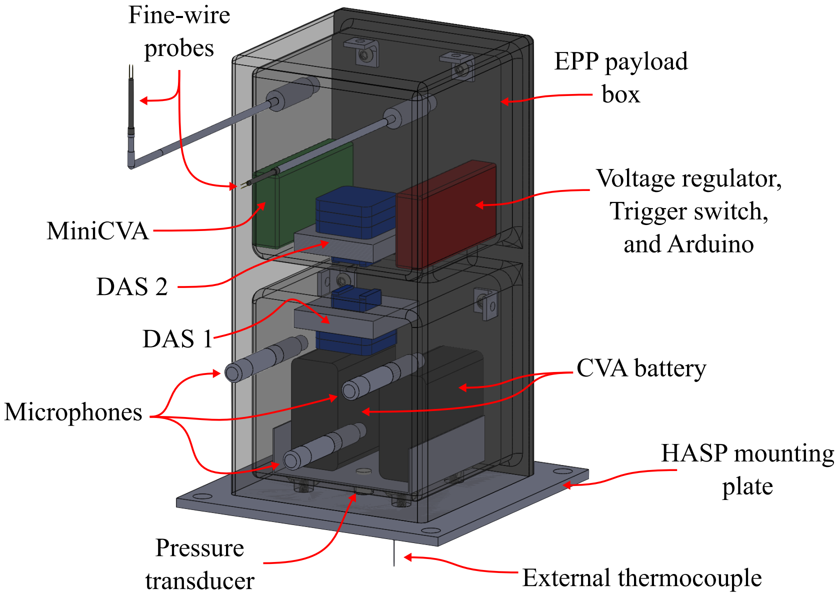


Figure 5: Schematic of HAAT payload internal layout.

to the payload mounting plate using an internal base-plate which the CVA batteries mount, as shown in figure 4. Four M6 fanged elevator bolts will hold the payload in place. Technical drawings of the payload are provided in Appendix B.

4.2 Thermal Management

As with HASP payloads 2017 and 2018, HAAT will not have active thermal management. The structure of the payload, EPP foam, will offer robust insulation as determined from FiSH flights. Based on the performance and experience gained of the electronics in previous HASP flight this configuration is expected to keep our payload within an acceptable temperature range. The expected performance of HAAT's internal temperature will also be verified by test. The entire HAAT system will undergo at least one thermal test, and one vacuum test, in the UMD thermal and vacuum chambers to verify payload operation down to $-60°C$ and $100Pa$, respectively, for a period of 6-7 hours. Additionally, all sensors and electronics in the 2019 HASP payload will also be flown at least six times on FiSH via high altitude sounding balloons. Lastly, HAAT will also be tested in the thermal-vacuum test at CSBF HASP integration.

The thermal chamber at UMD can go to both high and low temperatures, but for the purposes of this project will be used to test the system to a temperature of $-60°C$. The chamber will be held at the target temperature for a minimum of 6 hours to cold soak the hardware. On completion the chamber will be brought back to room temperature, and the data logs will be examined to ensure that all equipment remained functional. If necessary, this testing can be iterated along with hardware modifications until all systems function reliably for the entire duration of the test.

The vacuum chamber can achieve pressures similar to those at $100,000ft$. It does not have thermal controls, but can be used to identify potential issues with the electronics (*i.e.* arcing), which will be monitored for the duration of the testing.

HAAT's electronics and sensors will also be tested on a minimum of six altitude balloon flights prior to CSBF integration. Three of these flights flights will typically last 1.5 to 2 hours and reach a maximum altitude between $80,000$ and $100,000ft$. The other three will coincide with the development of a tandem sounding balloon flight train designed to enable FiSH to either float or descend slowly ($< 2m/s$). These flights are planned to last 5 to 7 hours and reach a maximum altitude between $80,000$ and $100,000ft$ also. Though these flights may not last long enough to cold soak the payload, it will provide a baseline assessment of flight readiness.

The closest simulation that can be achieved pre-flight will be the thermal-vacuum test at CSBF. All systems are expected to work during this test, but if they do not there are strategies that can be implemented to address the issue. If the electronics get too cold, additional insulation and/or resistive heating would be added. An alternative solution that could also be to integrate into the payload is passive heating in the form of exothermic disposable hand warmers. Conversely, if the electronics get too warm the DAS heat-sinks could be increased in size and utilized to remove heat from the payload.

4.3 Payload Mass and Power Budget

The payload will use the EDAC 516 connector to provide power to both DAS systems and subsequently ×3 microphones, ×2 thermocouples, and ×1 pressure transducer as indicated previously in figure 3. Voltage will be regulated and distributed according to each system's power requirements. The mass and power specifications of the payload remain within the limits of $+30VDC$ at $0.5A$ (15 Watts) and $3kg$, respectively, for the small payload classification.

Tables 1 and 2 outline the mass and power budgets respectively for the HAAT payload components. From table 1 it is anticipated that the HAAT payload will be $727.5g$ under the mass budget. For this reason the final design may incur a third CVA hot-wire probe. As all of the sensors and have been flown on FiSH several time and on HASP in 2017 and 2018, the mass of components is well understood and little uncertainty.

The MiniCVA from Tao Systems is not a commercially available piece of equipment, however is it in development with UMD and the AFOSR to enhance sounding balloon capability for high altitude turbulence measurements. On power-up, the MiniCVA will experience transient current draw that will exceeds $1.5A$. Additionally, under continuous payload operation the CVA's total current draw will exceed the HASP gondola's maximum current draw of $0.5A$ for the small class payload. For this reason, the

Item	**Mass (g)**
Slice System (DAS 1)	208
Slice System (DAS 2)	230
PCB Microphones (×3)	135
Microphone cables	72
MiniCVA	57
CVA batteries	771
Probe holders (×2)	100.5
Elbow joint	15
Fine-wire probes (×2)	4
Pressure transducer	17
Thermocouple (×2)	15
DTS thermocouple adapter (×2)	30
EPP housing	180
CVA battery cradle	165
Voltage Regulator	50
Arduino	40
3-cell Li-Po	133
Wiring	50
Total	2272.5

Table 1: Payload mass summary.

