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

Location:	New York City, NY
Date:	September 11, 2001
Time:	08:47 AM Eastern Daylight Time
Flight:	American Airlines Flight 11
Aircraft:	Boeing 767
NTSB#:	DCA01MA060

Location:	New York City, NY
Date:	September 11, 2001
Time:	09:03 AM Eastern Daylight Time
Flight:	United Airlines Flight 175
Aircraft:	Boeing 767
NTSB#:	DCA01MA063

Location:	Arlington, VA
Date:	September 11, 2001
Time:	09:38 AM Eastern Daylight Time
Flight:	American Airlines Flight 77
Aircraft:	Boeing 757-200, registration: N644AA
NTSB#:	DCA01MA064

Location:	Shanksville, PA
Date:	September 11, 2001
Time:	10:03 AM Eastern Daylight Time
Flight:	United Airlines Flight 93
Aircraft:	Boeing 757-200, registration: N591UA
NTSB#:	DCA01MA065

B. GROUP

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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 primary[1] 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 84th 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 84th 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 84th 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[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 84th RADES data contained radar-derived heights for the remainder of the flight.

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.

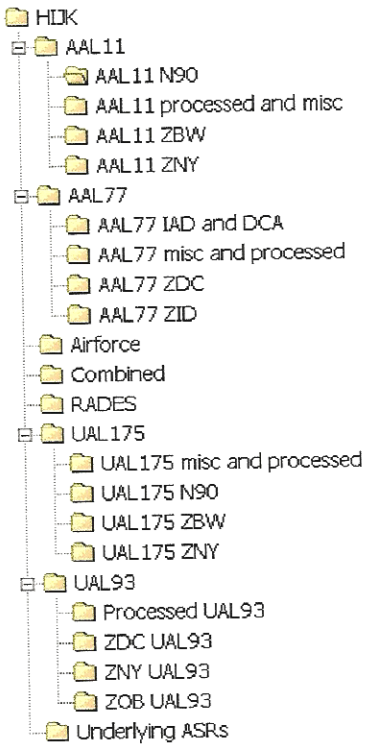
Section III – Radar Data

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

[3] Both the FAA and 84th 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



List of Files:

American Airlines Flight 11	**Source**
...\AAL11\AAL11N90	
AAL11 EWR TATU 1240 to 1248.txt	FAA
AAL11 SWF TATU 1229 to 1246.txt	FAA
EWR ASR UAL175 and AAL11 1235 to 1300.zip	FAA
EWR ASR UAL175 and prim 1300 to 1315.zip	FAA
EWR ASR UAL175 corrected beacons.txt	FAA
HPN ASR UAL175 and AAL11 1230 to 1300.zip	FAA
ASR UAL175 beacons and primaries in WTC area.txt	FAA
JFK ASR UAL175 and AAL11 1230 to 1300.zip	FAA
JFK ASR UAL175 and prim 1300 to 1315.zip	FAA

JFK ASR UAL175 corrected beacons.txt	FAA
N90 ERIT no coords 1200 to 1230.rs3	84th RADES
N90 ERIT no coords 1230 to 1300.rs3	84th RADES
N90 ERIT no coords 1300 to 1330.rs3	84th RADES
N90 TATUTG unk site 1235 to 1305.txt	FAA
N90 TATUTG unk site 1235 to 1305a.txt	FAA
Read Me.txt	
SWF ASR UAL175 and AAL11 1230 to 1300.zip	FAA

...\AAL11\AAL11 Processed and misc

AAL11 ACARS messages.txt	
Aal11 back converted from RVP - don't use targets with D.urf	84th RADES
Aal11 EWR RAPTOR procesed 1240 to 1247.txt	FAA
AAL11 primaries including height.txt	84th RADES
Aal11 RAPTOR processed unknown site.txt	FAA
Aal11 trimmed from RS3.rad	84th RADES
aal11 trimmed from RS3.txt	84th RADES

...\AAL11\AAL11 ZBW

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

...\AAL11\AAL11 ZNY

aal11 zny 1238 to 1240 prim.txt	FAA
aal11 zny 1240 to 1243.txt	FAA
aal11 zny 1242 to 1246.txt	FAA
aal11 zny 1245 to 1249.txt	FAA
aal11 zny 1245 to 1249a.txt	FAA

American Airlines Flight 77

...\AAL77

crw91101.txt	FAA

...\AAL77 IAD and DCA

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

...\AAL77\AAL77 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

...\AAL77\AAL77 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

...\AAL77\AAL77 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	84th RADES
filtered RS3 export showing all four airplanes.xls	84th RADES
N90 post impact TATU etc.txt	FAA

...\RADES

12541200.rs3	84th RADES
12541230.rs3	84th RADES
12541300.rs3	84th RADES
12541330.rs3	84th RADES
12541400.rs3	84th RADES
12541430.rs3	84th RADES
RADES timeline.doc	84th RADES

