

## Methodology for Comparing GPS Position Data to En Route Surveillance Radar Track Data

Dr. H. F. Ryan  
General Dynamics Network Systems  
[hollis.ctr.ryan@faa.gov](mailto:hollis.ctr.ryan@faa.gov)

M. M. Paglione  
FAA William J. Hughes Technical Center  
[mike.paglione@faa.gov](mailto:mike.paglione@faa.gov)

D. Zhou  
General Dynamics Network Systems  
[david.ctr.zhou@faa.gov](mailto:david.ctr.zhou@faa.gov)

D. Kolev  
The Titan Corporation  
[dimitar.ctr.kolev@faa.gov](mailto:dimitar.ctr.kolev@faa.gov)

*Mike Paglione is the Conflict Probe Assessment Team Lead in the Simulation and Analysis Group at the FAA W. J. Hughes Technical Center. He is currently supporting the development, testing, and evaluation of FAA air traffic management software. He holds B.S. and M.S. degrees in Industrial and Systems Engineering from Rutgers University.*

*Dr. Hollis F. Ryan is a Senior Systems Engineer with General Dynamics Corporation at the FAA W. J. Hughes Technical Center. He is currently evaluating aircraft surveillance sensors. He holds a B.A.Sc. in Engineering Physics from the University of Toronto, and M.S. and Ph.D. degrees in Electrical Engineering from the University of Illinois.*

*David Zhou is a Senior Database Specialist with General Dynamics Corporation at the FAA W. J. Hughes Technical Center. He holds a BA degree in computer science from China Science and Technology University in Beijing, and had two years graduate school in information engineering in Japan Nagoya University and one year graduate school in St. Joseph's University in Philadelphia.*

*Dimitar Kolev is a second year Intern/Coop. He joined the Titan Corp's Air Traffic Systems Division (ATS) at the FAA W. J. Hughes Technical Center. He is in his last semester at Stockton College, pursuing B.S. in Computer Science and a Minor in Mathematics.*

---

### Abstract

The Federal Aviation Administration (FAA) air traffic control system relies directly on aircraft locations provided by the long range en route surveillance radars. The accuracy of these radars is an important factor in determining the overall performance of the system. To support the planned modernization of the air traffic control system a study was conducted at the FAA's William J. Hughes Technical Center (WJHTC) to measure the accuracy of the radar tracking function of the current system. Aircraft radar tracks were compared to the positions produced by the Global Positioning Satellite System (GPS). The GPS data was available from the FAA's Reduced Vertical Separation Minimum (RVSM) Certification Program. Utilizing the Host Air Traffic Management

Data Distribution System (HADDs) at each Air Route Traffic Control Center that captures the radar tracking data, radar tracking data from 265 flight was compared to their GPS positions. Three distance metrics were used: the time coincident straight line distance, referred to as the horizontal track error, and its two orthogonal components, cross track error (side to side or lateral error) and along track error (longitudinal error). This paper describes the methodology used to prepare the data for analysis.

## **Introduction**

This paper describes how the Host's tracking of radar surveillance data was compared to time coincident Global Positioning Satellite System (GPS) aircraft positions. The principal steps in the methodology used to prepare the radar track and GPS position data for analysis are (1) recording, (2) archiving, (3) extraction, (4) reduction, and (5) comparison.

This study was performed by the staff of the Automation Metrics Test Working Group (AMTWG) at the Federal Aviation Administration's (FAA's) William J. Hughes Technical Center (WJHTC).

## **Previous Study**

A previous study of the Host radar tracking accuracy was completed by the Trios Corporation in November 2003 [1]. Their study developed a wide array of performance metrics including metrics for measuring the positional accuracy of the Host radar tracker. Trios ran a series of simulation runs using the FAA's Interfacility and Radar System simulation tool. The study examined two target motion states: steady state and maneuver state. Steady state referred to level and straight flight and maneuver state referred to time periods when the target underwent heading or speed changes, or time periods in which the tracker's statistical behavior was not in steady state.

