Design of Sense-and-Avoid Standards for RQ-7B Shadow under Loss-Link

Group Members

Francisco Jose Choi

Zach Moore

Sam Ogdoc

Jonathan Pearson

Sponsor

Andrew Lacher, MITRE CAASD

Table of Contents

Table of Figures

Table of Tables

Context

Unmanned Aircraft System (UAS)

An Unmanned Aircraft System (UAS) is comprised of the unmanned aircraft and all of the associated support equipment, control station, data links, telemetry, communications and navigation equipment, etc., necessary to operate the unmanned aircraft [1]. UAS are divided into five groups, primarily according to the operational altitude, sensor payload and airspeed, shown below in Table 1. This project will be focused on Group 4 UAS, specifically the RQ-7B Shadow. The reasons for this scoping will be covered thoroughly in later sections.

Table 1: UAS Groups

UAS Categories	Current System Attributes			
	Operational Altitude (ft)	Typical Payload	Airspeed (kts)	UAS Models
Group 1	> 40,000	RADAR	> 250	Global Hawk
Group 2	≤ 40,000			Predator Reaper
Group 3	≤ 10,000	Moving Target Indicator (MTI)	≤ 250	Pioneer Dragonfly Eagle Eye
Group 4	≤ 5,000		≤ 100	Shadow Silver Fox ScanEagle
Group 5	≤ 1,000	EO/IR	≤ 60	Hornet Raven MAV

Expanding Role of UAS in Civil Airspace [6]

The Unmanned Aerial System (UAS) is one of the numerous inventions created to maintain air superiority since man first took to the skies. Major Norman E. Wells wrote: "to win, you must control the skies – particularly the skies over your own territory. Air power does not guarantee that you will win a war, as in the cases of Korea and Vietnam; but without it, modern armies are destined to lose." [2] UAS are but one mechanism to achieve air superiority and therefore their applications are primarily military; however, UAS can also serve in a variety of other capacities including remote sensing for terrain mapping, meteorology monitoring and precision agriculture, disaster response, homeland security through surveillance of traffic along borders and the coast, search and rescue, cargo transport, and delivery of water to firefighting efforts or chemicals for crop dusting [3]. UAS are capable of performing these and many more missions without the necessity of a pilot on board. This has led to a consistent rise in demand for advancements in UAS technology across the globe. As the demand for UAS increases, the number of flight hours has also increased, shown below in Fig. 3. We project that by 2013, the Department of Defense (DoD) will perform over one million flight hours of UAS operations.
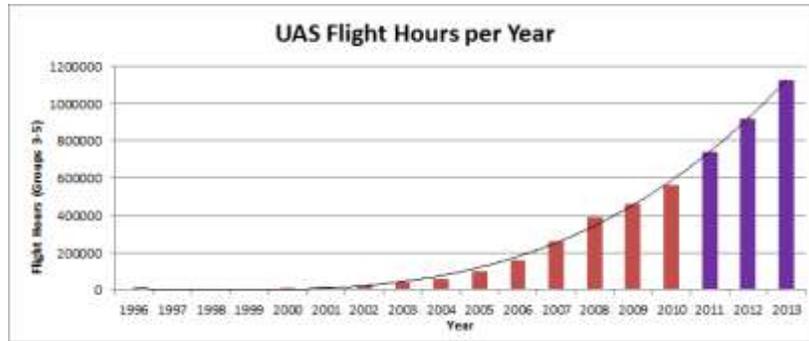
Figure 1: UAS Flight Hours

Manned vs Unmanned

The increase in flight hours and corresponding demand for UAS within the NAS leads to a number of key issues which must be addressed, seen below in Table 2. Many of these issues stem from the fact that there is no pilot onboard the UAS. This raises the largest concern facing integration of UAS into the NAS: visual scanning is not possible to accomplish see-and-avoid, the last line of defense in collision avoidance. Instead, UAS must rely on onboard sensors to accomplish Sense-and-Avoid (SAA). Until assurances can be made that SAA performs at or above the level of see-and-avoid, integration of UAS into the NAS is infeasible.

Another issue that arises from the need for SAA capabilities is the possibility of losing the command-and-control link while the UAS is in flight. To account for this possibility, UAS operators create a set of pre-programmed procedures for the UAS to execute if a loss of link occurs.

