## NATIONAL TRANSPORTATION SAFETY BOARD

Office of Research and Engineering  
Washington, D.C. 20594  

February 15, 2002

**Recorded Radar Data Study**  
**American Airlines Flight 11**  
**United Airlines Flight 175**  
**American Airlines Flight 77**  
**United Airlines Flight 93**  

by Daniel R. Bower, Ph.D.

### A. SUBJECT AIRCRAFT

<table>
<thead>
<tr>
<th>Location</th>
<th>New York City, NY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date</td>
<td>September 11, 2001</td>
</tr>
<tr>
<td>Time</td>
<td>08:47 AM Eastern Daylight Time</td>
</tr>
<tr>
<td>Flight</td>
<td>American Airlines Flight 11</td>
</tr>
<tr>
<td>Aircraft</td>
<td>Boeing 767</td>
</tr>
<tr>
<td>NTSB#</td>
<td>DCA01MA060</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Location</th>
<th>New York City, NY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date</td>
<td>September 11, 2001</td>
</tr>
<tr>
<td>Time</td>
<td>09:03 AM Eastern Daylight Time</td>
</tr>
<tr>
<td>Flight</td>
<td>United Airlines Flight 175</td>
</tr>
<tr>
<td>Aircraft</td>
<td>Boeing 767</td>
</tr>
<tr>
<td>NTSB#</td>
<td>DCA01MA063</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Location</th>
<th>Arlington, VA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date</td>
<td>September 11, 2001</td>
</tr>
<tr>
<td>Time</td>
<td>09:38 AM Eastern Daylight Time</td>
</tr>
<tr>
<td>Flight</td>
<td>American Airlines Flight 77</td>
</tr>
<tr>
<td>Aircraft</td>
<td>Boeing 757-200, registration: N644AA</td>
</tr>
<tr>
<td>NTSB#</td>
<td>DCA01MA064</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Location</th>
<th>Shanksville, PA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date</td>
<td>September 11, 2001</td>
</tr>
<tr>
<td>Time</td>
<td>10:03 AM Eastern Daylight Time</td>
</tr>
<tr>
<td>Flight</td>
<td>United Airlines Flight 93</td>
</tr>
<tr>
<td>Aircraft</td>
<td>Boeing 757-200, registration: N591UA</td>
</tr>
<tr>
<td>NTSB#</td>
<td>DCA01MA065</td>
</tr>
</tbody>
</table>
B. GROUP

Daniel Bower, Ph.D.
Senior Aerospace Engineer
NTSB, RE-60
490 L'Enfant Plaza E, SW
Washington, DC 20594

C. SUMMARY

This document describes information obtained from various sources of recorded radar of the subject aircraft both before and after the hijacking events, and a general overview of the time correlation of the data for all four aircraft with other data sources. Time synchronized ground tracks of the hijacked aircraft are presented.

D. RADAR DATA

Section I – Data Sources

Air Route Surveillance Radar (ARSR) data was obtained from the FAA’s New York, Washington, Boston, and Cleveland Air Route Traffic Control Centers (ARTCC), output using the National Track Analysis Program (NTAP). ARSR radar data was also obtained from the United States Air Force 84th Radar Evaluation Squadron (84th RADES). Airport Surveillance Radar (ASR) data was acquired from several airport facilities’ Terminal Radar Control (TRACON) areas. ASR radar normally records data approximately every 4½ seconds, but ARSR data is only recorded every 12 seconds. Both primary¹ radar data and secondary radar returns were recorded in the various radar data sets.

