Final Science Report

High Altitude Student Payload 2019

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Abstract

This paper discusses the University of Minnesota - Twin Cities HASP 2019 payload called the Stratospheric Hypersonics Airborne Dust Optical Measurement System (SHADOMS). The payload is a part of a larger research project examining the effect of particles on the order of micrometers in diameter in the stratosphere on the laminar-to-turbulent transition of hypersonic boundary layers. Specifically, this payload was designed to compare "low-cost," "mid-cost," and "high-cost" fan-based optical particle counters (OPCs) at stratospheric altitudes above 80 kft. The purpose of this comparison is to develop a method that will allow for routine data collection of stratospheric particulate content at low-cost. The results from HASP 2019 will be utilized to determine which OPCs are optimal and to plan the next steps of the overall research project. This year's flight provided insight on the performance of fan-based OPCs under stratospheric conditions and suggested that fan-based OPC systems may not be able to perform adequately in the extreme environment of the stratosphere. However, the results did show promise for the "low-cost" Plantower PMS5003 OPC, indicating that it may be able to follow the particulate counting and sizing profile of the "high-cost" LOAC particle counter up to HASP float altitude above 120 kft. Calibration of Plantower PMS5003 OPCs will be needed in order to fully characterize their effectiveness.

Introduction

The objective of the University of Minnesota - Twin Cities (UMN-TC) team for the 2019 HASP mission was to compare and characterize the performance of a "low-cost," "mid-cost," and "high-cost" optical particle counters (OPCs) in stratospheric conditions. This objective supports an on-going research project at UMN-TC that aims to characterize particles in the stratosphere between 80,000 ft (24.4 km) and 120,000 ft (36.6 km). The goal of this project is to better understand the role of micron and submicron sized stratospheric particles in laminar-turbulent transition of the boundary layer in hypersonic flows. This transition is important to understand because during travel through the stratosphere at hypersonic speeds, laminar-to-turbulent transition poses a major risk to the integrity of hypersonic flight vehicles. Specifically, vehicles at risk include spacecraft returning to Earth or entering the atmosphere of another planet, hypersonic missiles, and potential future commercial endeavors such as spacecraft from the space tourism industry and hypersonic passenger airliners. In this project, the UMN-TC team is tasked with finding the best OPCs that can be utilized to collect data on the aforementioned particles. The specific purpose of the Stratospheric Hypersonics Airborne Dust Optical Measurement System (SHADOMS) payload aboard the HASP gondola was to take steps toward completing this task.

SHADOMS aimed to directly compare three OPCs in three different classes, which are characterized by cost. The "low-cost" (tens of dollars) OPC flown on SHADOMS was the Plantower PMS5003, or simply the "Plantower". The "mid-cost" (hundreds of dollars) OPC was the Alphasense N3, or "N3" for short. The "high-cost" (thousands of dollars) OPC was the Light Optical Aerosol Counter - Recorder Version (LOAC-R), which is a highly adept sensor system proven at stratospheric altitudes[1][2]. By flying the LOAC-R alongside the N3 and the Plantower, the UMN-TC team hoped to determine if these lower-cost OPCs are capable of producing similar results at high altitudes. The HASP 2018 flight carried an N3 and suggested that it had possible issues with collecting data at high altitudes. In order to confirm the findings from the HASP 2018 flight, the N3 was flown again on the HASP 2019 flight.

SHADOMS Description

The main mission of the SHADOMS payload was to compare the performance of "low-cost," "mid-cost," and "high-cost" fan-based OPCs in stratospheric conditions. The main sensors of interest on the SHADOMS payload were one "low-cost," one "mid-cost," and one "high-cost" OPC. Table 1 shows the price of each OPC. The LOAC-R, a "high-cost" OPC, was taken to be the reference standard to which the other two OPCs would be compared. This is because this sensor model has been shown to be effective and reliable at high altitudes.[1][2] For the HASP flight, the LOAC-R was fitted with a fan system to introduce particles into the detecting region, as opposed to a pump system used on the LOAC - Telemetry Version (LOAC-T). Likewise, the

N3 and the Plantower OPCs both use a fan system to pull particles through their own detecting regions. By comparing the “low-cost” and “mid-cost” sensors to a “high-cost” and believed-to-be high quality LOAC-R fitted with a fan system, the effectiveness of fan-based OPCs as a whole could be evaluated. By keeping all three OPCs in their original states, with fans intact, it was thought that the most accurate comparison of performance could be made.

