Unmanned Aircraft Systems (UAS)

Broad Agency Announcement (BAA)

Call# 005

Final Report

Project Title:
Hybrid Onboard and Ground-Based Sensor Integration of ACAS Xr DAA

Company Name:
Sagetech Avionics

Contract Period of Performance:
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I. Executive Summary

The ‘Hybrid Onboard and Ground-Based Sensor Integration of ACAS X DAA’ project was performed to evaluate performance of the Sagetech prototype ACAS Xr system using onboard and ground-based radar sensors individually and in a hybrid configuration. Two ground-based radar systems (DeTect and Vantis) and one onboard radar (EchoFlight) were evaluated through the performance of three flight test events and subsequent data analysis for each. Each of the sensors were successfully integrated and provided useful intruder track data to the ACAS Xr system. A Flight Test Report for each flight test event provides details of the testing and the ACAS Xr performance. Observations, issues, and anomalies are described in the test reports. An important objective of the project was to communicate the test results and associated recommendations to RTCA Special Committees SC-147 and SC-228. This has been accomplished through Project Kickoff, Midpoint and Final (pending) briefings at scheduled committee meetings. This report provides a description of equipment integration, performance evaluation, and recommendations.

II. Introduction

Uncrewed ACAS Xr equipment class requires the ability to receive non-cooperative surveillance data from at least one source (onboard or offboard). Examples of non-cooperative surveillance sources include onboard Air-to-Air Radar, Ground-Based Radar, and Electro-Optical/Infrared sensors. This project included integration and evaluation of the ACAS Xr system with various non-cooperative sensors including two ground-based radars (DeTect and Vantis) and an onboard radar (EchoFlight).

The key objectives per the project Statement of Work were to

1) Integrate ground-based radar surveillance data via UAS C2 uplink (or separate dedicated link if needed as a backup, if UAS C2 is deemed technically insufficient) for receipt by the

on-board ACAS X surveillance tracking (sensor fusion) module.

2) Integrate on-board ADS-B IN, on-board radar, and ground-based radar data into ACAS X surveillance tracking (sensor fusion) module.

3) Ensure that potential translation errors between the different sensing modality reference frames are correctly managed and that vertical and lateral track accuracies are accounted for.

4) Integrate independent means of continuous validation and health monitoring of the non-cooperative tracks through cross-sensor checks.

5) Update Ground Control Station (GCS) displays to accurately show integrated traffic data that prevents mode confusion and mode jitter between airborne, ground-based, and hybrid integrated air pictures.

6) Update well clear separation criteria as necessary to account for latencies and tracking error within the overall integrated system.

7) Highlight key findings and provide recommended performance, design requirements and lessons learned validated by the results of the flight test campaign, to RTCA Special Committees SC-147 and SC-228.

    - Recommendations should include requirements for track integration, air picture usability attributes such as filtering of excessive false tracks, and pilot interface requirements related to the integrated air picture.

This report provides a description of the project methodology, a summary of the testing and evaluation, and important findings and recommendations.

III. Methodology

The project consisted of three flight test events with ACAS Xr equipment installed and tested on three different aircraft.

For the first and second flight test events two test aircraft, a ScanEagle UAS and a Skyfish M6 drone were equipped with the ACAS Xr prototype system and flown in various planned encounter scenarios against a crewed intruder aircraft. The primary purpose of these test events was to evaluate surveillance using radar track data provided by the DeTect ground-based radar located near Gorman Airfield near Grand Forks, North Dakota.

The third flight test event utilized an AiRangerX as the test aircraft. The AiRangerX was equipped with the ACAS Xr prototype system and two EchoFlight Radar panels mounted on the front of the aircraft to provide approximately +/- 120 degree detection in the forward direction of the aircraft. The primary purpose of the 3rd test event was to evaluate ACAS Xr surveillance as provided by the onboard EchoFlight radar and a ground-based Vantis system that includes radar tracks from a Thales (Terma) radar. The testing was performed near Williston, North Dakota where the Vantis system including the Thales Terma radar is located.

ACAS Xr provides surveillance capability that uses cooperative surveillance data (Active Mode S and Mode C, ADS-B), and non-cooperative Onboard Relative Non-Cooperative Track (ORNCT) data, from the EchoFlight radar and Absolute Geodetic Track (AGT) data,from the ground-based DeTect or Vantis radar. These data sources were utilized during the testing in various combinations to evaluate surveillance performance, accuracy, latency, and source correlation of the various surveillance sources (Cooperative (ASD-B/Mode S/Mode C), AGT and ORNCT) of the ACAS Xr system. Encounters were performed with all three sources enabled simultaneously and with every combination of a single or dual source (i.e. cooperative only, AGT only, ORNCT only, Cooperative with AGT, Cooperative with ORNCT, AGT with ORNCT).

Detailed descriptions of the test cards and planned encounters for all three test events are provided in the Flight Test Plan.

During the test events, real time observations were made, and data was collected for post flight analysis. The recorded data files and parameters are described fully in the Data Analysis Plan. Detailed test results are provided in a flight test report for each of the flight test events.

IV. Results and Discussion

The project consisted of three major activities including 1) system integration, 2) flight testing, and 3) data analysis and reporting. Key aspects of each of these activities are provided in this section.

A. Integration

Integration was accomplished for three separate aircraft. The ACAS Xr Prototype was installed on all three aircraft. The low SWAP (Size, Weight, and Power) system components (MXR and ACAS Xr computer) were physically mounted on each aircraft. The low SWAP characteristics greatly simplified the installations with no payload or power issues. The installation of an omni-directional antenna was also easily accommodated on each of the platforms. Own aircraft information was provided from existing aircraft systems or from a Garmin GPS puck through the ACAS Xr serial interface. There was an issue using the onboard GPS data discovered during installation checkout on the ScanEagle. The onboard GPS source used for the critical flight systems was compromised when also connected to the ACAS Xr system. In order to avoid risk of GPS failure a Garmin GPS puck was installed and used to provide the data to the ACAS Xr system.

Integration of the non-cooperative sensors to the Sagetech ACAS Xr prototype was a challenging aspect of the project. Each of the sensors were unique and required customization of data for it to be recognized and tracked by the ACAS Xr system as discussed below in subsections 1, 2, and 3.

The physical interface used for communication between the ground-based sensors and the airborne ACAS Xr system was accomplished with an Elsight Halo LTE communication system for the ScanEagle and SkyFish and through the StarLink LTE communication system for the AiRangerX. This was also the datalink for communication between ACAS Xr and the Mission Control GUI for uplink of control signals to the ACAS Xr and downlink of ACAS Xr traffic, guidance and advisory data for display. The systems provided ample bandwidth and adequate transmission speed. The installation and integration were straightforward, and the connection was reliable.

The onboard EchoFlight Radar was interfaced directly to the ACAS Xr through ethernet connection. The following figures illustrate the system interfaces as installed on each of the test aircraft. Figure 1 for the ScanEagle and SkyFish installations and Figure 2 for the AiRangerX installation which includes the additional interface to the onboard radar.