United Airlines Flight 175

...\UAL175\UAL175 misc and processed

N90 RAPTOR processed 1234 to 1303.txt	FAA
UAL175 ACARS messages.txt	
Ual175 export from RS3.rad	84th RADES
ual175 export from RS3.txt	84th RADES

...\UAL175\UAL175 N90

EWR ASR UAL175 and AAL11 1235 to 1300.zip	FAA
EWR ASR UAL175 and prim 1300 to 1315.zip	FAA
EWR ASR UAL175 corrected beacons.txt	FAA
HPN ASR UAL175 and AAL11 1230 to 1300.zip	FAA
ASR UAL175 beacons and primaries in WTC area.txt	FAA
JFK ASR UAL175 and AAL11 1230 to 1300.zip	FAA
JFK ASR UAL175 and prim 1300 to 1315.zip	FAA
JFK ASR UAL175 corrected beacons.txt	FAA
N90 ERIT no coords 1200 to 1230.rs3	84th RADES
N90 ERIT no coords 1230 to 1300.rs3	84th RADES
N90 ERIT no coords 1300 to 1330.rs3	84th RADES
N90 RT unk site 1300 to 1307.txt	FAA
N90 TA all sites 1300 to 1307.txt	FAA
N90 TATUTG unk site 1300 to 1307.txt	FAA
N90 TG all sites 1300 to 1307.txt	FAA
SWF ASR UAL175 and AAL11 1230 to 1300.zip	FAA

...\UAL175\UAL175 ZBW

ual175 and aal11 ZBW 1233 to 1315.txt	FAA
ual175 ZBW 1210 to 1330 1470 code only.txt	FAA
ual175 ZBW 1244 to 1303.txt	FAA

...\UAL175\UAL175 ZNY

ual175 zny 123730 to 124130.txt	FAA
ual175 zny 123920 to 124430.txt	FAA
ual175 zny 1242 to 1246.txt	FAA
ual175 zny 1245 to 1249.txt	FAA
ual175 zny 1245 to 1249b.txt	FAA
ual175 zny 1248 to 1254.txt	FAA
ual175 zny 1251 to 1257.txt	FAA
ual175 zny 1251 to 125930.txt	FAA
ual175 zny 125620 to 130150.txt	FAA
ual175 zny 1258 to 1304.txt	FAA
ual175 zny 1300 to 1304.txt	FAA
ual175 zny 130130 to 1304.txt	FAA

United Airlines Flight 93

...\UAL93

UAL93 Beacon JFK and EWR ASR.txt	FAA
ual93 PIT Tracon 1300 to 1440.txt	FAA

...\UAL93\Processed UAL93

Ual93 back exported from RVP, don't use D targets.urf	84th RADES
Ual93 combined NTAPs unfiltered.urf	84th RADES
Ual93 combined NTAPs.rad	84th RADES
ual93 end segment back exported from RVP.txt	84th RADES
Ual93 end segment only.rad	84th RADES
Ual93 from RS3.rad	84th RADES
ual93a export from RS3.txt	84th RADES
ual93b export from RS3.txt	84th RADES
ual93c export from RS3.txt	84th RADES

...\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	
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

[redacted]