The nature of the measurements made by OPCs are based on light-scattering techniques, where individual particles are detected and sized accordingly, resulting in samples of particle number counts per second (#/sec) for a corresponding size bin. Particle number concentration can then be obtained from post-analysis using the sample count and sample flow rate for each OPC. Each OPC sorts the particles detected into bins based on particle diameter. For example, the Plantower has one size bin that records the number of particles per second measured with diameters in the range of 0.3-0.5 μm. In total, the LOAC-R has 19 different size bins ranging from 0.2 μm to 50 μm, the OPC-N3 has 24 different size bins ranging from 0.3 μm to 40 μm, and the Plantower has 5 different size bins ranging from 0.3 μm to 10 μm.

Table 1: The price of each OPC in the SHADOMS payload

OPC	Price
Plantower PMS5003	~$40
Alphasense OPC-N3	~$500
Light Optical Aerosol Counter - Recorder (LOAC-R)	~$10,000

The SHADOMS payload also contained a suite of other sensors and hardware in order to generate flight data, monitor the internal environment, and complete other necessary tasks. The hardware included a Copernicus II GPS, three Dallas temperature sensors, two electric heating pads, 5V latching relays, and a 12V and 5V DC/DC converter.

All sensors listed above and the Plantower OPC were controlled by a Teensy 3.6 microcontroller which logged measurements to an on-board SD card. The LOAC-R and the N3 ran in a “standalone” mode, meaning that their data was logged completely independent of the Teensy 3.6 system. Logging the data this way allowed for the comparison of OPC data to environmental factors such as altitude either directly in the SD log or by post-processing the data. The LOAC-R had its own internal GPS, and its data was logged onto an on-board Raspberry Pi and stored on a USB flash drive.

In order to operate the equipment, a DC/DC converter was used to step the 30V supplied by the HASP gondola down to 12V. The supply current powered the LOAC-R then ran through a relay switch connected to the Teensy 3.6, in order to turn on or shut off the LOAC-R. The 12V was then stepped down to 5V using a second DC/DC converter in order to power the N3 (which was also connected to a relay switch) and the Teensy 3.6 microcontroller itself which, in turn, could output 5V and 3.3V. These two voltage levels supplied by the microcontroller were used to power the Plantower and the rest of the sensors and hardware.

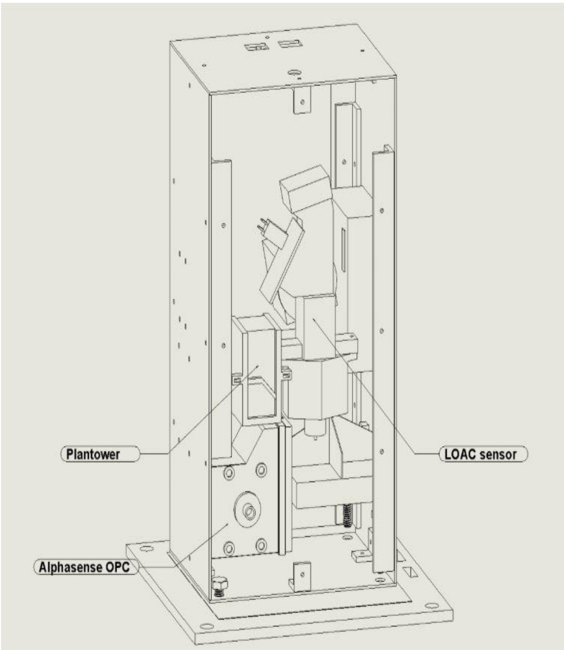
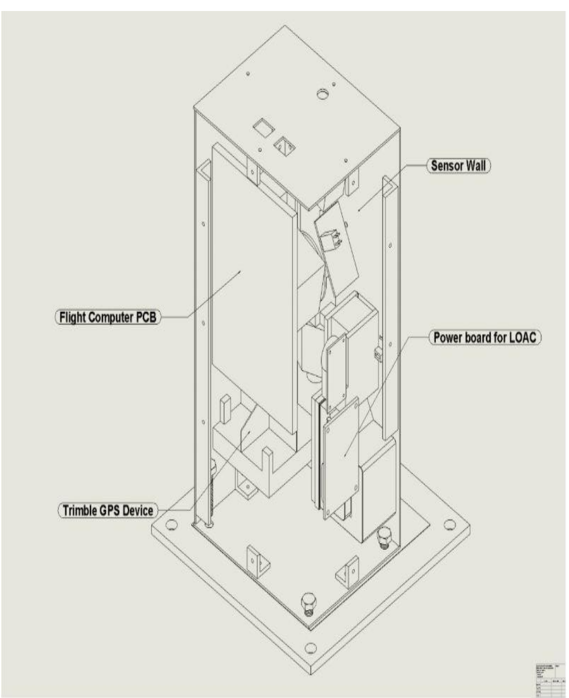


Figure 1:(above) shows a side view of SHADOMS
Figure 2:(below) shows an isometric view of SHADOMS



SHADOMS' dimensions were 11.5 cm by 14.5 cm by 29.4 cm. All three of the OPCs were integrated onto the payload walls so as to have clear access to the outside environment. Most of the other sensors were placed on the flight computer PCB which was mounted onto one of the side plates (see Figs. 1 and 2 to the left).