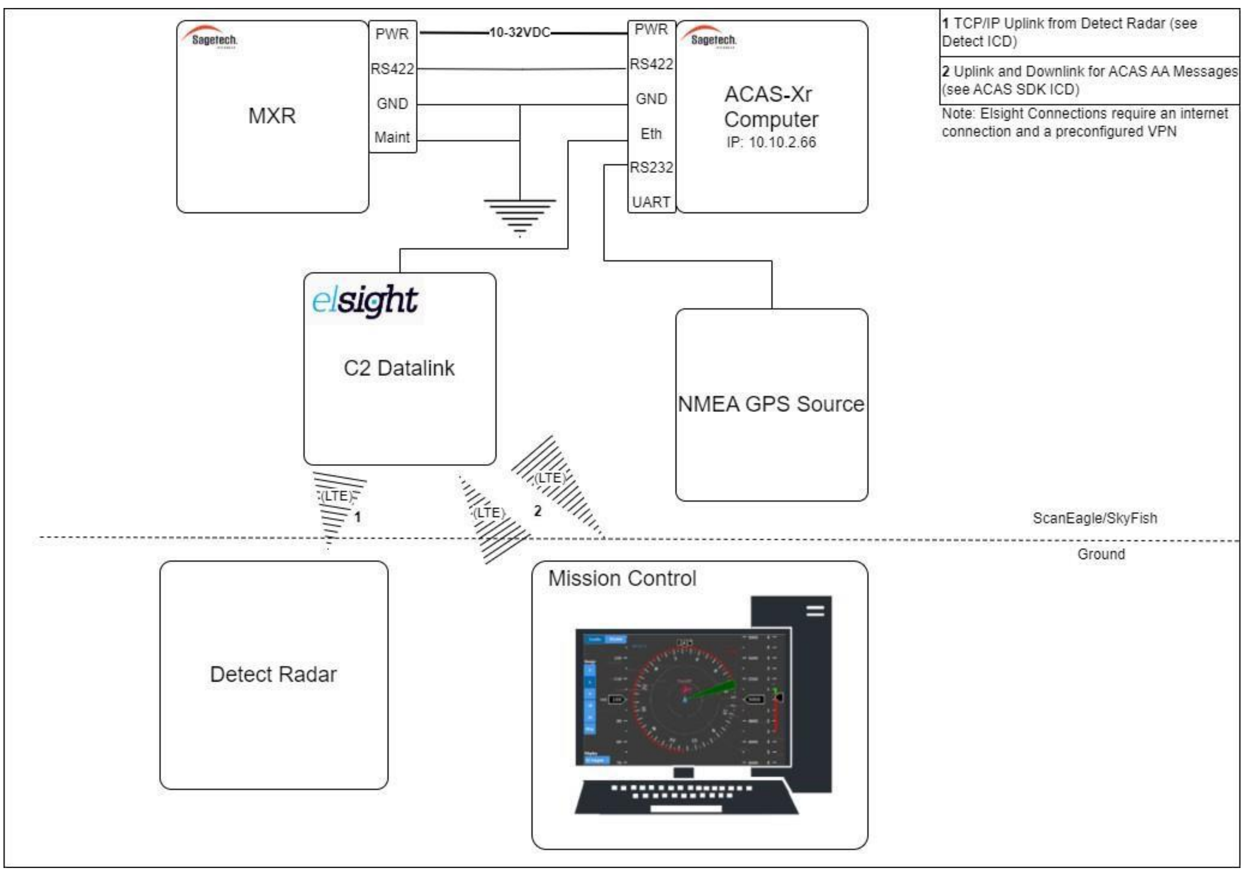


Figure 1 - System Diagram for ScanEagle and SkyFish

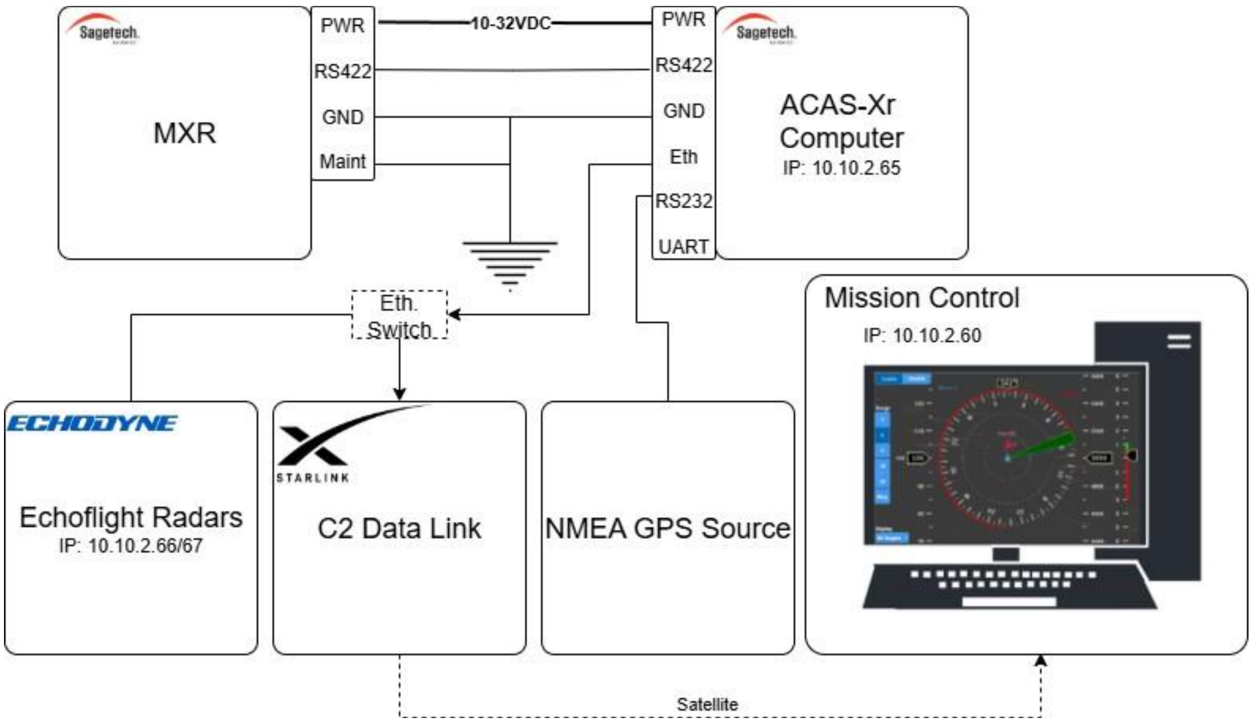


Figure 2 - System Diagram for AiRangerX

1. *Integration to DeTect Radar*

The DeTect radar provided AGT radar track data but did not comply fully with RTCA DO-381 requirements. Exceptions include absence of track altitude data, a slower update rate for data output, and accuracy data.

Prior to transmission to the ACAS Xr the DeTect track data was modified to ensure compatibility with the ACAS Xr interface. These modifications included:

1) The AGT track data was correlated with available ADS-B position reports and the ADS-B altitude was provided as AGT altitude.
2) The DeTect track update rate is 1/3 Hz. Since the ACAS Xr expects data nominally at 1 Hz additional processing was performed to duplicate the actual data and provide it to the ACAS Xr at a rate of 1 Hz.
3) The AGT data also had to be processed to make it compatible with the ACAS Xr input requirements. This involved the creation of both a horizontal and vertical covariance

matrix for each data input.

2. *Integration to Vantis*

The Vantis radar also had exceptions to the AGT track data requirements. Particularly with respect to the track accuracy covariance matrices. The data had to be processed prior to transmission to ensure the covariance matrices were compatible with the ACAS Xr input requirements.

When the Vantis system had availability of ADS-B data for an intruder track, the ADS-B data was provided by the system for transmission to the ACAS Xr. When no ADS-B data was available the Vantis system would transmit the radar track data. The radar was only capable of 2D detection and so radar tracks did not include altitude data.

3. *Integration to Echoflight*

Two Echoflight radar panels were mounted on the wings of the AiRangerX and integrated into the ACAS Xr via an Ethernet connection. The panels were aimed in the forward direction to provide a Field of View (FOV) of approximately 120 degrees in the forward direction.

Custom tuning of the radar devices was accomplished prior to and during the testing in an effort to optimize performance. This tuning included adjustments for:

1) Radar search range – reducing the azimuth and vertical search ranges to improve the likelihood of track formation.
2) Radar Cross Section (RCS) masking – expanding the acceptable range for RCS masking to improve track correlation.
3) Altitude mask – Increasing the altitude mask of the radar to reduce ground clutter.

B. Flight Test Events

Three flight test events were performed. Each of the events included multiple flights during a two-to-three-day timeframe. Data was evaluated following each day of testing and test card adaptations and system adjustments were made as appropriate prior to testing the following day.

1. *Flight Test Event 1*

Flight Test Event 1 was conducted near Gorman Field in Emerado, North Dakota. The testing was performed during the week of April 28 – May 2, 2025.

Two test aircraft were utilized including a ScanEagle UAS and a Skyfish M6 UAS. A third aircraft (Piper Archer TX) was utilized as an intruder aircraft for planned encounters. The test aircraft were both equipped with the Sagetech ACAS Xr prototype configured with the capability to receive ground-based radar track data. The evaluation primarily focused on radar track accuracy, latency of data and overall surveillance performance of the ACAS Xr system. Other analysis and evaluation such as threat logic, and traffic and advisory display were performed.

A total of 64 encounters were performed during the Flight Test Event. The ScanEagle encounters included head-on encounters with the intruder both above and below the test aircraft, encounters with the intruder passing by while the test aircraft flew a rectangular pattern and encounters where the intruder flew a raster pattern over the test aircraft while it flew a rectangular pattern. The SkyFish was flown in a circular orbit while the intruder aircraft flew a figure eight pattern crossing over it. These encounters provided various geometries between the test and intruder aircraft to evaluate surveillance performance and ACAS Xr guidance and advisory determination. The encounters were performed with intruder aircraft cooperative surveillance data available to ACAS Xr as well as unavailable to ACAS Xr. This provided evaluation capability to see how the ACAS Xr performed in comparison to cooperative surveillance and how it performed when cooperative surveillance was unavailable. For Flight Test Event 1, cooperative surveillance data (ADS-B and Active Mode S) was disabled by enabling a filter at the input to the ACAS Xr instead of turning the intruder transponder and ADS-B Out off. This allowed the ACAS Xr system to always operate with its transponder and ADS-B enabled while simulating the conditions of an intruder that did not have a cooperative surveillance source.

2. *Flight Test Event 2*

Test Event 2 was conducted near Gorman Field in Emerado, North Dakota. The testing was performed during the week of June 4 – June 6, 2025.

The aircraft and equipment were the same as used in Test Event 1. A total of 82 encounters were performed during the Flight Test Event. The encounter conditions were similar to those of Test Event 1 but they were modified so that head on encounters were performed with different approach ranges including ‘long’ (approximately 8 NM), ‘medium; (approximately 5 NM), and ‘short’ (approximately 3 NM). The encounters were performed with cooperative surveillance available and unavailable as described in Test Event 1

3. *Flight Test Event 3*

Test Event 3 was conducted near Williston airport in Williston, North Dakota. The testing was performed July 11 – July 13, 2025.

The test aircraft was an AiRangerX equipped with the Sagetech ACAS Xr prototype configured to receive cooperative ADS-B, Mode S and Mode C surveillance data and non-cooperative ground-based and onboard radar track data. The AiRangerX is a Cessna U206 set up to fully emulate the AiRanger UAS platform.

Two Intruder aircraft were used for the planned encounters. On July 11th the Intruder aircraft was a Piper Cherokee and on July 12th and 13th the Intruder aircraft was a Cessna 172S. Both Intruder aircraft were equipped with Mode S transponders and ADS-B Out capability.

A total of 124 encounters were performed during the Flight Test Event. The encounter conditions were specified by the test cards defined in the Flight Test Plan and Test Cards, Sagetech document PLN07178. Five basic test cards were used with varied intruder altitudes and approach ranges. Similar to Test Events 1 and 2, head on, rectangular pattern and raster pattern encounters were performed. 'Bow-tie' encounters were also performed where the intruder aircraft would cross the path of the test aircraft from a diagonal direction.

Test cards were performed with intruder cooperative surveillance both enabled and disabled to allow for clear comparison of radar and ADS-B track data and to demonstrate performance of the ACAS Xr system with only radar track data. Encounters were also performed for various combinations of AGT and ORNCT. For Test Event 3 the intruder cooperative surveillance was disabled by turning off the intruder transponder. This was necessary since the Vantis Network transmits intruder ADS-B data whenever available, so the intruder transponder had to be turned off in order for the Vantis Network to transmit the radar AGT data. The AGT and ORNCT data were enabled and disabled using a filter at the ACAS Xr input.

C. Surveillance Performance

The fundamental surveillance source for all testing was Cooperative ADS-B reports and Active Mode S replies received directly from the intruder aircraft transponder. Cooperative surveillance is accurate and reliable and was used as the benchmark for comparison to the non-cooperative sources being evaluated. Typically, the track probability when ADS-B/Mode S was enabled was 100%. For encounters with ADS-B/Mode S enabled the non-cooperative track data was directly compared to the ADS-B/Mode S data to measure latency and accuracy. The ACAS Xr records the input data from all available data sources (ADS-B, Mode C, Mode S, AGT and ORNCT) as well as the ACAS Xr STM correlated track data based on the selected (best) data source. The STM track data is used for threat resolution and display of traffic.

