HASP Student Payload Application for 2019

Payload Title: SHADOMS (Stratospheric Hypersonics Airborne Particulate Optical Measurement System)		
Institution: University of Minnesota - Twin Cities		
Payload Class (Enter SMALL, or LARGE): SMALL		Submit Date: 12/14/18

Project Abstract:
To make hypersonic vehicles more realizable in today's world, the complex multidisciplinary physics that are involved must be more understood. A current challenge involves accurately characterizing the particulate content at hypersonic cruise altitudes (stratosphere) and how they affect the performance of the vehicles. In this payload application, we propose to fly multiple optical particle detectors on the 2019 HASP mission to make multi-hour measurements of stratospheric particle concentrations at all altitudes up to and including float. The objective is to help compare/characterize low-cost, mid-cost, and high-cost optical particle detector performance in actual stratospheric conditions. This experiment will support an on-going research project to better characterize particulate content in the stratosphere above 80,000 feet for use in hypersonic flow computer simulations to assist in the design of future hypersonic vehicles.

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1. Introduction

The University of Minnesota - Twin Cities (UMN-TC) is part of an Air Force Office of Scientific Research (AFOSR) funded Multidisciplinary University Research Initiative (MURI) project to study the role of stratospheric particulates (also known as “particles”) and free-stream turbulence in hypersonic boundary layer transition. The University of Colorado is leading this effort, assisted by teams at the UMN-TC and Embry Riddle Aeronautical University in Florida. In particular, UMN-TC has been tasked with measuring the atmospheric particulate content at various altitudes in the stratosphere and using the resulting data as input to computational tools that simulate how particulates interact with the hypersonic flow field.

Over the past academic year, UMN-TC has been developing a preliminary, weather-balloon-based, particulate-measuring payload to perform such measurements. Great efforts have been made in perfecting weather ballooning techniques (flown locally) and calibrating particulate-measuring instruments such as optical particle detectors. Multiple weather balloon flights have been made in Minnesota with the goal of consistently reaching altitudes from 80,000 to 120,000 feet and floating for a short period of time (minutes, not hours) while collecting particulate data. In addition, UMN-TC included an optical particle detector as an add-on to our main payload on the 2018 HASP mission, which made measurements starting at an altitude of approximately 80,000 feet on ascent and throughout the duration of the flight until shortly before descent began. This HASP mission proved to be an excellent opportunity to evaluate these developing systems, as it consisted of a flight profile that is currently not possible in local stratospheric flights using weather balloons.

The UMN-TC’s objectives for the 2019 HASP mission are to perform in-situ measurements of particle concentrations and size distributions in the stratosphere and directly compare multiple optical particle detector measurements in stratospheric conditions. The payload to be used will include particle detectors from multiple manufacturers, including low-cost, mid-cost, and high-cost detectors, along with support from a UMN-TC-developed sensor suite, which will be used for functions including data logging, active heating (when necessary), and GPS-tagging of data sets.

The results from the 2019 HASP mission will not only provide valuable particulate data at higher altitudes and for a much-longer duration than is practical with local weather balloon flights, but it will allow in-situ collection of particulate data at a wide range of altitudes by multiple optical particle detectors for direct comparison/cross-calibration purposes. This second aspect of the experiment will provide useful insight towards which particle detectors to use for future stratospheric flights in the MURI project and how to interpret their data (i.e. simultaneous calibration of multiple types of detectors at the extreme temperature and pressure conditions experienced during a stratospheric mission).

1.1 Scientific Background

1.1.1 Hypersonic flight

The regime of hypersonic speeds, which are generally defined as above Mach 5 (five times the speed of sound), is encountered during the reentry of space vehicles, such as the Space Shuttle or Apollo capsules, and is currently achievable by some emerging aircraft and missile technologies. Understanding the physics of such high-speed flight is critical in further developing safe and efficient vehicle designs. Further, this could open the door for numerous commercial applications (such as significantly reduced intercontinental travel time and routine "space-tourism") and would improve the safety of spacecraft during their descent into a planet's atmosphere.

However, flying at speeds exceeding five times the speed of sound poses complex multidisciplinary physics problems and risks immense practical failures. In particular, the fluid mechanics involved in the extreme aerothermodynamic environment associated with high-speed flight are still not completely understood. As a result, there has been extensive efforts made by researchers to develop tools, both experimental and computational, to aid in solving such problems.

A specific problem is measuring the small-scale atmospheric disturbances that are present in actual hypersonic flight conditions and how they affect the flow physics. Such disturbances include turbulence on small spatial scales (centimeter scales, or even smaller) and suspended particulates. This problem is of particular interest as it is currently not known if atmospheric turbulence or particulates are the source of the disturbances that ultimately cause the skin friction and aerodynamic heating rate to the vehicle to dramatically increase. If the heating load is too extreme, it could compromise the flight entirely. Thus, in obtaining accurate data on these disturbances, researchers could use them as inputs to computational fluid dynamics simulations to better understand how they interact with the flow physics.

1.1.2 Atmospheric particles versus hypersonic boundary layers

Near the body of a vehicle, viscous effects of the fluid dominate and promote steep gradients in fluid properties such as velocity and temperature. The result of this is a thin layer of fluid on the surface of the vehicle known in aerodynamics as the boundary layer. When a hypersonic boundary layer transitions from smooth laminar flow to chaotic turbulent flow, the skin friction and aerodynamic heating rate to the vehicle dramatically increase. Thus, the aerothermodynamic design of hypersonic vehicles relies on the ability to predict laminar-turbulent transition. Transition usually occurs when small disturbances in the atmosphere are amplified by the boundary layer until they reach a critical amplitude. Then, the flow breaks down to turbulent motion. As described above, it is currently not known if atmospheric turbulence or particulates in the flow are the source of the disturbances that cause observed transitions. Therefore, it is important to characterize the atmospheric state and study how disturbances interact with hypersonic boundary layers. From an applied perspective, this would consist of accurately and reliably characterizing the local particulate content of the atmosphere before a test flight of a hypersonic vehicle.

1.1.2 Optical particle detectors

Characterization of atmospheric particulate content can be done using optical particle detectors, which operate on the principle of light scattering. Air is drawn into the instrument by means of a small fan or pump; as the air passes through a designated region, it is illuminated by a laser beam. The beam strikes individual particles in the air flow and creates a scattering pattern. The corresponding intensity of the scattered light is then related to the particle size based on Mie scattering theory, where the intensity of the scattered light is typically measured by a sensor, such as a photodiode, at a particular deflection angle within the instrument. The resulting data is generally reported in terms of "particle count per second" and is categorized into "particle-size bins". The concentration of particles can then be calculated in a post-processing routine (or some instruments calculate this internally) based on the particle counts and the recorded sample flow rate.

Optical particle detectors range in price from under one hundred dollars ("low-cost") up to one thousand dollars ("mid-cost") up to ten thousands of dollars or more ("high-cost"). For this reason, it is of particular interest to develop a payload using low-cost and/or mid-cost particle detectors and comparing their response to that of a well-characterized high-cost detector in an identical stratospheric environment. Ground calibration of optical particle detectors, though crucial, is expensive (and often cannot duplicate the extreme conditions encountered in the stratosphere). Therefore, it is important to fly multiple detectors on HASP to help determine the most suitable detector(s) for future weather-ballooning missions.

As an example, a depiction of the "LOAC" optical particle detector (more details described below) is shown in Figure 1 to illustrate the concept described above. This figure shows the orientation of the internal laser and photodiodes. The air flow inlet is on the bottom (not visible in image) and the air flow channel is perpendicular to the plane of the lasers and photodiodes. As the air crosses the laser beam it scatters the incident light, causing it to be sensed by the photodiodes at multiple deflection angles.

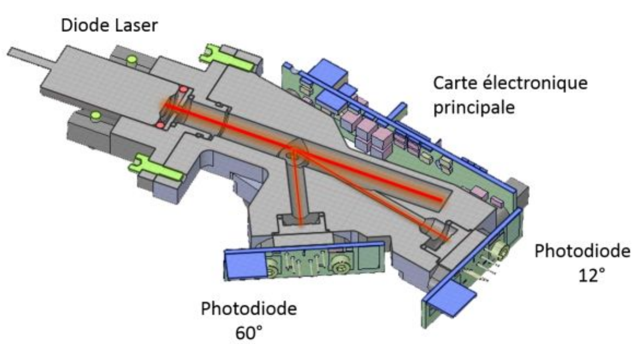

Figure 1. Depiction of the LOAC optical particle detector unit. Image from Renard et.al. [4].