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FIGURE 1

Ground Track of all flights
08:00 through 10:03 AM

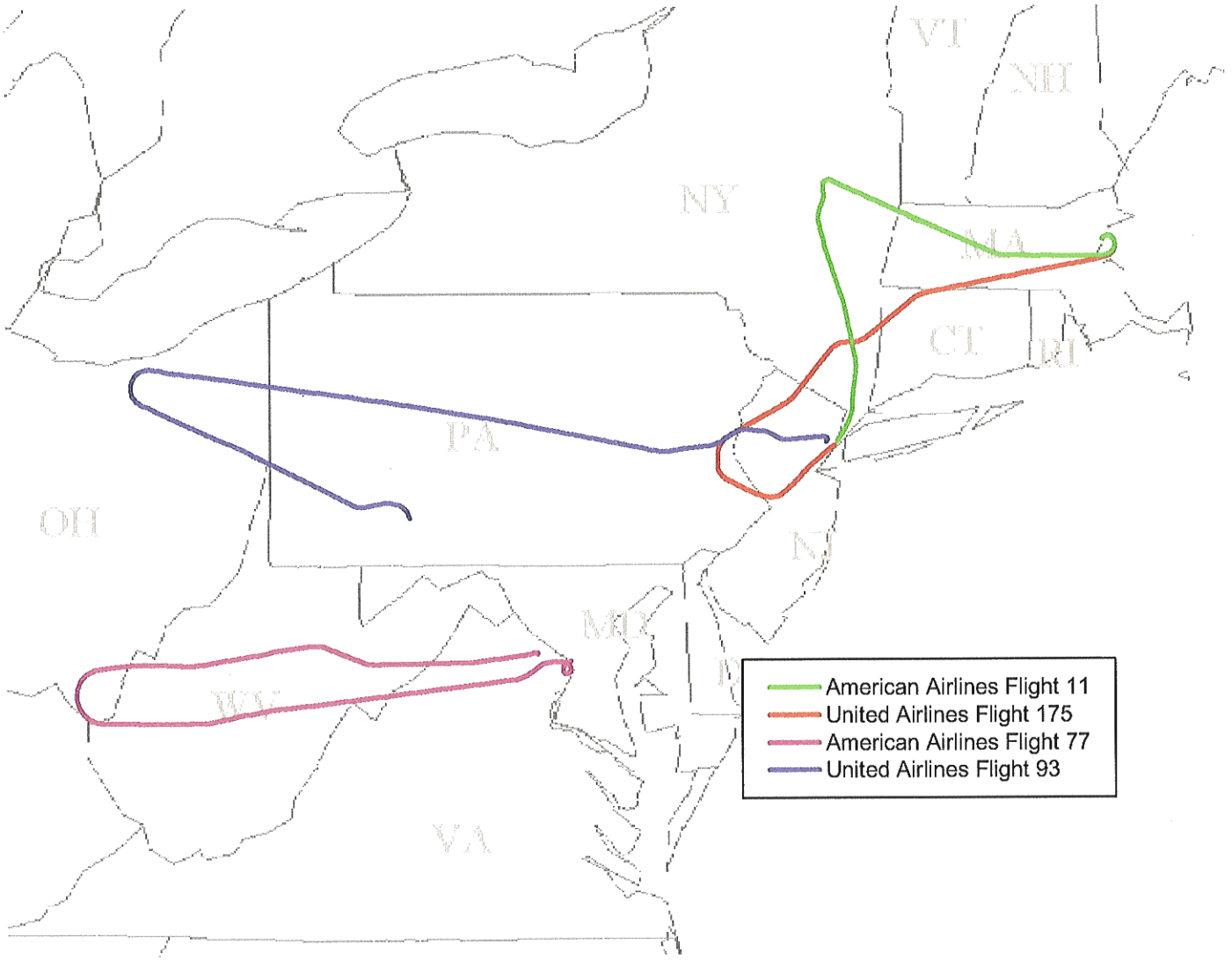