Radar data recorded by the Radar system was also used in the evaluation to show the effect of latency.

The following graphs (from test event 2 runs 5 and 6) provide an example of the comparison of STM track, radar track and ADS-B data. The first graph shows data when the intruder ADS-B Out was enabled, and the ACAS Xr used the ADS-B data as the selected track source. The STM track (1482, ADSB_1090ES), shown in purple, is directly beneath the ADS-B source data shown in black. The raw radar data, shown in red, depicts the calculated range of the intruder as detected by the radar. There is a slight but observable range difference between the radar calculated and the ADS-B/STM tracked range.

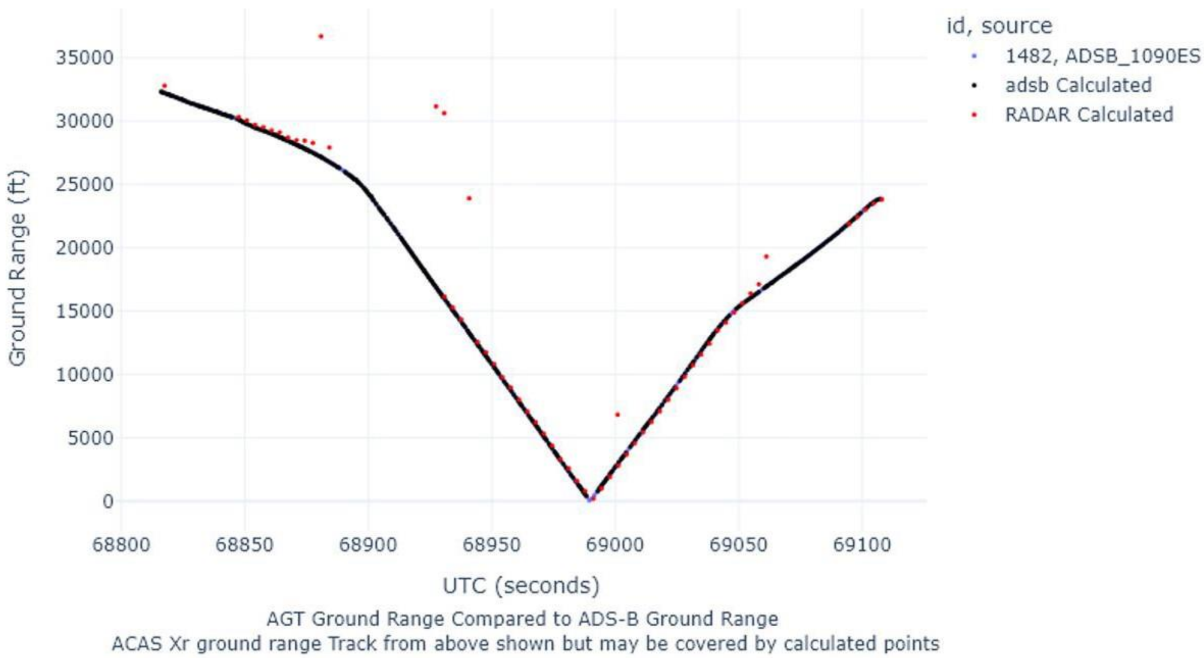


Figure 3 Radar/ADS-B Comparison (Example 1)

The second graph shows data for an encounter when the intruder ADS-B Out was disabled and so the STM chooses the radar track as the selected source (Event 2, Run 6). The STM track (1690, AGT), is shown as a purple 'x'. The raw radar data, shown in red, depicts the calculated range of the intruder as detected by the radar. This graph clearly shows a range difference between the radar calculated and the STM tracked range. The STM tracked range is delayed by approximately 3 seconds because of the AGT latency associated with processing and transmission.

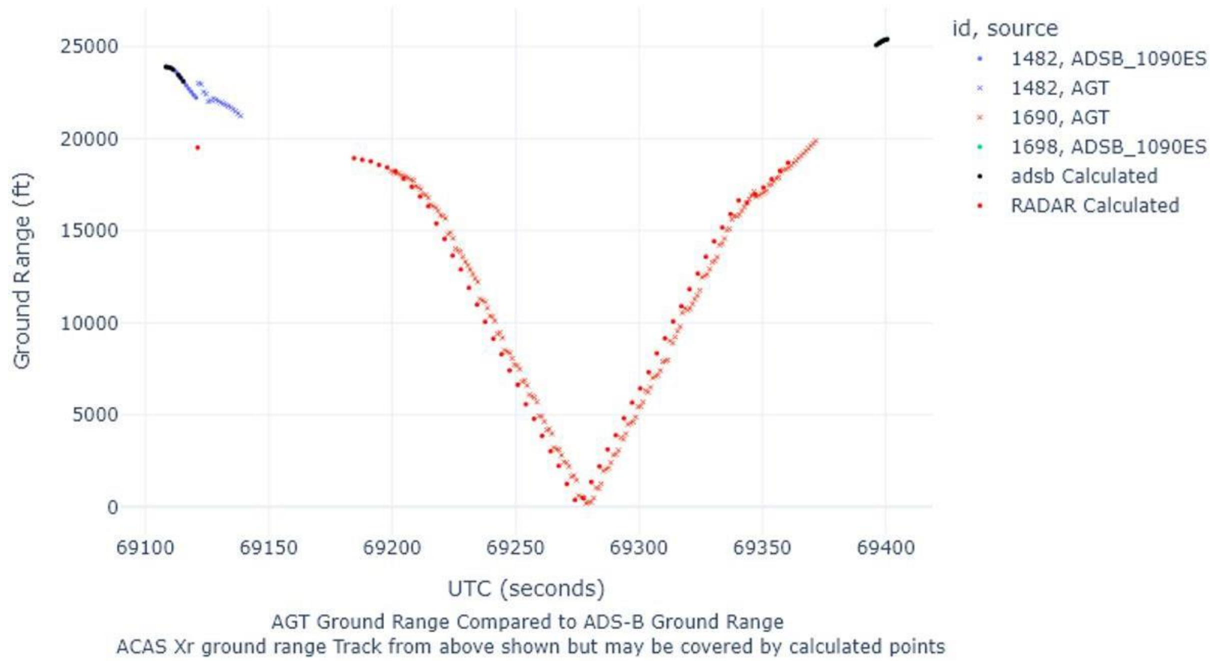


Figure 4 Radar/ADS-B Comparison (Example 2)

The following subsections provide a summary of the performance for each of the non-cooperative radar sensors utilized in the flight testing.

1. Surveillance performance of ground-based DeTect radar.

Track Probability (continuity) – The track probability of the DeTect AGT data ranged between 29% to 100% for the performed encounters with an average for all encounters of approximately 75%. During the 1st test event there appeared to be a correlation between track probability and the altitude of the intruder aircraft (higher altitude resulted in higher track probability). This correlation was not apparent during test event 2.

The DeTect radar did not meet the DO-381 requirements for track continuity(probability) of at least 95% of the time the aircraft is within the Declaration Volume. With respect to the requirement that the tracker stay free of split tracks for 90% of the time the aircraft is within the Declaration Volume of the AGT track data was adequate but because of data latency the overall tracking by ACAS Xr did have some split tracks, typically when the intruder was tracked with both ADS-B and AGT. The DeTect radar did not meet the requirement to output track reports at a rate of 1 Hz or faster with a rate of approximately 0.35 Hz.

The following figure provides an example of a track (Event 2, Run 37) that was broken into multiple separate segments that shift in range. It also has areas when the intruder aircraft is not tracked resulting in lower track probability.

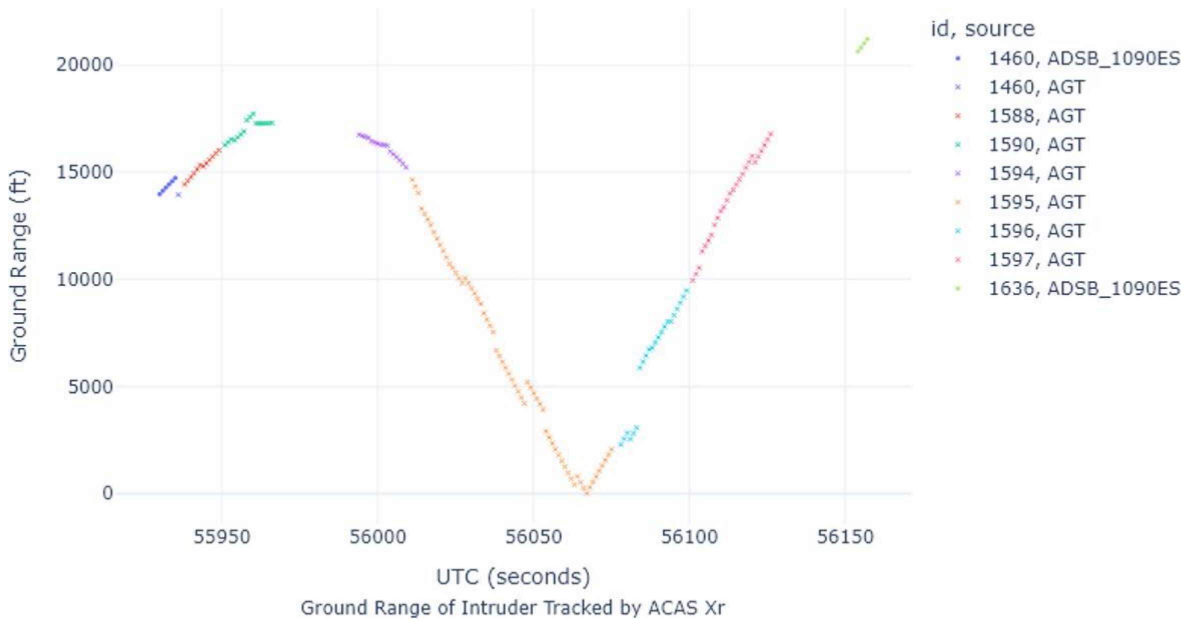


Figure 5A Example of Track Drops

The next figure provides an example of an intruder (Event 2, Run 34) that was tracked with both ADS-B and AGT simultaneously (split track).

