PASSIVE COLLISION ALERT SYSTEM (PCAS) DEMONSTRATION PROGRAM—FINAL REPORT

UtopiaCompression Corporation
New Mexico State University Physical Science Laboratory
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1   Introduction

In this BAA program, with joint funding from UtopiaCompression Corporation (UC) and the FAA, UC demonstrated its wide field-of-view (FOV) Passive Collision Alert System (PCAS) with partners at the New Mexico State University (NMSU) UAS Flight Test Center (FTC).

1.1   PCAS

PCAS uses optical sensors on an unmanned aircraft to detect intruding aircraft which present collision risks. In addition to detection, the intruders are tracked and their 3-D states are estimated. These estimates are used to predict collisions. Thus, PCAS is an integral part of a detect-and-avoid (DAA) system. Compared to other DAA systems, PCAS has several advantages. Since it uses only optical sensors, it is passive making it small, lightweight, and low-power. On the other hand, optical sensors are typically unable to estimate range to intruders. PCAS, however, is able to provide range—a crucial measurement for collision avoidance.

PCAS was developed over several years with funding from the USAF, DARPA, and UC IR&D. Initial efforts focused on proving the observability of intruder range from a camera. This result motivated the further development of PCAS into a flightworthy system which was demonstrated in several flight test activities.

1.2   FAA Test Program

All initial PCAS flight tests used a single relatively narrow FOV (40°) camera. While this was sufficient for demonstrations, it is too narrow to be useful for most DAA applications. Through a latter DARPA program, UC developed a new multi-camera system with a nominal FOV of 220° using three cameras. In addition to supporting multiple cameras, the DARPA program also culminated in a completely refactored code base with all modules written to support ROS (Robot Operating System). The ROS framework greatly simplifies development of new code modules as communication between them is seamless. The previous code base was stovepiped and difficult to manage. Thus, this FAA program provided an opportunity to test the refactored/ROS system as well as the multi-camera upgrades.

In addition to the multi-camera and ROS upgrades, this program saw testing on an embedded computer with a small form factor appropriate for UAS applications. Previous test efforts used a gaming laptop with a relatively high power draw and large footprint.

UC and NMSU conducted four test activities to demonstrate the multi-camera PCAS system.

1.3   Embedded Processor Issue

The PCAS detector uses image processing to find intruding aircraft in the camera imagery. These algorithms make use of the parallel processing capabilities of modern graphics processing units (GPUs). Specifically, AMD (Advanced Micro Devices) GPUs, supporting the OpenCL

framework, are necessary. Prior to commencement of the program, UC identified and acquired a single-board computer with AMD GPU capable of handling the computational load of PCAS from Sapphire Technology, Ltd using the AMD Ryzen series processor. The manufacturer, Sapphire Technology, customized this board for UC by installing three USB3 ports, which were needed for operating three USB3 cameras. We chose USB3 due to its very high data rate and ability to obtain very high-resolution images at sufficient frame rates.

However, early in the program it was discovered that the GPU on this computer was not performing adequately. UC and Sapphire Technical staff determined that the GPU Linux drivers were not capable of harnessing the GPU's capabilities and this was the root cause of the poor performance. Throughout the program, we stayed in touch with Sapphire to obtain updated drivers. Although updated drivers were released, they did not solve the problem. Sapphire also confirmed that their customer base almost exclusively uses Windows, explaining their lack of effort to solve the problem.

As a temporary workaround, Sapphire offered UC the use of a loaner older-generation computer (from the Merlin-Falcon family) with working drivers. Although this system was functional, it did not offer the power achievable from the Ryzen family. Furthermore, this computer had only two USB3 ports which meant (to the best of our knowledge) that only two USB3 cameras could be used simultaneously.

