Perhaps one of the most contentious aspects of the analysis of American Airlines Flight 77’s (AAL77) flight path is the reconciliation of the radar data released by the U.S. Air Force’s 84th Radar Evaluation Squadron (84 RADES), the Federal Aviation Administration (FAA), and National Transportation Safety Board (NTSB). However, this should not be the case since alignment of the individual data sets is rather straightforward in the case of AAL77. Also, the abundance of data from such a wide spectrum of sources and measurement systems, from take-off to within seconds of the termination of flight, gives a complete and unequivocal historical record.

Aligning the data with respect to time is the preferred method of correlating the multiple data sets. Ideally, a measurement made in one measurement system should reflect the same time ‘stamp’ as one made in another. However, all someone has to do is walk around their own home and compare the time ‘stamp’ on each of the clocks they have scattered around. In most homes, a difference of a few minutes between clocks would be quite normal. The same is true in the case of the multiple time ‘stamp’ clocks in use on 9/11. For example, each of the FAA Air Surveillance Radar (ASR) sites for which there is data should have been set to the same universal time ‘stamp’. However, as the data is collected at the site, it goes into a computer system where it is processed for output to the end user, Air Traffic Control (ATC). The ASR radar will ‘poll’ the transponder on an aircraft and retrieve information such as the Mode 3 identification (civilian transponder code) number which has been assigned to the aircraft by the ATC system. The returned signal and retrieved information will then be combined with flight plan information for that aircraft filed in the system and displayed to the ATC controller. This can result in a several second delay in some cases, with some rather dramatic differences in others.

Perhaps the worst-case scenario in respect to time ‘stamp’ variation for the 9/11 events and AAL77 is with the 84 RADES Northeast Air Defense Sector (NEADS) radar data. 84 RADES provided their radar data for the 9/11 events to the 911 Commission and
later to the public along with software (RS3) with which to review it. In his review of the 84 RADES data, a 911 Commission professional staffer Miles Kara noted a significant time difference between the 84 RADES radar and other sources. This was an issue for him in his discussions with the NTSB and developing a timeline for the various flights\(^1\). Ultimately, he settled upon assigning a 25.3 second offset which simplified his work. Due to time constrains, the issue was not developed further by his team.

The author began a more detailed examination of the time offset in 2008. Fortunately, the data included regular interval ‘quality control’ (BRTQC) returns for each of the reported 84 RADES radar sites. These sites utilized Air Route Surveillance Radar (ARSR) systems with 200 – 250 nautical mile ranges and antenna sweep intervals (one full rotation) of ~ 12 seconds. Another stroke of luck was that the data provided by 84 RADES included the Southeast Air Defense Sector (SEADS) radar data as well. An ARSR-4 (a newer version) site with a 250 nautical mile range located at Oceana, Virginia (OCA) fed its data into both sectors radar systems. Upon examination of the BRTQC signals for both sectors, the SEADS system exhibited a normal Gaussian distribution for the sweep intervals of the OCA site, while the NEADS site exhibited a clear non-Gaussian distribution. In layman’s terms, the SEADS data looked quite normal while the NEADS data did not.

![Chart 1 – SEADS BRTQC Histogram (OCA Site)](chart1.png)
Radar and NTSB Time Normalization

Chart 2 – NEADS BRTQC Histogram (OCA Site)

When compared one-to-one with another (NEADS/SEADS), the graph revealed a much more complex scenario than a simple 25.3 second offset.

Chart 3 – NEADS Time Anomaly
The time difference is segregated into a step-function waveform which increases by ~ 0.1 seconds every ~ 27 minutes. Making matters worse, the offset itself is unstable and produces a ± 0.09 second uncertainty across the affected interval. Although for the entire data set the difference averaged to 25.3 seconds, at the time of the Pentagon event, the time difference was only 25.1 seconds! When contacted with these findings, Cheri Gott with the NORAD USNORTHCOM HQ responded, “Like you, I was a ‘receiver’ of the 84th RADES radar data, and thus cannot speak authoritatively on the source of the timing error. While I was aware of the timing error, a simple manual correction to the data was good enough for my purposes.” This was essentially the same position taken by the 911 Commission staff in regards to the issue.

