Initial *airspace*Analyzer Evaluation of Impact of an Unmanned Aircraft Operating in Class A Airspace

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When the United States Air Force (USAF) planned to start operations of the Global Hawk Unmanned Aircraft System (UAS) *[1]* at Beale Air Force Base (AFB) (Figure 1) north of Sacramento, CA, they turned to The MITRE Corporation for a traffic feasibility analysis. MITRE documented general issues involved in integrating UAS into civil airspace in *[2]*. For the case of Beale AFB, MITRE evaluated the air traffic that flies in the area to estimate its impact on planned Global Hawk missions. Much of the analysis focused on airspace below 18000 feet Mean Sea Level (MSL) *[3]*.

MITRE was interested in also exploring in a bit more detail how the operation of a UAS might impact operations and traffic flows in positively controlled airspace, that is, operations in Class A airspace (above 18000 feet) where all traffic is under Air Traffic Control (ATC) and must file a flight plan with the Federal Aviation Administration (FAA). Our study asks what impact the Global Hawk might have on traffic in a specific Oakland Air Route Traffic Control Center (ARTCC) sector.

We obtained flight plans for traffic in the vicinity of the Global Hawk on a busy day in November 2007, and analyzed the complexity of the airspace in the impacted sectors for two scenarios—one with, and one without, Global Hawks. We used a tool developed at MITRE/CAASD, *airspace*Analyzer *[4, 5]* to measure sector complexity for the two scenarios. Our conclusion is that the Global Hawk has fairly minimal impact on the traffic complexity given the moderate traffic levels of the particular sectors of the study.

The Global Hawk Unmanned Aircraft System

The Global Hawk (RQ-4) *[6]* is a large, jet-powered unmanned aircraft (Figure 2). It has a wingspan of over 116 feet (increased in later models to 130 feet), larger than that of a Boeing 737. Its cruising speed approaches 340 knots. Its cruise altitude is well above most other aircraft, with service ceiling of more than 60,000 feet MSL. It requires a paved runway for takeoffs and landings such as the 12,000 foot runway at Beale AFB. While the Global Hawk can operate its mission autonomously, a remote pilot on the ground is required to make changes to its planned flight trajectory.

When Global Hawk first started to operate in the National Airspace System (NAS) it would typically climb and descend in military restricted airspace (also known as segregated airspace) and enter the NAS usually at altitudes well above most other NAS traffic (e.g., >50,000 feet MSL). However, with the basing of Global Hawks at Beale AFB for training and operations, they routinely must climb and descend in non-segregated Class E and Class A airspace. Our analysis focused on operations in Class A airspace where the Global Hawk would operate among routine civilian air traffic.

Figures 3 and 4 show horizontal and vertical projections of the Global Hawk's flight path. Takeoff is from the Beale AFB runway, at the center of the inner circle (cylinder) in the lower part of Figure 3. It stays inside that cylinder until it reaches an altitude of 18000 feet. As seen in Figure 4, this takes a little less than ten minutes. Then it flies north, still climbing, and begins a series of loops. It attains its peak altitude of 51,000 feet MSL, and starts to descend. It pauses at 45,000 feet MSL before resuming its descent while continuing to loop. Finally it flies south back to Beale AFB. Its final descent, from 18,000 feet MSL to the ground, is again within the cylinder of airspace.

The Oakland ARTCC

The FAA established 20 ARTCCs in the Continental US to provide air traffic control services to aircraft operating on instrument flight rules (IFR) flight plans within controlled airspace. Beale AFB is located under the Oakland ARTCC (ZOA). The sector most impacted by the Global Hawk planned flight path in is Sector 31 (abbreviated as ZOA31), shown in Figure 5. Its airspace includes altitudes 24,000 feet MSL and higher. The northern loop from Figure 3 can be seen in Figure 5 as well (at about half scale). Several other adjacent sectors were modeled (e.g. ZOA29, ZOA32, ZOA41 and ZOA42). Traffic in these sectors, however, did not come close enough to the Global Hawk's flight path to be impacted by it. Therefore, we present results only for sector ZOA31.

Obtaining Representative Civilian Traffic in the Vicinity of the Global Hawk Flight Path

We obtained eight hours of raw data for flight plans of traffic in the area in November, 2007. For each flight, our data included the airline, aircraft identifier, equipment type, departure and arrival airports, departure time, and filed flight plan. We looked at (non-Thanksgiving) Thursdays, since that day of the week historically has the heaviest traffic, and picked the one day that month with the heaviest traffic. Taking into account locations of airports, navigational aids, terminal area boundaries, en route sector boundaries, airspace fixes, altitude restrictions and wind data, we were able to generate the complete four dimensional trajectories for civilian traffic from departure airport to arrival airport.