These issues complicate the next key issue: there are no set standards or regulations for the manufacturing of UAS or for UAS flights in the NAS. A manned aircraft is issued an airworthiness certificate based on FAA regulations set in the FAR that allows the aircraft to fly in the NAS. However, there are no standards to determine that a UAS is airworthy. FAA Order 7610.4K: Special Military Operations gave the DoD a Certificate of Authorization (COA) which allows them to operate UAS in the NAS; however, the COA does not ensure the UAS are airworthy. This lack of standardization creates a huge gap that the FAA must address.

Table 2: Manned vs Unmanned

	Manned Aircraft	**Unmanned Aircraft System**
Pilot Location	Onboard	Ground Control Station
Collision Avoidance	See-and-Avoid	Sense-and-Avoid (SAA)
	Visual Scanning	Sensors
Avoidance Maneuver	Direct Pilot Commands	Pre-Programmed Procedure

Sense-and-Avoid Subsystems [8]

The FAA defined SAA in 2009 as "… the capability of a UAS to remain well clear and avoid collisions with other airborne traffic" [4]. SAA can be broken down into 8 subsystems: detect, track, evaluate, prioritize, declare, determine, command and execute. The first 4 subsystems comprise the "sense" half of SAA, while the latter 4 comprise the "avoid" half. Brief explanations of each subsystem are given below the figure.
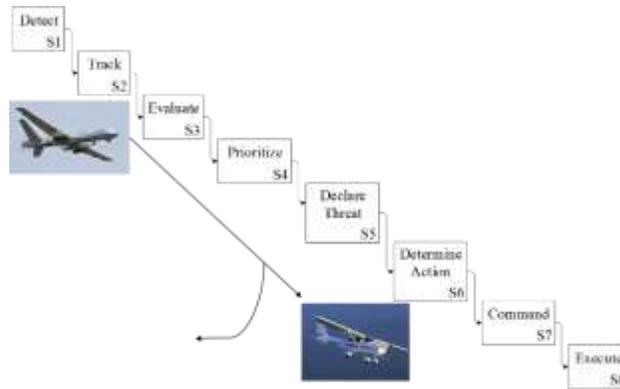
Figure 2: SAA Subsystems

The detect subsystem provides the indication that 'something' is there. Aircraft, terrain/obstacles and weather may all be detected; however, detecting aircraft takes precedence and we will focus solely on this aspect of SAA. There are four types of sensors which can fulfill the detection requirement: electro-optic, infrared, primary radar and acoustic sensors.

The track subsystem establishes the motion of the detected object. Not only does the objects position and trajectory need to be established, but it is also necessary to establish that the object is valid with sufficient confidence.

The evaluate subsystem establishes whether the valid object's trajectory can be predicted with sufficient confidence and tests the trajectory against criteria in order to determine if a SAA maneuver is needed.

The prioritize subsystem can be combined into either the evaluation or declaration subsystems, or it can remain separate. For the purposes of our project, only one other aircraft will be in the airspace at any time, so this subsystem can be ignored.

The declare subsystem establishes that the path of a tracked object, the UAS path, and remaining time until a separation conflict have reached a decision point that requires maneuvering to begin.

The determine subsystem establishes which specific maneuver, based on geometry of the encounter, maneuvering capabilities of UAS, and other relevant constraints such as airspace rules and the other aircraft's maneuvering capabilities.

The command subsystem simply tells the UAS to perform the maneuver chosen during the determine subsystem.

Finally, the UAS executes the chosen maneuver during the execute subsystem.

Stakeholder Analysis

The primary stakeholder is the FAA, whose objectives include developing policy, guidance material and standards for the NAS. The major tension the FAA faces is their lack of standardization requirements concerning UAS manufacturing/operation, certification of airworthiness, and SAA procedures. The focus of this project is finding the manufacturing requirements for sensors which allows SAA to be performed with enough time to ensure safe operation.

The next three primary stakeholders are the Department of Defense (DoD), Department of Homeland Security (DHS) and NASA. Each organization wishes to utilize UAS to perform a variety of missions as seen in Table 3. However, since the FAA has no standardization requirements, these departments are limited in their ability to perform these missions.

Other stakeholders include Air Traffic Controllers (ATC), manned aircraft pilots and UAS manufacturers. ATC is tasked by the FAA to secure and maintain the orderly flow of air traffic and is concerned with the increased workload which comes along with the increase in flight hours under their responsibility after integration occurs. Manned aircraft pilots are concerned with their own personal safety and require assurances that SAA can perform at or above the level of see-and-avoid, currently this is not assured. Finally, UAS manufacturers wish to stay in business and will benefit from integration because primary stakeholders will be able to perform more missions and will therefore require more UAS. However, manufacturers are concerned with how restrictive SAA standards become since they currently have difference procedures to perform SAA.

