FEATURE ARTICLE

Ganged Phased-Array Radar System: A Ground-Based Risk Mitigation Strategy for UAS Flight Operations in the National Airspace

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A significant obstacle to the integration of unmanned aircraft (UA) into the National Airspace System (NAS) is the requirement that they incorporate a system (or systems) that reduces the risk of midair collision to a level equivalent to, or lower than, that posed by operations of manned aircraft. As no on-board system presently exists, and the likelihood of such a system being developed and certified within the next decade is extremely remote, this creates a significant impediment to the development of a viable, potentially lucrative, civil unmanned aircraft systems (UAS) market.

Could the risks, however, be sufficiently mitigated, for limited test and evaluation purposes, by a ground-based system utilizing sensitive phased-array radars? What might such a system look like? This paper describes the University of North Dakota's efforts, through funding from the United States Air Force, to create a ground-based unmanned aircraft operations risk mitigation system based upon the fusing of multiple phased-array radars.

Background

AFS-400 Policy Memo 05-01, *Unmanned Aircraft Operations in the U.S. National Airspace System – Interim Operational Approval Guidance*, states that operators of unmanned aircraft (UA) must be able to provide an acceptable level of risk mitigation. With regard to Title 14 Code of Federal Regulations Parts 91.111 and 91.113 (generally referred to as the «right-of-way» rules), UA operations below 18,000 feet MSL outside of restricted airspace require either airborne or ground-based visual observers. Use of ATC radar alone, according to the memo, does not constitute sufficient collision risk mitigation in airspace where uncooperative airborne operations may be conducted. Ground Observers may be utilized when the UA is operated within one mile laterally and three thousand feet vertically of the observer. Airborne Observers must remain within one mile of the UA and the observer is not allowed to fly the chase aircraft.

The development of an airborne system to mitigate the risk of midair collision has become the «holy grail» of the UAS industry. Of the myriad systems developed to date, none have proven reliable or accurate enough in all situations to make the safety case desired by the Federal Aviation Administration. Whether radar-based, electro-optical, infrared, audio, or some combination thereof, the solution has proven to be frustratingly elusive (Marsh 2006).

Automatic Dependent Surveillance-Broadcast (ADS-B), a satellite/ground-based technology that is at the heart of the NGATS (Next Generation Air Traffic System), promises to increase safety by giving both the pilots in the air and the controllers on the ground the same air traffic picture. Incorporation of ADS-B might aid in UA/manned aircraft deconfliction in the future. Problems with its exclusive use for risk mitigation, at present, are that not all aircraft are so equipped (and those without a primary source of electrical power may never be required to do so) and ADS-B coverage is not available in all areas.

The authors of the policy memo leave open the possibility of a radar solution when they refer to special types of radar. When special types of radar are utilized to mitigate risk, the applicant must demonstrate that non-cooperative aircraft, including targets with low-radar reflectivity, such as gliders and balloons, can be consistently identified at all operational altitudes and ranges and that the system makes the chance of collision between those targets and the UA highly unlikely. The memo does not define what is meant by a special type of radar.

GPARS Risk Mitigation Strategy

Radar has been utilized for decades as a method to provide risk mitigation and separation of traffic participating in Air Traffic Control (ATC) systems worldwide. Studies of ground-based radar facilities in and around Beale Air Force Base (AFB) have concluded, however, that conventional ground-based radar assets are not suitable for the job of non-cooperative aircraft/UA deconfliction due, in part, to their inability to determine the position of non-cooperative aircraft to an acceptable level of certainty. This is due to the need to interrogate transponders to accurately determine aircraft altitude and identification information. Not all aircraft need to be equipped with transponders nor must all aircraft be in radio contact with Air Traffic Control (ATC). Such aircraft are termed «uncooperative». Often difficult to detect (such as sailplanes or hot-air balloons), the inability to accurately determine their position makes assuring separation between these uncooperative users of the NAS and unmanned aircraft difficult, at best.