Modeling the Global Hawk interaction with ATC

We modeled the Global Hawk as following the path shown in Figures 3 and 4. We assumed that this information is known to the controller.

We assumed that Global Hawks will not be given control instructions by ATC—e.g. if a Global Hawk and another aircraft were in conflict, the controller would have to maneuver the other aircraft. In reality, Global Hawk and other UAS can respond to ATC instructions. This assumption was used to assess the worst case impact on other traffic. Other than this assumption, we modeled a controller's extra workload in the same way for a Global Hawk as for an ordinary aircraft in today's existing traffic.

We modeled not just a single Global Hawk, but a series of them taking off from Beale approximately every hour, so that there was at least one airborne at all times, and eight over the eight hours. Repeated Global Hawk flights were used as a statistical technique to determine conflict frequency over a period of time. This does not represent the real operational tempo of Global Hawk flights at Beale AFB.

Using ***airspace*****Analyzer to measure Sector Complexity**

*airspace*Analyzer measures sector complexity by simulating ATC services to aircraft. *airspace*Analyzer automatically separates, sequences, spaces, and provides proper sector exit strategy for aircraft. It measures sector complexity not simply by looking at problems (e.g., counting aircraft, conflicts, transitions), but quantifying the effort required to resolve them. Its complexity metrics are derived from its resolutions. *airspace*Analyzer automatically resolves complex ATC problems using an algorithm that uses the x, y, and z positions of a set of aircraft at certain future times as variables in a linear program.

The input to *airspace*Analyzer includes traffic files, sector boundaries, and restrictions, which can be for spacing (miles-in-trail) or for altitude (e.g. aircraft exiting a particular sector must be at or below a specified altitude). The input also includes simulation parameters—e.g. when to start and end, how quickly to advance the simulation clock, and how far in the future to look ahead when simulating ATC services.

At each tick of the simulation clock, *airspace*Analyzer iterates the following steps:

(a) Resolve the scenario at the current simulation time, looking out into the future to some time horizon (set to 10 minutes for our analysis); aircraft predicted positions beyond the horizon are ignored

(b) Compute the complexity metrics as a function of the resolutions

(c) Advance the simulation clock by a fixed time-increment (here, two minutes) to a new simulation time, feeding back any resolution maneuvers requiring changes in aircraft positions at the new simulation time.

*airspace*Analyzer outputs each of its complexity metrics once per simulation clock tick for each sector modeled. In this analysis, we look at the ebb and flow of the following *airspace*Analyzer sector complexity metrics, as a function of time:

(1) Aircraft Count (Figure 6)

(2) airspaceAnalyzer's prediction of how a controller would evaluate the complexity of the sector, on a Workload Assessment Keypad (WAK). This is called the predicted_WAK metric, where 1 indicates lowest complexity, and 7 highest complexity. (Figure 7).

(3) Resolution Maneuver Count (Figure 8)

(4) Extra Distance Flown (due to resolution maneuvers) (Figure 9)

(5) Separation Effort (instances where maneuvered aircraft were at or slightly above the minimum required separation) (Figure 10).

The second metric in this list, the predicted_WAK metric, was developed in a 2009 MITRE/CAASD study to provide evidence for *airspace*Analyzer's validity in assessing sector complexity. As discussed in *[7]*, we asked former air traffic controllers to evaluate sector complexity on the 1-7 scale every two minutes, while simulating air traffic control operations in several busy en-route sectors in Indianapolis ARTCC. We calibrated an airspaceAnalyzer metric that correlated well with the controller's evaluations. Then, in a validation phase, using fresh scenarios, we found that *airspace*Analyzer's new metric was able to predict the human's evaluations with a root-mean squared error of less than 0.7 points on the 1-7 scale.

A major component of sector complexity, of course, is pure volume (Aircraft Count). However, ATC problems, such as clusters of interrelated conflicts, possibly compounded by ATC restrictions and/or cramped sectors, can increase the complexity (as reflected in predicted_WAK) above what might be attributed to volume alone.

Global Hawk Initial Results

We ran *airspace*Analyzer for the eight hours of traffic in ZOA31, and obtained sector complexity metrics every two minutes, for a total of 240 data points. The horizontal axis of Figures 6-10 is the time of each data point, in hours Greenwich Mean Time (from 15:00 to 23:00).