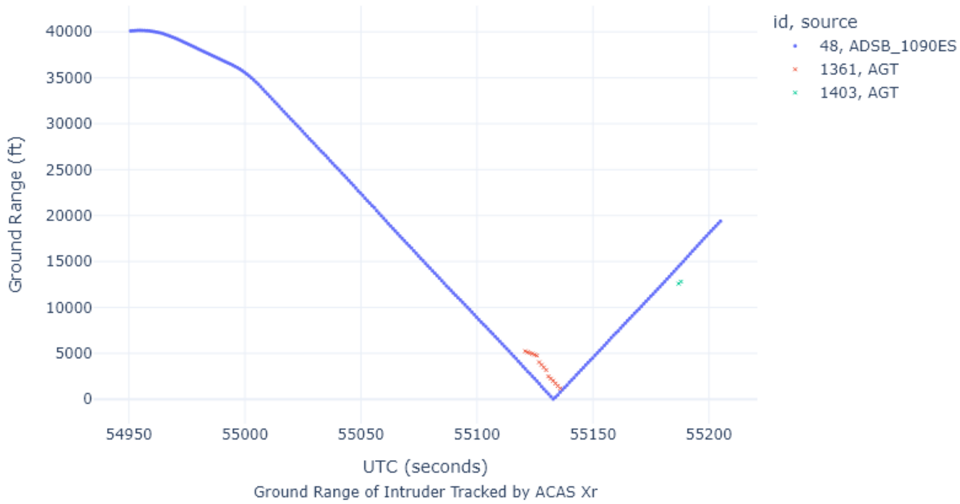


Figure 5B Example of Track Drops

Track Accuracy – There were instances when the track accuracy of the DeTect radar was excessive and unacceptable. Track Accuracy was affected by discrepancies between the time at which source data was measured and received by the tracking modules but sometimes seemed to result from STM tracker inaccuracies due to coasting. The following graph depicts inaccuracy that exceeds the latency error due to the coasting of the track even when there appears to be available radar track data (Event 2, Run 45).

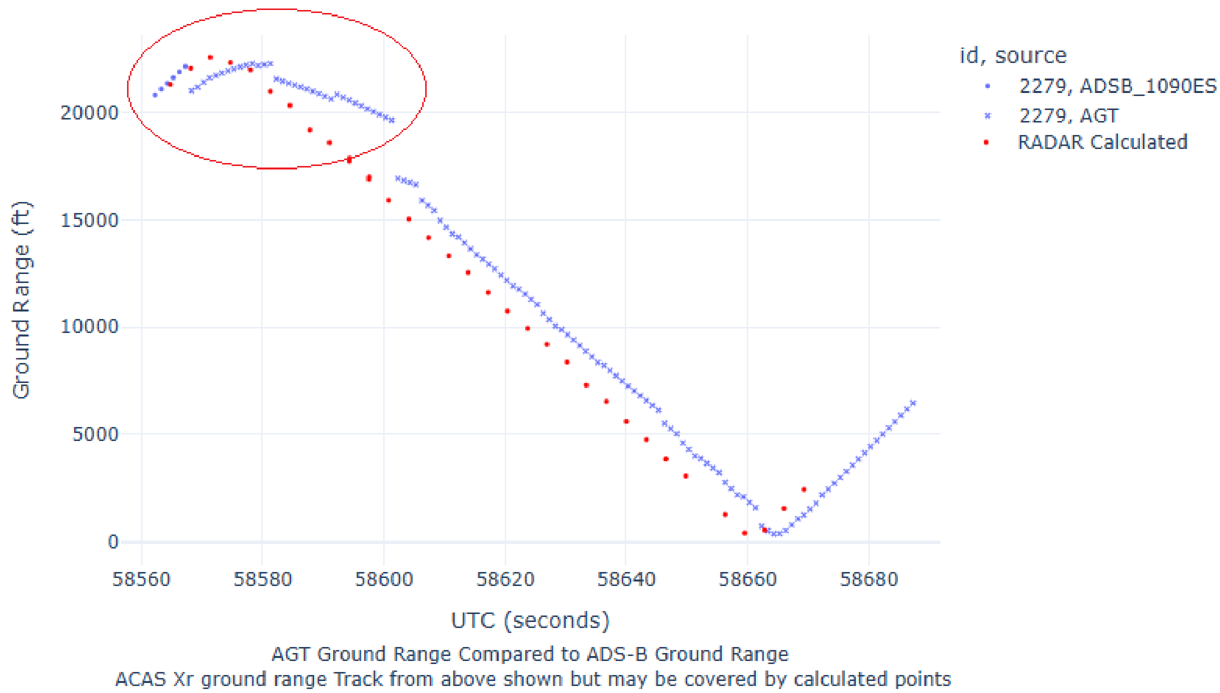


Figure 6 Potential Track Inaccuracy Due to Coasting

There was also evidence of AGT track error based on radar measurements. The following graph (from event 2, run 7) shows how the measured radar data (red) differs in position from the ADS-B data (black).

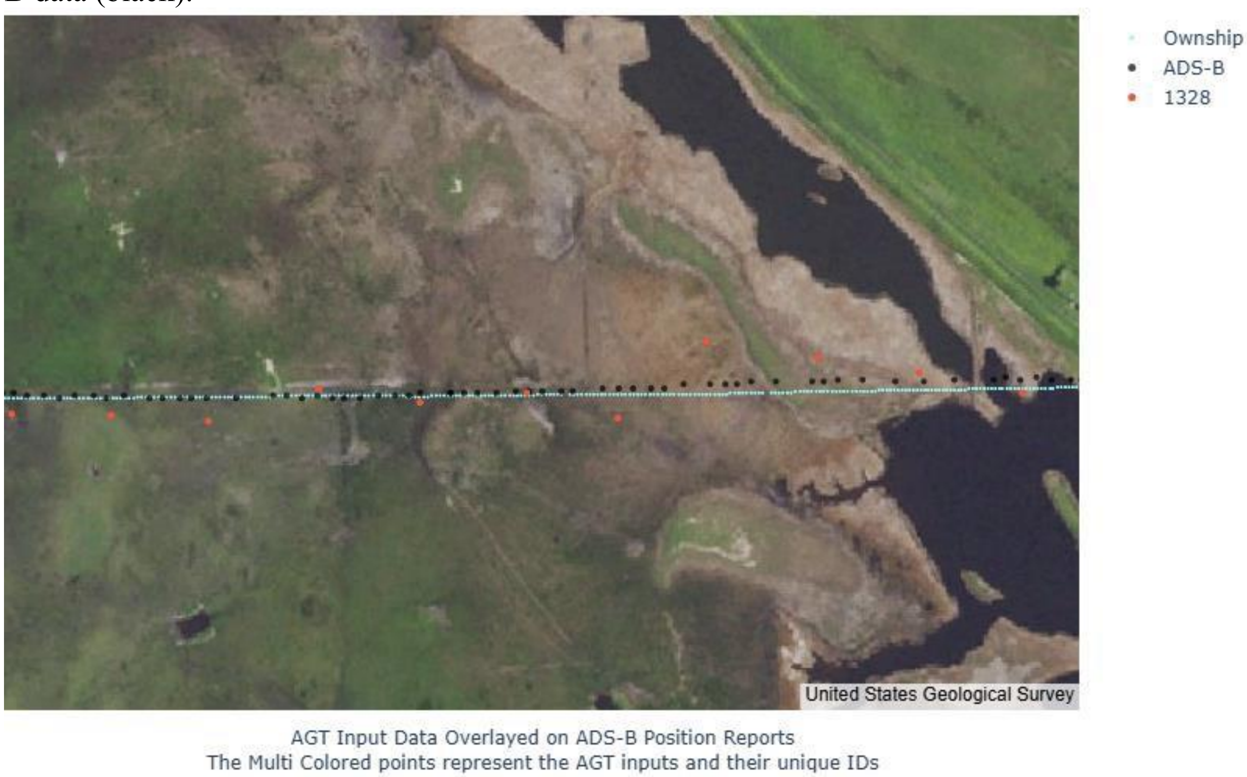


Figure 7 Inaccuracy of Radar Measured Data

False Tracks – The false track rate which is required to be less than one per hour per 0.3 square NM within the Declaration Volume was not calculated since only track data from the planned encounter intruder was formally evaluated. AGT track data seemed to be associated with the actual intruder aircraft, however, there were instances when the STM output multiple tracks based on that intruder at various ranges and altitudes. These are similar in nature to the split or inaccurate tracks described above and are at least partially due to the known latency errors associated with the radar track data. In the example below (Event 2 Run 46) the STM selected source is ADS-B but there are also five instances of the AGT data being tracked at inaccurate range and altitude.

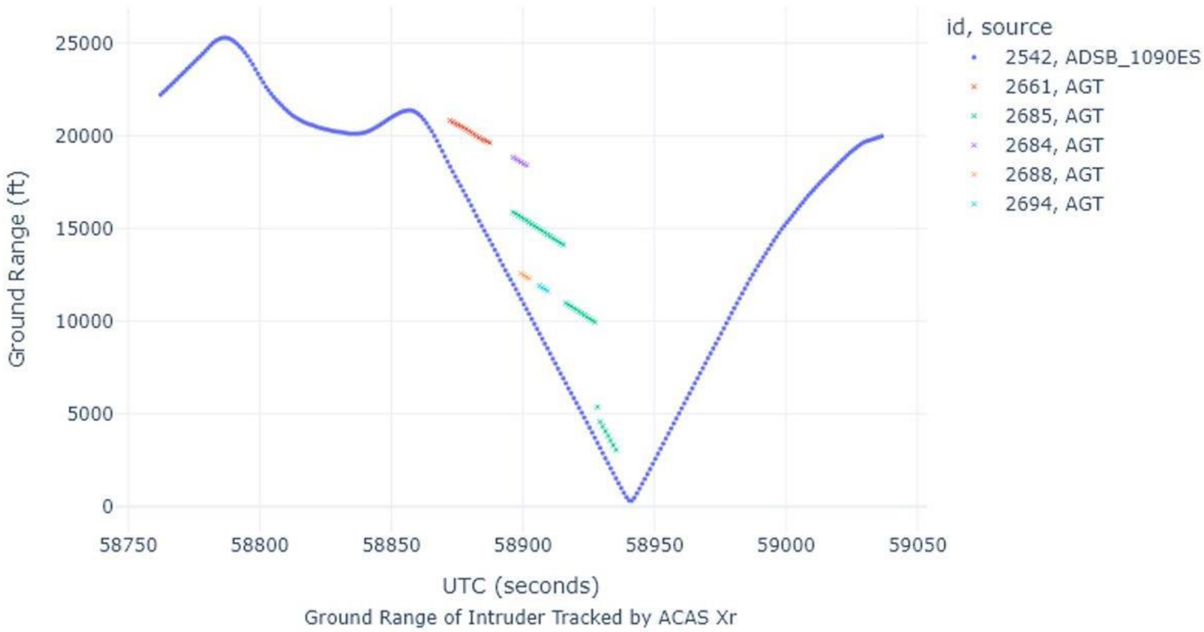


Figure 8 Example of Inaccurate/False Tracks (range plot)

