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HEURISTIC METHODS TO POST PROCESS AIRCRAFT RADAR TRACK DATA

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Abstract

The Conflict Probe Assessment Team of the Federal Aviation Administration (FAA) has evaluated several decision support tools within the National Airspace System. The evaluation required knowledge of the actual flight paths flown by the aircraft in the test scenarios used. The aircraft flight paths are determined from radar surveillance data as processed by the FAA's Host mainframe computers. The tracking data obtained from the FAA's Host computers contains errors and noise and must be corrected before the evaluation software can use it. This paper presents a set of carefully crafted heuristic data processing methods that have been developed and used to clean up the radar tracking data as it is supplied by the Host computers. The methods have been applied to numerous air traffic scenarios containing thousands of aircraft flights. The methods are described and representative statistical results are presented. For a typical air traffic five-hour scenario it was necessary to discard 2% of the aircraft radar tracks, 2.4% of the track position reports, and to correct 1.3% of the reports. The post processing of the track reports enabled the downstream software tools to satisfactorily process the radar data and establish ground truth for the testing and evaluation of the air traffic control systems.

Introduction

The Conflict Probe Assessment Team (CPAT) of the Federal Aviation Administration (FAA) has evaluated[7] several decision support tools within the National Airspace System (NAS) [1,3 & 2,4,9] that predict the future flight paths of aircraft in controlled airspace. The evaluation required knowledge of the actual flight paths flown by the aircraft. The paths flown by the aircraft are determined from radar surveillance data as processed by the FAA's Host mainframe computers. The positions of an aircraft are recorded by a Host computer system and are referred to as the track of the aircraft. As the tracking data obtained from the FAA's Host computer interfaces was faulty, it was necessary to correct it before it could be used by the evaluation software tools. A set of carefully crafted heuristic data processing methods has been developed and used to correct the radar tracking data. The methods have been applied to numerous air traffic scenarios containing thousands of aircraft flights. In this paper the methods are described and representative statistical results are presented.

Previous methods of improving the Host radar data in real time have been reported in References 6, 8, and 11. CPAT required a conservative post processing technique to be included in a set of data evaluation tools. The heuristic methods reported here fulfilled this need.

Radar Data

The nominal update rate of the Host Computer System (HCS) is 12 seconds. Every 12 seconds the HCS updates the positions and velocities of all of the aircraft in its airspace[5]. This data is available through an interface to the DSTs[10]. For this study, the radar data for a scenario was recorded for off line analysis. Prior to the correction processing the data was sorted by aircraft and by time. A time history of positions was generated for each aircraft in the scenario.

The HCS uses a rectangular Cartesian coordinate system based on stereographic projection. XY defines a horizontal plane. Positive X direction is east, the positive Y direction is north, and the positive Z direction is up. The time is in seconds of Universal Coordinated Time (UTC or Greenwich Mean Time), X and Y are in nautical miles, Z is in feet, and the velocity is in knots.

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Each position report has a time tag, values of X and Y coordinates, values for X and Y components of the aircraft velocity, and the altitude of the aircraft.

Data Characteristics

The data has a number of problem idiosyncrasies. For most of the aircraft tracks, less than 10 % of the track reports are affected. Using the methods described in this paper it was possible to fix the defective reports in most of the aircraft tracks. A few tracks could not be fixed and were discarded.

The following faults were found in the HCS track data:

- **Missing Track Reports –** The HCS dropped track reports, creating a gap in the position data (occasionally five or 10 minutes long).
- **Stationary Track Reports –** Sometimes the HCS gave two or more successive track reports that had identical values for X, Y, and Z. That is, according to the HCS the aircraft had not moved. Usually the HCS caught up with the next track report.
- **Inconsistent Track Reports** – Because of speed limitation an aircraft can only move so far in 12 seconds. Similarly it must move a minimum distance in order to keep flying. A track report is inconsistent when it reports an unreasonable aircraft velocity – either too fast (the position reports are too far apart) or too slow (the position reports are too close together). Usually consistency is regained within a few track reports.
- **Irregular Time Tags** – The HCS updates the radar positions of the aircraft in its airspace every 12 seconds. However the time tags as received downstream from the HCS interface did not show exactly 12 second time steps. Sometimes the time intervals were slightly less than 12 seconds and sometimes slightly more. Sometimes they were zero.
- **Missing Altitudes** – Occasionally in the middle of a track there is no altitude value (reported as zero) and frequently the first few track reports and the last few track reports have no altitude values.
- **Jitter –** The position reports "bounce around" rather than tracing out a smooth track as the aircraft is actually doing. This effect is noise or jitter on the position reports and is fairly small.