2   Flight Tests

2.1   Flight Test 1

The first of four flight test events took place at the NMSU FTC from 7/8/2020 to 7/14/2020. Due to the embedded computer issues described above we used a laptop computer running the refactored/ROS PCAS software stack in single-camera configuration with 40° FOV. Figure 1 shows the ownship MLB Bat-4 and the CTLS intruder.
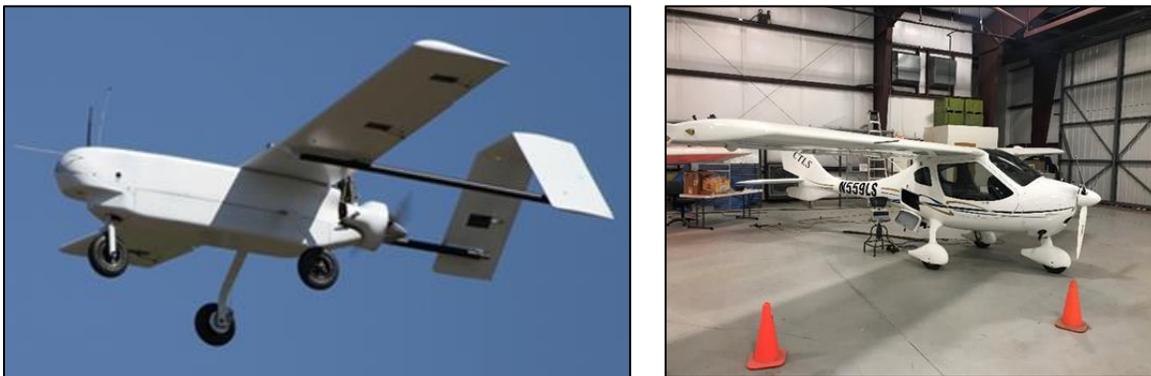

Figure 1: Ownship MLB Bat-4 (left) and Intruder CTLS (right)

2.1.1   Integration

The payload configuration is shown in Figure 2 and is described in detail in the FT1 post-event report. The camera was the VLG-40C gigabit ethernet (GigE) camera manufactured by Baumer,

Ltd, with a 40° FOV lens. The camera interfaced directly with the computer's network card build into the motherboard.
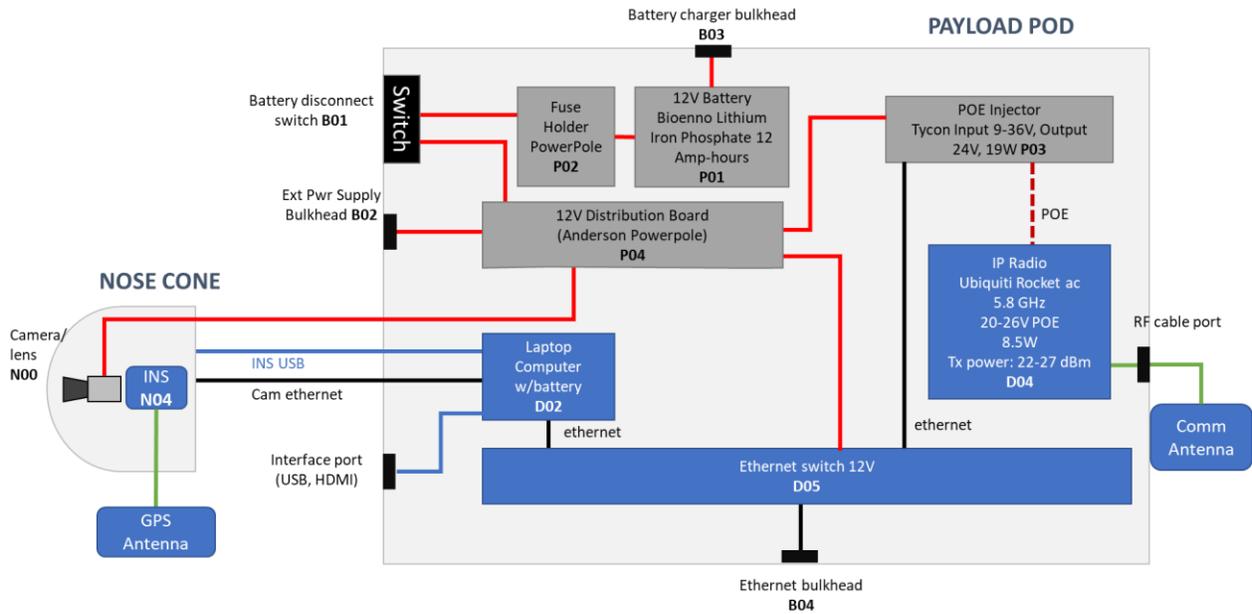