There was a robust thermal control system implemented in the SHADOMS payload. The DC/DC converters each had a high heat output that kept the payload warm. In order to keep the internal temperature within the payload's operating limits, a fan and two heating pads were integrated such that they could be turned on and off by autonomously by the Teensy 3.6. The fan and heater status were sent via downlink so that they could be autonomously controlled. As a last resort, a command could be sent from the ground that would turn off everything except for the Teensy 3.6 microcontroller, the Copernicus II GPS, and the Dallas temperature sensors. The decrease in power consumption would help lower the internal temperature of the payload. Once the payload reached safe temperatures, as indicated by the data downlink, the full payload could be powered on again. In addition to all of the active systems, passive thermal control was implemented on the surface of the payload structure by wrapping Mylar around it in order to reflect solar radiation.

The data string which the payload sent to the ground consisted mainly of flight telemetry data, sample measurements from the Plantower, and the on/off states of all three OPCs. The data string was 54 bytes long, and provided the necessary information needed in order to determine what commands to send to the payload from the ground. For reference, the three commands that could be sent to the SHADOMS payload could either cycle the power in the system, turn off the OPCs, or turn on the OPCs.

Payload Performance

During the HASP payload integration at the Colombia Scientific Ballooning Facility (CSBF), the SHADOMS payload met expectations. All systems were functional during the testing period and during the thermal-vacuum test. Specifically, during the thermal-vacuum cold test, all-system data was successfully recorded and data packets were sent through the HASP downlink system, commands were successfully sent through the HASP uplink system, and both the LOAC-R GPS and the Teensy 3.6 system's GPS maintained connection. Both independent OPC systems, the N3 and the LOAC-R, successfully recorded data. The other software systems worked as expected.

During the high-temperature testing, the payload reached a critical operating temperature after approximately 75 minutes. As designed, the payload ceased all OPC operations to maintain hardware integrity. This duration of operation was deemed as an acceptable amount of data collection, as it fulfilled the needs of the mission to compare OPC results in stratospheric conditions. Furthermore, the payload was able to cool down after shutdown, and so it was expected that if it overheated during float the payload would have adequate time to cool down to a point at which the OPCs could be safely turned back on. Thus, the team considered the thermal-vacuum test successful.

On flight day, the payload successfully collected data from power-on, at an altitude of 4 kft, to two hours and forty minutes after power-on, at an altitude of 102 kft, as shown by the purple box in Fig. 3 labeled “Ascent data”. At that point during the ascent the HASP gondola experienced internal electrical issues, which forced it to cycle power in order to resume operation. The SHADOMS payload successfully resumed data collection three hours into the flight, at 118 kft, once the HASP gondola resumed operation. The data collected during this time period is denoted by a green box in Fig. 3, labeled “float data 1”. At float at an average altitude of 121kft, three hours and forty eight minutes into the flight, the OPCs on SHADOMS were shut down due to high temperatures due to the DC/DC converters inside the payload. At five hours and fourteen minutes into the flight, the OPCs were powered on again, in order to collect more float data despite the persistence of high temperatures inside the payload. This data collection period is marked with a green box labeled “float data 2”. This data collection period lasted until five hours and fifty two minutes.

There were some key issues during flight. First, the GPS systems onboard experienced significant connection issues. The LOAC-R GPS, which was located inside the payload box, was unable to connect to any satellites despite being able to do so during ground tests at UMN-TC and CSBF. The suspected reason for this is two-fold. First, the payload structure was made of aluminum, which is not radio frequency transparent. Thus, the GPS connection was sensitive to electromagnetic interference. Second, the HASP team reported that there was a GPS anomaly in the area of the flight. However, other payloads, and the main gondola, did not experience GPS issues. The payload GPS system, which utilized an external active antenna, also had problems with GPS connection during the flight. This system, while successful in all tests prior to flight and on other weather ballooning flights in Minnesota, collected data only irregularly during the HASP flight. The suspected reason for this was due to the aforementioned GPS anomaly in the area of the flight.