Table 3: Stakeholder Analysis

Primary Stakeholders	Objectives	Conflicts/Tensions
FAA	• Developing policy, guidance material, and Standards for the NAS	• No Standardization Requirements
DoD	• Military Operations	
DHS	• Border Protection and maritime surveillance	• Put pressure on FAA to integrate UAS into the NAS to accomplish objectives
NASA	• Science and aeronautical research	
Stakeholder	**Objectives**	**Conflicts/Tensions**
Air Traffic Controllers	• Secure and maintain the orderly flow of air traffic	• Increased Workload
Manned Aircraft Pilots	• Avoid collisions	• Sense-and-Avoid << See-and-Avoid
UAS Manufacturers	• Manufacture UAS for operators	• Different procedures to perform SAA

Problem and Need Statement

Currently, UAS sensors do not perform at the level necessary to ensure that UAS meet the TLS of 10^{-7} is met while operating under loss-link. [10]

Gap

Figure 3 below depicts the gap in this project. Currently, the level sensors perform at allows UAS to achieve the Level of Safety shown with the red line, while the green line represents the TLS which must be met. As sensor capability is increased, the gap will be closed.
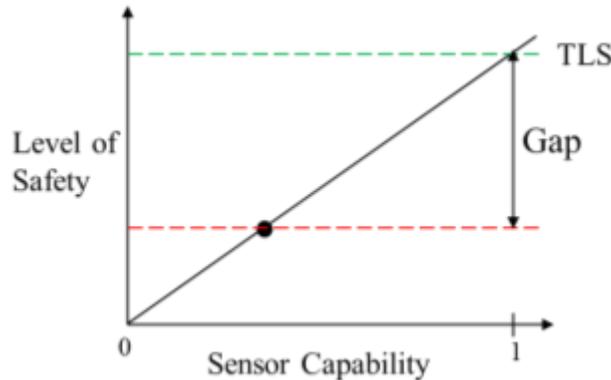

Figure 3: Gap

Need Statement

A safety analysis of sensor capabilities is needed to assure that sensors are capable of detecting the necessary amount of aircraft that allows the UAS to meet the TLS set forth by the FAA.

Scope

National Airspace System (NAS) [11]

An airspace is defined as "the space lying above the earth or a certain area above land or water; especially, the space lying above a nation and coming under its jurisdiction" [19]. The NAS is the airspace above the United States, governed by the FAA who is granted jurisdiction by Title 49 of the United States Code (49 U.S.C.) [1]. The FAA sets rules and regulations which govern the NAS with their Federal Aviation Regulations (FAR).

The NAS is broken up into six airspace classifications, seen below in Fig. 1. Classes A through E are known as controlled airspace because they are monitored by Air Traffic Control (ATC). Class G airspace is known as uncontrolled airspace.

Class A comprises the airspace above 18,000 ft. mean sea level (MSL) and is majorly operated in by commercial flights. Classes B, C and D surround international, regional, and small airports respectively.

Figure 4: Airspace Classifications

Class E airspace extends from 700 ft. above ground level (AGL) or 1,200 ft. AGL depending on terrain, up to Class A airspace at 18,000 ft. MSL. Although two-way radio communication is encouraged while operating in Class E airspace, it is not always necessary. This means that at any time there can be any number of non-commercial pilots flying in Class E airspace who are not in communication with ATC, any regional tower, or any other aircraft in the air; these aircraft are coined 'uncooperative' aircraft.

RQ-7B Shadow

The RQ-7B Shadow, produced by Aircraft Armament Inc. (AAI), provides near-real-time reconnaissance, surveillance, target acquisition and enforce protection. It is equipped with the POP300, an electro-optic/infrared (E-O/IR) sensor payload, produced by Israel Aerospace Industries (IAI).

E-O/IR Sensors [12]

Group 4 UAS are equipped with E-O/IR sensor payloads which provide day and nighttime capabilities. The electro-optic sensor is a visible light CCD camera which carries a high magnification and resolution, similar to a traditional camera, but can only operate during the daytime. The infrared sensor is a ranged light imaging system which senses and differentiates one object from another by their difference in temperature and can be used during the day as well as at night. As previously stated, the RQ-7B Shadow is equipped with the POP300 E-O/IR sensor, which will be the focus of our sensitivity analysis along with the HD version of this sensor by IAI, the POP300D. The resolution, azimuth and elevation specifications for these two E-O/IR sensors can be seen below in Table 4.

