technical note technical note

Heliport Critical Area Flight Test Results

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16. Abstract

The development of the microwave landing system (MLS) has resulted in the need for several different flight tests to optimize the utility of MLS. One such series of tests were designed to define criteria for siting MLS antennas at heliports. Due to the unique maneuver capabilities and the limited real estate available at heliports, flight tests were also conducted to determine the airspace and real estate surrounding the MLS antennas which must be protected when the MLS is sited at heliports. The need for this protected region is to guarantee signal coverage and quality. Based on the test flight results conducted at the Federal Aviation Administration (FAA) Technical Center, a minimum region (surrounding the MLS antennas and signal monitor poles) which must be protected is identified.

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EXECUTIVE SUMMARY

A series of flight tests were conducted at the Federal Aviation Administration (FAA) Technical Center's Demonstration and Concepts Development Heliport. These tests were designed to determine regions about the microwave landing system (MLS) antennas which, when sited at heliports, must be protected from interdicting ground vehicular traffic and maneuvering helicopters. At a heliport, due to restricted real estate availability, the MLS ground equipment will be installed in close proximity to operating helicopters and ramp vehicular traffic. The protection is necessary to prevent MLS signal blockage or degradation.

The flight test procedures were designed to depict representative uncontrolled traffic conditions at heliports. The signal interdicting traffic consisted of a UH-1 helicopter and a cargo van which was 22 feet in length. The interdicting traffic followed prescribed routes in front of the MLS antennas while the MLS receiving aircraft hovered at various decision heights (DH). An onboard data collection system collected full rate MLS data on the MLS receiving aircraft. Signal characteristics such as framing flag occurrence and received angle data variation were matched to the interdicting vehicle position through a time merge procedure. Additionally, simultaneous MLS approaches were flown by two helicopters under various spacing conditions.

The results of the tests indicated that, in general, the interdicting vehicle had little or no impact on MLS signal coverage or quality when it was more than 200 feet from the MLS antennas. However, when the interdicting vehicle was placed between the MLS antennas and signal monitor poles or in the immediate vicinity outside the poles, signal degradation was detected. As a result, the critical region identified included the area between the antennas and the monitor poles and the region abeam and immediately beyond the monitor poles. These results were obtained with a wide beam width antenna system. Different results might be obtained with other antenna systems.

INTRODUCTION

PURPOSE.

This report presents the results of a series of flight tests conducted at the Federal Aviation Administration's (FAA's) Demonstration and Concepts Development Heliport at the FAA Technical Center, Atlantic City International Airport, New Jersey. The results will be used to develop criteria for the establishment of the critical regions around microwave landing system (MLS) antennas when sited at heliports. The critical regions are the locations in the vicinity of the antennas which must be kept sterile to prevent MLS signal blockage or signal degradation.

BACKGROUND.

The siting of MLS antennas at heliports will not occur in as sterile an environment as that found at airports. Unlike at airports, MLS antennas at heliports will be installed in close proximity to helicopter landing, maneuvering, and parking areas. Ramp vehicular traffic may also operate in close proximity to the antennas. The unique ability of the helicopter to hover means that helicopter movement in the proximity of the ground need not be restricted to taxi lanes. These operations could cause signal interference to helicopters conducting Instrument Flight Rules (IFR) approaches to the heliport using the MLS signal.

At present, there are interim criteria for collocating MLS azimuth and elevation antennas at a heliport. However, the configuration of taxi lanes, landing, maneuvering, and parking areas is subjected to local operational requirements. For the purpose of this test, the only fixed components of the heliport are the landing and takeoff area, the MLS antennas, and the MLS monitor poles. The relationship of these components that were used in the tests described in this report are found in figure 1. It must be noted that each installation may result in a slightly different equipment layout.

The availability of real estate in close proximity of heliports is very limited, and, in many cases, acquiring additional real estate is cost prohibitive. As a result, it is necessary to define the minimum area needed to meet MLS signal integrity requirements. Integrity requirements include:

1. Azimuth and elevation signal coverage.

2. Azimuth and elevation signal quality.

3. Lack of false azimuth and elevation signal guidance.

While previous tests of MLS to date have been extensive, they have primarily focused on fixed wing applications at airports. This test program will consider previous test results and computer simulations as a starting point in determining effects of maneuvering helicopters or ramp vehicle operations on the MLS signal.

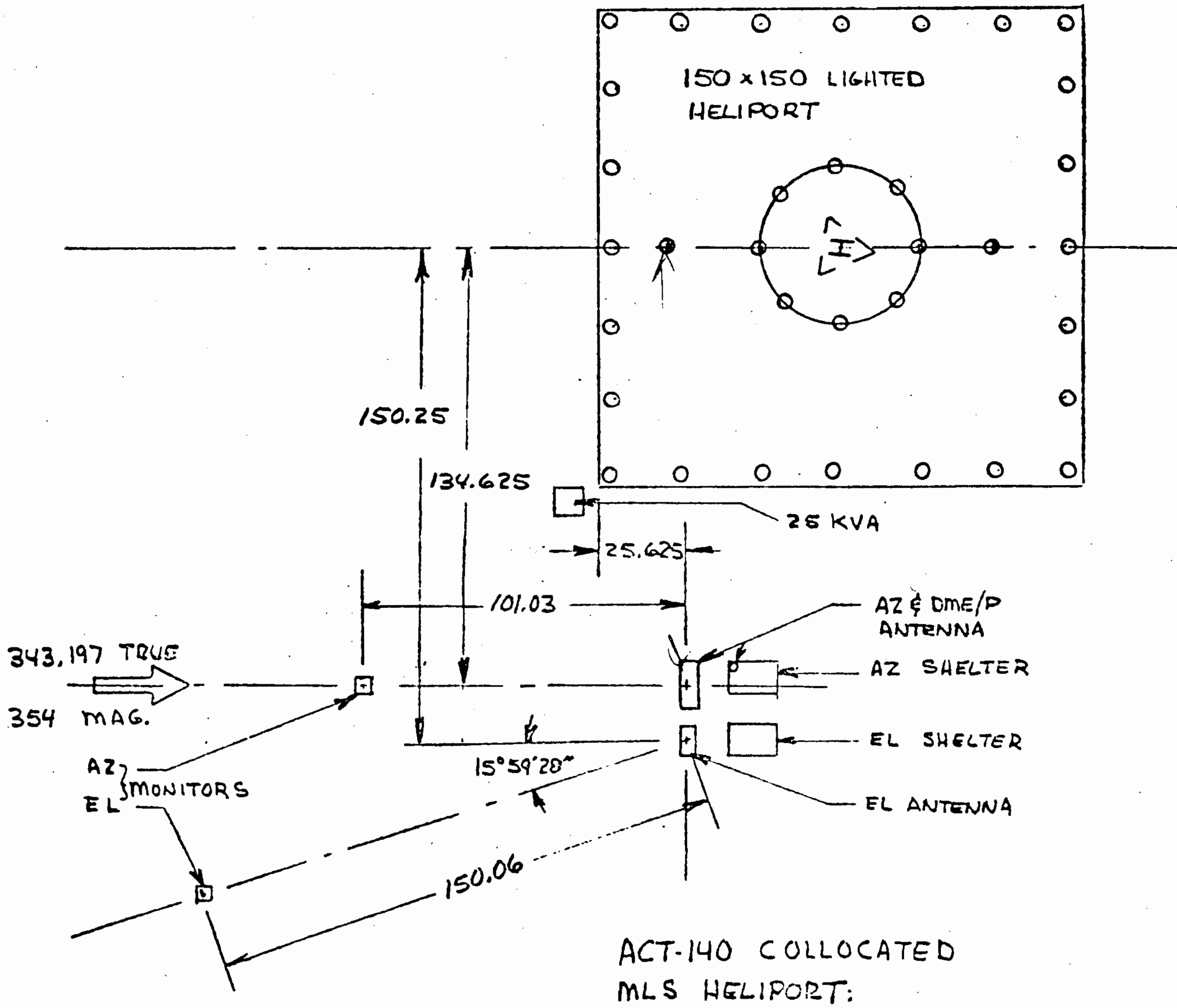


FIGURE 1. ATLANTIC CITY HELIPORT MLS EQUIPMENT LAYOUT

MLS SIGNAL CHARACTERISTICS.

Interference is defined as: (1) any degradation of signal beyond specification tolerances, (2) loss of signal being used for navigation purposes, or (3) a signal received in areas where no signal should exist (false guidance). Interference is also defined as the induced shutdown of the MLS due to degradation of the signal being received by the facility monitors.

Interference with the received MLS signal may be caused by in-beam reflections from a specular reflecting surface or by shadowing of the radiating source (azimuth (AZ) or elevation (EL) antennas) from the receiver. Specular reflecting surfaces may be helicopter rotor blades, fuselage surfaces, or surfaces on ground vehicles. Rotor blade modulation has been a problem in other portions of the electromagnetic spectrum. These surfaces may also shadow or block the MLS signal from the receiver.

The location of interference caused by a moving object can move in space introducing an infinite variety of experimental test conditions. However, two types of movement appear to be more significant. They are the movement of two or more helicopters in relation to the MLS site and the movement of rotor blades while acting as reflecting surfaces.

MLS data transmission occur at two different rates. The MLS transmitters transmit data at 39 hertz (Hz) for EL and 13 Hz for AZ. Internal logic within the airborne MLS receiver monitors the received signal. Each transmission from either the EL or AZ transmitter is checked for proper decoding. When faults are detected in the decoded data, framing flags are set. When the occurrence of framing flags exceed 50 percent of the time for the particular MLS component, a system failure flag is set for that component. The system failure flag is displayed to the pilot in the form of a vertical or lateral guidance failure flag on the horizontal situation indicator.

OBJECTIVES.

The flight tests were conducted to determine the influence on received MLS signal structure caused by interdicting helicopter and ramp vehicle traffic. The primary objective of the testing was the determination of the critical regions about the MLS antennas which must be protected when the MLS antennas are collocated at heliports. The resulting critical regions are the regions within which interdicting traffic could degrade the MLS signal integrity below the tolerances specified in reference 1.

The test flights were designed to address the following specific questions.

1. What are the boundaries about the MLS antennas which define the limits of airspace and terrain which must be protected?

2. How does the interdicting traffic influence the received MLS signal when the receiving aircraft is located at various decision heights (DH's)?

3. What happens to MLS signal integrity when an interdicting helicopter flys a similar approach profile between 1/4 and 2 miles in front of a helicopter making an MLS instrument approach?

DISCUSSION

TEST EQUIPMENT.

The MLS equipment installed at the Demonstration and Concepts Development Heliport is a prototype system manufactured by the Hazeltine Corporation. The system, a Hazeltine Model 2400 system, is a low profile precision approach and landing system utilizing microwave phased array antenna technology, microprocessor control, and solid-state electronics. The time reference scanning beam (TRSB) format is transmitted on one of 200 C band (4 - 8 gegahertz) frequency channels.

The scanning beams are scanned rapidly (39 times a second for elevation and 13 times a second for azimuth) "To" and "Fro" throughout the coverage volume. Each aircraft receiving these beams derives its own position angle directly from the time difference between the TRSB beam pulse pairs. In addition, data such as airport and runway identification, course clearance sector size, and other operational data are transmitted on the same channel. The equipment recently underwent modification to conform to the International Civil Aviation Organization (ICAO) 08C format. This permits the model 2400 system to be interoperable with Cabin Class MLS receivers. The installed accuracy results of the model 2400 system installed at the Demonstration and Concepts Development Heliport at the FAA Technical Center are reported in reference 2.

The azimuth proportional guidance is provided in a sector -10° to + 10° from the approach course centerline. Clearance guidance provides a full scale fly left or fly right presentation to the pilot. The clearance sectors are from -40° to -10° and +10° to +40° about the approach course centerline. Table 1 presents the characteristics of the model 2400 system.

TABLE 1. HAZELTINE MODEL 2400 MLS CHARACTERISTICS

Characteristic	AZ	EL
Beam Width*	3.5°	2.4°
Course Width	+/-3.6°	EL angle/3°
Proportional Sector	+/-10°	1° to 15°
Clearance Sector	+/-10° to +/-40°	Full fly up below 1°
Range	20 nmi	20 nmi
Antenna Aperture Size	5 ft x 3.5 ft	6 in x 6 ft
Phase Shifters	8	8
Transmitter Power	10 W nominal	5 W nominal

* Beam widths are wider than specified in reference 1.

Testing has shown that the model 2400 meets signal tolerance requirements of FAA Standard 022C, "Microwave Landing System (MLS) Interoperability and Performance Requirements." The results of the model 2400 system testing are reported in reference 3.

The aircraft used during these tests consisted of two Bell UH-1 helicopters. The use of these helicopters was obtained through an interagency agreement with the United States Army. One helicopter was equipped with a System Test and Evaluation Program (STEP) MLS receiver manufactured by Bendix Corporation. This aircraft was also equipped with a digital airborne data collection system. A description of the data recorded can be found in reference 3. The other UH-1 acted as the interdicting aircraft. A variety of interdicting aircraft flight profiles were flown. These profiles included hovering flight to simulate a helicopter hovering over a predetermined pattern in close proximity to the MLS antennas and MLS approaches flown in front of the MLS receiving aircraft. A panel side van 22 feet in length was also used as a signal interdictor. It simulated ramp vehicular traffic in the vicinity of the antennas.

MLS EQUIPMENT SITING.

The model 2400 MLS system is sited in a collocated fashion abeam the Demonstration and Concepts Development Heliport at the FAA Technical Center. The AZ antenna is sited 150 feet to the right of the center of the heliport. The EL antenna is abreast and outside the AZ antenna. The 0° AZ is aligned with a magnetic course of 354°. This was the final approach course utilized for these tests. The siting configuration is depicted in figure 1.

TEST MEASURES.

Experimental data collection focused on measures which could be used to evaluate signal presence and signal quality. Full data rate data collection of both the MLS elevation and AZ digital angle information was made. All MLS data were collected on board the MLS receiving aircraft. The data rates for azimuth and elevation information was 13 and 39 Hz, respectively. Signal presence was determined through the analysis of the occurrence of framing and determined navigation system failure flags. Signal quality was analyzed in several ways.

Estimates of control motion noise (CMN) and path following error (PFE) for both the azimuth and elevation signals were obtained in the presence of the interdicting aircraft or van. CMN is a high frequency error component and PFE is a low frequency error component of both the EL and AZ signals. Further discussion of these error components and methodologies for determining estimates of them are presented in reference 1. Statistical analysis of the received angle data was made to determine differences in received angle variability when measures obtained in the presence of the interdictor were compared with controled measures which were obtained without the interdictor being present.

TEST PROCEDURES AND RESULTS

SIMULATED RAMP TRAFFIC.

The first test procedure was designed to evaluate MLS signal loss or degradation when a ramp vehicle was driven in front of the MLS antennas. During this test three different sets of test conditions were present. The vehicle which was used as the interdictor was the panel van. The position at which the receiving MLS aircraft was hovered is depicted in table 2. The interdictor's pattern could accurately be replicated since the pattern was marked with stakes. During each test run the MLS receiving aircraft was hovered at various positions representing different DH's. The van transversed the area in front of the antennas along the perpendicular "S" pattern shown in figure 2. Three control runs in which the interdicting van was not present were also made.

TABLE 2. LOCATION OF MLS RECEIVING AIRCRAFT FOR RAMP VEHICLE INTERDICTOR TESTS

Run No.	Glidepath Angle (degrees)	DH (feet)	Slant Range (feet)
1	3	200	3821
2	3	100	1910
3	2	125	3648

The MLS receiving aircraft was hovered with the pilot referencing MLS displaced position and radar altitude. Each test run lasted about 7.5 to 8 minutes. That was the time required for the van to transverse the pattern shown in figure 2. The van moved at a constant rate of 10 miles per hour throughout the testing.

Flight technician logs were reviewed for each of the three runs. No indications of signal loss or degradation was apparent to the flight crew. Post-flight data analysis was conducted to evaluate signal loss or degradation. Using data merge techniques, the position of the interdicting ramp vechicle was merged with the airborne recorded data. Figures 3 to 5 depict the percentage of MLS elevation framing flags which occurred for each segment of the pattern traversed with the interdicting ramp vehicle. The maximum observed percentage was less than 1 percent. Where no numbers are presented, framing flag occurrences were not detected. The largest elevation framing flag percentages occurred on run 3 in the immediate vicinity of the antennas. This run also placed the receiving aircraft at the lowest glidepath angle tested. However, the percentage of framing flags never exceeded 1 percent.

The percentage of azimuth framing flags which were observed for each segment is depicted on figures 6 to 8. The percentage did not exceed 3 percent for any segment. The largest percentages occurred in close proximity to the antennas abeam the monitor poles or at the pattern turning points where the chance of spectral reflections were the greatest. The actual location of the interdicting van when the framing flags occurred are presented on figures 9 to 14. The location is indicated by an "F" plotted adjacent to the vehicle track. The increased concentration of flags in the vicinity of the monitor poles (between position marked ML1, MR1, ML2, and MR2) is apparent on figures 9 and 14.