A second issue that occurred was in regards to temperature management. The payload reached its critical/maximum operating temperatures faster than anticipated. As a result, the payload was not able to collect data for long periods at float. The significant susceptibility to overheating was not known in advance, as a result of the mostly-low-temperature testing regimens that the payload underwent in Minnesota and at integration. The thermal tests on the payload performed intensive, long duration low temperature tests before the long duration high temperature tests. This made the payload take much longer to heat up on tests, compared to during the actual HASP flight. Thus, the conclusion that the payload was sufficiently resistant to overheating was false. One reason for unexpected overheating was because the DC/DC converters are more efficient, and hence generate less heat, if they are cold. Therefore, the payload did not heat up as quickly during tests as it did during the HASP flight.

Third, the screws holding the DC/DC power converters to the PCB within the payload were shaken out of their nuts. As a result, the converters were loose within the payload after it was returned. It is unknown if this occurred due to vibration during ground transportation of the payload before flight, during flight, upon landing, or due to vibration during ground transportation of the payload after the flight. The reason that this occurred was because the screws were held in place only by nuts. If the nuts and screws were additionally restrained by being glued together, then the payload would not have experienced this failure. On the other hand, the payload seemed to operate correctly during flight. Thus, the DC/DC converters coming loose at some point did not result in in-flight payload failure.

Fourth, the Plantower experienced issues with data collection over long periods of time. In some circumstances, the sensor was unable to send proper data when requested, which resulted in failure to record data points. The reason that this transpired is due to the design of the Plantower's data stream, which sent data in a way that sometimes would push data before it had been fully processed, resulting in a jumble that triggered a failure byte to be sent instead. This did not hinder the collected data useless, but it did lead to marginally lower data quality and has raised concerns about the sensor. Flying the Plantower OPC on HASP was critical for helping to identify this issue due to the ability to collect flight data for an extended period of time.

Despite these issues, the payload was able to successfully gather information that proved invaluable to making observations about the nature of the optical particle detectors. The data collected, both during ascent and upon achieving float, allowed for a direct comparison between the three OPCs on board and allowed for observations on the nature of fan-based optical particle detectors in stratospheric environmental conditions.

Problems Encountered and Lessons Learned

HASP 2019 proved invaluable in alerting the general MURI team to certain issues with the MURI payload design for weather balloon flights. The HASP experience highlighted the need for redundancy in both hardware and software. The GPS failures pushed the team to do two things. First, if the GPS failure had occurred on a weather balloon flight where decisions regarding altitude and flight length are controlled autonomously, the flight would have been left to the whims of the wind, making payload recovery difficult. Thus, the team has now designed several fail safes to the control the system if a GPS failure were to occur, including timers, pressure-based altitude calculations, and altitude estimations based on the most-recent valid GPS data. While this logic was already partially in place, it was not designed in a way that would control the payload in the event of a GPS failure. Second, the GPS failure highlighted the importance of logging all data with multiple different stamps that indicate when and where the data was taken. Then, in the event of a GPS failure, the data is not useless. The only reason that data could still be compared between different sensors from the HASP flight, despite the failure of the LOAC-R GPS and the incomplete GPS record from the Teensy 3.6 system, was through the absolute and relative timestamps recorded by all devices. For future flights, this backup no-GPS logic has been deemed critical.

The Plantower data collection issue led to a redesign of the way that the UMN-TC team handled low cost particle detectors. Namely, the software system used to collect data was redesigned so that each “low cost” sensor is forced to send multiple data packets per collection period. This way, when a sensor experiences a failure when sending data there are other packets that can still be used, and the data point is not compromised.

The team also learned about the particular vulnerabilities that this payload design had to high temperature, low pressure environments. As a result, the need for an even more rugged thermal management system for future long duration flights aboard HASP, or in other situations, has been highlighted. Thus, future ground testing has been re-thought to emphasize situations where the payload experiences both low and high temperatures at low pressure. Future payload preparation will include an explicit high temperature, low pressure endurance test to ensure that payloads can operate for longer periods in such an environment. Furthermore, components on board future HASP flights will be selected in part based on their ability to safely operate at higher temperatures. If any components cannot survive in high heat, but are mission critical, then extensive strategies to cool such components will be implemented. This way, future payloads will be able to collect data for more-extended periods of time.

Results

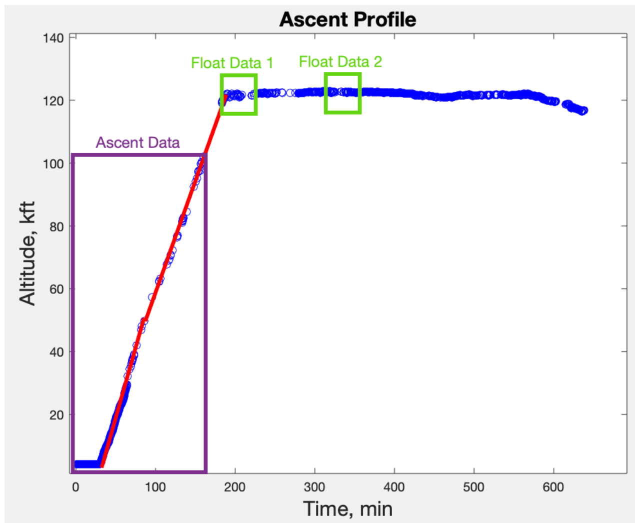


Figure 3: SHADOMS altitude profile.