Table 4: E-O/IR Sensors

	Resolution (pix)	Azimuth (deg)	Elevation (deg)
POP300	640x480	$\pm 60 - 130$	-60 – +15
POP300D	1280x1204	± 180	-90 – +25

Scope Summary

Before moving into the design alternatives and method of analysis for this project, a summary of the scope is necessary. The UAS selected for this project is the RQ-7B Shadow, a Group 4 UAS, at a constant operating altitude of 3000 ft. MSL. This means that the simulation will only

take place within a two-dimensional (X-Y) plane and E-O/IR sensor elevation will not be considered. In addition, only the horizontal dimension for resolution will be used. The RQ-7B Shadow will be operating under a loss link with no outside communication. Only the RQ-7B Shadow and a single other aircraft will exist in the airspace at any given time. Finally, there will be no elevated terrain within the airspace at any time and weather disturbances will not lead to false positives.

Design Alternatives

There are 8 design alternatives shown in Table 5, which have varied pixel resolution and azimuth range. Each sensor will perform at a different level when it comes to detection range and NMAC detections.

Table 5: Design Alternatives

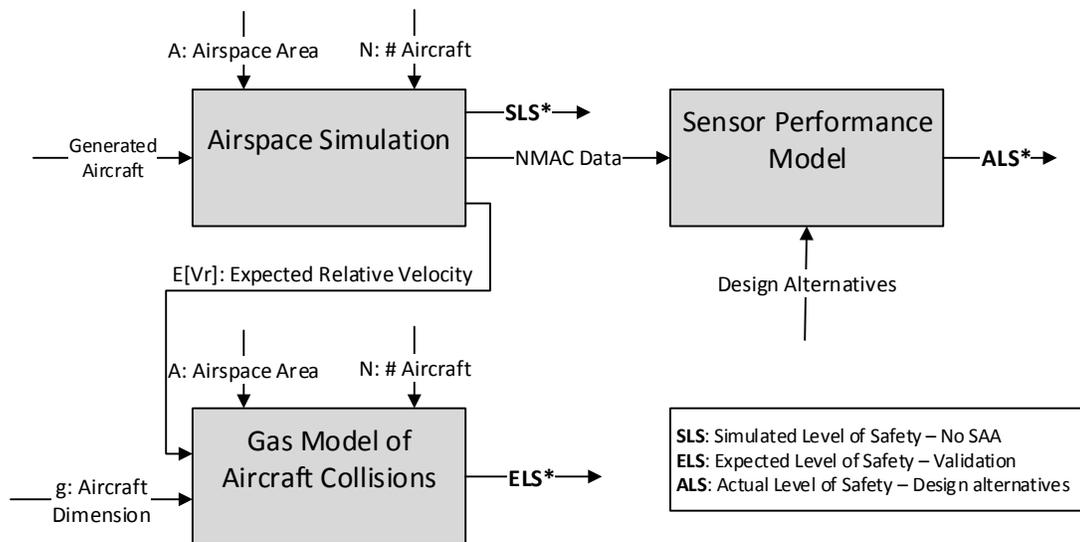| Sensor Model	Horizontal Resolution (pix)	Azimuth (deg)
POP300	640	$\pm90°$
		$\pm110°$
		$\pm130°$
POP300 x 2	1280	$\pm130°$
		$\pm150°$
		$\pm170°$
POP300D	1605	$\pm180°$
POP300D x 2	3210	

Method of Analysis

Figure 5: Method of Analysis

The Method of Analysis has three main components: Phase 1 Simulation, Gas Model of Aircraft Collisions and Phase 2 Model of detection sensor performance. Phase 1 is a Monte Carlo simulation of an airspace which generates probabilities and distributions for use in the Gas Model and Phase 2 Model. The Gas Model of Aircraft Collisions uses the distribution of relative velocities of simulated aircraft to predict the Expected Level of Safety (ELS) of the airspace. Phase 2 is a model which provides the ELS for each design alternative.