At face value this seems like a significant issue, and it is for any kind of accurate time correlation. However, as verified by the OCA comparison, all of the other collected data was intact and corresponded one-to-one between the NEADS and SEADS data set. The time ‘stamp’ is the only data impacted by the anomaly. In the case of AAL77, a significant portion of the flight path common to both systems can be checked against one another to verify that this is the case. After consultation with computer science experts at the University of Memphis Electrical Engineering Department, Dr. Steven T. Griffin stated that the anomaly “could be a number of things related to processor architecture including multiprocessor issues.” This was ultimately verified by Jeff Richardson at 84
RADES who advised that there was indeed a processor architecture issue on 9/11 which has since been resolved.

Since the NEADS radar data covers the majority of the flights in question on 9/11, it is an excellent baseline (once the offsets are understood as indicated above) with which to align the other sources of flight data related to AAL77. To bring everything into alignment with ‘real world’ time, one event witnessed by millions of people ‘live’ as it happened was the impact of United Airlines Flight 175 (UAL175) into the South Tower of the World Trade Center. Since the time stamps of the various archived videos of this event vary, the author’s own observations indicate that the broadcast time of this event was at 13:03:00 ± 2 seconds (GMT). Mike Williams⁵ who operates a website called “911 Myths”, did a similar study and determined the time to be 13:02:59, which agrees with that range estimate.

The FAA has provided very limited radar data from the New York TRACON. However they did provide a print-out of radar data from John F. Kennedy International Airport (JFK)⁶ ASR for UAL175⁷. This data is in a very unfriendly and technical format (Figure 1); but can be adapted for comparative purposes with the more straight-forward 84 RADES data.

```
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<th>RANGE</th>
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Figure 1 – JFK ASR Print-Out

The critical information in the files includes range and azimuth (relative to the radar site) for each return, along with the Mode 3 altitude reading (polled from the aircraft transponder). The FAA print-out gives the altitude in Azimuth Change Pulses (ACP), for example “3192” as in the case of the 13:01:43.5 return. There are 4096 ACP...
units in a complete circle\(^8\), so to convert them to degrees of azimuth the following equation is used:

\[
\text{Equation 1)} \quad \theta = \frac{360}{4096} \times ACP
\]

This equation gives \(~ 280.5\) degrees as the radar azimuth for the 13:01:43.5 return.

The range value is given in another odd format as “17/9”. This is not the normal format used for FAA range values which use increments of 1/8th of a nautical mile. After some lengthy trial-and-error, it was determined that “provided target position … for all secondary targets at resolutions of +/- 1/64 nm”\(^9\) was the format being employed. The first number given is in whole nautical miles, while the second number after the “/” is the numerator of a fraction with a denominator of 64. This gives a decimal equivalent for range as 17.140625 nautical miles for the return.

The azimuth also presents another obstacle in matching with the NEADS data. FAA Air Traffic Controllers deal with magnetic, not true headings, and as such the azimuth is given in degrees relative to magnetic north, rather than true north. Since the NEADS data provides latitude (lat) and longitude (long) positional coordinates, the magnetic declination used for the JFK site must be estimated for calculation of similar coordinates. On 9/11/2001, this declination value was 13.4 degrees west\(^10\). This value increases annually and is not necessarily updated regularly. For the purposes of this study, 13 degrees was found to be the best fit.

I am going to develop the equation used for converting the spherical coordinates (azimuth, range and altitude) into geographical coordinates (latitude and longitude) for the sake of those interested in working with the FAA radar data for other purposes. Since most people will use a spreadsheet application for that purpose, the equation will be developed with that purpose in mind and will not necessarily conform to rigorous technical standards in presentation.

First, consider the range which must be in nautical mile units. It is important also to remember that by definition, 1 nautical mile = 1 minute in angular measurement at the surface of the Earth, and there are 60 minutes (or nautical miles) in a degree. Keep in
mind that the Earth is not perfectly spherical, but more of an ellipsoid, where the radius is
greater at the equator than at the poles. That is why a datum is normally used to
compensate for this variation. For the purposes of this study, the distances involved (200
– 250 nautical miles) are negligible so a datum is not used for the sake of simplicity. The
resultant errors from this difference at the latitudes involved are less than the inherent
effects resulting from the radars themselves. The general angular functions in MS Excel
(the most widely used spreadsheet application) are evaluated in radians, so all angular
values (remember, a nautical mile is an angular measurement) will have to be converted
to radians first, and then converted back after evaluation. Another factor to keep in mind
is that the range to an aircraft at 35,000 feet is the hypotenuse of a right triangle. At
ranges close to the radar site, where the plane is at high altitude, the range to the point on
the ground under the aircraft will need to be calculated (if known).