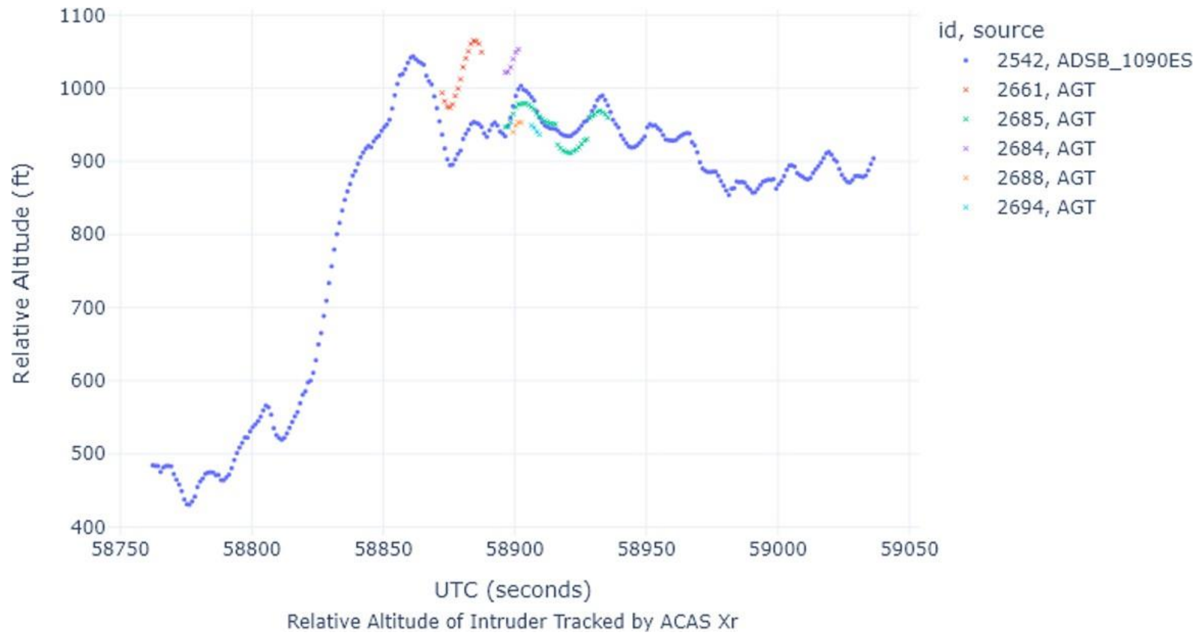


Figure 9 Example of Inaccurate/False Track (altitude plot)

Data Latency

The latency of data from radar transmission to ACAS Xr availability was evaluated using two methods: 1) comparing AGT data with the ADS- B data for the same target, 2) comparing UTC timestamps associated with the data by the radar at time of output and associated with the data by the ACAS Xr at time of reception. This latency included post processing of the data (to format data appropriately for the ACAS Xr interface) as well as uplink of the data to ACAS Xr. The ACAS Xr draft MOPS requires that the system place RWC caution data and RA warning data on the output interface within 2.3 seconds of receipt of the sensor data at the system surveillance interface which updates the target's track. The latency exceeded that limit due to the additional processing needed to ensure data compatibility with the ACAS Xr. Typical latency for AGT data from the DeTect radar was greater than three seconds. In addition to delayed advisories this latency contributed to split tracks.

2. *Surveillance performance of ground-based Vantis (Thales Terma) radar.*

In general, the performance of the Vantis Network AGT data appeared better than that of the

DeTect AGT data. In particular, the latency was considerably less, and the data was more accurate. The Vantis Network provides intruder ADS-B data whenever available, so the AGT data has similar probability and accuracy as the cooperative ADS-B data received by ACAS Xr when ADS-B is available. When ADS-B is not available the Vantis Network provides AGT data based on radar measurements which are less accurate and have lower probability of reception. The Vantis system only provides altitude when the track data is based on ADS-B data. The radar track does not include altitude (2D only). The following graph shows the difference between when ADS-B is available (T=62000 to 63300) and when it is not available (T=63300 to 64000).

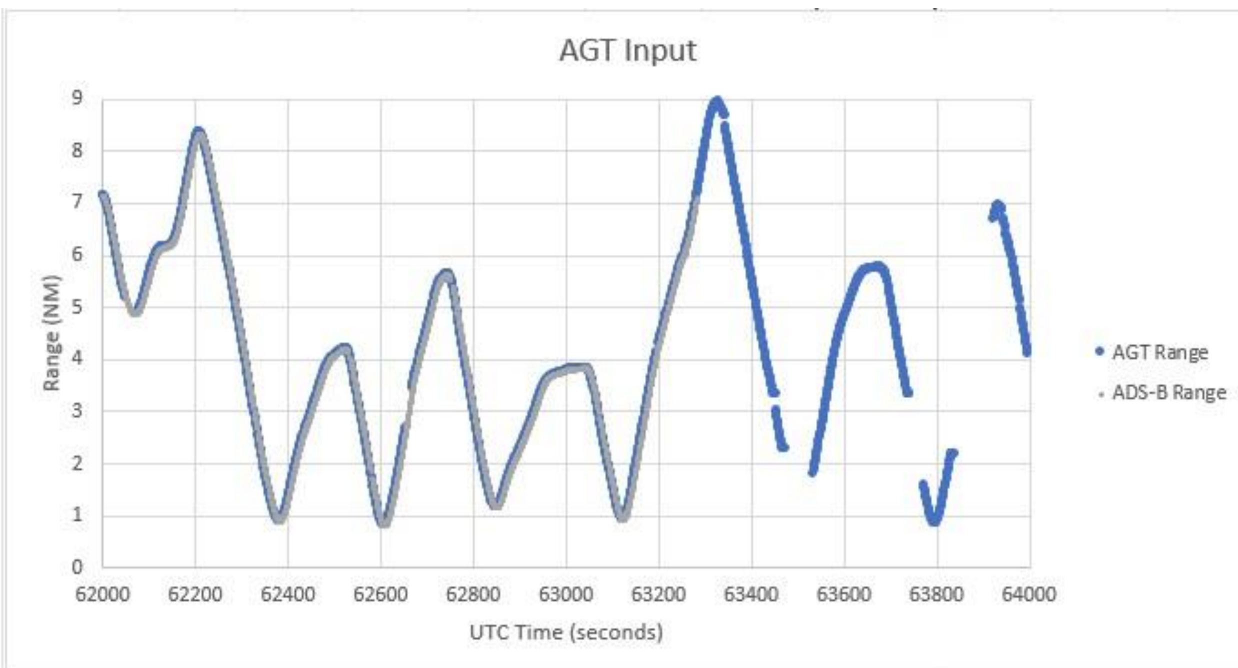


Figure 10 Vantis AGT Track Data With and Without ADS-B

The track probability of the Vantis AGT data based on radar measurements varied between 34% to 100%. The following graphs show an example with 100% track probability (Figure 11) and an example with low track probability (Figure 12).

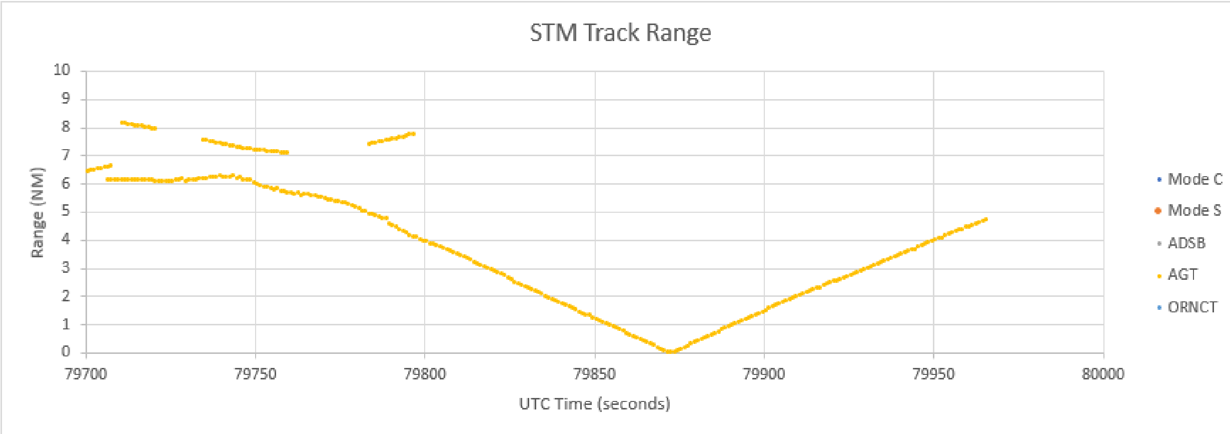


Figure 11 STM Track With 100% Track Probability (Event 3 Run 18)