The study described in this paper differs from the Trios simulation study in that it uses real radar tracks, not simulated radar data.

## **Scope**

A sample of 265 Reduced Vertical Separation Minimum (RVSM) certification flights from all of the twenty Centers from the January-February 2005 time period was selected for the tracking comparison. The differential GPS position data was available for these flights from the RVSM database [2] and since the flights were recent, the radar track data was still available for comparison. The radar tracks for all aircraft in en route controlled airspace are recorded and the data is kept for several months.

The comparison was done in the horizontal plane only; the differences in reported altitudes were not addressed in this study. For this study, the GPS data is considered to be the true position of an aircraft and the difference between the GPS data and the radar data is considered to be the Host's radar tracking error.

The comparison between the GPS data and the radar data was done on a point-by-point basis. Only a portion of each flight was used for the certification and therefore not all of

the radar track points have a matching GPS point. A radar track point was matched to a GPS position point that had the same time tag as the radar track point.

### **Radar Track Data Recording and Archiving**

The Host Computer System (HCS) in a Center receives all the radar reports from the long range surveillance radars in the Center. It processes the reports into tracks for each of the aircraft observed by the radars. The track data is sent in real time to a data distribution system which converts the data into digital “messages” for external air traffic applications. The messages are in what is called the Common Message Set (CMS) format. The messages include position reports for all of the aircraft currently in the Center airspace. The radar track data from the data distribution system, the Host Air Traffic Management Data Distribution System (HADDSS), at the twenty Centers, is sent to the William J. Hughes Technical Center (WJHTC) where it is archived for possible later use.

### **GPS Data Recording and Archiving**

The GPS data for a flight is a sequence of positions (a track). Each position is defined by a latitude, a longitude, an altitude, and a time. The data for an aircraft is obtained by temporarily installing a portable recording system with its GPS antennas in the cockpit of the aircraft to be certified. The recording is made when the aircraft is in straight and level flight. After the flight, the data is transferred to the RVSM database at the WJHTC for certification analysis. When the RVSM rules went operational in the continental US in January 2005, approximately 10,000 aircraft had been certified.

### **Extraction of the Radar Track Data**

The processing of the data after it has been archived is illustrated in Figure 1. The top left part of the figure shows the radar track data from each of the HCSs that was obtained by the HADDSS at each Center and archived in a network server at the WJHTC. The Structured Query Language (SQL) search capabilities of the HADDSS Server were used to obtain the radar tracks for the 265 specific flights in the study from the WJHTC network server. As illustrated in Figure 1, the radar track data was queried for the selected aircraft and date and downloaded manually, one day at a time. Only the CMS flight plan and track messages were downloaded for the target flights. This data, which is in binary format, was transferred for processing to a DR&A (Data Reduction and Analysis) Server as illustrated in Figure 1.

### **Extraction of the GPS Data**

The GPS data used for the RVSM certification was available in ASCII format at a network server at the WJHTC. The GPS track data was downloaded from this server to the DR&A server for analysis – one data file for each flight. This data transfer is illustrated in the lower left hand corner of Figure 1.