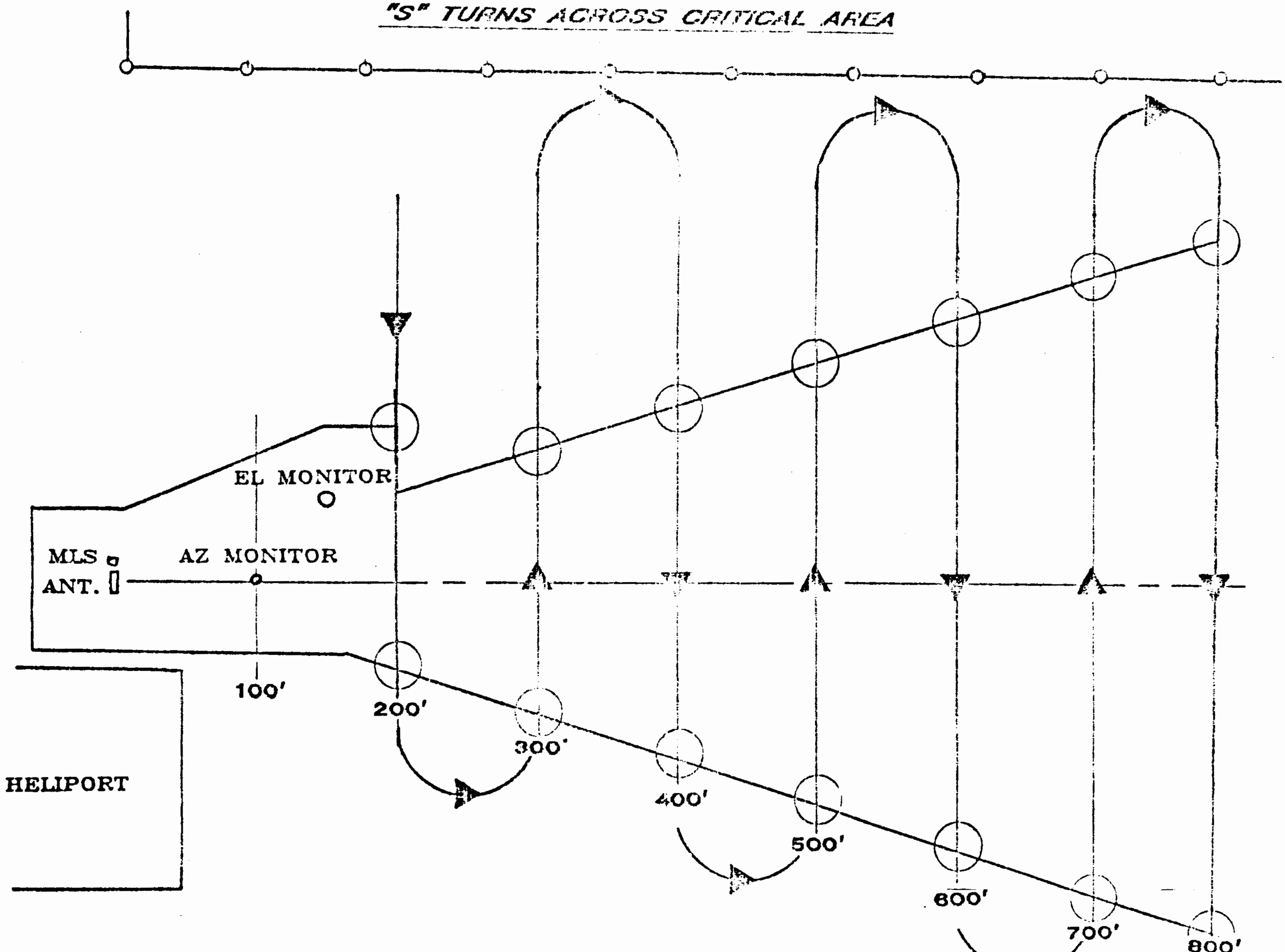


FIGURE 2. PERPENDICULAR "S" PATTERN TRAVERSED BY INTERDICTING VAN

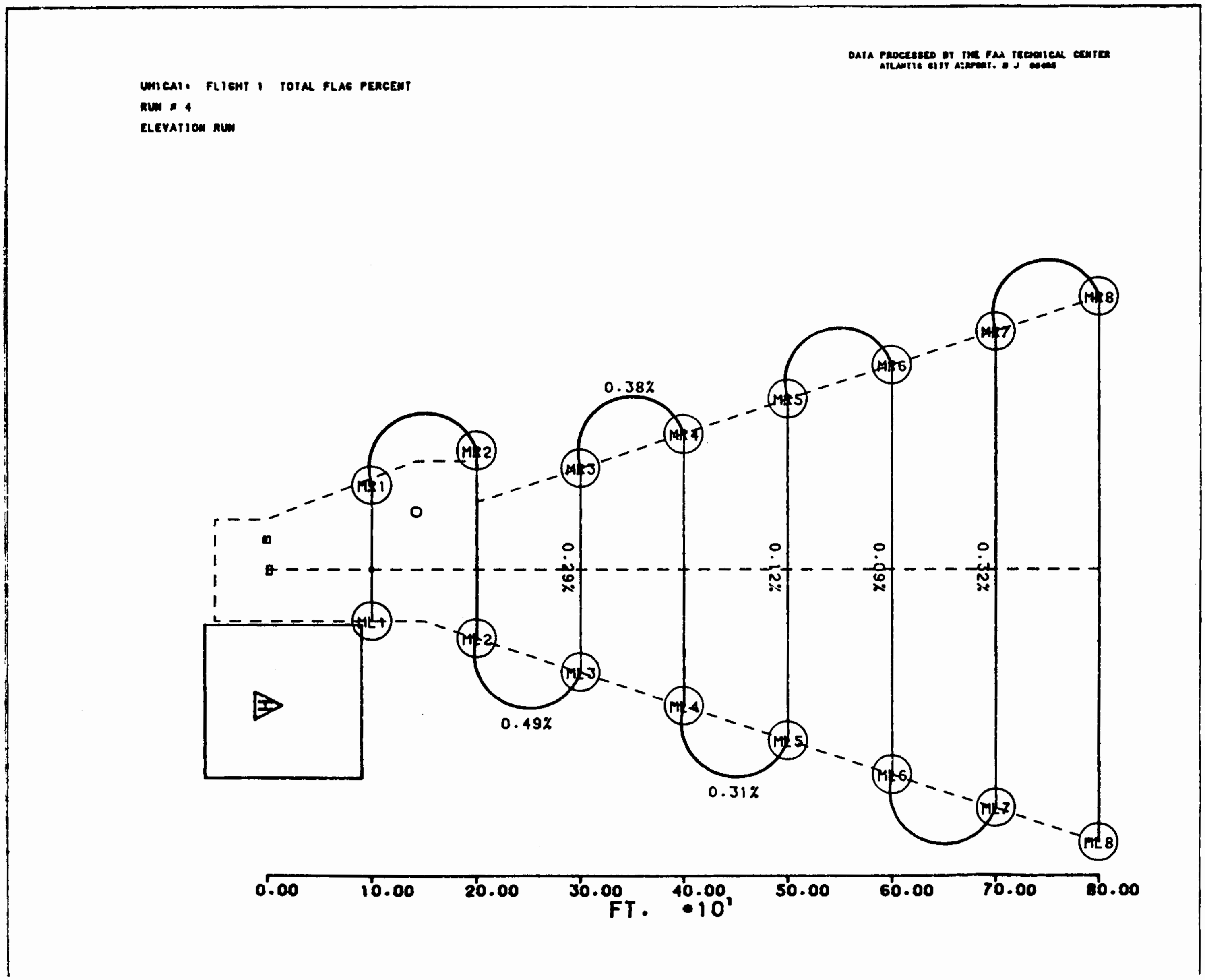


FIGURE 3. INTERDICTING RAMP VEHICLE ELEVATION FRAMING FLAG RESULTS - RUN 1

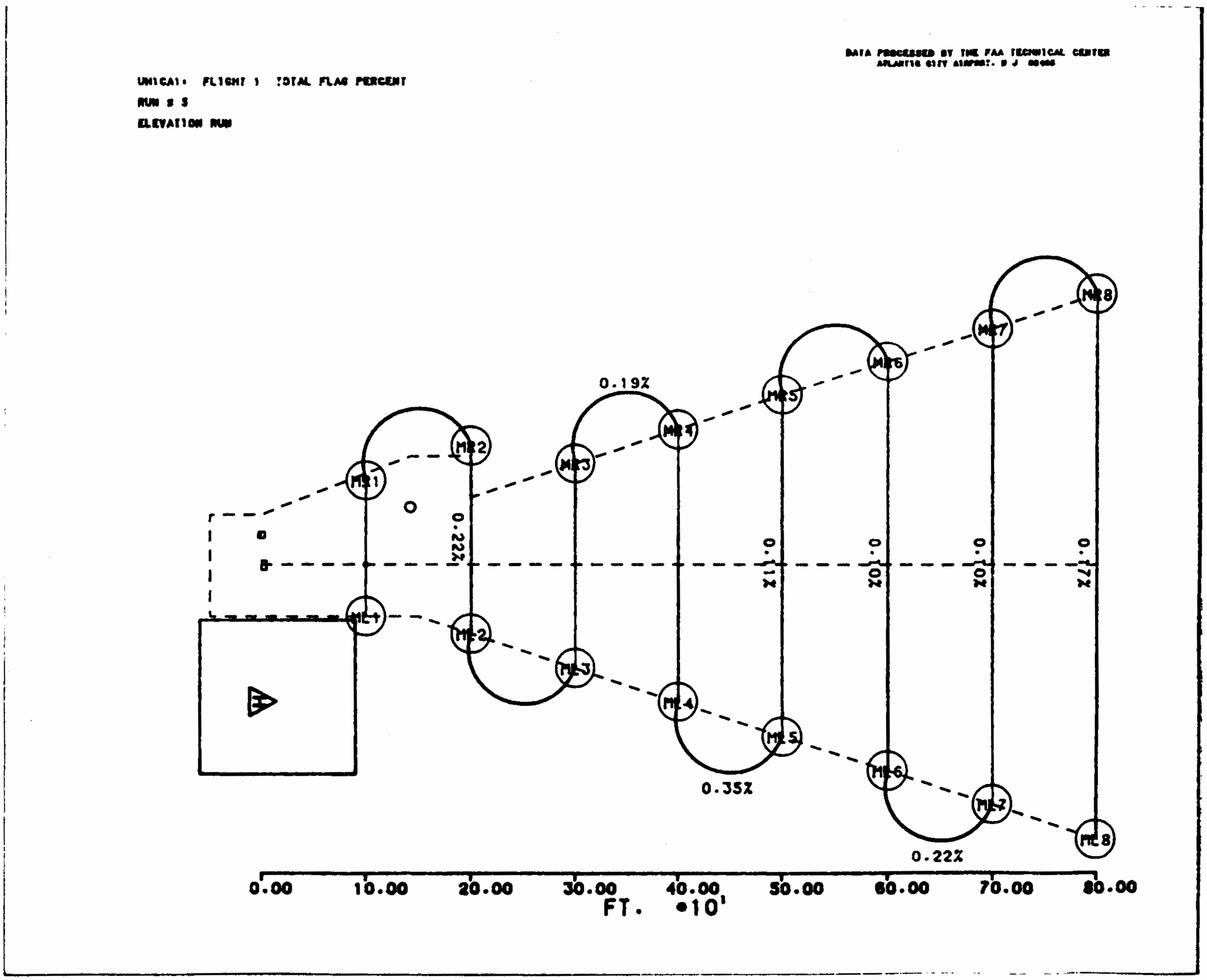


FIGURE 4. INTERDICTING RAMP VEHICLE ELEVATION FRAMING FLAG RESULTS - RUN 2

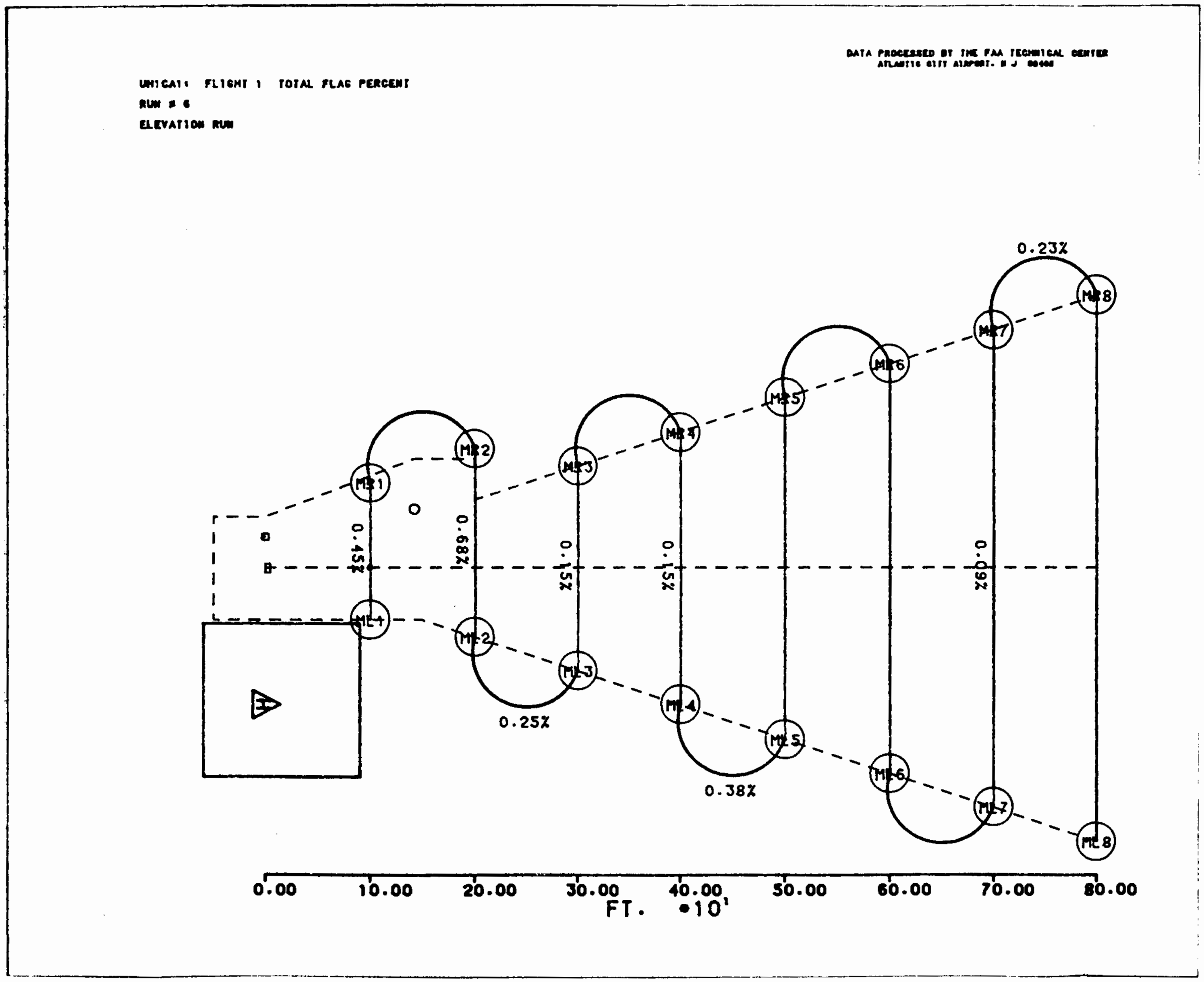


FIGURE 5. INTERDICTING RAMP VEHICLE ELEVATION FRAMING FLAG RESULTS - RUN 3

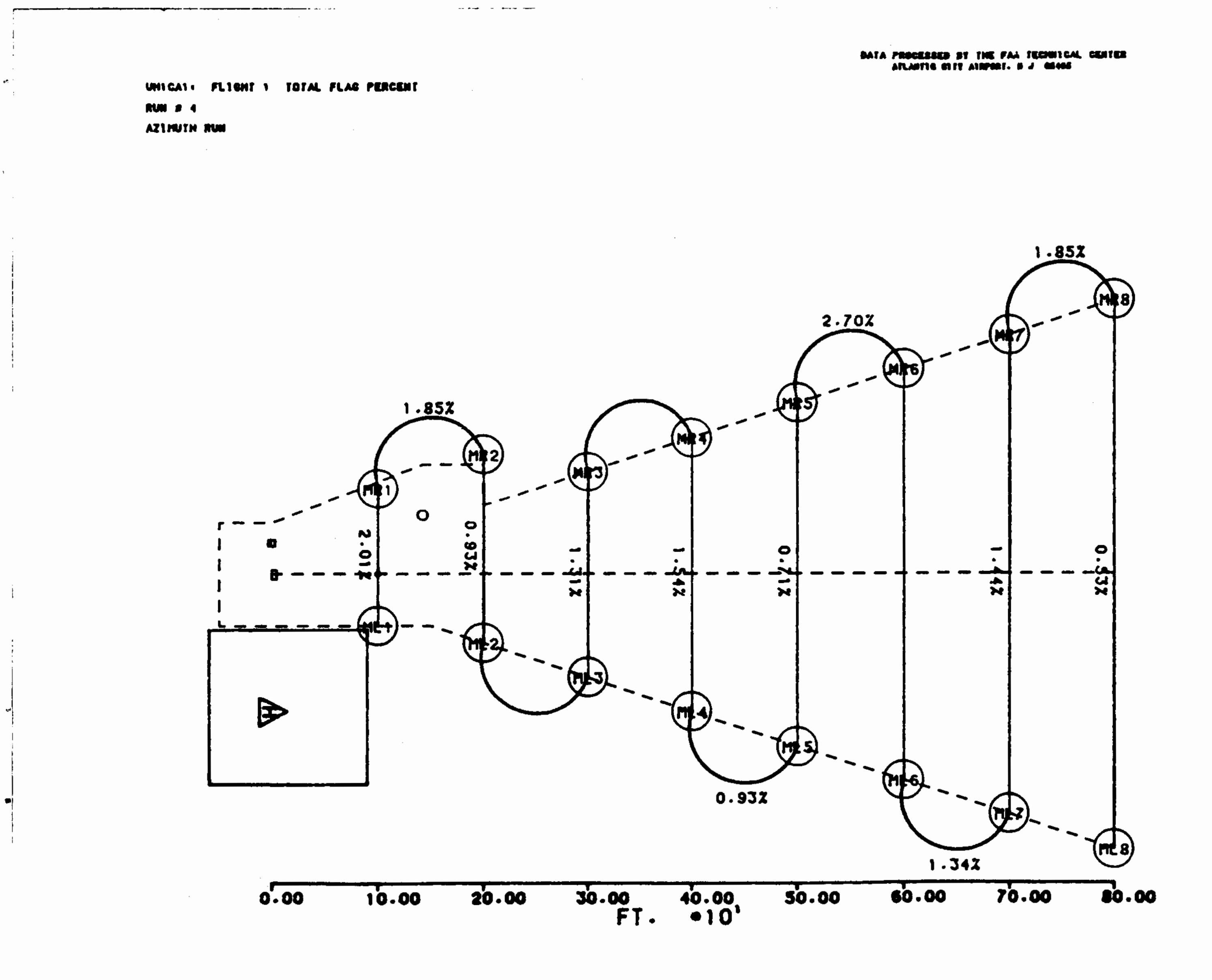


FIGURE 6. INTERDICTING RAMP VEHICLE AZIMUTH FRAMING FLAG RESULTS - RUN 1

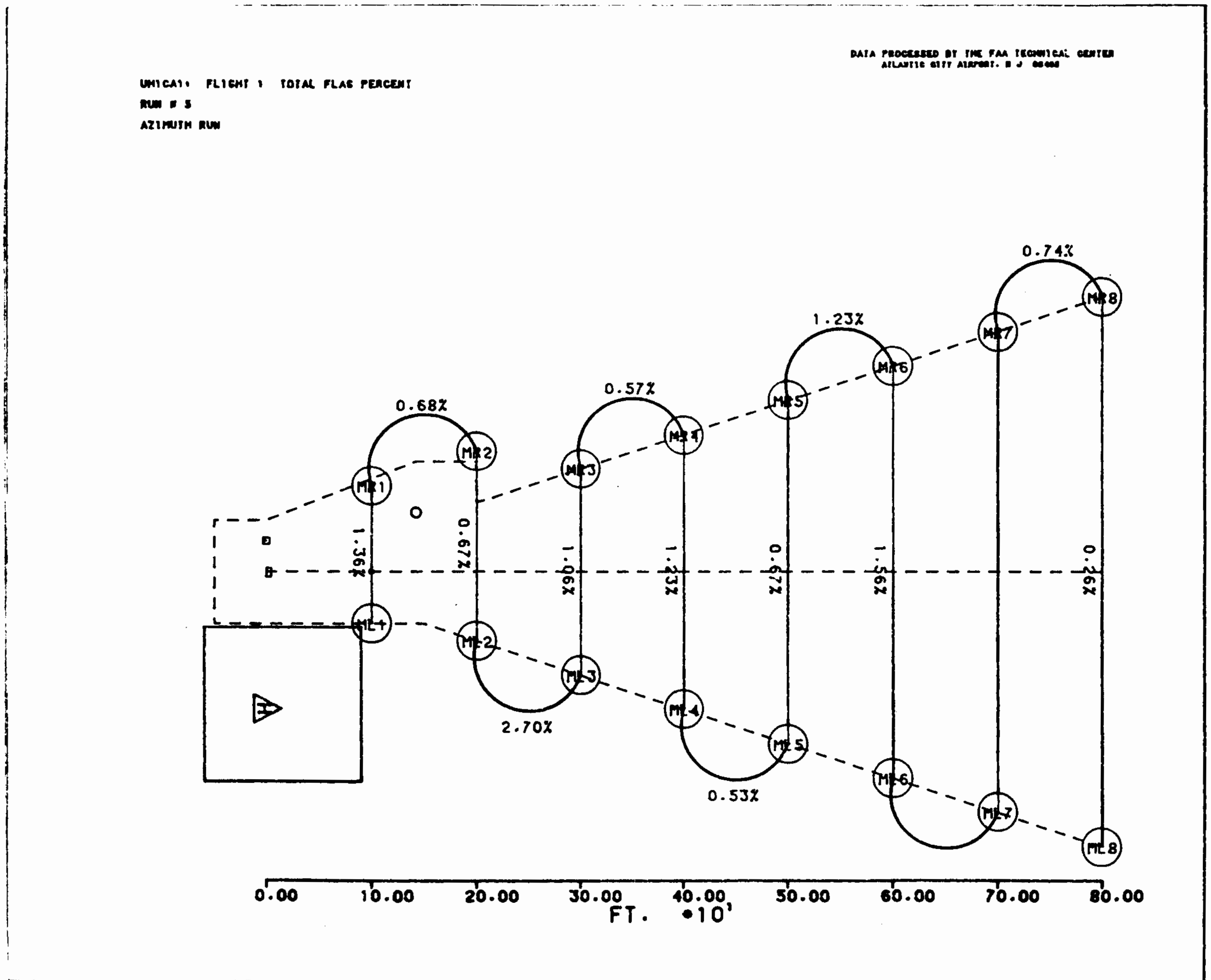


FIGURE 7. INTERDICTING RAMP VEHICLE AZIMUTH FRAMING FLAG RESULTS - RUN 2

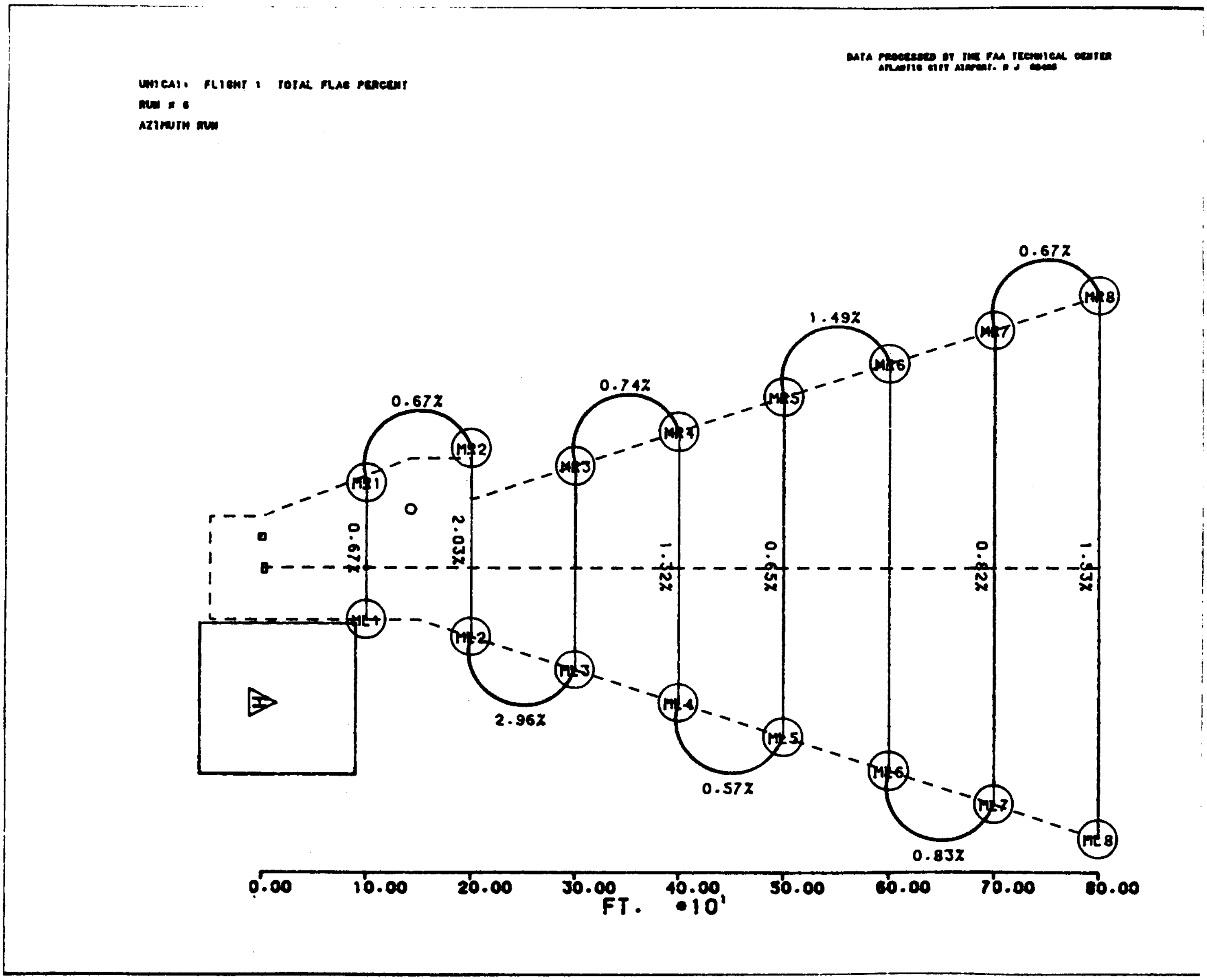


FIGURE 8. INTERDICTING RAMP VEHICLE AZIMUTH FRAMING FLAG RESULTS - RUN 3

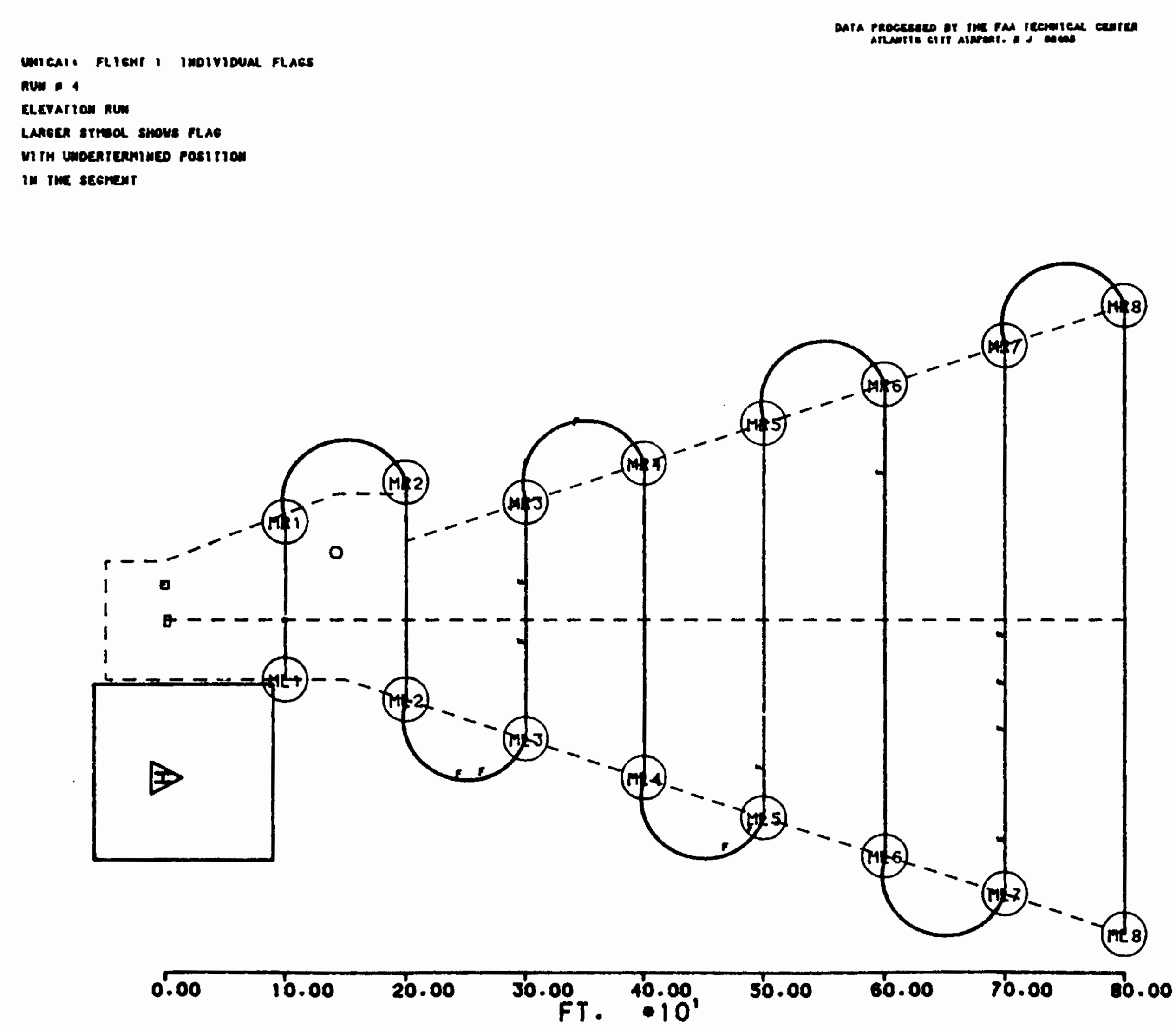


FIGURE 9. ELEVATION FRAMING FLAG LOCATIONS - RUN 1

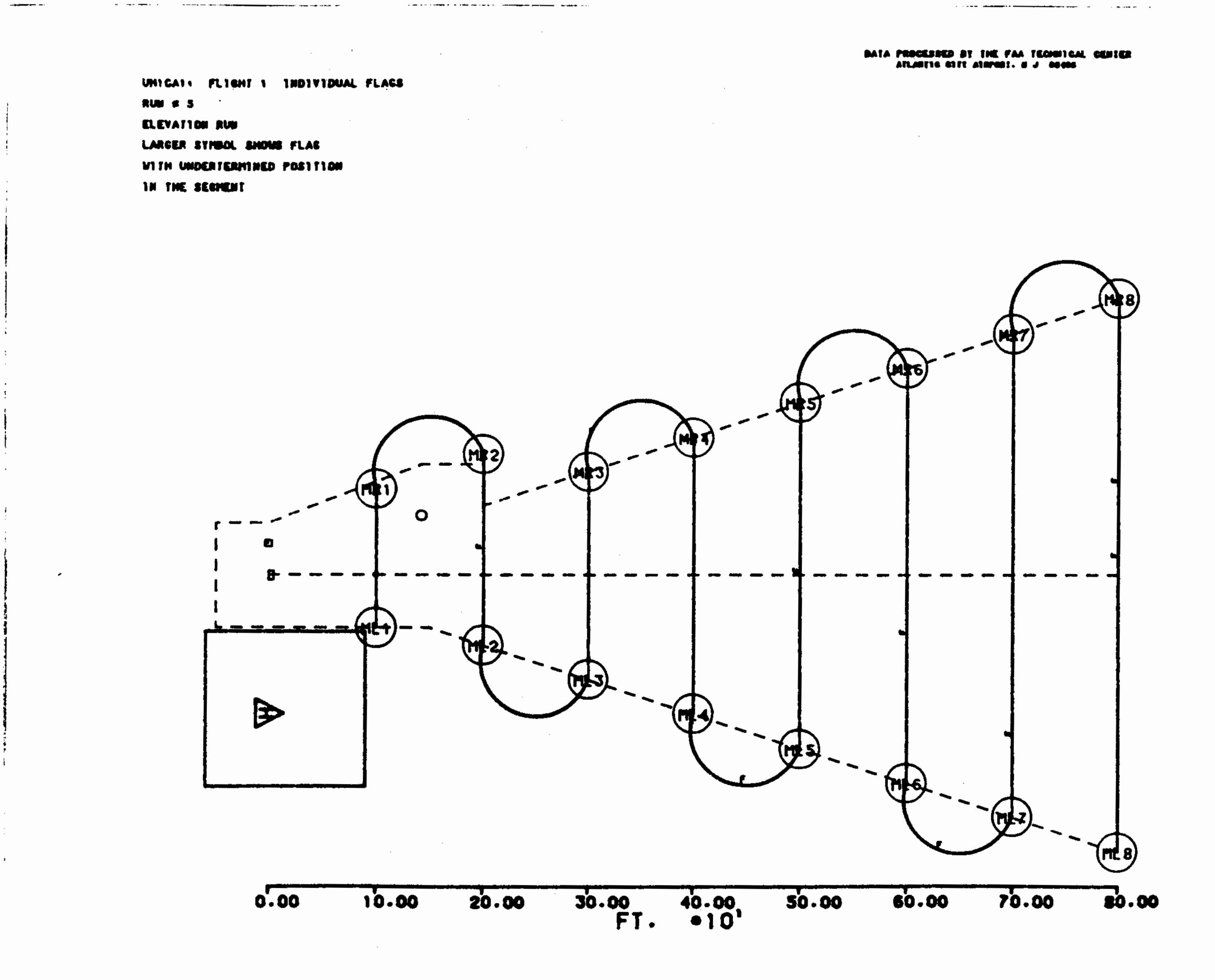


FIGURE 10. ELEVATION FRAMING FLAG LOCATIONS - RUN 2

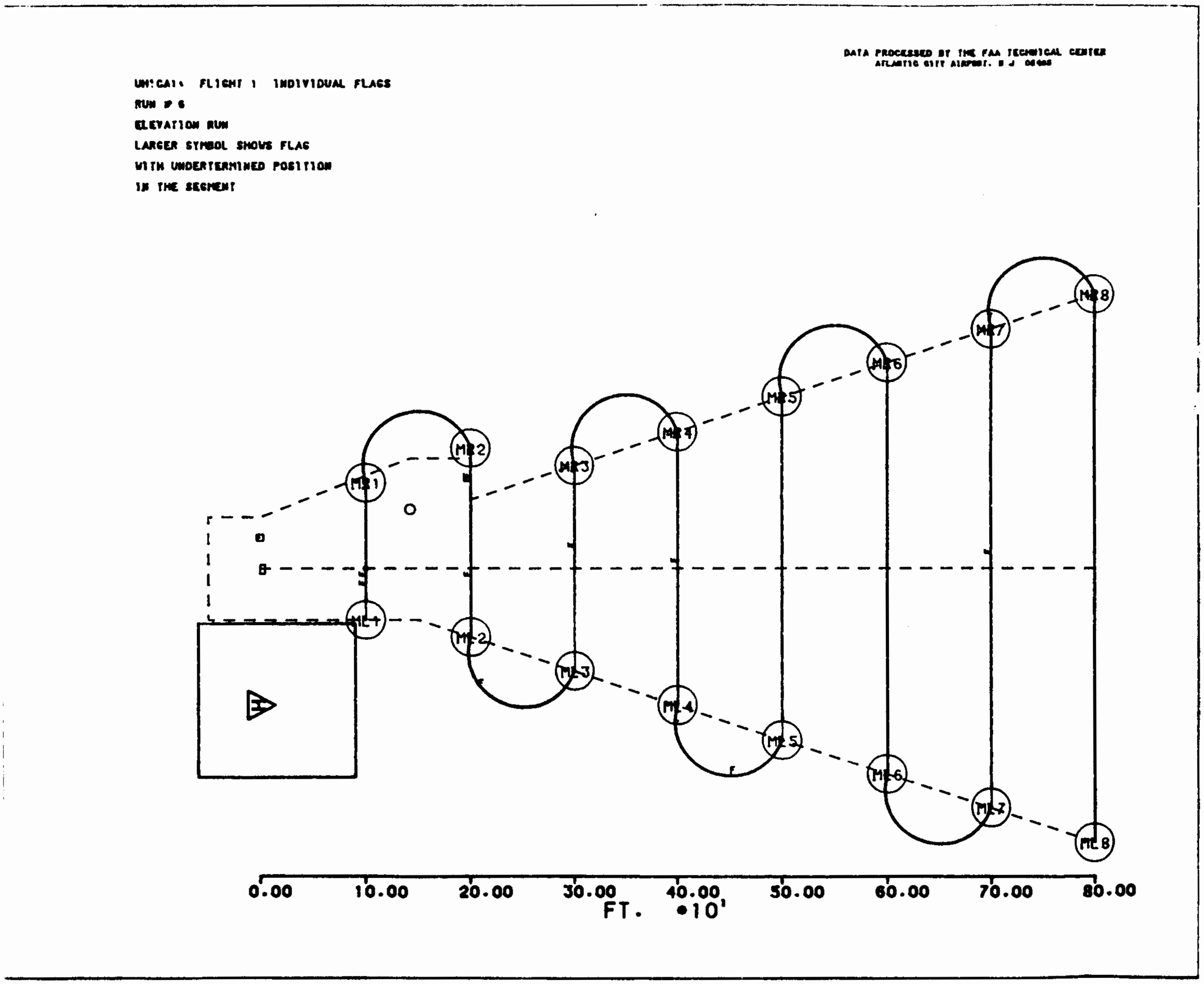


FIGURE 11. ELEVATION FRAMING FLAG LOCATIONS - RUN 3

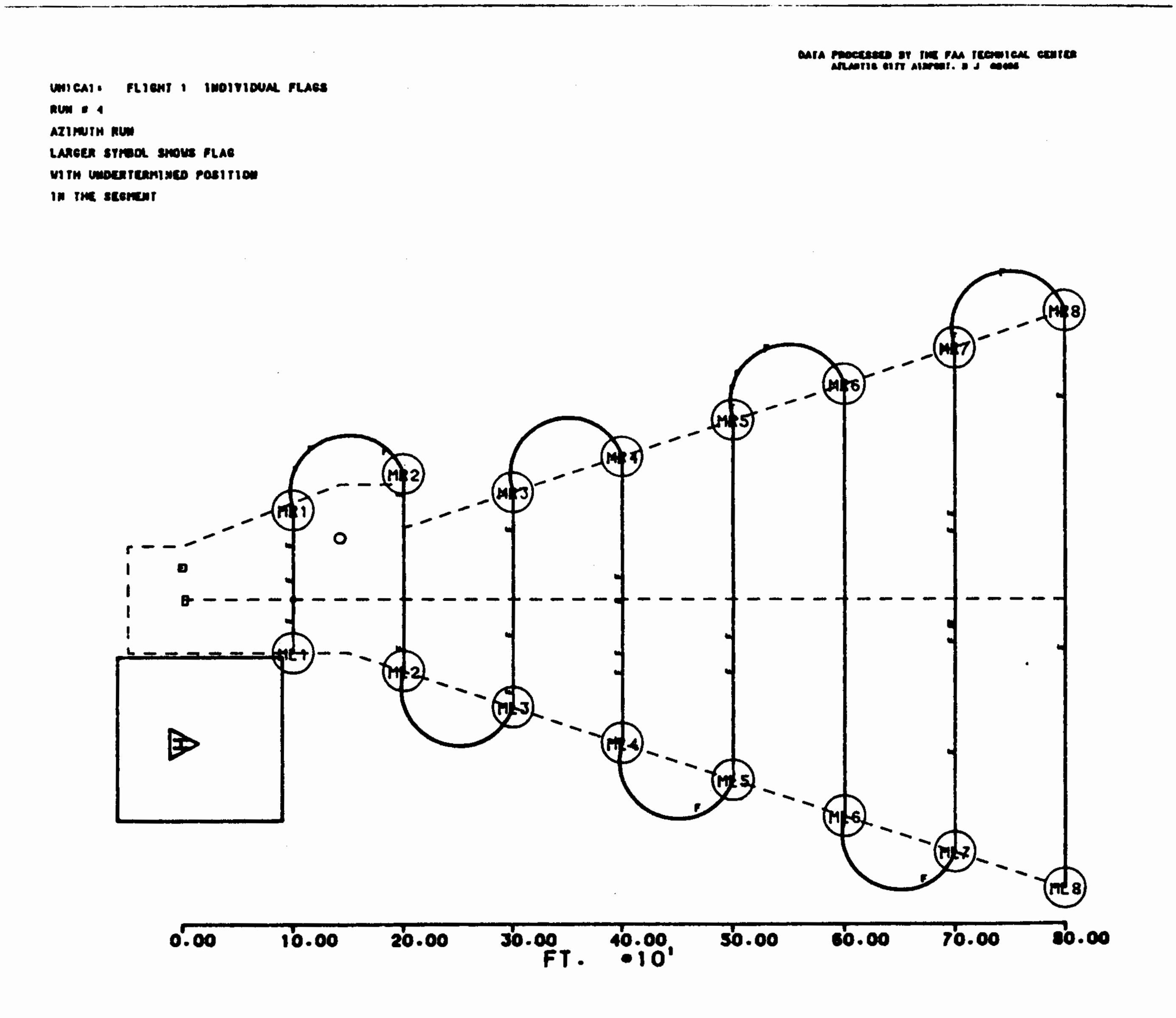


FIGURE 12. AZIMUTH FRAMING FLAG LOCATIONS - RUN 1

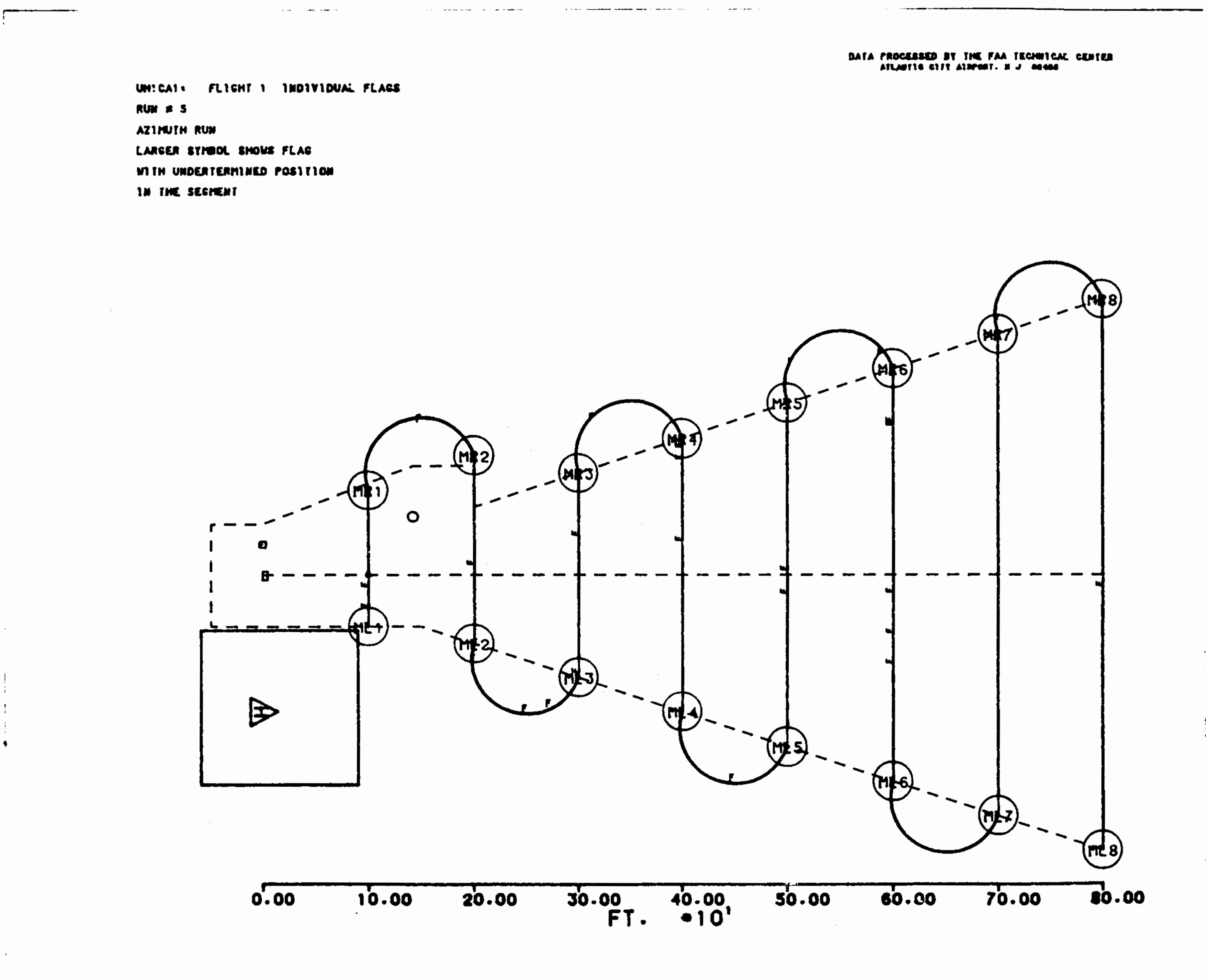


FIGURE 13. AZIMUTH FRAMING FLAG LOCATIONS - RUN 2

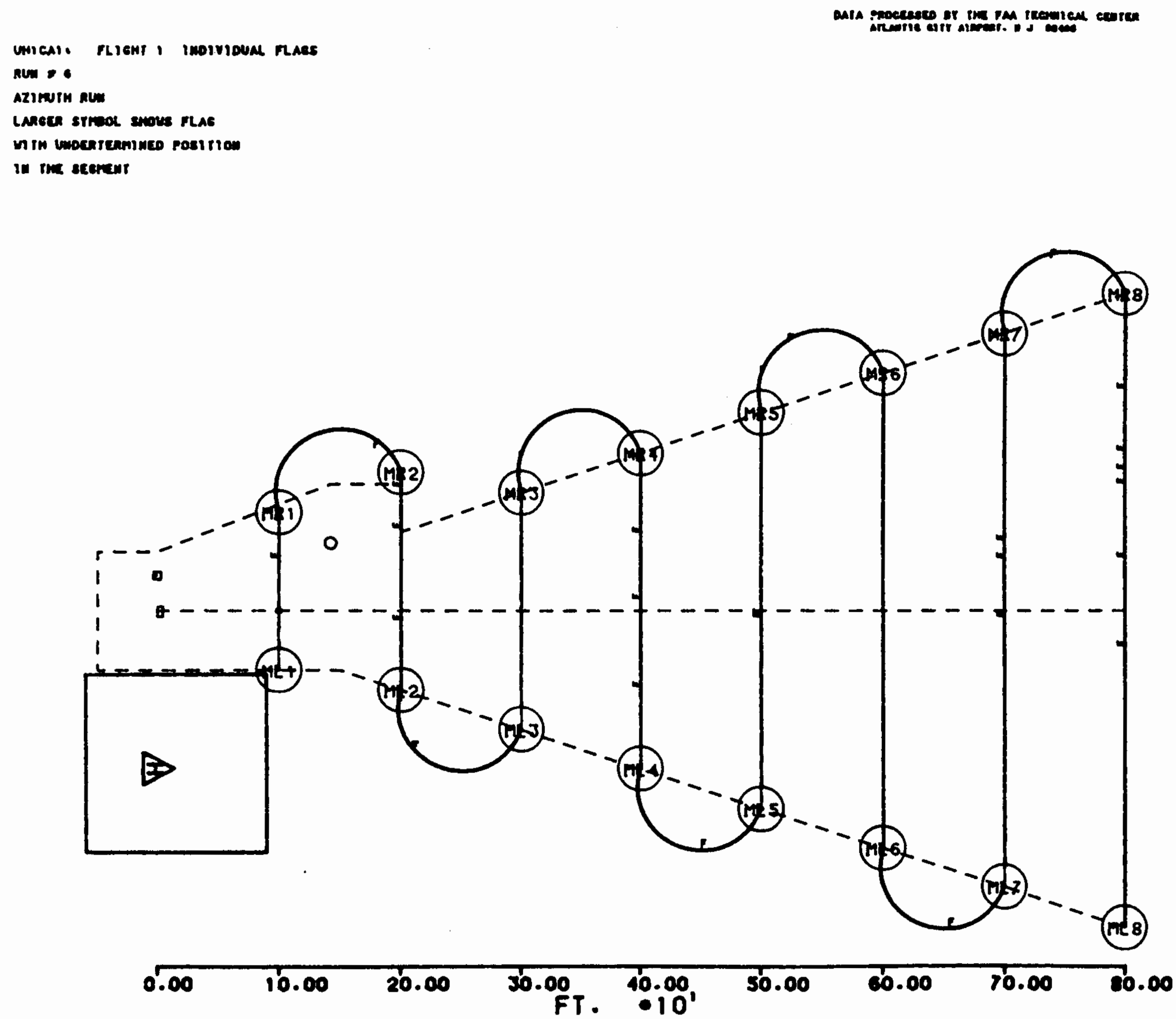


FIGURE 14. AZIMUTH FRAMING FLAG LOCATIONS - RUN 3

Signal quality data were obtained by filtering the received raw angle data through the CMN and PFE filters described in reference 1. This procedure eliminates variations in receiver signal processing of the raw received angle data. PFE and CMN plots for both EL and AZ were obtained for each segment of the interdicting vehicle pattern. Examples of these data are presented in figures 15 to 18. These plots also include flight technical error (FTE) since no reference tracking system was used during the critical area testing. FTE represents the ability of the pilot to precisely position the aircraft in response to course deviation information displayed to the pilot in the cockpit. Throughout the testing, results contain FTE since the pilot manually flew the receiving aircraft MLS aircraft and no reference tracking system was in use. The large bias on figure 10 is due to FTE and is not the result of the interdicting van.

The AZ CMN and PFE results (figures 15 and 16) indicate that reference 1 specified tolerances were met more than the required 95 percent of the time. Similar AZ results were obtained for the other pattern segments. EL CMN results were similarly within tolerance. However, there was a consistant bias between 0.25° and 0.40° for all segments. Because of the consistency of the data regardless of interdicting vehicle position and the fact that a similar bias was detected during the controlled condition runs (no interdictor), the bias is not being caused by the interdictor. The bias is probably due to the pilot's ability to track vertical deviation indications while hovering at a constant radar altitude.

SIMULTANEOUS MLS APPROACHES.