A method was developed and applied for each of these problems.

Input Data

The input data to the computer program that implements the processing methods is a list of time ordered track reports for a single aircraft flight. Each record contains a time tag and values for the aircraft's X, Y, and Z coordinates. The data record also has the X and Y components of the ground velocity of the aircraft. The format of the data records is illustrated in Table 1. A radar track report has nine data fields. They are listed in this table. The ACID (AirCraft IDentifier) is an aircraft identifier - the airline's initials followed by a flight number or the registration number of the aircraft. The CID (Computer IDentifier) is another aircraft identifier assigned by the HCS. The Sector is the number of the sector controlling the aircraft.

Table 1. Radar Track Report Data Fields

Field Number	Field Data
1	Time (UTC)
2	ACID
3	CID
4	Sector
5	Altitude
6	X Coordinate
7	Y Coordinate
8	Ground Speed X Component
9	Ground Speed Y Component

Output Data

The output data from the computer program is a repeat of the input data after some changes have been made. Some track reports have been deleted, some track reports have been added, and some of the values of the variables have been altered.

Program Design

The processing steps used to clean up the data are illustrated in four top level flow charts (Figures 1, 2, 3, and 4) which describe the logic of the overall structure of the program which implements the methods developed. The following text traces the steps in the figures. The numeric data is from a five hour test scenario created by CPAT.

Start – Select Radar Track

Refer to Figure 1. The starting point is the selection of a radar track for an individual aircraft flight for processing. The input data file is a set of time ordered aircraft radar tracks. The program processes each radar track in sequence until all of the tracks have been processed.

Delete Small Time Step Reports

Although the step size is nominally 12 seconds sometimes it is zero – two sequential reports have the same time tag. The second report is deleted. In addition if a second report is less than seven seconds later, it is deleted also. This action avoids the down stream problem of time steps later being rounded down to zero seconds, thus re-introducing zero time steps.

