# Commercial Air Surveillance for Sovereign Maritime Domain Awareness

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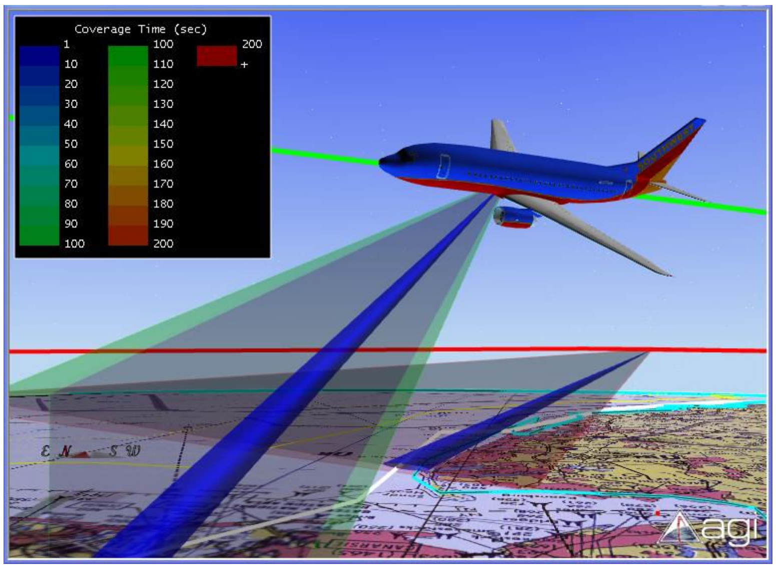


***Abstract***

This study examines the use of commercial aircraft outfitted with surveillance equipment to provide maritime domain awareness (MDA) in coastal waters surrounding the United States. Specifically it examines the *in situ* surveillance potential of U.S. sovereign coastal water by aircraft flying an easterly commercial route over a 24 hour period. The scope of the study is limited to a commercial route flown by a single carrier on a typical weekday schedule. The purpose of this study is to explore the concept of non-traditional surveillance assets as part of an indications and warning net that could cue U.S. Coast Guard, and other national assets to investigate or provide assistance. The additional sensor coverage would provide an alternative to the acquisition of dedicated broad area surveillance assets.

This work was conducted under an effort by the U.S. Coast Guard Research and Development Center (RDC) to examine the application of STK[1] for operations research (OR) studies in support of key Coast Guard mission areas. For this study, STK was chosen by RDC to examine alternatives to dedicated systems and trade-offs in force structure and force employment to achieve greater MDA. This work is solely conceptual OR to provide quantitative data and point out some non-quantitative issues which may require further examination by others. This paper compliments a stand-alone 3-D visualization file, available for viewing by contacting the analysts/authors.

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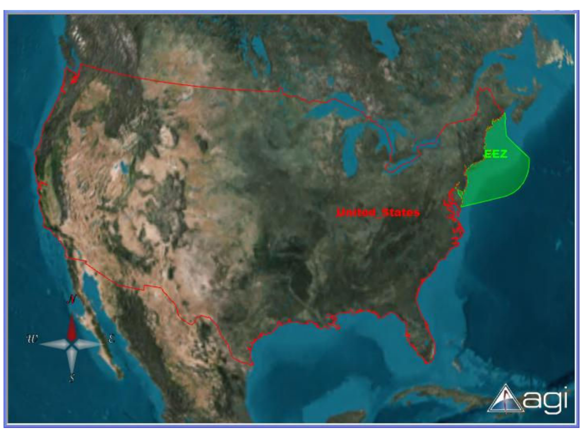
### *Background*

While international treaties prohibit the explicit use of commercial aircraft for military means[2], the use of commercial aircraft and vessels for non-military use such as weather reporting, sea-state monitoring, search and rescue, and increased visibility of commercial shipping may be permissible due to sovereign water and homeland security rights. Precedence for civil sovereign water surveillance may be found in activities related to the use of civil aircraft[3] and vessels[4] in 1942 for maritime surveillance in response to U-Boat attacks off the eastern coast of the United States and border surveillance. Some of these employments were prior to the declaration of war by the United States[5]. The requirement to augment defense patrols was more then a patriotic gesture by civilians, it was accepted and codified by the government due to the enormous size of the surveillance areas compared to the available assets and known threats. The non-military nature of sovereign water surveillance and the requirement to provide detailed shipping traffic data in coastal waters provides an opportunity for legal review of this concept. This paper provides some measurements of effectiveness and a framework for additional analysis however, it does not provide a legal argument to support employment of commercial aircraft in this role.

### *Analytical Method*

Commercial air routes and schedules provide a repetitive pattern suitable to OR methods to produce quantifiable measurements. To perform this research a computer model of aircraft and sensors was built in a 3-D land, air and sea commercial product (STK) designed to perform these types of OR. The routes modeled are flown by single airframes which fly at similar speeds and altitudes. The surveillance area (Figure 1) was bounded east-west by the coastline out to the Exclusive Economic Zone (EEZ, 200 nm), and north-south from Maine to Maryland (42º-38º north latitude). The lines in the right picture below are one degree latitude and longitude representing 60 by 60 nautical mile squares providing a total study area of 99,968 nm$^2$.



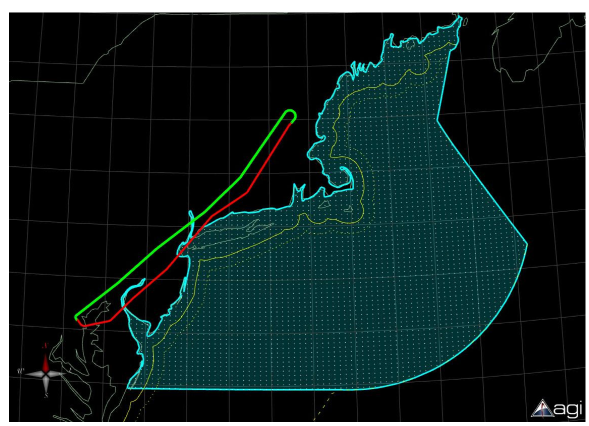


**Figure 1 – Northeast study area out to Exclusive Economic Zone (EEZ)**

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[2] *Convention on International Civil Aviation (Chicago Convention)* 7 December 1944, Ninth Edition, 2006 (Doc 7300/0), Article 4, http://www.icao.int/icaonet/dcs/7300.html

[3] *Establishing Civil Air Patrol*, Administrative Order 9, 1 December 1941, F. H. LaGuardia, U.S. Director of Civilian Defense

[4] Coastal Picket Force formed July 1942. "USCG Auxiliary enrolls large sailboats and motorcruisers and mans a number along with newly recruited yachtsmen for anti-submarine work along 50-fathom curve of Atlantic Coast," The Coast Guard Auxiliary: Past and Present, http://history.auxpa.org/

[5] *Joint Resolution Declaring That a State of War Exists Between The Government of Germany and the Government and the People of the United States and Making Provision To Prosecute The Same*, 11 December 1941

The flights modeled were selected for their proximity to the Atlantic seaboard, common domestic airframe and frequency. The modeled flights represent a typical weekday schedule for Southwest Airlines which flies Boeing 737 aircraft, 22 flights per weekday between Manchester, NH (KMHT) and Baltimore, MD (KBWI).