The accuracy of the radar returns decreases with increasing distance from the radar sites. Since the relative distances of all the radar sites are different, there is a differing amount of error in the position of the aircraft determined from each radar source. An effort was made to account for the error in each radar data set, such that the best alignment of all radar data sets was achieved. The typical range for the ASR antennas is approximately 60 miles, so ASR information was obtained from those sites that captured the radar returns for the final portions of the flights in New York City. The USAF RADES data were obtained to capture the entire flights, from the initial radar contact with the

¹ A “primary” only target is received as a reflection of radar energy only. A “secondary” or “beacon” only target is recorded as a response of the aircraft’s transponder to interrogation by the radar system. A “reinforced” target is recorded by the radar system in lieu of a primary or secondary target when transponder information is coincident with and reinforces a reflection of radar energy. Generally, secondary and reinforced returns are referred to as “secondary” targets.
RADES facilities to the final radar returns. Since the RADES data covers the entire east coast of the United States, the RADES data contained all of the data for all of the flights in a consistent time base.

The FAA provided the ASR range/azimuth transponder secondary radar data and primary radar data for the hijacked flights. The data included radar clock time, range from the respective ASR radar antenna, magnetic azimuth angle, and flight level. The format supplied by the FAA for the ASR data contains time in hours, minutes, seconds, range from the radar site in nautical miles (NM), azimuth in ACP's (4096 ACP's = 360°), flight level in 100's of feet-msl, and beacon codes. The range-azimuth-altitude format for each data set was converted to latitude-longitude-altitude format using site data for each ASR radar site\(^2\). NTAP data and USAF RADES data was obtained in latitude-longitude-altitude format.

Occasionally, the clock time of day recorded at the individual radar sites may not be consistent. Since transponder altitude is recorded in every aircraft data set, the altitude data is a common piece of information for all the radar data. For example, if an aircraft is ascending after takeoff, it should pass through 10,000 feet altitude at the same time of day at every radar site. In cases of inconsistencies, the time of day of a radar data set must be adjusted to be consistent in altitude and time. The time of day at the airport ASR facilities is set at each facility, such that each ASR facility's radar data could have a slightly different time of day.

In this study the time of day used as the standard time is from the USAF 84\(^{th}\) RADES data, which covers all of the flights from takeoff to respective impacts. Initial comparisons of the radar data from the USAF and the FAA showed that an offset in time was present. The 84\(^{th}\) RADES found that the clock for the North East Air Defense Sector (NEADS) lagged the clocks for the other sectors by 25.3 seconds. The other sectors were all in agreement with the Global Positioning Satellite (GPS) time. Therefore, 25.3 seconds must be added to the radar data from the 84\(^{th}\) RADES.

Comparison of the altitude data from the various NTAP centers and RADES showed no offset in time required for the FAA data from Washington, Cleveland, and Boston centers. An offset of 8 seconds was corrected in the NTAP radar data from New York center to align with the time of day from the RADES and other center NTAP radar data sets.

The ARSR-4 long-range radar systems utilized by the FAA and the USAF have the capability to estimate the altitude of primary targets with a certain degree of accuracy. This capability is only available from the ARSR antennas

\(^2\) The range-azimuth-altitude format for each data set was converted to latitude-longitude-altitude format using the appropriate magnetic variation and antenna elevation for each radar site, with a WGS84 Earth surface model.
that have been specially modified for this purpose. The published\textsuperscript{3} root-mean square accuracy of the height estimated by the radar system is +/- 3000 feet. After 08:21 EDT, American Airlines flight 11 no longer contained transponder altitude information. However, primary returns in the 84\textsuperscript{th} RADES data contained radar-derived heights for the remainder of the flight.

\textbf{Section II - Time Correlation}

A time correlation was made between the RADES radar data, NTAP radar data, ASR radar data sets, FDR data (when available), and Air Traffic Control (ATC) radio transmission transcript data. Times indicated with the USAF RADES radar data were used as the reference time, and the FDR and ATC clocks were adjusted accordingly. Times given in this report are in 24-hour format, in the form HH:MM:SS Eastern Standard Time (EST). The FDR records information relative to an elapsed time in seconds, and are assigned a time of day correlation using the technique outlined below.