Figure 2: Payload + Nose Cone Block Diagram

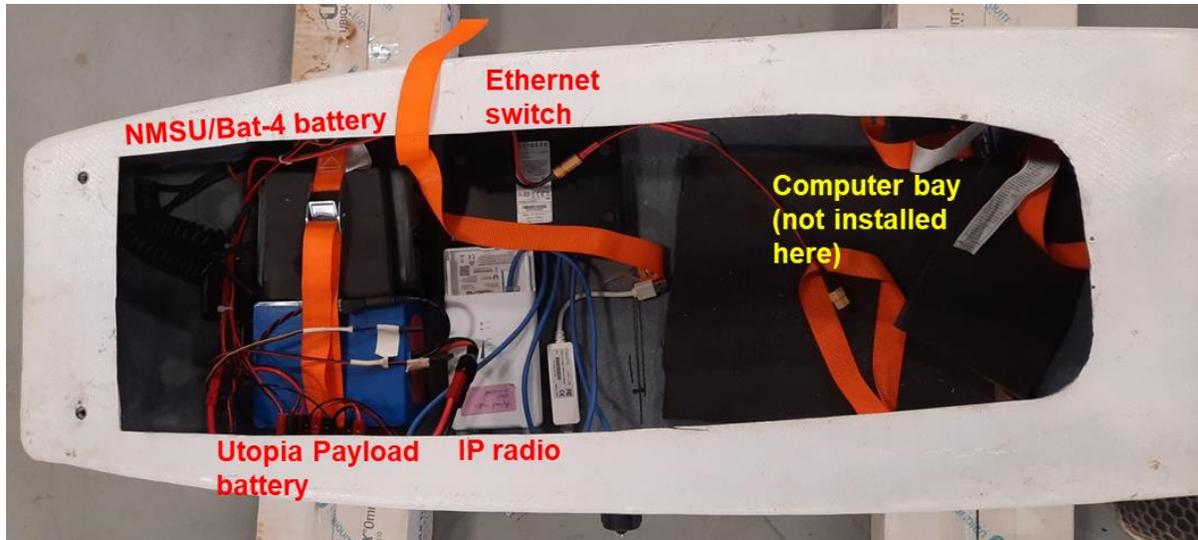*Figure 3: Integration activities at NMSU*

Figure 4: Integrated Payload

Payload, nose cone, and vehicle integration and ground testing was done on 7/8 and 7/9/2020. All components were installed into the payload pod and nose cone. Additionally, as shown in Figure 2, several bulkheads, switches, and ports were installed allowing ease of access while the vehicle is on the ground. An L-bracket was fabricated to install the camera/lens in the nose cone. The GPS antenna was installed on the top of the fuselage and the RF radio antenna was installed on the underside of the payload pod. Some of the integration activities are shown in Figure 3. Figure 4 shows the integrated payload sans computer.

2.1.2   Test Summary

Flight testing was conducted over two days. The FT1 post-event report provides details on each of the encounters run. In total 17 head-on encounters were run. The PCAS system was able to detect, track, and range to the intruder in some cases, but not all. The main problem was determined to be insufficient lighting in the imagery, which is easily resolved by adjusting the camera's exposure setting. In previous test events, UC had used an autoexposure algorithm which automatically adjusted the exposure to provide the correct lightning in the image even as conditions change. Unfortunately, the autoexposure algorithm was not used in FT1 and this affected the image quality.