\[
\text{Equation 2) } \quad Lat = \sin^{-1}\left[ \sin(Lat_{\text{site}})\cos\left(\frac{Range_{\text{ground}}}{60}\right) + \cos(Lat_{\text{site}})\sin\left(\frac{Range_{\text{ground}}}{60}\right)\cos(Azimuth_{\text{true}}) \right]
\]

where,

\[
Range_{\text{ground}} = \sqrt{(Range_{\text{radar}})^2 - \left(\frac{\text{Altitude}}{6076.12}\right)^2}
\]

and,

\[
Azimuth_{\text{true}} = \left(\frac{360}{4096} ACP_{\text{radar}}\right) - Dec_{\text{magnetic}}
\]

Range values are in nautical miles, altitude is in feet (in the JFK printout, altitude
is given as multiples of 100), and angles in degrees. Once the latitude has been
calculated, then the longitude can be estimated.
Radar and NTSB Time Normalization

Equation 3)

\[
Long = Long_{site} - \sin^{-1}\left[ \frac{\sin(Azimuth_{true}) \sin\left(\frac{Range_{ground}}{60}\right)}{\cos(Lat)} \right]
\]

Longitude is calculated using positive values. Since the longitude is west, it can be represented by a “W” after the value, or by ascribing it a negative value (74.7937 W or -74.7937).

![Chart 5 – UAL175 Positional](image)

Chart 5 plots the positional data calculated for UAL175 using equations 2) and 3), using a magnetic declination value of 13(W) degrees. As can be seen, the plot matches the positional data from the Gibbsboro, NJ ARSR-4 site (GIB)\(^{12}\) as reported by the 84 RADES NEADS data.
Chart 6 – UAL175 Altitude

Chart 6 plots the Mode 3 altitude values from the JFK and GIB radar data by time. There is no adjustment applied and the Mode 3 value is being pulled by the radar site at the time of the return from the aircraft as recorded by the sites. The difference in time is a function of the clocks in use by the two sites. Fortunately for the purposes of this study, the Mode 3 altitude is also the same value being recorded by the flight data recorder (FDR) on the aircraft. Since this is a value that is being recorded ‘real-time’ by all of the various data sources, it can be used to align other values recorded by the measurement systems (such as position and time) with one another. This will become very important when the NTSB FDR data for AAL77 is discussed and aligned with the radar data. In this case, the plots for JFK and GIB do not align in time. As mentioned before, the time stamp is a function of the computer system recording the data.
In chart 7, a time adjustment is made, \(\text{Time}_{\text{NEADS}} = \text{Time}_{\text{JFK}} - 3.3\sec\). Now, the Mode 3 altitude aligns in time for both data sources. The ARSR sites used by 84 RADES sweep once every \(\sim 12.1\) seconds and the ASR sites (such as JFK) sweep once every \(\sim 4.7\) seconds. In the case of UAL175, the JFK site is also much closer (12.06 nautical miles) than the GIB site (66.9 nautical miles) and is much more accurate (\(\pm 1/64^{\text{th}}\) nautical mile). For these reasons, to correlate the two clocks to ‘real-time’ (as determined by the broadcasts earlier), the JFK data will be used.

The final position for UAL175 was recorded at 13:02:39.2 at a position of 40.70935453 latitude, -74.01497851 longitude, by the JFK site. This is a mere 0.12 nautical miles from impact as captured on live television. So impact would have been \(\sim 1\) second after the last return, or at 13:02:40 JFK time, \(\text{Time}_{\text{JFK}} = \text{Time}_{\text{TV}} - 20\sec\).