1.1.3 Rarefied environment

A significant challenge that cannot be overlooked is the effect that the rarefied conditions of the upper atmosphere has on the optical particle detectors. Specifically, the effect of a low pressure and density environment on the performance of the detectors has not been quantified by low-cost and mid-cost instrument manufacturers. As the air becomes more vacuum-like, the drag force on the particles will decrease. If the drag becomes too small, the inertia of the particles will dominate and they may no longer follow the air flow streamlines through the detector. Thus it is speculated that they may not pass through the laser region of the instrument and be detected at all, or at least not as efficiently as anticipated, resulting in an inaccurate (low) particle count. Furthermore, as the air density decreases, there will be less mass influx per sample volume of air. Not all particle detectors account for the extreme variation in air density encountered in a stratospheric mission, resulting in an inaccurate sample flow rate and hence in an inaccurate particle concentration.

To deal with this challenge, UMN-TC is making an effort to calibrate multiple particle detectors in a low pressure, low density environment. Such a calibration will characterize the response of the detectors at high altitudes and quantify how their performance is affected.

1.2 Previous Work

A primary focus over the past academic year has been experimenting with one type of mid-cost optical particle detector, namely the Alphasense OPC-N2. This instrument uses a small fan to draw in air samples and is capable of sizing and categorizing particles into 16 separate size bins, ranging from 0.35 μm to 17 μm. It has been flown on six local weather-balloon flights in Minnesota to date, as well as the 2018 HASP mission. Efforts have been made to rigorously calibrate our Alphasense OPC-N2 detectors using NIST traceable monodisperse PSL spheres [1]. The calibration consisted of evaluating and comparing the response of four OPC-N2s with a previously calibrated TSI Optical Particle Sizer Model 3330, as a reference standard, at 1 atmosphere and room temperature conditions (i.e. NOT extreme conditions) using four different sizes of monodisperse PSL spheres: 400 nm (0.400 μm), 702 nm (0.702 μm), 1030 nm (1.030 μm), and 5027 nm (5.027 μm).

The 2018 HASP mission was ultimately successful in terms of payload functionality. The flight resulted in approximately 9 hours of data that was obtained between approximately 75,000 and 122,000 feet and it was the first flight using an OPC-N2 detector that had been calibrated beforehand. Figures 2 and 3 in Appendix A show data collected by the OPC-N2 during the 2018 HASP mission.

Figure 2 shows the average concentration (number of particles per cubic centimeter) of 0.35-0.54 μm size particles versus altitude (kilo-feet). The vertical error bars represent the altitude range over which the average concentration was taken. The horizontal error bars represent the uncertainty in concentration, which was determined based off calibration and the standard deviation of the averaged values. All other size bins (greater than 0.54 μm) measured zero and thus were not included in the figures.

Figure 3 shows the average concentration (number of particles per cubic centimeter) of 0.35-0.54 μm size particles versus time (orange) and altitude (kilo-feet) versus time (blue). The vertical error bars represent the uncertainty in concentration, which was determined based off calibration and the standard deviation of the averaged values. The horizontal error bars represent the time period over which the average concentration was taken. The origin (t = 0 min) is relative to the time at which particle sampling began, at approximately 80,000 feet during the ascent. From t = 0 to t ≅ 60 min, the balloon is in ascent; from t ≅ 60 to t ≅ 560 min, the balloon is in float, or slow descent; after t ≅ 560 min, the electronics of the payload are powered "off" before descent begins.

From an altitude of 80,000 to 120,000 ft., the OPC-N2 only detected particles in the size range of 0.35-0.54 μm. Figure 2 shows that from an altitude of approximately 80,000 to 120,000 ft., the particle concentration appears to have a relatively constant order-of-magnitude, near 10^{-1} particles/cc. Over an altitude of 110,000 feet, the concentration appears to decrease by approximately one order-of-magnitude, approaching 10^{-2} particles/cc. These magnitudes are fairly consistent with Renard et. al. [2] shown in Figure 4, which consist of measurements made up to slightly-lower altitudes (33 km, 108 kilo-feet) using weather balloons, but at a different location (France), time, and a better-characterized but high-cost "LOAC" optical particle detector..

Of significance importance to note is that the OPC-N2 did not detect any particles in size bins larger than 0.35-0.54 μm. Despite the measurements being made at different locations and time, this is inconsistent with measurements made by Renard et al. [2], who showed the presence of larger particles (up to 0.9 μm) in concentrations of similar magnitude to the smaller particles described above. They also show the existence of much larger particles (3-7.5 μm) in concentrations of the order less than 10^{-2} particles/cc at altitudes up to 108 kilo-feet.

For 2019 HASP, UMN-TC plans to fly the same high-cost LOAC optical particle detector as Renard et. al., as well as both mid-cost and low-cost detectors, in hopes of explaining this discrepancy.

Finally, Figure 5 shows a collage of pictures from the work outlined above: the top left shows the OPC-N2 (wrapped in gold-Mylar blanket) attached to the 2018 HASP payload; the bottom left shows a preliminary sensor suite inside a payload that supports the OPC-N2 on local weather balloon flights; the top right shows two weather balloons at apogee on a local flight, where the upward-facing camera captured the instant when the first balloon burst (right) initiates the burst of the second (left); and the bottom right shows the launch of the OPC-N2 payload on a local weather balloon flight.

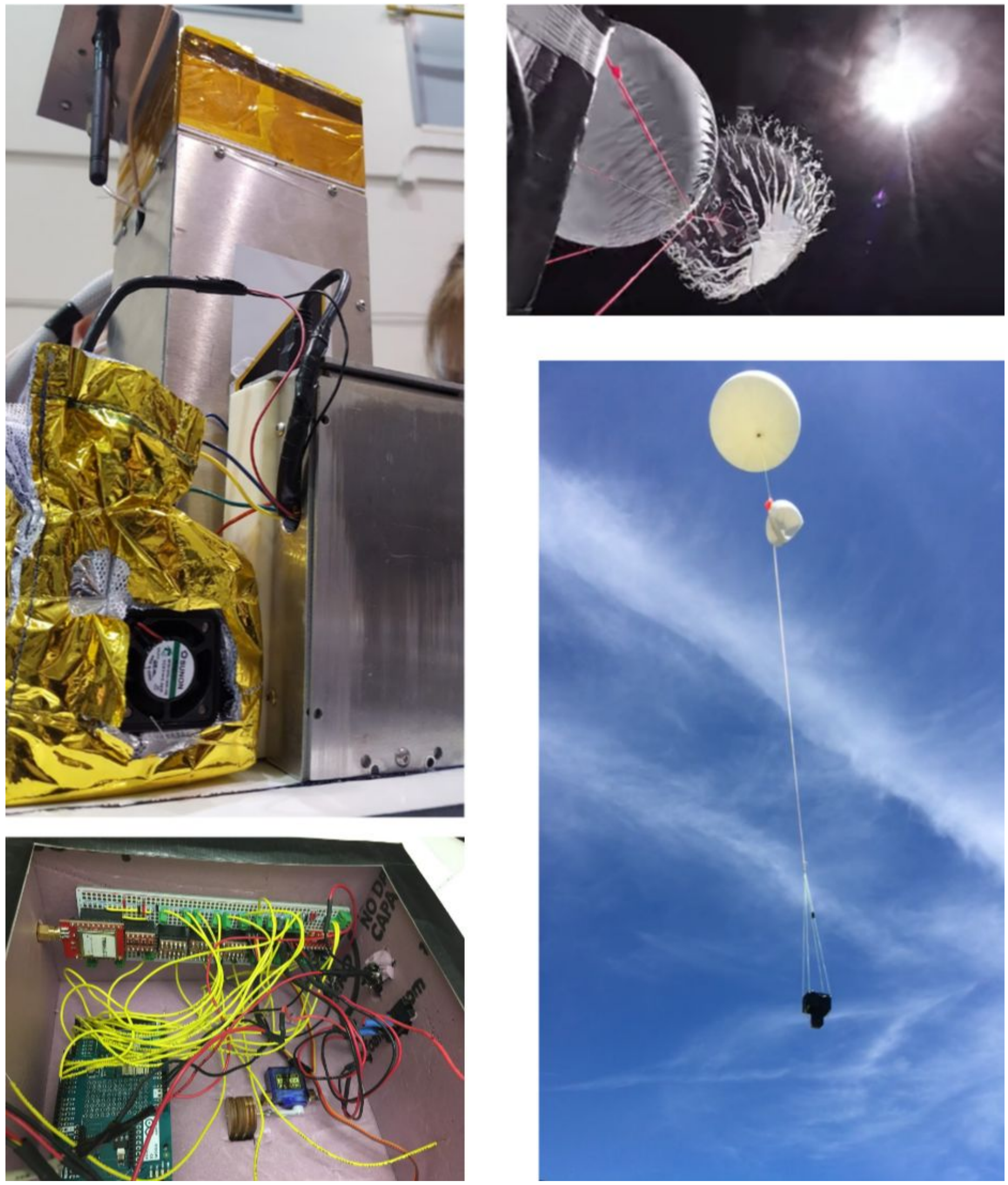

Figure 5. Collage of pictures taken over the past academic year from MURI project.