Performance of the system in the 17 runs is detailed in the FT1 post-event report. Since the intruder was not always detected and ranged to, the loss of well-clear (LoWC) risk ratio was 0.65, greater than the ASTM requirement of 0.50.
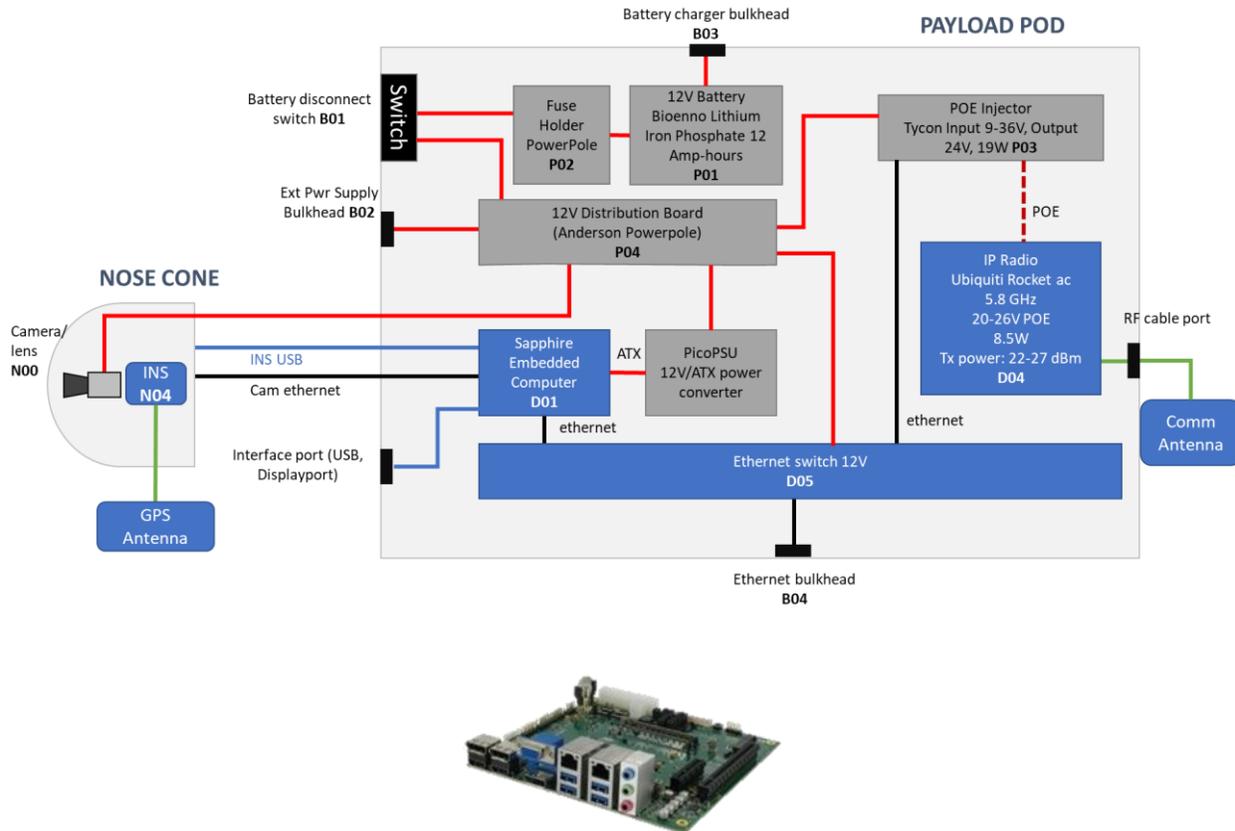
Figure 5: Payload + Nose Cone Block Diagram and Sapphire Embedded Computer

2.2 Flight Test 2

The second flight test took place from 10/12/2020 to 10/16/2020. This test was similar to FT1, but this time, the single-board embedded computer was used instead of the laptop. The payload configuration is shown in Figure 5. Importantly, the autoexposure algorithm was used in this test to provide a consistent image quality sufficient for detection of the intruder. Recall that this algorithm was not used in FT1, which degraded the detection performance.

2.2.1 Integration

Integration took place on 10/12/2020. The payload was mostly integrated from FT1 and thus integration was quick. The Baumer VLG-40C camera with 40° FOV lens was used again in this test.

2.2.2 Test Summary

Flight testing was conducted over four days, from 10/13—10/16/2020. However, on two days, 10/13 and 10/15, we were not able to fly due to interference on the 900 MHz comm channel from WSMR.

During the two days of testing, 10/14 and 10/16, we successfully ran 14 head-on encounters and 7 abeam encounters. We also ran several more encounters, which did not yield useful data. These include: four abeam encounters with insufficient data rate (possibly due to low batteries), seven head-on encounters with reduced luminance which yielded no data due to a recording error, and

nine head-on encoutners with reduced luminance which worsened the detector performance. Thus a total of 41 encounters were run during FT2, 21 of which were useful.

Performance of the system in the 22 runs is detailed in the FT2 post-event report. With the addition of the autoexposure algorithm, the LoWC risk ratio improved relative to FT1. For FT2, the LoWC risk ratio was 0.29, meeting the ASTM requirement of 0.50.