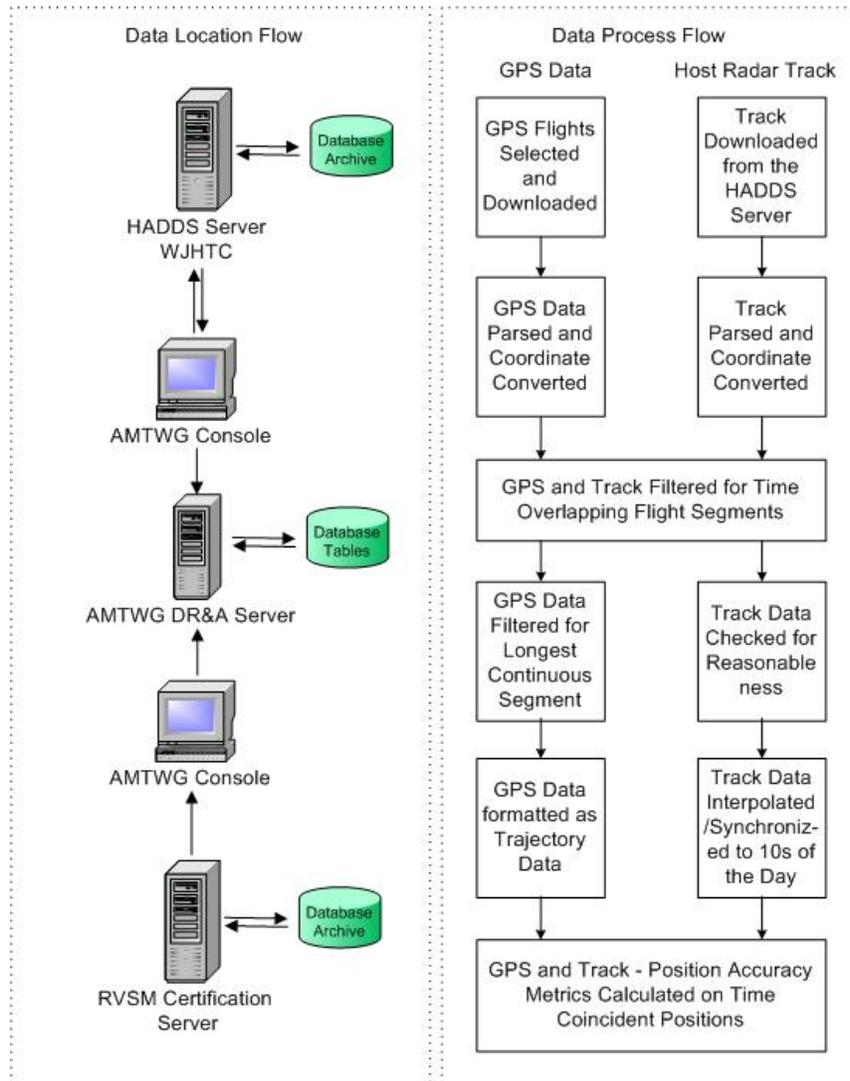


Figure 1: Data Process Flow

### Coordinate Conversion

The aircraft positions are given in latitudes and longitudes in both the radar and GPS data. Because the comparison metrics are defined in the stereographic XYZ coordinate system, it was necessary to convert both the radar and GPS coordinate data from latitudes and longitudes to XYs. Since each Center has its own coordinate system, it was necessary to identify the Center ownership of each data point before its conversion.

## Reduction of the Radar Track Data

The reduction of the radar data is illustrated in the right hand side of Figure 1. The Host's radar track data is recorded by the HADDS as a time ordered sequence of binary messages using the CMS format [3]. A given flight may fly through several Centers and the GPS recorded portion of the flight may go through only a subset of these Centers. Because the required coordinate conversion and the legacy software tools required the processing on individual Centers, each flight was split into one or more flight segments where a flight segment was that portion of the flight contained in a single Center. Then the flight segments were grouped into their respective Centers. For processing convenience, the CMS messages were converted from their binary format to an ASCII format.

Only a portion of each flight has GPS data. Flight segments<sup>1</sup> that did not have matching GPS data were discarded. Only the flight segments in the Centers common to both GPS and Host were retained for further analysis. The time tags were used to determine the overlap between the GPS data and the radar data. After eliminating the unmatched radar data, the latitudes and longitudes were converted to XYs.

To summarize, referring to Figure 1, the right side of the figure, the Host radar track data is extracted and downloaded by SQL queries from the HADDS Server, split into Center segments, grouped by Center, and parsed (converted from binary to an ASCII format). Then the flight track segments are compared to the GPS data and filtered for time overlap accordingly. This step eliminates flight data for which GPS data was not available. Then the latitudes and longitudes were converted to XY stereographic coordinate frames.