Item	**Average Current (mA) at 30 V**	**Peak Current (mA) at 30 V**	**Line**
MiniCVA	400	400	CVA battries
Thin film 1	100	100	CVA battries
Thin film 2	100	100	CVA battries
Total (internal power)	**600 mA**	**600 mA**	
DAS 1	60	155*	HASP power
DAS 2	60	290*	HASP power
Microphones (×3)	4	10	HASP power
Total (from HASP)	**124 mA**	**455 mA**	

Table 2: Power budget summary. Values marked with * is the absolute maximum possible current draw DAS arrangement with sensors connected to all channels; note, not all DAS channels are connected.

MiniCVA is connected to internal battery power, as shown in figure 3. It is also indicated that the peak current draw for DAS 1 and DAS 2 are the absolute maximum possible current draw with all sensor channels occupied on both DASs. DAS 1 has all three channels occupied by microphones, however DAS 2 has one free sensor channel.

A description of parts, distributors, and part numbers are given in table 3. It is highlighted that DAS 1 is composed of ×1 SLICE Micro Base+ and ×1 SLICE Micro IEPE Slice which is subsequently connected to the three microphones. DAS 2 is composed of ×1 SLICE Micro Base+ and ×2 SLICE Micro Bridge Slices which is connected to the MiniCVA (fine-wires), the thermocouples, and the pressure transducer. For a reference to how components are wired together refer to figure 3. For the component layout within the HAAT payload refer to figure 5.

Part	**Distributor**	**Product Number**
SLICE Micro Base+	Diversified Technical Systems, Inc	BA00088
SLICE Micro Bridge Slice	Diversified Technical Systems, Inc	BA00190
SLICE Micro IEPE Slice	Diversified Technical Systems, Inc	BA00013
MiniCVA	Tao Systems	4-100
MiniCVA Batteries	Tenergy	31892
Probe Holder	TSI, Inc.	1150-6
Probe Elbow	TSI, Inc.	1152
Fine-Wire Sensor	TSI, Inc.	1210-T1.5
Microphone	PCB Piezotronics	378A06
Microphone	PCB Piezotronics	378A04
Microphone	PCB Piezotronics	378B02
Pressure Transducer	Kulite	CTL-312(M)
Thermocouple (K-type)	TC Direct	206-590
Arduino Mega 265	Adafruit	191191
3 Cell Li-Po	HeliPal	LPB-111525-Pro

Table 3: Breakdown of HAAT components.

4.4 Payload Location and Orientation

The majority of the experimental goals are independent of the physical location on the HASP gondola. However, the stern side of the gondola is deemed to be best suited as it is farthest from the launch vehicle prior to launch [15], thus favoring either payload locations 06 or 07 as indicated in figure 6. The HAAT payload much be orientated with probes pointing away from the main gondola (orientation shown in figure 6), and will therefore have very fragile (and sharp) fine-wire probes pointing out beyond the ground footprint of the gondola. It is though that having HAAT mounted on the stern-side, away from the launch vehicle, will minimize the chances of damaging the probes prior to launch. Necessary modifications to the HASP mounting plate are shown in figure 10 (Appendix B).

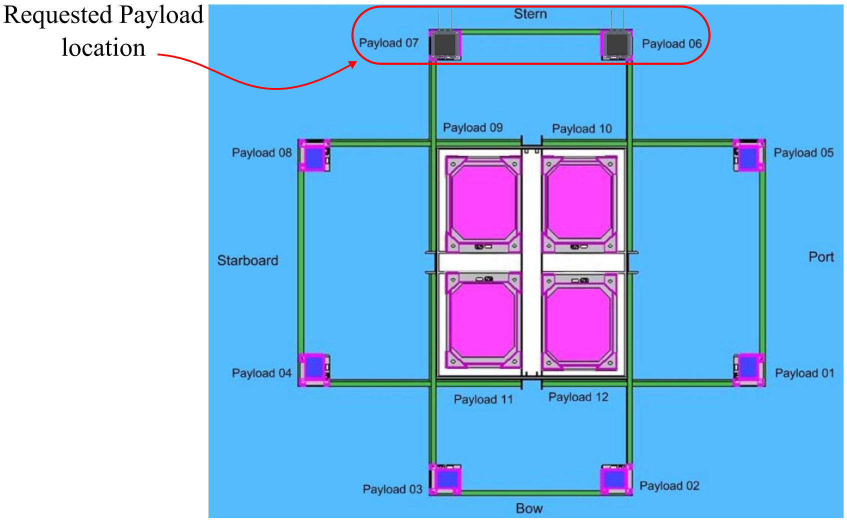


Figure 6: Requested payload location on the stern of the HASP gondola; payload orientation must have probes pointing away from main gondola as shown. View is top down.

4.5 Payload Operation

During the HASP 2017 flight, the payload encountered issues due to a lack of a robust serial interface with HASP and the time dependency of the discrete commands. Functionality of the payload could not be determined until after the flight's conclusion, and data acquisition time was restricted due to the lack of triggering and power cycling options. All of the electrical systems relied on mechanical switches that had to be removed prior to flight, which was logistically difficult. Furthermore, with no way to trigger data acquisition, the DAS had to begin logging data immediately upon start-up meaning that a significant portion of the data logging took place on the ground or during ascent.

Based on this experience, we have taken the time to become much more fluent in serial interfacing and identified a number of serial commands that we will be using the HASP serial interface to execute. One serial command will be to turn on the DAS, and secondly to turn on the data acquisition at altitude. This will allow for much more robust data acquisition and for all of the data acquired to occur at float when the data is of most interest. It will also allow for non-consecutive acquisition, meaning that we can examine how the magnitude and intermittency of stratospheric turbulence varies with the diurnal cycle.

The release of the TRIC drop module, in HASP 2018, could be triggered via the serial lines. This redundancy with the discrete lines enabled the ability to trigger the drop with either method, instead of having to hard-code the time of drop into the flight code when the discrete signaling fails. The data acquisition of the microphone suite in HASP 2018 failed, however, not due to failure to trigger. It failed due to faulty wiring.

HASP 2019 will utilize the same triggering system that HASP 2018 used, however how systems communicate will be more robust. Once the float altitude is reached HAAT will simultaneously all senors and acquire data for the duration of the flight.

