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Development of a Sense and Avoid System

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Remotely Operated Aircraft (ROAs) currently do not have convenient access to civil airspace due to their inability to provide an onboard capability to "see and avoid" air traffic. Defense Research Associates, Inc. and AFRL/SNJT have developed affordable technology based on silicon charge couple device sensors and passive moving target detection algorithms. Previously, a flight demonstration proved real-time implementation of complex detection and tracking algorithms with multiple sensors providing a wide field of regard was feasible. This paper documents lessons learned from that demonstration, subsequent improvements made to the prototype system, resulting performance improvements, and planned next steps.

I. Introduction

Federal Aviation Administration (FAA) Regulation 7610.4 states remotely operated aircraft must provide an "…equivalent level of safety, comparable to see-and-avoid requirements for manned aircraft" in order to operate like manned aircraft in the National Air Space (NAS). The capability must be effective against all air traffic, with or without active, transponder-based collision avoidance systems. Currently, no ROA "see and avoid" capability exists. ROAs operating in the NAS must obtain Certificates of Authorization, a cumbersome process, and/or use either chase planes or ground-based observers. Plans to deploy Predator ROAs in National Guard and Homeland Security applications increase the urgency of the need for a solution. The Air Force Research Laboratories' Sensors Directorate (AFRL/SN), and Defense Research Associates, Inc. (DRA) have developed technology called Sense and Avoid (SAA) that has the potential to meet the FAA's "see and avoid" requirement.

The first step in developing SAA was to reduce the phrase "… equivalent level of safety…" to engineering performance requirements, the most difficult of which was detection range. DRA used a validated AFRL/SN human vision model called OPEC and custom simulation software to numerically quantify the required detection ranges along with actual human capability for a complex set of scenario parameters developed in conjunction with the Air Force Aeronautical Systems Center, Air Force Air Combat Command, and industry [McCalmont et al 2002, Bryner et al 2003]. Next, the team examined a variety of potential technologies including radar, infrared, and silicon band sensors. The team selected an approach based on silicon sensors and complex image processing algorithms based on detecting motion of intruder aircraft relative to the background scene. A series of flight demonstrations using a small field of regard sensor and post-processing of recorded sensor data verified predictions that SAA technology could meet Global Hawk and Predator requirements, as shown by [McCalmont et al 2002]. Next, the team built a real time implementation of the detection and tracking algorithms using field programmable gate array chips and microprocessors operating with multiple sensors to increase system field of regard. Another series of ROA surrogate flight demonstrations verified real time SAA implementation was practical [Deschenes et al 2004] and provided some important "lessons learned." Based on these demonstrations, the Air Force funded the AFRL team to undertake development of the technology into a product starting in 2005 with subsequent transition to the field starting in 2007 via a phased Advanced Technology Demonstration (ATD) program [McCalmont et al 2005].

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II. Review of Real-Time Demonstration Hardware and Methodology

The Sense and Avoid (SAA) concept uses several key technologies: CCD sensors, new discrimination algorithms, and field programmable gate arrays (FPGAs). The SAA concept is to use three sensors to provide adequate non-cooperative target collision avoidance protection. The sensors are high resolution (megapixel), low cost, digital video cameras available in the commercial market. The selected sensor provides high spatial resolution (~0.5 milliradian) while maintaining a large field of view. Detection and tracking algorithms characterize global scene motion, Sense objects moving with respect to the scene, and classify the objects as threats or non-threats.

The demonstration utilized the six-seat, twin-engine Aero Commander aircraft as a surrogate ROA. The Beech Bonanza shown in the same figure was the intruder aircraft. The processing and data recording equipment were installed in a custom-designed rack, which replaced the middle row of seats in the Aero Commander. The aircraft were flown toward each other in a series of near-collision "engagements." A 500' altitude separation was maintained for safety purposes. Engagements concentrated on nose-on geometries since this was the most challenging (smallest profile of the approaching aircraft and longest detection range requirement). Figure 1 shows the flight demonstration hardware assets; the hardware shown in Figure 1 was christened the Air Traffic Detection Sensor System (ATDSS).