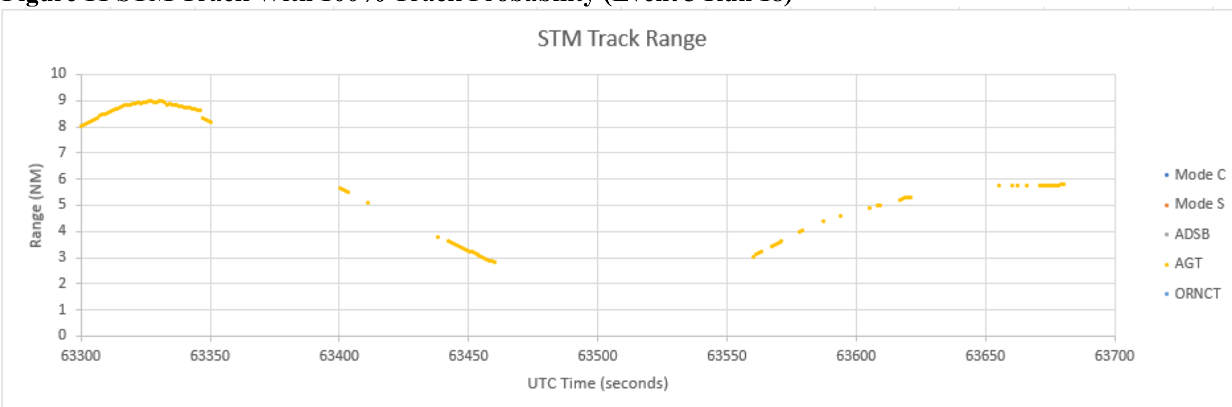


Figure 12 STM track With Low Track Probability (Event 3 Run 30)

The Vantis radar did not meet the DO-381 requirements for track continuity of at least 95% of the time the aircraft is within the Declaration Volume. Only six out of 34 test runs using radar AGT data as the surveillance source resulted in track probability of at least 95%. The overall track probability of the system is improved however, since the AGT data sometimes fills in gaps within the cooperative surveillance. See the following graph where a brief gap in cooperative surveillance (ADS-B in gray) track is filled with AGT track data (in yellow).

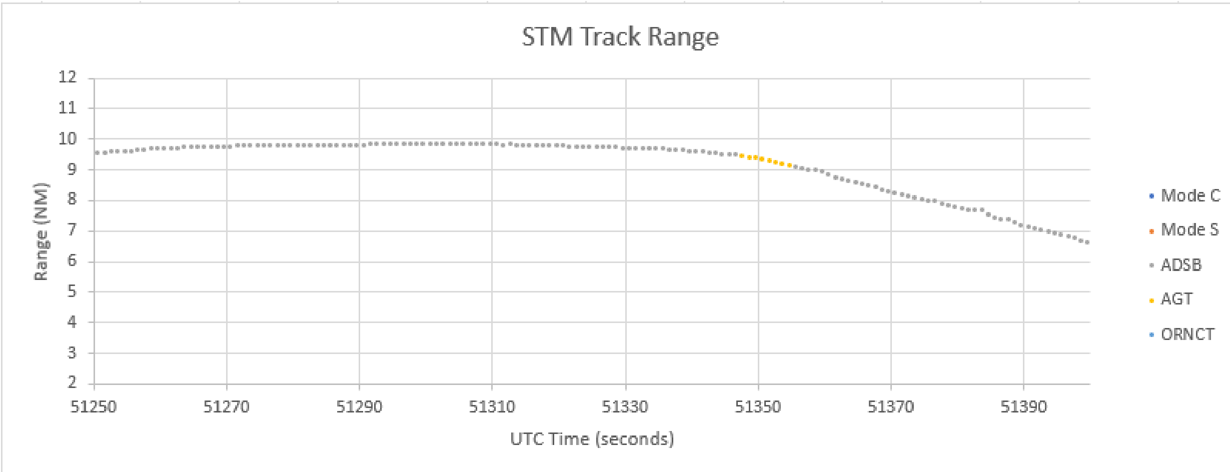


Figure 13 ADS-B/AGT Surveillance (Test Event 3 Run 76)

It does appear to meet the requirement that the tracker stay free of split tracks for 90% of the time the aircraft is within the Declaration Volume. It also meets the requirement to output track reports at a rate of 1 Hz or faster.

Track Accuracy – For the most part the Vantis Network track accuracy was consistent with that of ADS-B. There were limited instances when the AGT radar track data did not correlate to the ADS-B. The example in the following graph (from Test Event 3, Run 4) shows an AGT track that does not correlate with the ADS-B (between T = 65413 and 65445). (During this time the Vantis system provides both an ADS-B and a Radar track). This implies that the radar and ADS-B did not meet the correlation criteria of the Vantis system and also did not meet the correlation criteria of the ACAS Xr thus a split track was displayed. The other AGT track from T = 65500 to 65550 could also be related to the intruder aircraft since it is unlikely that another aircraft would be in that area. This would represent a much larger error of unknown origin.

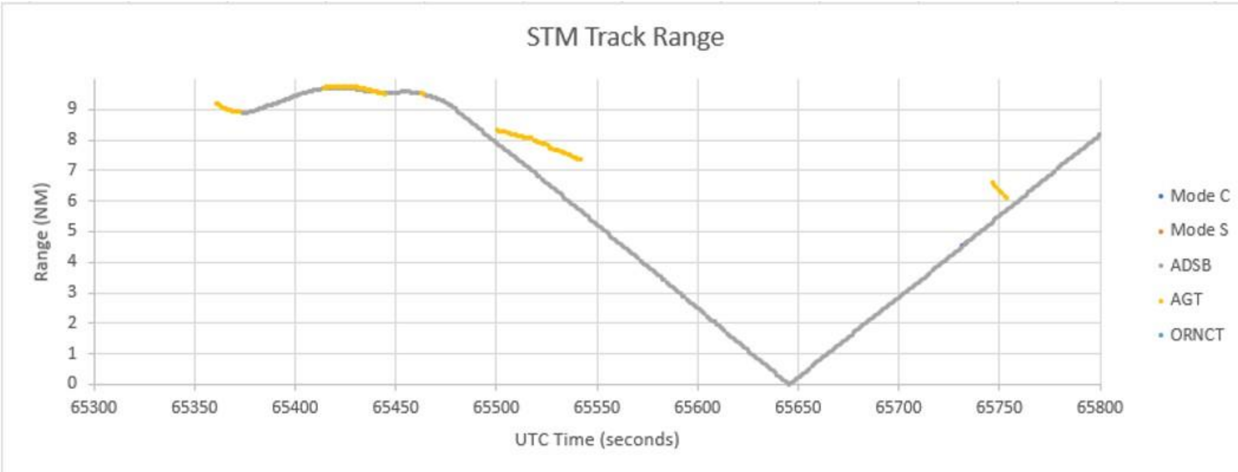


Figure 14 Example of Vantis Network Track Accuracy

False Tracks – The false track rate which is required to be less than one per hour per 0.3 square NM within the Declaration Volume was not calculated since only track data from the planned encounter intruder was evaluated. There were instances that could have been considered false tracks even though they were possibly associated with the intruder aircraft as shown in the previous example (see Figure 14).

Data Latency

The latency of data from ground-based radar to ACAS Xr availability was evaluated. This was evaluated using two methods. 1) comparing availability of AGT data with the availability of ADS-B data for the same target. 2) comparing UTC timestamps associated with the data by the radar at time of output and associated with the data by the ACAS Xr at time of reception. This latency included post processing of the data as well as uplink of the data to the ACAS Xr, The ACAS Xr draft MOPS requires that the system place RWC caution data and RA warning data on the output interface within 2.3 seconds of receipt of the sensor data at the system surveillance interface which updates the target's track. The latency as measured was typically less than 1.5 seconds and on average approximately 0.5 to 0.7 seconds depending on the method of measurement. While the AGT to ACAS Xr latency is not the only component in the total system latency these measurements could be supportive of the overall latency requirement. Additional mechanisms to reduce or compensate for the latency are also possible.

3. *Surveillance performance of onboard EchoFlight radar.*

The EchoFlight radar provided track data that was typically not useful for surveillance or threat resolution. Although the data could sometimes be correlated to actual intruder aircraft position, it was usually represented as multiple tracks and included a lot of false track data. These results were not solely due to radar performance but were affected by other considerations including,

1) radar tuning – attempt to adjust search range, radar cross section and altitude masking of the radar resulted in better results on later tests.atmospheric considerations (smoke) – there was smoke present in the air due to wildfires.

   The smoke was less prominent during days 2 and 3 of the testing when results were better.

2) ground clutter – later tests were flown at higher altitudes in an effort to minimize the effects of ground clutter which results in excessive false tracks.

Track Probability and Accuracy - ORNCT track data is typically available whenever an intruder aircraft is within one NM and in the forward direction. Actual track data can be difficult to differentiate from false tracks due to ground clutter or other interference. The following graphs demonstrate ORNCT track data improvements from day 1 (Figure 15) with excessive track data to day 3 (Figure 16) after tuning, higher altitude, and less smoke in air. Even the improved AGT track data is disjointed and includes multiple tracks.

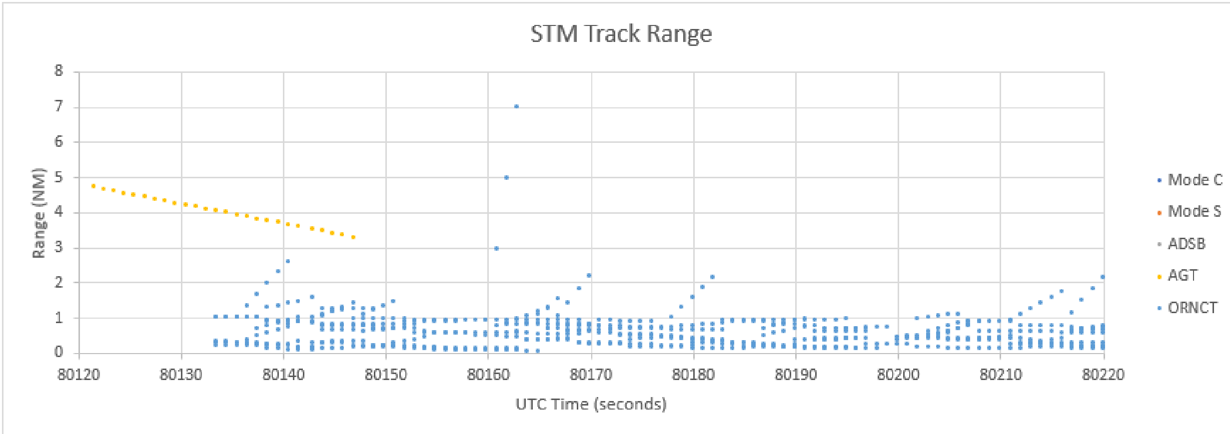


Figure 15 ORNCT Track Day 1 (Run 4)