Unlike the GPS data, which is fairly smooth and clean, Host track data may contain gross errors due to lags in the recording process or other anomalous reasons. It was necessary to run the track data through a post-processing tool that checked for reasonableness. This process is documented in detail in Reference [4]. The final radar data reduction step was to interpolate the track reports to 10-second intervals, synchronized to the hour of the day. This step was in preparation for later comparison to its companion GPS data.

## Reduction of GPS Data

Most of the software used in this study was adapted from tools developed for previous studies to examine the trajectory accuracy of decision support tools [5]. Since the legacy tools were designed to process one Center's flight segments at a time by comparing radar track and trajectory predictions, it was necessary to alter the format of the GPS data to match the legacy trajectory formats.

As with the radar data, an important part of the processing was the conversion of the latitude and longitude aircraft positions into stereographic XY positions. Each Center has its own unique stereographic coordinate system and therefore it was essential to know the Center identification for every GPS position report. The processing used the time tags to

---

<sup>1</sup> For this study there is a distinction between a flight and flight segments. A flight may travel through many Centers, but a flight segment is just the portion of the flight within a Center.

match a GPS position report to a Host radar track data that was already segregated by Center. This matching assigned a Center to the GPS report and then this Center was used to determine the coordinate conversion parameters of the GPS latitude and longitude.

The GPS data was nominally sampled at a one-second sampling rate. However, many flights contained time gaps of much larger durations. For each GPS flight, the longest contiguous segment of position reports were identified and saved; the rest of the data was discarded. A contiguous segment was defined to be one in which there were no gaps longer than ten seconds. The longest segment of position reports for each GPS flight was written to a relational database table along with its identifying information. Approximately 15% of the data was discarded during this process to obtain contiguous GPS data.

Once all of the GPS data for all the selected flights was stored to the database, another software program extracted the data to 10-second intervals and stored the data in flat files, one for each Center, consistent in format with legacy software tools. Now segregated by Center, each of these GPS data files provided the input for the comparison with the radar track data.

### **Comparison Processing**

After the extraction and reduction, the radar and GPS data for each Center was ready for processing by the FAA's legacy software tools that calculate the error metrics. The radar track data was now parsed, coordinate-converted, checked for reasonableness, interpolated, time synchronized to 10-second intervals, and resided in a set of relational database tables. The GPS positions were now parsed, coordinate-converted, sampled at 10-second intervals, but not time synchronized, and formatted into trajectory files.

The comparison of the radar data to the GPS data required that the GPS data samples be time synchronized to the radar data sample. The GPS data samples were synchronized by re-sampling using linear interpolation. Even though the GPS positions were originally supplied at 1-second time intervals and would not require any interpolation, due to compatibility issues with legacy software tools, it was necessary to sample the GPS data at 10-second intervals and then later use interpolation to time synchronize to the track data. It was determined that the impact of these two steps on the study results to be negligible.

After the time synchronization, every radar track point had a corresponding GPS position report where corresponding means the two points have the same time tag; that is, the radar measurement and the GPS measurement of the aircraft location were made at the same time. In an error free world, the radar measurement and the GPS measurement would be identical. Since the GPS data is much more accurate than the radar data, the difference between them is considered to be radar error.

Three spatial metrics were calculated for each pair of reports: (1) horizontal error, (2) along track or longitudinal error, and (3) cross track or lateral error. The details of the computation have been given in References [6] and [7]. The horizontal error is the unsigned straight line distance between the time coincident radar track and GPS position. Along and cross track errors are the signed orthogonal components of the horizontal

error. A positive value of along track error indicates the track is ahead of the GPS position and a negative along track error indicates that it is behind the time coincident GPS report. A positive cross track error indicates the track is to the right of the GPS position and negative is to the left.