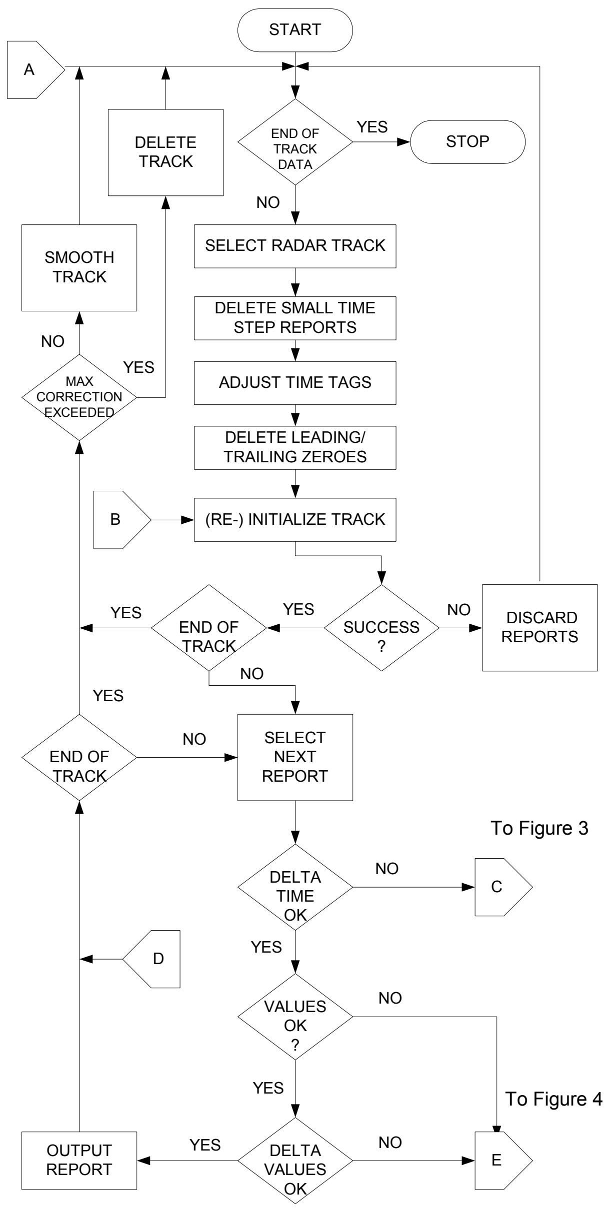

Figure 1. Heuristic Tests on the Radar Track Data

Adjust Time Tags

The times are first all rounded to the nearest second. After rounding, the time steps typically may have values of 10, 11, 13, or 14 seconds. When reports are missing, the time steps are equal to, or close multiples of, 12 seconds. It is assumed that the time tags are in error and that the true values of the time intervals are either 12 seconds or some multiple of 12 seconds. The entire track is processed as a whole, rounding the individual time tag values to the nearest integer multiple of 12 seconds. This adjustment is done in a way that minimizes the total of the time adjustments for the whole track.

Table 2 lists the frequency of selected time gaps after the times have been rounded to the nearest second and all gaps less than seven seconds have been deleted for the example scenario. The smallest gap is 10 seconds. There are 3 gaps larger than 1200 seconds. Table 3 lists the frequency of selected time gaps after the times have been adjusted to multiples of 12 seconds. The numbers have been reduced slightly in this table by not counting the gaps for tracks that have not been initialized or have been suppressed (see the program description).

Delete Leading and Trailing Zero Altitude Reports

The third processing step is to strip off the first few contiguous records that contain zero values for the aircraft altitude. Similarly the last few contiguous

Table 2. Gaps in the Input Data – Before adjustment

Gap Size (Seconds)	Number of Occurrences
10	537
11	44315
12	214573
13	44693
14	558
22	5
23	406
24	873
25	143
26	2
35	51
36	75
37	15
47	16
48	12
49	1
59	3
60	9
61	1
…	…
1044	1
1140	1
>1200	3

Table 3. Gaps in Input Data – After Adjustment

Gap Size (Seconds)	Number of Occurrences
12	303213
24	1405
36	136
48	28
60	13
72	4
84	2
…	…
1044	1
1140	1
>1200	3

records that also contain zero values for the aircraft altitude are stripped off. There are usually two or three records to be removed at the beginning and at the end of the track.

Initialization

After completing the above cleanup processing steps, the track is initialized. Initialization is the determination of three good, contiguous track reports. The search is started at the beginning of the track data. Three tests are applied to the data. The track is initialized when three contiguous records pass the following tests. These tests are used both for initialization and subsequent processing of the track data.

Values Test

The values of X, Y, and Z are checked to see if they are in normal range. This test eliminates outliers.

Delta Time Test

The time interval must be equal to 12 seconds (no missing track reports).

Delta Values Test

An aircraft is in motion and travels some distance between position reports. There is both a minimum horizontal distance and a maximum horizontal distance that the aircraft must travel in a 12 second interval. Similarly there is a maximum reasonable climb rate and descent rate. The distance the aircraft moves from one track report to the next, that is the distance covered in 12 seconds, is calculated in the horizontal plane and in the vertical plane. The report passes the test if the horizontal distance is bounded by the minimum and maximum acceptable distances and if the vertical distance traveled is less than the maximum accepted.

The parameter values used by this test are a maximum of 3 nautical miles and a minimum of 0.1 nautical miles horizontally and a maximum of 2000 feet vertically. The horizontal thresholds correspond to aircraft speeds of 900 knots and 30 knots respectively. The vertical threshold corresponds to a rate of climb (or descent) of 10,000 feet per minute. These threshold values were chosen empirically.