Figures 6 and 7 show Aircraft Count in sector ZOA31 (with and without the Global Hawks), and the predicted_WAK metric (with and without the Global Hawks). Not surprisingly, the aircraft count with the Global Hawks is usually 1 higher than without. The aircraft count (without the Global Hawks) varies over the eight hours from 14 to occasional periods where there are no aircraft. The predicted_WAK metric (Figure 7) varies in near lock-step to the volume, from a high of 3.5 (on the WAK scale from 1-7), when the aircraft count reaches its maximum, to 1 (its lowest possible value) when there are no aircraft. What this means is that the addition of the Global Hawk causes no significant ATC problems, other than adding an additional aircraft to the volume.

The impact is minimal but measureable, as seen in Figures 8, 9 and 10. Each figure has two parts, the top (no Global Hawks) and bottom (with Global Hawks).

Figure 8 shows a count of resolution maneuvers. A resolution maneuver is counted if it is larger than a threshold of ½ mile horizontally, or one flight level vertically. There were never more than two maneuvers observed in any 2-minute time segment. With the Global Hawks, there were a few additional maneuvers needed—in each case the result of maneuvering a civilian aircraft to assure separation from a Global Hawk.

Figure 9 shows the impact of the maneuvers, in terms of cumulative extra distance flown by the maneuvered aircraft. The maximum delay observed without the Global Hawks was about 0.4 nmi (two aircraft requiring a separation maneuver). The maximum delay with the Global Hawks was 1.7 miles; there were two other instances with a maneuver-induced delay of about a mile. This represents a very minimal impact on traffic, over an eight-hour interval.

Figure 10 tells a similar story. It shows a count of instances where two aircraft on their resolution maneuvers are separated by a minimal required distance. Since the Global Hawks introduce no problems other than an occasional isolated one-on-one conflict with another aircraft, we may conclude that the Global Hawks cause relatively little increased sector complexity to ZOA31.

Next Steps

It is fortunate that there is relatively low level of civilian traffic in the area of Beale AFB making it a good choice from an air traffic impact perspective. There are a number of other areas where the Department of Defense may be interested in flying UAS, where civilian traffic is significantly denser. We look forward to performing similar studies with *airspace*Analyzer and other analytic techniques to determine whether operation of UAS such as the Global Hawk are feasible in these denser traffic environments.