The test profiles used for the simultaneous approach testing are shown in figure 19. For these series of tests the interdicting aircraft was placed at a position between the MLS antennas and the MLS receiving aircraft. During these tests the receiving aircraft flew a normal 3° MLS approach. The approach plate is depicted in figure 20. On approaches 1 and 2 the interdicting aircraft was placed 1.5 nmi in front of the receiving aircraft at the start of the approach. On approach 1, both aircraft maintained 90 knots indicated airspeed throughout the approach. As a result, the relative spacing between the two aircraft remained nearly constant. On approach 2, the receiving aircraft closed on the interdictor since the receiving aircraft had a 30-knot higher approach speed. On the final approach both aircraft started the approach within 1/4 nmi of each other. However, the relative spacing increased throughout the approach since the interdictor's approach speed was 30 knots higher than the MLS receiving aircraft's approach speed. The start positions for both aircraft at the beginning of each runs are shown in table 3.

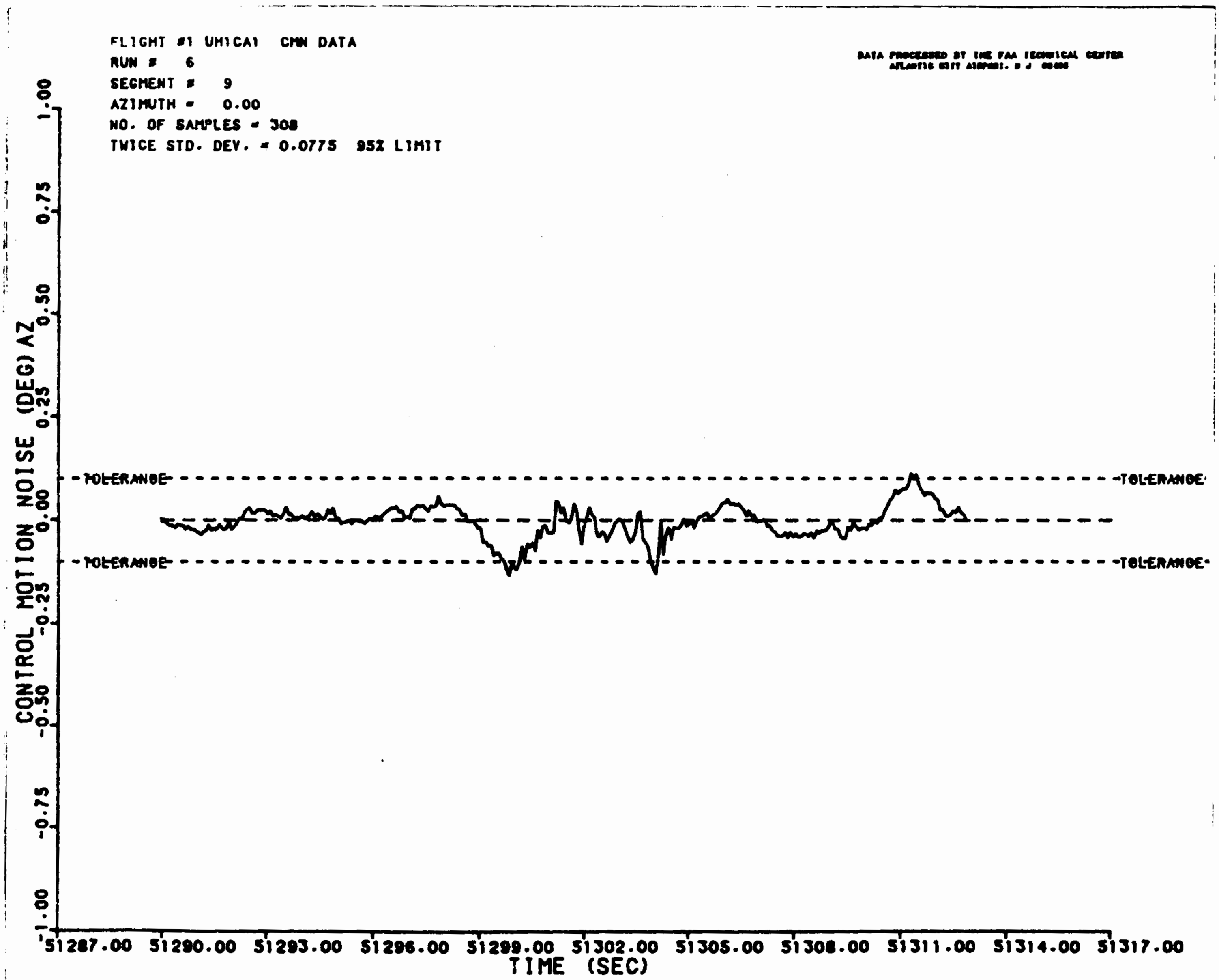


FIGURE 15. AZIMUTH CMN RESULTS IN THE PRESENCE OF THE INTERDICTING VAN

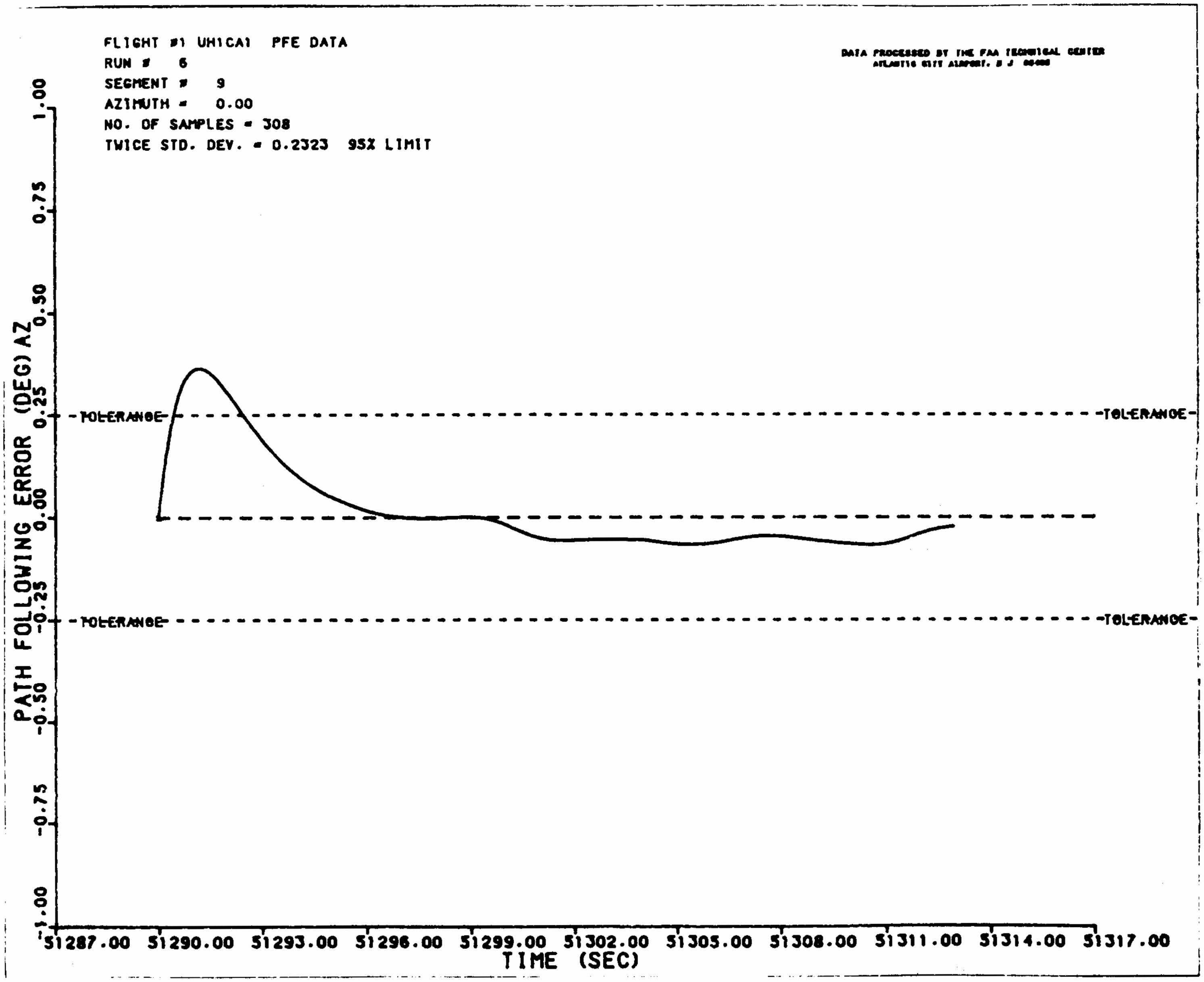


FIGURE 16. AZIMUTH PFE RESULTS IN THE PRESENCE OF THE INTERDICTING VAN

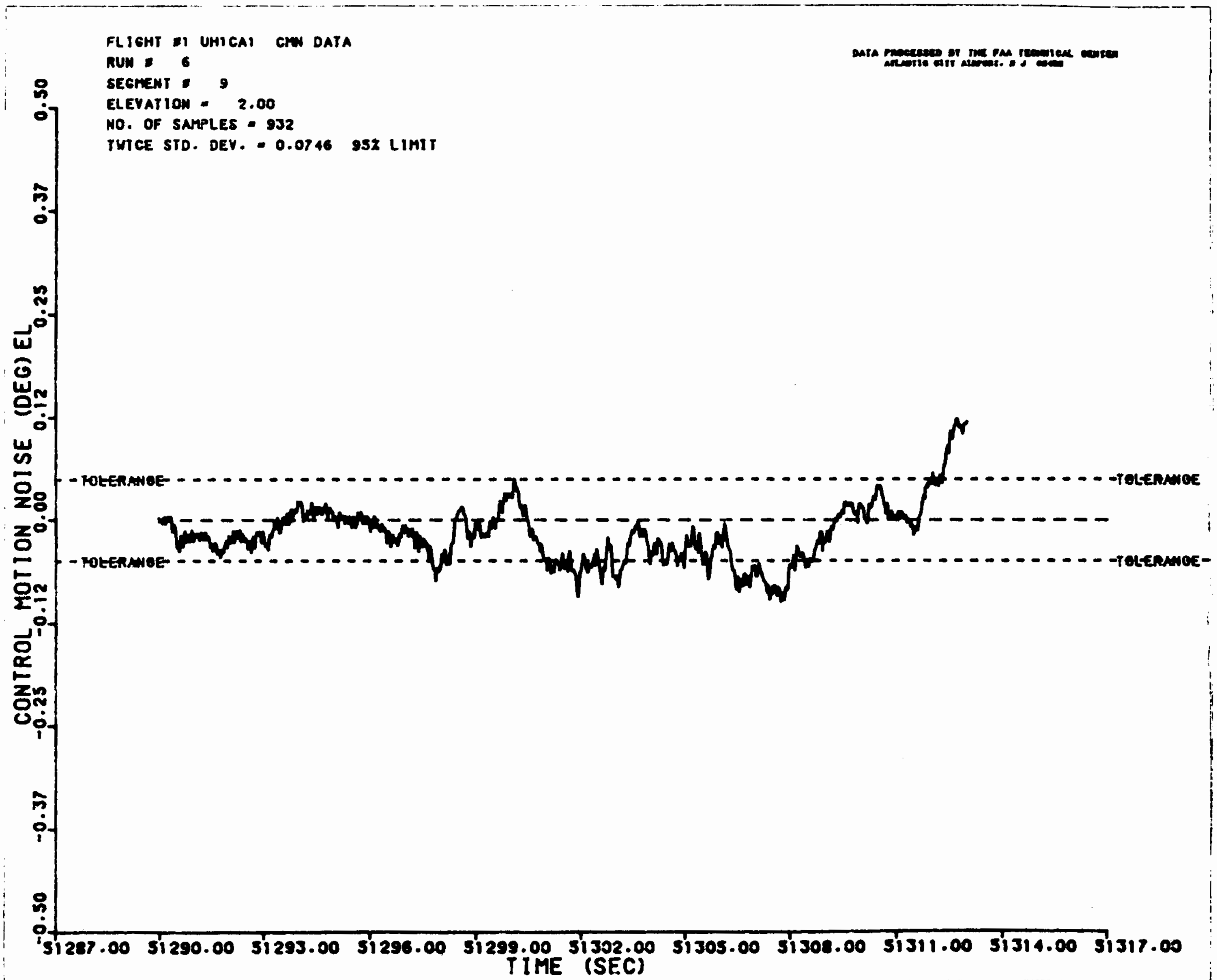


FIGURE 17. ELEVATION CMN RESULTS IN THE PRESENCE OF THE INTERDICTING VAN

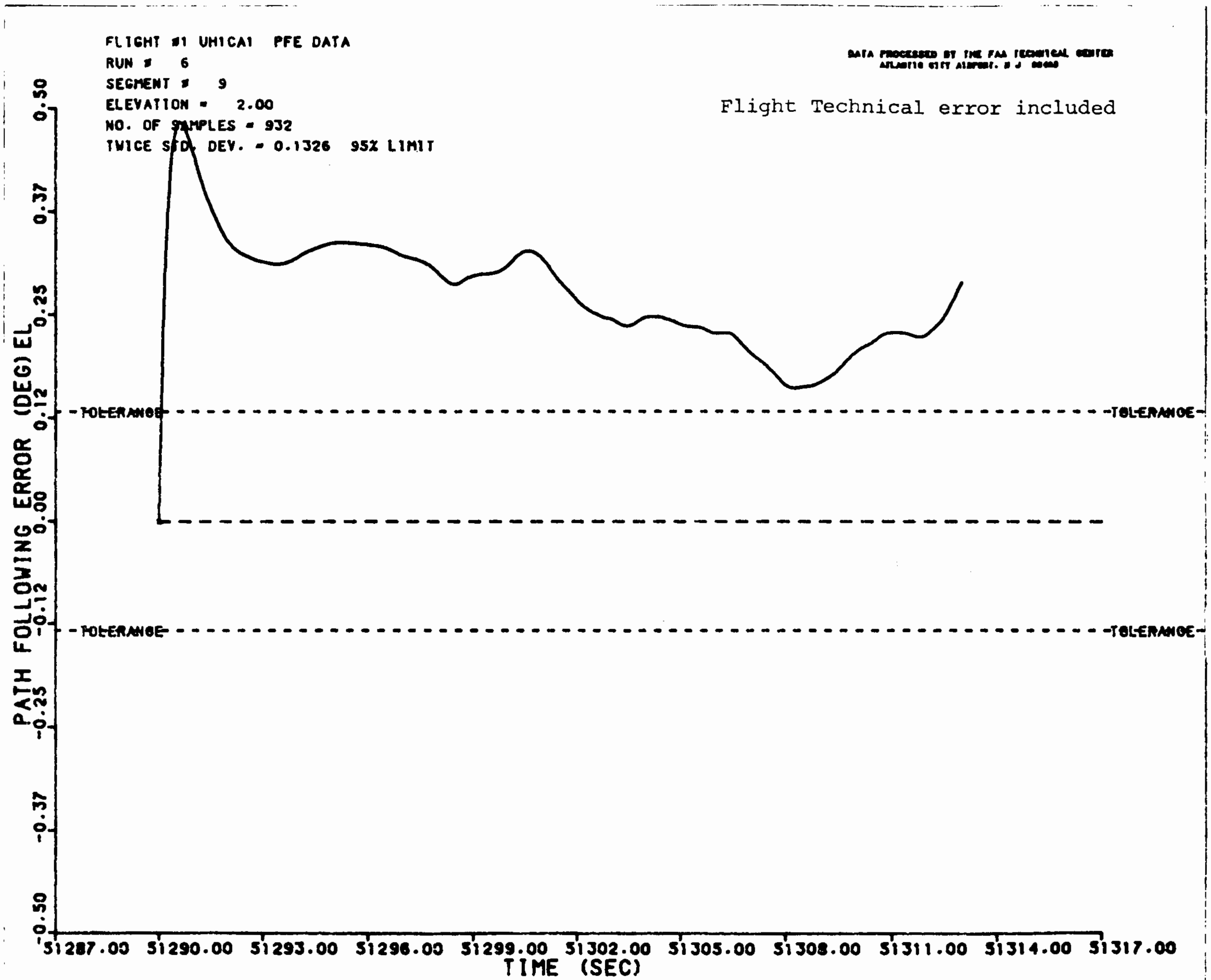


FIGURE 18. ELEVATION PFE RESULTS IN THE PRESENCE OF THE INTERDICTING VAN

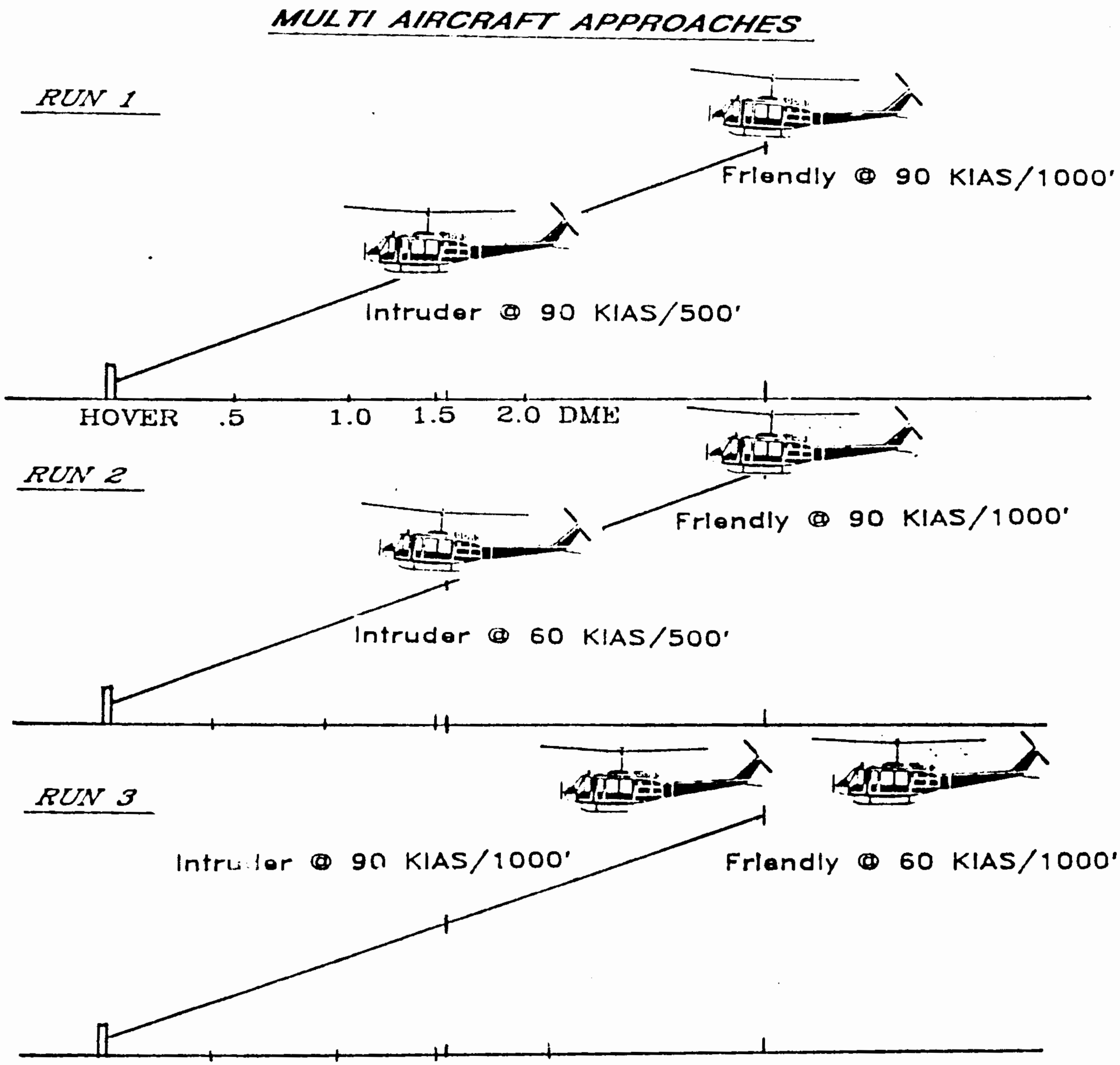


FIGURE 19. SIMULTANEOUS APPROACH TEST PROFILES

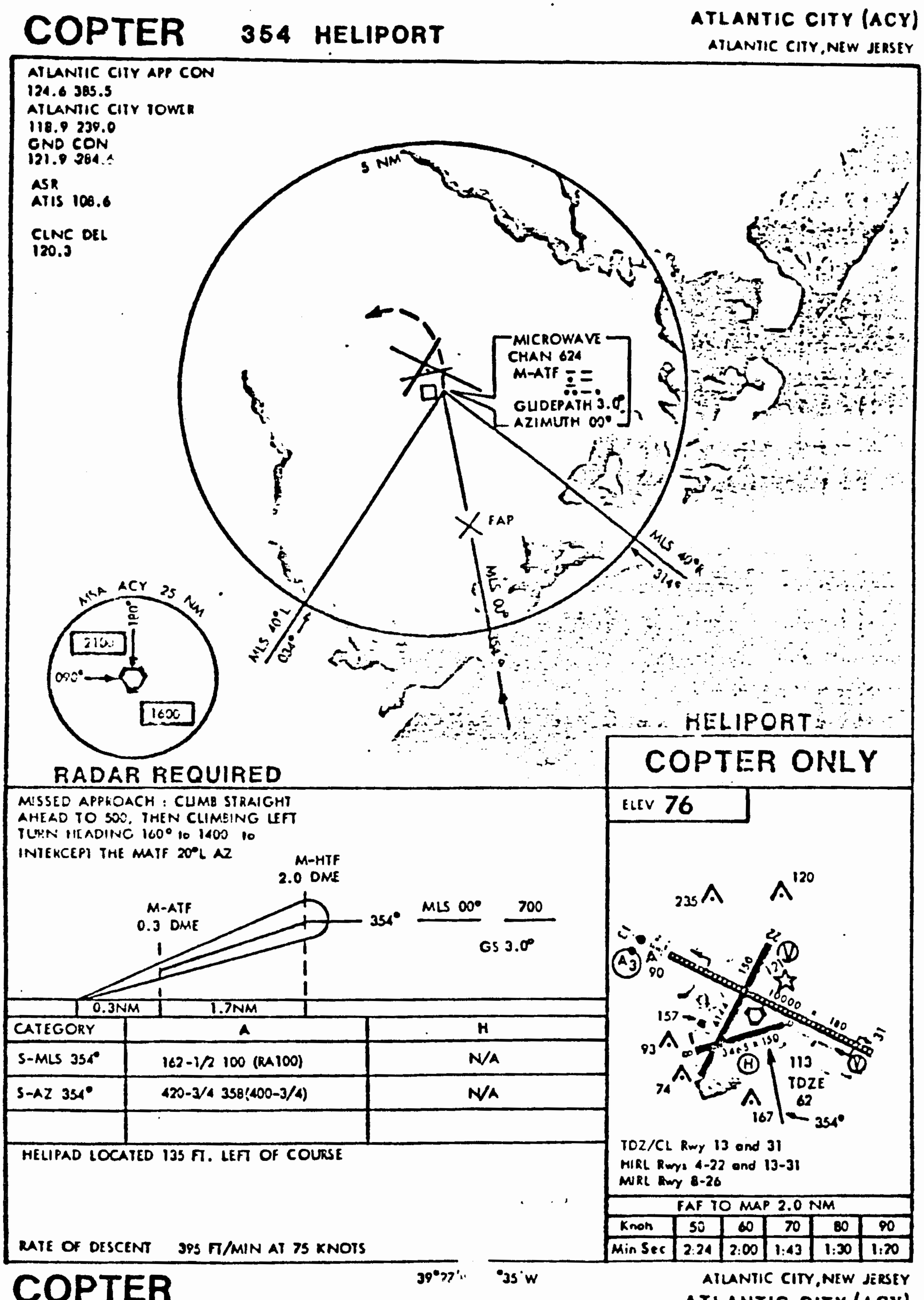


FIGURE 20. ATLANTIC CITY MLS APPROACH PLATE

TABLE 3. MULTIPLE AIRCRAFT TEST APPROACH START POSITIONS

	Approach Interdictor Start		Receiving MLS Start	
	Position		Position	
No.	DME (nmi)	IAS (kts)	DME (nmi)	IAS (kts)
1	1.6	90	3.1	90
2	1.6	60	3.1	90
3	3.1	90	3.1	60

The number of framing flags for both elevation and azimuth on all three runs were quite low. The location of the AZ framing flags which occurred for each run are plotted on figures 21 to 23. The plotted location represents the interdictor's position at the time the framing flag occurred. The higher proportion of the framing flags occurred when the interdicting aircraft was between 1 to 1.5 nmi from the antenna. This fact indicates spectral reflections rather than signal blockage caused the framing flags. If signal blockage were a problem, the higher proportion would have occurred as the interdictor approached the antennas. This follows because a larger angular signal coverage volume is subtended by the aircraft profile the closer it gets to the antennas. In any case, the proportion of AZ framing flags which occurred on the simultaneous approaches was very low. Similar EL framing flag results were obtained. EL framing flag locations for the multiple aircraft test runs are shown in figures 24 to 26.

Signal quality was investigated during the simultaneous approaches. Plots of the estimates of azimuth CMN during approach 1, when both aircraft maintained the same relative position, are shown in figure 27 (2 sheets). The excursions beyond the tolerance limits initially on figure 27a represent pilot induced azimuth deviations at the beginning of the approach. However, generally excellent azimuth CMN results were observed on this approach. The elevation CMN plots for simultaneous approach 1 are presented in figure 28 (2 sheets). These plots also indicate excellent results. The largest observed 95 percent limit for elevation CMN did not exceed 0.07°.