Substitution gives \(\text{Time}_{\text{NEADS}} + 3.3\sec = \text{Time}_{\text{TV}} - 20\sec\), or \(\text{Time}_{\text{NEADS}} = \text{Time}_{\text{TV}} - 23.3\sec\). In the earlier comparison of the NEADS clock to the SEADS clock, it was determined that at this time the difference (charts 3 and 4) between the two was \(\sim 25\) seconds, so \(\text{Time}_{\text{SEADS}} - 25\sec = \text{Time}_{\text{TV}} - 23.3\sec\), or \(\text{Time}_{\text{SEADS}} = \text{Time}_{\text{TV}} + 1.7\sec\). The 1.7 second difference between SEADS time and the estimated television broadcast time is within the \(\pm 2\) seconds of error for that estimate, so for the purposes of this study, all data will be
aligned to the SEADS clock which is the best representation of ‘real time’ among the data sets.

Now that the appropriate ‘clock’ has been determined independent of the aircraft of interest, the data for AAL77 can be aligned to a common timeline (SEADS). The best opportunity to do that is the time segment when AAL77 departs from Dulles International (IAD) under normal flight conditions. For that purpose, 4 measurement systems will be used, the ASR located at IAD\textsuperscript{13}, the ARSR located at The Plains, VA (PLA)\textsuperscript{14}, and the FDR located on-board the plane. The ASR data is provided in a similar output as the JFK data from the FAA, the ARSR data from 84 RADES, and the FDR data from the NTSB in a comma-delimited file format (FDR CSV)\textsuperscript{15}. This is ideal for the purposes of this study since the data comes from 3 entirely different government agencies, with completely different measurement systems involved, and wholly independent of one another.

The NTSB has provided a raw file dump\textsuperscript{16} for the FDR; however that file requires specialized proprietary aviation software\textsuperscript{17} and the appropriate frame matrix specific to Boeing aircraft. Fortunately, the NTSB provided a partial output of the FDR data represented in the FDR CSV, which is used for the first phase of the correlation. The focus is upon the actual position of the plane at any given point in time, which in this case will be SEADS time.

As mentioned previously, the Mode 3 altitude used to align UAL175 with radar data is pulled directly from the plane at the time of the radar return (as recorded by the radar site). That same information is collected and saved to the FDR onboard the plane at one-second intervals. Also a lot of other useful parameters (heading, speed, etc) are stored along with the altitude values. Unfortunately, the geographic positional data represented by the FDR CSV file is grossly inaccurate. For example, the position at 12:19:00 is given as 38.933 latitude, -77.800 longitude. At this time the aircraft is at an altitude of 41 feet according to the FDR CSV, and with a barometric pressure adjustment of 300 feet would place the aircraft at ~ 340 feet above sea level. If the FDR CSV position data is taken seriously, then at this time the aircraft was located ~ 16 nautical miles west of IAD and 110 feet underground! However, the IAD ASR radar data places
the aircraft on the runway at IAD at this point in time and the Air Traffic Control records confirm this.

The PLA data is very straight-forward and gives the geographic location and Mode 3 altitude (as polled from the aircraft) in a ready to use format as before. The IAD ASR data was provided in a text file output consisting of raw target reports such as the one copied below.

```
TARGET REPORTS                                      9/11/01             PAGE 697
STIME                RANGE    ACP     DEG  QUA STR    BEACON       ALT               SYS    SCAN
12:20:21.518  19    35.53      2432      214       7      S         2464-3          106-3               RB      0   136
9.25      2442      215       7      S          3214-3           42-3               RB      0   136
1.19      2460      216       7      S          6553-3             4-3               RB      0   136
23.11      2344      206       7      S          1200-3           16-3               BT      0   136
```

The file also has tracking data where the data from the target report is combined with flight plan information.

```
TRACKING DATA                        9/11/01             PAGE 710
TIME             ACID     TRK ABC  RBC FRM RALT  PACP  PDEG PRAN      X          Y      DDEG   DRAN    XV   YV  HDG  SPD     MI   DI ADS    C      SYS SCAN
12:20:32.945  N6579X  185  6523   6523    38    4500    2612     230    22.71   -17.06   -14.69     229      22.51   -104    -4 5    246     113                  DEP   0C        0       139
12:20:32.947   AAL77   55   6553    6553    20      800    2758     242      1.42     -1.06     -0.75     234       1.30    -14 3     73    297     160                  DEP   1D        0       139
```

For the purposes of this study, it is the raw target reports which are of interest. As indicated before, there can be several seconds of lag time associated with the computer system matching the returns with other data and processing for use by the air traffic controllers (ATC). Unlike the JFK data used earlier, the range is already formatted into decimal equivalents and is ready for use with no further processing. Although the azimuth is presented in degrees, the resolution is to the whole degree and not suitable for the purposes of this study, so the ACP values will be used as before. The altitude, “4 -3” in the example above, is 400 feet above mean sea level (MSL). The left value of “4” is a multiple of 100 as in the JFK exercise earlier.