A notional sensor was modeled on the airframe similar to the Multi-Mission and Overland Surveillance Radar AN/APY-10, developed for the Navy P-8A Poseidon aircraft which is also a Boeing 737 airframe. The geometry of the sensor swath field of regard (FOR) and field of view (FOV) are shown below (Figure 2). The FOR was used to calculate the coverage for computational efficiency. Alternatively, the sweeping FOV could be used for coverage analysis. Results would vary depending on the speed of the sweep and aircraft. Since this sensor is notional, the FOR provided adequate analysis data. Also, the FOR in this study is gimbal mounted so that its geometry does not change as the aircraft banks and always points perpendicular to the flight path.

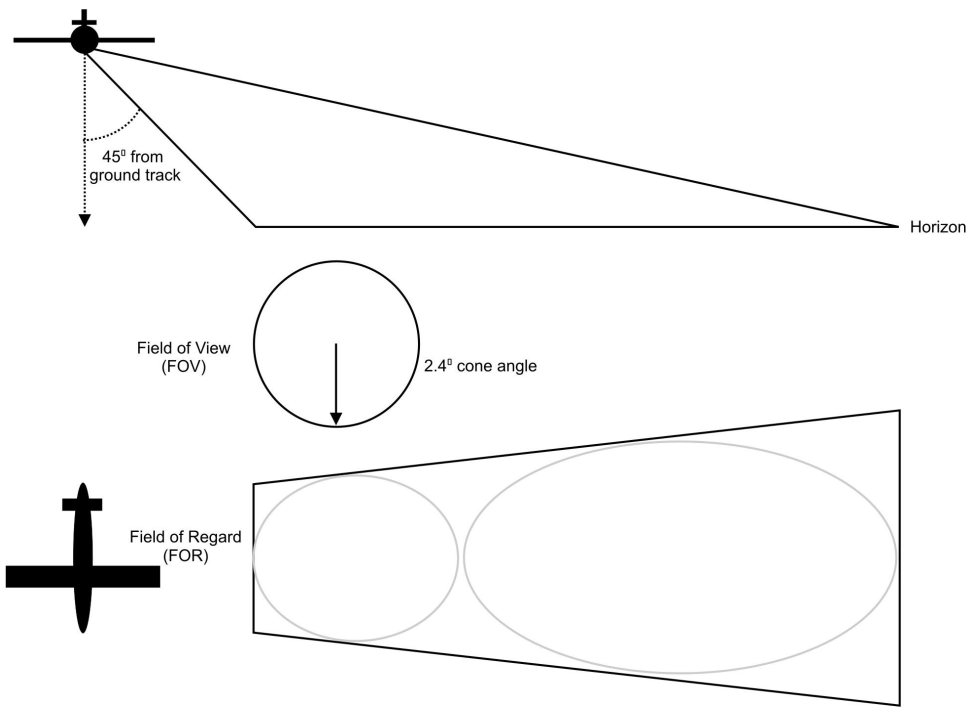



**Figure 2 –Aircraft sensor swath geometry**

The analysis simulation was set up with the following parameters:

| | | |
|---|---|---|
| Time Period | 24 hrs | 2 Jul 2007 00:00:00.000 to 3 Jul 2007 00:00:00.000 Local |
| Flight Duration | ~ 1 hr | Includes take off/ landing/ climb/ descent |
| Flight Altitude | 37,000 ft | Above Mean Sea Level (MSL) |
| Sensor Swath | Trapezoid | Approximates a 2.4 conical sweep beginning 45° from ground track to horizon |
| Number Flights | 22 | 11 northbound and 11 southbound |

Representative high altitude routes were modeled between KMHT and KBWI airports as seen below (Figure 3). Aircraft chart overlays and Digital Aeronautical Flight Information File (DAFIF) data were used to create airports and waypoints.

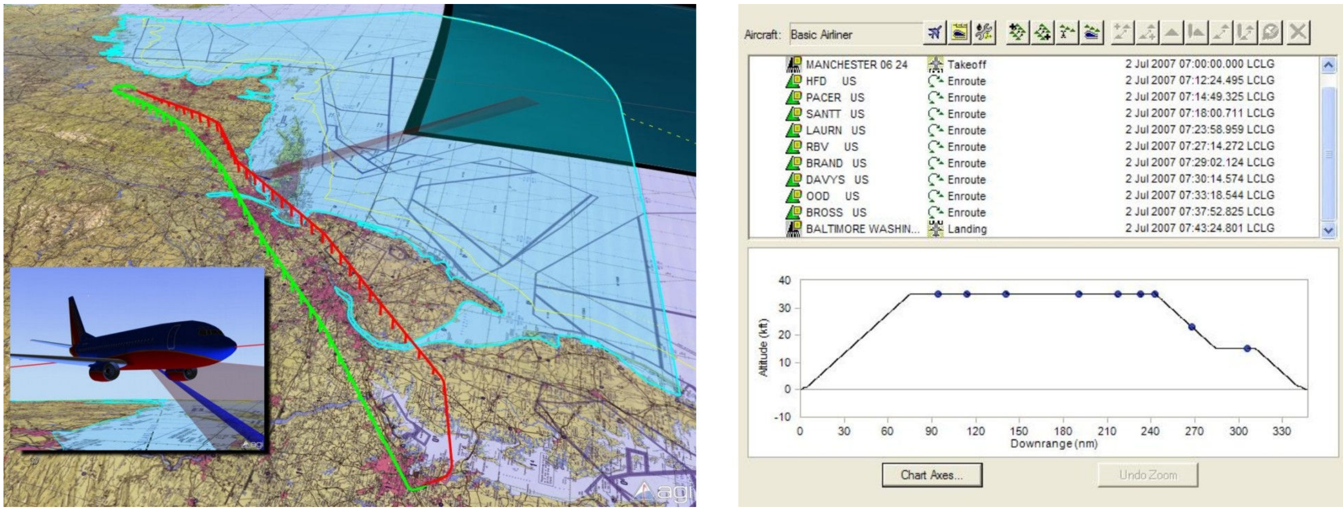



**Figure 3 - North and south high altitude air routes in vicinity of study**

The aircraft modeled was a notional Boeing 737-700 with the following performance profile (Figure 4).