Data was collected in three separate portions throughout the flight, as shown in Fig. 3. The first portion was during ascent prior to the HASP shutdown, as indicated by the purple box in Fig. 3. The second and third data collection periods occurred during float, as indicated by the green boxes in Fig. 3. During the analysis, data was split into ascent data and float data. The ascent data was plotted against altitude. The graphs of the float data are shown together, and are plotted against time.

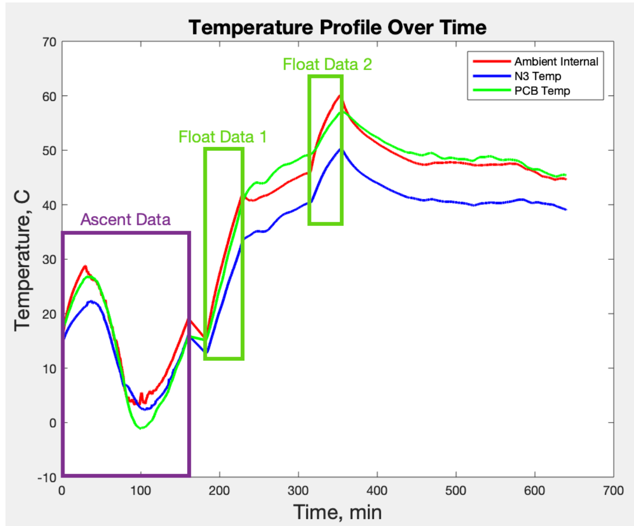


Figure 4: Temperature as a function of time measured by three different sensors inside SHADOMS.

The temperature in the payload, as seen in Fig. 4, illustrates the difficulty with high temperatures that the payload encountered during float. The red line represents the air temperature inside the payload; the blue line represents the surface temperature of the N3; and the green line represents the surface temperature of the PCB. When the system is powering all the OPCs, the temperature inside the payload increased rapidly, as seen during the collection of float data marked by the green boxes. The payload reached the maximum safe operating temperature of 42ºC and shut down. However, to collect more data and to test the operation of the OPCs at elevated temperatures, the system was powered on again by command from the ground. During this "Float Data 2" time that payload was able to successfully collect data until shutdown, even when the temperature inside the payload reached the peak temperature of 61ºC.

The OPCs were all able to collect data during the flight. However, the N3 was unable to collect reasonable data above 60 kft, or any data at all above 88 kft. The LOAC-R and the Plantower collected data for the fraction of the flight when they were powered on. In order to directly compare the sensors, the LOAC-R bins were concatenated to be match the Plantower bins. The Plantower and LOAC-R bins were then averaged over one minute, in order to reduce the noise in the graphs. In order to compare the data between the OPCs, the particle data is shown as the particle number concentration normalized by the log of the bin width. Of the Plantower's five size bins, the smallest three bins are discussed for the ascent data, and the smallest bin is discussed for the float data. The other bins of data confirm the conclusions drawn from the graphs that are shown.

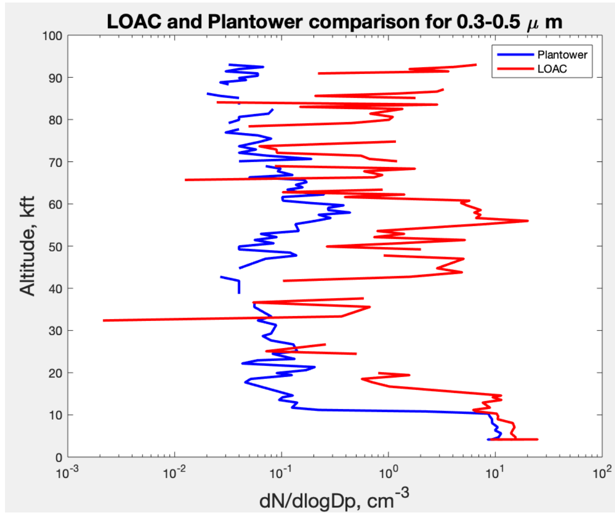


Figure 5: Particle concentration as a function of altitude during ascent for the Plantower and LOAC-R for particle sizes between 0.3 µm and 0.5 µm.