In the chart above, the 3 data sets have been aligned in time. The FDR CSV required a time correction of 1 second, $Time_{IAD} = Time_{CSV} - 1\text{sec}$, for the altitude to align above 18,000 feet MSL, while the PLA data ($Time_{NEADS}$) required a 23 second correction. It is important to note that below 18,000 feet MSL, the IAD values are offset by 300 feet. This is because a local barometric pressure correction is applied at IAD to adjust the altitude to local conditions and reflect a more accurate altitude. At the end-of-flight it will be critical to understand that true altitude is ~ 300 feet greater than the pressure altitude reflected in the FDR CSV locally.

The result of this alignment is that the IAD radar is 2 seconds slower than the SEADS standard, $Time_{IAD} = Time_{SEADS} - 2\text{sec}$ and that AAL77’s geographic location and FDR CSV flight parameters can be matched to the IAD position at any given moment in time. The FDR CSV also reports the frequency of the VHF Omni-directional Radio (VOR) selected by the on-board Distance Measuring Equipment (DME) and the distance of the plane from it. There are two such channels recorded (Left and Right) and the distance given is generally accurate to ±0.1 nautical miles for ground station, with the error range between the ground and aircraft generally less than ± 0.5 nautical miles, or 3% of the distance (whichever is greater) \(^{19}\). Once the geographic location is
established in time, then the distance to a given VOR can be calculated and compared with the value stored in the FDR CSV.

Using the method developed in equations 2) and 3) earlier; the IAD radar indicates a position of 38.9164 latitude, -77.6220 longitude, at 12:22:27. The FDR CSV indicates that the VOR – Left is tuned to 116.3 (MHz), the frequency of the CSN VOR located at 38.6412 latitude, -77.8655 longitude. Either by plotting the two points in Google Earth, or by direct Great Circle calculation, the distance between these two positions is ~ 20 nautical miles. The value recorded in the FDR CSV at 12:22:28 for the DME – Left distance is indeed 20 nautical miles. So, the alignment of the radar positional data with the FDR CSV agrees with the other parameters stored in the FDR CSV.

After leaving the IAD ASR coverage area, the aircraft remains within the range (200 nautical miles) of the PLA ARSR until 12:51:04. It is picked up by numerous Indianapolis radar facilities (QBE, QHY, QRI, QWO and CLE), in particular the ARSR facility in Bedford, Virginia, QBE. The aircraft was acquired by the QBE facility at 12:45:46, permitting a 6 minute overlap of data for alignment purposes with the PLA data. The aircraft was most certainly within range of the QBE site before this, but this is all of the data available for study. Altitude matching with all of the ZID ARSR sites indicates that they are all in time alignment with the IAD ASR (up until this point). All of the ZID sites returned data from the transponder until the final 3743 beacon return acquired by the QWO site at 12:56:31. There is one additional beacon return for 6743 recorded by the QBE site at 12:56:33 corresponding with the projected location of AAL77. After this, no further beacon activity can be associated with the plane.

After the transponder (beacon) was turned off, the QBE site became the primary source of radar data returns, or primary radar data, until the aircraft returns to the PLA ARSR range of coverage. Due to how the radar sort boxes were configured for ZID, this meant that the aircraft was lost to ZID ATC for a time. This is a topic beyond the scope of this study; however Tom Lusch\textsuperscript{20} has completed an in-depth analysis of this issue. The radar coverage was continuous and unbroken by the QBE site. As the aircraft turned back towards the east, it returned to the PLA coverage area at 13:09:55. The positional data continues to correspond with the time correlation for QBE and PLA at this point. The altitude values recorded in the FDR CSV are used to plot the geographic positional values
once the transponder was turned off. The QBE coverage ends at 13:11:53, 4 minutes later.