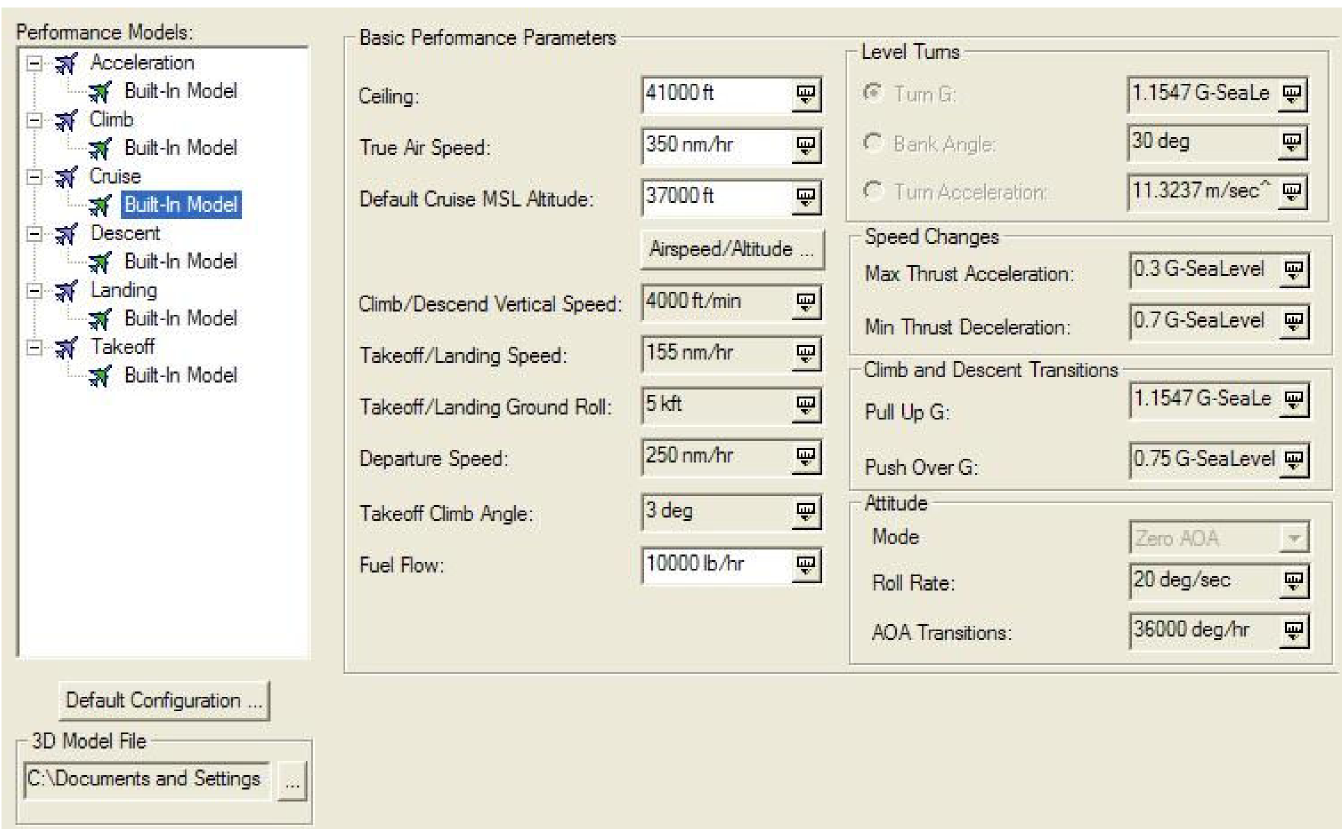



**Figure 4 - Aircraft performance model**

### *Coverage Analysis*

Coverage analysis was performed with STK. The coverage capability allows an area to be defined as a grid of points with a desired resolution (degrees). The higher the resolution, the more granular the analysis as the sensor intersects the area. For this analysis a 0.1 degree grid provided a satisfactory level of detail for the notional sensor. The image below (Figure 5) illustrates variable resolution settings used to determine resolution for this analysis.

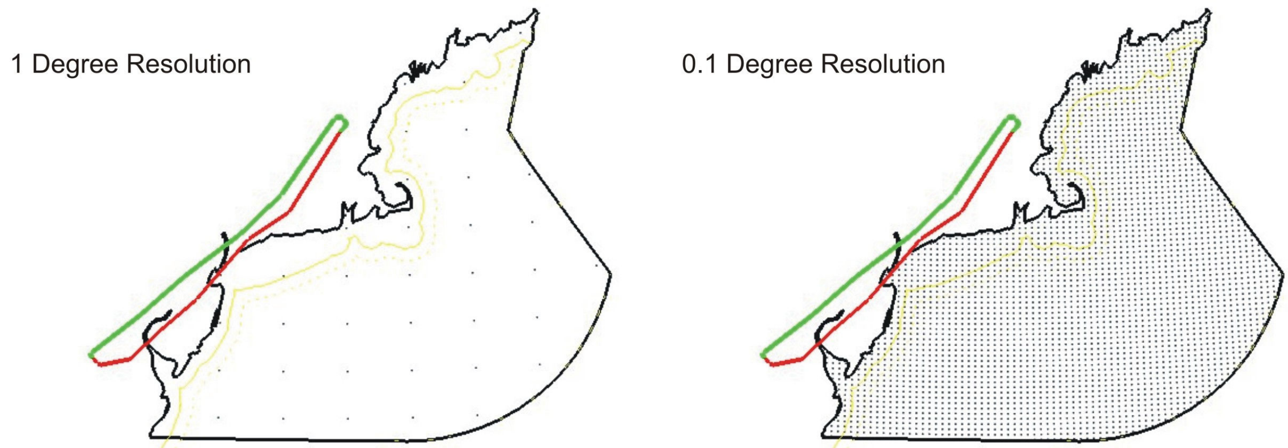



**Figure 5 – Coverage resolution**

To provide qualitative measure of coverage, the following Measurements of Effectiveness (MOE) were analyzed:

- **Simple Coverage.** Calculation of the area covered by the aircraft's sensor. A binary analysis returning a zero or a one.