5 Design Changes

5.1 Changes to HAAT from 2017 HASP

5.1.1 Atmospheric Data Measured

Regarding boundary layer transition, we are interested in fluctuations with length scales on the order of 1 cm. This corresponds to pressure fluctuations at frequencies above 10kHz, as the appropriate scaling velocity for acoustic fluctuations is the freestream speed of sound. In order to avoid aliasing of the most interesting frequencies, the sampling rate of the DAS was increased to 40kHz for the 2018 campaign. A much lower sampling rate could be employed last year because the appropriate scaling velocity for temperature and velocity fluctuations was the relative payload velocity.

5.1.2 Structure

In the HASP 2017 Payload, most of the structural components and outside body panels that made up HAAT-TRIC were made out of PLA (Polylactic acid) or ABS (Acrylonitrile butadiene styrene) 3D printed plastic. These components displayed performance issues, and while their failure did not impede mission success, it raised concerns on their use in future flights.

During the flight, several body panels on HAAT, especially those darkly colored, deformed. The temperature of these plastic panels likely reached above the glass transition temperature, causing the material to become rubbery and flexible, without completely melting. The panels in question bulged outward, but did not deform to the point of breaking the nylon bolts holding them together. As a result, **no future outside structural body panels will be made out of 3D printed plastic**, particularly PLA, as it has a lower glass transition temperature.

The upper part of the Payload, HAAT, was affixed to the payload plate using 4 plastic brackets. These structural brackets were 3D printed out of PLA plastic with a 10% infill. ABS plastic would have been a better choice along with a higher infill setting, as this would have made a stronger part. Issues did not arise until landing. The impact was harder than expected, and all 4 of the brackets failed causing the upper half of the payload to separate from the payload plate. Only the internal electrical wires were holding the payload together, as could be seen from recovery photos. **For all future critical structural components, 3D printed plastic will not be used**, particularly low density plastics that are not intended for structural components. These corner brackets will be replaced with an aluminum flange.

5.1.3 Data Relay

The entire system for relaying probe data on the previous HASP 2017 flight consisted of many different discrete parts on both HAAT and TRIC in order to convert the analog signal to digital, splice the data, and then store the data.

The ADC on the DRS on HASP 2017 were both in the top, HAAT, portion of the payload. The data was routed into the DRS, sent to the teensy microcontroller, and then rerouted back to the DRS to be sent down to the TRIC portion of the payload for data storage. Onboard TRIC was the Raspberry Pi used for storing all of the converted data.

Our HASP 2018 redesign consolidated all of these tasks onto a single DRS board that is located in the TRIC portion of the payload. The data lines will be sent directly from HAAT to TRIC via the same magnetic release cable, and was able to be routed to the DRS. The DRS contained an onboard ADC to convert the data, as well as flash storage and an SD card to store the data. This proved to be a much simpler system.

5.1.4 Arduino Unit

On HASP 2017, we flew a custom Arduino unit known as a Balloonduino. The Balloonduino has the same processor as an Arduino Mega, although it contains a suite of onboard sensors including an IMU, RTC, and pressure and temperature sensors. While these boards are convenient for BPP projects since they require no additional shields to create a sensor dependent payload, they vastly complicated the design of the HASP project since there was little to no use for the additional features provided by using a Balloonduino. One of the most notable issues with the Balloonduinos for the HASP project was their unreliability: all of the units brought to New Mexico for flight were unable to pick up the timer line of the discrete signal. The unit used for integration was unable to be used since the serial driver had stopped working and was unable to flash code.

For many reasons, therefore, our payload on HASP 2018 switched to using an Arduino Mega unit to minimize design complexity. The Arduino Mega was be able to both send and receive packets to and from the HASP pallet. It has the capacity, upon receiving the signal from HASP, to start the actuators that release the drop module from the payload plate. All of these changes removed the unnecessary complications and reduce possible points of failure.

5.2 Changes to HAAT from 2018 HASP

5.2.1 Atmospheric Data Measured

The entire TRIC module, and its associated system, will not fly on HASP 2019. Aduino unit will be the same as on the HASP 2018.

The HAAT 2019 payload will fly the microphones which composed HAAT 2018 in addition to a similar system that successfully flew on HASP 2017. The HASP 2019 will fly calibrated hot and cold fine-wire probes, whereas HASP 2017 flew uncalibrated thin-film probes. Additionally, HAAT 2019 will monitor ambient temperature and pressure which previous versions of HAAT have not done.

A primary focus of HAAT 2019 will be to ensure that the mistakes from the HASP 2018 flight are not repeated; i.e. failure to trigger data acquisition. This 2019 system will be simpler, more robust, and inherently full proof. For more information, please refer to Section 3.3.

6 Payload Summary

In summary, HAAT (HASP 2019) payload is a small class payload that will measure pressure, velocity, and temperature fluctuations with an array of microphones and fine-wire probes. Data will be recorded onto a robust data acquisition systems. A summary of the HAAT payload is shown in table 4.

Item	**Units**
Total Mass	$2272.5g$
Average Current Draw from HASP	$124mA$
Peak Current Draw from HASP	$455mA$
Payload Size	Small
Payload Footprint	$149.23 \times 149.23mm$
Microphone Overhang	$50mm$
Wire Probe Overhang	$190mm$
Thermocouple Overhang	$53mm$
Payload Height	$300mm$ above mounting plate
Payload Location	Stern side of gondola; locations 06 or 07
Payload Orientation	Sensors pointed away from HASP Pallet
Discrete Commands	DAS On/Off (F, N)
Serial Downlink	1200 baud payload status
Serial Uplink	0101 DAS Turn On 0202 DAS Trigger
Analog Telemetry	None

Table 4: HAAT payload summary.

A detailed mass and power budget can be found in tables 1, and 2, respectively.

7 Integration Procedures

Upon arrival at CSBF for HASP integration, HAAT will be bolted to the top of the payload mounting plate. Once secure fine-wire probes will be mounted and protective microphone caps removed. Testing shall include verification that the microphones and fine-wires are picking up data, and ensuring that both serial and discrete signaling is properly routed and working. Once systems are operating as planned the payload hatch will be secured. Upon arrival at Ft. Sumner for the HASP flight, similar testing will be done to ensure the payload is functional before flight. This is outlined in Table 5.