A thorough review was conducted to examine the use of ground-based radars for unmanned aircraft (UA) midair collision risk mitigation. Little has been written about systems specifically used to provide a risk-mitigation strategy for UAS operations. SAVDS (Sense and Avoid Detection System) is advertised to be capable of scanning a volume dependent upon the particular radar being utilized, providing tracks of known traffic, evaluating the collision potential, and prioritizing the collision threat. The system utilizes a single radar to scan a 360 degree volume up to 18,000 feet (Herwitz 2008). INSITU (Scan Eagle) utilizes ground-based radar for risk-mitigation purposes during flights of their unmanned aircraft when not operating in segregated airspace (INSITU 2007). One wonders if these single-radar systems are adequate or whether a multiple-radar approach might provide a significantly greater level of risk mitigation.

The GPAR Risk Mitigation System (RMS)

The utilization of radars as the key observational tool for aircraft deconfliction places some significant requirements upon them. In order to investigate this approach, an intensive literature review regarding radar technologies, radar clutter mitigation, target identification, target tracking, and existing radar systems was conducted. One key indicator of success in this role would be their ability to rapidly scan the volume of interest. Phased array technology affords the beam agility required for rapid scanning (Cheston and Frank 1990). Secondly, accurate determination of aircraft position is vital. The worst-case scenario for this involves uncooperative aircraft. Without the use of other systems (e.g., ADS-B, Mode C/S) for the identification of a target, the radars, themselves, must be capable of very accurately determining the positions of these targets. Again, phased array technologies enable this by employing techniques such as monopulse detection (Wirth 2001, §11.3).