- **Coverage Time.** The cumulative amount of time the sensors cover an area.

- **Revisit Time.** The amount of time before each point in the area is revisited by a sensor (duration of the gaps).

- **Duration.** Accumulation of sensor time over an area.

- **Gaps.** The number of periods when an object or area is not covered.

- **Access.** Specific sensor to object analysis (e.g., a ship).

These MOEs were set up in STK by creating figures of merit (FOM) on the coverage area and assigning the sensor assets for calculation. FOMs can provide static or dynamic (time dependent) analytical information. Constraints such as angle of attack, daylight, multiple asset coverage, angle off bore sight and other sensor performance criteria can be measured over an area. Additionally, user-defined satisfaction criteria can be set up (e.g., signal to noise levels for radar) so that a value is only returned when those specific criteria are met. This is helpful for determining probability of detection and other system specific values in trade studies.

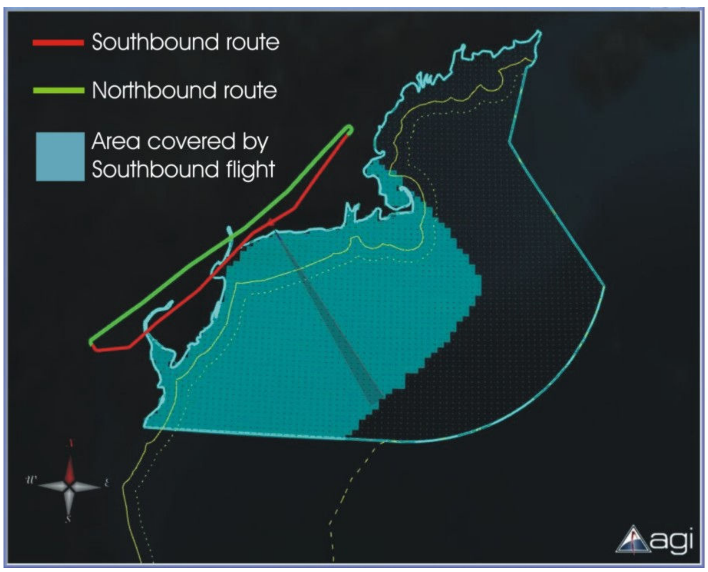
***Analysis Cases***

Three cases were examined. The first case of a single southbound aircraft was used to determine the portion of the study area that could possibly be covered constrained by these routes. Since the southbound aircraft fly a more easterly route, their sensor coverage represents the furthest east point this sensor could cover. Once this area was established, the remaining qualitative analyses were performed on this sub area. In this way we can examine the total area's potential for coverage from these routes and qualitatively measure the sub area. If we did not establish this sub area, the statistical information would include data on areas that can never be reached by the flight paths. The second case analyzed all the aircraft flown on a weekday schedule northbound and southbound. Finally, a ship was modeled to examine the surveillance persistence measured in the previous cases and to illustrate the concept.

***Single Flight Southbound***

To establish the portion of the study area that can be covered by aircraft flying these routes, a baseline single aircraft was modeled along the high altitude route from KMHT to KBWI. The sensor is fixed to the aircraft scanning out the port side of the aircraft in a single flight of approximately one hour.

> **Simple Coverage.** This analysis provided the size, percent and measurement of the extents of the surveillance capable from a single aircraft flying the southbound route. The resulting coverage analysis shows that 49,974 $nm^2$ (49.99%) of the study area is covered at least one time as the aircraft flies its route (Figure 6).




```
                                                      17 Jul 2007 12:02:40
FigureOfMerit-SimpleCov


                          Coverage Properties
--------------------------------------------------------------------------
Custom Regions Coverage
Grid Altitude: 0.0000 (ft)
Resolution: 0.1000 (deg)
Number of Points: 3153
Assets required for a valid access: At Least 1
Assigned Assets:
    Aircraft/Southbound1/Sensor/FOV_Southbound:    Active
Access Interval: 2 Jul 2007 00:00:00.000 to 3 Jul 2007 00:00:00.000
Regional Acceleration: Off
Light time delay: Ignored
Maximum Sampling Time Step: 360.000 secs
Minimum Sampling Time Step: 0.010 secs
Time Convergence: 5.000e-003 secs
Value Convergence: Relative 1.000e-008 - Absolute 1.000e-014


              FOM Properties
----------------------------------------
Simple Coverage FOM
Satisfaction is not enabled
FOM value range check is not enabled.


% Satisfied    Area Satisfied (nm^2)
-----------    ---------------------
      49.99                 49974.57
```

**Figure 6 - Simple coverage, single aircraft southbound**

The simple coverage analysis resulted in the creation of a sub area (Coverage Area) within the study area. This sub area represents the surveillance potential for aircraft flying this route. For the purpose of this study, there is no variance in theses routes. Variation and actual track data could be used to provide additional fidelity on the coverage[6]. The sub area was created to closely approximate the region covered in the simple coverage analysis. To ensure 100% coverage of this sub area as a baseline, the borders were drawn slightly within 0.1 degree covered grids resulting in an area of 46,737.66 $nm^2$ (Figure 7). A single southbound flight was analyzed to confirm this area to be 100% covered by southbound flights; defining the extents of the surveillance area.

[6]The use of track data from commercial flights for analysis was investigated and determined feasible, but beyond the scope of this study. Data sources and methods were identified such that this model could be extended to support such analysis and is discussed in the section regarding future work.