8 Special Requests

In order to ensure that the microphones and fine-wire probes are measuring data that is uncorrupted by turbulent flow around the pallet structure, they must stick out slightly from the HAAT payload housing, and face away from the rest of the gondola. For this reason, we are requesting permission for our microphones to extend out of the prescribed footprint by $50mm$, and the wire probes to extend out by $190mm$. Should this request be denied, we risk compromising the data acquired by the microphones and rendering it useless. If deemed necessary the wire probes can be retracted a maximum of $30mm$, however this does increase the risk of corrupting the data via increased influence of the HAAT payload itself. There is also a semi-rigid thermocouple with is intend to freely hang beneath the payload by $53mm$. This can easily be shortened or re-orientated if necessary, however it is preferable to position the thermocouple so that it remains in shadow during the flight.

9 Preliminary Flight Operations Plan

Table 5: Preliminary flight plan.

Time from launch	Event name
- 01:00:00	Turn on payload
- 00:30:00	Check DAS
+00:00:00	Balloon launches
+02:00:00	Balloon reaches altitude
+02:01:00	Send trigger command to begin data acquisition
+08:30:00	Send trigger command to end data acquisition
+24:00:00	Flight ends

10 Project Management

There are four student leads: 1) Cameron Butler, a doctoral student in Hypersonics, who will aid in the science instrumentation and data analysis; 2) Lorenzo Narducci, who will provide oversight of all documentation and software necessary for this project; 3) Jessica Queen who will direct electronics design and integration of associated systems; and 4) Quinn Kupec, who will be directing manufacturing and assembly of HAAT. There are also two subsystem leads: 1) Tiffany Ramcharan who will take charge of mechanical subsystems and thermal management; and 2) Mathew Fowler who will take charge of sensor integration and software. Three other undergraduates will be assisting on the HASP project as well; see table 7 in Appendix A for full team personal and key personnel contact information.

The team is advised by Dr. Stuart Laurence and Dr. Mary Bowden, with the team being project managed by Dr. Shaun Skinner who will lead the science and engineering of the HAAT payload. Dr. Mary Bowden is the director for the University of Maryland's ballooning payload program (sponsored by the Maryland Space Grant Consortium) and provides expert advice in balloon flight operations. Dr. Stuart Laurence is the lead PI for UMD's Air Force Small Business Technology Transfer Program (AFSTTR) with Tao Systems Inc., an aerodynamic sensor development company based in Hampton VA. Dr. Shaun Skinner is a Post Doctoral researcher at UMD funded through the AFSTTR program.

Table 6 outlines the major tasks to be completed in through January 2019 to June 2019 to have HAAT ready for CSBF integration and, subsequent, flight on HASP. Planned FiSH flights have been included in to the time-line as FiSH and HAAT will share sensors, electronics, and data acquisition systems. It is anticipated that between three and six students will be available to participate in integration at CSBF, and between two and three students will participate in flight operations at Ft. Sumner.

11 Previous Balloon Flights

11.1 HASP

11.1.1 2008 - 2009

On the 2008 and 2009 HASP flights, the UMD ABC payloads (University of Maryland Advanced Balloon Communications Experiments) tested various configurations of GPS antennas and radio downlink systems. These GPS antennas successfully communicated with a ground station throughout the flight.

Table 6: Description of work.

2019 Time-line	Description of work
January	Additional hardware aquisition.
	FiSH flight.
14th January	Announcement of student payloads
February-March	Structure development.
	Circuit design and manufacture.
	Design refinement.
	Hardware tests.
February	FiSH flight.
March-April	Payload housing manufacture.
April	FiSH flight.
15th April	NASA On-site Security Clearance Document due
26th April	Preliminary PSIP document due
May	Complete integration of HAAT payload and sensors.
	Thermal and vacuum tests.
	FiSH flight.
June	Full sensor calibration.
	2nd Thermal and vacuum tests.
	FiSH flight.
28th June	Final PSIP document due.
19th July	Final FLOP document due.
≈ 15th-19th July	Student payload integration at CSBF.
≈ 25th-29th August	HASP flight preparation.
≈ 30th August	Target flight ready.
≈ 2nd September	Target launch date and flight operations.
≈ 5th-8th September	Recovery, packing and return shipping.
November	Post-flight calibration of sensors.
November	FiSH flight.
≈ 6th December	Final Flight / Science Report due.

11.1.2 2010 - 2012

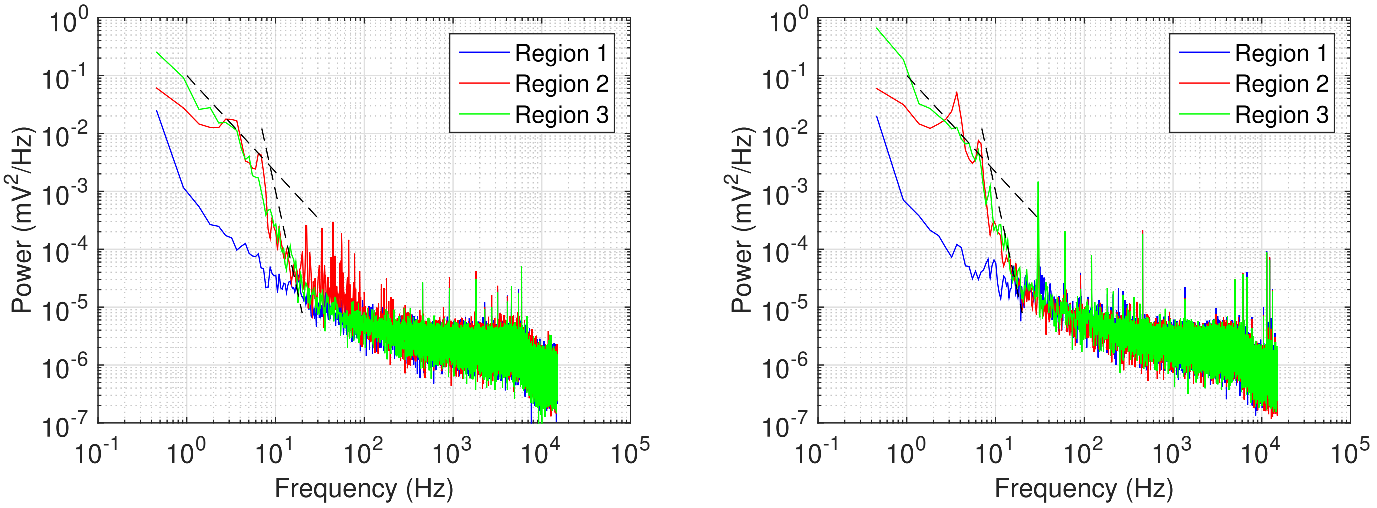
HASP 2010 was the first flight of the UMD payload StratoPigeon, which would acquire data for a few hours before dropping. StratoPigeon received its drop command through a ground station telemetry network similar to that tested during the ABC experiments. The 2010 flight was a systems check operation to ensure full system functionality. The 2011 and 2012 flights both demonstrated successful drops, but only the 2011 drop module was successfully tracked and recovered.