Simulation Requirements

With these assumptions made, we are able to derive the model requirements:
1. The simulation shall be able to simulate aircraft in level flight.
2. The simulation shall calculate the relative angle between the UAS and other aircraft.
3. The simulation shall calculate the relative velocity between the UAS and other aircraft.
4. The simulation shall provide the rate of collisions per unit time
5. The simulation shall generate an Expected Level of Safety (ELS) based on the E[Vr].

Airspace Simulation

Phase 1 is a Monte Carlo Simulation with the following input parameters:
- Initial coordinates - (x,y)
- UAS and manned aircraft velocities – v
- Aircraft headings – p
- Diameters of the aircraft – g.

The UAS will always be located at the center of the airspace for the simulation with coordinates (0, 0), a constant velocity of 70 NM/h, a constant heading of 90º N, and a diameter of 14 ft.

The simulation begins by generating an aircraft with values for its velocity, v, and its area g. The simulation then randomly chooses a side of the airspace that the aircraft will enter from, and uses that value to determine its initial x and y coordinates as well as its heading p.

Using these inputs Phase 1 simulates 10,000,000 hours of flight time for the RQ-7B Shadow. Throughout the simulation all relative velocities between the RQ-7B and another aircraft were found using the following equation [15].

The relative angle of the two aircrafts, β, is calculated by projecting the vector of aircraft j, onto aircraft i. The outputs from Phase 1 are shown below:
- Expected Relative Velocity – E[ ]
- Number of Near Mid-Air Collisions (NMAC)
- Total Number of Aircraft Generated in Phase 1

Expected Relative Velocity, E[ ], was calculated by simply averaging all of the recorded relative velocities for each generated aircraft with respect to the RQ-7B Shadow. Near midair collisions (NMAC) are defined as any incidence where a manned aircraft comes within 500 ft. of the RQ-7B Shadow. Finally, the Actual Level of Safety (ALS) for the airspace is defined as the probability of a collision, shown below in equation 2.

Gas Model of Aircraft Collisions [15]

The Gas Model of Aircraft Collisions is a prediction of the airspace's ELS as a comparison to the ALS. The Gas Model uses the following inputs to calculate the ELS.

- E[ ]
- E[g] - Expected area of aircrafts in airspace
- N - Number of aircraft in airspace
- A - Area of airspace

With these values the Gas Model applies the following formula to determine the ELS.

$$\overline{}$$

The difference between the ALS and ELS represents the gap which can be closed by improved technology and utilization of that technology. If the ELS is found to be greater than the ALS then the Phase 1 simulation data will be deemed invalid.

Sensor Performance Model [16], [18]

The POP 300 sensor has an IR detector lens that is 640 pixels x 480 TVL. The assumption that our aircraft operates only in the x-y plane implies that the z-plane will not be visible to our sensor. So we reduce the IR lens to 1 pixel x 480 TVL. TV Lines are a bit smaller than pixels. TV Lines can be converted to pixels using:

$$1 \text{ TVL} = 0.75 \text{pixels}$$

After converting the TVL value to pixels we end up using a sensor with a lens that is 1 pixel x 640 pixels. Using the provided sensor parameters, manned aircraft velocities, and manned aircraft areas we are able to determine the maximum distance that the POP300 sensor can detect an intruding aircraft. First we define the minimum detection threshold, Ω, as the minimum projected angle that the manned aircraft subtends onto the pixel array grid defined above [27]. In order to calculate Ω we must first set the amount of pixels that the subtended angle must cover in order for detection. We define the minimum detection threshold to be 1 pixel for our simulation. We calculate Ω with,

$$\overline{} = .0015625$$

We leave Ω unit-less for now but we will use it in a few steps to determine the minimum distance needed to detect an aircraft. Next we calculate our FOV and the number of degrees/pixel,

$$\overline{} \quad \overline{} \qquad \overline{}$$

The FOV tells us the total number of degrees that are visible to the sensor with the given azimuth angle. We calculate the ―― so that we have the size of the minimum angle that will be subtended onto the sensor lens which allows the RQ-7 Shadow to detect an aircraft. We already know the E[g] for all manned aircraft in the airspace and we use it with the other values that we have found to determine the minimum distance d that is required for detection below,

$$\overline{\qquad} \qquad \overline{\qquad}$$

$$\overline{\qquad}$$

So, the minimum distance to detection is:

$$\frac{\overline{\qquad\qquad\qquad}}{\overline{\qquad}}$$

The equation above assumes that d and E[g] are two sides of a right triangle and that the angle opposite the side of E[g] is equal to the value for――. These assumptions allow for simple geometric application of the tangent function,