In the smallest size bins for both sensors (0.3 µm to 0.5 µm), shown in Fig. 5, it is apparent that the LOAC-R (red) showed more variation of data than the Plantower (blue). While both sensors experienced gaps in data (i.e. measured zero particles upon occasion), the LOAC-R gaps are larger and more frequent. Furthermore, the LOAC-R experienced multiple nearly instantaneous jumps of an order of magnitude or more above 20 kft. At low altitudes, below 10 kft, the sensors present relatively similar trends in the data. However, at higher altitudes, the LOAC-R measured higher particle concentrations than the Plantower at nearly all altitudes. The profile of the particle concentration measured by the LOAC-R is difficult to determine due to the significant variation in data, but it seems to follow a similar pattern to the Plantower, with the exception of the data at the highest recorded altitude where the LOAC-R reports an increase in the particle concentration compared to the Plantower.

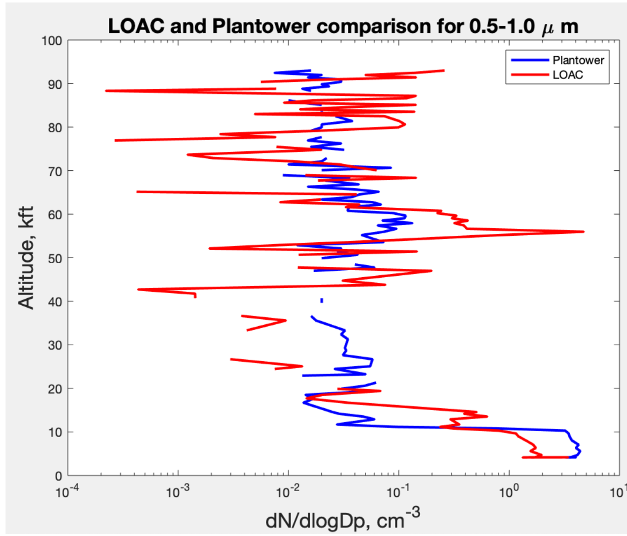


Figure 6: Particle concentration as a function of altitude during ascent for the Plantower and LOAC-R for particles sizes between 0.5 µm and 1 µm.

The next bin (0.5 µm to 1.0 µm), as seen in Fig. 6, shows more data variation in the LOAC-R (red) than before, with a generally greater magnitude. The Plantower (blue) has less variation than the LOAC-R in this plot as well. The initial particle concentrations below 10 kft are not as similar as in Fig. 5. The Plantower reports a greater particle concentration than the LOAC-R below 10 kft. On average throughout the course of ascent in this size bin, the Plantower shows about the same number of particles present as the LOAC-R, unlike the smallest size bin (Fig. 5) where the LOAC-R clearly reported more particles at nearly all altitudes during ascent. The particle concentrations measured by both OPCs seem to follow a similar profile, with the exception of the increase in concentration detected by the LOAC-R just above 90 kft. Both OPCs generally reported less particles in this bin size than in the first bin size – note the difference in horizontal axis scales between Fig. 5 and Fig. 6.

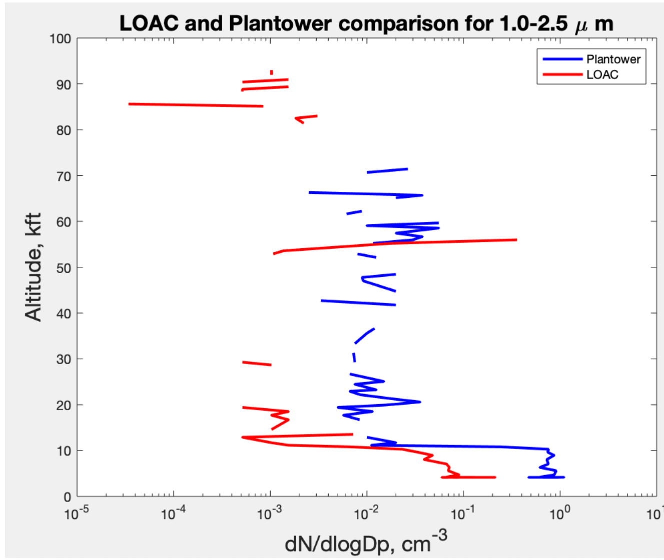


Figure 7: Particle concentration as a function of altitude during ascent for the Plantower and LOAC-R for particle sizes between 1 μm and 2.5 μm.

The third size bin (1.0 µm to 2.5 µm), as shown in Fig. 7, begins to show significant gaps in the data. This is indicative of zero particles being detected. The Plantower was able to detect more particles than the LOAC-R. The same trend as the smaller size bins of significant variation in data from the LOAC-R continues, noted by large jumps in the recorded concentrations.