11.1.3 2017

The UMD HASP 2017 payload was a spiritual successor to StratoPigeon dubbed HAAT-TRIC. This was a partnership between the Balloon Payload Program (BPP) and the High-speed Aerodynamics and Propulsion Lab (HAPL), both research labs in the Aerospace Engineering Department at UMD. BPP provided the droppable module while HAPL supplied the scientific instrumentation. HAAT used a constant voltage anemometer coupled with thin-film probes to measure perturbations in velocity and temperature within the upper stratosphere, while TRIC contained a Raspberry Pi for data logging that was to be dropped when commanded with a HASP discrete signal. Due to hardware difficulties before flight, the drop module was dropped on a 4 hour timer instead of using the discrete command lines, and there was no serial downlink of the payload status.

Spectral data from the hot and cold thin-film probes from three regions between the altitude of $107.7kft$ and $109kft$ are presented in figure 7. Data was sampled at $30kHz$ for over 7 hours. Both $-5/3$ and -7 decay trends are observed, though the signal drops into noise at around $20Hz$. No measurements of the relative wind speed is available from HASP to derive length scales, hence the spectra is plotted in terms of frequency rather than wave number. This flight was a significant milestone in demonstrating the capabilities of our HAAT system for disturbance measurements for extended periods of time above $100kft$.

Although the HASP 2017 flight was successful in terms of data acquisition, HAAT-TRIC suffered structural failure on landing. The 3D printed structure was also found to degrade under intense ultraviolate light experienced at high altitude.



(a) Hot-film power spectra.

(b) Cold-film power spectra.

Figure 7: Data collected from thin-film probes on HASP 2017 flight; dashed lines indicate decays of $-5/3$ and -7.

11.1.4 2018

In the HASP 2018 flight UMD the second iteration of the HAAT-TRIC payload. This payload was primarily focused on improving the previous year's design. However, the mini-CVA and film probes were replaced, in HAAT, with a suite of microphones for the purpose of measuring high altitude acoustic fluctuations. Unfortunately, faulty connections prevented any microphone data from being recorded, although the payload proved fully operational during thermal vacuum testing at CSBF. TRIC functioned as planned.

11.2 FiSH

FiSH (Fluctuations In Stratosphere by Hot-film) is a sensor package that has been in development over the past year and a half through an Air Force Small Business Technology Transfer Program (AF STTR) with Tao Systems Inc, a small aerodynamic sensors company in Hampton VA. FiSH is currently equipped with a hot-wire probe for velocity measurements, a cold-film probe for temperature measurements, and three PCB microphones for acoustic measurements. These are the same microphones flew during the 2018 HASP campaign, and will fly again on the 2019 campaign.

The most recent FiSH flight was performed on 2^{nd} December 2017 with the instrumentation mentioned above. Example data from this flight is presented in figure 8, over the altitude range of 78 to $88kft$. Time-series for the hot-wire and cold-film probes, and the low-noise microphone (378A04 PCB microphone) are shown in the left column; these traces have been high-pass filtered to accentuate and high frequency activity. The hot-wire and cold-film probes were uncalibrated, thus the y-axis has been left as the recorded voltage output. For the microphone, factory calibrations along temperature and pressure corrections have been applied. The power spectra for three $10s$ intervals ($150ft$) are shown, where the blue trace ($78,382ft$) is for a region of relatively low disturbance, red ($79,760ft$) is a high disturbance region, and green ($87,111ft$) is a region of intermediate disturbance.

In the hot-wire spectra (figure 8b) the difference between high and low disturbance regions are clear. At the sample from $79,760ft$ clear evidence of a $-5/3$ trend transitioning to a -7 trend at higher wave numbers is observed. This is less clear for the cold-film probe which does not have as high a sensitivity. It is observed that that the signal becomes lost in noise at a wave number between approximately 400^{-1} and 500^{-1}, which corresponds to a wavelength slightly larger than $1cm$. This demonstrates the ability of fine-wire probes to make measurements down to the length scales relevant to hypersonic boundary-layer transition.

Results from this flight for the most sensitive microphone are shown in figures 8e and 8f. It is worth noting that the maximum disturbance within this altitude range is approximately $0.6mPa$. Clearly, this microphone is capable of resolving disturbances above the noise floor until approximately $2kHz$ (refer to figure 8e), at least in regions of large disturbances. As discussed previously, the disturbances relative to hypersonic boundary layer transition are typically at frequencies on the order of $10kHz$, so this microphone is approaching the desired resolution.