$$\overline{\qquad\qquad}$$

or

$$\overline{\qquad} \qquad \overline{\qquad}$$
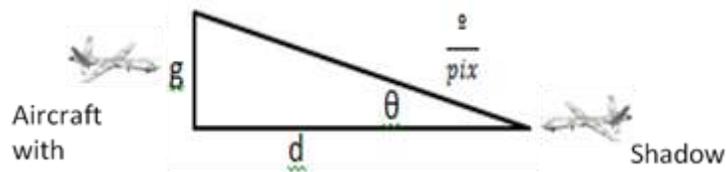
This calculation is depicted in Figure 11.

Figure 6: Distance Calculation

After analyzing each design alternative the ALS corresponding to each design alternative can be found with:

Results

Airspace Simulation Results

The simulation of 10,227,820 flight hours led to 24,471,439 aircraft being generated, resulting in 56,887 NMACs. This corresponds to a probability of a NMAC, P(N), of 5.56E-03. In other words, approximately 5 in every 1000 aircraft will fly within 500 feet of the UAS.

3,095 of the 56,887 NMACs resulted in a collision. This corresponds to an ALS of 3.03E-04 for the simulated airspace when the RQ-7B Shadow does not perform any SAA maneuvers.

Finally, the probability of a collision given a NMAC, P(C|N) is found using Bayes' Theorem, assuming the probability of a NMAC given a collision is 1, seen in equation 11.

———

Figure 6 is a plot of NMACs at when the manned aircraft breaches the 500ft range and becomes a conflict. The plot has X, Y ranges that are just large enough to show the 189,573 ft^2 conflict zone in the airspace surrounding the RQ-7B Shadow.

Gas Model Results

The Phase 1 simulation generated an E[ ] of 120.70 NM/hr. Using equation 3, the Gas Model predicts an ELS of 4.89E-05. Since the ELS is smaller than the ALS, our Phase 1 results can be considered valid and improvement to safety in the simulated airspace is possible through SAA.

Sensor Performance Model Results

Table 4 shows the results for each design alterative. As you can see there is an inverse relationship between %NMAC detected and detection distance. This corresponds to the increase in elevation but no change to pixel resolution. If a sensor has a wider azimuth it can detect more aircraft but in return it cannot detect aircraft as far away. The POP300D sensor far outperforms the POP300 sensor due its much greater azimuth range and much better pixel resolution.

Table 6: Initial Results

Sensor	Azimuth (deg)	Avg. Detection Distance (NM)	Avg. TBN (s)	% NMACs Detected
POP300	±90	1.10	8.88	16.53
	±110	0.91	7.19	27.62
	±130	0.82	5.90	32.33
2x POP300	±130	1.67	12.91	47.97
	±150	1.41	11.09	69.16
	±170	1.28	9.73	91.17
POP300D	±180	1.50	11.92	99.97
2x POP300D	±180	3.07	25.10	99.99

The following table shows the ALS results for each design alternative.

Table 7: Final Results

Sensor	Azimuth (deg)	Actual Level of Safety	Utility
POP300	±90	2.53×10^{-4}	0.2899
	±110	2.19×10^{-4}	0.3201
	±130	2.05×10^{-4}	0.3349
2x POP300	±130	1.57×10^{-4}	0.3958
	±150	9.33×10^{-5}	0.5250
	±170	2.67×10^{-5}	0.7944
TLS Threshold 10-7			
POP300D	±180	8.51×10^{-8}	0.9995
2x POP300D	±180	3.72×10^{-8}	1.0000

The red highlighted sections show the design alternatives that did not allow the UAS to meet the TLS set forth by the FAA and the green highlighted sections show the design alternatives that did. Recall that the TLS is 10^{-7}. Both POP300D alternatives allow the UAS to meet the TLS. This is because its FOV is 360 in comparison to the second best design alternative where the FOV was 340 . It is evident that for this particular UAS and this particular scenario that a sensor capable of detecting aircraft coming from any angle is necessary.