The low frequency noise component (PFE) for both the azimuth and elevation signal on simultaneous approach 1 generally were within tolerances identified in reference 1. This resulted despite the fact that the approaches were manually flown. Figure 29 presents a sample of the elevation PFE results for simultaneous approach 1. The initial overshoot shown on figure 29 is due to initialization of the PFE filter.

On simultaneous approach 2 the receiving MLS aircraft closed on the interdicting aircraft during the approach. A sample of the azimuth CMN results for approach 2 is presented in figure 30. The low frequency oscillation apparent in figure 30 is due to pilot-induced deviations which were intended to keep the interdictor directly between the receiving MLS aircraft and the MLS antennas. The other MLS signal error components on simultaneous approach 2 were also analyzed. Table 4 depicts the results of this analysis.

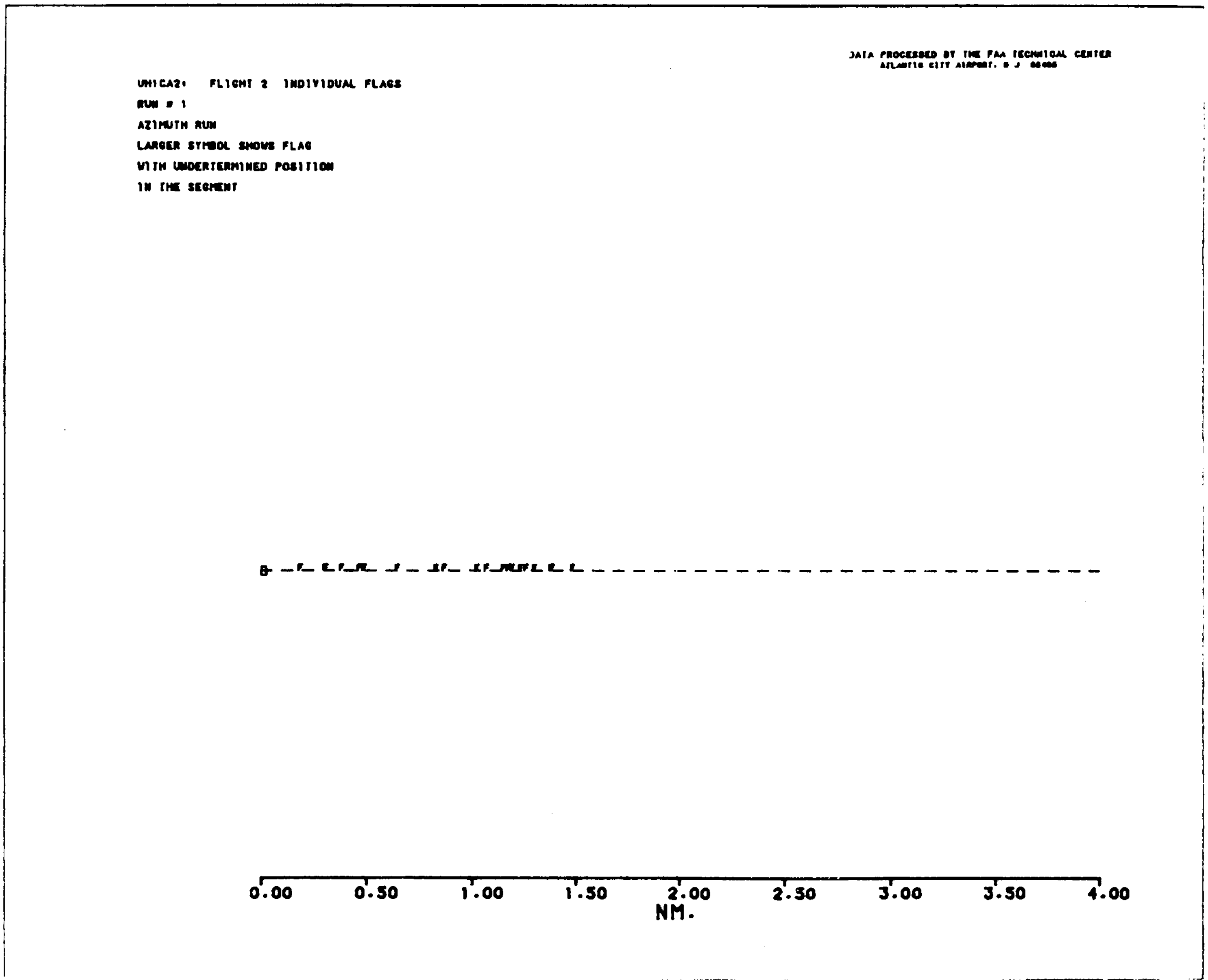


FIGURE 21. AZIMUTH FRAMING FLAG LOCATIONS SIMULTANEOUS APPROACH 1

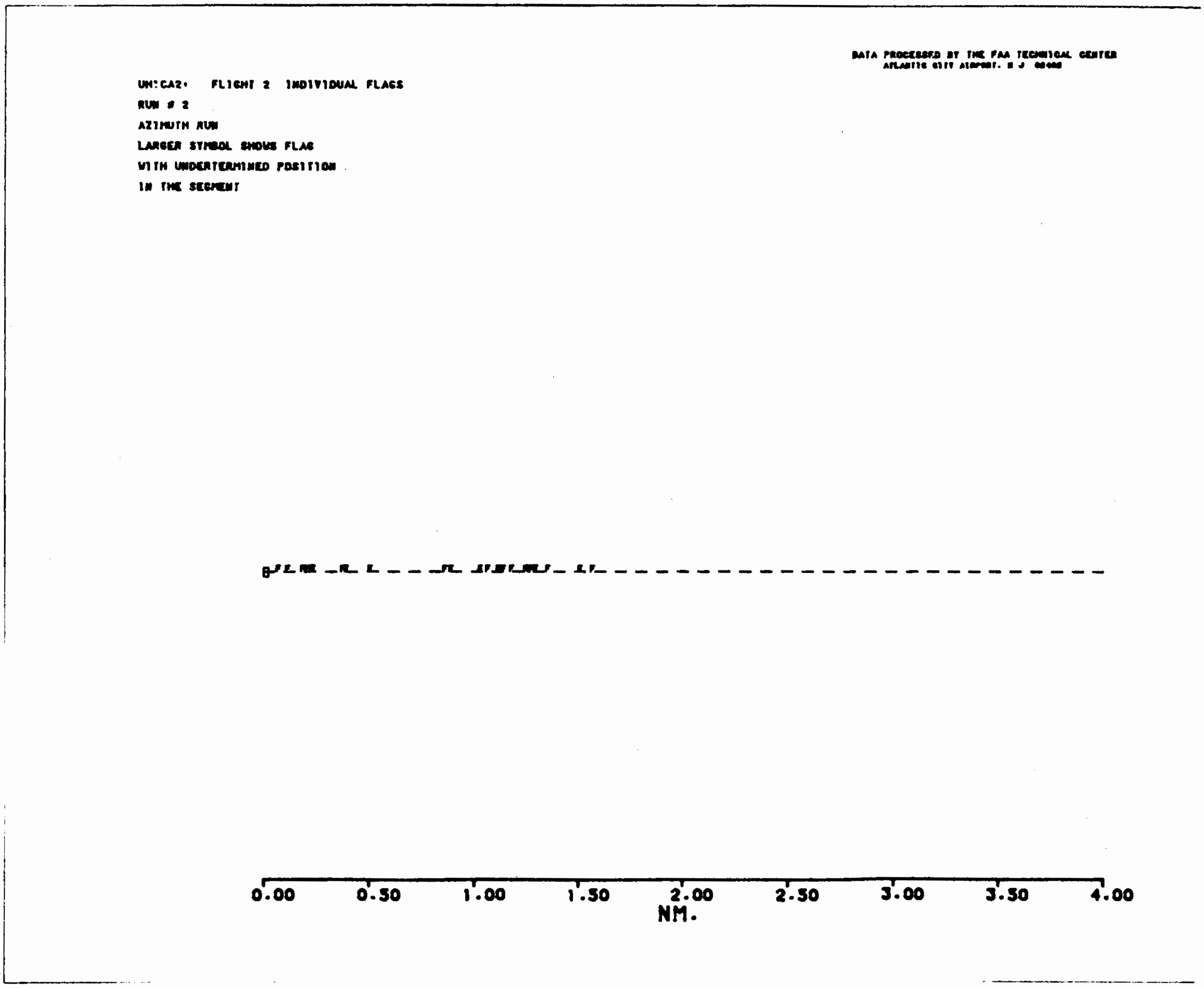


FIGURE 22. AZIMUTH FRAMING FLAG LOCATIONS SIMULTANEOUS APPROACH 2

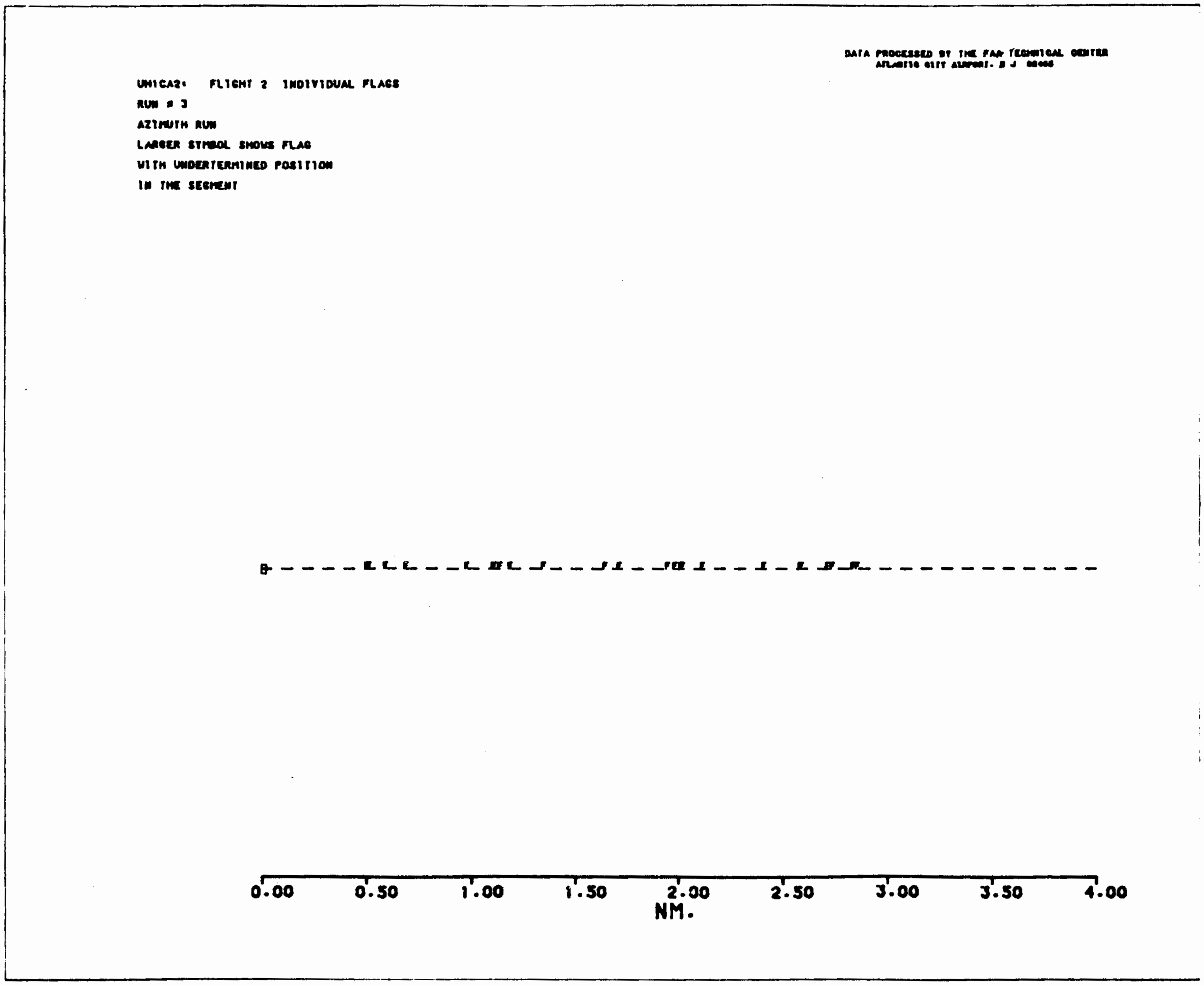


FIGURE 23. AZIMUTH FRAMING FLAG LOCATIONS SIMULTANEOUS APPROACH 3

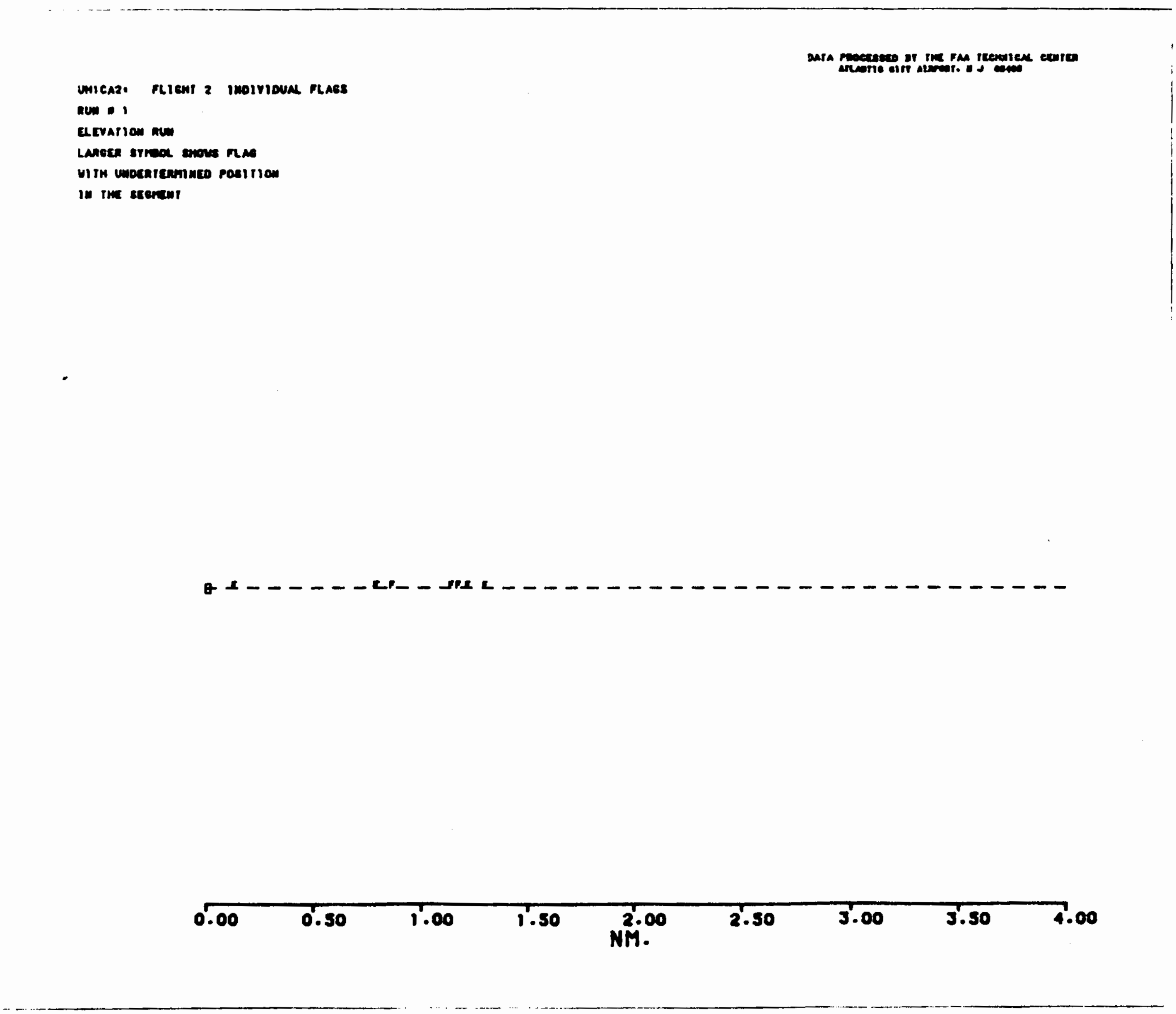


FIGURE 24. ELEVATION FRAMING FLAG LOCATIONS SIMULTANEOUS APPROACH 1

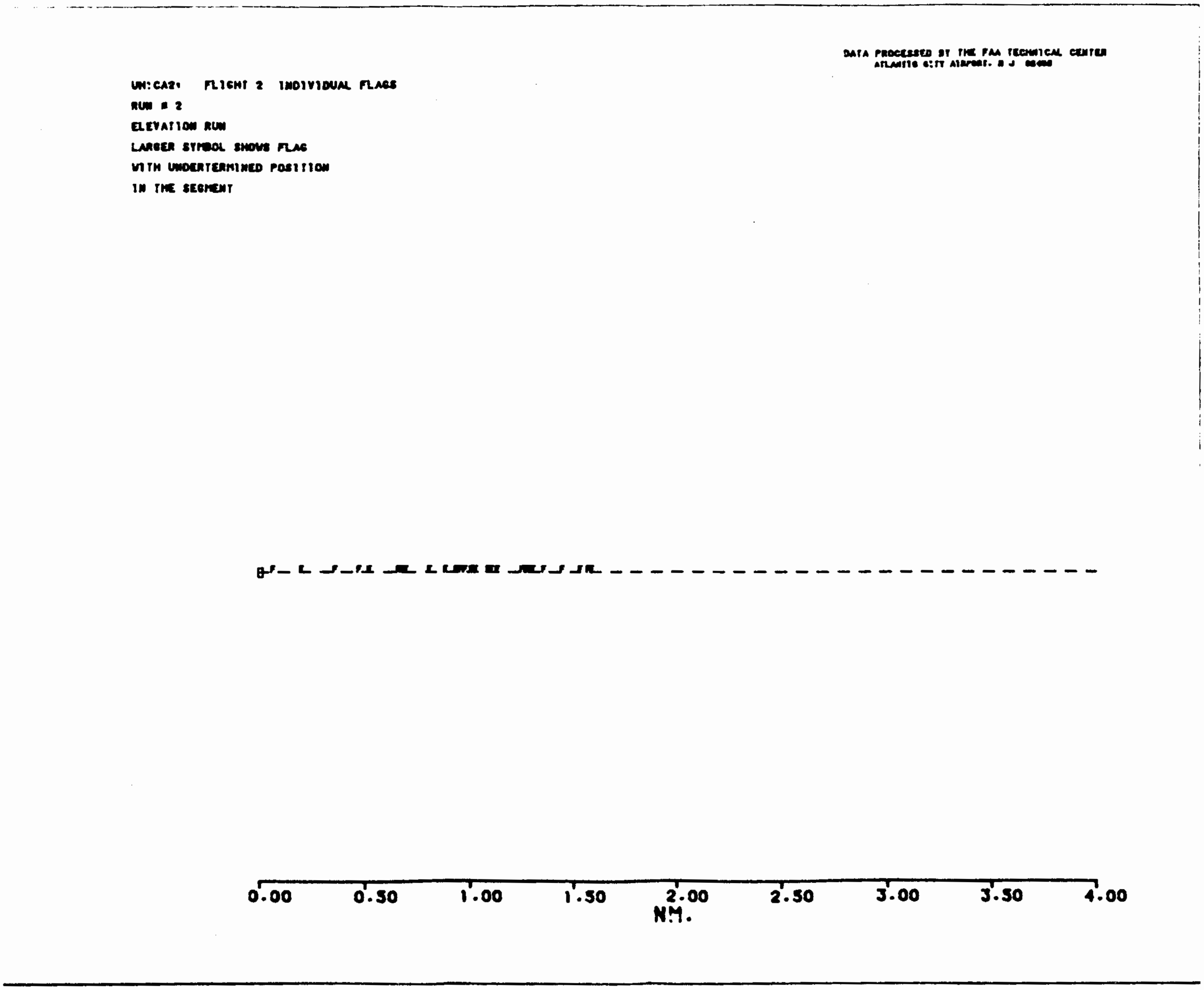


FIGURE 25. ELEVATION FRAMING FLAG LOCATIONS SIMULTANEOUS APPROACH 2

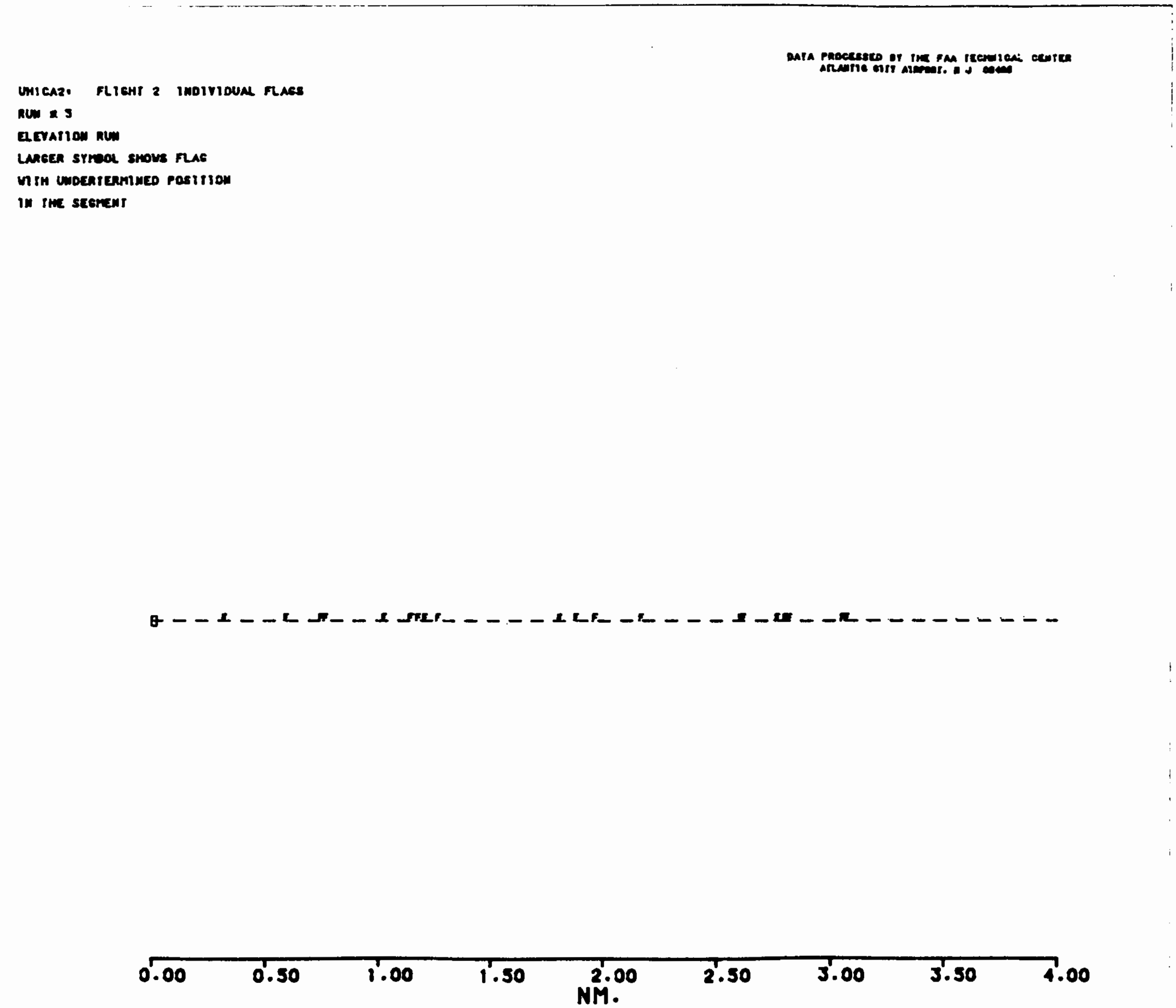
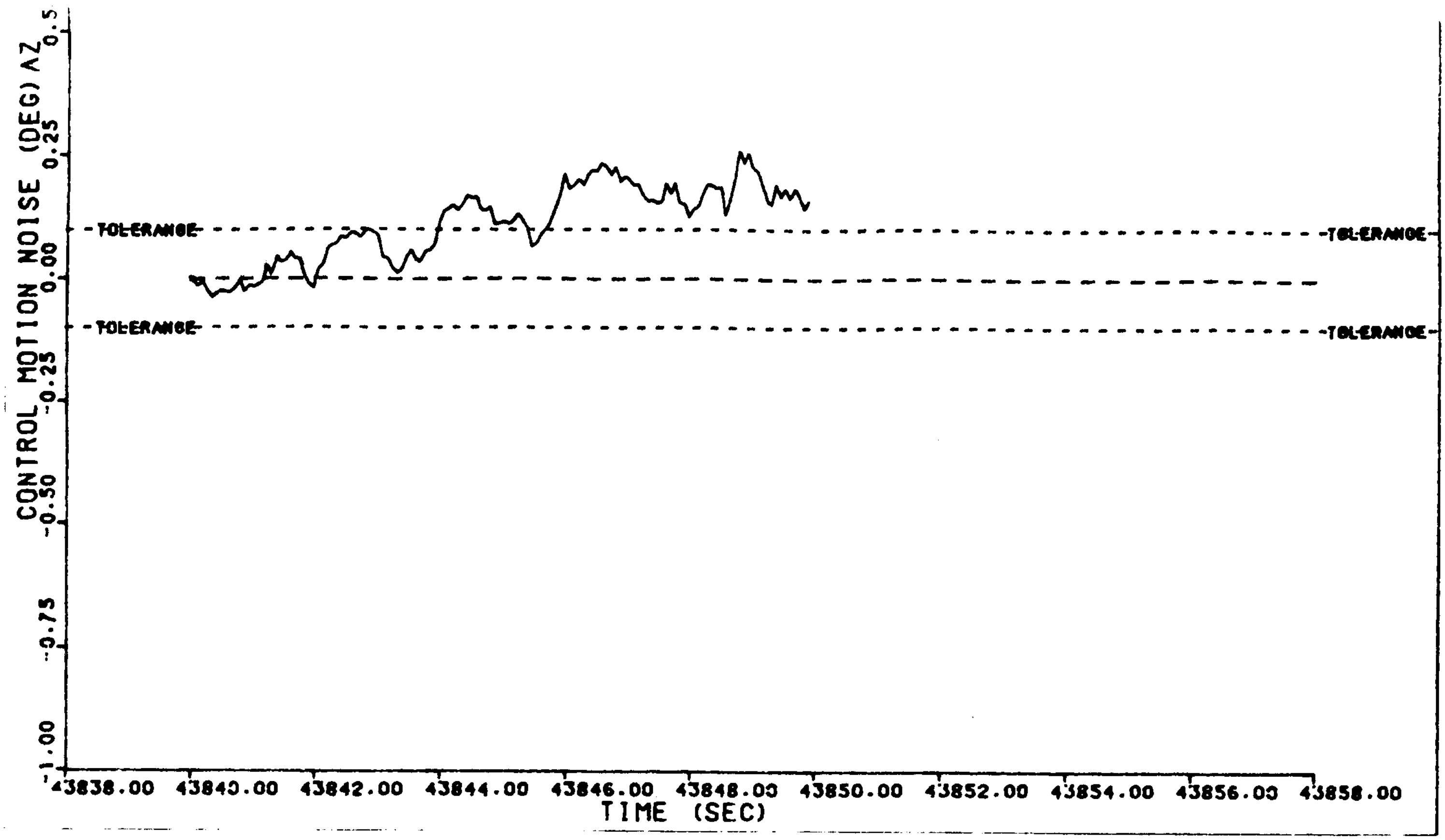