FIGURE 2

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

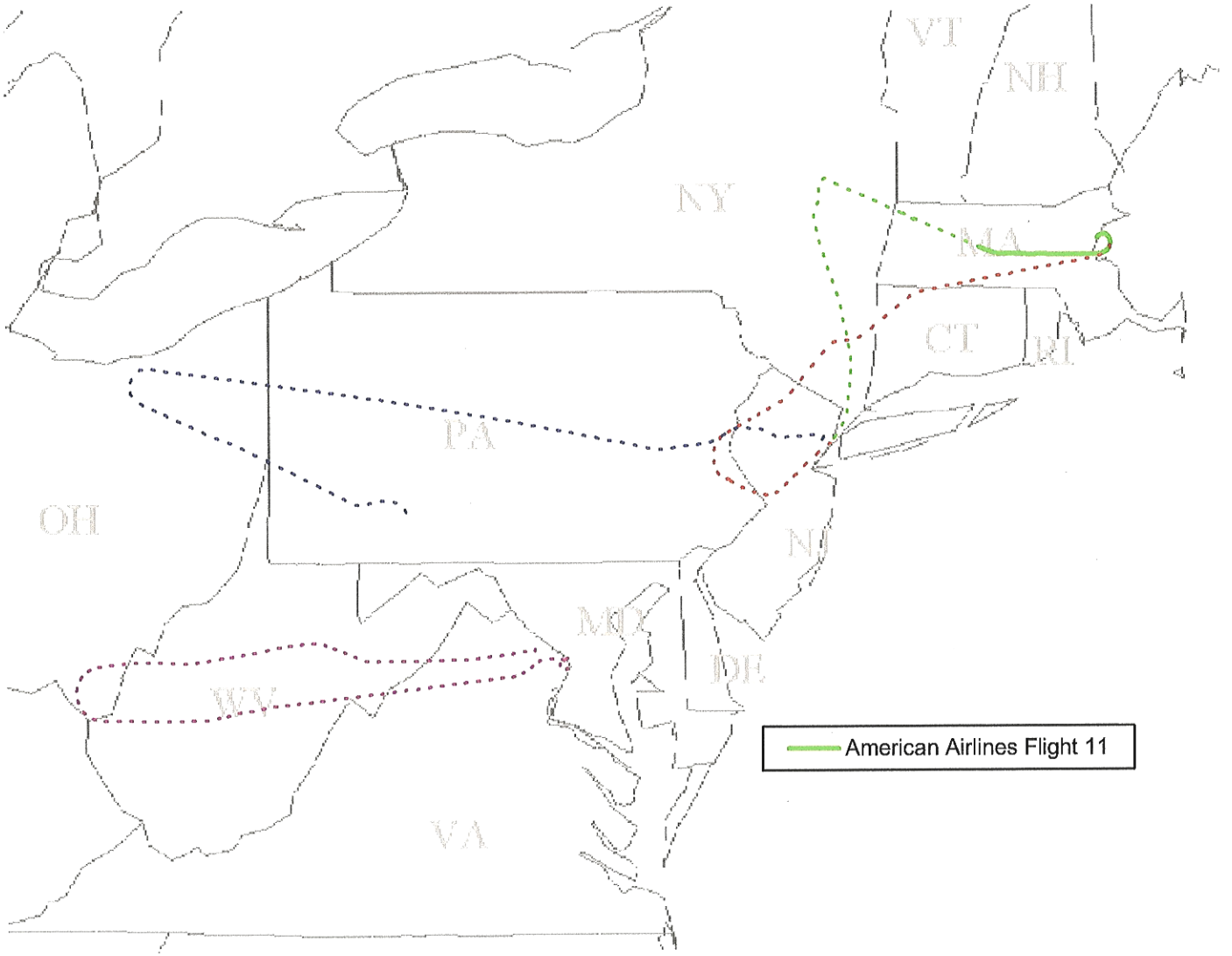

FIGURE 3

Ground Track of all flights
08:15 through 08:30 AM