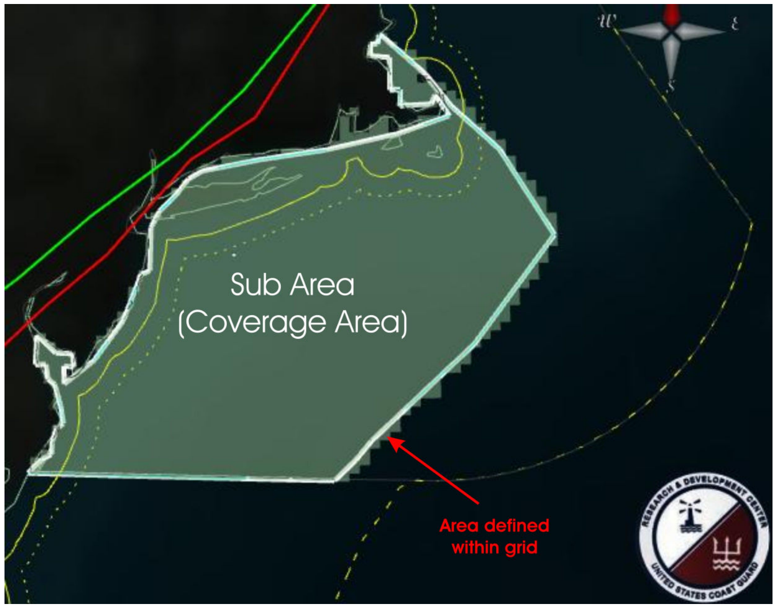
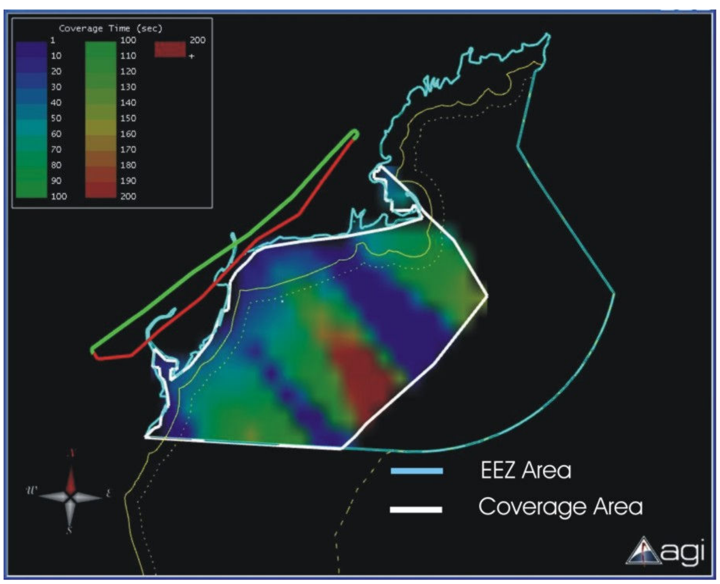



**Figure 7 - Sub area creation within covered area**

**Coverage Time.** This analysis shows us how much time the sensor is on any point in the coverage area (dwell time) over a 24 hour period. The varying time each point is covered is due to the sensor being fixed to the aircraft's airframe with the swath perpendicular to the flight path. The turns in the route cause the sensor to overlap areas. An image of the analysis is provided below (Figure 8). The legend displays coverage time from one to 200+ seconds.




```
                                                   17 Jul 2007 16:46:43
FigureOfMerit-CovTime

                        Coverage Properties
-------------------------------------------------------------------
Custom Regions Coverage
Grid Altitude: 0.0000 (ft)
Resolution: 0.1000 (deg)
Number of Points: 1519
Assets required for a valid access: At Least 1
Assigned Assets:
    Aircraft/Southbound1/Sensor/FOV_Southbound:    Active
Access Interval: 2 Jul 2007 00:00:00.000 to 3 Jul 2007 00:00:00.000
Regional Acceleration: Off
Light time delay: Ignored
Maximum Sampling Time Step: 360.000 secs
Minimum Sampling Time Step: 0.010 secs
Time Convergence: 1.000e-004 secs
Value Convergence: Relative 1.000e-008 - Absolute 1.000e-014


             FOM Properties
-------------------------------------
Time Covered Per Day
Satisfaction: At Least 1.000000 sec
FOM value range check is not enabled.


Minimum (sec)    Maximum (sec)    Average (sec)
-------------    -------------    -------------
        2.160          300.594           70.341
```

**Figure 8 - Coverage time, single aircraft southbound**

This Coverage Time MOE data tells us that during a 24 hour period the sensor of a single aircraft covers the sub area for a minimum of two seconds per day with some areas having a dwell time of 300 seconds per day.

The single southbound flight analysis provided baseline data for an analysis of all flights in a single day. Going into the following analyses, we know from the simple coverage analysis that this particular commercial route will provide about 50% coverage for a period of time over the entire study area. A single aircraft on this route provides at least two seconds of sensor dwell on about 50% percent of the study area per day. Despite this being a very small amount of time in a 24 hour period, it is not without operational value given the slow transit of most shipping and the high speed of the aircraft. For example, a ship moving parallel to the coast at 12.5 kts made good, would still be in this area (approximately 300 nm coastal route) when the same flight occurs on this southbound leg the next day.

### *All Flights Southbound/Northbound Over 24 Hours (Weekday)*

Once the coverage area was established in the above baseline case all flights over a 24 hour period for a weekday (Monday, 16 July) schedule were set up in the model between KMHT and KBWI (Figure 9).

**Southwest Airlines Schedule for Manchester to Baltimore**

| Flights | Departs | Arrives | Stops | Travel Time (hh:mm) | Frequency Mon Jul 16 | Tue Jul 17 | Wed Jul 18 | Thu Jul 19 | Fri Jul 20 | Sat Jul 21 | Sun Jul 22 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 387 | 6:50am | 8:15am | N/S | 1:25 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | |
| 1085 | 7:20am | 8:45am | N/S | 1:25 | | | | | | ✓ | |
| 71 | 7:35am | 9:00am | N/S | 1:25 | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ |
| 2581 | 8:05am | 9:30am | N/S | 1:25 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 1259 | 9:00am | 10:25am | N/S | 1:25 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 489 | 10:15am | 11:40am | N/S | 1:25 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 1540 | 12:00pm | 1:25pm | N/S | 1:25 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 503 | 3:10pm | 4:40pm | N/S | 1:30 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 2138 | 4:20pm | 5:45pm | N/S | 1:25 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 1902 | 6:15pm | 7:45pm | N/S | 1:30 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 237 | 7:45pm | 9:10pm | N/S | 1:25 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 613 | 9:10pm | 10:35pm | N/S | 1:25 | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ |

✓ - Scheduled Flight

**Southwest Airlines Schedule for Baltimore to Manchester**

| Flights | Departs | Arrives | Stops | Travel Time (hh:mm) | Frequency Mon Jul 16 | Tue Jul 17 | Wed Jul 18 | Thu Jul 19 | Fri Jul 20 | Sat Jul 21 | Sun Jul 22 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 382 | 7:20am | 8:35am | N/S | 1:15 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | |
| 1661 | 8:20am | 9:35am | N/S | 1:15 | | | | | | ✓ | |
| 1319 | 8:25am | 9:40am | N/S | 1:15 | ✓ | ✓ | ✓ | ✓ | ✓ | | |
| 972 | 8:30am | 9:45am | N/S | 1:15 | | | | | | | ✓ |
| 154 | 10:20am | 11:35am | N/S | 1:15 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 1744 | 12:00pm | 1:15pm | N/S | 1:15 | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ |
| 120 | 12:10pm | 1:25pm | N/S | 1:15 | | | | | | ✓ | |
| 615 | 1:45pm | 3:00pm | N/S | 1:15 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 1155 | 4:25pm | 5:45pm | N/S | 1:20 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 746 | 6:00pm | 7:20pm | N/S | 1:20 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 96 | 6:50pm | 8:10pm | N/S | 1:20 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | |
| 877 | 6:50pm | 8:10pm | N/S | 1:20 | | | | | | | ✓ |
| 2847 | 7:30pm | 8:45pm | N/S | 1:15 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 388 | 8:10pm | 9:25pm | N/S | 1:15 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 2293 | 9:45pm | 11:00pm | N/S | 1:15 | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ |

✓ - Scheduled Flight

**Figure 9 - Modeled airline schedule for weekday[7]**

[7] Copyright © 2007 Southwest Airlines Co. All Rights Reserved, www.southwest.com

**Coverage Time.** The analysis of the 22 flights shows an average coverage time, with a minimum satisfaction level of one second, to be 1,601 seconds (~27 minutes) per day. The minimum time was 24 seconds and the maximum time was 4,736 seconds (~80 minutes) in the 24 hour period (Figure 10).

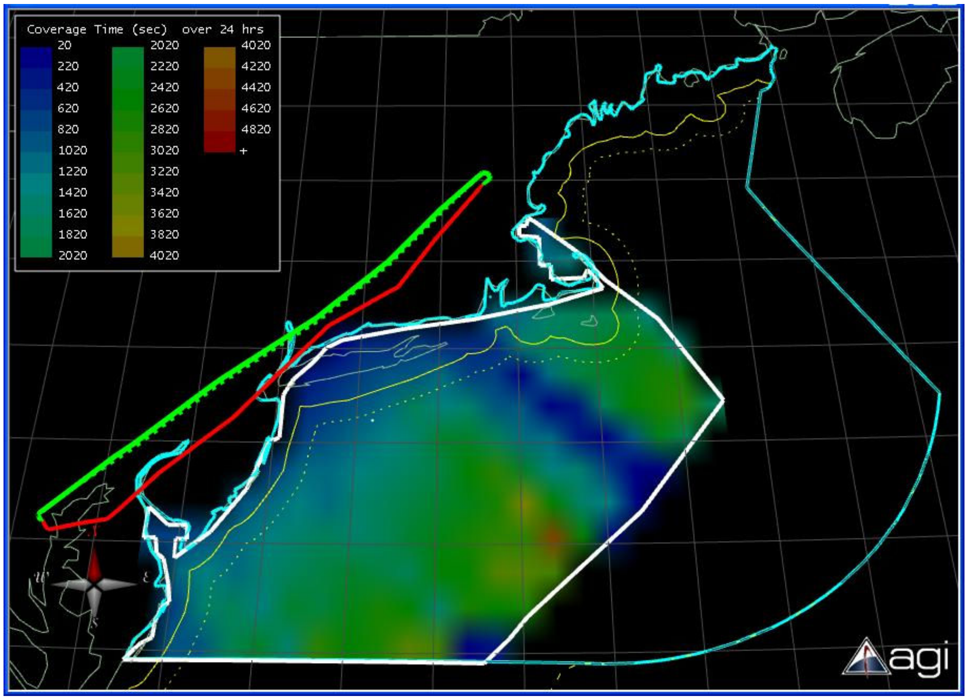



**Figure 10 – Twenty-four hour coverage for a commercial weekday schedule**

**Revisit Time**. Three MOE revisit time calculations were performed to show statistics on the gaps within the surveillance area. Minimum and maximum gap statistics were analyzed over a 24 hour period and an average gap was calculated over the active flight hours.

***Maximum Revisit Time.*** The report below (Figure 11) provides data on the maximum revisit time analysis in the coverage area over a 24 hour period. The data shows a maximum gap of 7.72 hours (27795 seconds). This is due to the commercial schedules gaps during where no flights occur between 2247 and 0650 EST. The "Minimum number of assets required: 1" means that only one sensor is required to constitute a valid period of coverage[8].

[8] The number of assets specifies the minimal number of simultaneous assets required for coverage. A value of greater then one may be used in the analysis of multiple sensor coverage requirements such as stereo imagery or triangulation.

```
                 FOM Properties
------------------------------------------------
Maximum Revisit Time
Minimum number of assets required: 1
Gaps at ends of analysis interval are considered
Satisfaction is not enabled
FOM value range check is not enabled.


Minimum (sec)    Maximum (sec)    Average (sec)
-------------    -------------    -------------
    24743.474        27795.014        26142.238
```

**Figure 11 - Maximum gap time over 24 hours**

***Minimum Revisit Time.*** By comparison, an analysis of the minimum revisit time across the area in a 24 hour period produced the data below (Figure 12). These data show statistics for the minimum time each point waits for another sensor access. A minimum revisit time was calculated for each point and then statistical data produced showing an average of 4.26 minutes (256 seconds).

```
                 FOM Properties
------------------------------------------------
Minimum Revisit Time
Minimum number of assets required: 1
Gaps at ends of analysis interval are considered
Satisfaction is not enabled
FOM value range check is not enabled.


Minimum (sec)    Maximum (sec)    Average (sec)
-------------    -------------    -------------
        0.020         1797.824          256.231
```

**Figure 12 -Minimum gap time over 24 hours**

***Average Revisit Time during Flight Hours.*** Lastly, the time period for revisit analysis was adjusted to reflect the period of time from first take off to the last scheduled landing (0700-2300 EST) and then an average gap time calculated. This period of time represents the commencement and termination of daily *in situ* surveillance by this carrier, on this route. For this MOE, the average gap time was calculated as the average of the durations of the gaps in the coverage during this 16 hour period. The results are shown below (Figure 13), with an average gap time of 2,307 seconds (38.45 minutes).

```
Access Interval: 2 Jul 2007 07:00:00.000 to 2 Jul 2007 23:00:00.000
Regional Acceleration: Off
Light time delay: Ignored
Maximum Sampling Time Step: 360.000 secs
Minimum Sampling Time Step: 0.010 secs
Time Convergence: 1.000e-004 secs
Value Convergence: Relative 1.000e-008 - Absolute 1.000e-014


                 FOM Properties
------------------------------------------------
Average Revisit Time
Minimum number of assets required: 1
Gaps at ends of analysis interval are considered
Satisfaction is not enabled
FOM value range check is not enabled.


Minimum (sec)    Maximum (sec)    Average (sec)
-------------    -------------    -------------
     1174.758         5157.235         2307.588
```