Although the results of the analysis indicate strongly that the POP300D is the best alternative, it helpful to perform a cost vs utility analysis. Each POP300 costs $260,000 [12]; however, the cost of the POP300D is unknown as it is proprietary knowledge. Because of this, the assumption that the POP300D costs 1.5 times the POP300 was made. Figure X below depicts the cost vs utility breakdown.
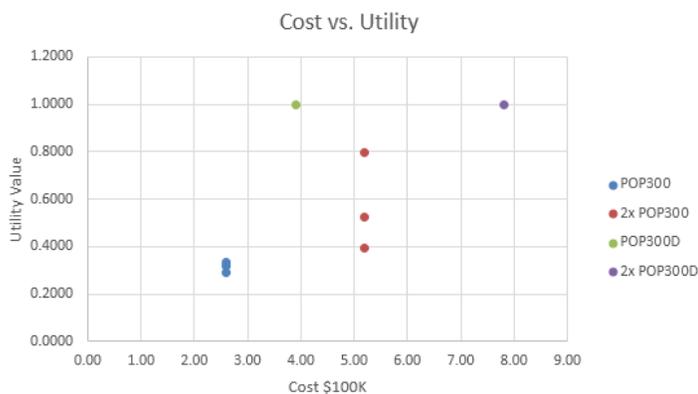

Figure 7: Cost vs Utility

Conclusions and Recommendations

In order for the RQ-7B Shadow to meet the TLS the sensors it is equipped with must have an azimuth range of 180 , or be able to scan a 360 Field of View. The only sensor that performs at the level necessary to meet the TLS set forth by the FAA is this POP300D with an ELS of 8.51E-08. If the RQ-7B Shadow is equipped with 2 POP300D sensors the ALS improves to 3.72E-08. It is recommended that the RQ-7B Shadow's onboard sensors be upgraded from the POP300 to the POP300D to assist the FAA in their goal of safely integrating UAS's into the NAS.

Project Plan

Figure 12 shows the Work Breakdown Structure (WBS) which we have divided into four categories of tasks which must be fulfilled: project management, concept-of-operations (Con-Ops), experimental procedures and analysis/interpretation. Each task is further broken down into subtasks.
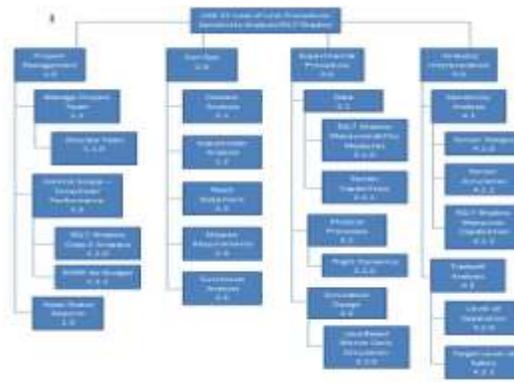

Figure 8: WBS

Figure 13 shows a Gantt chart of the project schedule, whose tasks were derived from the WBS.
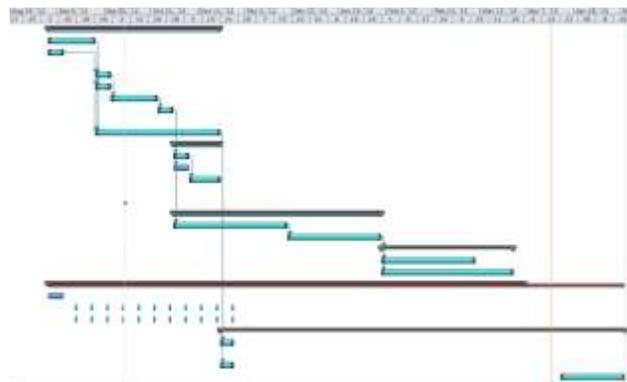

Figure 9: Gantt Chart

For this project we have planned to work 40 hrs/wk at a rate of $150/hr. The project duration is 34.6 wks. To calculate the earned values and planned values we need to account for the fact that we are doing research for GMU and earn only $.43 for every $1. To do this we use a scale factor of 2.12766. Using these values we calculate the Budget at Completion (BAC) which is the