1.3 Flight Objectives

The objective of the 2019 HASP mission is to fly multiple optical particle detectors to make multi-hour measurements of stratospheric particulate concentrations and size distributions, and to compare low-cost, mid-cost, and high-cost optical particle detector measurements in actual stratospheric conditions. We propose to use and compare the following optical particle detectors:

1. Alphasense OPC-N2 (mid-cost)
2. Light Optical Aerosol Counter (LOAC) (high-cost)
3. Plantower PMS5003 (low-cost)

For convenience, these sensors will be referred to as just, the “OPC-N2”, “LOAC”, and “PMS5003” respectively. Note: we have the least experience with the Plantower PMS5003 device which was recommended to us by the HARBOR stratospheric ballooning team from Weber State University in Utah, so that is currently being tested to determine if it will be beneficial to include in our HASP payload.

The LOAC appears to be the “gold standard” for making particle measurements [2] [4] at high altitudes, so the goal of the direct comparison between detectors is to determine if the low-cost and/or mid-cost detectors are capable of producing similar results to that of the LOAC, at least with suitable ground and flight experiments to help calibrate them for use in extreme (stratospheric) conditions.

2. Team Description

The Candler-MURI project at the UMN-TC is under the direction of Dr. Graham Candler of the Aerospace Engineering and Mechanics Department. Dr. Candler is an expert in hypersonic aerodynamics and computational fluid dynamics, and is responsible for investigating the role of atmospheric particles and turbulence in hypersonic boundary layer transition, as well as the financial aspect of the project. Working closely with Dr. Candler on the flow simulations is Joseph Habeck, an aerospace engineering graduate student at UMN-TC. Mr. Habeck will continue to also play a key role in calibrating the particle detectors in cooperation with the Mechanical Engineering Department at UMN-TC, as well as parsing and interpreting the recorded particle detector data from ground and flight tests.

The payload engineering will be performed under the guidance of Garrett Ailts, an aerospace engineering undergraduate at UMN-TC. Mr. Ailts has had previous experience with HASP as part of the CubeSat team which flew a mock-up of the SOCRATES CubeSat (still under development) on the 2018 HASP mission. Faculty advisors for the payload engineering will be Dr. James Flaten and Dr. Demoz Gebre-Egziabher. Dr. Demoz Gebre-Egziabher currently works as a faculty advisor for the CubeSat team and has overseen previous UMN-TC small-sat HASP flights. Dr. James Flaten works as the Assistant Director of the Minnesota Space Grant Consortium (MnSGC) and has headed the UMN-TC Stratospheric Ballooning team for over a decade. He provides valuable experience concerning the challenges of building and operating payloads in the “near-space” environment, both on HASP and on local weather balloon missions.

Development of the electronics and flight computer for the payload will be led by Simon Peterson, an electrical engineering undergraduate, and will be assisted by undergraduate students Jackson Holl and Asif Ally. It is anticipated that Mr. Ailts and a representative from the three subtreams (detectors, flight computer/ electrical, and structural) will be present at the HASP 2019 flight next summer. The team and their respective roles are summarized in Table 1. These are students already involved in the Candler-MURI project but we anticipate some evolution of student team members on the HASP project as summer 2019 availability for these students, and others working in parallel on the Ballooning Team, becomes more clear.

Name	Email	Role
Dr. Graham Candler	candler@umn.edu	Project Lead
Dr. James Flaten	flate001@umn.edu	Faculty Advisor
Dr. Demoz Gebre-Egziabher	gebre@umn.edu	Faculty Advisor
Joseph Habeck	habec021@umn.edu	Particle Detector Lead
Garrett Ailts	ailts008@umn.edu	Engineering Lead
Simon Peterson	pet0029@umn.edu	Electrical / Flight Computer Lead
Jackson Holl	hollx047@umn.edu	Engineering Team Member
Asif Ally	allyx004@umn.edu	Engineering Team Member

Table 1. UMN-TC Candler-MURI team.

2.1 Timeline

Date	Activity
January	Purchase LOAC sensor. Construct and test circuits; esp. current limiter configuration. Begin construction and test of thermal-vacuum chamber for particle detector calibration.
February	Build flight management code, closely based on the code currently implemented in local Candler-MURI flights. Debugging!
March	Continue debugging process and finalize physical layout (location of sensors, PCB, etc.). Calibrate particle detectors in thermal-vacuum chamber and analyze results.
April	PSIP preliminary document finished
June	Final PSIP document finished- finalize

July	Cold soak testing, payload integration, FLOP due. Integration trip to Palestine, TX.
August	Final HASP preparation. HASP flight (late Aug. / early Sept.) from Fort Sumner, NM.
September, October, November	Data analysis and preparation for final scientific paper
December	Flight report due

Table 2. Timeline of events.

3.0 Payload Description

3.1 Payload Specifications

The "main" part of the HASP payload will consist of the two particle detectors (OPC-N2 and LOAC), with a possibility of adding a third (PMS5003). All other payload parts - the Teensy 3.6 microcontroller, temperature sensors, GPS, heating pads, and physical structure are secondary payload parts tasked with supporting the flight of the particle detectors in various ways, and/or to test their functionality in doing so (as explained later for the Copernicus GPS). The Teensy 3.6 is responsible for logging GPS and sensor data as well as controlling heating and sensors through the relay switches. GPS and sensor data will be used by the Teensy 3.6 to determine appropriate heating and power management measures, such as turning particle detectors and heaters on and off.

Although the area of interest for particulate measurements for the Candler-MURI project lies between 80,000 and 120,000 feet, the sensors will be turned on at payload activation and kept on for the duration of the flight unless they need to be temporarily turned off for power management reasons. (It is possible that the particle detectors may need to be off when heating elements are on, such as part way through the ascent (near the tropopause).). This will be done to compare the effectiveness of the various particle detectors at sub-stratospheric levels, of which there have been many successful flights of the LOAC [2], but fewer of the OPC-N2. These sub-stratospheric measurements will allow a more complete characterization of the atmosphere, as well as a better overview of the various sensors.

3.1.1 Hazards

Each optical particle counter houses a class 3B laser that is used for counting and sizing particles as they move through the flow channel. These lasers are completely self contained and should not be a hazard to any systems on the HASP gondola, the balloon, or any of the surrounding payloads.

3.2 Physical Description

3.2.1 Shell

Technical leaflets provide limited information on the physical structure of the LOAC, but it has been confirmed by Renard et. al. in [4] that the LOAC optical unit and pump can fit in rectangular box with dimensions 20 x 10 x 5 cm. With this knowledge, a preliminary structure has been designed that is modeled after a 3U cubesat structure flew previously by the UMN Small Sat team on HASP. The casing is made of 6061 - T6 aluminum and held together with #4-40 self-locking 18-8 stainless steel socket head cap screws. The payload attaches to the HASP plate with 1.25” ATSM A307 $\frac{1}{4}$”-20 bolts that run through the bottom wall of the payload. The shell will be coated in alternating layers of mylar and insulating fabric which will inhibit energy loss and absorption due to radiation. This should keep the payload warm in the cold tropopause and prevent overheating at altitude. Below are preliminary CAD drawings for the shell and the OPC-N2. As mentioned earlier, the LOAC was modeled as a 20 x 10 x 5 cm box in order to create the shell. Once we have a LOAC detector in hand, an accurate CAD model of the optical unit will be drafted, and interior mounting specs will be finalized. Mechanical drawings are provided in Appendix A.

3.3 Electrical Description

3.3.1 Power and weight

The payload will make use of the provided HASP 30 volt power. The LOAC sensor runs at 12 V, requiring the voltage from the HASP to be stepped down to 12 volts and also stepped down to 5 Volts for use by the OPC-N2, heaters, and flight computer. All particle detectors and heaters are controlled through relays by the Teensy 3.6 microcontroller. Temperature sensors and GPS data are used to determine when to power the particle detectors and when to actively heat payload components using mesh heating pads.