Figure 1. Real-Time Demonstration Assets Including ATDSS Hardware

III. Lessons Learned

The real-time multi-sensor demonstration hardware functioned reliably during the demonstration thereby successfully achieving the stated demonstration objectives. However, the demonstration hardware also produced thousands of false tracks during the relative short cumulative flight duration. Figure 2 shows a typical frame of video from the demonstration with the symbol "+" superimposed on all track positions. No statistical analysis is needed to conclude the false track rate demonstrated substantially exceeds any operationally reasonable number.

Subsequent analysis of the flight data identified several factors contributing to the excessive false tracks. Before discussing these, a brief recap of terminology is in order. Detection algorithms operate directly on sensor video to extract candidate features. Tracking algorithms operate on the candidate features ("detections") to correlate them over time forming "tracks.' Declaration algorithms operate the track set to classify them as threat or non-threat based on their temporal behavior.

The chief false track factors were sensor vibration and discrimination algorithm sensitivity. The sensor vibration caused excessive false detections by impairing the effectiveness of the scene motion quantification algorithms. In turn, these detections impair tracker effectiveness. Because initial attempts at understanding the issue were focused on comparing the new real-time implementation to the existing all-software implementation using the same recorded data in order to identify errors, this problem was not immediately identified. Once vibration was suspected, a flight was undertaken with accelerometers installed on the sensor mount plate. The mount plate was stiffened and the surrogate ROA propellers were then balanced and a subsequent flight was conducted. Accelerometer traces taken before and after the improvements are shown in Figure 3.

Figure 2. Frame of Video from ATDSS Hardware Showing False Tracks

The detection algorithms were optimized for sensitivity during the ATDSS demonstration in the interest of maximizing declaration range. The detection algorithms exhibited motion estimation noise sensitivity, which was easily corrected by adding a noise floor with results shown in Figures 4 and 5 for typical scenarios. The improvements for Scenario 1 are striking and those for Scenario 2 are noticeable.