product of these values and get $441,702.22. The Planned Value (PV) for 12 weeks of project completion is the value of work that we planned to do which comes out to be $153,195.50. The Earned Value (EV) at this point is the value of the work that we have actually done which is $116,170.20 and the Actual Cost (AC) or the cost of this work is equal to $119,361.71. Using these values we can calculate the Cost Performance Index (CPI) and the Schedule Performance Index (SPI). Which have values of .99 and .783 respectively. Figure 14 below shows the CPI vs. SPI per week. Figure 15 below shows the PV vs. EV per week.
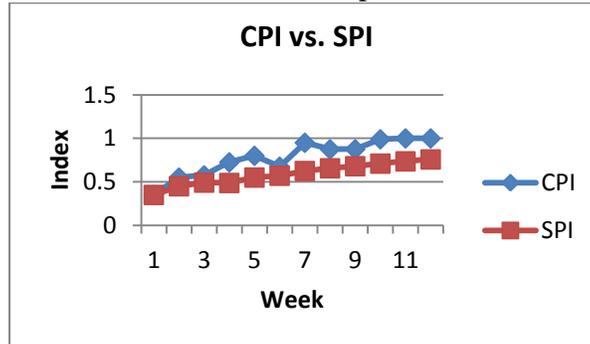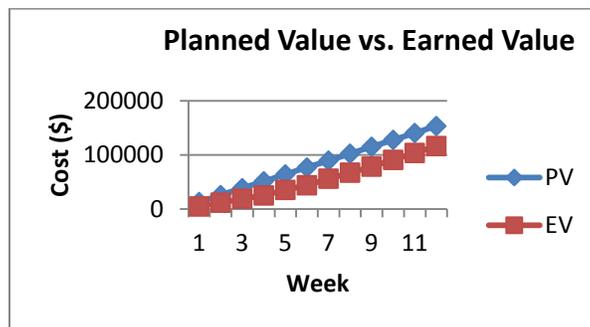

Figure 10: CPI vs SPI

Figure 11: Planned vs Earned Value

References

[1] *49 U.S.C. Title 49 – Transportation*. 03 Jan. 2012.

[2] Wells, Norman E. *Air Superiority Comes First.* Air University Review. Colorado Springs, CO. Nov. 1972.

[3] Muraru, Adiran. *A Critical Analysis of Sense and Avoid Technologies for Modern UAVs.* Advances in Mechanical Engineering 2.1 (2012): 1-7. Print.

[4] Weatherington, Dyke. *Unmanned Aircraft Systems.* DoD Publication 10-S-1660. 20 Apr. 2010.

[5] Federal Aviation Administration. *Order 7610.4K: Special Military Operations.* 19 Feb. 2004.

[6] *Unmanned Systems Integrated Roadmap FY2011-2036.* 2011.

[7] *FAA Modernization and Reform Act of 2012: Conference Report.* 1 Feb. 2012.

[8] Federal Aviation Administration. *Sense and Avoid (SAA) for Unmanned Aircraft Systems (UASs).* Oct. 2009.

[9] Code of Federal Regulations. *Part 91: General Operating and Flight Rules.*

[10] *FAA Systems Safety Handbook.* 30 December, 2000.

[11] Code of Federal Regulations. *Part 71: Designation of Class A, B, C, D, and E Airspace Areas; Airways; Routes; and Reporting Points.*

[12] Israel Aerospace Industries. *POP300: Lightweight Compact Multi Sensor Stabilizing Plug-in Optronic Payload.* Web. 30 Mar. 2013.

[13] Israel Aerospace Industries. *POP300D-HD High Definition Plug-In Optronic Payload – 'Designator.'* Web. 30 Mar. 2013.

[14] *Cessna 172.* Wikimedia Foundation, 29 Mar. 2013. Web. 31 Mar. 2013.

[15] Endoh, S. *Aircraft Collision Models.* Department of Aeronautics and Astronautics, Massachusetts Institute of Technology, Cambridge, MA. 1982.

[16] Chamlaibern, Lyle, Christopher Geyer, and Sanjiv Singh. "Avoiding Collisions Between Aircraft: State of the Art and Requirements for UAVs Operating in Civilian Airspace." (n.d.): n. pag. Robotics Institute at Carnegie Mellon University, 28 Jan. 2008. Web.

[17] Load Factor (aeronautics)." *Wikipedia.* Wikimedia Foundation, 29 Mar. 2013. Web. 31 Mar. 2013.

[18] Griffith, J. Daniel, Mykel, J. Kochenderfer, and James K. Kuchar. *Electro-Optical System Analysis for Sense and Avoid.* 21 Aug. 2008. Web. 10 Jan. 2013.

[19] Airspace. (n.d.) In Merriam Webster.com online. Retrieved 17 April, 2013, from http://www.merriam-webster.com

[20] Lacher, Andrew R., David R. Maroney, Dr. Andrew D. Zeitlin. *Unmanned Aircraft Collision Avoidance – Technology Assessment and Evaluation Methods.* The MITRE Corporation, McLean, VA, USA.