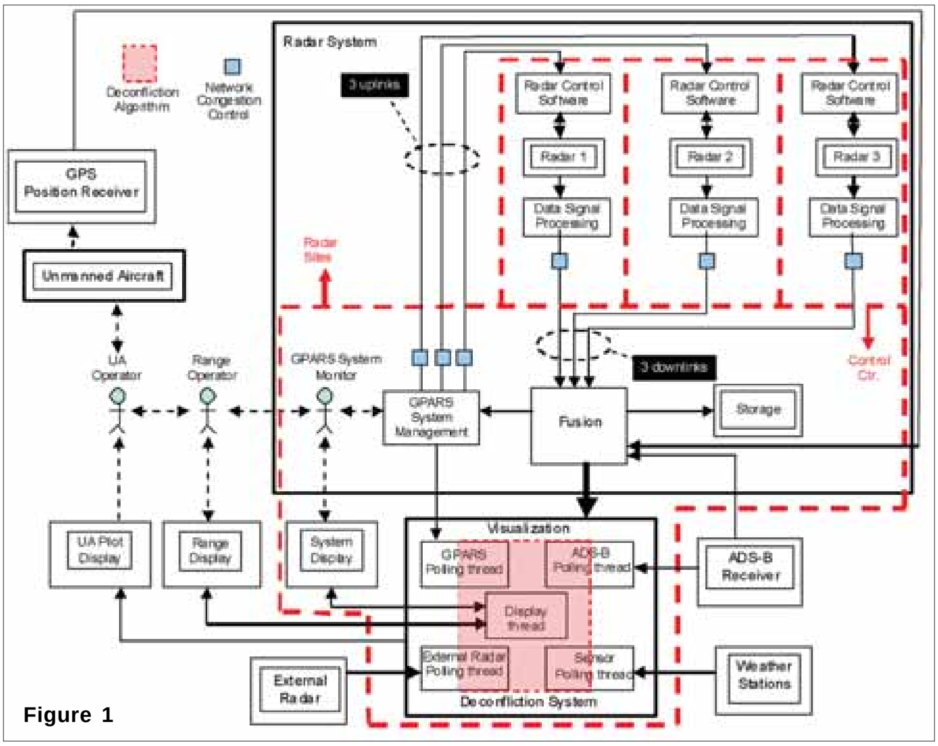


Figure 1

Another requirement is the ability to sense targets of interest. Since some of these will likely have relatively small radar cross sections (e.g.: hot air balloons, fiberglass sailplanes, the UA itself, and, possibly, parachutists), the radar must be very sensitive. The final major challenge is target detection/clutter mitigation. Most radar systems employ frequency-domain filtering to separate «clutter» from targets (Wirth 2001, §s 8.1-8.3). These techniques typically rely upon the Doppler-shift typical of fast-moving targets to separate them from background noise. In this application, however, targets of interest, which include relatively-slowly-moving UA, birds, etc., likely will not satisfy this requirement. Consequently, the development of filtering techniques that do not throw out important signals will be one of the challenges faced in the establishment of the GPAR RMS.
A review of existing radar systems revealed many excellent candidates for the GPAR RMS. One such system, identified early in this research, is the CASA radar system (Collaborative Adaptive Sensing of the Atmosphere; http://www.casa.umass.edu/). It is a low cost and highly portable system, making it a particularly attractive candidate. The development schedule of the CASA system, however, is such that it will not be ready in time to be utilized in this research project. However, once tested and proven effective, low cost systems like it will likely be the key to widespread use in risk-mitigation systems like that described herein.