A comparison of the radar altitude versus local time for the several radar data sets with the FDR data (UAL83 and AA77) provided the basis for correlating the respective FDR data to the time of day. FDR altitude versus elapsed time was transposed to the radar data time of day using a single anchor point, i.e. a specified number of elapsed seconds on the FDR = 00:00:00 EDT. This anchor point is different for each FDR, and is further verified using radio callouts on the ATC transcript and microphone keying on the FDR.

As discussed in a previous section, transponder altitude data was recorded from several radar facilities. All of the radar systems from the USAF RADES utilized the same time of day clock, and this time of day was also consistent with the adjusted NTAP and ASR radar time of day. After the correlation was applied to the FDR data, the ATC transcript provided an additional check of the correlation for the radio transmissions. All the FDR and radar data in this report are given in the correlated local time (EDT). Refer to the FDR Factual Report for FDR data extracted for UA flight 93 and AA Flight 77.

\textbf{Section III - Radar Data}

The recorded radar data from the various sources is contained on a CD-ROM. The data is organized with separate directories for the data for each flight. Within each flight’s directory are subdirectories that contain data either from a specific source as labeled, or combined from several sources to capture the flight. There are also directories for data that contains returns for all of the flights together in the same files. The directory structure is shown below, and this

\textsuperscript{3} Both the FAA and 84\textsuperscript{th} RADES have documented the capabilities of the radar sensing antennas in their respective technical manuals.
section provides a brief description of each file in the directories and sub directories.

**Radar Data CD-ROM Directory structure**

- HJK
  - AAL11
    - AAL11 N90
    - AAL11 processed and misc
    - AAL11 ZBW
    - AAL11 ZNY
  - AAL77
    - AAL77 IAD and DCA
    - AAL77 misc and processed
    - AAL77 ZDC
    - AAL77 ZID
  - Airforce
  - Combined
  - RADES
  - UAL175
    - UAL175 misc and processed
    - UAL175 N90
    - UAL175 ZBW
    - UAL175 ZNY
  - UAL93
    - Processed UAL93
    - ZDC UAL93
    - ZNY UAL93
    - ZOB UAL93
    - Underlying ASRs

**List of Files:**

**American Airlines Flight 11**

...\AAL11\AAL11N90

- AAL11 EWR TATU 1240 to 1248.txt
- AAL11 SWF TATU 1229 to 1246.txt
- EWR ASR UAL175 and AAL11 1235 to 1300.zip
- EWR ASR UAL175 and prim 1300 to 1315.zip
- EWR ASR UAL175 corrected beacons.txt
- HPN ASR UAL175 and AAL11 1230 to 1300.zip
- ASR UAL175 beacons and primaries in WTC area.txt
- JFK ASR UAL175 and AAL11 1230 to 1300.zip
- JFK ASR UAL175 and prim 1300 to 1315.zip

**Source**

- FAA
- FAA
- FAA
- FAA
- FAA
- FAA
- FAA
- FAA
- FAA
- FAA
JFK ASR UAL175 corrected beacons.txt
N90 ERIT no coords 1200 to 1230.rs3
N90 ERIT no coords 1230 to 1300.rs3
N90 ERIT no coords 1300 to 1330.rs3
N90 TATUTG unk site 1235 to 1305.txt
N90 TATUTG unk site 1235 to 1305a.txt
Read Me.txt
SWF ASR UAL175 and AAL11 1230 to 1300.zip

...\AAL11\AAL11 Processed and misc
AAL11 ACARS messages.txt
Aal11 back converted from RVP - don't use targets with D.urf
Aal11 EWR RAPTOR procesed 1240 to 1247.txt
AAL11 primaries including height.txt
Aal11 RAPTOR processed unknown site.txt
Aal11 trimmed from RS3.rad
aal11 trimmed from RS3.txt

...\AAL11\AAL11 ZBW
aal11 zbw prim 1219 to 1235.txt
AAL11 ZBW prim 1233 to 1315.txt
aal11 zbw prim 1235 to 1248.txt
ZBW AAL11 beacon only 1155 to 1300.txt