A data processing run calculating the three metrics for each pair of reports was made for each of the twenty Centers. Each run populated a relational database table with the position errors for all of the matched radar reports for all of the flights in that Center. A GPS flight that flew through more than one Center's airspace has part of its error data assigned to each of the airspaces that it traverses. For analysis purposes, the twenty metric tables were combined into a single database table.

### **Analysis**

Descriptive statistics defining the Host tracker's accuracy were computed for the spatial metrics obtained from the sample population of the 265 flights. Inferential statistical methods were applied to evaluate if other factors had an impact on the Host tracker's accuracy. A small number of outliers representing 5.8% of the data were excluded from the data. The outliers did not represent the basic accuracy of the Host radar tracking capabilities and represented artifacts produced from the data collection process.

The descriptive statistics were selected to summarize and quantify the accuracy data collected for the horizontal and along and cross track error metrics. The statistics selected were average, root mean square, standard deviation, and quantiles.

Inferential statistics were used to determine if the error rates were affected by (1) the Center, (2) turn status (whether the track is within a turn or not), (3) vertical transition status (whether the track is climbing, descending or level), or (4) altitude interval.

### **Summary**

A methodology was developed for comparing GPS position data to en route surveillance radar track data. Applying the methodology to recorded radar track data and GPS data measures the accuracy of the Host radar tracker. The principal steps to process the data using the resources of the WJHTC have been described. They are (1) recording, (2) archiving, (3) extraction, (4) reduction, (5) comparison, (6) analysis.

This paper has addressed the methodology for measuring the accuracy of the en route radar tracking; the results of applying the methodology will be reported in a future paper.

### **Acronyms**

AMTWG	Automation Metrics Test Working Group
ARTCC	Air Route Traffic Control Center
ASCII	American Standard Code for Information Exchange
CMS	Common Message Set
DR&A	Data Reduction and Analysis

FAA	Federal Aviation Administration
GPS	Global Positioning Satellite System
HADDS	Host Air Traffic Management Data Distribution System
HCS	Host Computer System
Host	ARTCC main frame computer
RVSM	Reduced Vertical Separation Minima
SQL	Structured Query Language
WJHTC	William J. Hughes Technical Center

### References

- [1] Trios Associates, Inc., November 2003, "Host Tracker Performance Assessment," FAA, Washington, D.C.
- [2] Separation Standards Analysis Group, 2004, "RVSM Monitoring Procedures – Appendix 2," FAA, William J. Hughes Technical Center.
- [3] FAA, March 2001, "Interface Requirements Document for the ARTCC Host Computer System," NAS-IR-82170001, Revision N.
- [4] Ryan, H. F. and M. M. Paglione, August 2003, "Heuristic Methods to Post Process Aircraft Radar track Data," Proceedings of the American Institute of Aeronautics and Astronautics (AIAA) Guidance, Navigation, and Control Conference, Austin TX.
- [5] Cale, M. L., M. M. Paglione, H. F. Ryan, R. D. Oaks, J. S. Summerill, and S. Liu, December 2001, "A Generic Sampling Technique for Measuring Aircraft Trajectory Prediction Accuracy," 4<sup>th</sup> USA/EUROPE Air Traffic Management R&D Seminar, Santa Fe, NM.
- [6] Paglione, M. M., H. F. Ryan, R. D. Oaks, J. S. Summerill, and M. L. Cale, May 1999, "Trajectory Prediction Accuracy Report User Request Evaluation Tool (URET) / Center-TRACON Automation System (CTAS)," DOT/FAA/CT-TN99/10, FAA W. J. Hughes Technical Center.
- [7] Ryan H. F., M. M. Paglione, and S. M. Green, August 2004, "Review of Trajectory Accuracy Methodology and Comparison of Error Measurement Metrics," Proceedings of the American Institute of Aeronautics and Astronautics (AIAA) Guidance, Navigation, and Control Conference, Providence, RI.