FIGURE 26. ELEVATION FRAMING FLAG LOCATIONS SIMULTANEOUS APPROACH 3



TN86/64-27a

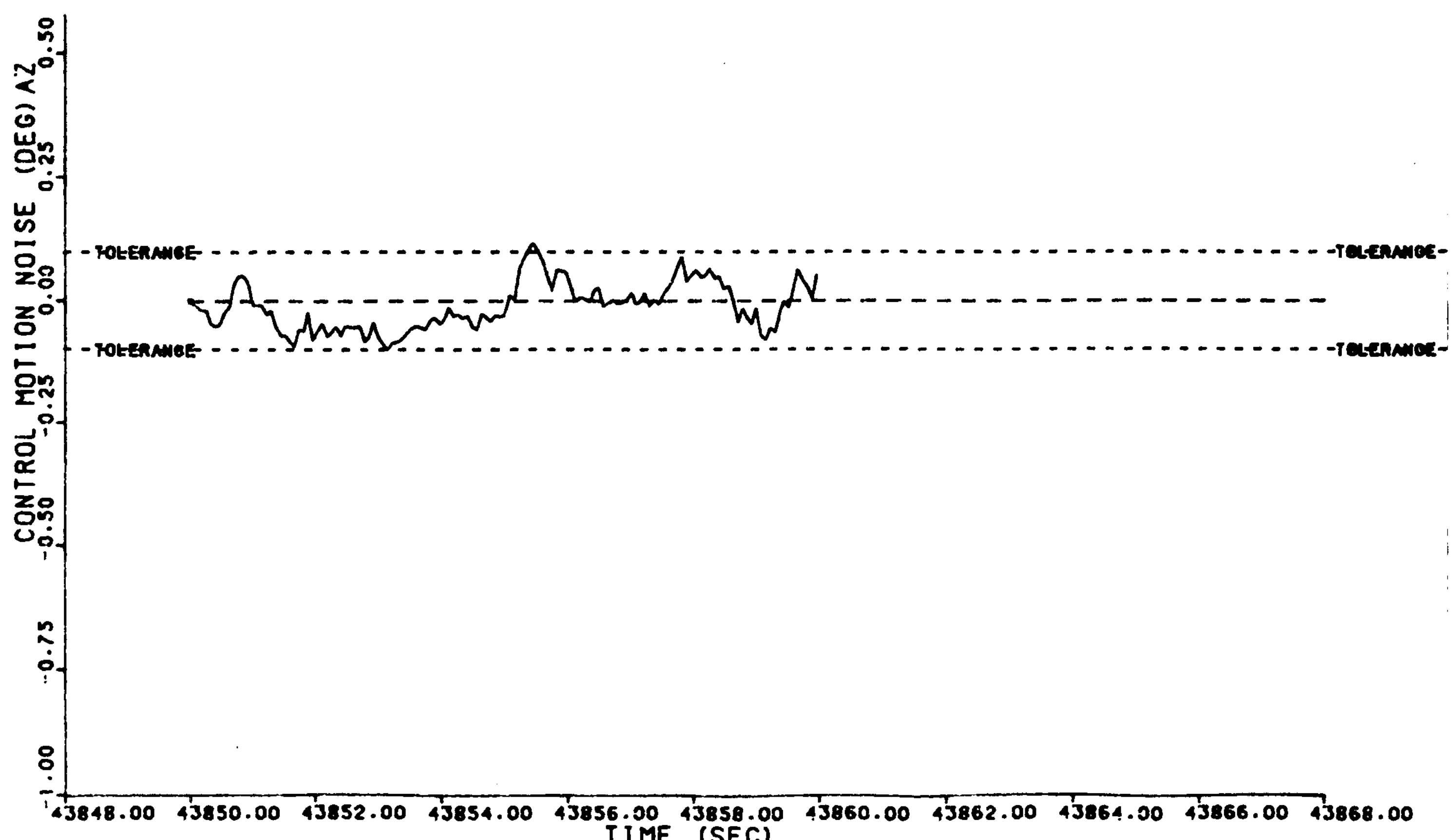


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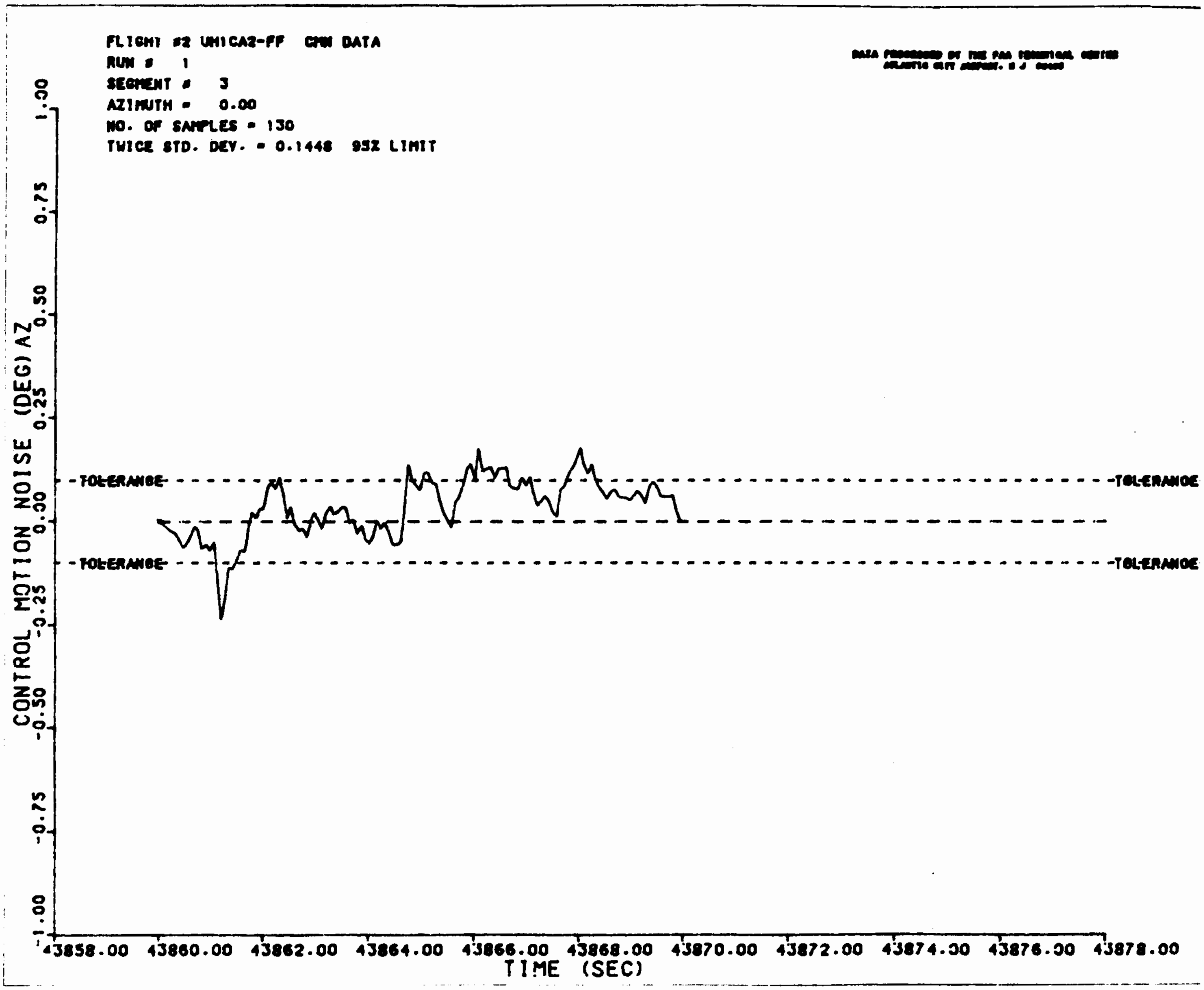
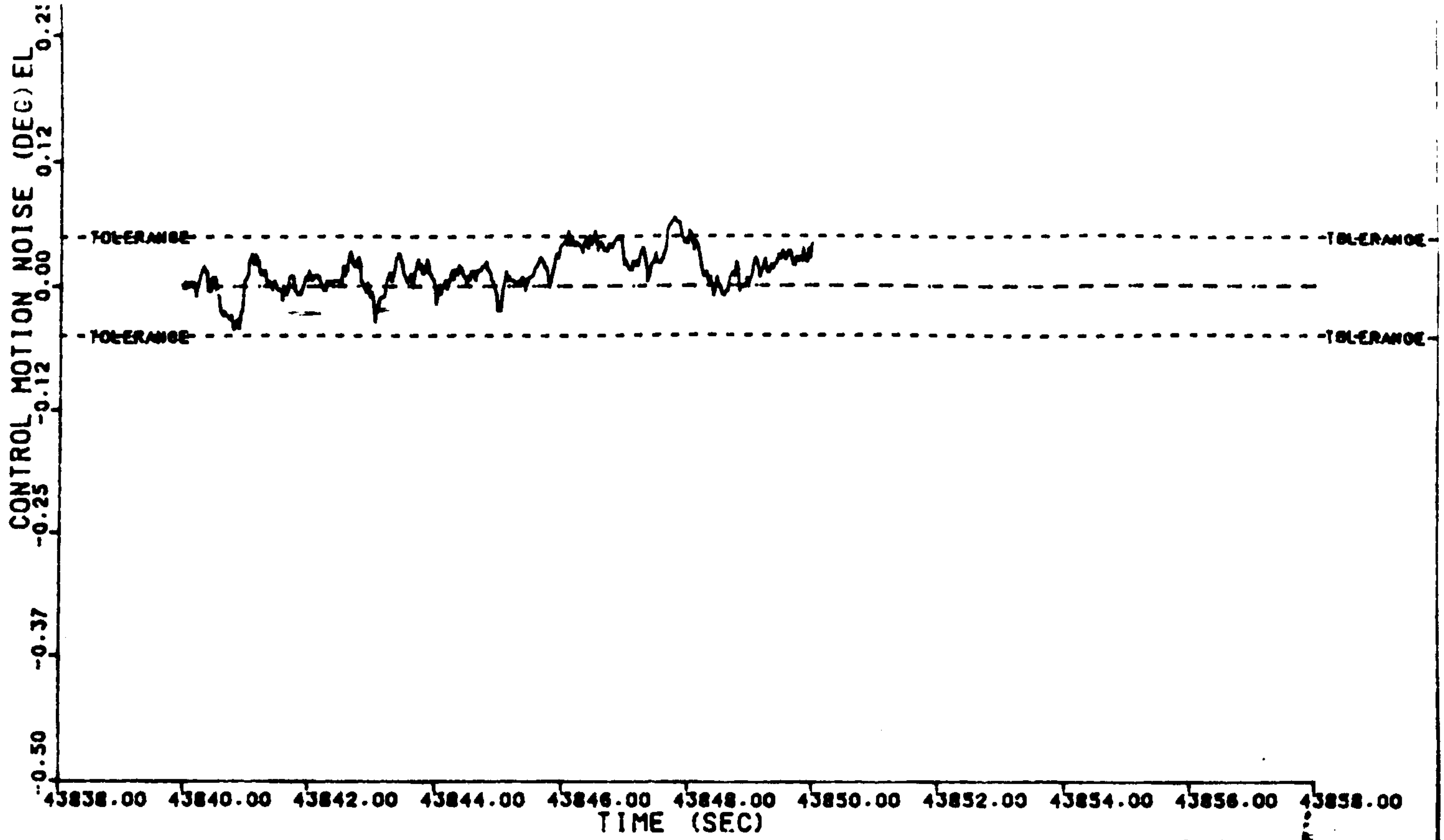
FIGURE 27. AZIMUTH HIGH FREQUENCY ERROR COMPONENT PLOTS FOR SIMULTANEOUS APPROACH 1 (SHEET 1 OF 2)

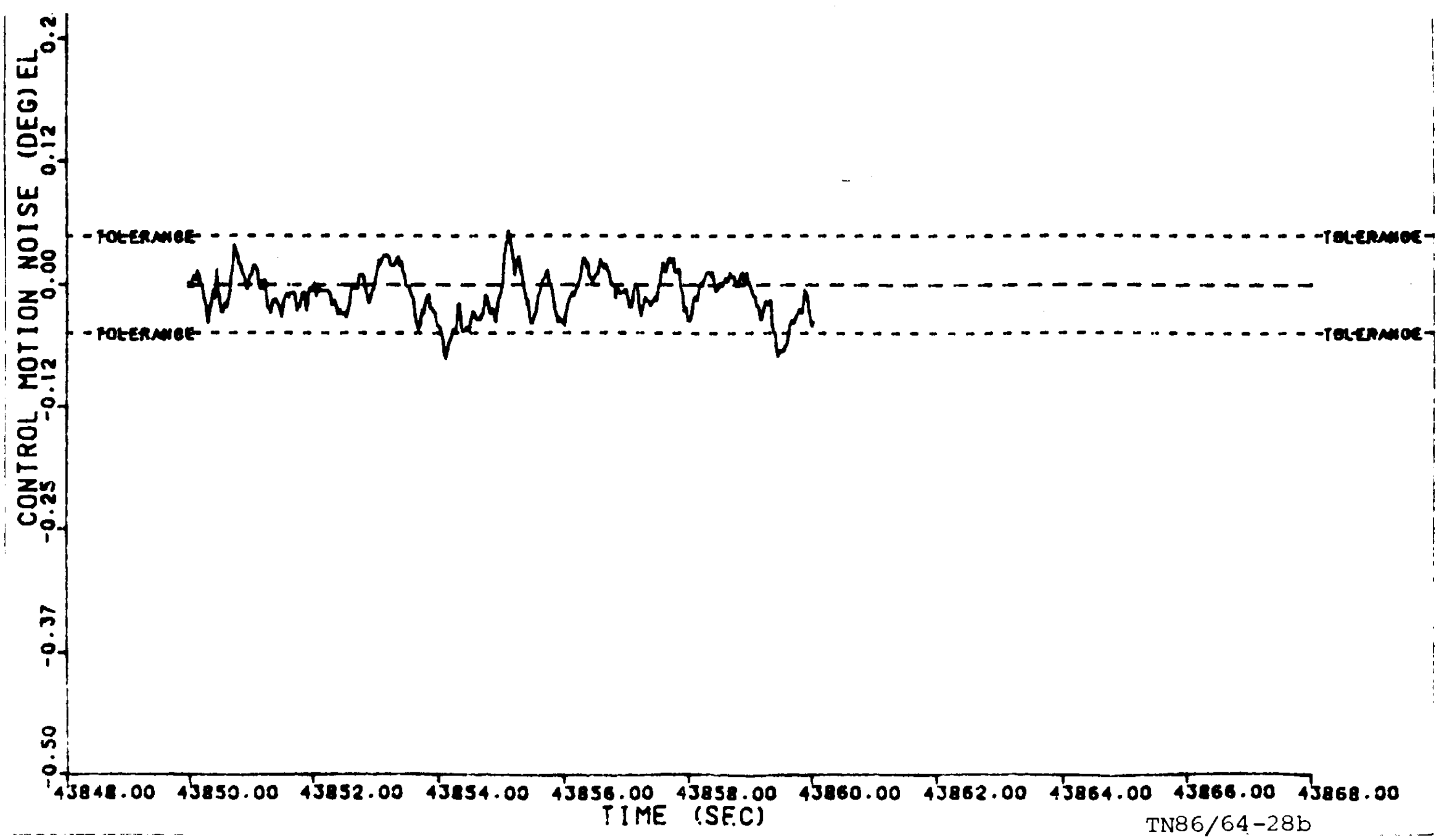


TN86/64-27c

FIGURE 27. AZIMUTH HIGH FREQUENCY ERROR COMPONENT PLOTS FOR SIMULTANEOUS APPROACH 1 (SHEET 2 OF 2)

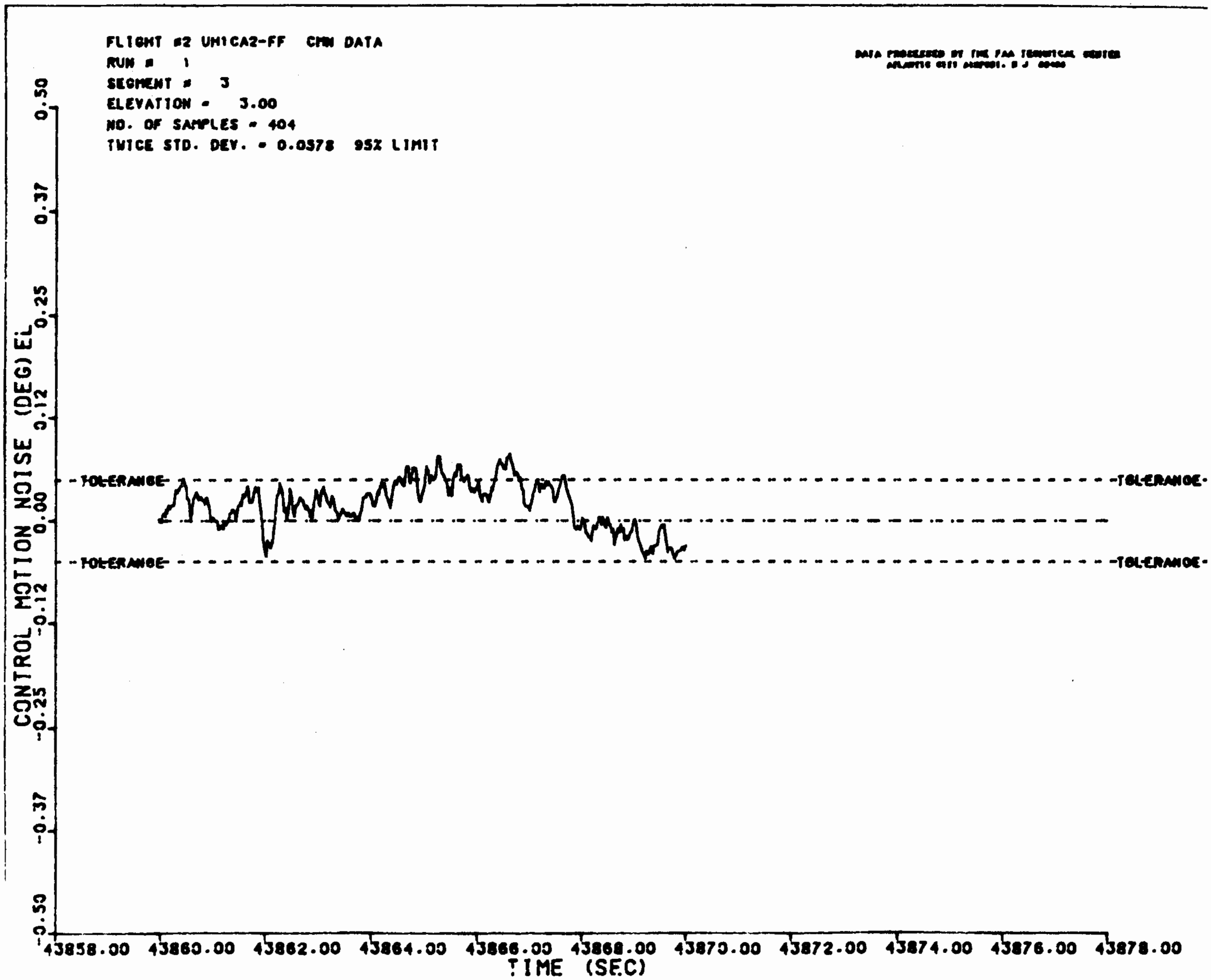


TN86/64-28a



TN86/64-28b

FIGURE 28. ELEVATION HEIGHT FREQUENCY ERROR COMPONENT PLOTS FOR SIMULTANEOUS APPROACH 2 (SHEET 1 OF 2)



TN86/64-28c

FIGURE 28. EVALUATION HEIGHT FREQUENCY ERROR COMPONENT PLOTS FOR SIMULTANEOUS APPROACH 2 (SHEET 2 OF 2)

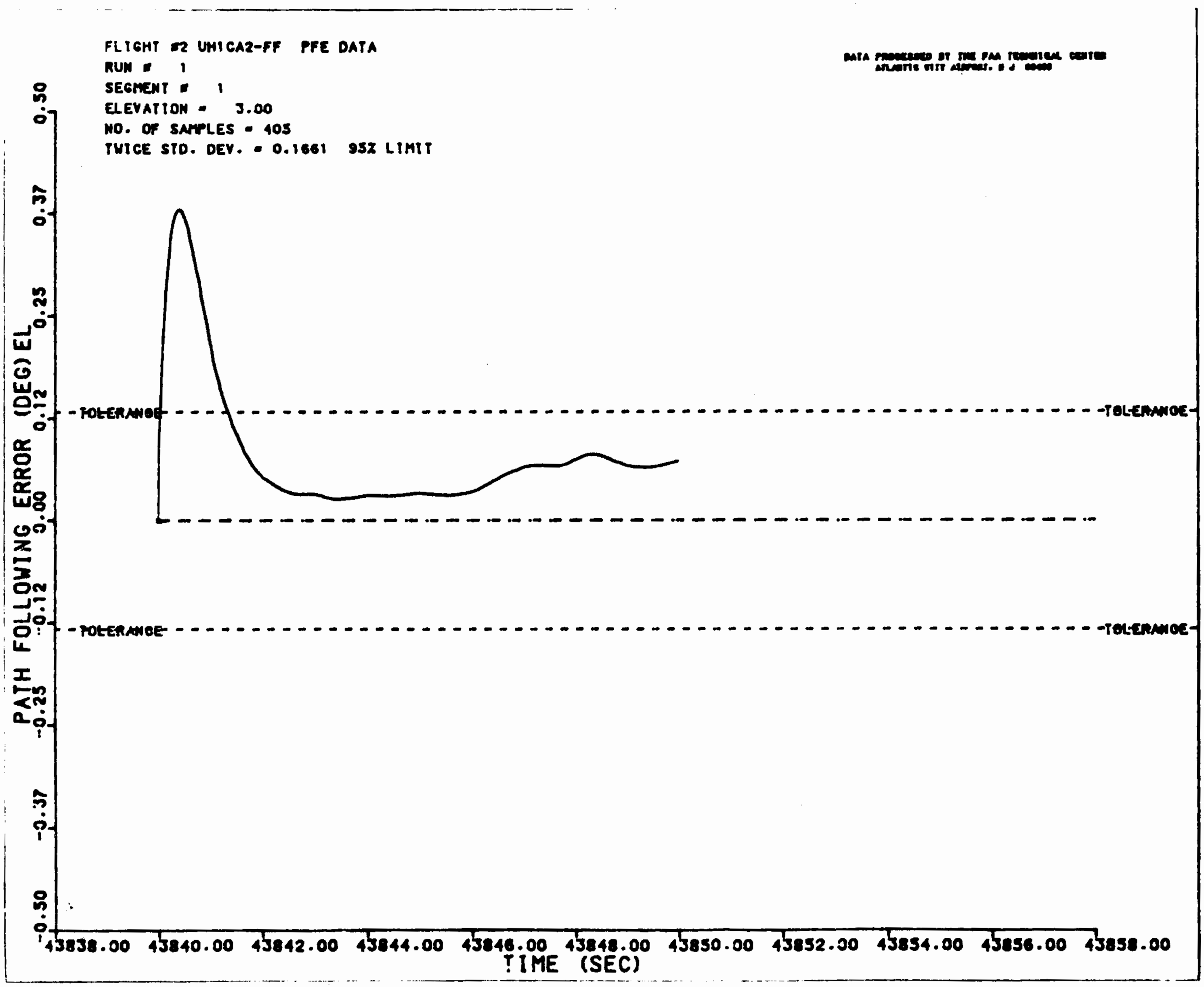


FIGURE 29. A SAMPLE OF ELEVATION PFE RESULTS ON SIMULTANEOUS APPROACH 1

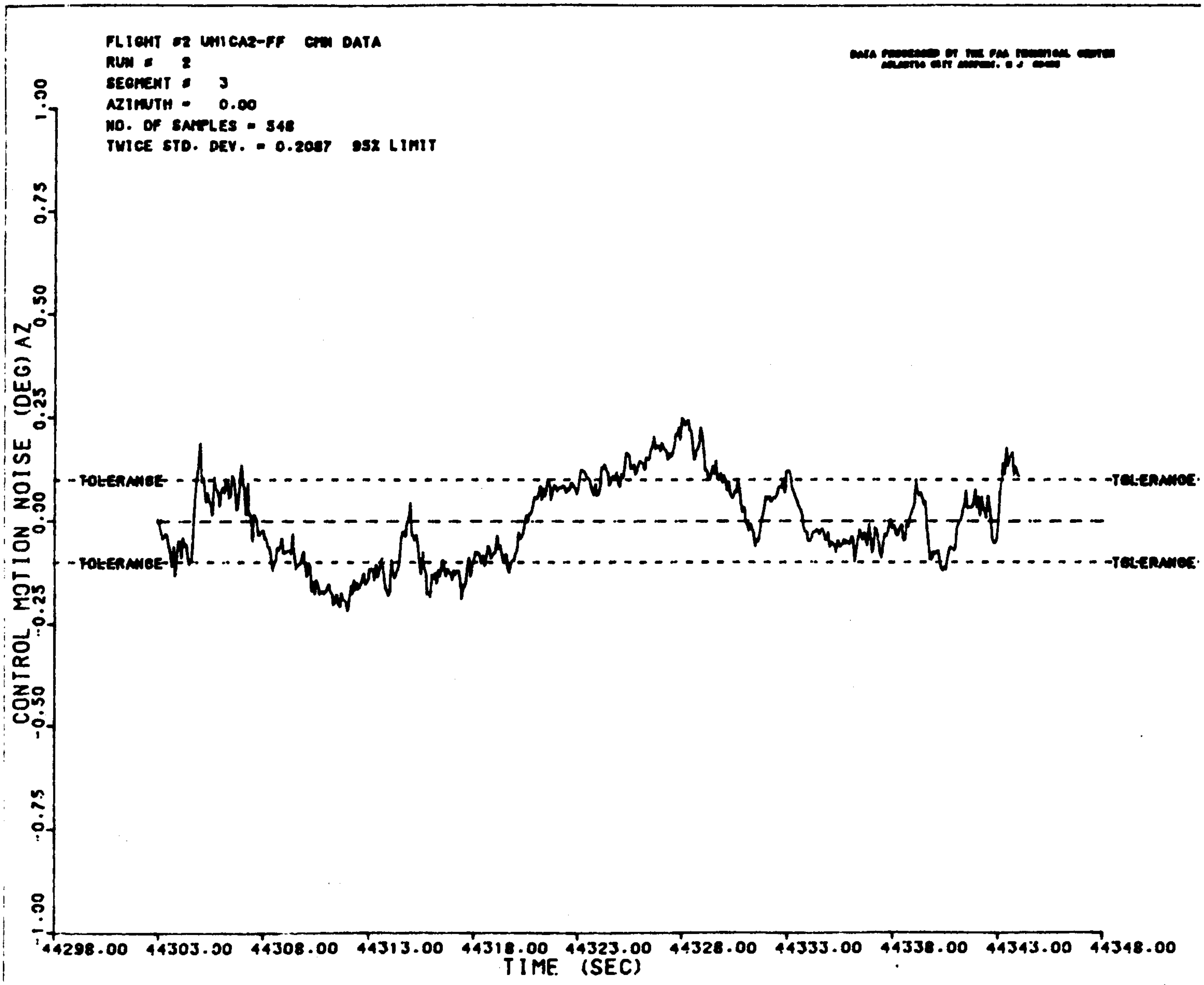


FIGURE 30. A SAMPLE OF AZIMUTH CMN RESULTS ON SIMULTANEOUS APPROACH 2

TABLE 4. SIMULTANEOUS SIGNAL ERROR COMPONENT ANALYSIS

Function	Error Component	Sampled 95% Limit	Tolerance Limit
Azimuth	CMN	0.099°	0.120°
	PFE	0.208°	0.250°
Elevation	CMN	0.091°	0.100°
	PFE	0.261°	0.250°

The slightly larger than specified tolerance limit in the case of elevation PFE was due to bias induced by the pilot attempting to keep the interdictor directly between the MLS receiving aircraft and the antennas.

On the third approach in this test series, the receiving MLS aircraft and the interdictor diverged. The first portion of the approach represents the portion during which the interdictor and receiving MLS aircraft were closest together. A review of figures 23 and 26 indicate a higher proportion of the extremely low number of framing flags which did occur on approach 3 resulted during the initial portion of the approach when the aircraft were separated by the minimum distance.

Figures 31 to 34 present plots of the estimates of the signal error components which were obtained during the initial portion of the approach. On figures 33 and 34 the biases which resulted were attributed to the receiving aircraft pilot maneuvering the aircraft to position the interdictor directly between the receiving MLS aircraft and the antennas.

HOVERING INTERDICTING AIRCRAFT TESTS.

Several tests were conducted in which the interdicting aircraft was hovered in a designated pattern in the vicinity of the MLS antennas. Movement sequences were designed to represent possible signal interdiction by helicopters maneuvering about the heliport. Three different patterns were used and are presented in figures 35 to 37. These patterns include a perpendicular "S" pattern, a parallel "S" pattern, and a pattern during which the interdictor performed 360° hovering turns at various locations on the 0° azimuth. Table 5 presents the experimental conditions used for the various hovering interdictor test flights.

During the "S" patterns the interdictor hovered at the indicated height and at a constant 5-knot ground speed. On the 360° turn pattern the interdictor made a 360° pedal turn about the aircraft's main rotor mast.

For the hovering interdictor flights, additional data were obtained on signal quality. These data were statistical in nature. Before starting the pattern with the interdicting helicopter, the receiving MLS aircraft was hovered at the particular DH and 5 minutes of static data were taken. The standard deviation of the course deviation indicator (CDI) and the vertical deviation indicator (VDI) indications were obtained for the static data. Then similar statistics were developed for each segment of the hovering pattern while the interdictor was