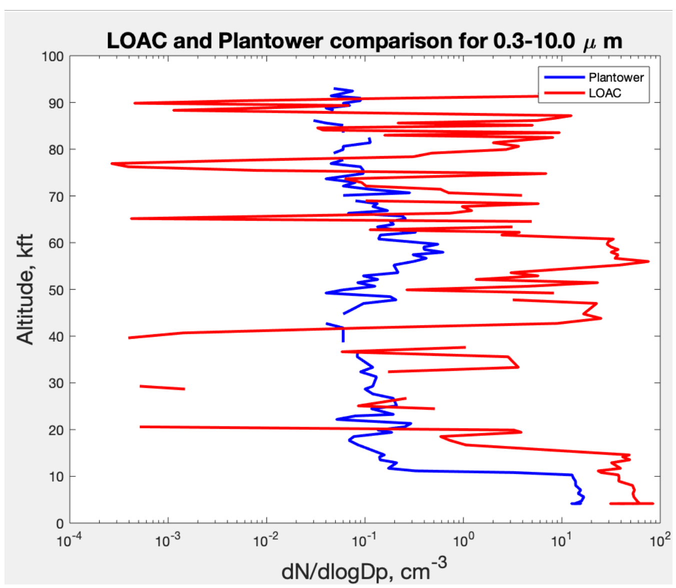


Figure 8: Particle concentration as a function of altitude during ascent for the Plantower and LOAC-R for particle sizes between 0.3 μm and 10 μm.

Fig. 8 shows the summation of size bins from 0.3 µm to 10 µm. Overall, the Plantower data spanned a much smaller range than the LOAC-R. While the variation in the Plantower data was within one order of magnitude across most altitudes, the LOAC-R data varied by six orders of magnitude over those same altitudes. Despite this wide variation, the average of the LOAC-R data and the Plantower data seem to roughly follow the same profile, with higher numbers of particles generally matching between the sensors. The Plantower seemed to detect fewer particles overall when compared to the LOAC.

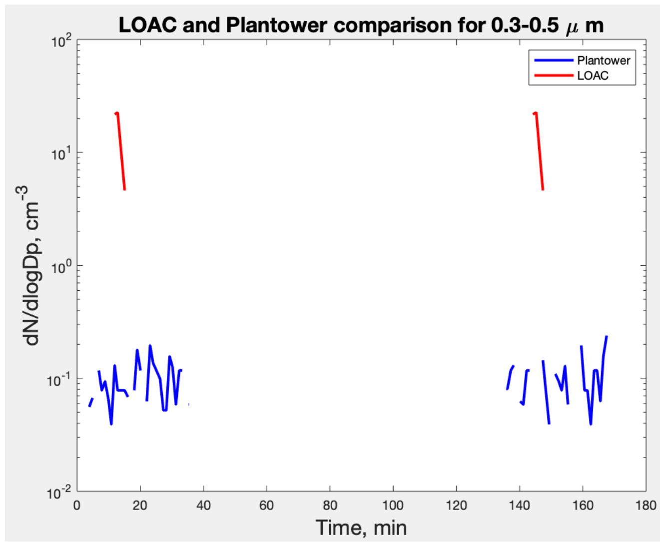


Figure 9: Particle concentration as a function of altitude during float for the Plantower and LOAC-R for particle sizes between 0.3 μm and 1 μm.

Small-size particles measured during float are shown in Fig. 9, where particle data is now plotted against the time (with time = 0 indicating the start of float, as marked by the green Float Data 1 box in Fig. 3). The large gap in the middle of the graph is the gap between the two float data collection time periods due to overheating as described earlier. The Plantower detected particles more often than the LOAC-R, but the particle concentration was two orders of magnitude lower than the LOAC-R. It should be noted that in the larger size bins at float, the Plantower detected more particles than the LOAC-R. The two pairs of LOAC-R non-zero data points collected during each portion of float in Fig. 9 are nearly an order of magnitude apart in concentration. Both sensors at least appear to be consistent between the two different float data collections, despite the OPCs being hotter during the second float data collection period.