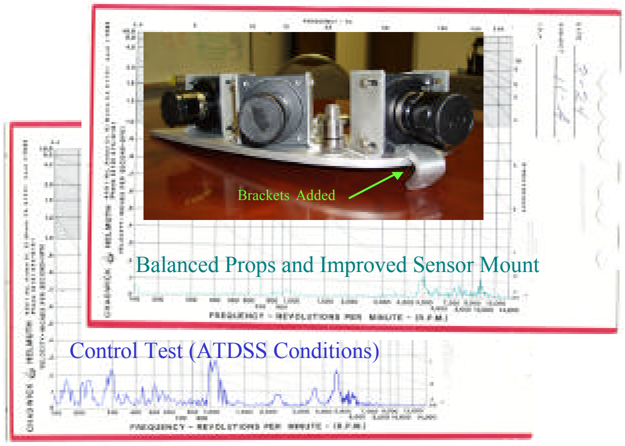


Figure 3. ATDSS Sensor Vibration Before and After Improvements

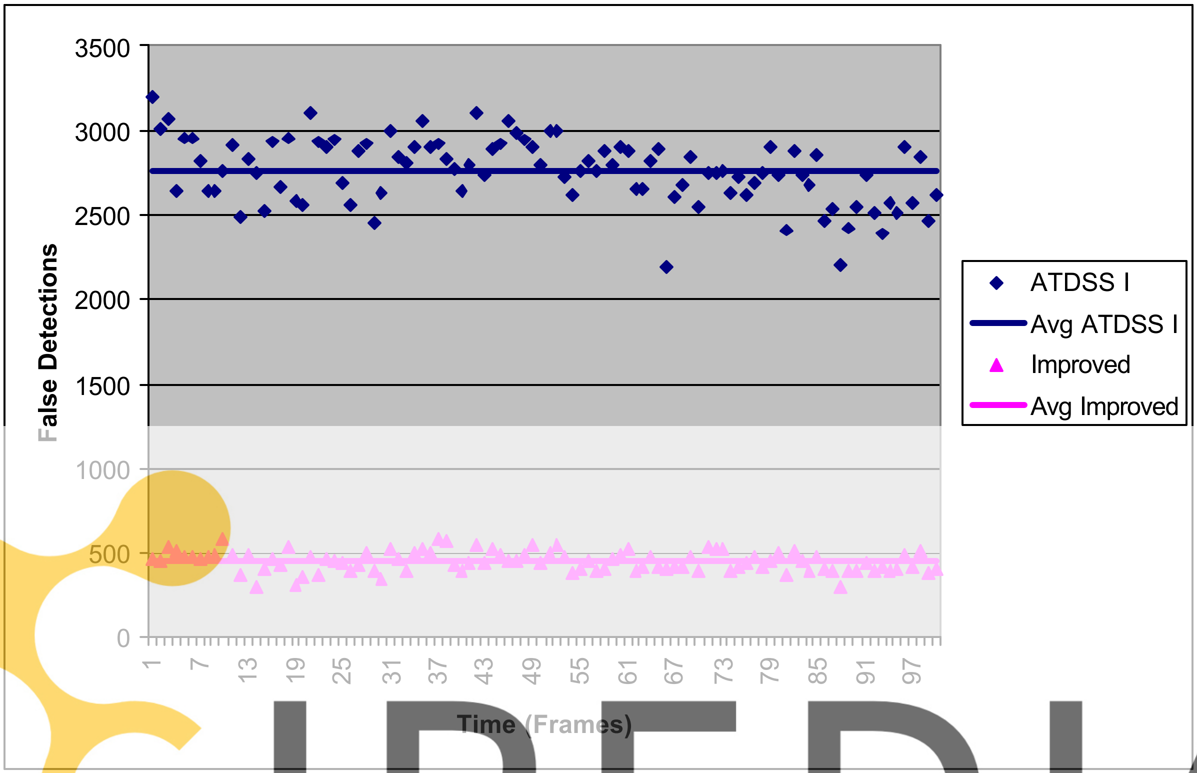


Figure 4. Detection Algorithm Noise Floor Improvements for Scenario 1

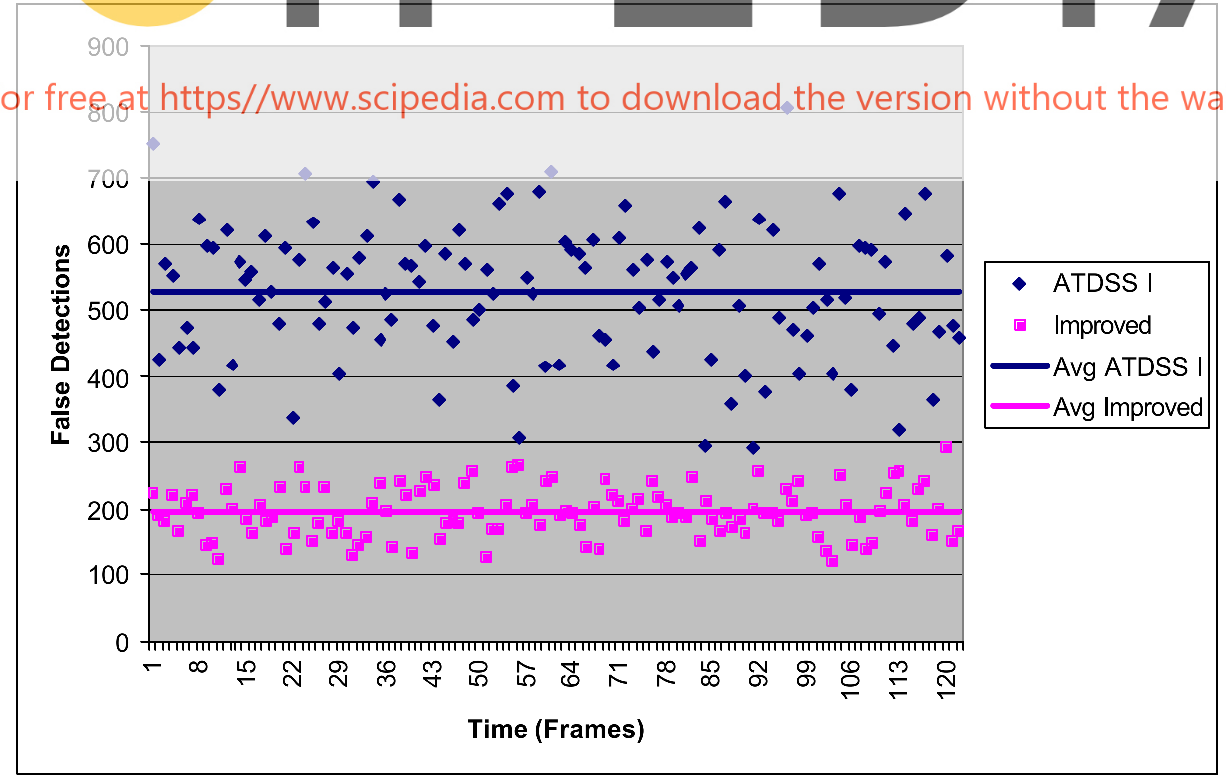
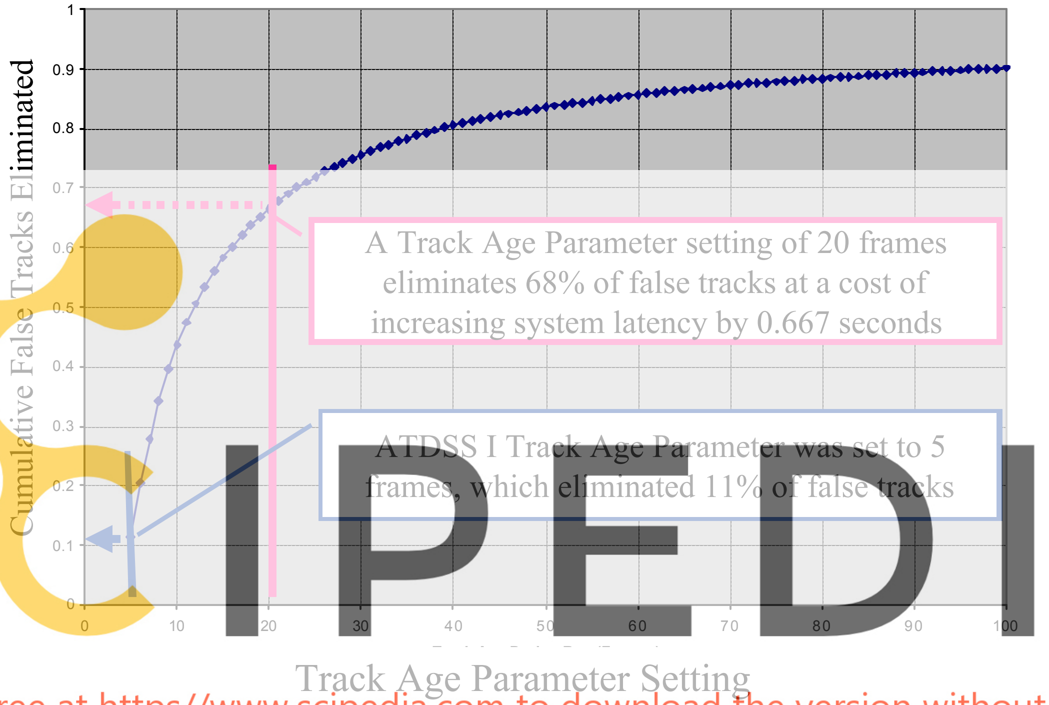


Figure 5. Detection Algorithm Noise Floor Improvements for Scenario 2

The declaration algorithms were optimized for sensitivity during the ATDSS demonstration in the interest of minimizing declaration latency. This resulted in many transient (ie short duration) tracks. Figure 6 shows a cumulative histogram of tracks recorded by the ATDSS hardware during the demonstration; tracks are binned by their age (in sensor frames) upon extinction. One algorithm parameter is minimum age for a declaration. During the demonstration, this parameter was set to five frames. Figure 6 shows that increasing this to 20 frames would have eliminated 68% of the false tracks reported at a cost of 0.667 seconds increased latency. Additional modifications were also made to the declaration algorithms in favor of increased discrimination capability.