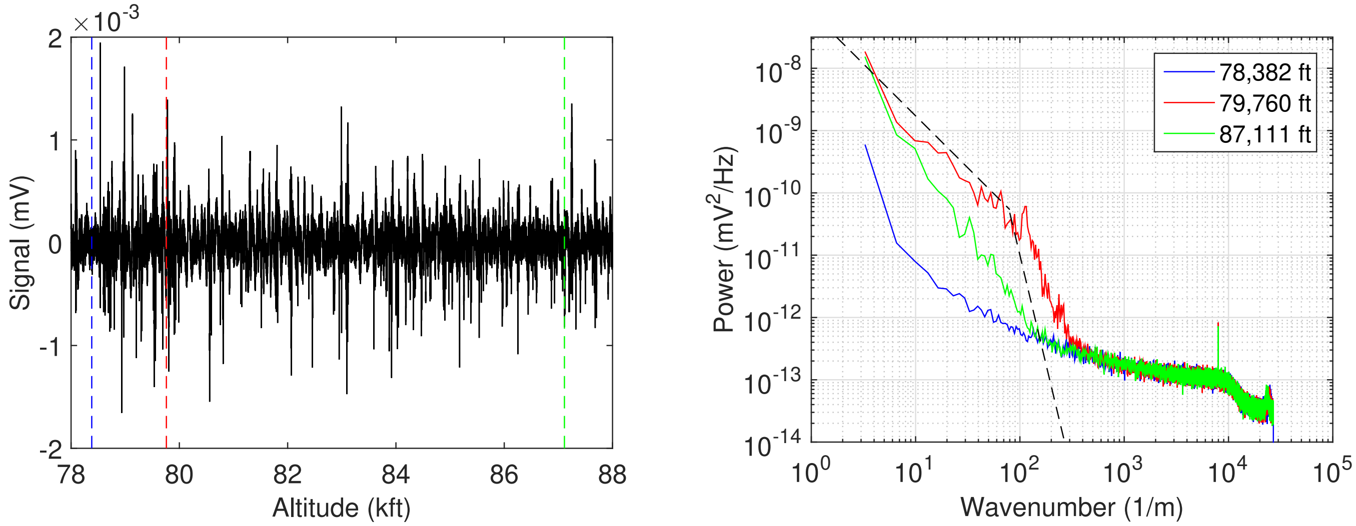
Currently, techniques are being considered for lowering the noise floor even further, including the procurement of a microphone with even higher sensitivity. FiSH flights are planned to resume in January 2019 with a minimum of six flights planned for 2019. The payload will be instrumented with both hot and cold fine-wire probes (CVA and CVT) in addition to the microphone suite. FiSH will be equipped with a tri-axial gyroscope, tri-axial accelerometers, pressure transducers, thermocouples, and an optical particle counter. Furthermore, in conjunction with this project UMD will be developing a calibration facility capable of calibrating the probes for stratospheric conditions.

11.3 DataPigeon

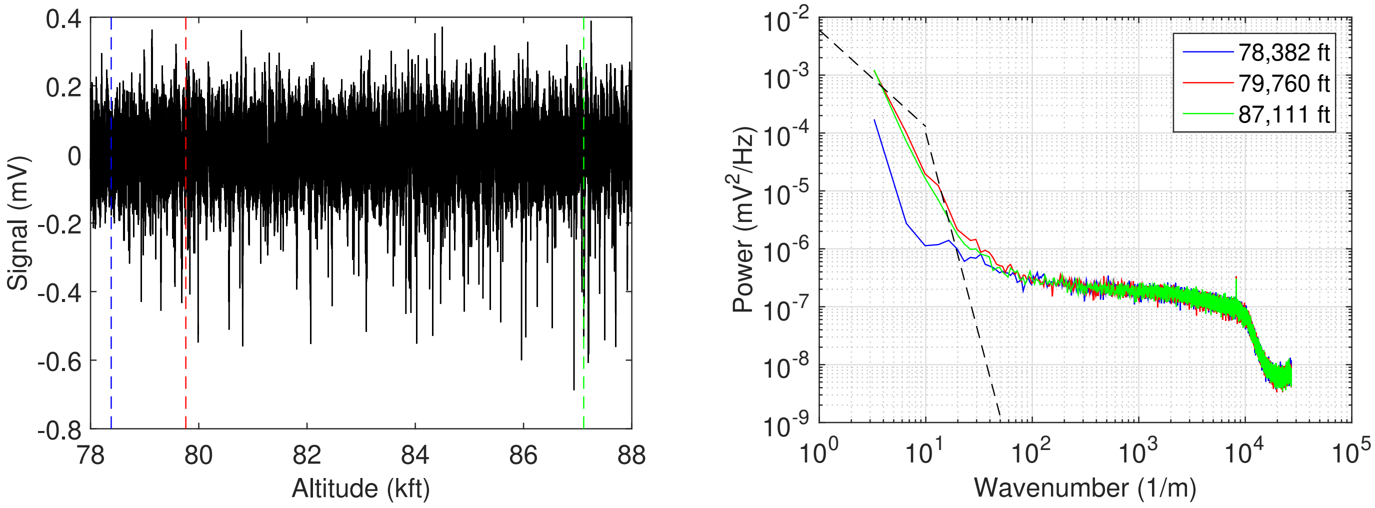
DataPigeon was a project, inspired by StratoPigeon, that started in the summer of 2016 until the fall when it became part of our HASP 2017 effort. DataPigeon utilized a cut-down device called MARS (Mechanically Actuated Release System) to perform a tethered drop on a balloon flight after a set time from balloon launch. A USB cable with a magnetic detachment was used to cleanly break the data line when the payload was dropped. DataPigeon flew on two flights. The first one in the late summer of 2016 was fairly successful, as the payload logged data and then dropped, severing connection with the module it was connected to. The second flight, in the early fall, was less successful due to a timing error in the code which prevented MARS from activating. The module also failed to record data throughout this second flight. DataPigeon was then combined with FISH for the 2017 HASP proposal.