Applying the Initialization Tests

The initialization is implemented as a search loop shown in Figure 2. The first record remaining after the leading records having zero valued altitudes have been stripped off is selected as the candidate to be the first of the three initialization records. The *Values Test* is applied. If this record passes, the next record is selected for testing to be the candidate for the second initialization record. The *Value Test*, the *Delta Time Test*, and the *Delta Values Test* are applied to this second record. If the record passes all three tests, the next record is selected to be the candidate for the third initialization record and the three tests are applied to this third record. If the third record passes, the track is initialized.

If anyone of the tests is failed, all of the candidate records selected at that point (either one, two, or three) are discarded and the initialization process is restarted with the next record in the input track.

The search continues through the track records until the initialization is successful (Exit 2) or the end of the track is reached (Exit 1). If the track is initialized, the three reports are output to the output queue of track reports. If the track cannot be initialized it is discarded and is missing from the output data.

Sequential Processing of Track Records

Once three initialization records have been found, the track reports following are processed in succession. The *Delta Time Test* is first applied to the next record. If it is passed, the *Values Test* is applied. If this test is passed also, the *Delta Values Test* is applied. If it is passed, the record is accepted and sent to the output report queue for the track being processed. Then the processing moves on to the next track report - the program flow loops back to select the next track report. When the last report for the track has been processed, the program moves on to the next aircraft track. These processing steps are shown in Figure 1.

Recovery from Failure of the Tests

If the next track report fails one or more of the tests, a gap in the data has been found. Either the data is missing – a time gap – or the data is bad – a bad data gap. The program goes into a recovery mode. For a time gap, the program exits the first flow chart of Figure 1 at Connector C and enters the third flow chart (Figure 3) at Connector C. For a bad data gap, the program exits the first flow chart at Connector E and enters the fourth flowchart (Figure 4) at Connector E.

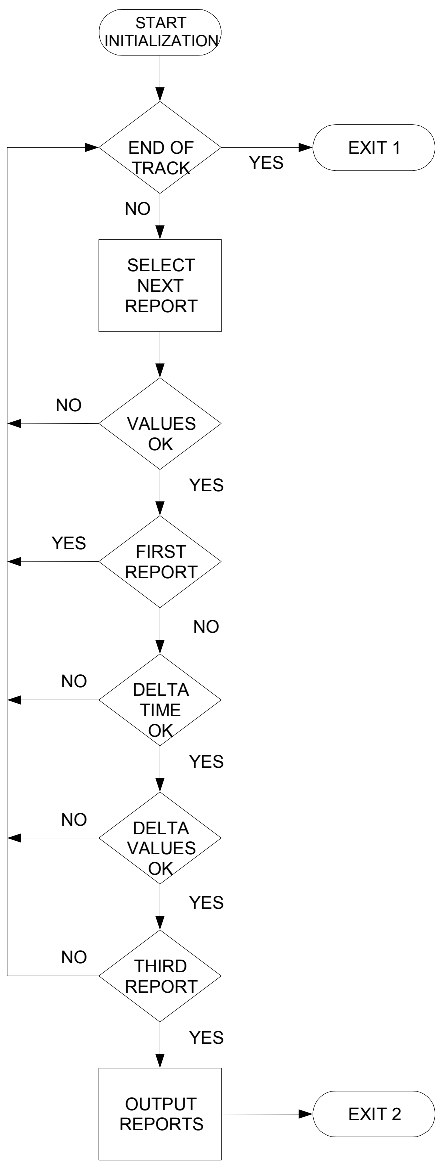

Figure 2. Radar Track Initialization

Processing a Time Gap

If the report has failed the time gap test, but is otherwise acceptable, it can be kept. Four additional tests are applied to the report. The flow chart in Figure 3 illustrates the tests. They are the *Values Test*, the *Variable Deltas Test*, the *Prediction Test*, and the *Maximum Time Gap Test*. If the report passes all of the tests, it is kept and the missing track reports are replaced by linear interpolation.