A Track Age Parameter setting of 20 frames eliminates 68% of false tracks at a cost of increasing system latency by 0.667 seconds

ATDSS I Track Age Parameter was set to 5 frames, which eliminated 11% of false tracks

Figure 6. Cumulative Histogram of False Track Age at Extinction

Although there is no way to quantify the interaction between algorithm improvements and the vibration reduction, the team measured aggregate performance for the modified sensor mount and improved algorithms. An ATDSS sensor equipped with a digital video recorder was flown in the nose-on intruder scenarios conducted during the ATDSS demonstration. The recorded data, having been subjected to substantially less sensor vibration, was then played through the improved algorithms. Figure 7 shows a typical frame of data with "+" symbols overlaid on track positions.

The combination of improvements discussed above succeeded in eliminating all false tracks in the data set available with one exception: small (~1 milliradian) brightly lit cloud bits. Figure 8 shows an example of cloud phenomenology resulting in a false track. DRA has devised and implemented a method for discriminating against this phenomenon, but test results are not yet available.

IV. Next Steps

The team is working to integrate SAA technology incorporating the improvements described in Section III into an Aerostar ROA as shown in Figure 9 for a flight demonstration. The primary objective of this demonstration, called ATDSS II, is to show ATDSS can Sense and track aircraft in the vicinity of the host platform and to declare, as threats, those aircraft on a collision course. Because the SAA system will be installed on an unmanned vehicle being operated in the National Airspace, remote control and operation capabilities must be incorporated into the design. The demonstration will occur during January 2006 using military and general aviation aircraft as the intruders and the Aerostar UAV as the demonstration platform.