...\AAL11\AAL11 ZNY
aal11 zny 1238 to 1240 prim.txt
aal11 zny 1240 to 1243.txt
aal11 zny 1242 to 1246.txt
aal11 zny 1245 to 1249.txt
aal11 zny 1245 to 1249a.txt

American Airlines Flight 77

...\AAL77

crw91101.txt
...\VAA77 IAD and DCA

AAL77 DCA ASR 1300 to 1400.txt FAA
AAL77 IAD ASR 1210 to 1400.txt FAA

...\VAA77\VAA77 misc and processed

Aal77 back converted - don't use D targets.urf 84th RADES
Aal77 export from RS3.rad 84th RADES
aal77 export from RS3.txt 84th RADES

...\VAA77\VAA77 ZDC

Aal77 zdc 1320 to 1339.txt FAA
aal77a zdc 1303 to 1321.txt FAA
Aal77a1 zdc 1258 to 1306.txt FAA
Aal77a2 zdc 1256 to 1302.txt FAA
Aal77a3 zdc also 1256 to 1302.txt FAA
aal77c zdc 1220 to 1249.txt FAA
ZDC AAL77 NTAP 6553 code.txt FAA

...\VAA77\VAA77 ZID

AAL77 zid 1234 to 1258 beacon only.txt FAA
ZID AAL77 beacon only.txt FAA
ZID AAL77 prim1.txt FAA
ZID AAL77 prim2.txt FAA
ZID AAL77 prim4.txt FAA
ZID bad NTAP.txt FAA

Air Force Data (all flights)

...\Airforce

First.edt 84th RADES
second.edt 84th RADES
Sept11_a.edt.xls 84th RADES

...\Combined

all four from RS3.rad 84th RADES
filtered RS3 export showing all four airplanes.urf
filtered RS3 export showing all four airplanes.xls
N90 post impact TATU etc.txt

84th RADES
84th RADES
FAA

.\RADES
12541200.rs3
12541230.rs3
12541300.rs3
12541330.rs3
12541400.rs3
12541430.rs3
RADES timeline.doc

United Airlines Flight 175

.\UAL175\UAL175 misc and processed

N90 RAPTOR processed 1234 to 1303.txt
UAL175 ACARS messages.txt
Ual175 export from RS3.rad
ual175 export from RS3.txt

FAA

84th RADES
84th RADES

.\UAL175\UAL175 N90

EWR ASR UAL 175 and AAL11 1235 to 1300.zip
EWR ASR UAL175 and prim 1300 to 1315.zip
EWR ASR UAL175 corrected beacons.txt
HPN ASR UAL175 and AAL11 1230 to 1300.zip
ASR UAL175 beacons and primaries in WTC area.txt
JFK ASR UAL175 and AAL11 1230 to 1300.zip
JFK ASR UAL175 and prim 1300 to 1315.zip
JFK ASR UAL175 corrected beacons.txt
N90 ERIT no coords 1200 to 1230.rs3
N90 ERIT no coords 1230 to 1300.rs3
N90 ERIT no coords 1300 to 1330.rs3
N90 RT unk site 1300 to 1307.txt
N90 TA all sites 1300 to 1307.txt
N90 TATUTG unk site 1300 to 1307.txt
N90 TG all sites 1300 to 1307.txt
SWF ASR UAL175 and AAL11 1230 to 1300.zip

FAA
FAA
FAA
FAA
FAA
FAA
FAA
FAA
FAA
FAA
FAA
FAA

84th RADES
84th RADES
84th RADES
FAA
### UAL 175

<table>
<thead>
<tr>
<th>File Name</th>
<th>FAA</th>
</tr>
</thead>
<tbody>
<tr>
<td>ual175 and aal11 ZBW 1233 to 1315.txt</td>
<td>FAA</td>
</tr>
<tr>
<td>ual175 ZBW 1210 to 1330 1470 code only.txt</td>
<td>FAA</td>
</tr>
<tr>
<td>ual175 ZBW 1244 to 1303.txt</td>
<td>FAA</td>
</tr>
</tbody>
</table>