Component	Mass (g)	Mass Uncertainty (g)	Power (W)	Power Uncertainty (W)
OPC-N2	105	10	0.875	0.035
LOAC (including pump)	300	10	6	0.025
Flight computer, board based sensors	20	5	0.37	0.015
Structure	960	20	0	0
Thermal (active and passive)	60	10	6	0.5
Total	1445	55	13.245	0.575

Table 3. Power and mass specifications.

Table 3 gives the power consumption for the payload. As shown in Figure 13, there will be two voltage converters in series- the first will convert from 30 to 12 volts to power the LOAC, and the second will step 12 volts down to 5 to power the Teensy and OPC-N2. Not shown in Figure 13 is current limiting circuit to limit the input current to the maximum allotted 500 mA (The design for the limiter was decided upon at the time of the proposal). The total power consumption of 13.245 watts is under the maximum power provided by HASP. However, even though total consumption lies under the given limit, the flight computer will ensure that the major power-consuming devices - particle detectors and the heating pads - never exceed the power limit (and hence might not be allowed to be on at the same time). Based on previous balloon flight experience, it is only necessary to apply active heating during the ascent phase near the tropopause to keep the payload adequately warm, as at higher altitudes decreased convection occurs due to a very thin atmosphere.

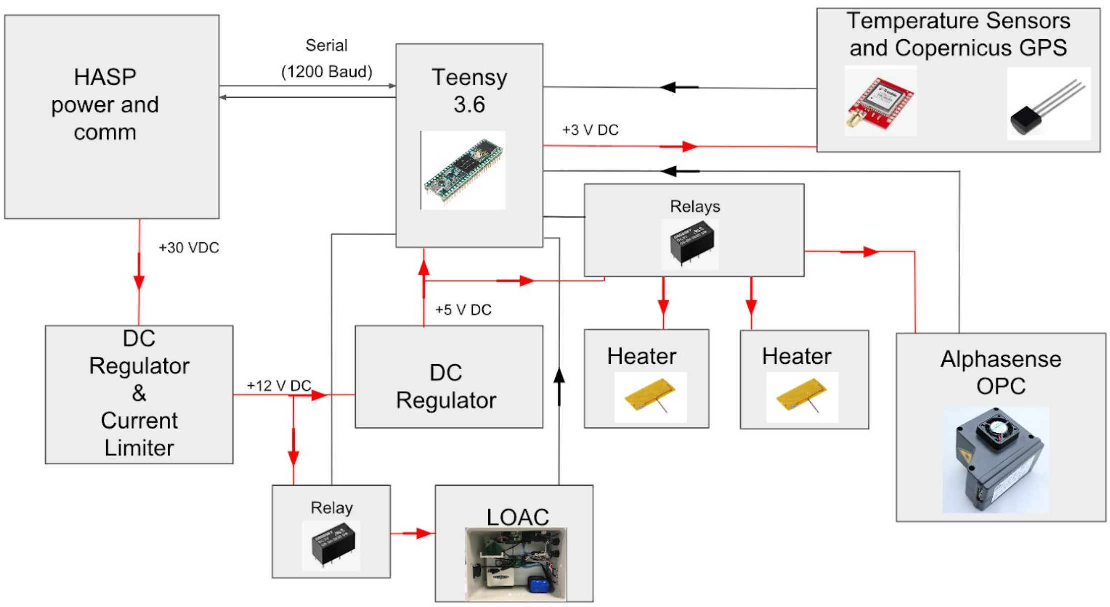

Figure 6. Electrical and power layout of the payload. The LOAC will log data in stand-alone mode (except for sending GPS data to the Teensy for comparison), but the OPC-N2 detector and the PMS5003 detector (if flown) will be logged by the Teensy 3.6 system.

3.3.2 Inter-Device and Hasp interfacing

The Teensy 3.6 microcontroller will be connected with the DB9 interface and programmed to receive and log GPS data. Figure 14 shows the electrical connections to and from the Teensy 3.6 microcontroller. Although local Candler-MURI weather balloon flights do not include a downlink, the HASP downlink will be utilized to send real time sensor and detector readings to the ground. As GPS data has occasionally been problematic on past HASP flights, and also to evaluate the effectiveness of mid-cost ($75) GPS units for future Candler-MURI weather-balloon flights, a Copernicus GPS unit will also be flown. The LOAC sensor also has a built in GPS system which will be logged by both the LOAC unit and the Teensy system. This data will be used, much like the Copernicus GPS unit, to help evaluate the effectiveness of the components for use on future Candler-MURI weather-balloon missions.

Appendix A. Figures

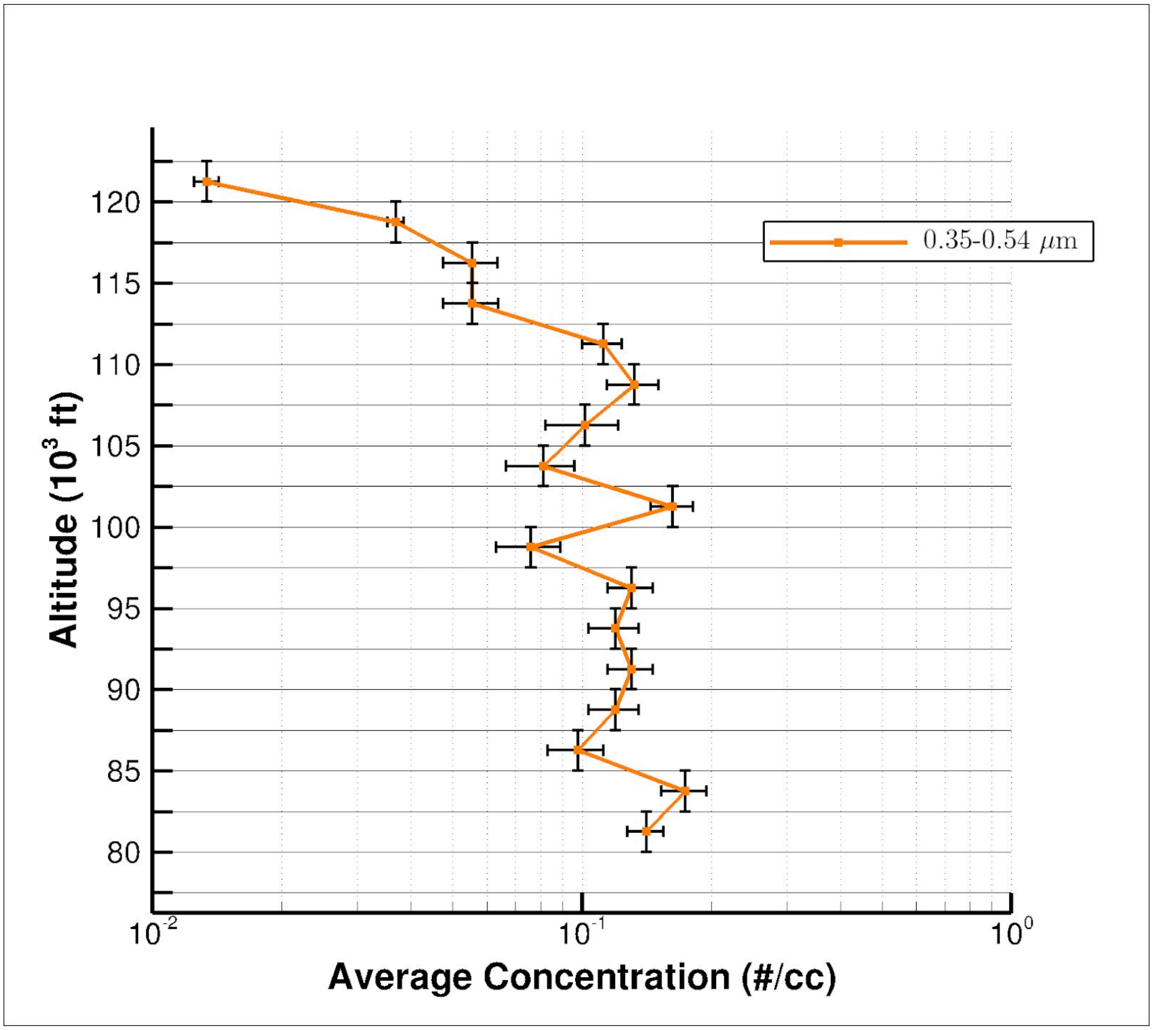

Figure 2. Average concentration (number of particles per cubic centimeter) of 0.35-0.54 µm size particles versus altitude (kilo-feet). This OPC-N2 data was collected on the 2018 HASP mission.