**Figure 13 - Average gap time during flight hours**

These three revisit MOEs provide a basis for gap filling by other means and also reveal a potential shortcoming to all commercial passenger air *in situ* MDA surveillance based on restrictions for evening flights and/or the lessened demand time periods (7.72 hour gap). Fortunately, this is cyclical and necessary gap filling surveillance operations could be conceived. Other MDA suitable airline schedules will likely reveal different gaps, but domestic schedules are fairly comparable so surveillance gaps may be a similar along the coasts, as opposed to longer cross country flights (e.g., overnight).

### *Ship Transit through Coverage Area*

To illustrate surveillance persistence in the coverage area, a ship was modeled heading from north to south along the coast at about 9 kts. The aircraft sensors were analyzed for the periods of time when the ship was in the sensor sweep over the 24 hour period. There were 29 separate periods of time when the ship was in the sensors swaths (Table 1). These periods of time are referred to in this paper as "*access*" periods; when the sensor has visibility to the ship (Figure 14).

| Start Time (LCLG) | Stop Time (LCLG) | Duration (sec) |
|---|---|---|
| 2 Jul 2007 07:06:57.396 | 2 Jul 2007 07:08:24.340 | 86.94464769 |
| 2 Jul 2007 07:53:15.322 | 2 Jul 2007 07:54:37.346 | 82.02465233 |
| 2 Jul 2007 07:56:18.149 | 2 Jul 2007 07:57:47.265 | 89.11660118 |
| 2 Jul 2007 08:24:03.790 | 2 Jul 2007 08:25:24.009 | 80.21924336 |
| 2 Jul 2007 08:29:56.186 | 2 Jul 2007 08:30:40.519 | 44.33245546 |
| 2 Jul 2007 08:59:39.226 | 2 Jul 2007 09:01:05.737 | 86.51159906 |
| 2 Jul 2007 09:20:27.935 | 2 Jul 2007 09:21:50.547 | 82.61160956 |
| 2 Jul 2007 09:24:53.741 | 2 Jul 2007 09:24:56.091 | 2.35008874 |
| 2 Jul 2007 09:25:43.180 | 2 Jul 2007 09:27:07.015 | 83.83506490 |
| 2 Jul 2007 10:37:29.071 | 2 Jul 2007 10:38:52.221 | 83.15013001 |
| 2 Jul 2007 10:39:50.330 | 2 Jul 2007 10:39:52.681 | 2.35105034 |
| 2 Jul 2007 10:42:42.976 | 2 Jul 2007 10:44:04.958 | 81.98221938 |
| 2 Jul 2007 10:54:08.559 | 2 Jul 2007 10:54:10.783 | 2.22401338 |
| 2 Jul 2007 12:30:30.675 | 2 Jul 2007 12:31:50.063 | 79.38822186 |
| 2 Jul 2007 12:31:32.994 | 2 Jul 2007 12:33:00.015 | 87.02121027 |
| 2 Jul 2007 14:13:51.419 | 2 Jul 2007 14:15:16.756 | 85.33733212 |
| 2 Jul 2007 15:45:35.323 | 2 Jul 2007 15:46:50.009 | 74.68611618 |
| 2 Jul 2007 16:49:45.074 | 2 Jul 2007 16:51:10.568 | 85.49426952 |
| 2 Jul 2007 16:57:27.082 | 2 Jul 2007 16:58:04.519 | 37.43705547 |

| | | |
|---|---|---|
| 2 Jul 2007 18:20:55.718 | 2 Jul 2007 18:22:21.003 | 85.28439710 |
| 2 Jul 2007 18:22:36.937 | 2 Jul 2007 18:23:44.253 | 67.31614777 |
| 2 Jul 2007 18:53:08.016 | 2 Jul 2007 18:54:11.255 | 63.23878144 |
| 2 Jul 2007 19:09:39.292 | 2 Jul 2007 19:11:04.063 | 84.77137833 |
| 2 Jul 2007 19:48:38.033 | 2 Jul 2007 19:50:02.653 | 84.61996422 |
| 2 Jul 2007 20:25:25.910 | 2 Jul 2007 20:26:36.738 | 70.82843372 |
| 2 Jul 2007 20:27:36.778 | 2 Jul 2007 20:29:01.104 | 84.32610889 |
| 2 Jul 2007 21:52:52.188 | 2 Jul 2007 21:53:53.925 | 61.73747990 |
| 2 Jul 2007 22:00:11.964 | 2 Jul 2007 22:00:48.184 | 36.21914451 |
| 2 Jul 2007 22:00:49.218 | 2 Jul 2007 22:01:34.916 | 45.69859602 |