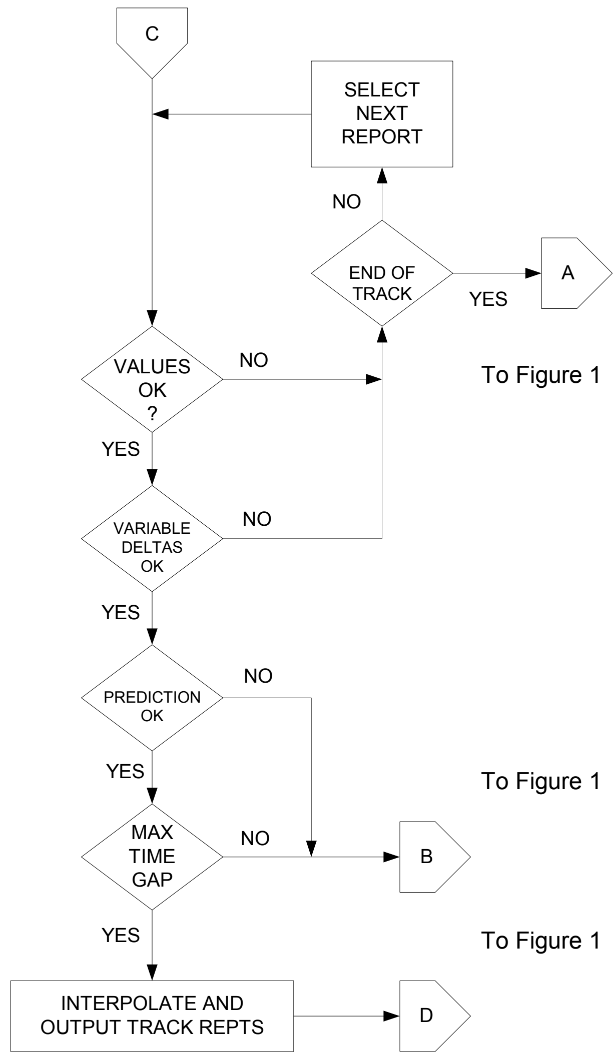

Figure 3. Recovery from Time Gap in Data

The *Values Test* has previously been defined. The other three tests will now be described.

Variable Deltas Test

The *Variable Deltas Values Test* is the same as the *Delta Values Test* except that the thresholds are increased to match the increase in the time step from the previous report. In the above processing by the *Delta Values Test* the thresholds for a 12 second time step were 3.0 nautical miles and 2000 feet. In this test, the thresholds used for a 24 second time step are 6.0 nautical miles and 4000 feet, increased to match the increase in the time step from the previous report. Similarly, the thresholds used for a 36 second time step are 12.0 nautical miles and 6000 feet.

<u>Prediction Test</u>

The candidate track report is next tested by the *Prediction Test*. The previous reports which have been accepted are used to predict the next report after the time gap. A linear prediction assuming a straight line track at constant velocity is used to make the prediction. The prediction is compared with the values in the report. If the values are close enough to the predictions, the report passes the test. The thresholds used are 3.0 nautical miles (horizontal) and 2000 feet (vertical).

<u>Maximum Time Gap Test</u>

There is a caveat in applying the interpolation. If the time gap is greater than two minutes, no interpolation is done. There will be no data for that time period. In the flowcharts of Figure 3 and 4, if the time gap is less than the maximum value, the test is passed and the YES branch is taken.

<u>Interpolation</u>

The interpolation assumes a straight line track and a constant velocity.

<u>Exits</u>

The program searches for a report satisfying the constraints required by the tests. If an acceptable report is found, the program exits the flowchart at Connector D, after sending the report found and the interpolated reports to the output.

If a candidate report fails either the *Prediction Test* or the *Maximum Time Gap Test*, the program exits at Connector B and the track is re-initialized.

If the end of the data for the track being processed is reached, all of the reports after the time gap are discarded and the program moves on to the next track, exiting at Connector A.

The three exits return the program to the flowchart in Figure 1.

<u>Processing a Bad Data Gap</u>

The processing for a bad data gap is similar to the processing for a time gap. In the first flowchart (Figure 1), if a report fails either the *Values Test* or the *Delta Values test*, the program exits at Connector E. The subsequent processing is illustrated in the flowchart of Figure 4.