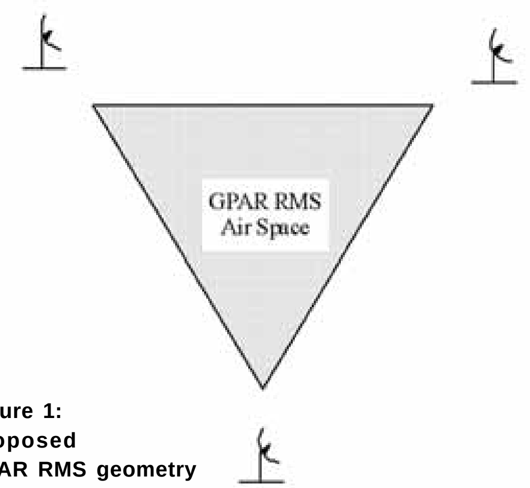


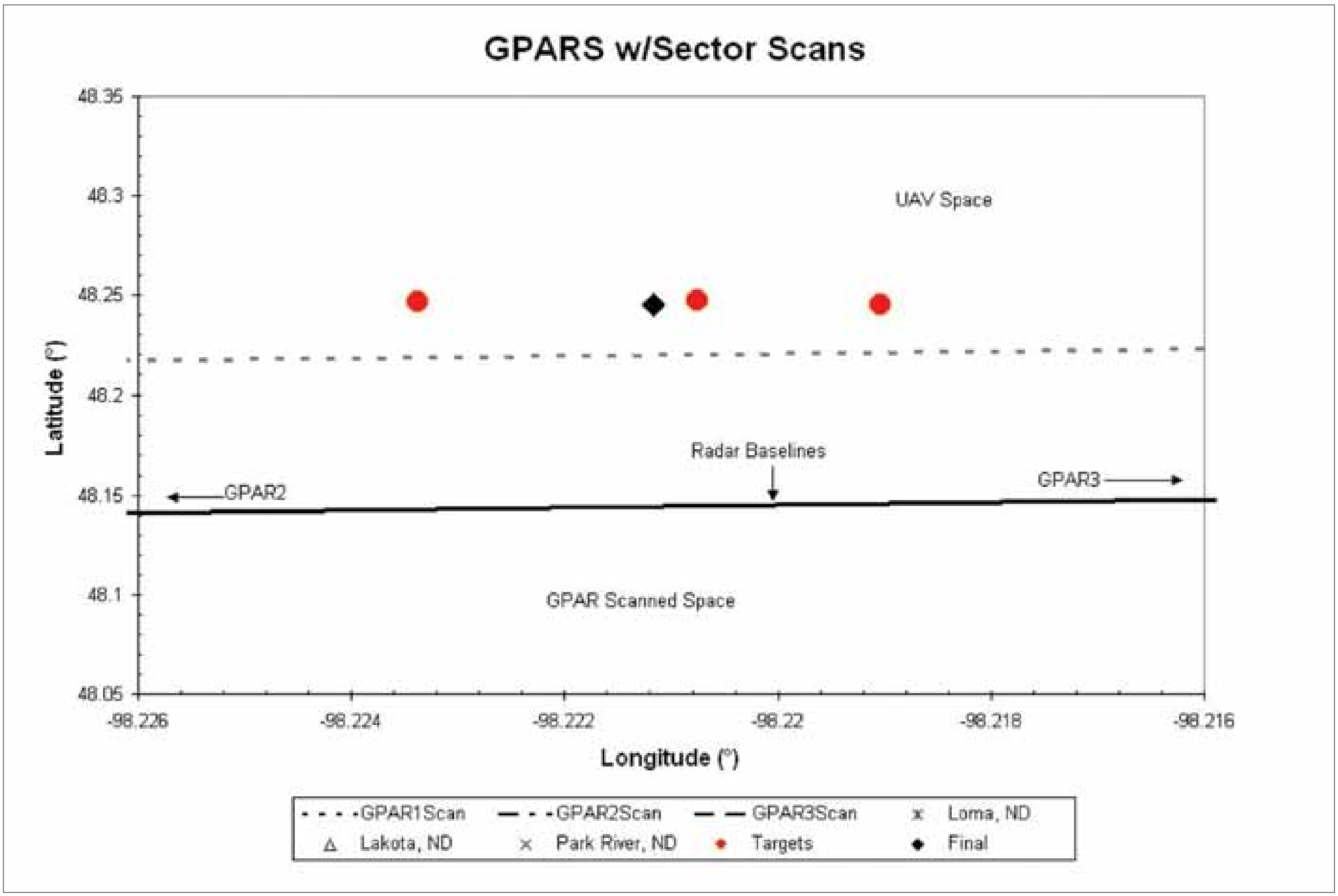
Figure 1: Proposed GPAR RMS geometry

GPAR RMS Geometry

In order to better identify required radar characteristics, properties of an RMS space were delineated through mutual consideration of user requirements and radar capabilities. Through this process, an RMS space having a triangular shape was designed (Fig. 1).
Multiple radar systems are utilized to help meet the requirement that a risk mitigation system provide a level of safety comparable to, or better than, that provided by pilots of manned aircraft. Their arrangement has the advantage of minimizing volume scan times while maximizing the volume of space covered while providing the maximum redundancy possible given multiple (3) radar systems. Additionally, the use of multiple systems allows the volume to be scanned if one or even two of the three radar systems should fail. Moreover, individual radars may be directed to focus upon certain regions within the volume, or specific targets, when conditions warrant (e.g., two aircraft are getting close to each other). The remaining radar(s) can continue to scan the entire RMS space uninterrupted.
Evaluation of this geometry shows that the use of multiple radars «looking in» enhances the detection of objects with small radar cross sections (e.g., small UA, low-observable manned aircraft, birds or weather) and mitigates, to a degree, issues involving the aspect-dependence of radar cross sections that are inherent to using a single radar.
Given the characteristics of the RMS space, radars that would enable effective surveillance of this space have been identified. Moreover, the volumetric coverage of this space, including strategies and limitations, has been determined.

The GPAR RMS Architecture

Based upon the requirements of the GPARS RMS, an initial architecture comprised of four major subsystems: Radar, Fusion, System management, and Visualization (Fig. 2), was developed
In addition to the data provided by the three GPARS radars, other data sources, including UA GPS position data, ADS-B data, additional radar data, etc., will be incorporated to provide the most complete level of «air truth» possible.



System Testing

In order to understand the performance of such an RMS, including strengths, weaknesses, and failure modes, a GPARS simulation system was developed. The main steps within this simulation system are the production of atmospheric conditions using a state-of-the-art numerical weather prediction model, synthetic radar «sampling» of these conditions using a radar simulator, target insertion, target detection, and data fusion. As can be imagined, all of these steps have involved significant complexities.
Two in particular are the detection of targets against a background of weather returns and the fusion of the radar data to provide the most accurate estimates of aircraft position. The first is the same «clutter» problem discussed previously and will be an area of significant research. The later challenge includes the complex structure of the overlapping range resolution volumes (from different radars) that contain a target and temporal differences in target identification. These will also be areas of significant research, although important steps (i.e., determining the volume that contains a target) have already been made through these efforts. An illustration of output from the data fusion step is provided in Fig. 3.

Conclusion

Next steps in the system's development include validation using a single radar, testing and validation using multiple radars, and system refinements, validation, and deployment. It is believed that GPARS will provide the risk mitigation necessary to enable the test and evaluation of UA in non-segregated airspace. Moreover, with the continued migration towards high performance low cost phased-array radar technologies, it is believed that this system could provide an affordable, highly effective risk-mitigation solution for more routine operations of unmanned aircraft in the National Airspace System.

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