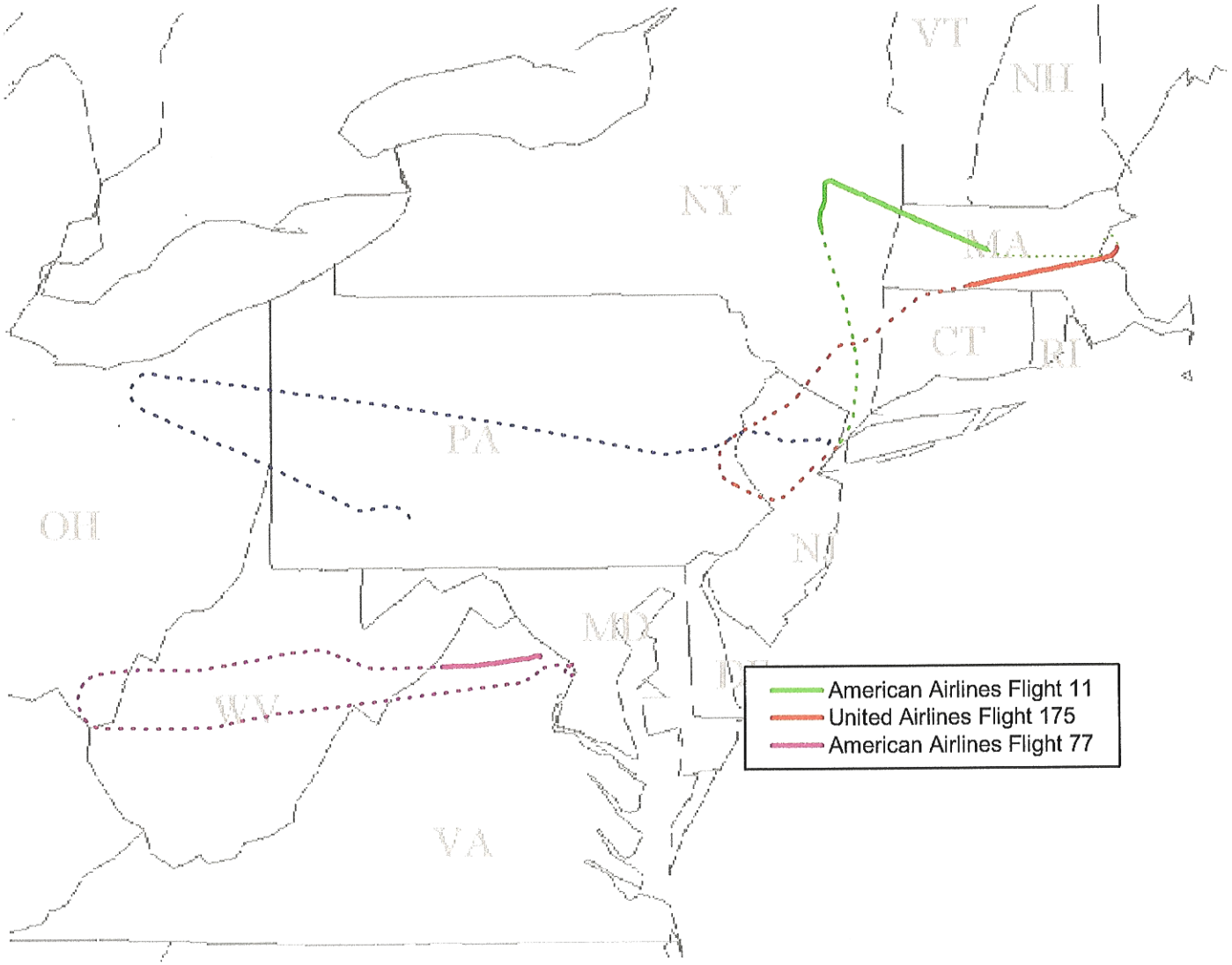

FIGURE 4

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

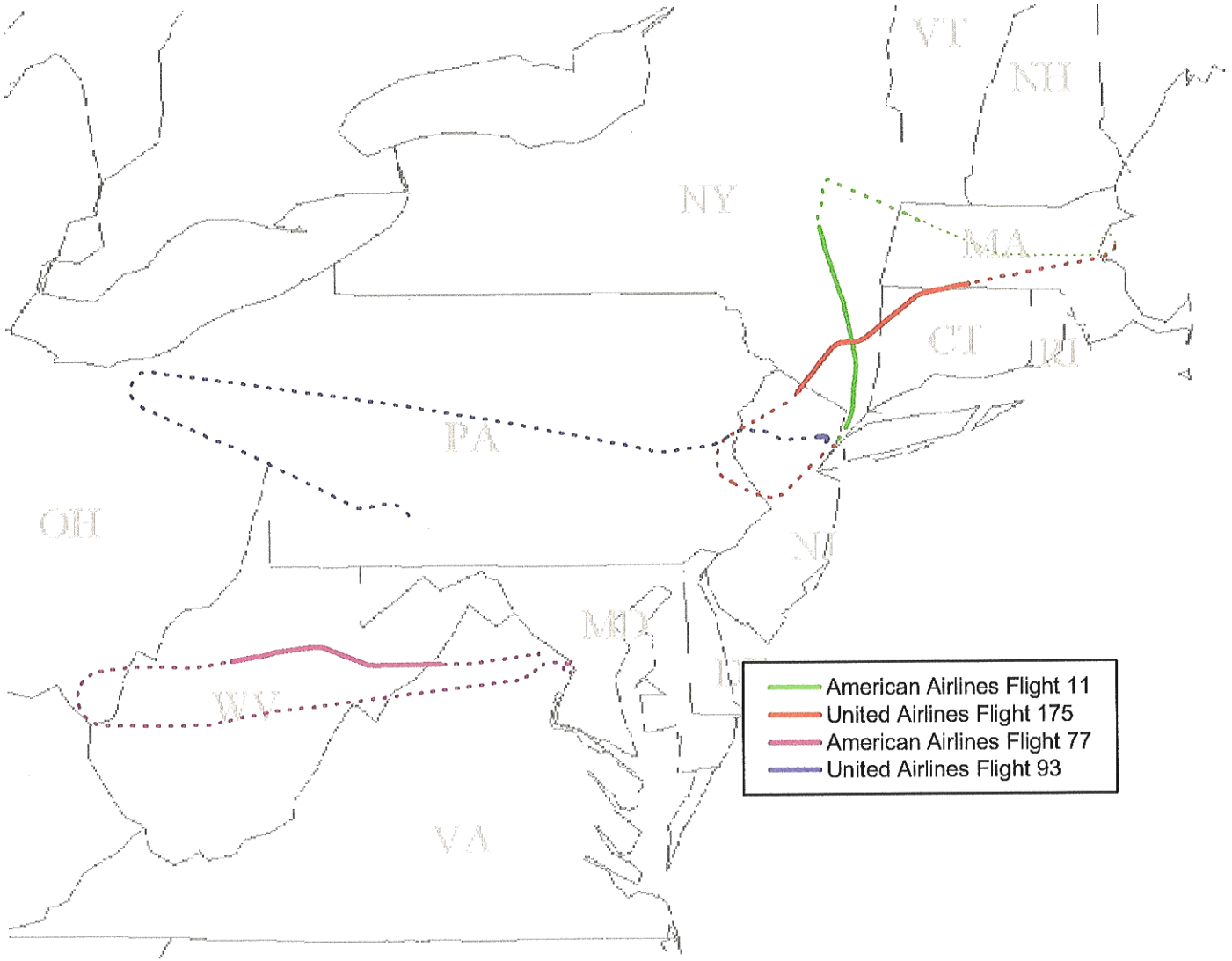