11.4 MARS

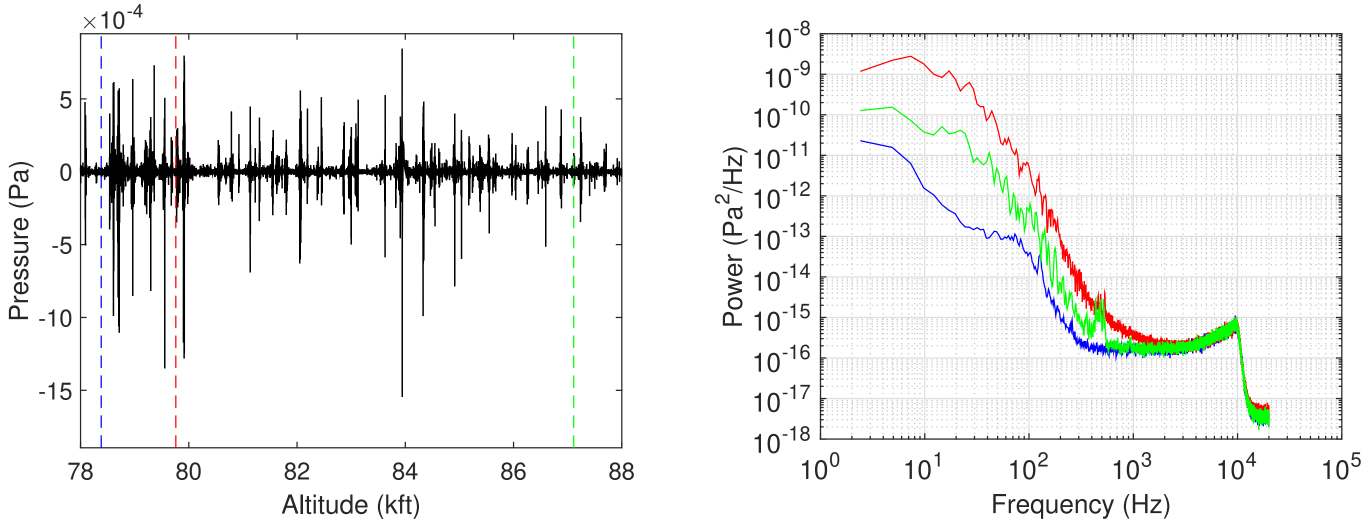
The design for the release mechanism of TRIC is an adaptation of the MARS cut-down device. MARS is an actuator release mechanism used to disconnect the bottom payload from the rest of the payload string on one of our sounding balloon flights. Instead of serial commands from the main payload gondola, MARS uses XBee radio signals to communicate with the balloon's command and tracking module and with the ground. The first flight of MARS was in November 2015 and it has flown on a variety of flights since then. The MARS system has successfully dropped the intended payload on almost all of its test flights.



(a) Hot-wire time-series. (b) Hot-wire power spectra.



(c) Cold-film time-series. (d) Cold-film power spectra.



(e) 378A04 PCB microphone time-series. (f) 378A04 PCB microphone power spectra.

Figure 8: Data collected from FiSH, measured by hot-wire, cold film, and microphone over an altitude range of 78 to 88kft The dashed vertical lines on the left plots indicate the altitudes at which the spectra in the right plots were calculated; the dashed lines on the velocity and temperature spectra indicate decays of $-5/3$ and -7.

A Full Team Personnel

Table 7: Full team personnel.

Name	Start Date	End Date	Role	Student Status	Race	Ethnicity	Gender	Disabled
Cameron Butler	11/15/16	Present	Graduate Science Lead	Graduate	White	Non-Hispanic	Male	No
Lorenzo Narducci	11/15/16	Present	Undergrad Student Lead	Undergrad	White	Non-Hispanic	Male	No
Jessica Queen	12/01/17	Present	Electronics and Systems Lead	Undergrad	White	Non-Hispanic	Female	No
Arnold Chonai	09/15/15	Present	Electronics	Undergrad	Asian	Non-Hispanic	Male	No
Quinn Kupec	11/15/16	Present	Mechanical Lead	Undergrad	White	Non-Hispanic	Male	No
Tiffany Ramcharan	09/15/15	Present	Mechanical Design and Thermal Management	Undergrad	Asian	Non-Hispanic	Female	No
Theo Kuiper	03/03/18	Present	Mechanical Design	Undergrad	White	Non-Hispanic	Male	No
Matthew Fowler	11/15/17	Present	Sensor Integration and Software	Undergrad	White	Non-Hispanic	Male	No
Zachary Burnett	11/15/16	Present	Sensor Integration and Software	Undergrad	White	Non-Hispanic	Male	No
Shaun Skinner	11/01/18	Present	Project Manager (Post-Doc)	N/A	White	Non-Hipanic	Male	No
Arun Mangalam	11/15/16	Present	Industry partner (Tao Systems Inc.)	N/A	Asian	Non-Hispanic	Male	No
Mary Bowden	2000	Present	Faculty Advisory	N/A	White	Non-Hispanic	Female	No
Stuart Laurence	2013	Present	Faculty Advisory	N/A	White	Non-Hispanic	Male	No

Table 8: Key personnel contact information.

Dr. Shaun Skinner	Project Manager	skinner1@umd.edu
Cameron Butler	Graduate Science Lead	cameron.mech@gmail.com
Lorenzo Narducci	Student Lead	lzonarducci@gmail.com
Dr. Mary Bowden	Faculty Adviser	maryb@ssl.umd.edu
Dr. Stuart Laurence	Faculty Adviser	stuartl@umd.edu