### UAL 175

<table>
<thead>
<tr>
<th>File Name</th>
<th>FAA</th>
</tr>
</thead>
<tbody>
<tr>
<td>ual175 zny 123730 to 124130.txt</td>
<td>FAA</td>
</tr>
<tr>
<td>ual175 zny 123920 to 124430.txt</td>
<td>FAA</td>
</tr>
<tr>
<td>ual175 zny 1242 to 1246.txt</td>
<td>FAA</td>
</tr>
<tr>
<td>ual175 zny 1245 to 1249.txt</td>
<td>FAA</td>
</tr>
<tr>
<td>ual175 zny 1245 to 1249b.txt</td>
<td>FAA</td>
</tr>
<tr>
<td>ual175 zny 1248 to 1254.txt</td>
<td>FAA</td>
</tr>
<tr>
<td>ual175 zny 1251 to 1257.txt</td>
<td>FAA</td>
</tr>
<tr>
<td>ual175 zny 1251 to 125930.txt</td>
<td>FAA</td>
</tr>
<tr>
<td>ual175 zny 125620 to 130150.txt</td>
<td>FAA</td>
</tr>
<tr>
<td>ual175 zny 1258 to 1304.txt</td>
<td>FAA</td>
</tr>
<tr>
<td>ual175 zny 1300 to 1304.txt</td>
<td>FAA</td>
</tr>
<tr>
<td>ual175 zny 130130 to 1304.txt</td>
<td>FAA</td>
</tr>
</tbody>
</table>

### United Airlines Flight 93

### UAL 93

<table>
<thead>
<tr>
<th>File Name</th>
<th>FAA</th>
</tr>
</thead>
<tbody>
<tr>
<td>UAL93 Beacon JFK and EWR ASR.txt</td>
<td>FAA</td>
</tr>
<tr>
<td>ual93 PIT Tracon 1300 to 1440.txt</td>
<td>FAA</td>
</tr>
</tbody>
</table>

### Processed UAL 93

<table>
<thead>
<tr>
<th>File Name</th>
<th>FAA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ual93 back exported from RVP, don't use D targets.urf</td>
<td>84th RADES</td>
</tr>
<tr>
<td>Ual93 combined NTAPs unfiltered.urf</td>
<td>84th RADES</td>
</tr>
<tr>
<td>Ual93 combined NTAPs.rad</td>
<td>84th RADES</td>
</tr>
<tr>
<td>ual93 end segment back exported from RVP.txt</td>
<td>84th RADES</td>
</tr>
<tr>
<td>Ual93 end segment only.rad</td>
<td>84th RADES</td>
</tr>
<tr>
<td>Ual93 from RS3.rad</td>
<td>84th RADES</td>
</tr>
<tr>
<td>ual93a export from RS3.txt</td>
<td>84th RADES</td>
</tr>
<tr>
<td>ual93b export from RS3.txt</td>
<td>84th RADES</td>
</tr>
<tr>
<td>ual93c export from RS3.txt</td>
<td>84th RADES</td>
</tr>
</tbody>
</table>
...UAL93\ZDC UAL93

ual93 all zdc ntaps merged together.txt  FAA
ual93 zdc 1305 to 1325.txt  FAA
ual93 zdc 1318 to 1320.txt  FAA
ual93 zdc 1324 to 1330.txt  FAA
ual93 zdc 1324 to 1330a.txt  FAA
ual93 zdc 1324 to 1330b.txt  FAA
ual93 zdc 1325 to 1345.txt  FAA
ual93 zdc 1346 to 1356.txt  FAA
ual93 zdc 1353 to 1403.txt  FAA
ual93 zdc 1354 to 1359.txt  FAA
ual93 zdc 1354 to 1359a.txt  FAA
ual93 zdc 1402 to 1410.txt  FAA