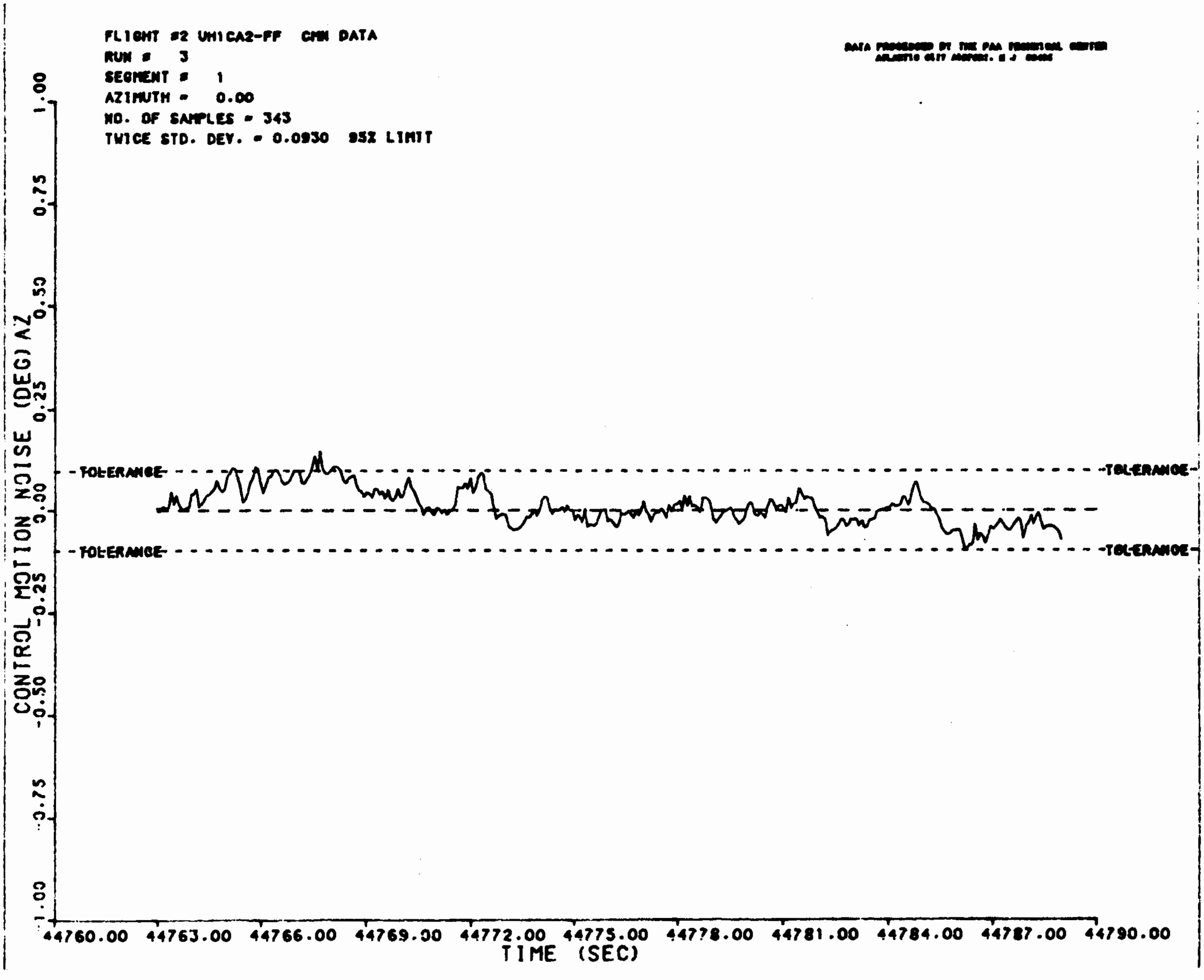


FIGURE 31. AZIMUTH CMN RESULTS FOR INITIAL PORTION OF SIMULTANEOUS APPROACH 3

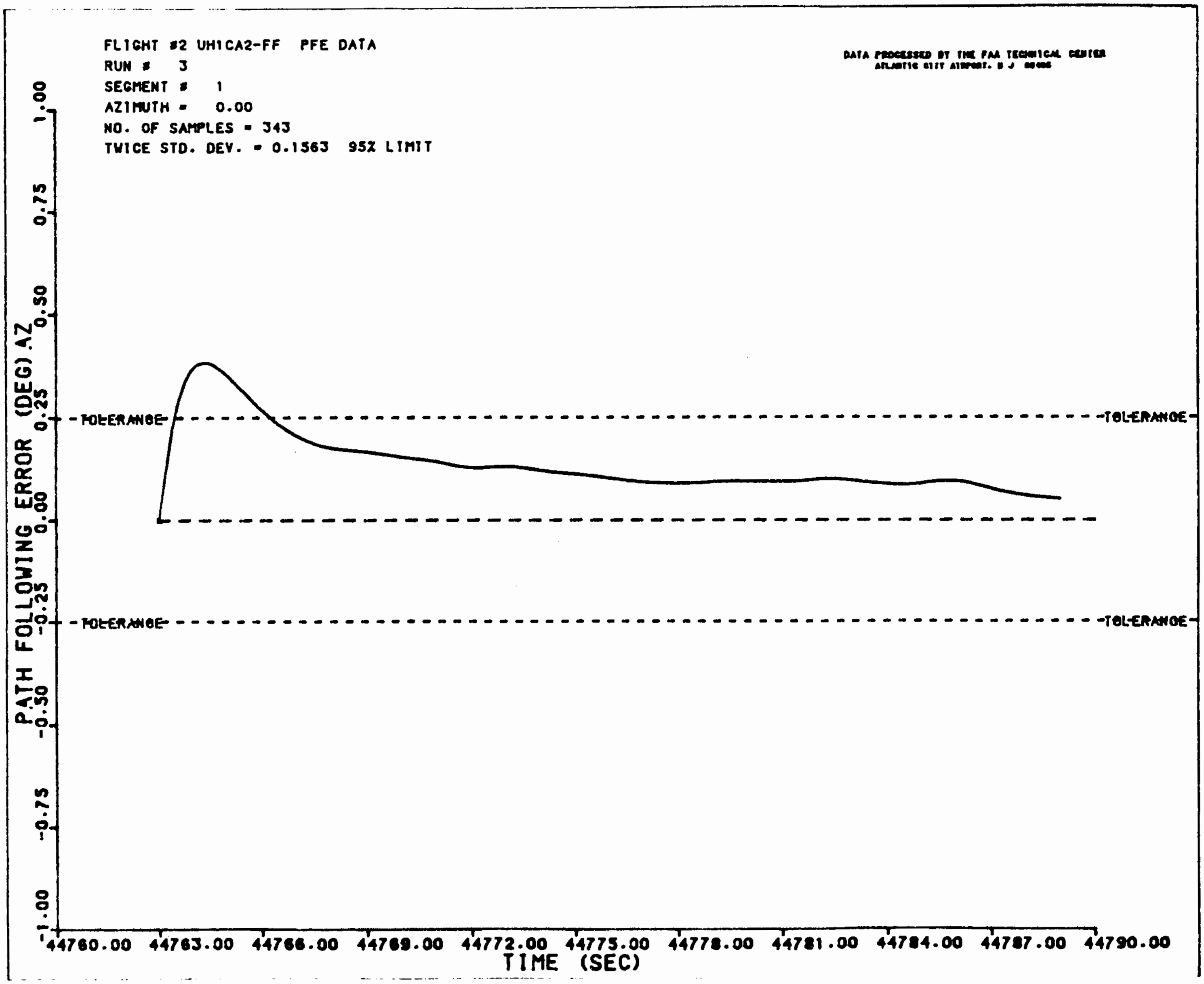


FIGURE 32. AZIMUTH PFE RESULTS FOR INITIAL PORTION OF SIMULTANEOUS APPROACH 3

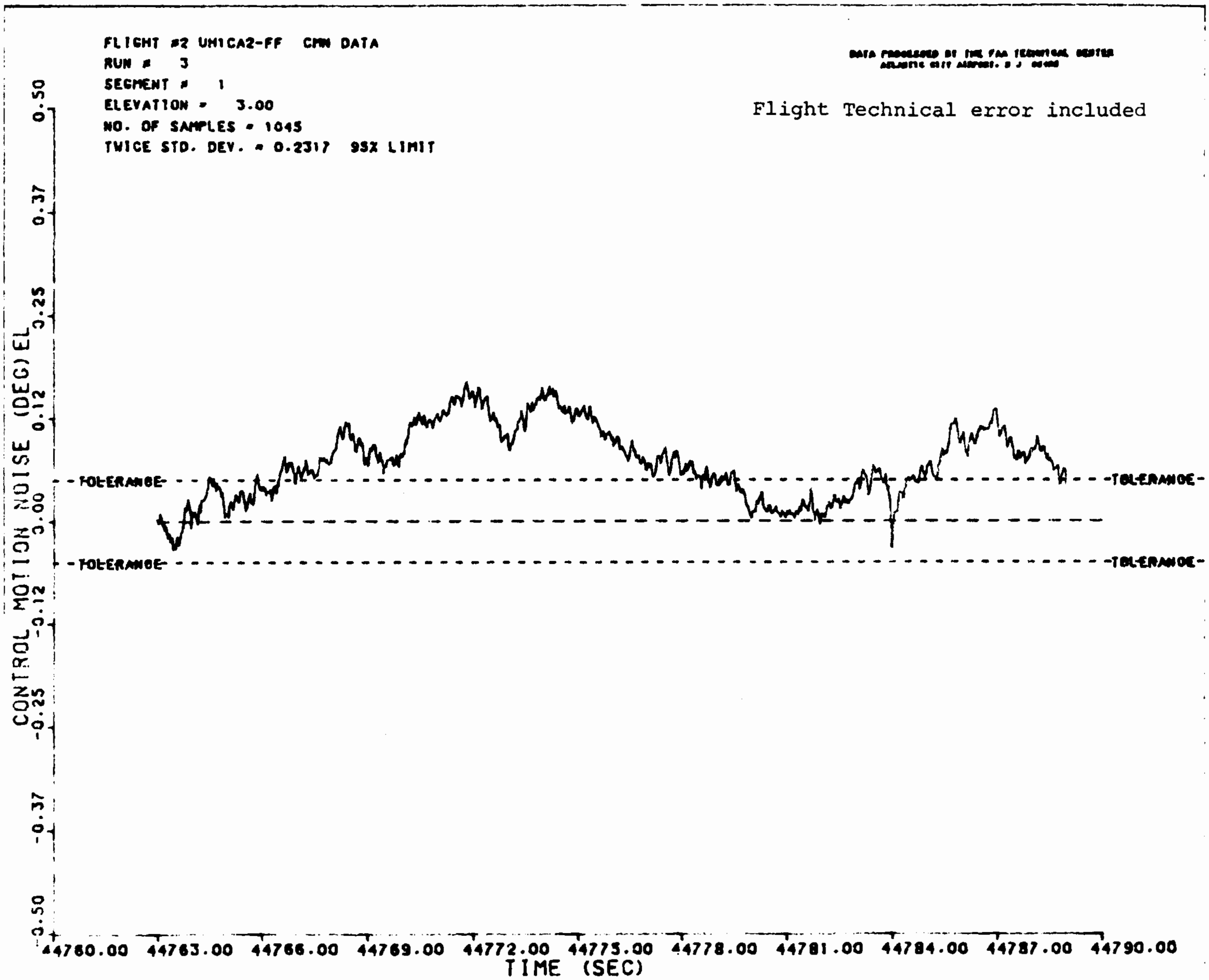


FIGURE 33. ELEVATION CMN RESULTS FOR INITIAL PORTION OF SIMULTANEOUS APPROACH 3

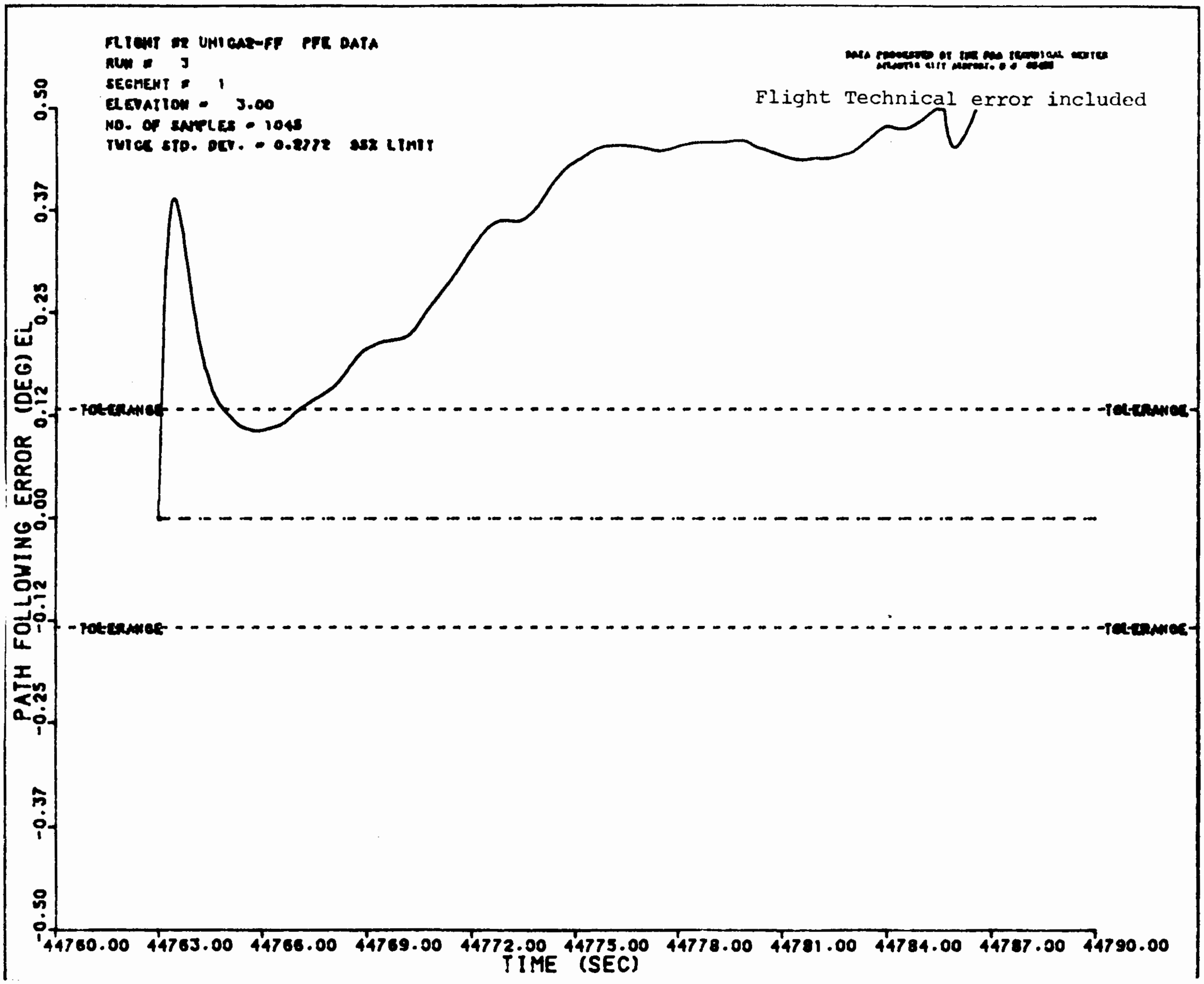


FIGURE 34. ELEVATION PFE RESULTS FOR INITIAL PORTION OF SIMULTANEOUS APPROACH 3

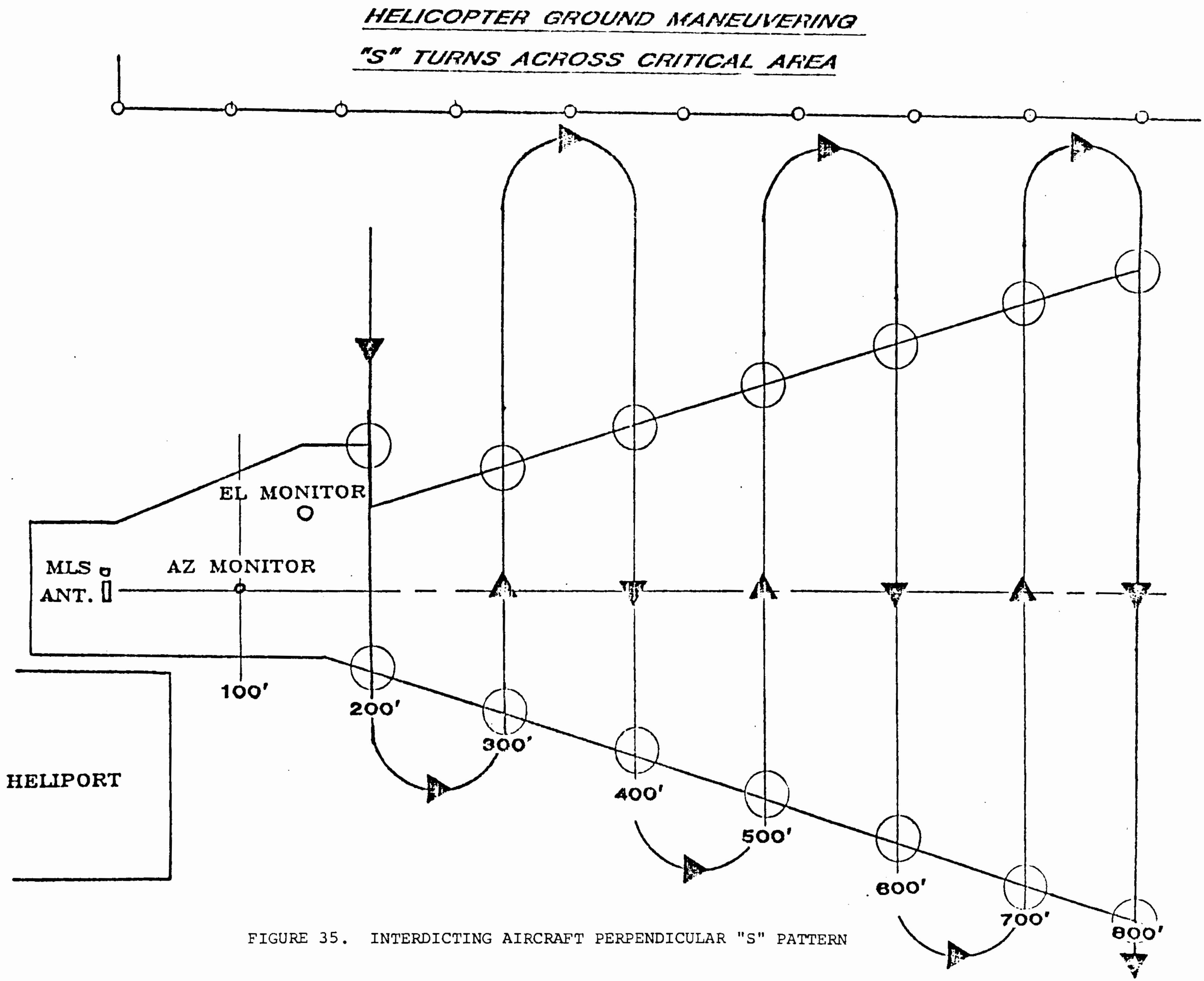


FIGURE 35. INTERDICTING AIRCRAFT PERPENDICULAR "S" PATTERN

HELICOPTER GROUND MANEUVERING

"S" TURNS ALONG CRITICAL AREA

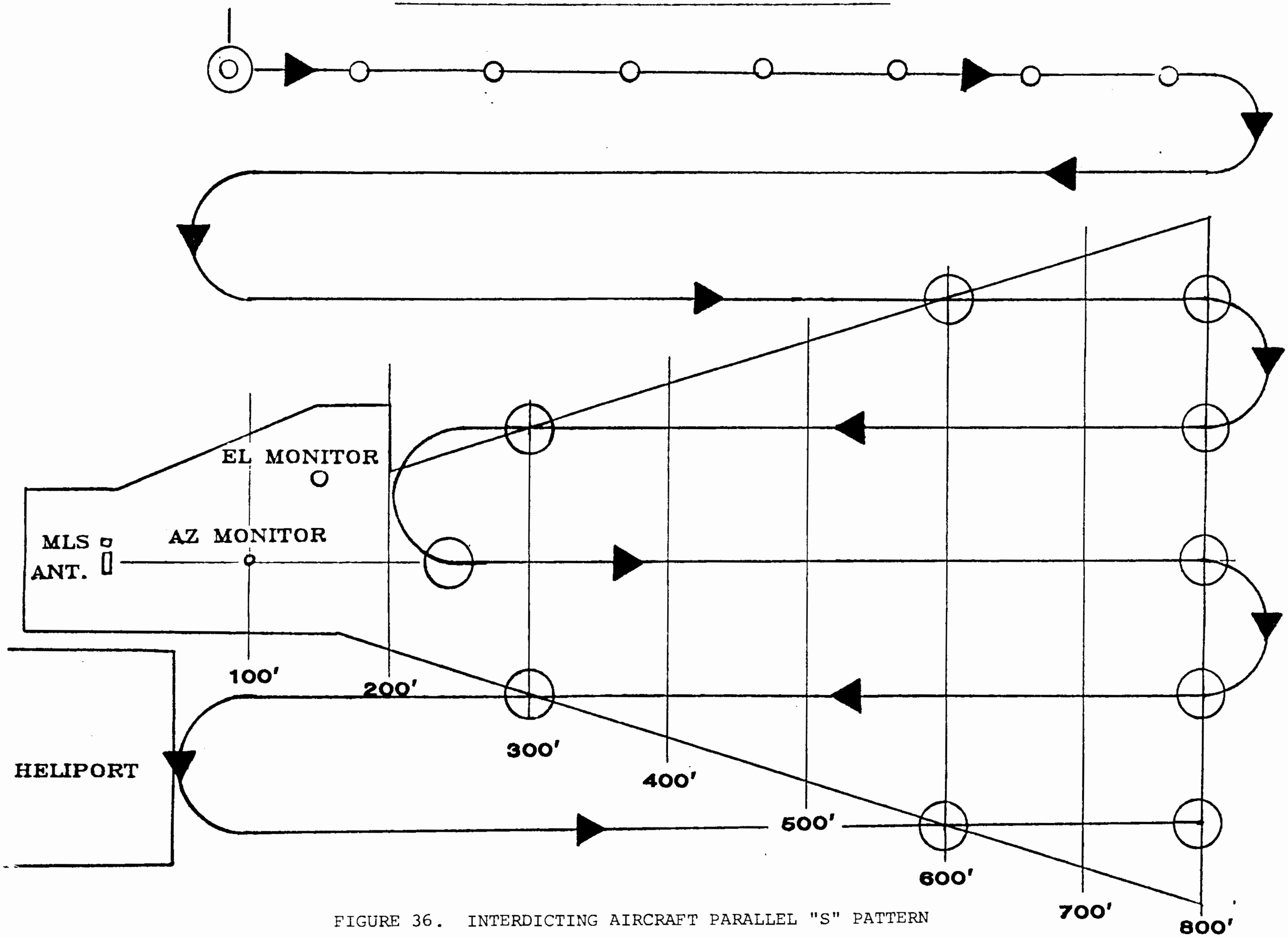


FIGURE 36. INTERDICTING AIRCRAFT PARALLEL "S" PATTERN

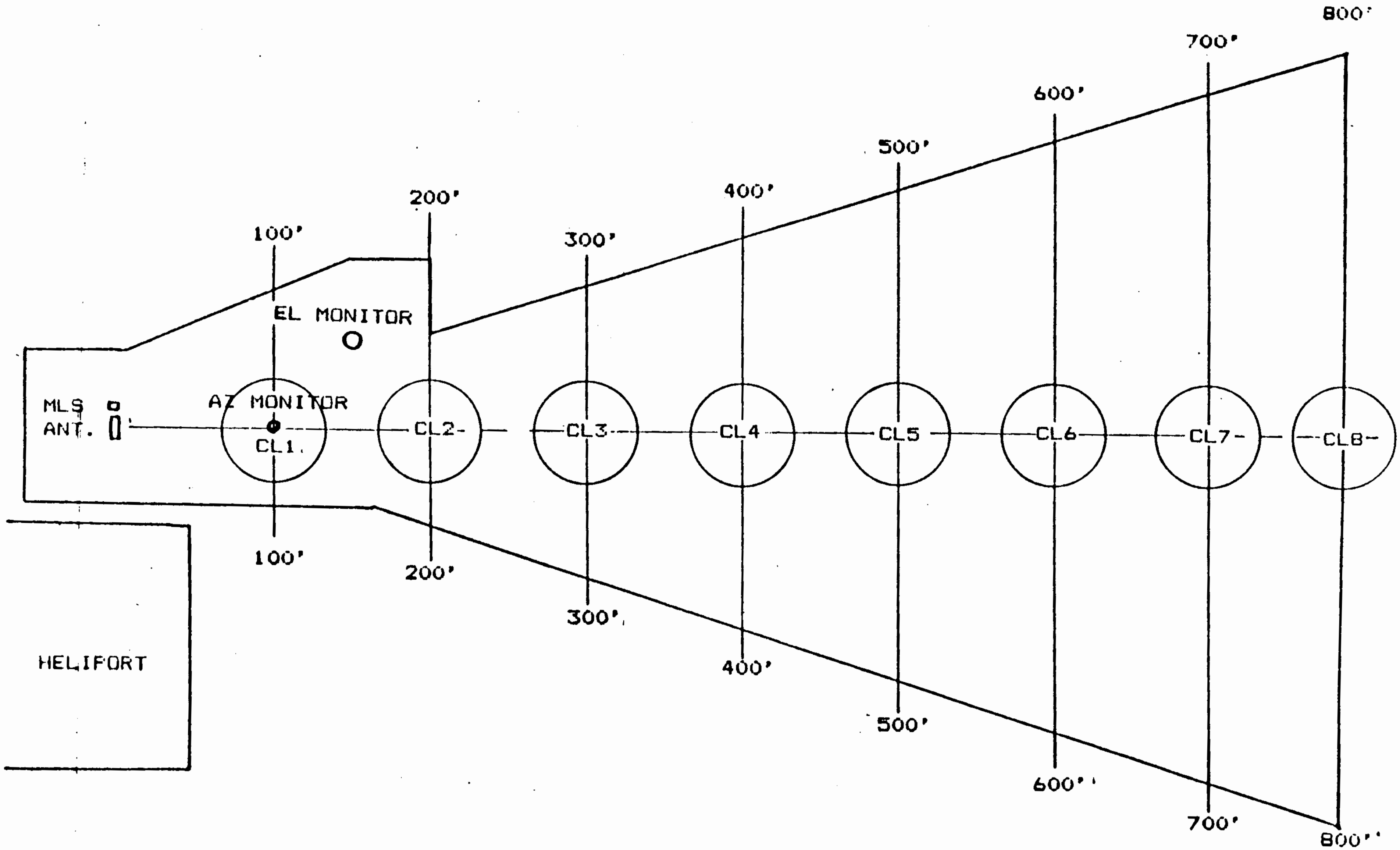


FIGURE 37. INTERDICTING AIRCRAFT 360° HOVERING TURN PATTERN

present. By using a standard Fisher's F Test for detection of differences in VDI or CDI variation, interdictor locations which had a significant effect on signal quality were identified. The F Test statistic used was the ratio static CDI or VDI variation to the variation when the interdictor was present. This procedure was also repeated for the received digital azimuth and elevation angle data.

TABLE 5. HOVERING INTERDICTOR TEST FLIGHT EXPERIMENTAL CONDITIONS

Flight No.	Run No.	Pattern	Interdictor Hover Height (ft)	Receiving Aircraft Position EL Angle (°)	Receiving Aircraft Position Height (ft)
3	1	Perpendicular "S"	4	3	200
	2	Perpendicular "S"	25	3	200
	3	Perpendicular "S"	50	3	200
	4	Perpendicular "S"	100	3	200
	5	Perpendicular "S"	4	3	100
	6	Perpendicular "S"	25	3	100
	7	Perpendicular "S"	50	3	100
5	1	Hovering 360° Truns	4	3	200
	2	Hovering 360° Turns	4	3	100
	3	Hovering 360° Turns	4	2	125
		Hovering 360° Turns			
6	1	Parallel "S"	4	3	200
	2	Parallel "S"	25	3	200
	3	Parallel "S"	50	3	200
	4	Parallel "S"	100	3	200
	5	Parallel "S"	4	3	100
	6	Parallel "S"	25		
	7	Parallel "S"	50	3	100
	8	Parallel "S"	100	3	100
	9	Parallel "S"	4	2	125
	10	Parallel "S"	25	2	125
	11	Parallel "S"	50	2	125
	12	Parallel "S"	100	2	125
7	1	Perpendicular "S"	4	3	200
7	2	Perpendicular "S"	25	3	200
7	3	Perpendicular "S"	50	3	200
7	4	Perpendicular "S"	100	3	200
7	5	Perpendicular "S"	4	3	100
7	6	Perpendicular "S"	25	3	100
7	7	Perpendicular "S"	50	3	100
7	8	Perpendicular "S"	100	3	100
7	9	Perpendicular "S"	4	2	125

Plots were generated to identify interdictor "S" pattern segments which resulted in a statistically significant difference in signal quality. The plots are contained in the appendixes. For those segments where a significant difference was detected, the significance level is identified on the pattern segment. If no value is plotted, no difference was detected. Appendix A presents significant difference plots for digital azimuth for flights 6 and 7. The only locations where a significant difference in the received digital azimuth was detected repeatedly was within 300 feet of the antennas and to the extreme right of the azimuth pattern centerline. This probably represents multipath interference. Appendix B contains the plots for significant difference in received digital elevation data. On flight 7, a large number of segments indicated a difference in signal quality when the interdictor was hovered at 25 and 50 feet. This indicates the volume of airspace that requires protection must be three-dimensional.

Appendix C contains the plots for the significant differences in CDI indication. (analog azimuth). Except for test runs number 5, 6, and 11 on flight 7, the repeatable significant differences occurred within 400 feet of the azimuth antenna. Further analysis was conducted for the three runs in question. It was determined that the differences in CDI variation were caused by FTE.

Appendix D contains the plots for the significant differences in VDI indication (analog elevation). The results were similar to the analog azimuth results.

FLIGHT 3 RESULTS. On flight 3, framing flag data were obtained for each of the seven test runs. For each test run, the maximum observed percentage of framing flags and the "S" pattern segment location on which they occurred were identified. The segment location is specified in distance from the antennas. This information for both EL and AZ signal is presented in table 6.

TABLE 6. FLIGHT 3 AZ AND EL FRAMING FLAG RESULTS

Test Run	EL Results Max. %	EL Results Location (ft)	AZ Results Max. %	AZ Results Location (ft)
1	0.53	600	1.86	200
2	0.62	100	2.48	100
3	0.29	300	0.88	300
4	0.12	500	1.71	200
5	0.36	100	1.65	600
6	0.41	500	0.68	100
7	0.25	100	5.02	100

The percentage of framing flag occurrences was low thoughout all seven test runs on flight 3. On only one run did the percentage exceed 2.50 percent. This was on run 7, and then that value was only exceeded on one segment of the interdictor's pattern. At no time were system flags observed by the flight crew in the MLS receiving aircraft. The highest percentages, although quite small, occurred on the segments only 100 or 200 feet in front of the antennas. This placed the interdictor in close proximity to the monitor poles.

The least number of azimuth framing flags occurred on run 3. The locations of the azimuth framing flags are shown in figure 38. The largest number occurred on run 7 and are shown in figure 39 . The symbol W indicates an azimuth lag did occur and was detected by the recording system. This system flag was not observed by the flight crew. This system flag occurred on the segment which resulted in AZ framing flag count exceeding 5. Again, this result was obtained when the interdictor was very close to the monitor poles.

The lowest number of EL framing flags occurred when the interdicting aircraft was at the higher hover heights (run 3, 50 feet; run 4, 100 feet; run 7, 50 feet). The test run with the least number was run 4. Figure 40 depicts the EL framing flag locations for this run. When the interdictor was hovering at 100 feet, it was well above the 3° elevation glidepath signal which formed the reference elevation position for the receiving MLS aircraft. The largest number of EL framing flags occurred on run 2. The location of these number flags is presented in figure 41.

FLIGHT 5, 360° PEDAL TURN RESULTS. Flight 5 consisted of three test runs during which the interdicting helicopter performed 360° hovering turns at 4-foot hover heights on the AZ centerline. The MLS receiving aircraft was hovered at various DH's as shown on table 5. The hovering turns were performed starting 100 feet in front of the AZ antenna and repeating every 100 feet out to a range of 800 feet. Additionally, a hovering turn was completed abeam of the EL monitor pole approximately 150 feet in front of the antenna. The percentage of AZ framing flags which resulted during the hovering turns are depicted on figures 42 to 44. The largest number of framing flags occurred when the interdictor was performing hovering turns in the immediate vicinity of the monitor poles at location CL1, CL2, and CL3. Outside of locations marked CL1, CL2, and CL3, the percentage of azimuth framing flags never exceeded 0.66 percent.

The percentage of EL framing flags which occurred at each hover turn location are depicted on figures 45 to 47 for runs 1 to 3, respectively. The only location where EL framing flags occurred was in the immediate vicinity of the monitor poles (locations CL2 and CL3). EL framing flags did not occur when the interdictor performed hovering turns over the AZ monitor pole.

Signal quality was also analyzed during test flight 5. For run 1 the AZ CMN results during the time the interdictor was hovering over the monitor pole is presented in figure 48. The noisy condition of the AZ signal is apparent. The high frequency error component exceeds the specified tolerance limits. Some data loss is also evident on the extreme right side of the plot. This result coincides with the high AZ framing flag percentage (9.94 percent) which was observed when the interdictor was hovering over the AZ monitor pole. Figure 49 presents the AZ signal quality which was observed when the interdictor was not in the vicinity of the monitor pole. Excellent low frequency error characteristics are apparent. When the interdictor was not in the vicinity of the monitor pole, the high frequency error component generally did not exceed specified tolerance limits despite the fact the receiving MLS aircraft was being flown manually. This result was consistent across all three hovering turn test runs.