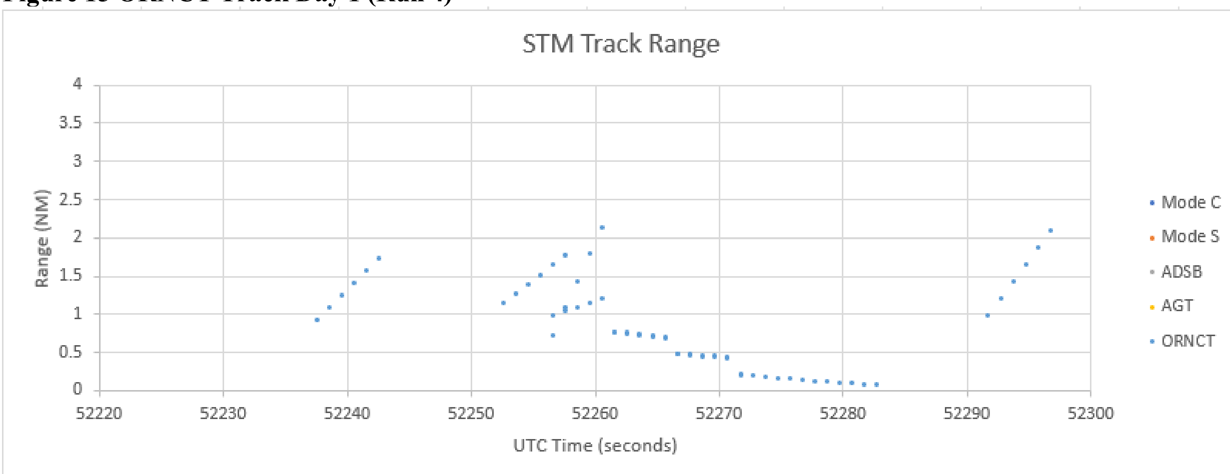


Figure 16 ORNCT Track Day 3 (Run 78)

The raw radar track data appears more accurate than the STM track using the radar data. The following graphs from Test Event 3 Run 19 illustrate this. The first graph (Figure 17) shows the ORNCT track data input to the ACAS Xr STM. The second graph (Figure 18) shows the STM tracks initiated from the ORNCT input data. The actual intruder approaches from about 4 NM at T=80130 and passes within about 0.2 NM at approximately T=80200. While the ORNCT input data does not look like a single intruder aircraft on a steady path the STM track data looks even worse, initiating multiple tracks that move in a more parallel direction as they coast out.

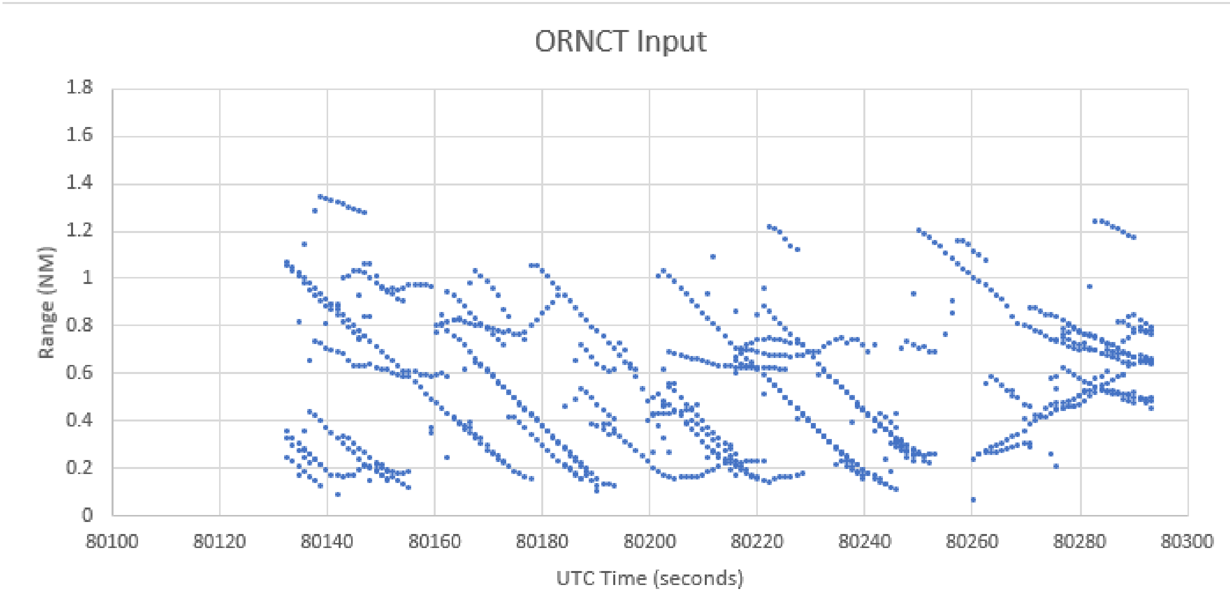


Figure 17 ORNCT Raw Input Data

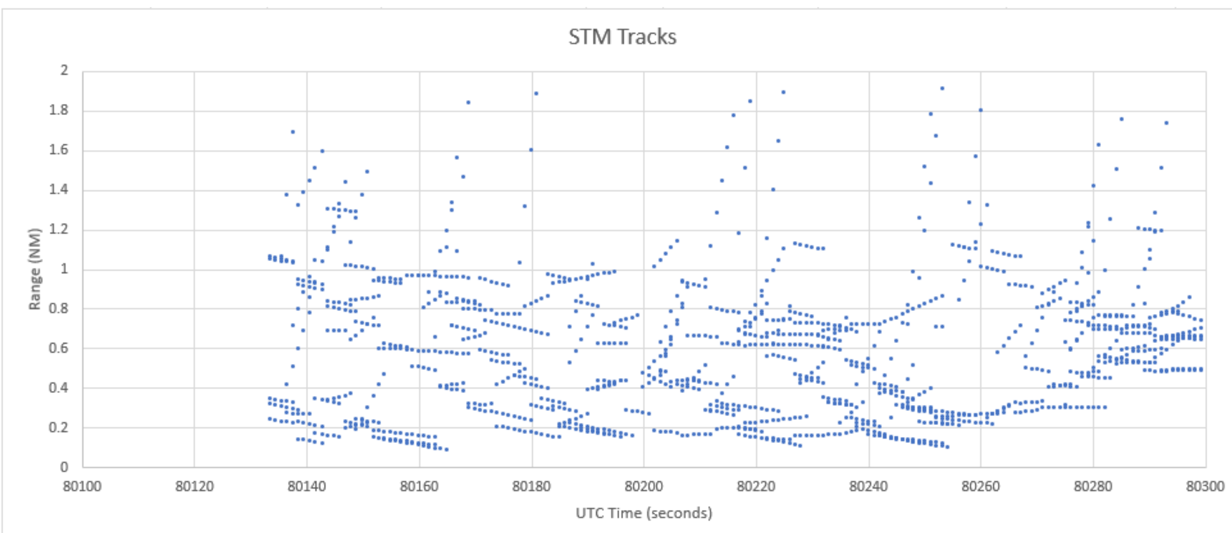
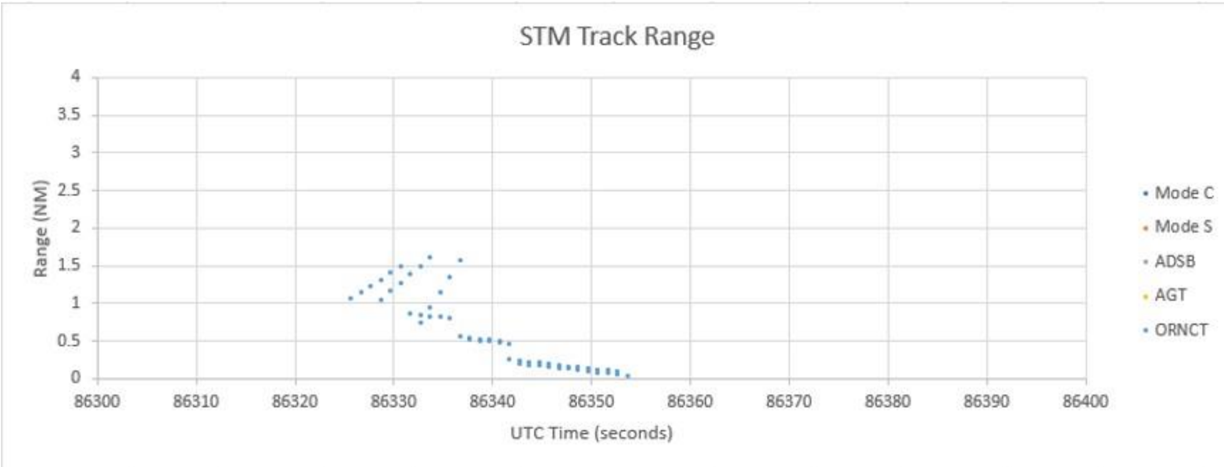


Figure 18 STM Track with ORNCT Source

ORNCT altitude tracking lacks accuracy. The ORNCT data would span an altitude range of approximately 2000 feet even when the intruder aircraft was flying straight and level. The relative altitude span did shift from above to below depending on whether the intruder was above or below the test aircraft. The following graphs (Figure 19 and Figure 20) show how the altitude reflects whether the intruder is above or below the test aircraft.