**Table 1 – Access periods from all aircraft to ship**

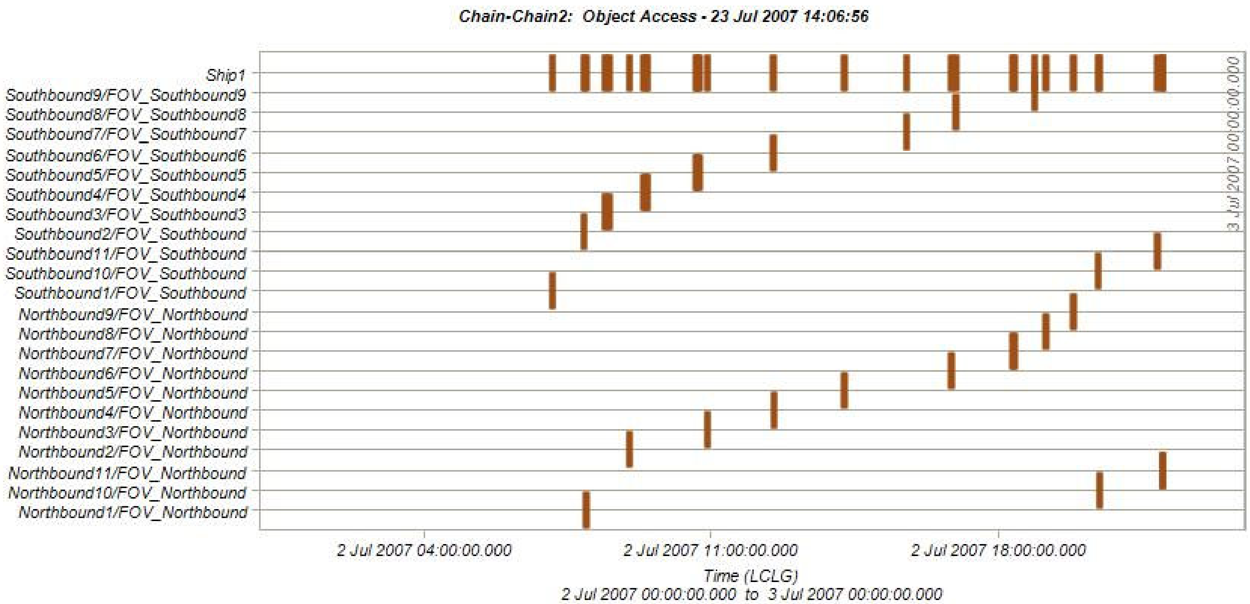



**Figure 14 –Times the sensors have access to the ship in 24 hours**

During certain legs of the aircraft routes, the sensor has more than one access to the ship since it is perpendicular to the flight path. For example, aircraft *Southbound3* has two access periods as its sensor sweeps over the ship, then turns and sweeps over the ship again (Figure 15).

```
                                                               23 Jul 2007 14:13:07
Aircraft-Southbound3-Sensor-FOV_Southbound3-To-Ship-Ship1:  Access Summary Report


FOV_Southbound3-To-Ship1
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                  Access       Start Time (LCLG)          Stop Time (LCLG)       Duration (sec)
                  ------    -----------------------    -----------------------    --------------
                       1    2 Jul 2007 08:24:03.790    2 Jul 2007 08:25:24.009            80.218
                       2    2 Jul 2007 08:29:56.186    2 Jul 2007 08:30:40.520            44.334

Global Statistics
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Min Duration           2    2 Jul 2007 08:29:56.186    2 Jul 2007 08:30:40.520            44.334
Max Duration           1    2 Jul 2007 08:24:03.790    2 Jul 2007 08:25:24.009            80.218
Mean Duration                                                                             62.276
Total Duration                                                                           124.553
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**Figure 15 - Multiple access times to ship from single aircraft**

### *Operational Concept*

Unlike dedicated assets, this surveillance concept would not impact the operation of the commercial aircraft in flight or schedule. The aircraft would not be under any operational control of the Coast Guard, likely not even in communication. This *in-situ* asset provides value inherent to its commercial operational environment. These data gathered during flights could feed into an indications and warning (I & W) net monitored by the Coast Guard to cue their, and other national assets to investigate. This is similar to Anti-Submarine Warfare (ASW) where limited search and weapon assets are cued by less consumable, persistent towed acoustic arrays. A progressive MDA surveillance system that begins with broad, low fidelity coverage and then ramps toward discrete sensor tasking, maximizes the utility of limited resources, increases cost effectiveness of operations and provides for vast area coverage.

### *Conclusions*

*In situ* commercial aircraft flying coastal routes with surveillance equipment could provide substantial sovereign maritime domain awareness. The geometry and schedule frequency of the route chosen, with a single commercial carrier, provided relatively small gaps in a 24 hour period; about one third of the day. Upon commencement of the daily schedule in the morning, to the last flight in the evening, sensor coverage provides an average gap of 38 minutes over the surveillance area.

The predictability of commercial aircraft positions makes them ideal for measurable surveillance activities allowing for other dedicated Coast Guard resources to be applied to the MDA surveillance mission judiciously.

This model assumed all aircraft fitted with sensors. The level of coverage on this particular route, with a single carrier was significant enough that a small percentage of the fleet so equipped would likely provide adequate coverage, providing a more cost effective approach.

High altitude commercial routes along the coast are ideal for attaching a sensor, camera or Automated-Identification System (AIS) receiver to any aircraft given their horizon in the 30 kft altitude range. Broad area maritime surveillance for the purpose of increasing situational awareness of afloat activities in U.S. sovereign waters is a routine, perpetual, low intensity activity over an enormous area with the potential to consume resources beyond a measurable benefit. *In situ* commercial aircraft provide an alternative, quantifiable, predicable surveillance potential that should be considered as part of an overall indications and warning net.

STK proved to be an invaluable operations research tool, requiring no modification to perform these analytical tasks. STK's coverage analytics, along with the land/sea/air/space sensor and communications modeling, allowed for MOE reports, graphs and 3-D visualization in a physically accurate environment. The conduct of further studies, at a more detailed level to include radar modeling, probability of detection, over the horizon communications, platform trade studies, sun obscuration, cloud coverage and other factors, are existing capabilities of the technology that could benefit RDC across mission areas.

### *Future Work*

Additional OA with empirical track data over a week or month on additional routes would reveal more data on the coverage measurements of effectiveness. Variability in route, altitude and cross track position would provide greater variety in the surveillance characteristics of these *in situ* aircraft. Additionally, different sensor models, sea-state and other weather phenomena will add additional fidelity to the baseline analysis performed.

Other air routes, some spending more time over open water, could be modeled with other sensors (e.g., IR, camera) and sweep patterns to further quantify the MOEs. Cargo routes should also be examined for differences in schedule and possible benefits of their non-passenger status. The data produced in this analysis is also suitable for extended geospatial analysis, where Coast Guard stations, meteorological data, shipping routes and historical track data can be analyzed for optimal routes and placement of additional maritime surveillance assets. Additionally, this model, with track data and/or additional routes could be run with AIS antennas modeled on the commercial aircraft for analysis of over the horizon commercial ship tracking capabilities which would inevitably lead to more interesting and relevant data for increased maritime domain awareness.

Finally, this OA model is extensible to include other land, sea, air and space assets by nature of the tools employed (e.g., satellite catalog, aircraft, ships, facilities and land vehicles). A complete model of the MDA areas in this environment facilitates ad hoc trade studies, communication and sensor research in an overall accurate physical model. This model could be used to perform scientific analysis of a networked indications and warning cueing system spanning land, sea and space assets across civil and government resources. This would help identify platform requirements and operational concepts for MDA with satellites, dirigibles, unmanned aerial vehicles and patrol craft.