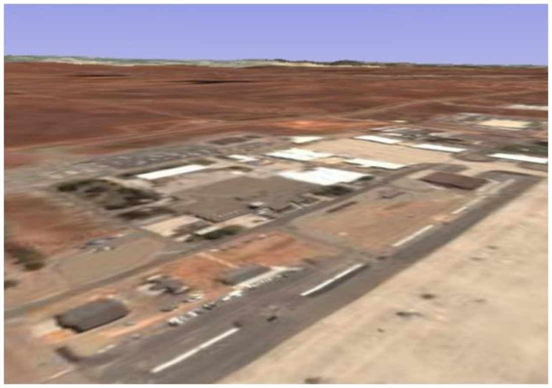


Figure 1: Beale Air Force Base

Figure 2: Global Hawk

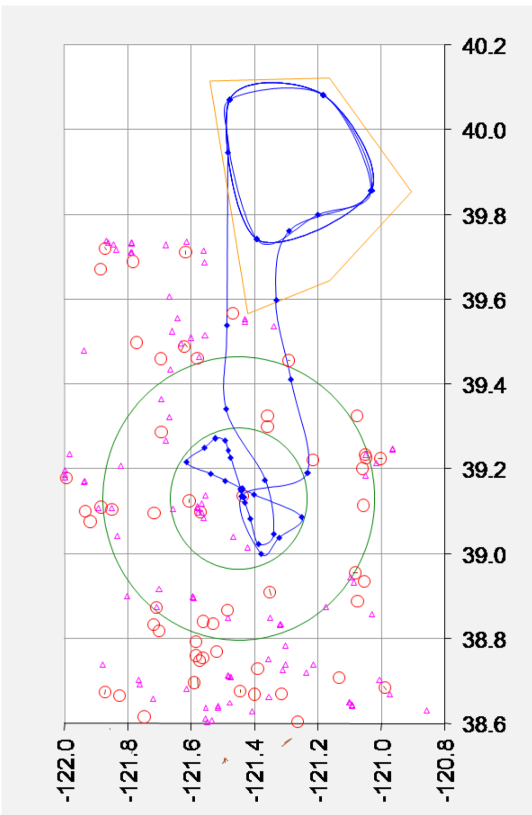


Figure 3: Horizontal Profile

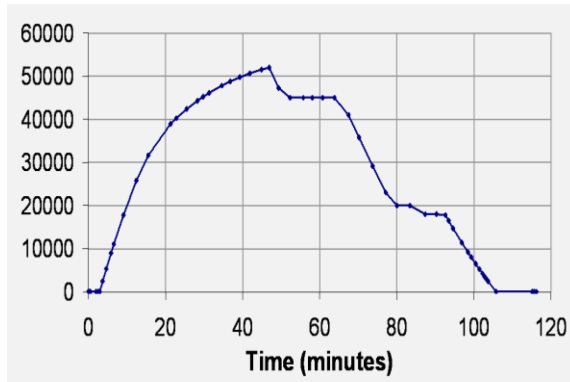


Figure 4: Vertical Profile

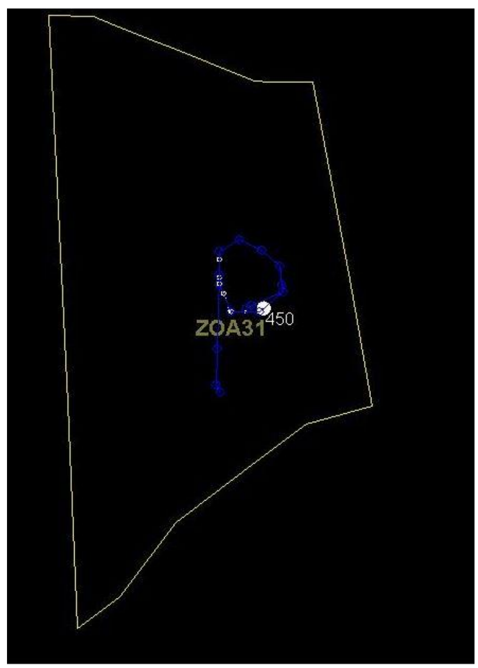
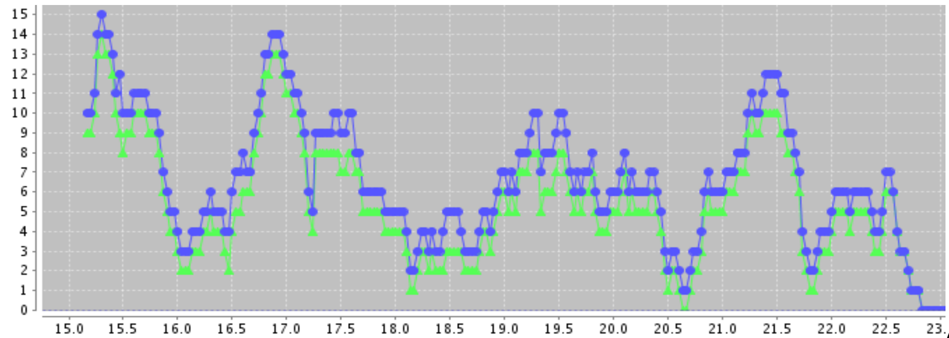