At 13:23:20, the aircraft is picked up once again by the IAD ASR. At 13:25:46, it is also acquired by the ASR at Reagan National (DCA). With the coverage now including both the PLA and IAD site, a similar altitude correlation can be done for DCA.

![Mode 3 Altitude Matching](image)

**Chart 9 – Mode 3 DCA Altitude**

In chart 9, the Mode 3 Altitude values are plotted for all three radar sites against the raw data time stamps. The NEADS (PLA) time is moving slower than both of the FAA sites, but also the DCA clock is running slightly ahead of the IAD clock.
This confirms the earlier equivalency of $Time_{IAD} = Time_{NEADS} + 23\text{sec}$ and $Time_{IAD} = Time_{SEADS} - 2\text{sec}$ and gives another, $Time_{IAD} = Time_{DCA} - 5\text{sec}$. The DCA ASR is the closest radar facility to the Pentagon (1.7 nautical miles) and the impact event. With time correlations in hand, it is now possible to estimate the Pentagon impact event within a few seconds independent of the NTSB data. At 13:27:28 (DCA time) a helicopter from Andrews AFB (M3 = 5175) passes between the Doubletree hotel and the Pentagon and is captured on a security camera on the north side of the building (9:23:47 video time). 10 minutes and 23 seconds later (9:34:10 video time), the first hint of a fireball is seen emerging from behind I - 395 (which obscures a view of the impact area). This places the impact ~ 13:37:51 DCA time. Using the time correlation, this gives a time of impact at ~ 13:37:47 NTSB CSV time. The NTSB CSV last recorded sub-frame is at 13:37:44, leaving at least three seconds of flight unaccounted for using this method. However, the Doubletree recording and time stamp is very ‘jerky’ and prone to errors, so additional review of the positional information contained in the FDR is required. Similarly, another helicopter (M3 = 5161) is observed on the Citgo video as its shadow is cast on the ground in passing at 9:56:07 video time. This corresponds to a 9:53:23 position based on DCA radar data. The Pentagon impact event is noted as a flash of light.
appearing at 9:40:37 video time, translating to 9:37:53 DCA time. The average of these 2 estimates gives an impact time of 9:37:49 ± 1 second SEADS time.

Clearly the NTSB CSV data ends prematurely. This was established by the author in 2007 when the RADES data was released and a rough positional correlation was completed. That correlation predicted that 6 ± 2 seconds of data was ‘missing’ from the CSV file. Drift in the internal navigational system (INS) was also observed as the plane completed a 330 degree turn just prior to its final approach which also introduced a longitude shift of ~ 0.1 nautical miles west. This longitude shift was ‘correcting’ during the approach, leading to additional and difficult to predict positional error. The time correlation thus far refines that prediction to 3 ± 2 seconds. Unfortunately, although the flight data recorder (FDR) raw data file was released by the NTSB, the file was in a compressed form using a modified Huffman encoding.

<table>
<thead>
<tr>
<th>Site</th>
<th>Site Latitude</th>
<th>Site Longitude</th>
<th>Declination Correction</th>
</tr>
</thead>
<tbody>
<tr>
<td>JFK</td>
<td>40.639555</td>
<td>73.766416</td>
<td>13</td>
</tr>
<tr>
<td>IAD</td>
<td>38.9565</td>
<td>77.463397</td>
<td>10.0</td>
</tr>
<tr>
<td>DCA</td>
<td>38.845181</td>
<td>77.033131</td>
<td>9.8</td>
</tr>
<tr>
<td>ADW</td>
<td>38.812252</td>
<td>76.867051</td>
<td>9.8</td>
</tr>
<tr>
<td>QBE</td>
<td>37.517264</td>
<td>79.51013</td>
<td></td>
</tr>
<tr>
<td>QHY</td>
<td>38.699726</td>
<td>81.532519</td>
<td></td>
</tr>
<tr>
<td>QRI</td>
<td>36.916207</td>
<td>82.890857</td>
<td></td>
</tr>
<tr>
<td>QWO</td>
<td>39.846022</td>
<td>83.481694</td>
<td></td>
</tr>
<tr>
<td>CLE</td>
<td>41.302247</td>
<td>81.683345</td>
<td></td>
</tr>
</tbody>
</table>

Table 1 – FAA Site Values Used

In 2009, an independent programmer, Warren Stutt was able to reverse-engineer the Huffman encoding and extracted the data from the raw data file. Data is stored in the FDR in frames of 1020 12-bit WORD’s over 4 seconds, with each second of data representing a sub-frame. What he found was that the final frame recorded slightly less than a complete frame, 1007 12-bit WORD’s, or only 3.95 seconds of data. The software used by the NTSB and others was designed to read only complete frames and hence did not extract the data from the final frame. Comparing the time stamp in the Warren decode
Radar and NTSB Time Normalization

to the NTSB CSV for equivalent sub-frames leads to the correlation,

\[ Time_{CSV} = Time_{FDR} - 4 \text{ sec} \]

<table>
<thead>
<tr>
<th>Latitude Offset</th>
<th>Longitude Offset</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.0004</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Table 2 – Positional Offsets

With the new time correlation, it is now possible to further correlate the FDR positional data. As mentioned, there is a significant amount of drift in the INS at this time which tends to be correcting over time. The applied positional corrections are (valid ONLY for the final seconds of flight) given in Table 2 and the final positional data after alignment with the IAD radar and topography (based on radar altitude) measurements is given in Table 3.