2.3   Flight Test 3

In Flight Test 3, the decision was made to use three cameras. As mentioned earlier, we chose USB3 cameras for their high data rate and ability to transmit high resolution images at a fast frame rate. As we also mentioned above, the loaner Merlin-Falcon computer has only two USB3 ports and we believed this would preclude using three cameras simultaneously. However, using a USB3 hub, we were able to capture data from all three cameras at a frame rate of 10 fps. Figure 6 shows the configuration for FT3. For more details, refer to the FT3 post-event report.
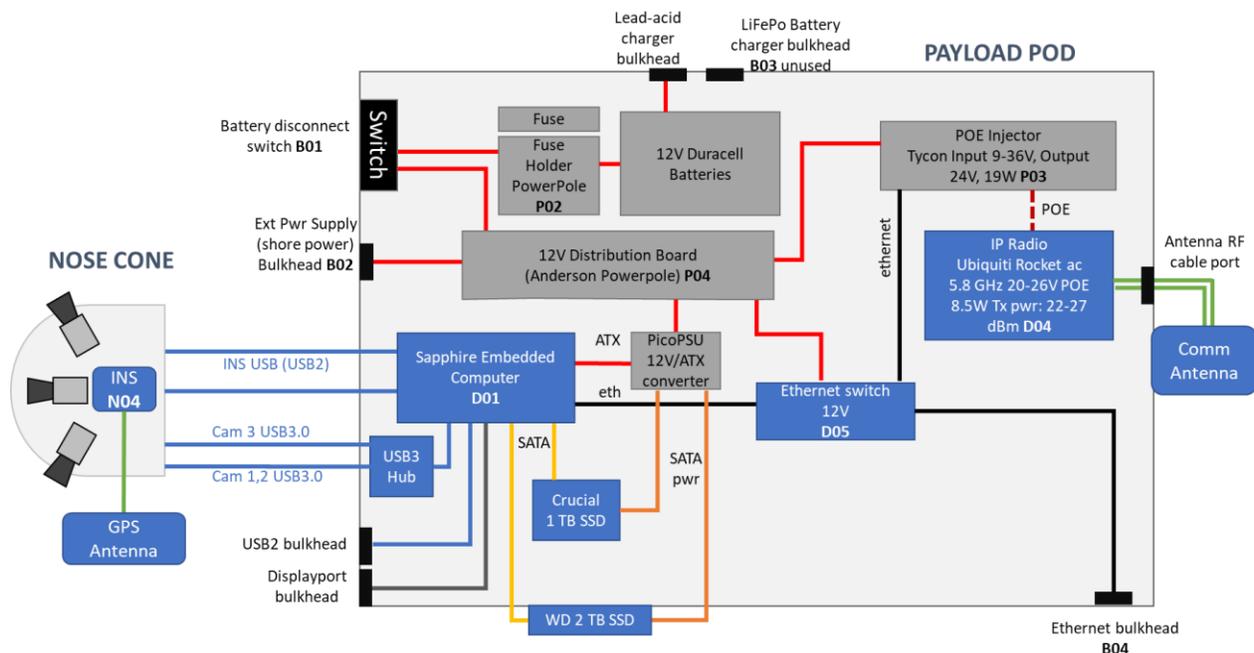
Figure 6: Payload + Nose Cone Block Diagram

2.3.1   Integration

Payload, nose cone, and vehicle integration and ground testing was done on 3/10/21—3/12/21. All components were installed into the payload pod and nose cone. A new mounting plate was fabricated for the three-camera system. The aircraft was deemed safe to fly at this time and the aircraft was transported to the Jornada test range for flight activities planned the week of 3/15/21.

2.3.2   Electromagnetic Interference (EMI) Issues

Ultimately, no flights were run during FT3 because of severe electromagnetic interference (EMI) caused by the USB3 cameras. The remainder of FT3 was spent diagnosing and troubleshooting the issue. Details are provided in the FT3 post-event report. A summary of the issue is presented below. Figure 7 illustrates the effects of EMI.

2.3.2.1   Diagnosis and Attempted Fix

The problem was first noticed on Monday 3/15/21. During ground testing, it was immediately observed that the vehicle's GPS signal was lost when the Utopia payload was powered on and regained when it was powered off. Of even more concern, an autopilot malfunction was also observed during power on of the payload which caused the ailerons to maximally deflect. After some initial troubleshooting, the problem was traced to the USB3 cameras and cables. After swapping cables and re-testing it became more evident that the cameras themselves were causing the problem because of EMI from USB3 ports or cables.