FIGURE 5

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

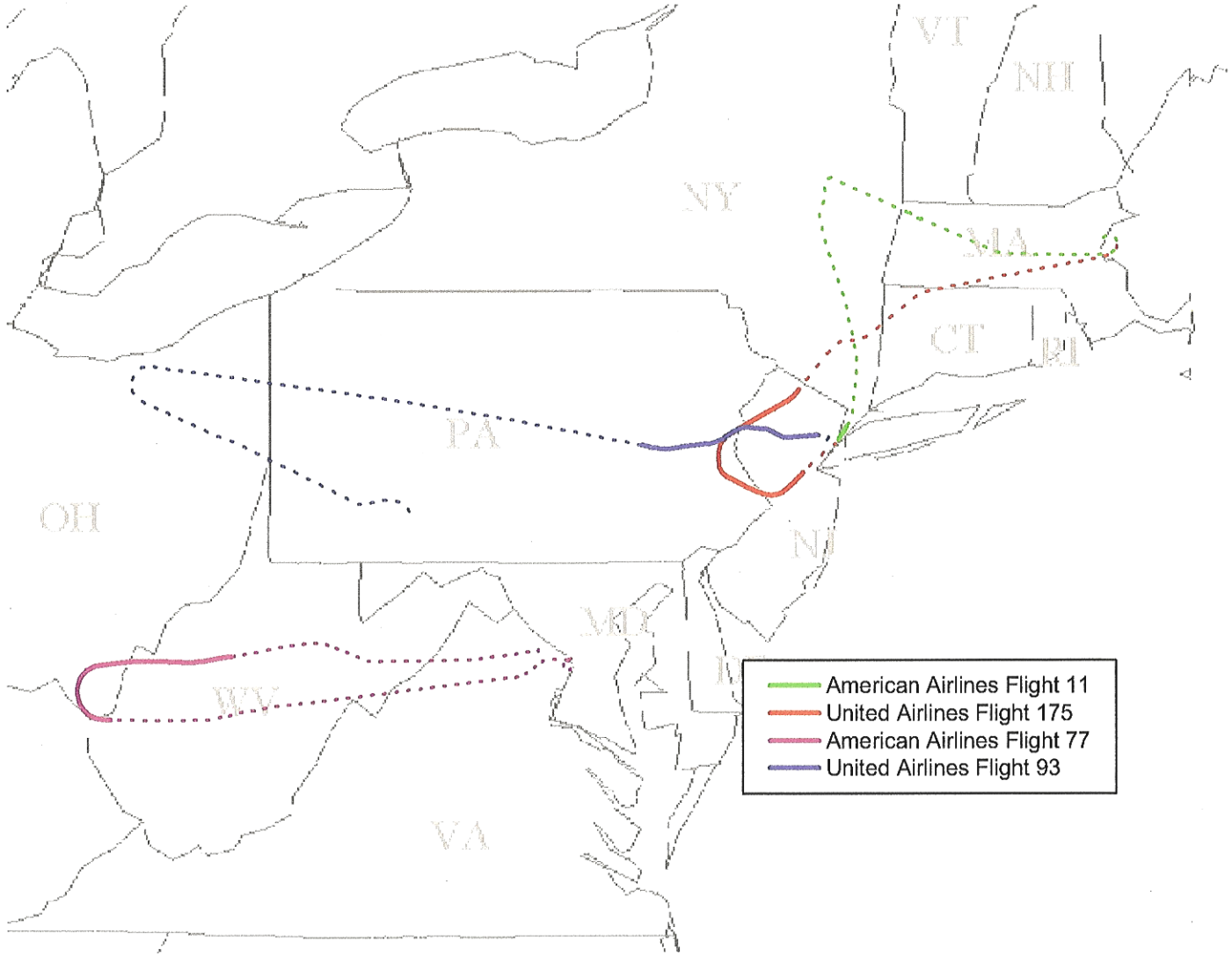

FIGURE 6

Ground Track of all flights
09:00 through 09:15 AM