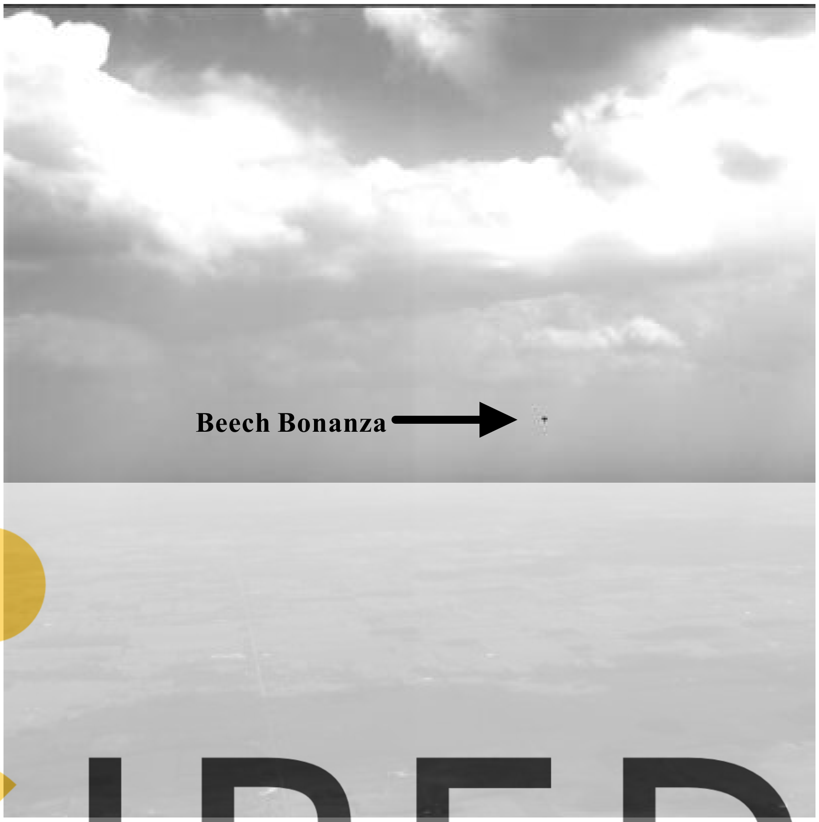


Figure 7. Frame of Video Showing Correct Track with No False Tracks

Figure 8. Example of Cloud Phenomenology Inducing False Track

The SAA subset identified for the ATDSS II demonstration consists of one sensor mounted with an inertial measurement unit (IMU), a Global Positioning System (GPS) antenna, a data recorder, a tracker/processor, and a comm-link to down-link declarations and control the system remotely. The sensor, IMU and GPS antenna will be mounted in the nose of the UAV aircraft. The data recorder, tracker/processor and comm-link system will be mounted in the payload bay. The real-time detection processing hardware and track processor will be located on the Aerostar and declarations will be down-linked to a ground station. Components and Aerostar integration are shown in Figure 10.

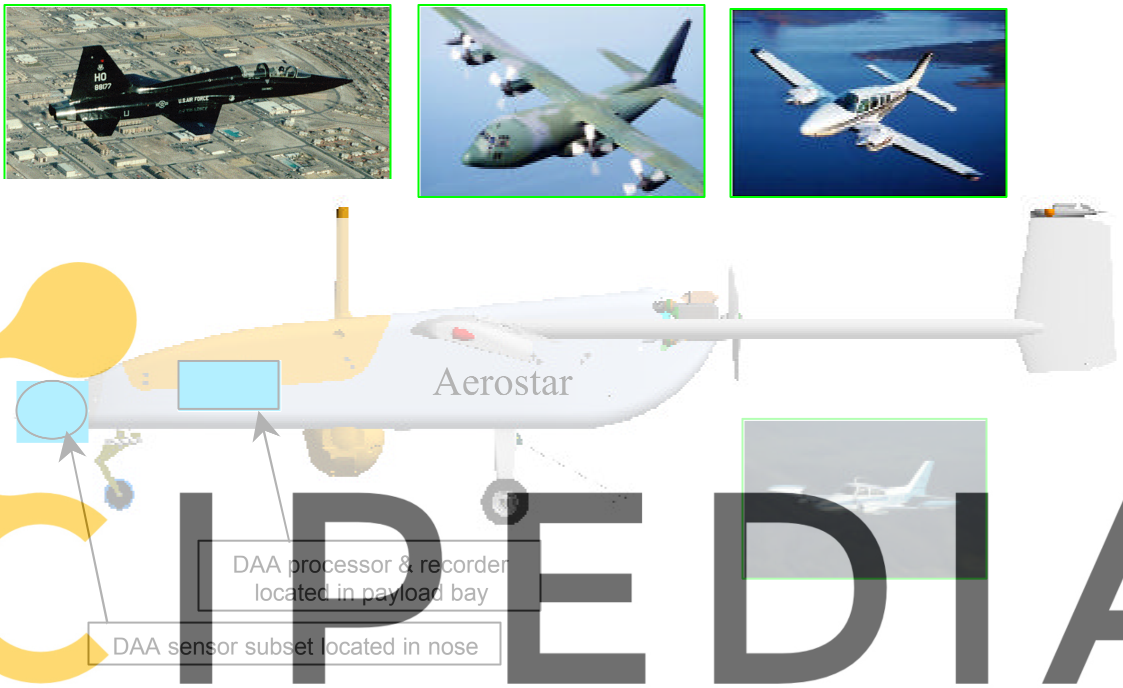


Figure 9. The Aerostar ROA and Intruder Aircraft Planned for ATDSS II Demonstration