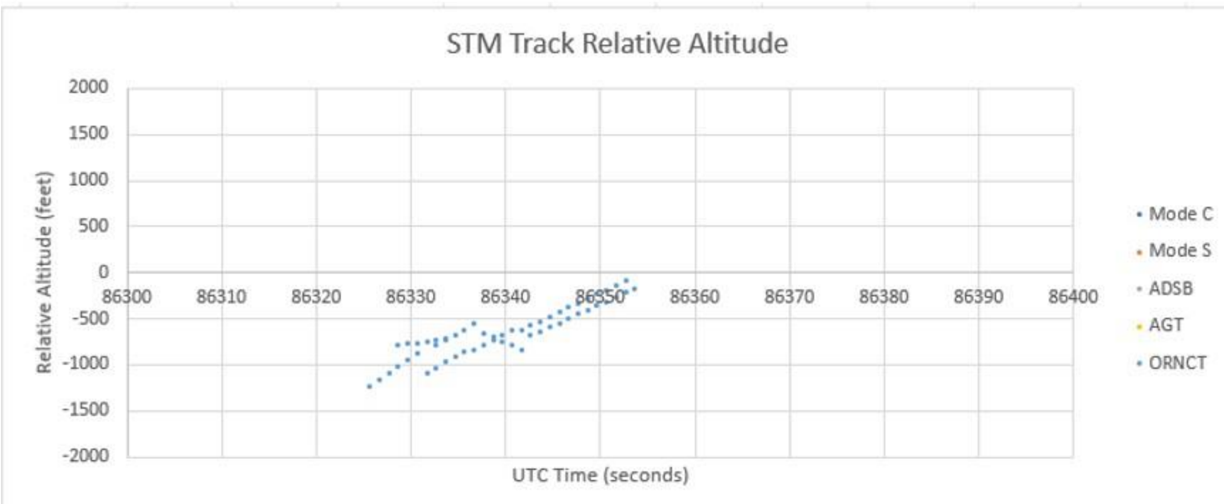
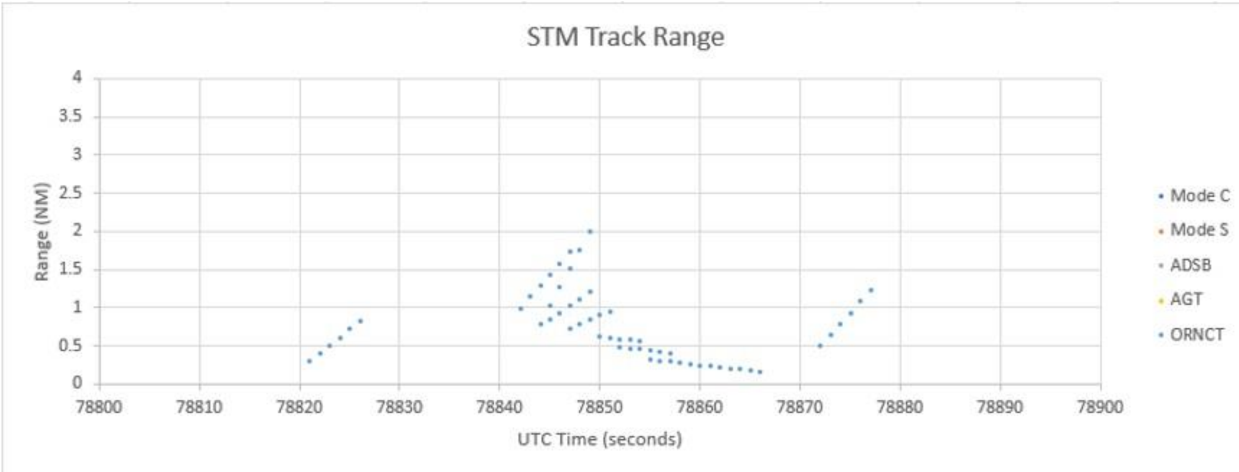


Figure 19 ORNCT Track with Intruder below (Event 3, Test Run 67)



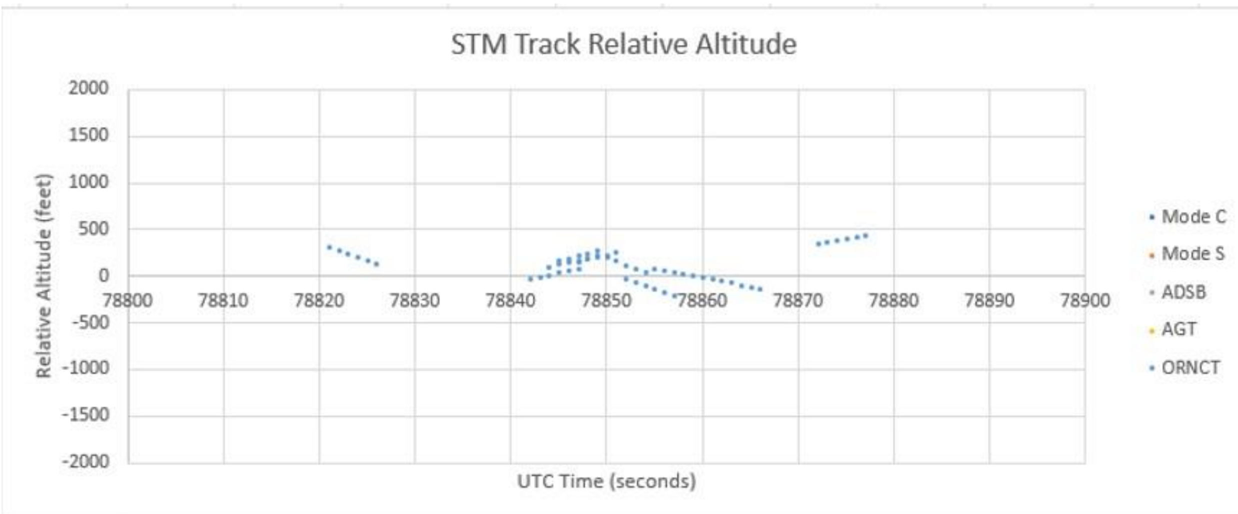


Figure 20 ORNCT Track with Intruder above (Event 3, Test Run 42)

D. Track Correlation

Track correlation was performed by the suggested algorithms included in Volume II of the Draft ACAS Xr MOPS. The correlation of data sources including ADS-B, Mode C, Mode S, AGT and ORNCT was accomplished according to the required prioritization. There were instances when data from two or more sources did not correlate and multiple tracks for a single target were initiated. These were with respect to spatial correlation and resulted from latency or accuracy of the radar track data.

E. System Latencies and Data Transmission Capacity/Bandwidth

There were no issues associated with the uplink/downlink of data between the system components.

Radar track data was reliably uplinked to the ACAS Xr system onboard the test aircraft and ACAS Xr traffic and advisory data was reliably downlinked to the Mission Control GUI.

F. Guidance and Advisories

Flight test encounters often resulted in RWC guidance and Resolution Advisories. For the most part the guidance and advisories were reasonable and pertinent. There were however, several potential issues observed. These include:

- RWC guidance that intermittently is removed then returns after several seconds. This is apparent from the displayed guidance and confirmed in the ACAS Xr recorded display data.
- As an intruder approaches Closest Point of Approach (CPA) the horizontal RA will often reverse (Turn Left to Turn Right or vice versa). This is common among many of the test runs.
- As the intruder passes CPA the horizontal RA transitions to a Maintain Heading RA. Sometimes, this RA persists for many seconds beyond the CPA. This occurs for many of the test runs.
- When a Maintain Heading RA is issued the appropriate green and red bands are not displayed on the Sagetech Mission Control GUI (This is a display issue).

G. Conclusion and Recommendations

Throughout the project the ACAS Xr performance when integrated with two different ground-based surveillance systems and an onboard radar sensor were tested and evaluated. There were integration challenges and deficiencies with each of the ground-based and the onboard sensors. To the extent possible the deficiencies were mitigated as indicated in section A, and flight testing was performed to observe, evaluate and analyze the performance of the ACAS Xr and the surveillance sensors.

The ACAS Xr successfully accepted and correlated the data from the various sources, demonstrating its ability to utilize data from both cooperative and non-cooperative surveillance sources and make use of the best available data.

Track data from the ground-based and airborne radar sensors did not meet the requirements for track probability but was usually sufficient for the ACAS Xr to provide meaningful traffic and advisory information in the absence of cooperative surveillance data.

The following list provides recommendations to facilitate integration of equipment and ensure required system performance.

1) Ensure compatibility of requirements between On Ground Radar specification (DO-381) and the ACAS Xr AGT input requirements.
2) Ensure compatibility of requirements between Onboard Radar specification (DO-366A) and the ACAS Xr ORNCT input requirements.
3) Ground Based Radar performance (DeTect and Vantis)
    - Track probability, accuracy, and duplicate track issues need to be further evaluated and resolved to meet DO-381 requirements.
4) Onboard Radar performance (EchoFlight)
    - The draft ACAS Xr MOPS requires that the ORNCT data be provided according to the DO- 366A requirements for a Class B radar. The EchoFlight radar does not meet these requirements and is more compatible with DO-366A requirements for a Class A3 radar.

It is recommended that compatibility to either Class be acceptable for ACAS Xr.

- The track probability, accuracy, and duplicate track issues associated with the radar need to be further evaluated and resolved to meet the appropriate DO-366A requirements.

5) Appropriateness of ACAS Xr guidance and advisories

ACAS Xr guidance and advisories were sometimes confusing or seemed unnecessary or inappropriate. Some of these issues have already been addressed and fixes incorporated into ACAS Xr V5. It is recommended that V5 testing be performed to verify corrections and further ensure that advisories are correct and appropriate. Some issues include:

- Seemingly unnecessary (nuisance) advisories
- RA switching between intruders (Resolved in ACAS Xr Version 5)
- Horizontal reversals at Closest Point of Approach
- RWC guidance (blinking) that is displayed, goes away for several seconds, then returns.
- Maintain Heading RA that persists after intruder aircraft has passed by.

6) Additional review of flight test data

A tremendous amount of data was collected during the three flight test events. Additional analysis of the data for identification of other issues and resolution of already mentioned issues is recommended.1

V. References

1) Flight Test Plan for Hybrid Onboard and Ground-Based Sensor Integration for ACAS X DAA Project

   Document number PLN07178 Revision C

2) Data Analysis Plan for Hybrid Onboard and Ground-Based Sensor Integration for ACAS X DAA Project

   Document number PLN07166 Revision -

3) Flight Test Event 1 Report for Hybrid Onboard and Ground-Based Sensor Integration for ACAS X DAA Project, Document number PLN07166 Revision -

4) Flight Test Event 2 Report for Hybrid Onboard and Ground-Based Sensor Integration for ACAS X DAA Project, Document number PLN07201 Revision -

5) Flight Test Event 3 Report for Hybrid Onboard and Ground-Based Sensor Integration for ACAS X DAA Project, Document number PLN07203 Revision -