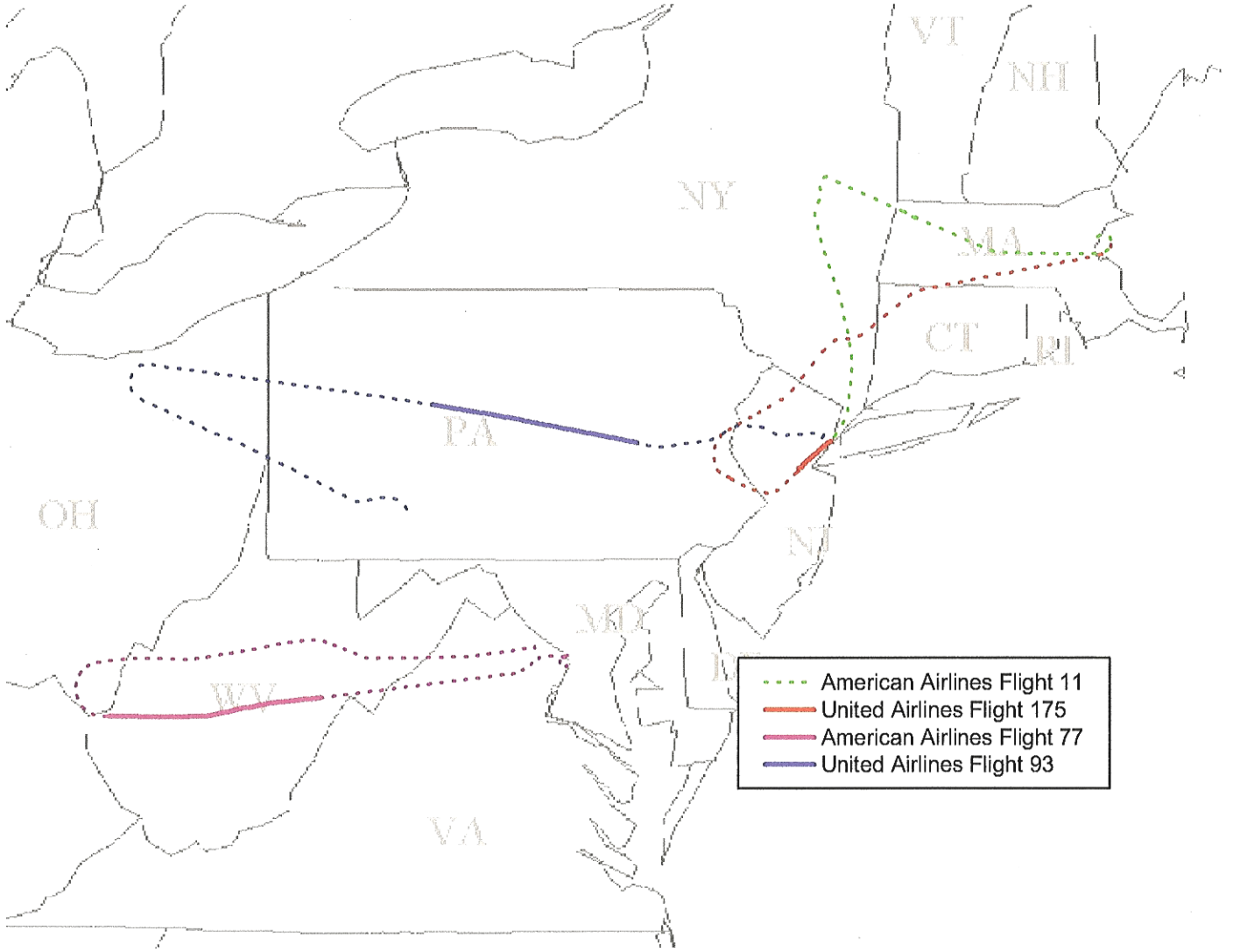

FIGURE 7

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

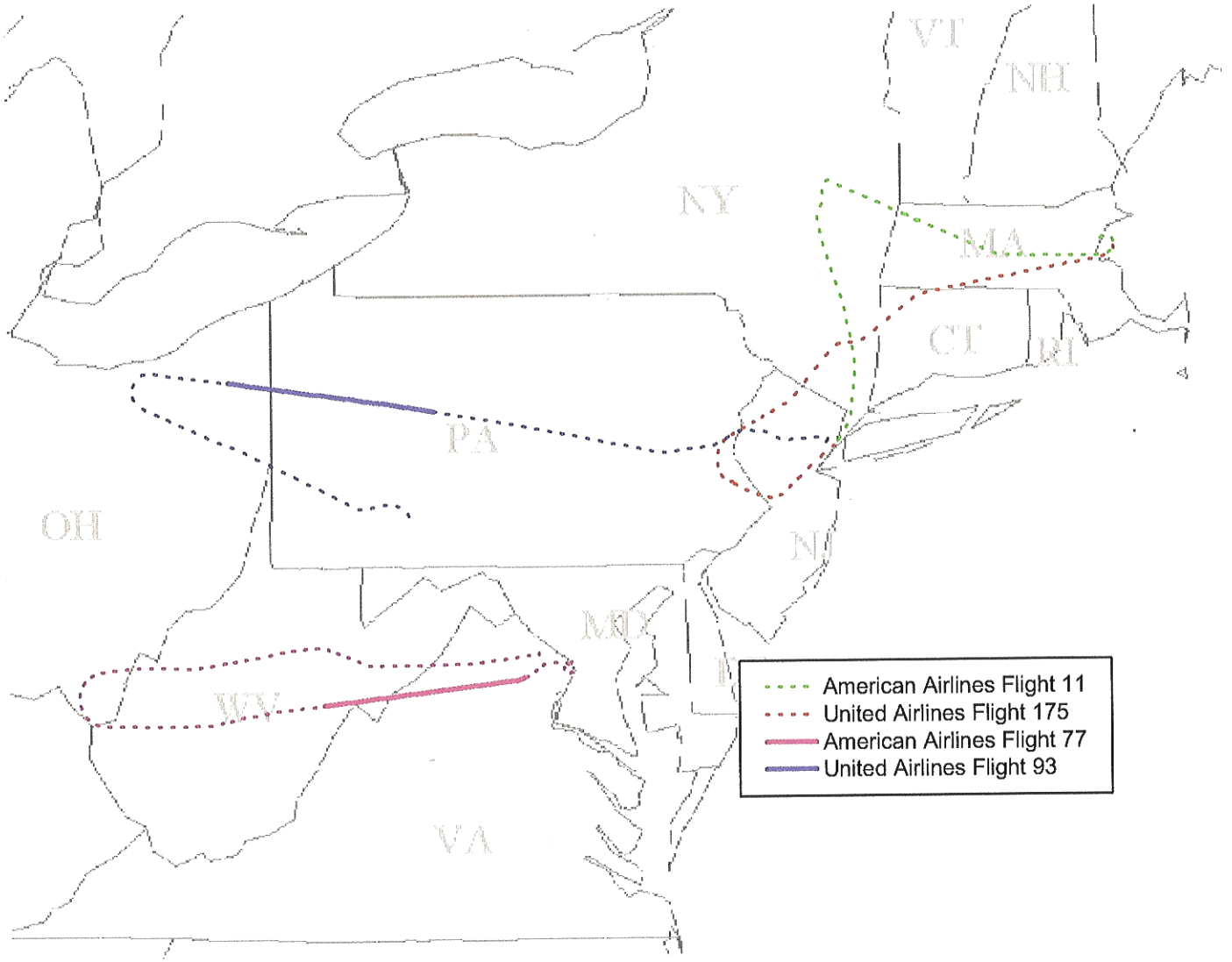

FIGURE 8