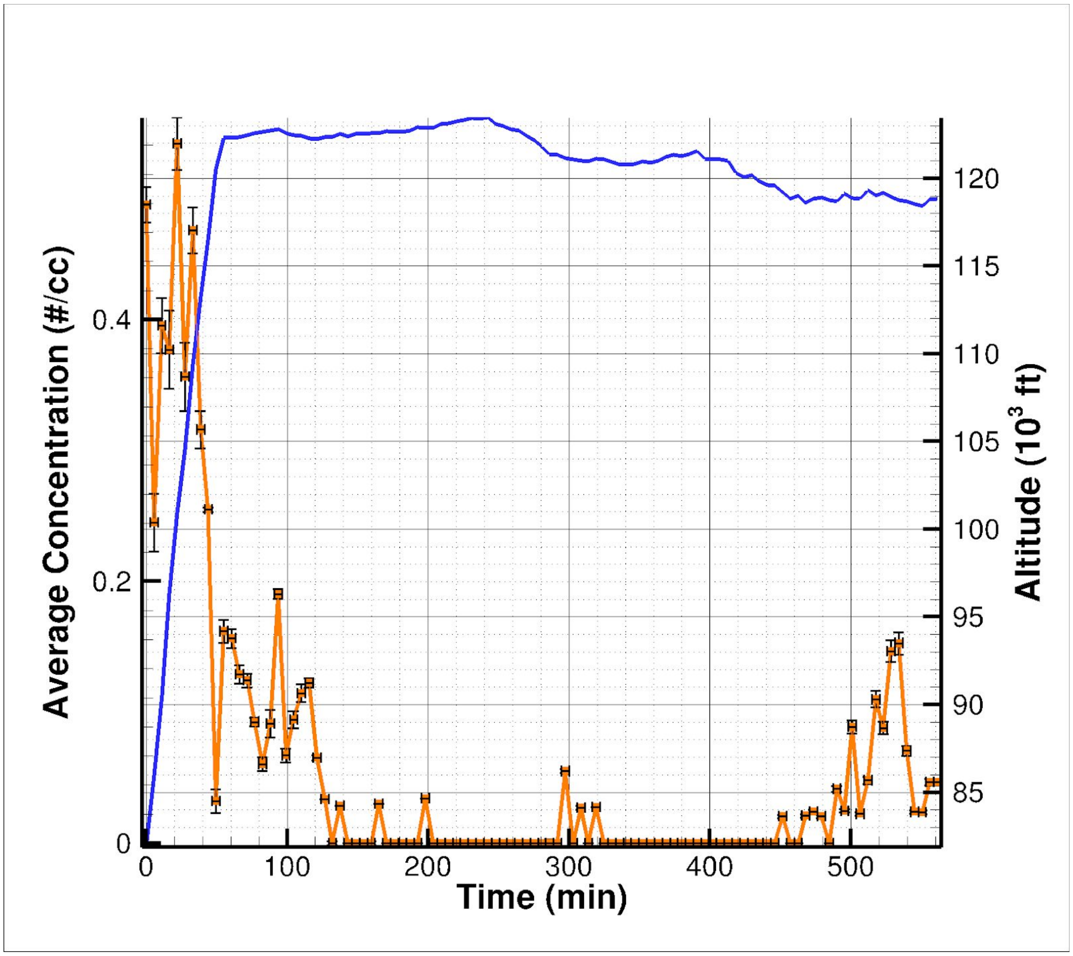

Figure 3. Average concentration (number of particles per cubic centimeter) of 0.38-0.54 μm size particles versus time (orange) and altitude (kilo-feet) versus time (blue). This OPC-N2 data was collected during the 2018 HASP mission.

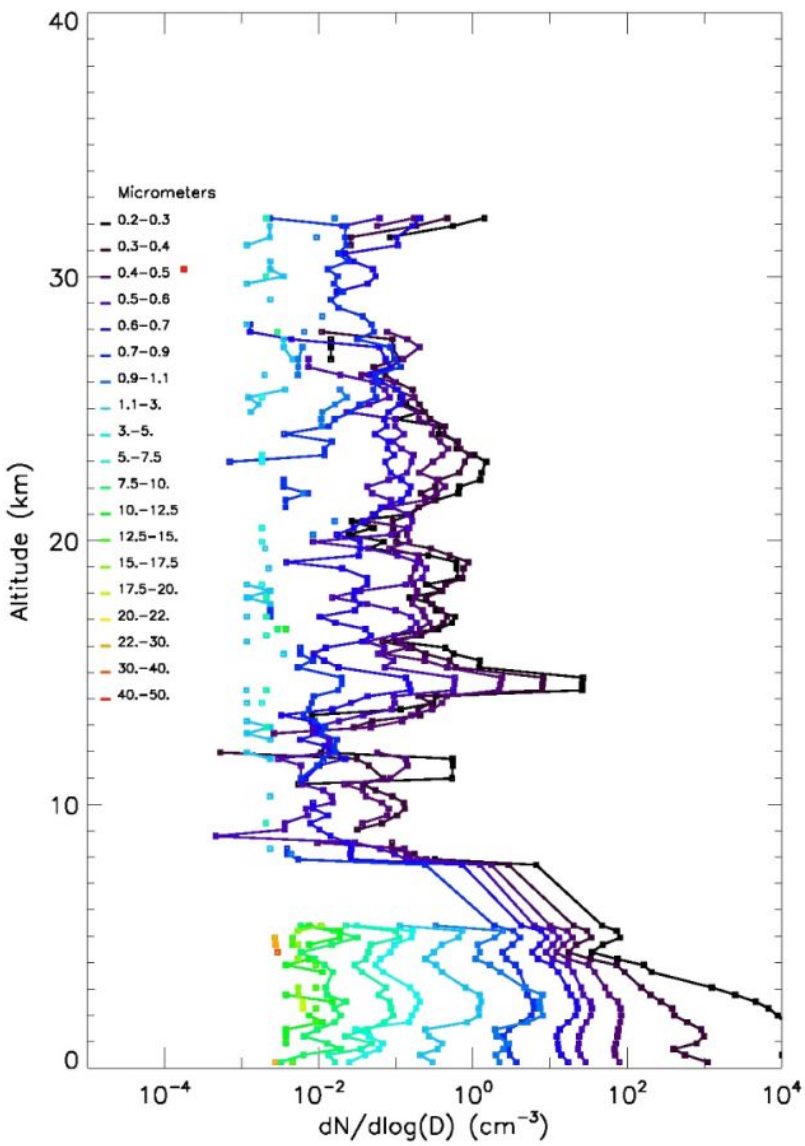

Figure 4. Particle concentrations for several size bins up to 32 km (105,000 feet) using the LOAC optical particle detector. This plot was taken from Renard et. al. [2].