The next report is selected and the four tests described above are applied. A search through the track reports is conducted until a report that passes all of the tests is found. If the report passes the tests, it is kept and the reports between the last good report found and this report are replaced with interpolated reports and output. The program flow then exits Figure 4 at Connector D. The

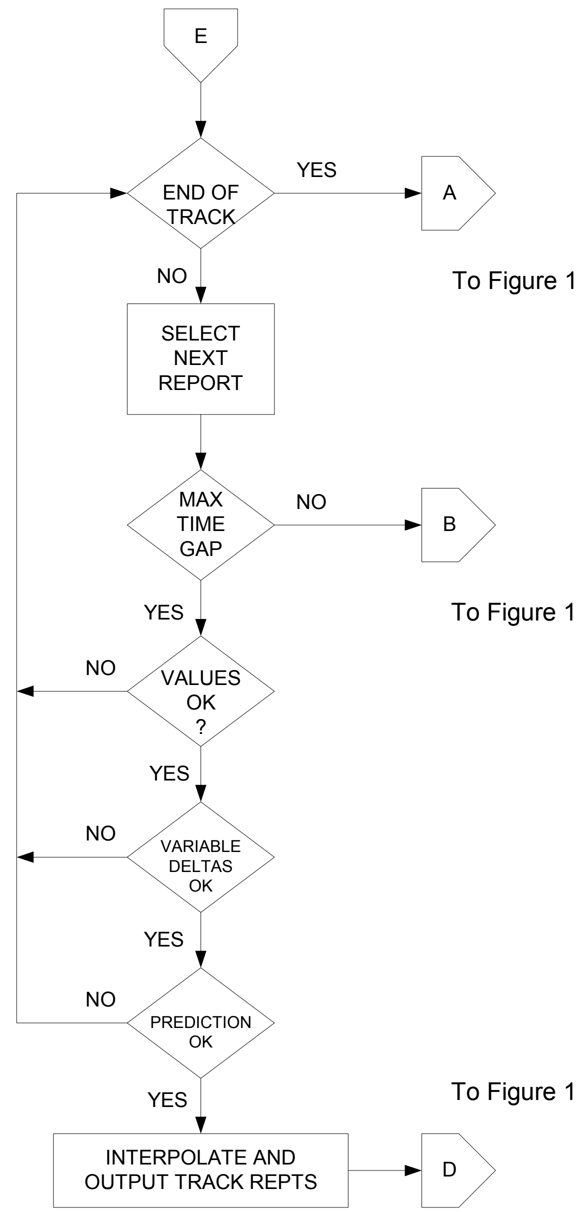

Figure 4. Recovery from Bad Data Gap

flow returns to Connector D in Figure 1 where the program returns to examining each report in turn.

If the search for the next good track report runs out of reports to test, the flow exits at Connector A (Figure 4) and enters Connector A on the flowchart in Figure 1 to select the next aircraft track.

If the two minute maximum time gap is exceeded in the search, the processing exits at Connector B, returning to the flowchart of Figure 1 where the track is re-initialized.

Result of Applying the Tests

The input to the program implementing these tests is an aircraft radar track, a time series of position reports. The output of the program is also an aircraft radar track, a time series of position reports. Most of the output track reports are identical to the input track reports. Some of the gaps in the track data will have been filled with synthesized reports, some new gaps will have been added where bad data has been deleted, and some of the X, Y, and Z values will have been altered.

Maximum Correction Test

An exit test is applied to the resulting track, checking the altered values. If any position report has been altered above a fixed threshold value, the entire track containing the position report is discarded. The maximum allowed change in the horizontal location of the aircraft is 4.0 nautical miles, the maximum allowed change in aircraft altitude is 700 feet. This test is shown in Figure 1.

Smoothing Filter

A non-causal low pass filter was applied to smooth the data – to remove the jitter on the position reports. This test is shown also in Figure 1. The filter calculates a weighted moving average of each of the variables at each track report. The reported values of the aircraft position coordinates are averaged with the values immediately preceding and immediately following. The averaged value replaces the original value. It is applied to the X coordinate values, the Y coordinate values, and the Z coordinate values independently. The filter is implemented as a triangular sliding window in the time domain. The window is two minutes long – averaging 11 report values. The benefit of this processing is a reduction in the jitter in the position reports; the disadvantage of the averaging is a reduction of the response of the filtered data to turns in the aircraft's flight path.