Ground Track of all flights
09:30 through 9:45 AM

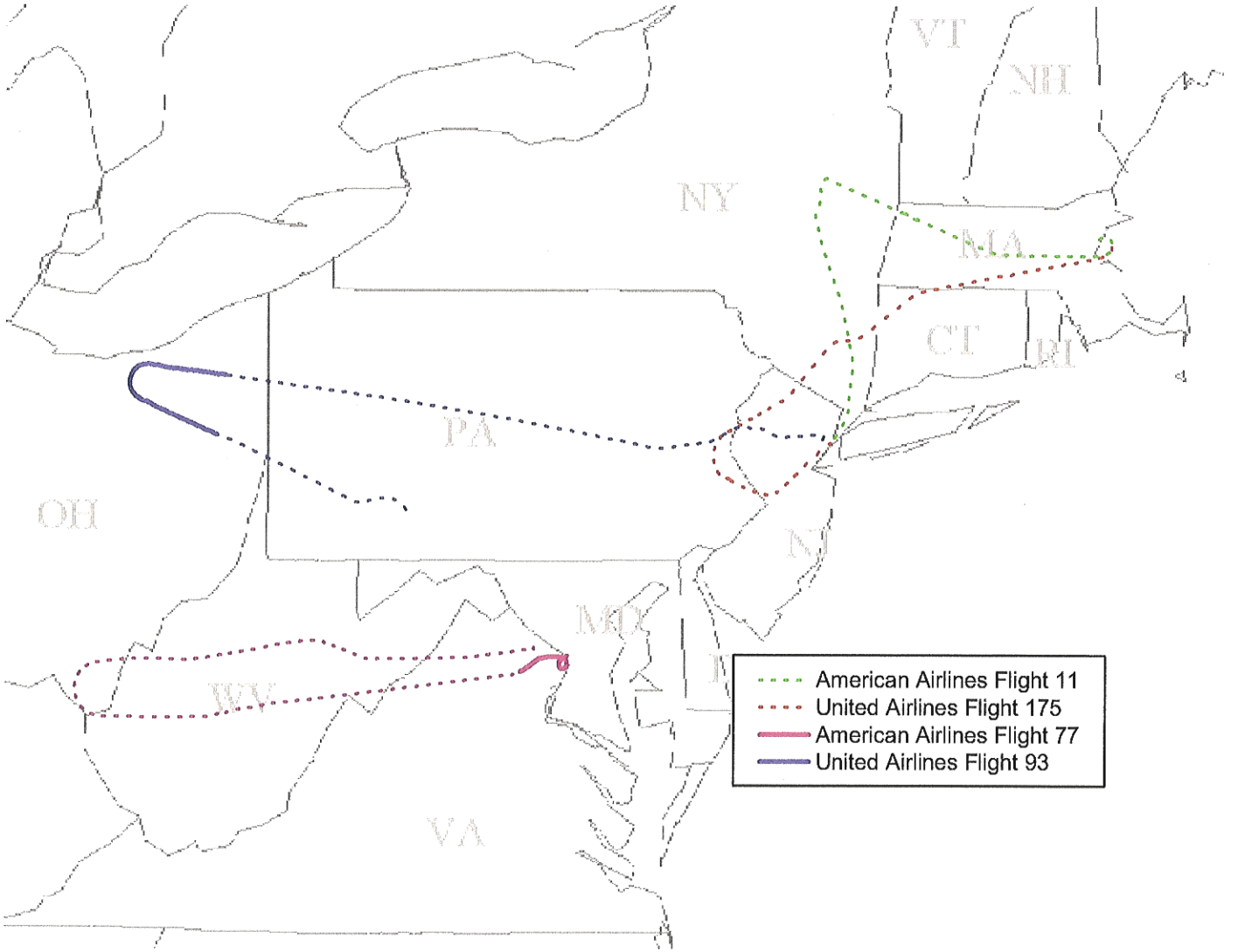

FIGURE 9

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