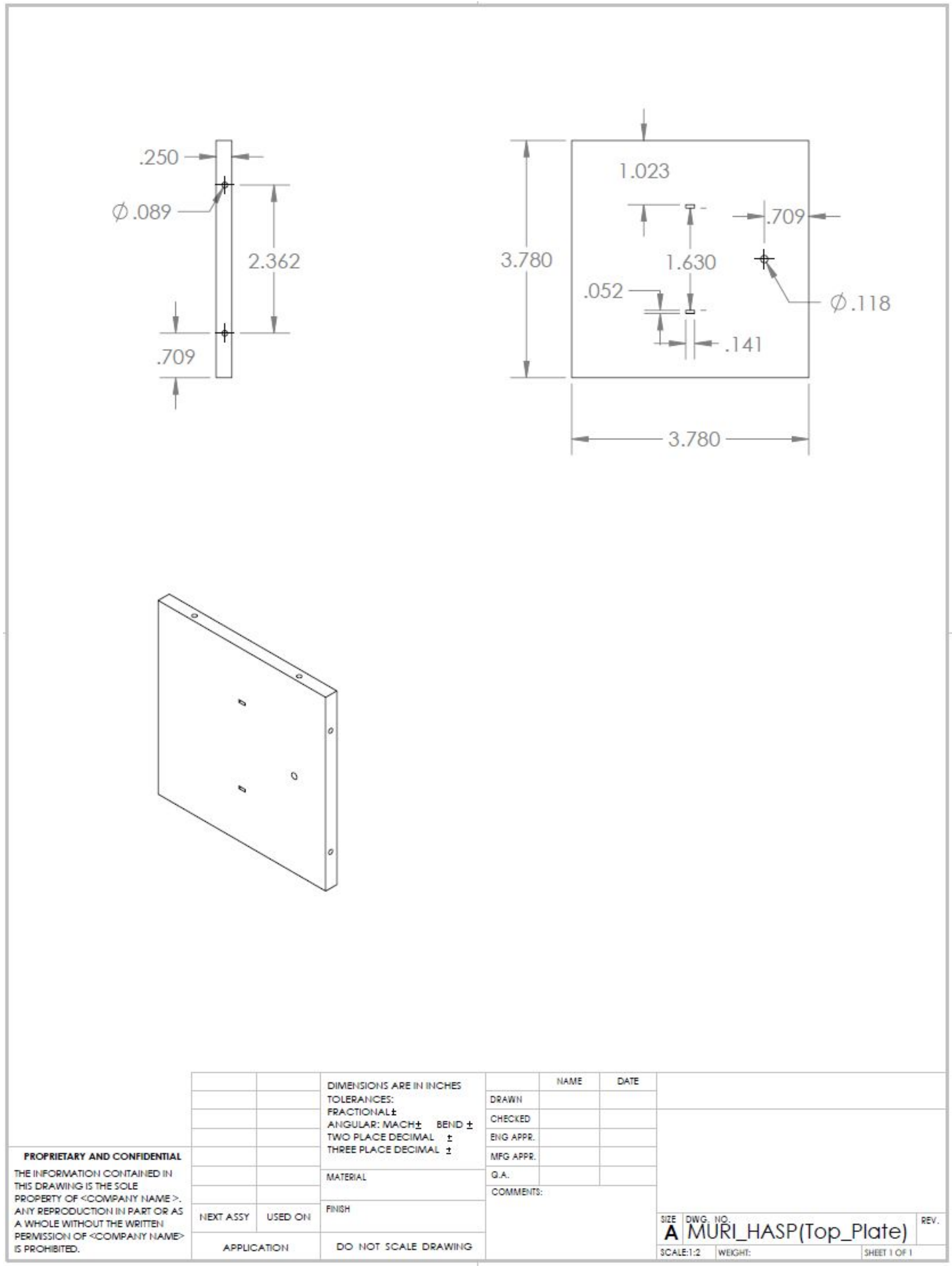

Figure 7. Mechanical drawing of top plate of MURI shell.

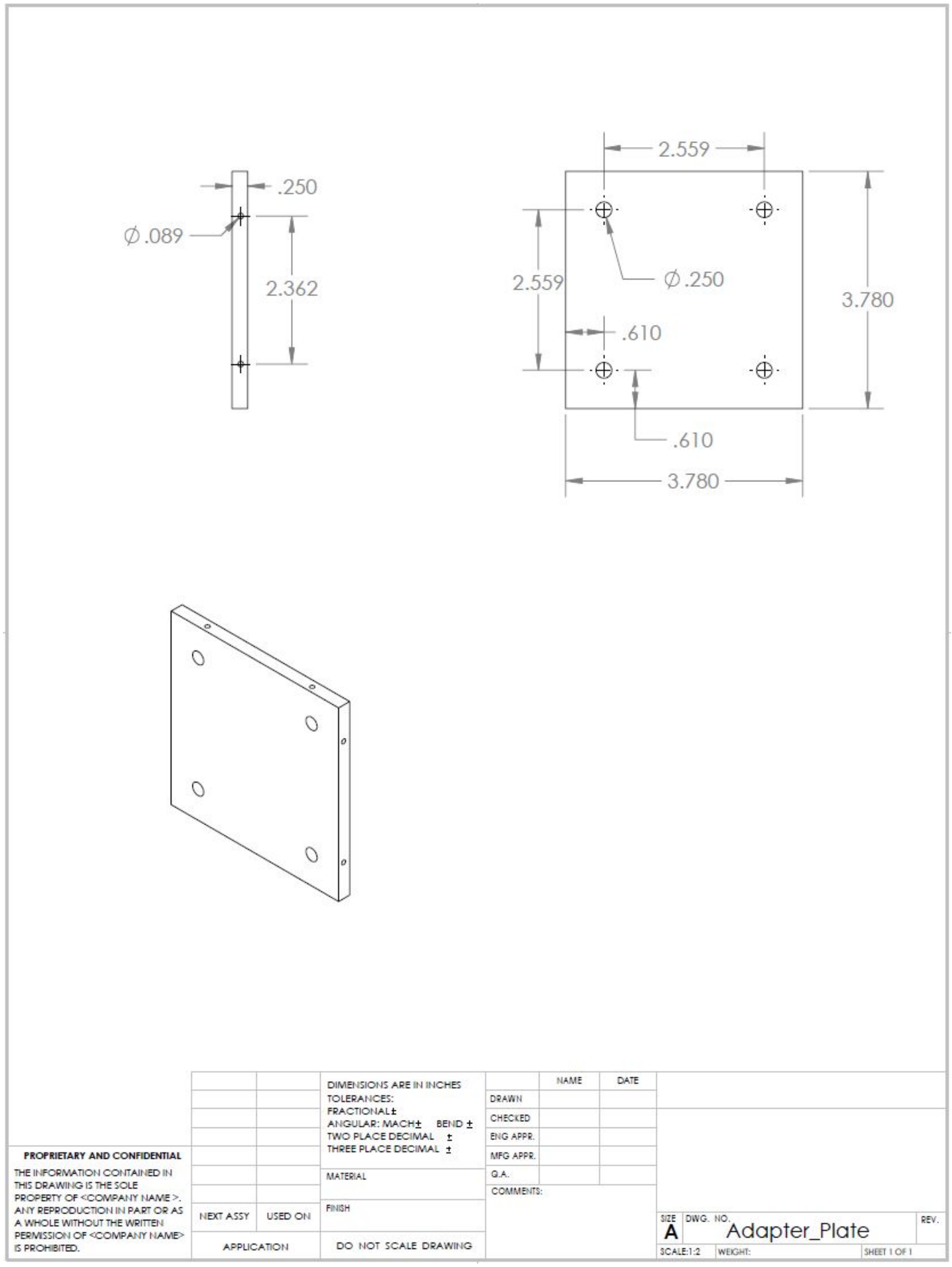

Figure 8. Mechanical drawing of the MURI shell adapter plate that will attach to the HASP plate.