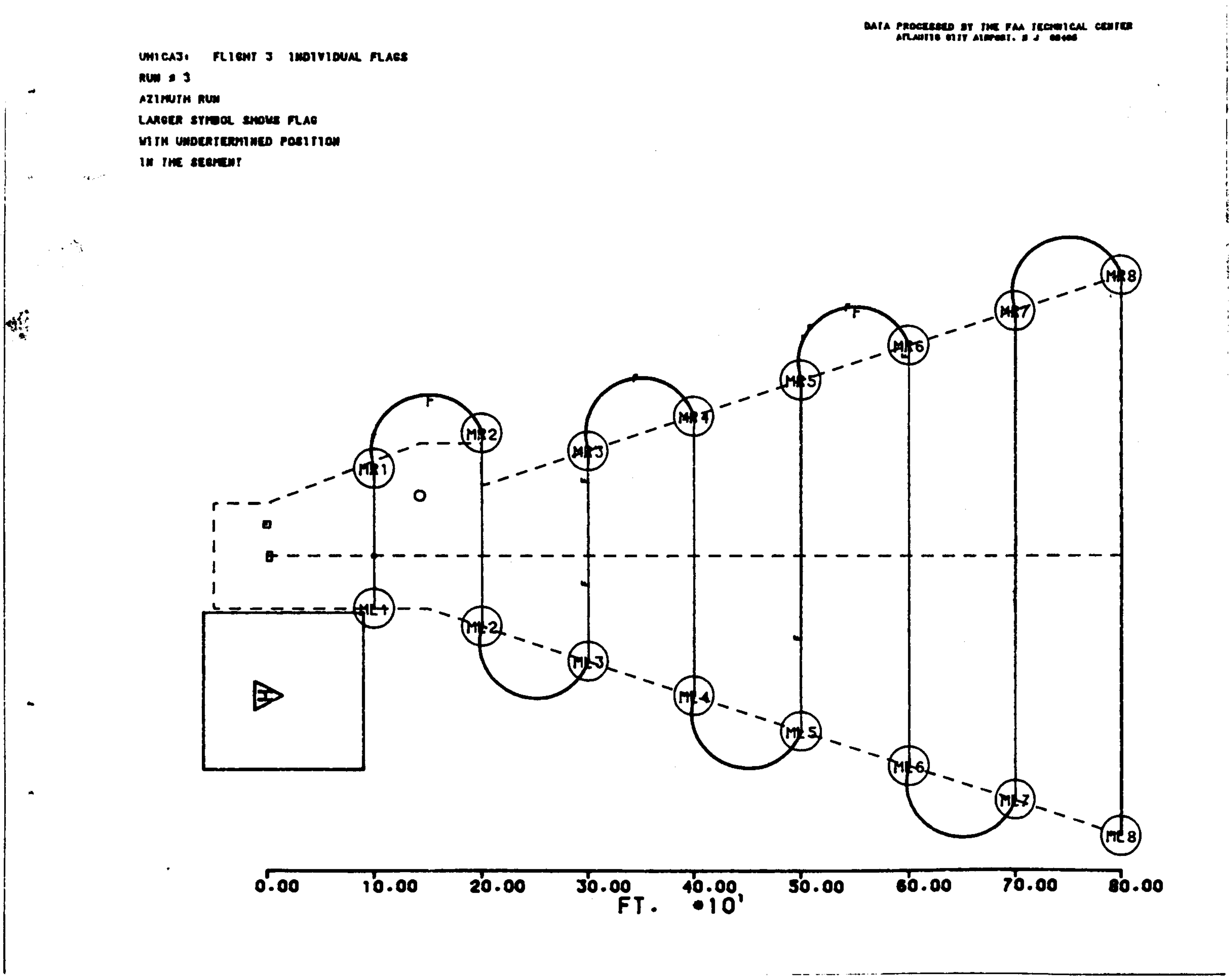


FIGURE 38. LOCATION OF AZIMUTH FRAMING FLAGS RUN 3, FLIGHT 3 (LEAST OCCURRENCE)

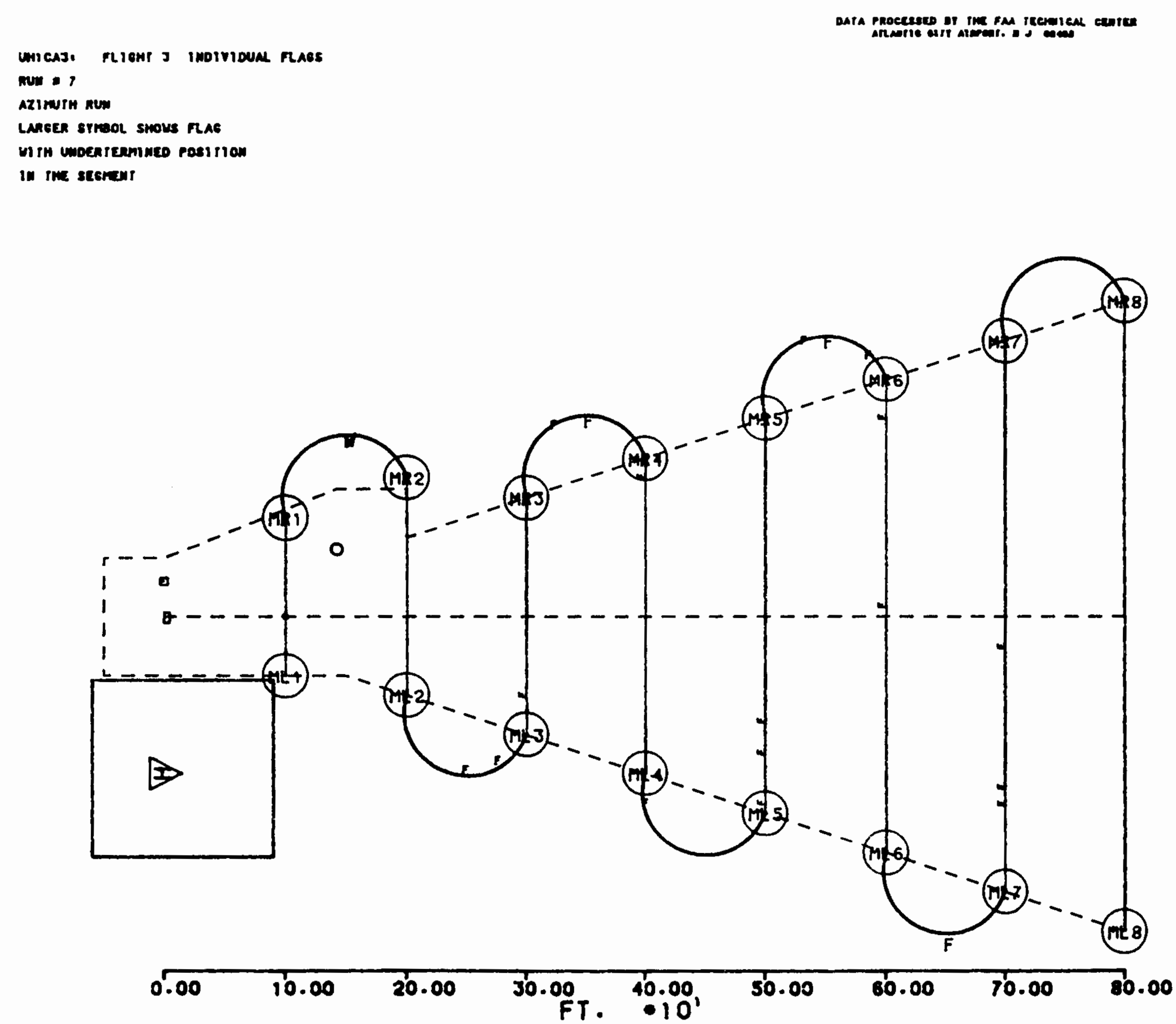


FIGURE 39. LOCATION OF AZIMUTH FRAMING FLAGS RUN 7, RUN 3 (LARGEST NUMBER)