The remainder of Monday 3/15 and the rest of the week were spent at the PSL hangar attempting to fix the EMI issue. We were able to re-create the problem by turning off the GPS repeater and moving the aircraft outside. Again, the GPS signal was lost when the payload was powered on.

The most common mitigation method for USB3 EMI is conductive shielding. This involves wrapping cables, connectors, and any other emitting components with aluminum or copper tape and tying the shield (tape) to electrical ground. This captures the emissions and sends the signal to ground, protecting other devices (i.e., the GPS antenna) from the EMI.

Figure 7: Illustration of EMI issue.

Unfortunately, although shielding was applied, we were not able to again remove the interference completely. To ensure all USB3 emissions were shielded, we performed the following:

1. Wrapped the three camera USB3 ports as well as the camera housings in aluminum tape and grounded the shield.

2. Wrapped the USB3 hub and all the ports in aluminum tape and grounded the shield.
3. Wrapped the USB3 ports on the embedded computer with aluminum tape and grounded the shield.
4. Constructed a shielded enclosure by wrapping a plastic box with electrical tape and placed the embedded computer in this shielded enclosure, with shield tied to ground.

Even after all these mitigation methods, the GPS signal continued to be lost.

2.3.2.2 Troubleshooting Post-Event

The NMSU electrical engineer measured the RF emissions around the payload using a spectrum analyzer. The EE determined that the USB3 cables contributed the largest RF frequency measurement across the 1GHz to 2GHz frequency band as seen on a Spectrum Analyzer, with a 30dB difference on the noise floor. Also, a 10dB noise floor increase was observed under the cameras. It was determined that cameras were radiating in the L1/L2 (GPS) bands. The EE's recommendation was to add metal braid to shield the cables and aluminum tape around the cameras. Based on the EE's recommendation, the team did the following:

1. Acquired four EMI dongle filters which claim to reduce EMI. These filters were attached to each of the four USB3 ports on the hub.
2. Added an additional layer of shielding using braided metal harnesses around the camera USB3 cables.

The addition of the braids seemed to improve the noise floor, but radiations were still seen near the cameras causing a noise floor increase of 10 dB. An electrostatic bag was then placed around the cameras. This seemed to decrease the noise floor increase to 3 dB, but not persistently. Furthermore, another troubling observation was seen. The autopilot's horizon jumped and then the IMU measurement drifted. They may have been the cause of the aileron deflection seen on 3/15/21.

Ultimately, the decision was made to move away from the USB3 camera system and use gigabit ethernet (GigE cameras) instead.

2.4 Flight Test 4

In FT4, we tested the 3-camera PCAS system using GigE cameras. We used three Baumer VLG-40C cameras and purchased new lenses giving each camera an 86.26° FOV. The cameras were mounted such that a total FOV of 238.8°. The single-board computer has two Ethernet ports on the motherboard, one of which is used for the IP radio. Thus a PCI network interface card was added for each camera to connect to. Note that using an Ethernet switch did not work due to collisions. Instead, three separate ports (on the card) were configured each on a separate subnet. This enabled the three cameras to work simultaneously.