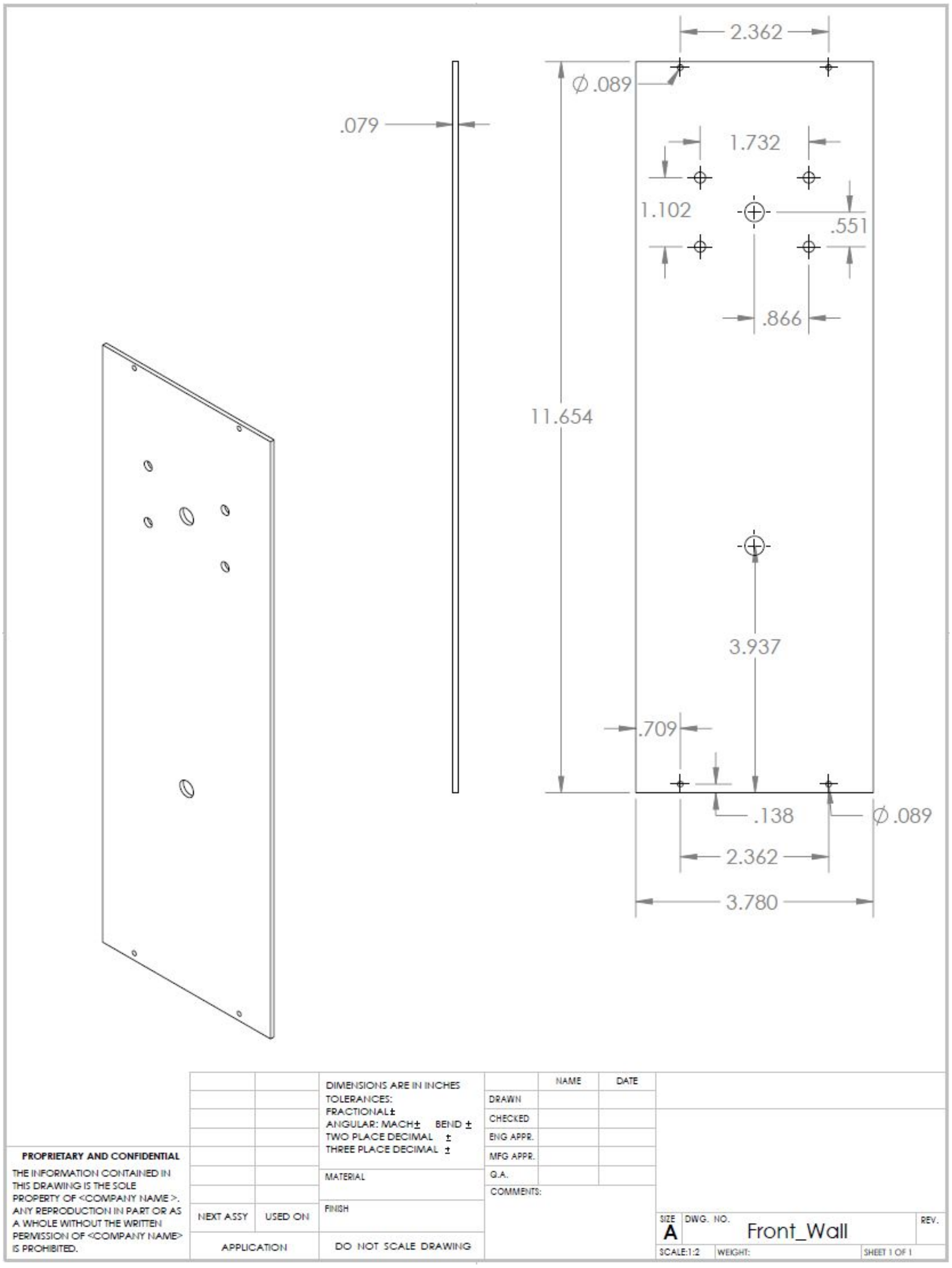

Figure 9. Mechanical drawing of the front wall of the MURI shell. The air intakes of all the optical particle counters will be flush with this wall.

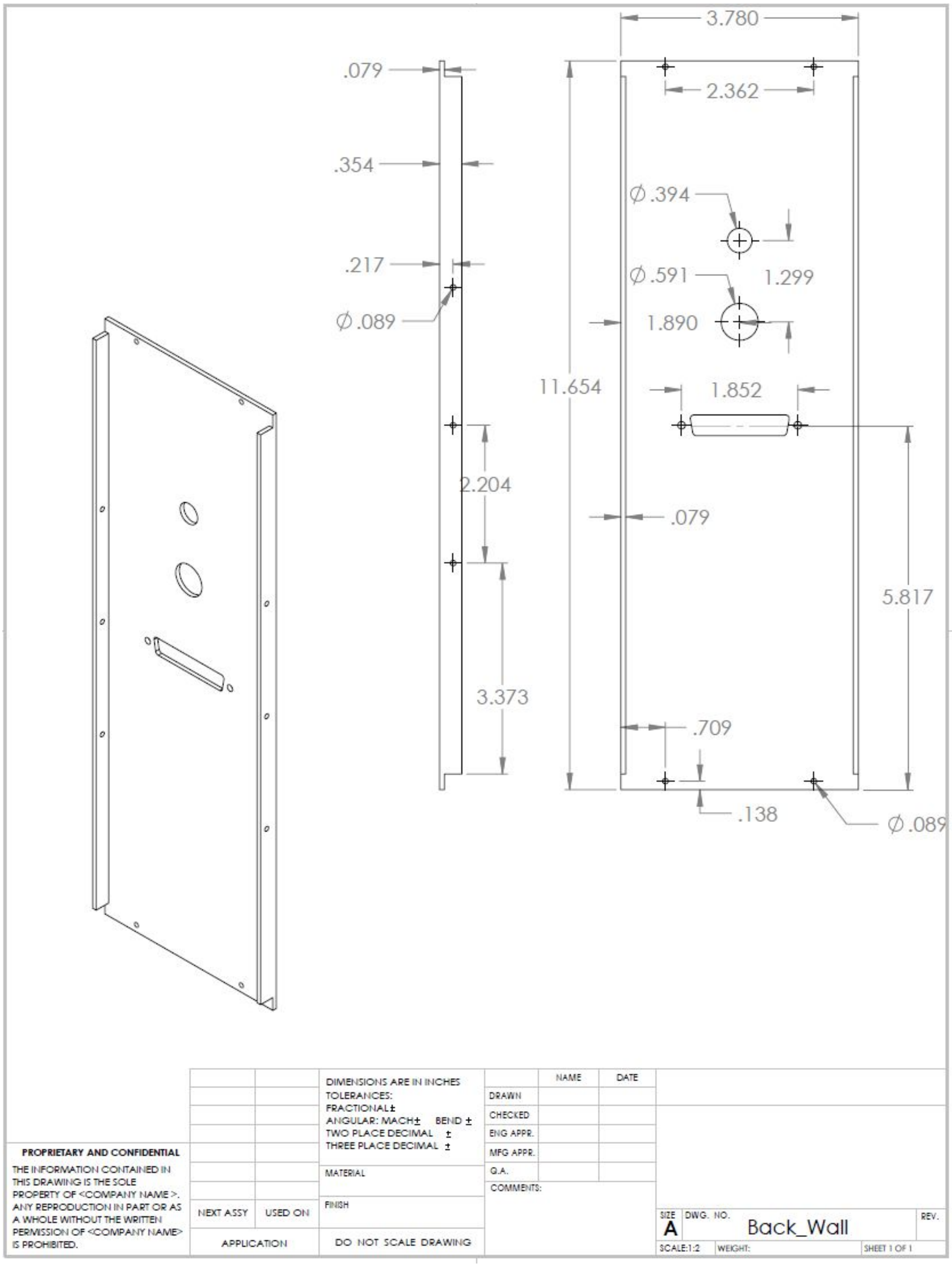

Figure 10. Mechanical drawing of the back wall of the MURI shell. The back wall has a hole for a DB-25 connector that provides power and serial communication from the HASP gondola as well as two exhaust holes for the particle counters.