<table>
<thead>
<tr>
<th>Model (seconds)</th>
<th>FDR</th>
<th>IAD</th>
<th>Latitude (aligned)</th>
<th>Longitude (aligned)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-18</td>
<td>13:37:34</td>
<td>13:37:29</td>
<td>38.85241</td>
<td>-77.10157</td>
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<tr>
<td>-17</td>
<td>13:37:35</td>
<td>13:37:30</td>
<td>38.85326</td>
<td>-77.09951</td>
</tr>
<tr>
<td>-13</td>
<td>13:37:39</td>
<td>13:37:34</td>
<td>38.85687</td>
<td>-77.09109</td>
</tr>
<tr>
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<td>13:37:40</td>
<td>13:37:35</td>
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<td>-77.08886</td>
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<tr>
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<td>13:37:42</td>
<td>13:37:37</td>
<td>38.85962</td>
<td>-77.0844</td>
</tr>
<tr>
<td>-7</td>
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<td>13:37:40</td>
<td>38.86253</td>
<td>-77.07753</td>
</tr>
<tr>
<td>-6</td>
<td>13:37:46</td>
<td>13:37:41</td>
<td>38.86356</td>
<td>-77.0753</td>
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<tr>
<td>-5</td>
<td>13:37:47</td>
<td>13:37:42</td>
<td>38.86459</td>
<td>-77.0729</td>
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<tr>
<td>-3</td>
<td>13:37:49</td>
<td>13:37:44</td>
<td>38.86665</td>
<td>-77.06792</td>
</tr>
<tr>
<td>-2</td>
<td>13:37:50</td>
<td>13:37:45</td>
<td>38.86768</td>
<td>-77.06552</td>
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<tr>
<td>-1</td>
<td>13:37:51</td>
<td>13:37:46</td>
<td>38.86871</td>
<td>-77.06294</td>
</tr>
<tr>
<td>0</td>
<td>13:37:52</td>
<td>13:37:47</td>
<td>38.86992</td>
<td>-77.06054</td>
</tr>
</tbody>
</table>

Table 2 – Positional Modeling
The model scale is based on the final recorded position as 0. Based on the final recorded speed of ~ 483 knots, the plane would travel ~ 770 feet before the FDR stopped recording. The model however is data driven and as such is an approximation of the final recorded position. Estimated error for the approximation is ± 0.25 seconds, which translates to ± 202 feet along the flight path at 483 knots. As a reality check, the actual distance along the flight path from the model position 0 to the impact area at the Pentagon is ~ 690 feet. This is a difference of 80 feet, well within the estimated error range. Another estimate based on WORD positions by Warren Stutt estimates the distance at ~ 590, a difference of 180 feet which is also within the estimated error range²².

An additional sanity check is to compare recorded DME values with actual distances from the model positions to the DCA VOR. The DME values are recorded in 0.25 nautical mile increments in the FDR and are sampled after the positional data, which means that by the time the DME is recorded, the aircraft travels a distance beyond the last recorded position. At model position -5, the DME is sampled at 1.5 nautical miles and the actual distance from that position to the DCA VOR is 1.74 nautical miles. At model position -1, the DME is sampled at 1.25 nautical miles and the actual distance is 1.36 nautical miles. Both results are within the expected range of error (DME accuracy as noted earlier is ± 0.5 nautical miles) and reasonable. The FDR terminates at ~ 13:37:50 (SEADS time) consistent with an impact at the Pentagon.