The FT4 flights were initially planned to be run on the Bat-4 UAV as in the previous flight tests, and integration was done on the Bat-4 payload. However, we later decided to use the Aeronautics Aerostar Tactical UAV instead, as described in the FT4 post-event report. The payload components and sensors were transferred to the Aerostar and the flights were done on the Aerostar.
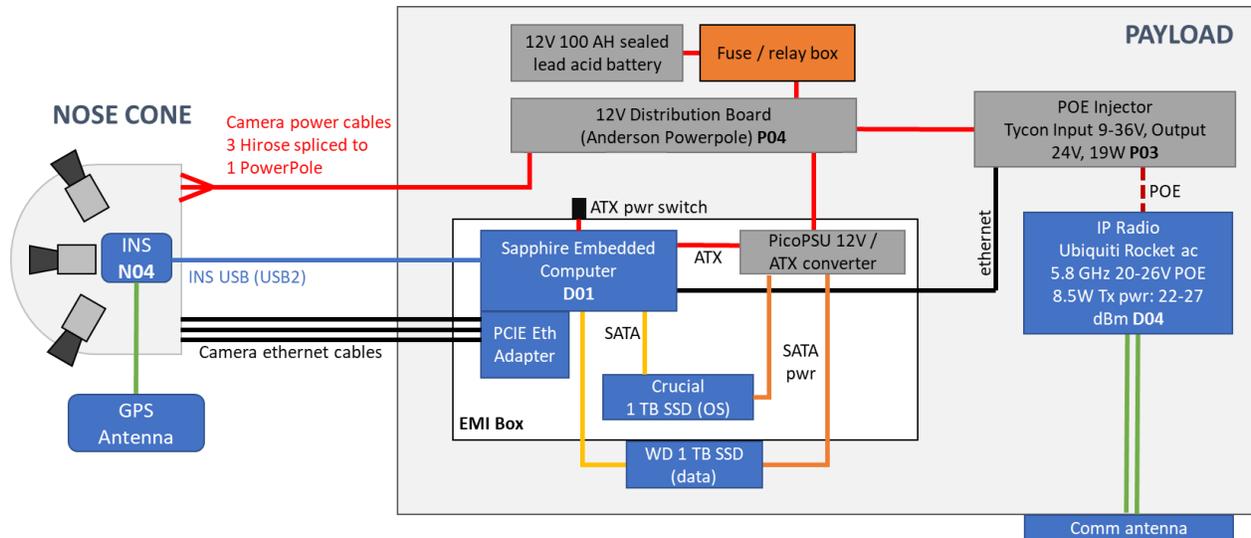
Figure 8: Payload + Nose Cone Block Diagram

Figure 9: EMI enclosure

2.4.1   Integration

Bat-4 integration was done on 6/21/21—6/25/21. This activity is detailed in the FT4 post-event report. Due to bad weather as well as previous commitments by NMSU in late June and early July, the continued FT4 activities were deferred to the week of 7/12/21. At that time, the payload was integrated onto the Aerostar UAV. The payload diagram is shown in Figure 8. The EMI enclosure which houses the computer, power supply, ethernet adapter card, and one SSD hard drive (with the operating system) is shown in Figure 9.

2.4.2   Test Summary

The FT4 data was processed and the results presented in the FT4 post-event report. As FT4 was the first time 3-camera data was collected, several issues not seen before presented themselves. This affected the ability to consistently track the intruder. As a result, the range estimator could not converge. Therefore, we cannot compute the LoWC risk ratio for FT4 at this time. UtopiaCompression is continuing to work with the three-camera data and will report further findings as we make progress.

3   Conclusions

3.1   Program Summary

This program has focused on flight testing of UtopiaCompression's PCAS system. The experiences have proven extremely valuable. Many milestones for PCAS were met in this program including the following:

- Flight tested PCAS on an embedded computer for the first time
- Flight tested PCAS with multiple (three) cameras for the first time
- Tested and utilized the PCAS ROS system for the first time
- Developed diagnostic and performance analysis tools for the PCAS ROS system
- Learned valuable lessons on camera integration, especially as relating to USB3 cameras and EMI
- Developed 3-camera GigE system using PCI network card
- Developed and tested air-to-ground communication system using IP radios

The program culminated in flight testing of the 3-camera system with GigE cameras. While the data processing showed that the system needs more work, we are committed to resolving all issues and developing and providing wide FOV collision alert systems for UAV DAA in the future.

3.2   Path Forward

As described in the FT4 post-event report, the 3-camera system is currently not functioning properly due to issues with the tracker and its interface with the gate detector. It is important to note that the PCAS framework of detector, tracker, and range estimator is sound and was demonstrated in FT1 and FT2 of this program as well as numerous flight tests in previous programs. The three-camera system continues to use the detector, tracker, and range estimator of these earlier incarnations, but with modifications, for example the gate and patch detectors. The issues uncovered in this program (specifically FT4) pertain only to these modifications and can be resolved, but more time is needed.

UtopiaCompression believes strongly that PCAS is a valuable product for UAS DAA. The ability to range passively without maneuvers is a huge advantage that only PCAS can provide. We have demonstrated successful ranging with a single camera system and have now tested the multi-camera, large FOV system. We are committed to working out the issues in the multi-camera system and will do so in the coming months.