Experimental Results

The methods presented here were implemented in a C computer program and run on a Sun workstation under a Unix operating system (Sun's Solaris). Numerical results summarizing the behavior of the program on a five hour scenario of air traffic recorded at the Indianapolis Center (ZID) on May 26, 1999 are provided here as an example of the application of these methods.

Data Loss

The scenario's 1705 flights and 308,056 track reports were processed in ten minutes by the program. 27 tracks could not be initialized. 7 tracks were not output because the corrections exceeded the maximum allowed. Two tracks had a position report corrected by more than four nautical miles and five tracks had a position report corrected by more than 700 feet. The net number of tracks output by the program was 1671 (98.0% of those input) totaling 300,718 track reports (97.6% of those input). The processing has shortened the tracks slightly.

Time Adjustments

The scenario as input had a total of 306,351 time intervals or time steps. 214,573 or 69.7% were 12 second time steps. 303,581 or 98.5% were either 11 second, 12 second, or 13 second time steps. The maximum time error was two seconds.

Time Gaps

In the input data there were 51 gaps in the track data longer than two minutes. There were six gaps longer than 15 minutes and three longer than 20 minutes.

Table 4 lists the frequency of selected time gaps in the data after processing. In the output data there were 58 gaps of 2 minutes, 12 seconds. These gaps were

Table 4. Gaps in Output Data

Gap Size (Seconds)	Number of Occurrences
12	298882
24	3
36	1
48	1
84	1
96	2
108	1
132	58
144	3
156	2
168	6
…	…
1092	1
1140	2
>1200	4

generated when the interpolation limit of 2 minutes was exceeded and the track was successfully re-initialized on the first try. There were 86 time gaps greater than 2 minutes and less than 15 minutes. There were 12 time gaps longer than 15 minutes and four longer than 20 minutes.

Report Types

The program assigns number codes to the track reports which designate how they were processed. The codes are:

1. This report was the first report of a three contiguous report initialization.
2. This report was the second report of a three contiguous report initialization.
3. This report was the third report of a three contiguous report initialization.
4. This report was passed through the processing unchanged.
5. This report was the last report before a gap in the data.
6. This report was interpolated from a preceding report and a following report. It may have replaced an existing report or there may have been no report for the sample time.
7. This report was the first report following a gap in the data. The gap could have been caused by missing track reports or by a run of bad data.

Table 5 lists the frequencies of the track report types.

Table 5. Frequencies of Output Track Report Types

Record Type Code	Number of Occurrences
1	1836
2	1836
3	1799
4	284292
5	3560
6	4021
7	3374
Total	300718

Initializations

Table 5 shows 1799 successful initializations (Report Type 3). 1678 tracks were initialized. Re-initialization occurred 121 times, or on the average 7.25% of the tracks required re-initializations.

Data Corrections

Of the 300,718 track reports output, 4021 (Report Type 6) or 1.34% were corrected. This is an average of 2.4 reports per track. The average track length was 36 minutes or 180 position reports.

Conclusions

A successful solution to a key data processing problem in the FAA's system test and evaluation work has been developed using a combination of heuristic techniques tailored to the specific data characteristics and a standard filtering method. The majority of the radar data is error free, but the glitches in the data are sufficient, if uncorrected, to make later test and evaluation processing inaccurate.

List of Acronyms

Acronym	Definition
ACID	Aircraft Identifier
ACT-250	Engineering and Integration Services Branch of the FAA/WJHTC
AOZ	Free Flight Program Office of the FAA
ARTCC	Air Route Traffic Control Center
CID	Computer Identifier
CPAT	Conflict Probe Assessment Team
DST	Decision Support System
FAA	Federal Aviation Administration
HCS	Host Computer System
TRACON	Terminal Radar Approach Control
UTC	Universal Coordinated Time
WJHTC	William J. Hughes Technical Center of the FAA

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