Conclusions and Future Work

The HASP 2019 flight played a crucial role in identifying the next steps for the UMN-TC research project by allowing for several key conclusions to be drawn. First, the Alphasense N3 is unable to collect particle data within the target region for research. The reason for this is not immediately clear, but the UMN-TC team suspects that the internal design of the N3, along with the fan used to pull air through the sensor, are unable to generate an adequate flow to pull particles past the laser detector in the decreased air density of the stratosphere. Likewise, the fan system on the LOAC-R struggled with producing a consistent flow rate due to stratospheric conditions. This caused significant issues with data variation, rendering the "high-cost" OPC only marginally effective. This leads to two key conclusions: (1) the LOAC system should always be used with a pump during stratospheric flights and (2) lower-cost fan-based OPCs require further examination. The poor performance of the fan-based LOAC system raises concerns that the data collected from the lower-cost sensors which also use fans may not be valid. However, during the HASP flight the Plantower appears to have been able to collect data more effectively than the LOAC-R. Further research is needed to determine if all fan-based sensors are ineffective in stratospheric conditions or if some OPCs, especially the Plantower, may yet show promise. Additionally, ground calibration of all OPCs in low-pressure and low-and-high temperature conditions (i.e. stratospheric conditions) will be crucial to identifying the accuracy of each sensor. The differences in the particle data are significant, but the profiles of the data share some similar characteristics which could be promising. Furthermore, the overall number of particles counted during ascent are similar between the Plantower and the LOAC-R. Thus, it is likely that the Plantower, which is not calibrated for extreme conditions like those found in the stratosphere, needs to undergo specific calibration in order to count particles accurately. Lastly, the payload design needs to be modified to address heat management concerns in order to be capable of flying in stratospheric conditions for a long durations. This is critical for future HASP flights, and may also be important for weather balloon flights which are intentionally floated and/or undergo "slow descent" rather than fast (parachute) descent.

In the immediate future, the UMN-TC will continue work on ground calibration systems in which particles of know size and concentration can be introduced into chambers containing OPCs in which pressure and temperature can be modified. Currently, an extreme-environment calibration chamber is being designed that will allow for future flights with pre-calibrated OPCs and other sensors. This is a more-robust and particle-injection-capable version of the current, low-cost thermal-vacuum chamber system. As a result of the data from the HASP flight, designs for retrofitting "low-cost" and "mid-cost" OPCs with pumps instead of fans to draw particles in are also being designed. These will be compared to one another and to a pump-based LOAC system, in order to determine the most cost-effective system for counting particles in the stratosphere.

Student Involvement

Name	Start Date	End Date	Role	Student Status	Race	Ethnicity	Gender	Disabled
Nathan Pharis	01/04/19	Present	Student Project Lead	Undergrad	White	non-Hispanic	Male	No

Joseph Habeck	12/01/18	Present	Particle Detector Lead	Graduate	White	non-Hispanic	Male	No
Patrick Collins	05/20/19	Present	General Team Member	Undergrad	American Indian	non-Hispanic	Male	No
David Richardson	01/15/19	9/01/19	Structural Lead	Undergrad	White	non-Hispanic	Male	No
Asif Ally	12/01/18	9/01/19	Electrical Lead	Undergrad	Indian	Hispanic	Male	No
Billy Straub	01/04/19	9/01/19	General Team Member	Undergrad	White	non-Hispanic	Male	No
Jacob Meiners	05/20/19	9/01/19	General Team Member	Undergrad	White	non-Hispanic	Male	No
Jacob Wagner	5/28/19	9/01/19	General Team Member	Undergrad	White	non-Hispanic	Male	No
Vinh Nguyen	1/04/19	9/01/19	General Team Member	Undergrad	Asian	non-Hispanic	Male	No
Andrew Van Gerpen	1/04/19	9/01/19	General Team Member	Undergrad	White	non-Hispanic	Male	No
Garett Ailts	12/01/18	6/01/19	Student Project Lead (Left For Internship)	Undergrad	White	non-Hispanic	Male	No
Jackson Holl	01/04/19	5/15/19	Electrical/Flight Computer Lead (Left For Internship)	Undergrad	White	non-Hispanic	Male	No
Jacob Meyer	12/01/18	5/15/19	General Team Member (Left For Internship)	Undergrad	White	non-Hispanic	Male	No
Simon Peterson	12/01/18	2/22/19	General Team Member	Undergrad	White	non-Hispanic	Male	No
Akshay Naik	5/28/19	9/01/19	General Team Member	Undergrad	Indian	non-Hispanic	Male	No
Steele Mitchell	5/28/19	9/01/19	General Team Member	Undergrad	White	non-Hispanic	Male	No
Jack Stutler	12/01/18	1/04/19	General Team Member	Undergrad	White	Hispanic	Male	No

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[1] Renard, J.-B., "LOAC: a small aerosol optical counter/sizer for ground-based and balloon measurements of the size distribution and nature of atmospheric particles - Part 1: Principle of measurements and instrument evaluation", *Atmospheric Measurement Techniques Discussions Papers*, 2015.

[2] Renard, J.-B., "LOAC: a small aerosol optical counter/sizer for ground-based and balloon measurements of the size distribution and nature of atmospheric particles - Part 2: First results from balloon and unmanned aerial vehicle flights", *Atmospheric Measurement Techniques Discussions Papers*, 2015.