...UAL93\ZNY UAL93

ual93 zny 1239 to 1249.txt  FAA
ual93 zny 1245 to 1255.txt  FAA
ual93 zny 1245 to 1255a.txt  FAA
ual93 zny 125430 to 1304.txt  FAA
ual93 zny 1300 to 1310.txt  FAA
ual93 zny 1306 to 1316.txt  FAA
ual93 zny 131230 to 132230.txt  FAA
ual93 zny 1318 to 1324.txt  FAA

...UAL93\ZOB UAL93

ual93 zob 1255 to 1300.txt  FAA
ual93 zob 1330 to 1334.txt  FAA
ual93 zob 1334 to 1338.txt  FAA
ual93 zob 1338 to 1342.txt  FAA
ual93 zob 1342 to 1346.txt  FAA
ual93 zob 1346 to 1350.txt  FAA
ual93 zob 1350 to 1354.txt  FAA
ual93 zob 1358 to 1402.txt  FAA
ual93 zob 1402 to 1406.txt  FAA
ual93 zob 1406 to 1410.txt  FAA
Airport ASR Data

Underlying ASRs

BDL Approach TDTG 1200 to 1300.txt  FAA
BOS Approach TD 1200 to 1228.txt  FAA
BOS Approach TD only AAL11 UAL175 and DAL1989.txt  FAA
BOS Approach TG 1155 to 1355.txt  FAA
Cape Approach TATUTG 1200 to 1300.txt  FAA
MHT Approach TATUTG 1200 to 1300.txt  FAA
PVD Approach TDTG 1200 to 1300.txt  FAA
Read Me.txt  FAA
UAL175 ABE CDR TATUTG 1243 to 1256.txt  FAA

Section IV - Ground Tracks Description

The following figures show the ground track of all four hijacked flights, American Airlines Flight 11, United Airlines Flight 175, American Airlines Flight 77, and United Airlines Flight 175. The ground tracks are based on radar data obtained from the Federal Aviation Administration’s Air Route Traffic Control Centers and the U.S. Air Force 84th Radar Evaluation Squadron. Where available, flight data recorder (FDR) information was used to supplement the radar data. All figures show the ground track of the flights overlaid on a simplified map of the northeast United States. The first figure shows the entire ground track for all four flights. The subsequent figures show the ground track for successive 15-minute periods, as specified on the figure. In these figures the entire flight path is shown with a dotted line, and the ground track for the specified 15-minute period is shown with a solid line. The beginning of the solid line corresponds to the initial time specified, and the end of the solid line corresponds to the final time specified.

The figures shown are:

Figure 1:  Ground Track for duration of all flights
Figure 2:  Ground Track for all flights, 8:00 AM through 8:15 AM
Figure 3:  Ground Track for all flights, 8:15 AM through 8:30 AM
Figure 4:  Ground Track for all flights, 8:30 AM through 8:45 AM
Figure 5:  Ground Track for all flights, 8:45 AM through 9:00 AM
Figure 6: Ground Track for all flights, 9:00 AM through 9:15 AM

Figure 7: Ground Track for all flights, 9:15 AM through 9:30 AM

Figure 8: Ground Track for all flights, 9:30 AM through 9:45 AM

Figure 9: Ground Track for all flights, 9:45 AM through 10:03 AM

Daniel R. Bower, Ph.D.
Senior Aerospace Engineer
FIGURE 2

Ground Track of all flights
08:00 through 08:15 AM
FIGURE 4

Ground Track of all flights
08:30 through 08:45 AM

[Map showing flight tracks in the northeastern United States, with different colored lines representing different flights.]

- American Airlines Flight 11
- United Airlines Flight 175
- American Airlines Flight 77
- United Airlines Flight 93
FIGURE 5

Ground Track of all flights
08:45 through 09:00 AM
FIGURE 7

Ground Track of all flights
09:15 through 09:30 AM

Legend:
- American Airlines Flight 11
- United Airlines Flight 175
- American Airlines Flight 77
- United Airlines Flight 93
FIGURE 9

Ground Track of all flights
09:45 through 10:03 AM