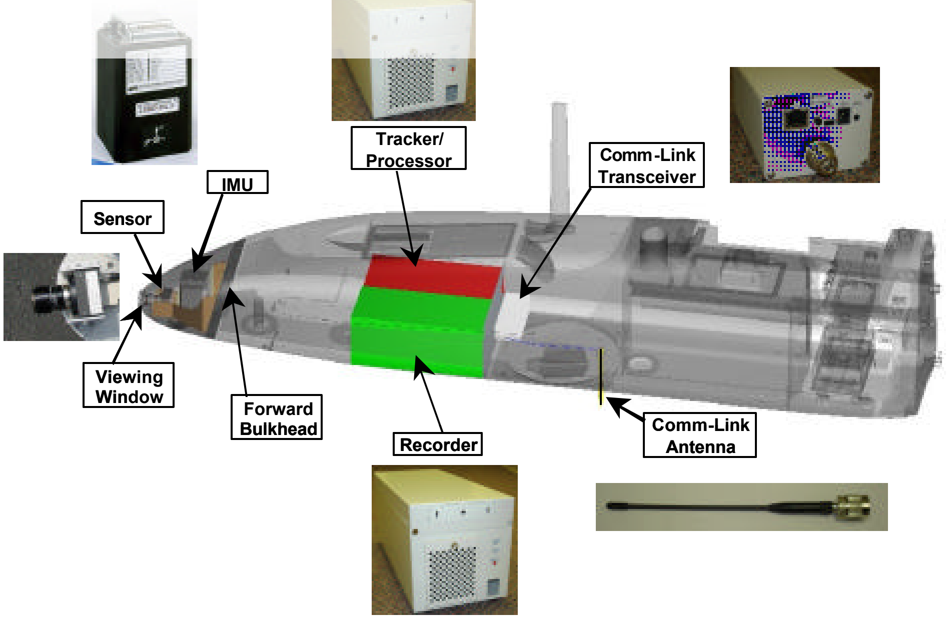


Figure 10. Planned ROA Sense and Avoid Installation

V. Summary

The Air Force Research Laboratories' Sensors Directorate (AFRL/SN), and Defense Research Associates, Inc. (DRA) have developed technology called Sense and Avoid (SAA) that has the potential to meet the FAA's "sense and avoid" requirement. The key pieces of technology required to implement Sense and Avoid have been demonstrated over the past three years. Lessons learned from the most recent demonstration are being addressed prior to the next flights in an Aerostar ROA. Based on these demonstrations, the Air Force has launched an Advanced Technology Demonstration program to transition Sense and Avoid to the field.

VI. Acknowledgements

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VII. References

1. Global Hawk ORD CAF 353-92-I/II-C Basic Systems for the Global Hawk Unmanned Aerial Vehicle (ROA) System, Air Force Command and Control & Intelligence, Surveillance, and Reconnaissance Center, September 2002
2. RQ-1 Predator ORD # CAF 003-90-I-A, 24 June 1997
3. MQ-9 Capability Development Document, 30 Sep 2003
4. FAA Order 7610.4K: Special Military Operations, 2004
5. Air Force Instruction 11-202, Vol. 3, General Flight Rules, June 1998
6. Unmanned Aircraft Systems Roadmap, 2005 – 2030, Office of the Secretary of Defense, 2005
7. White Paper, Sense-and-Avoid Requirements for Remotely Operated Aircraft, HQ ACC/DR-UAV SMO, 18 February 2004
8. ASTM F 2411-04, Specification for Design and Performance of an Airborne Sense-and-Avoid System
9. McCalmont, J., Utt, J. and Deschenes, M., "*Detect And Avoid Technology Demonstration*," Proceedings of the American Institute of Aeronautics and Astronautics Infotech, 2002
10. Bryner, M., McCalmont, J., Utt J., "*Global Hawk Definition of Equivalent Level of Safety Requirements See and Avoid (SAA),*" Proceedings of the 2003 UAV Technical Analysis and Applications Conference, 2003
11. Deschenes, M. McCalmont, J., and Utt, J. "*Test and Integration of a Detect and Avoid System*," Proceedings of the American Institute of Aeronautics and Astronautics Infotech, 2004
12. McCalmont, J., Utt, J. and Deschenes, M., "*Sense and Avoid Phase 1 (Man-in-the-Loop) Advanced Technology Demonstration*," Proceedings of the American Institute of Aeronautics and Astronautics Infotech, 2005