B Technical Drawings

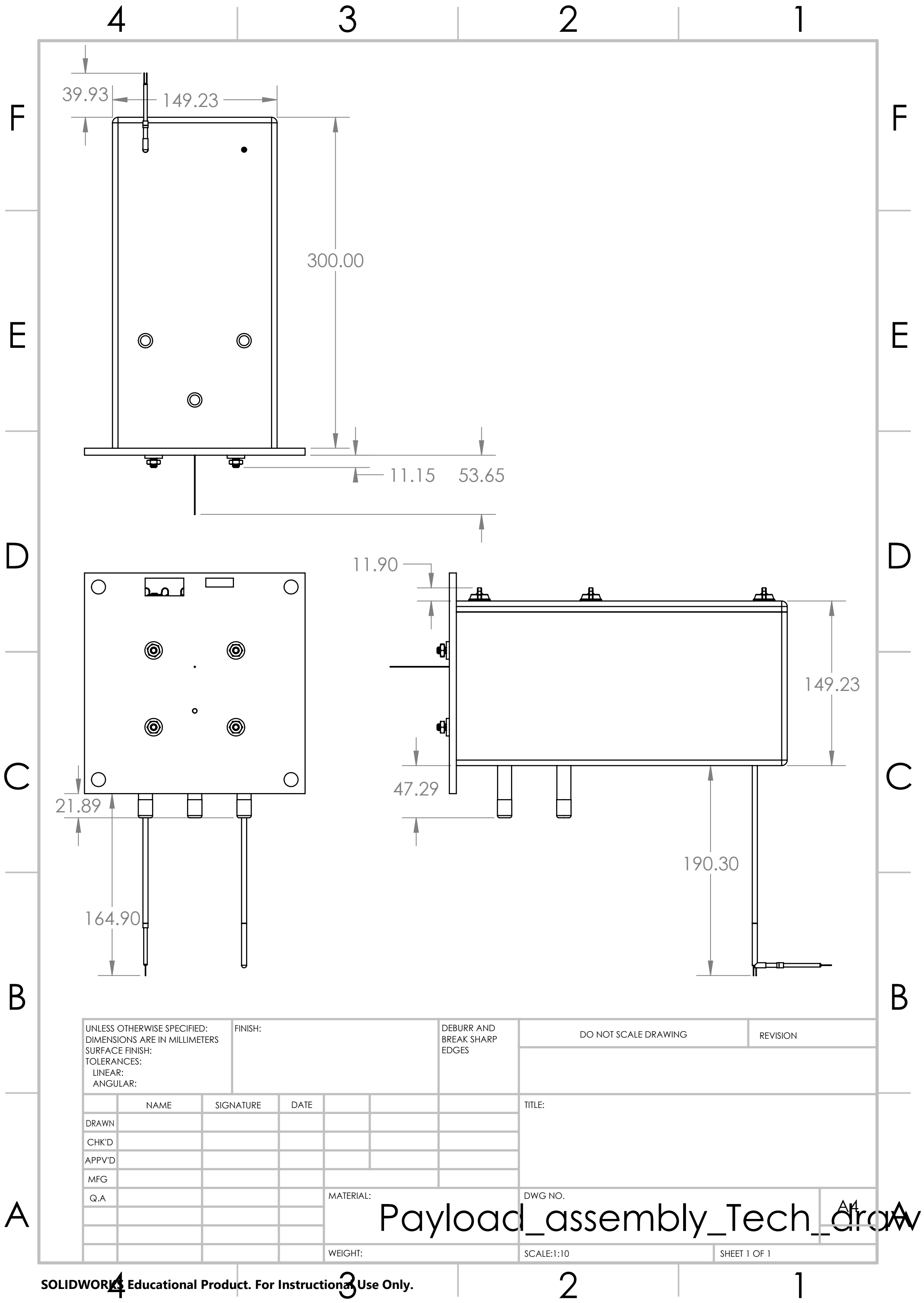


Figure 9: Technical schematic of payload on HASP mounting plate. Dimensions in *mm*.

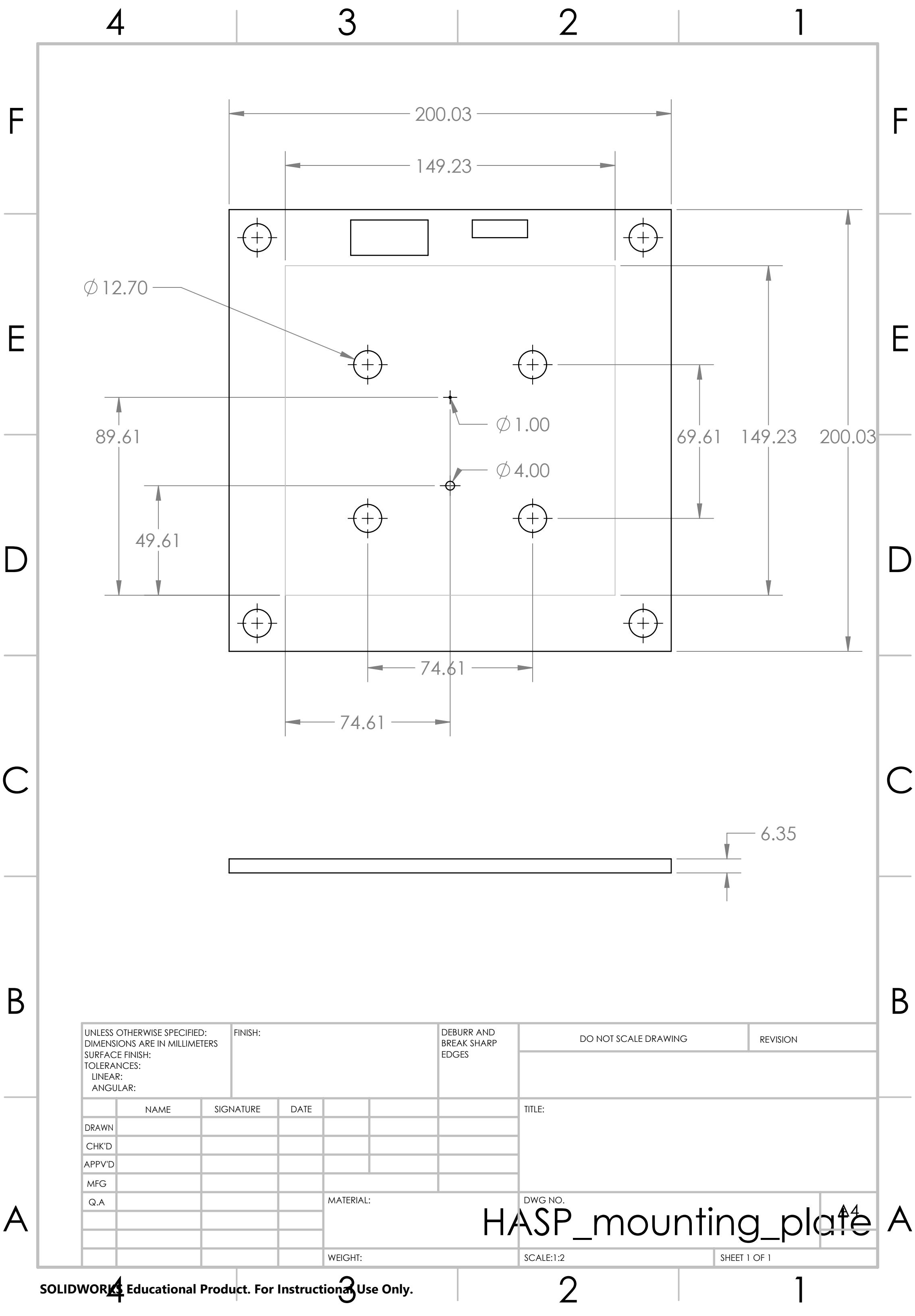


Figure 10: HASP mounting plate; note that of the footprint of the main HAAT payload does not enter the ‘Keep Out Area’. Dimensions in *mm*.

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