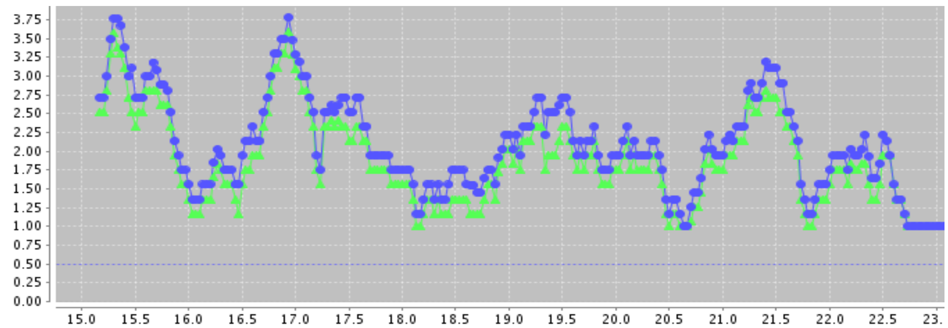
Figure 5: Sector ZOA31



Aircraft Count

Light: Without UAS
Dark: With UAS

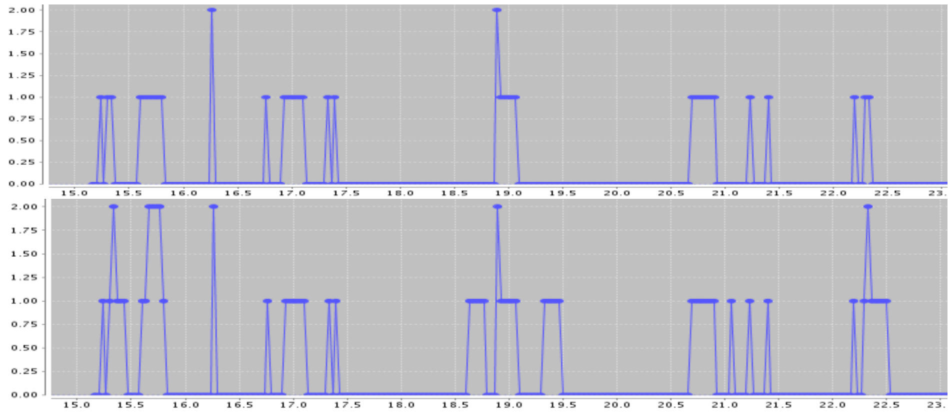
Aircraft Count



airspaceAnalyzer's Prediction of Controller's **WAK** on 1 to 7 scale

Light: Without UAS
Dark: With UAS

Predicted Workload Assessment Keypad (1=easiest; 7 = most complex)

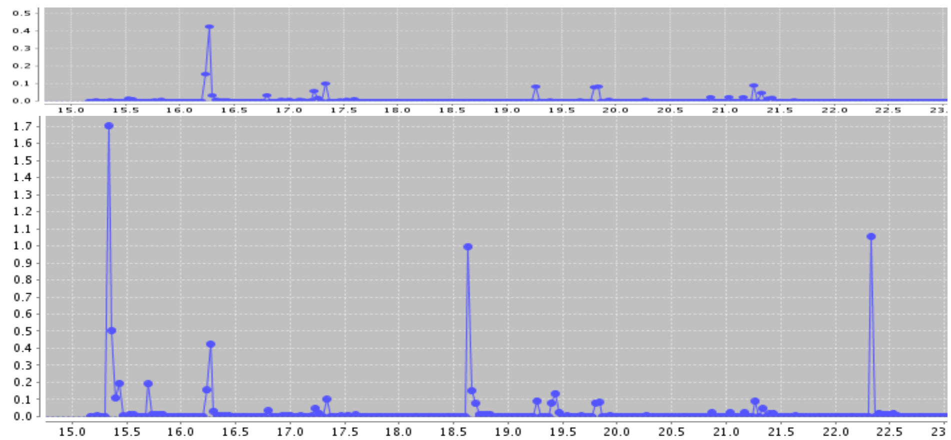


Count of **Maneuvers** in airspaceAnalyzer's Resolution

Top: Without UAS

Bottom: With UAS

Count of ATC Maneuvers Issued (0, 1 or 2)

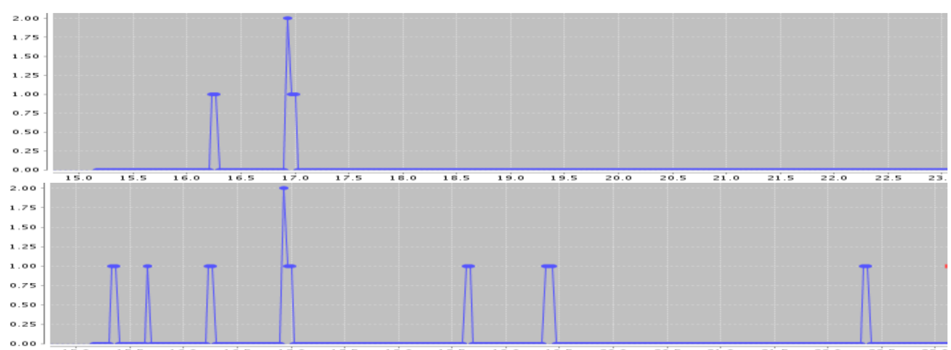


Extra Distance Flown, in nmi, due to airspaceAnalyzer's Resolution maneuvers

Top: Without UAS

Bottom: With UAS

Extra Cumulative Distance Flown (nmi)



Separation Effort

Top: Without UAS

Bottom: With UAS

Count of Separation Effort (0, 1 or 2)

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