**Time Correlation Summary**

\[
\begin{align*}
Time_{SEADS} &= Time_{TV} + 2 \text{ sec} \\
Time_{SEADS} &= Time_{IAD} + 2 \text{ sec} \\
Time_{SEADS} &= Time_{NEADS} + 25 \text{ sec} \\
Time_{SEADS} &= Time_{DCA} - 3 \text{ sec} \\
Time_{SEADS} &= Time_{CSF} + 1 \text{ sec} \\
Time_{SEADS} &= Time_{FDR} - 3 \text{ sec}
\end{align*}
\]
The alignment was done to SEADS since it is the data set that has the greatest number of alignment points. It is noteworthy that IAD does equal TV (broadcast) time as estimated at the beginning of the study.

**Radar Coverage Chart Summaries**

by Glen Schulze
Radar and NTSB Time Normalization

Footnotes:

1 Miles Kara, email to Julius Chris (NTSB) dated August 11, 2003 2:06pm
   “It is clear that NEADS clock was slow by 25.3 seconds. What is not clear is how that correction
   was applied, if at all.”

2 Cheri Gott, email dated October 03, 2008 4:51 PM

3 Dr. Steven T. Griffin, email dated August 01, 2008 1:22 PM

4 Jeff Richardson, email dated November 19, 2008 11:14 AM
   “Raw radar data does not have time associated with it. The radar data is assumed to be real-time
   (or near real-time) upon input into the military command and control systems and/or the FAA
   ATC systems. The 84 RADES data recorders time stamp the data as the data is recorded at the
   ADSs [Air Defense Sectors]. I'm not sure what our timing source was in 2001 (NTP, GPS, or ?)
   but a precise timing method was used to periodically update our recorders and keep them time
   synched. There evidently was problem with the way our NEADS recorder time was being updated
   as seen in the 25 second late timing during the 911 event. Without periodic time updates, our data
   recorders internal time it used which we found can drift considerably. Since 911 we have changed
   the architecture of our recorders to prevent the time drift.”
   “Also, there can be considerable system delays from the radar antenna to the C2 / ATC facilities
   caused by local radar site data processing, the comm systems, and the central C2 and/or ATC
   computer system processing that in total can amount to a couple of seconds.”

5 Mike Williams, “911 Myths”, email dated Sat 10/3/2009 2:03 PM,

6 ASR coordinates, 40.639555 latitude, -73.766416 longitude

7 FAA, “4 N90 67 Plot & Printout UAL175 ERIT”, pg 25-27

8 Tom Lusch, email dated Fri 10/2/2009 10:09 AM

   (accessed October 4, 2009)


11 84 RADES, “MEMORANDUM FOR FEDERAL BUREAU OF INVESTIGATION (FBI)”, September
    13, 2001, pg 3
“The primary range accuracy limitation for both primary and secondary radar systems is 1/8 nmi due to the target reporting format employed by the radar system. Azimuth accuracy is limited to approximately 0.2 degrees for both primary and secondary radar systems.”

12 ARSR-4 coordinates, 39.824722 latitude, -74.954167 longitude
13 ASR-9 coordinates, 38.956617 latitude, -77.463278 longitude
14 ARSR-3 coordinates, 38.882306 latitude, -77.703056 longitude
15 “AAL77_tabular.csv”, NTSB, January 29, 2002
16 “American 77.fdr”, NTSB
17 ROSE, Fairchild L-3 Engineering
18 “I IAD 6 CDR extraction IADAAL.txt”, FAA
22 Warren Stutt, email dated 12/16/2009 10:27 PM

“The position is recorded at words 59 to 62 of each subframe, so if the position recorded was the position of the aircraft at word 59 then there would make 185 words that were recorded after this and given that word 243 was the last word recorded would take 0.723 seconds or be about 590 feet at 483 knots. This would be the shortest possible time and distance. If the position was not recorded immediately after it was read, the time and distance would be longer.”