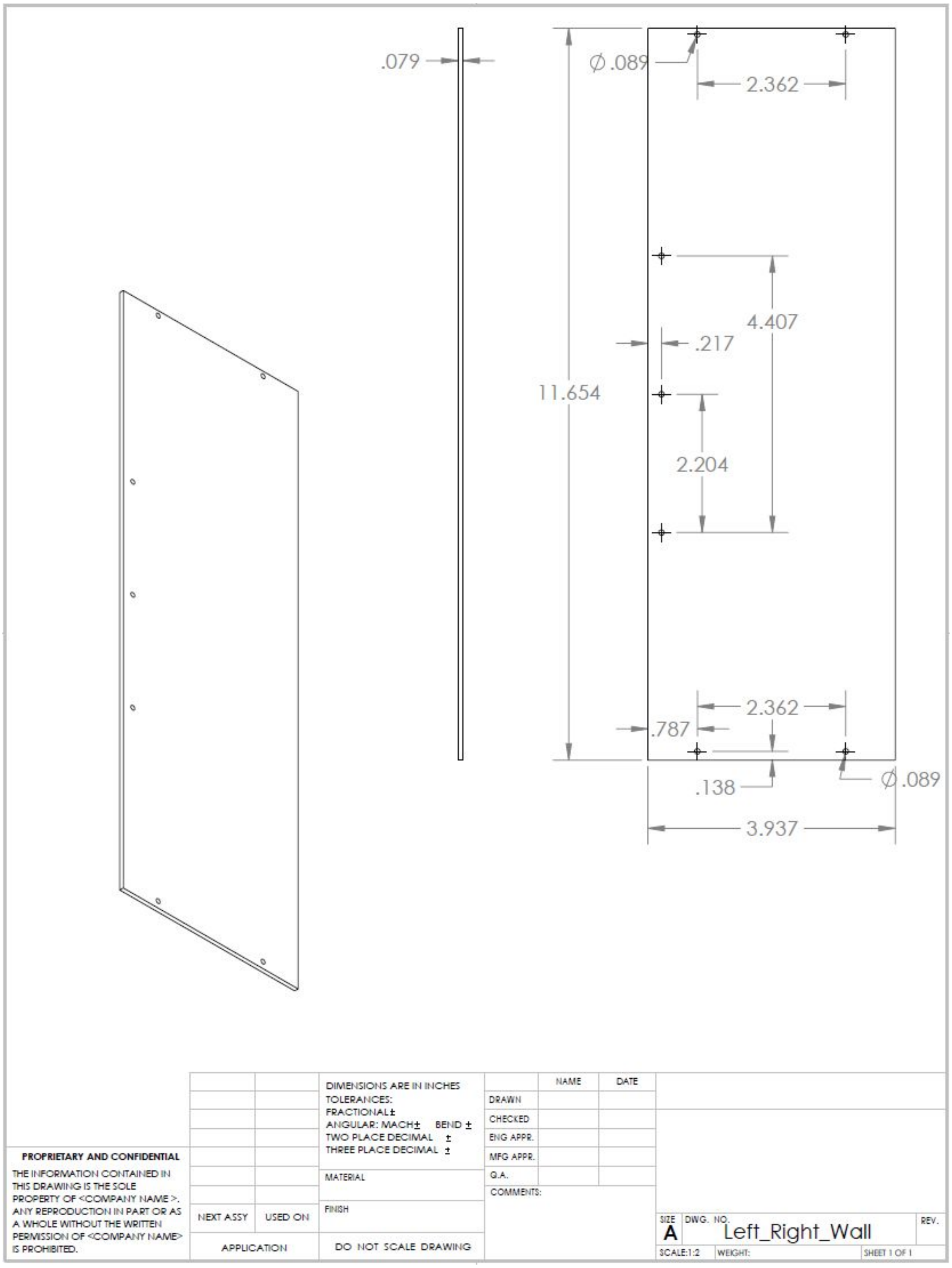

Figure 11. Mechanical drawing of left/right walls of the MURI shell.

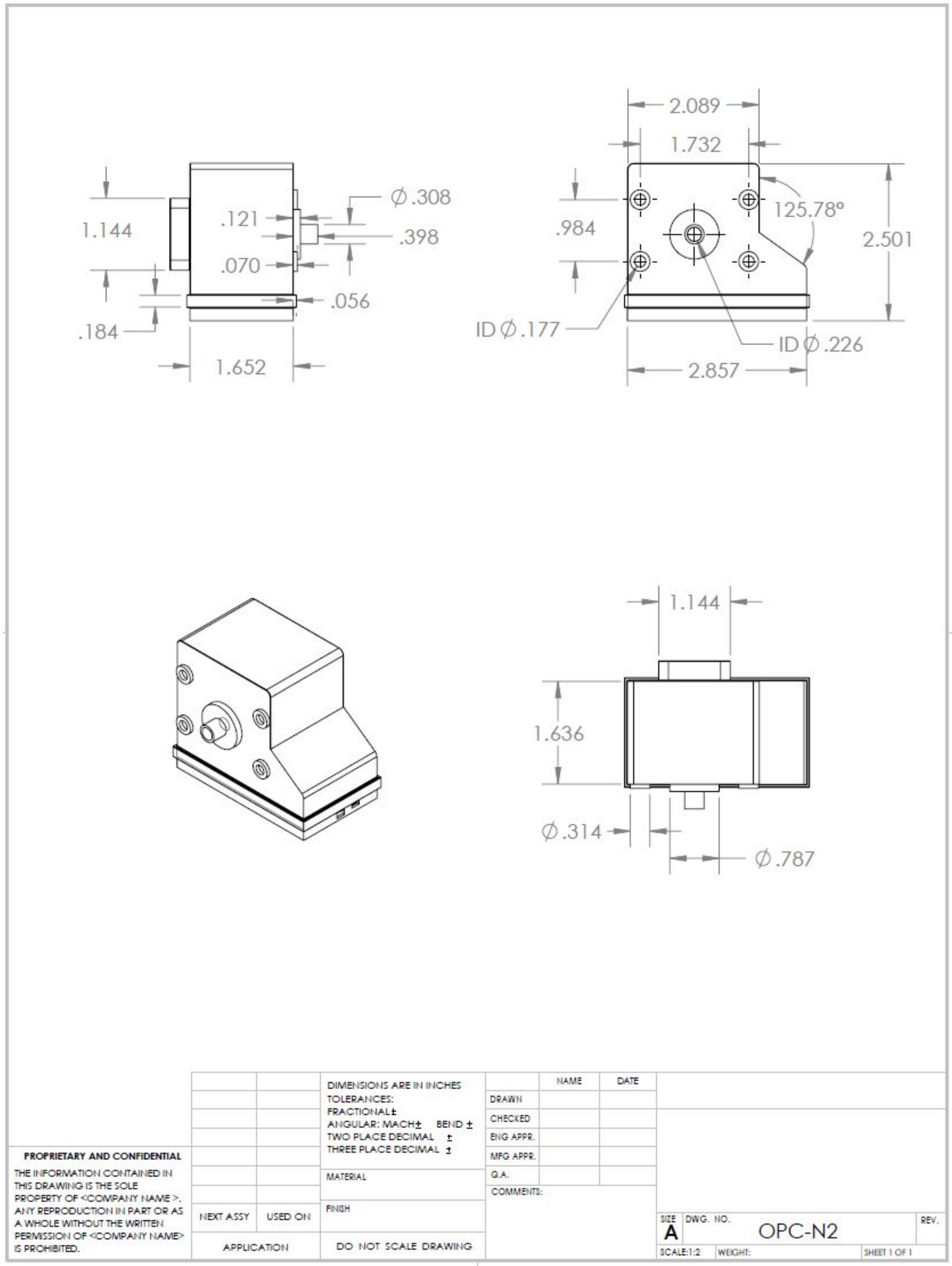

Figure 12. Mechanical drawing of the OPC-N2 (Alphasense optical particle detector). This detector was flown on the HASP 2018 mission.

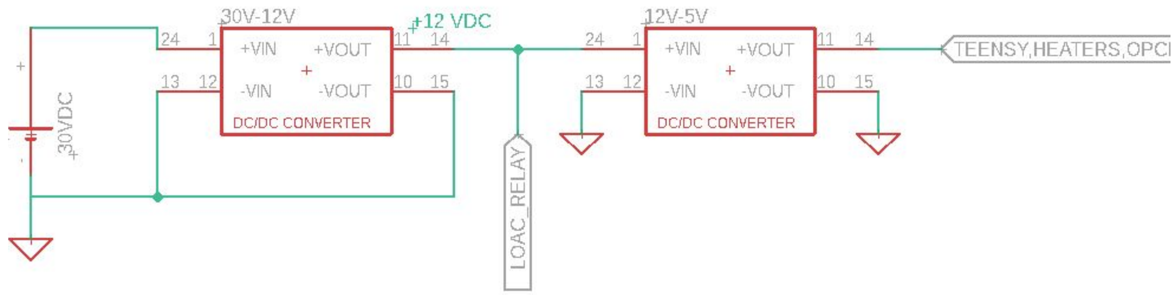

Figure 13. The basic power layout. The current limiter is not shown.

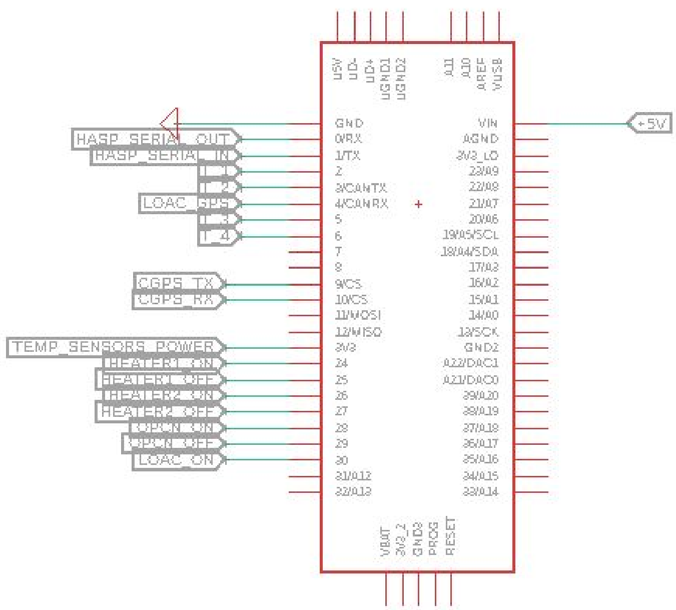

Figure 14. The connections to the Teensy 3.6 Microcontroller. Note that the 3.3 V pin provides power to the GPS and temperature sensors, as well as "On" and "Off" pins which can flip relays associated with various components (LOAC, OPC-N2, mesh heaters, etc.).

References

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