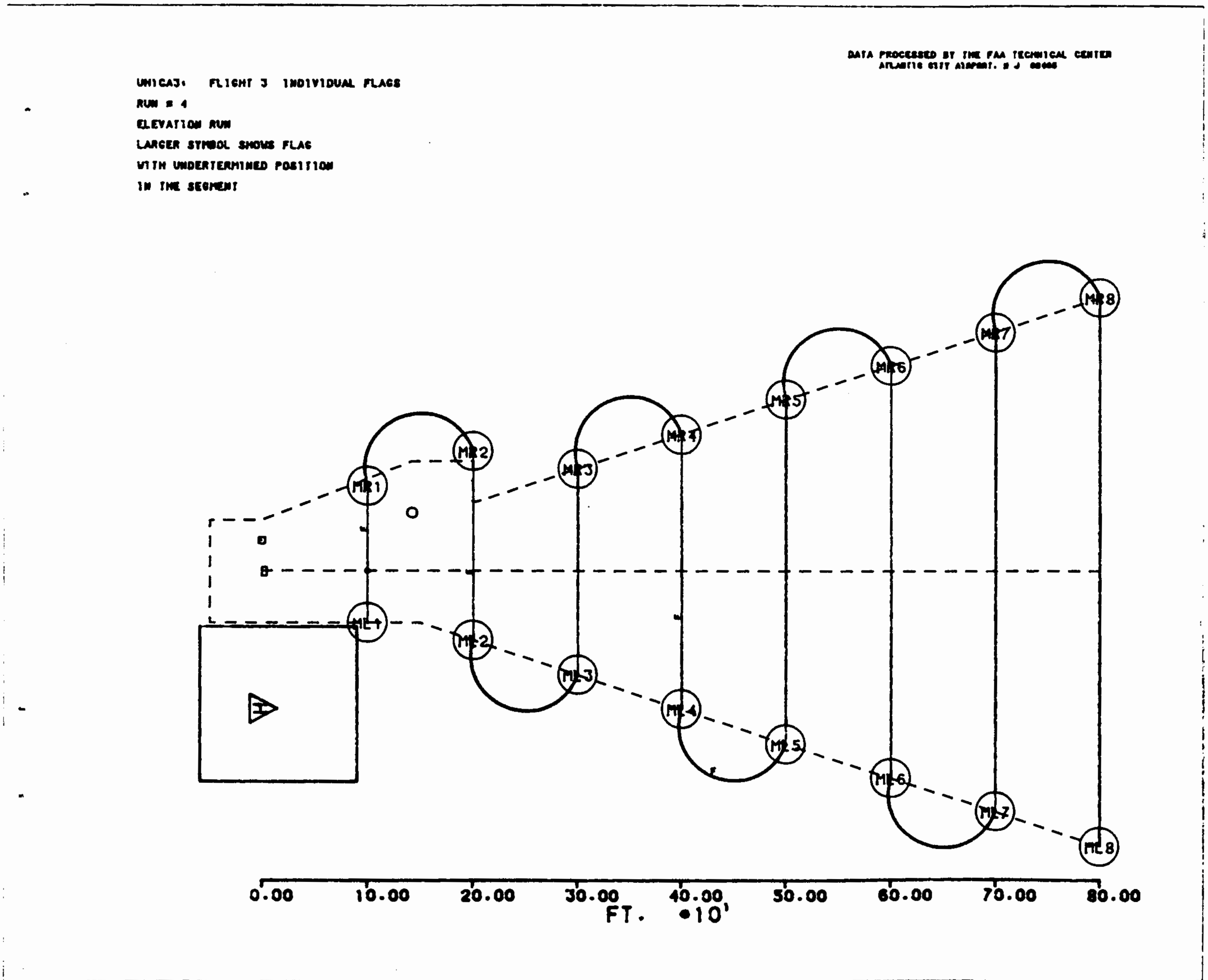


FIGURE 40. LOCATION OF ELEVATION FRAMING FLAGS ON THE RUN WHICH RESULTED IN LEAST NUMBER OF FRAMING FLAGS

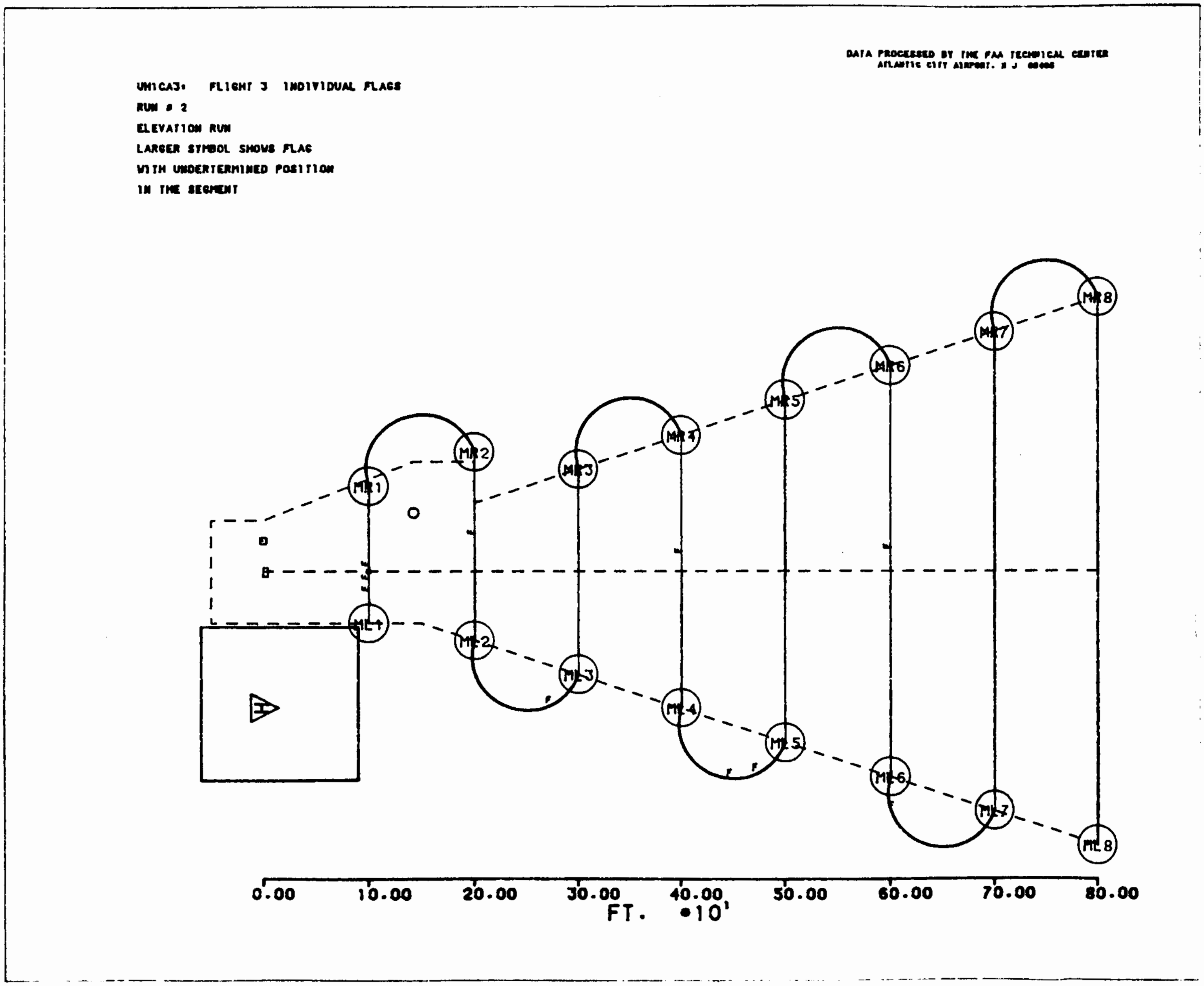


FIGURE 41. LOCATION OF ELEVATION FRAMING FLAGS ON THE RUN WHICH RESULTS IN LARGEST NUMBER OF FRAMING FLAGS

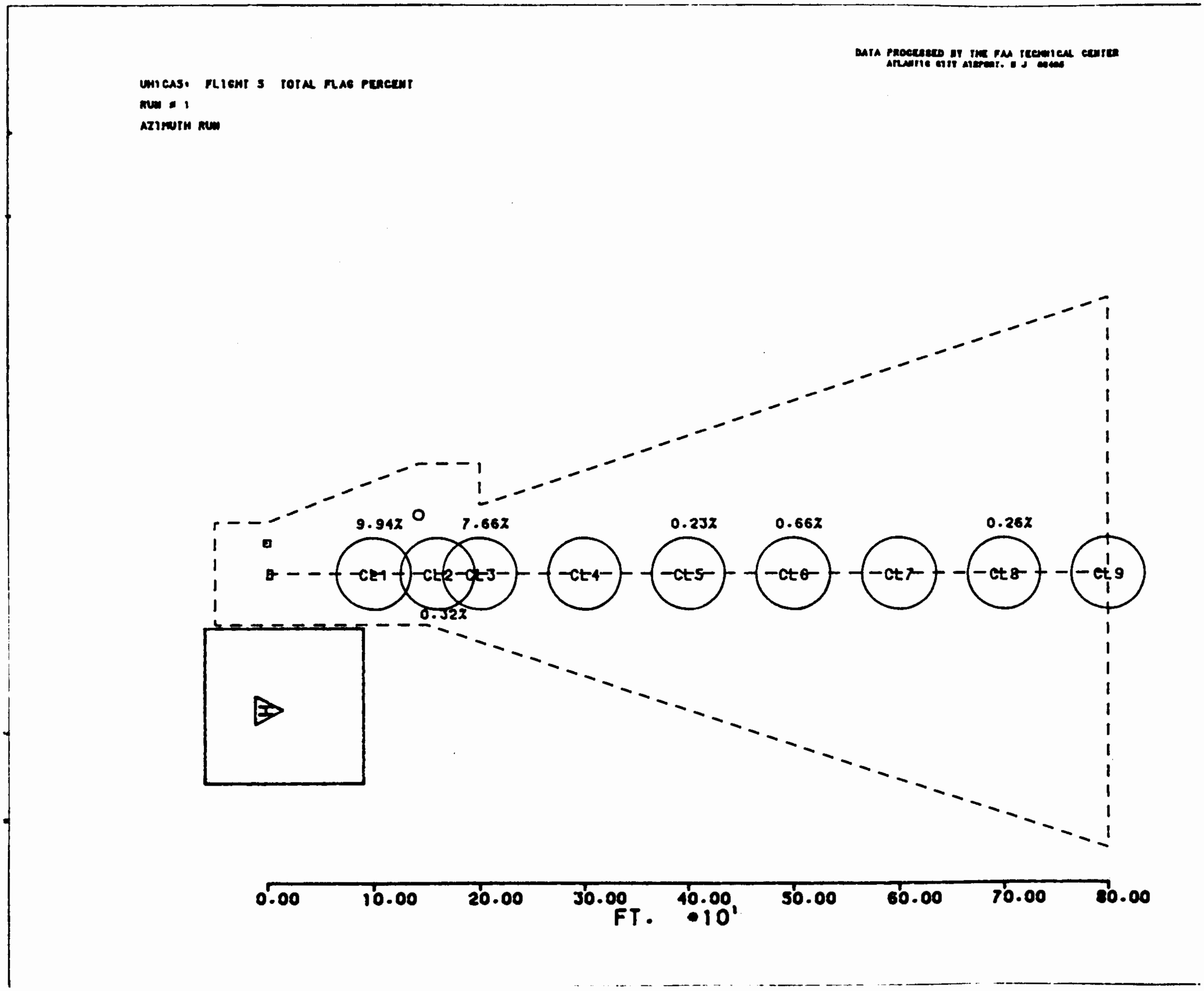


FIGURE 42. AZIMUTH FRAMING FLAG RESULTS, RUN 1, FLIGHT 5

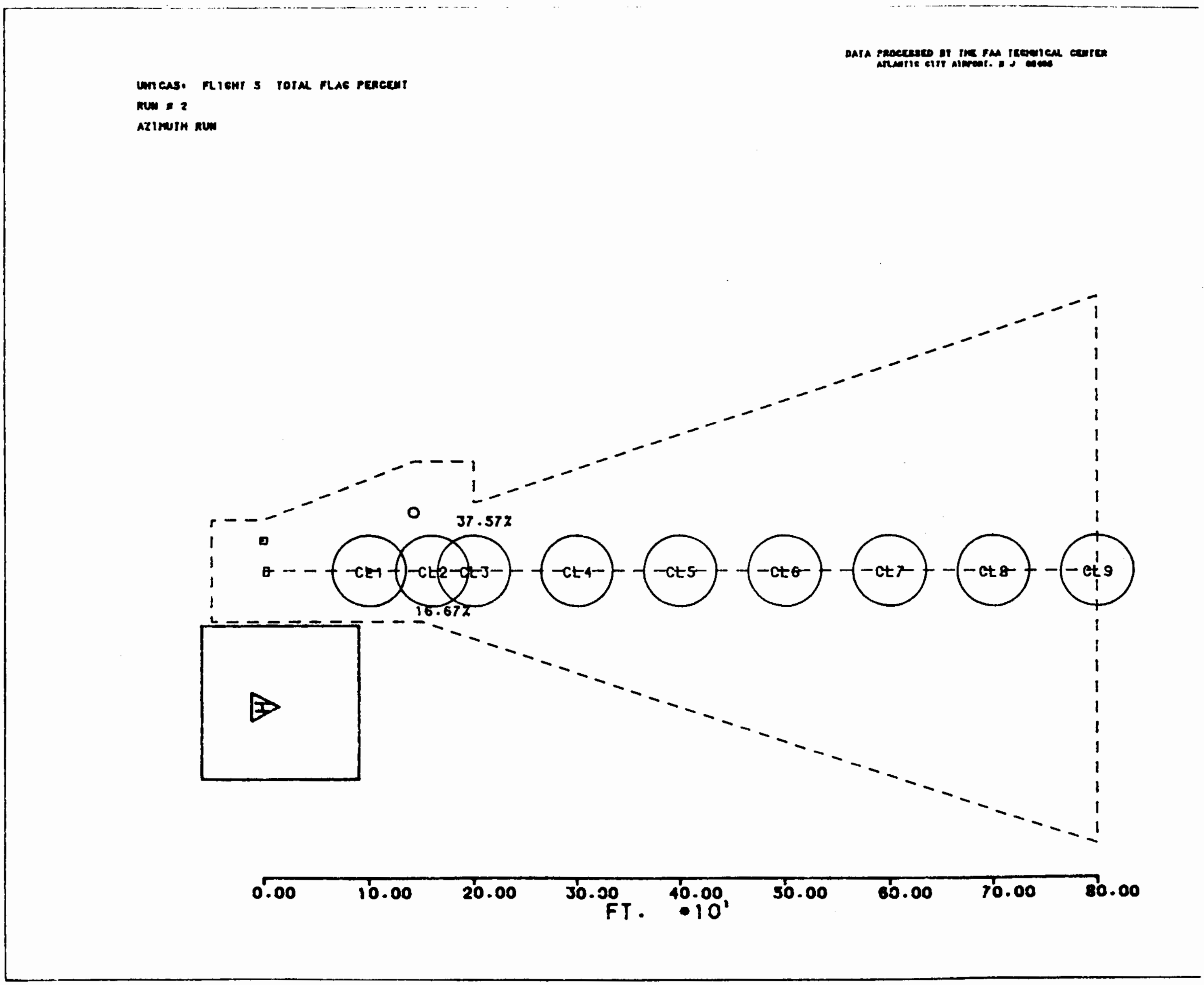


FIGURE 43. AZIMUTH FRAMING FLAG RESULTS, RUN 2, FLIGHT 5

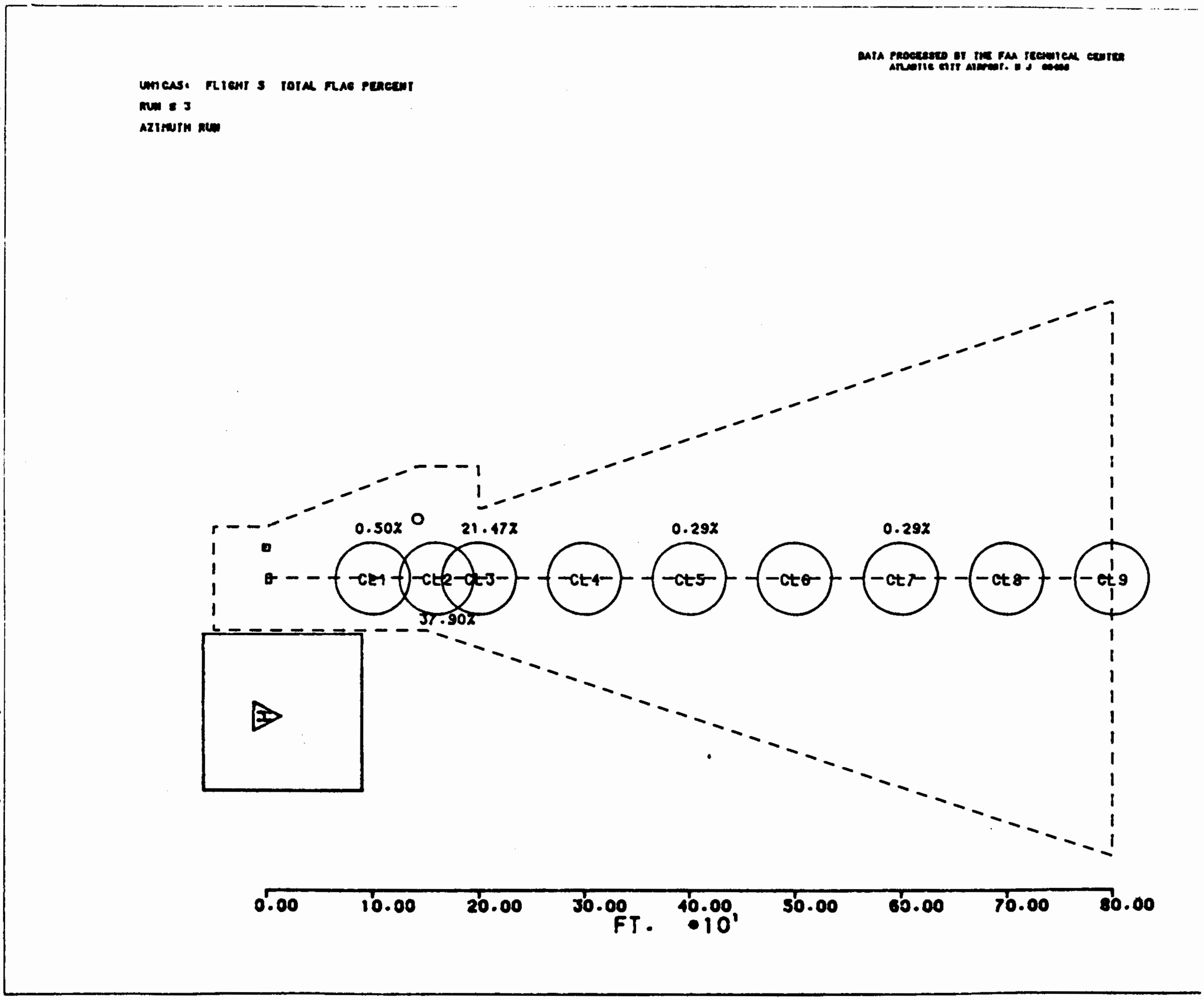


FIGURE 44. AZIMUTH FRAMING FLAG RESULTS, RUN 3, FLIGHT 5

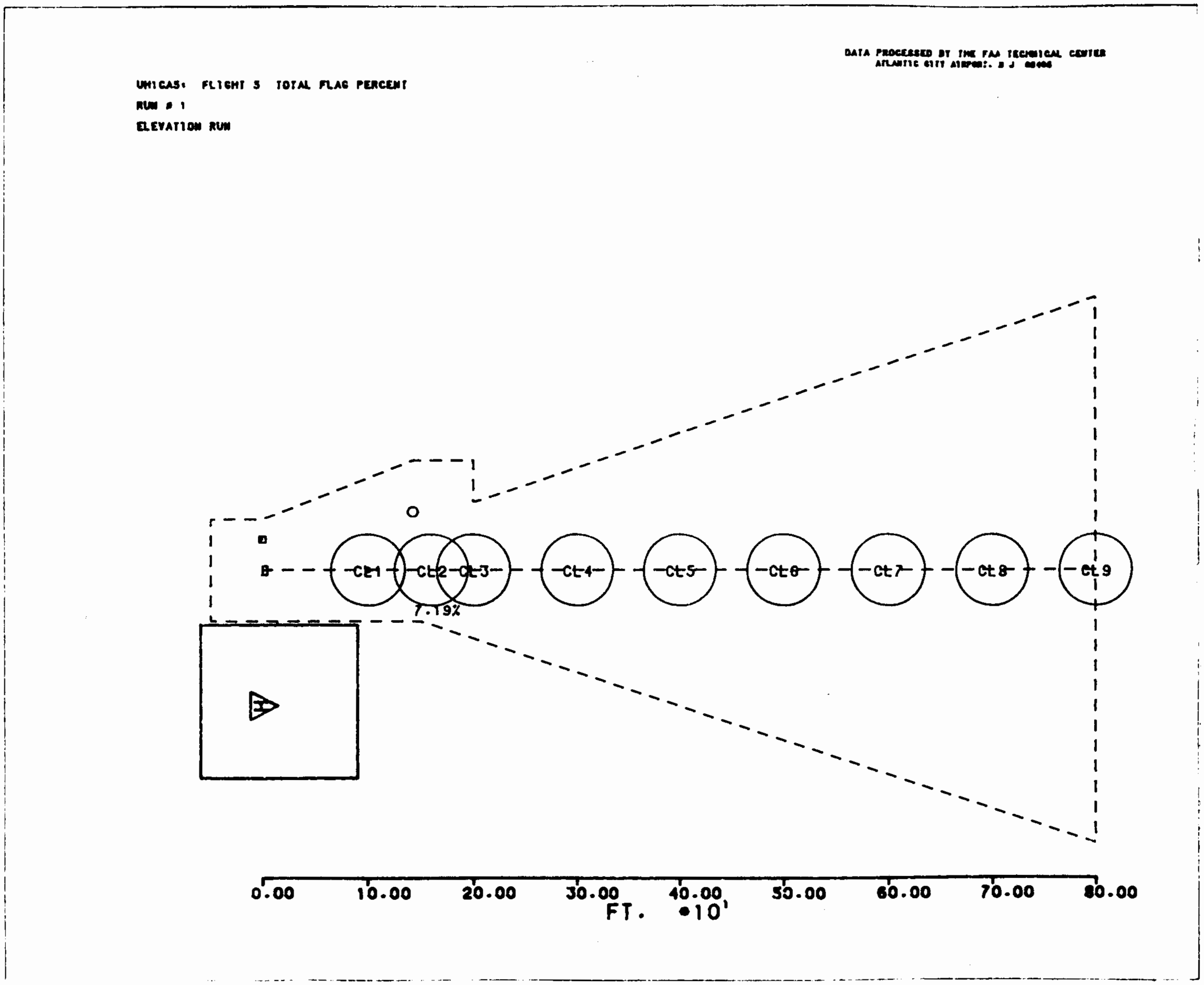


FIGURE 45. ELEVATION FRAMING FLAG RESULTS, RUN 1, FLIGHT 5

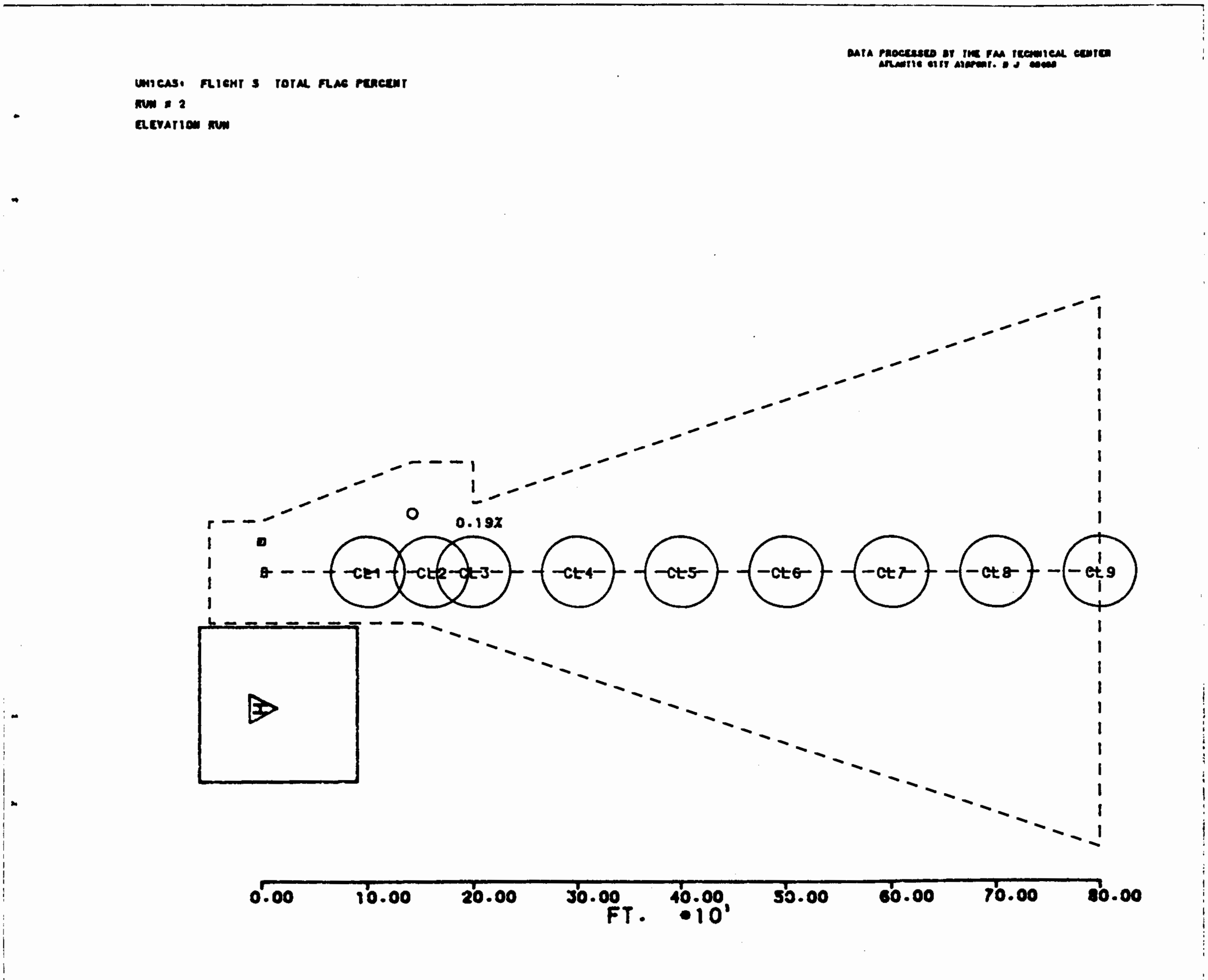


FIGURE 46. ELEVATION FRAMING FLAG RESULTS, RUN 2, FLIGHT 5

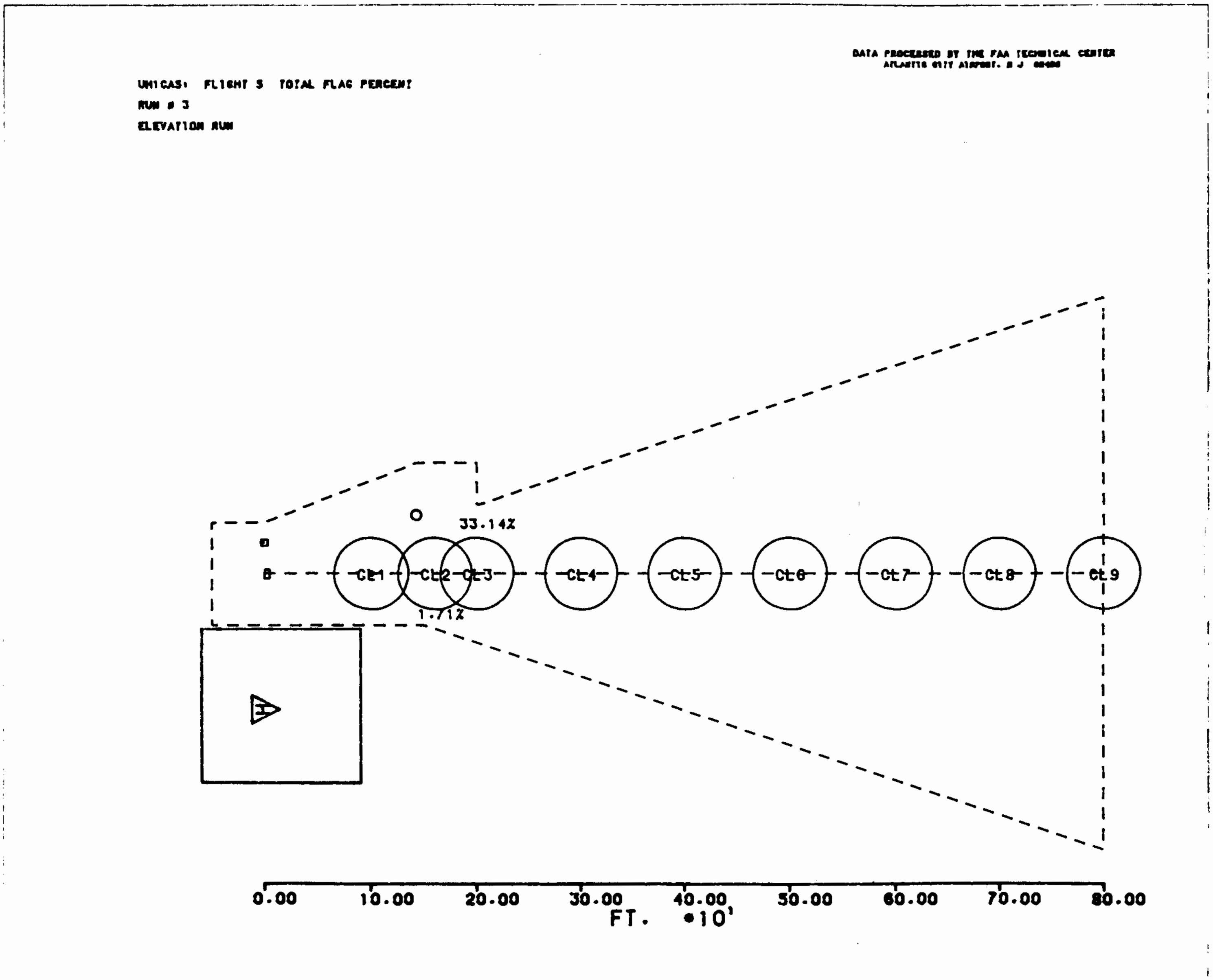


FIGURE 47. ELEVATION FRAMING FLAG RESULTS, RUN 3, FLIGHT 5

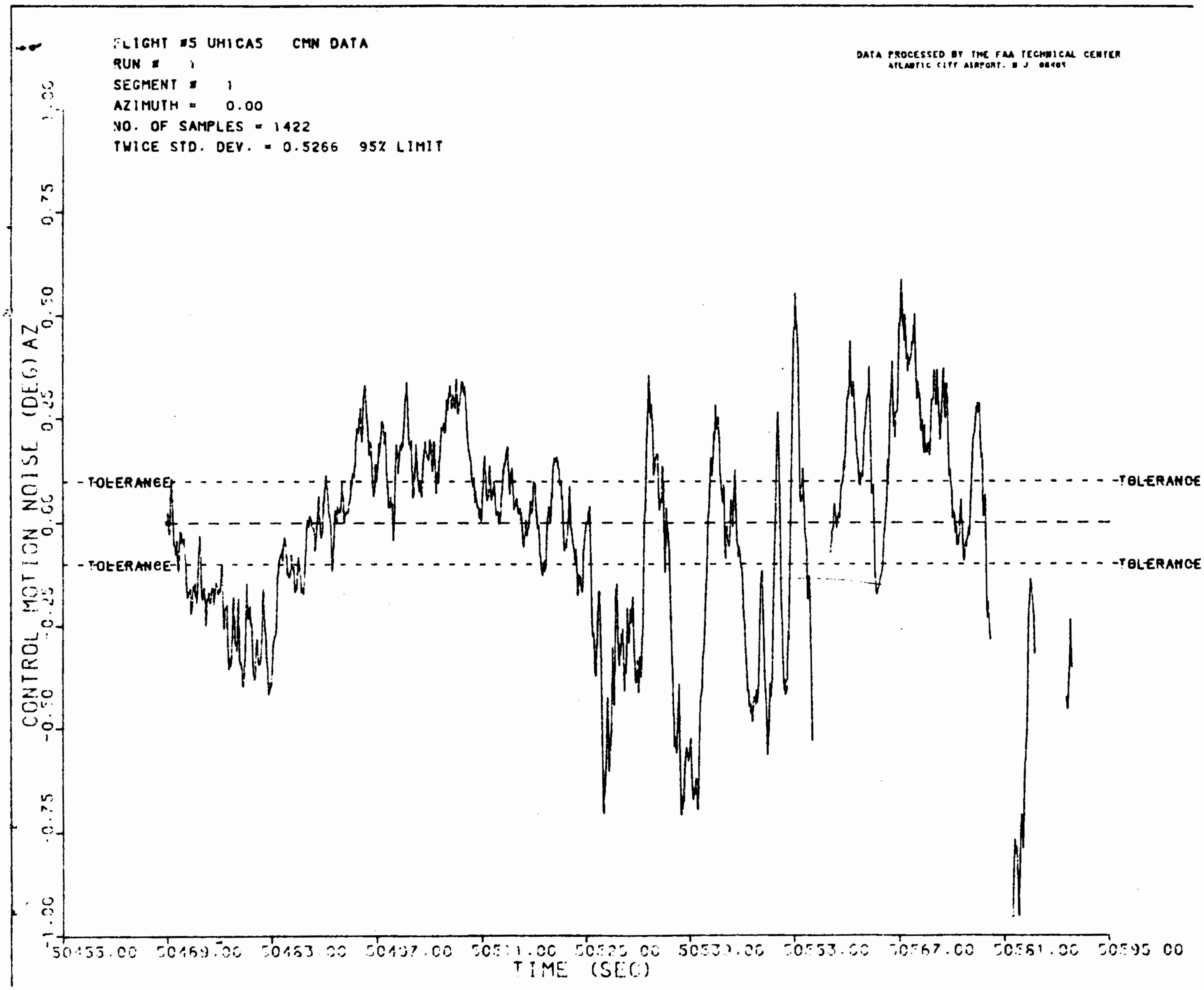


FIGURE 48. POOR AZIMUTH CMN RESULTS OBTAINED WHILE INTERDICTOR WAS PERFORMING TURNS OVER AZIMUTH MONITORING POLE

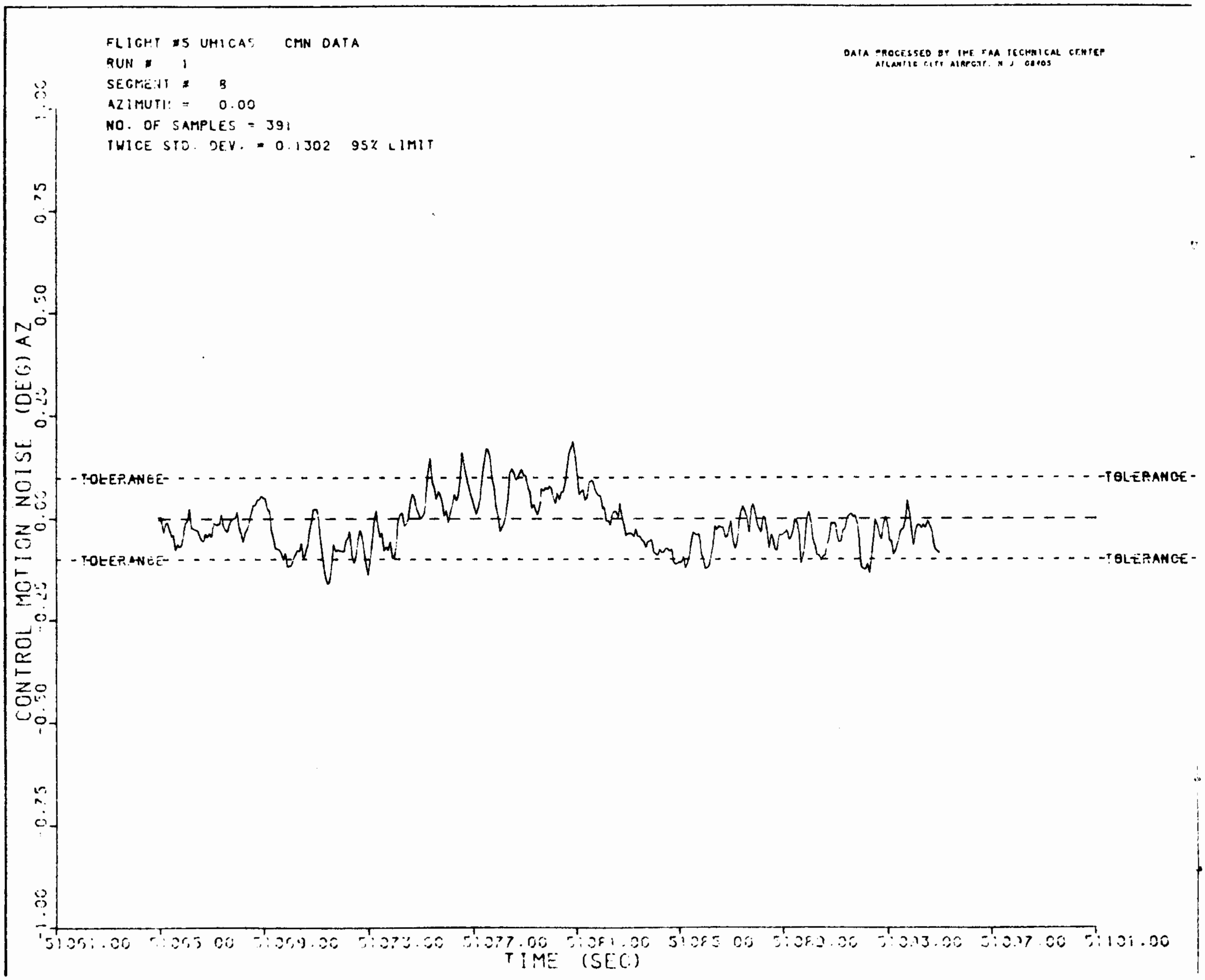


FIGURE 49. EXCELLENT AZIMUTH CMN RESULTS ON RUN 1, FLIGHT 5

A similar comparison of the plots of the elevation high frequency error component was made. Figure 50 depicts the poor elevation CMN results which were obtained when the interdictor hovered abeam the EL monitor pole (location CL2) on run 1. Figure 51 depicts an example of EL CMN results which were obtained at locations not in the immediate vicinity of the EL monitor pole.

For the low frequency error components, excellent performance was obtained when the interdictor was not making hovering turns in the vicinity of the monitor poles. Examples of the excellent low frequency error component results which were obtained when the interdictor was not close to the monitor poles are presented in figures 52 and 53. The bias present on the plot in figure 53 is due to the receiving MLS aircraft being hovered manually at DH.

The poor low frequency error results which were obtained when the interdictor was hovering near the monitor poles are illustrated in figures 54 and 55. The AZ PFE results in figure 54 was obtained when azimuth framing flags occurred more than 16 percent of the time. Signal loss is apparent between 51359 and 51363 seconds. The poor EL PFE results were obtained when the interdictor hovered immediately abeam the EL monitor pole. Framing flag occurrence exceeded 79 percent of the time.

FLIGHT 6, PARALLEL "S" PATTERN RESULTS. During the parallel "S" pattern testing on flight 6 a consistently smaller number of framing flags occurred than resulted on the perpendicular "S" patterns. This is directly due to the lower aspect ratio of the interdicting helicopter when it was hovered parallel to the MLS receiver's line of sight to the antennas. Table 7 depicts the maximum framing flag percentages which occurred for each test on flight 6. The location where this maximum percentage occurred is specified as a distance from the antenna in question.

The total number of framing flags which occurred during flight 6 was quite low. The majority of those that did occur resulted when the interdictor was closer to the monitor poles. EL signal quality was verified through the analysis of CMN and PFE plots. EL signal quality remained excellent throughout a large portion of the interdictor's pattern. However, when the interdictor was in the vicinity of the EL monitor pole, signal quality degraded. The worst results were obtained on run 9 where the framing flag count exceeded 34 percent. Figures 56 and 57 depict the plots of the high and low frequency error components of the EL signal when the interdictor was in the vicinity of the monitor pole.

AZ signal quality also was quite good throughout a large portion of the interdictor's pattern. Figures 58 and 59 depict AZ signal quality on segments where no AZ framing flags occurred. Most of the AZ framing flags occurred when the interdictor was on the AZ centerline near the AZ monitor pole. At this location, the interdictor's influence on signal quality can be seen on the AZ PFE plot in figure 60.

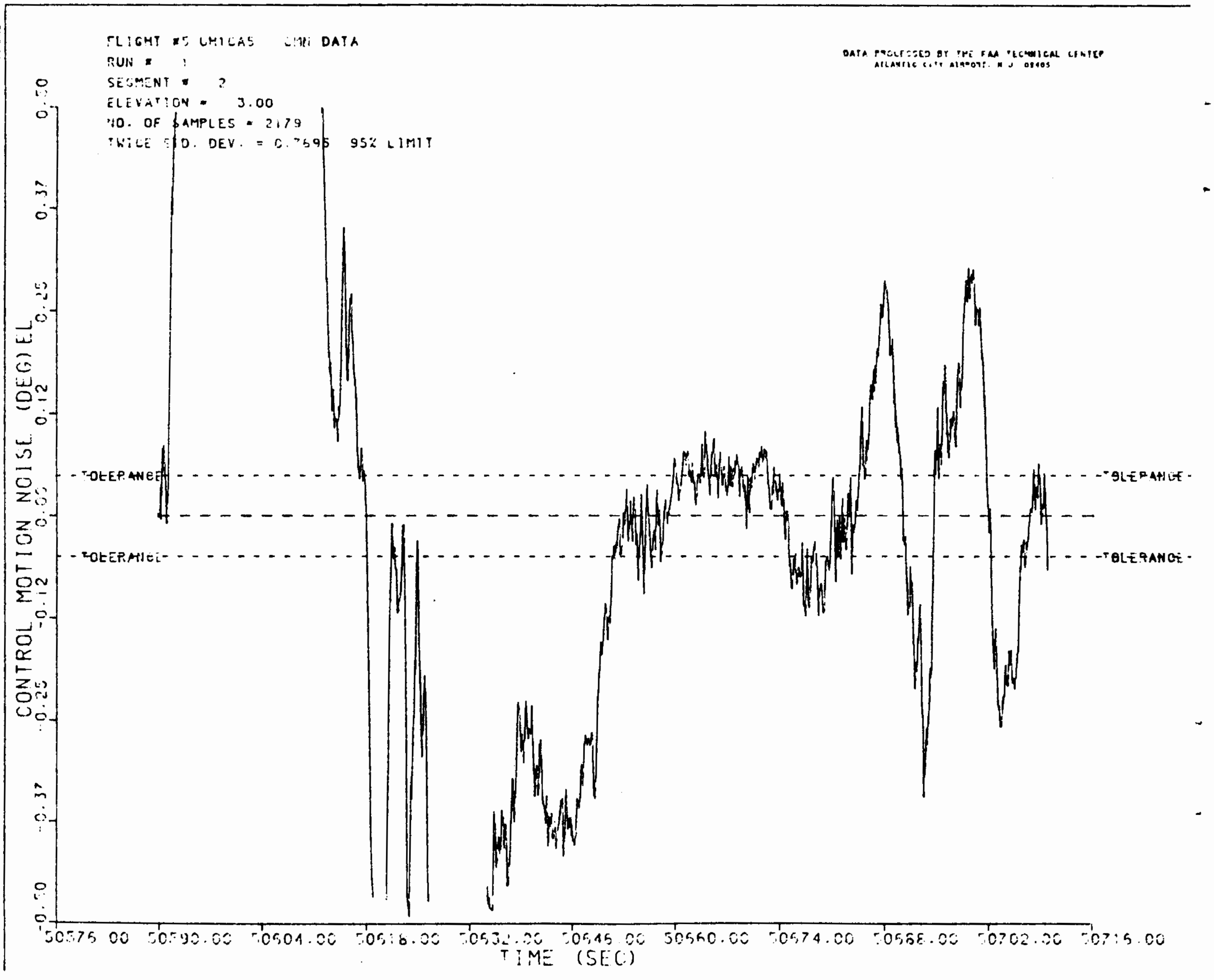


FIGURE 50. POOR ELEVATION CMN RESULTS WHILE INTERDICTOR WAS ABEAM THE ELEVATION MONITORING POLE

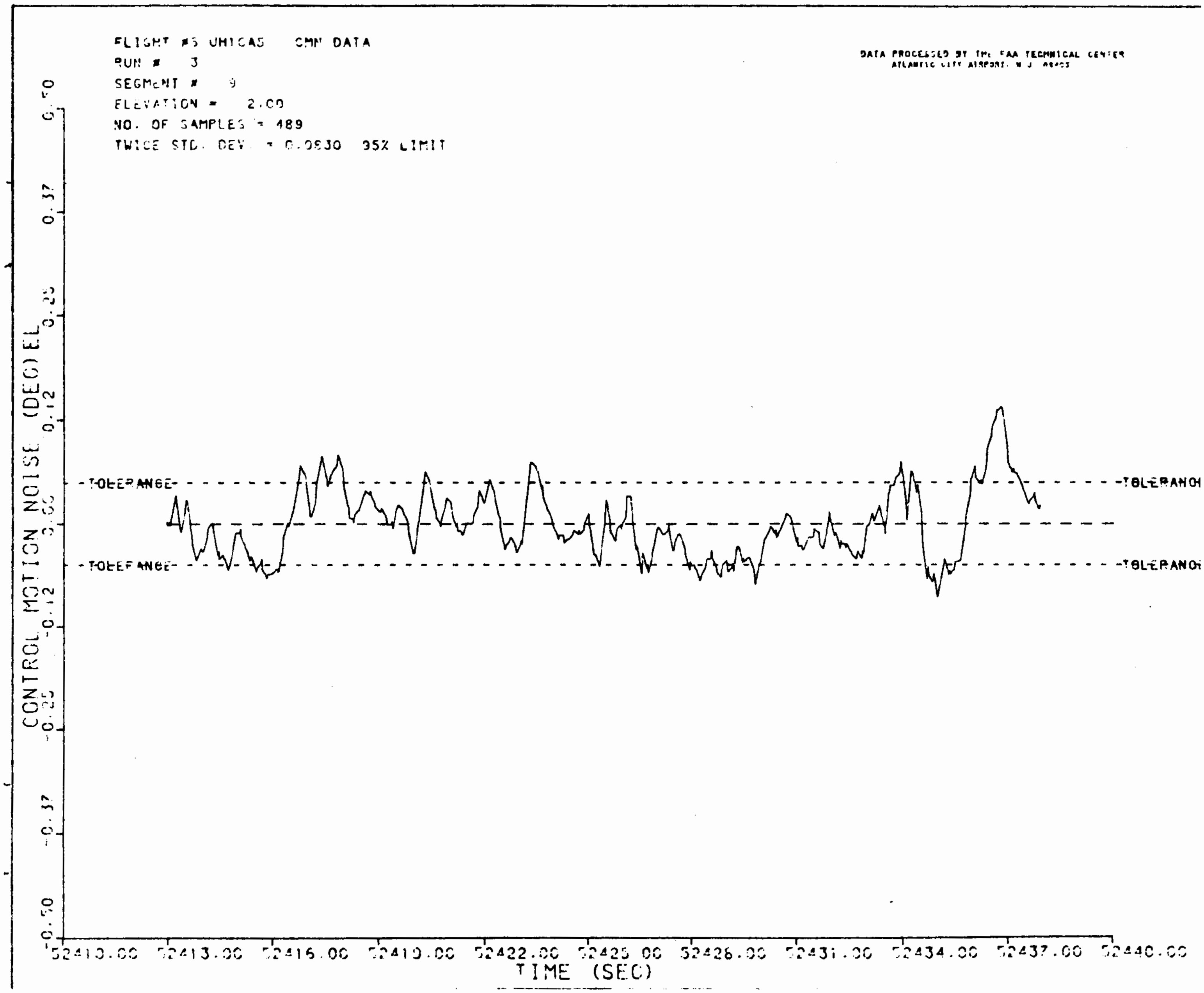


FIGURE 51. AN EXAMPLE OF EXCELLENT ELEVATION CMN RESULTS ON FLIGHT 5

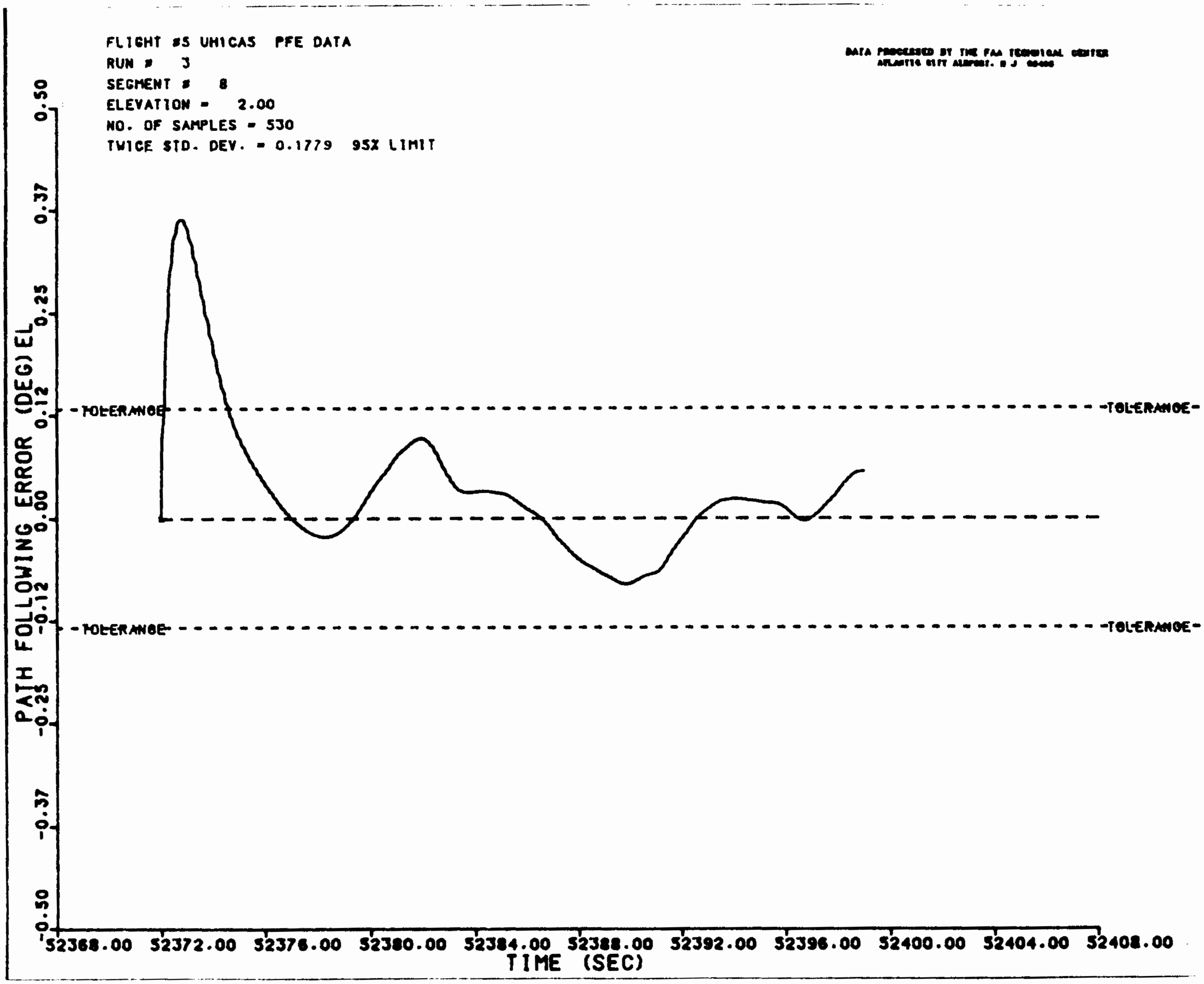


FIGURE 52. AN EXAMPLE OF EXCELLENT ELEVATION PFE RESULTS OBTAINED WHEN INTERDICTOR WAS NOT HOVERING NEAR THE ELEVATION MONITOR POLE ON FLIGHT 5

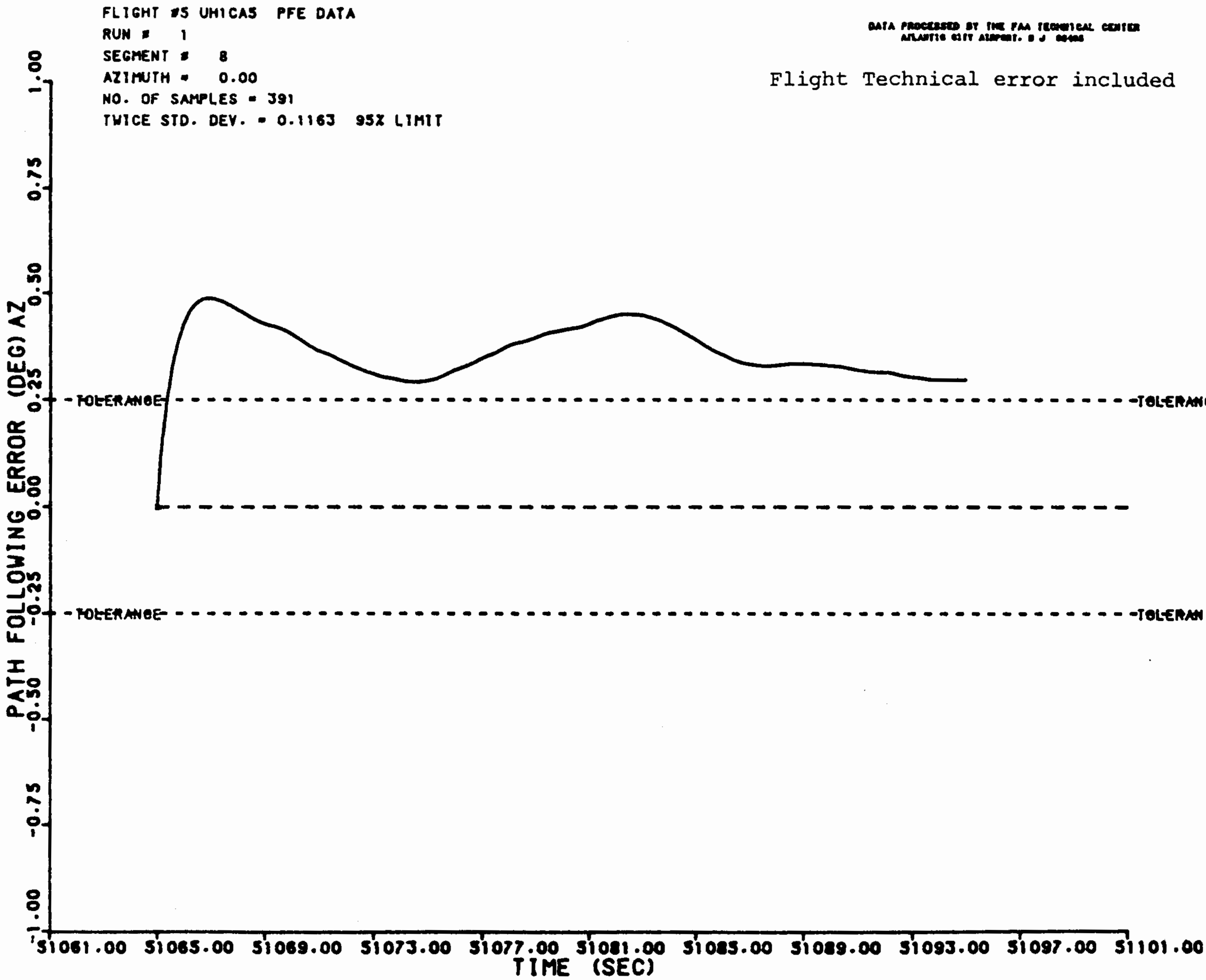


FIGURE 53. AN EXAMPLE OF EXCELLENT AZIMUTH PFE RESULTS OBTAINED ON FLIGHT 5 WHEN THE INTERDICTOR WAS NOT HOVERING THE AZIMUTH MONITOR POLE

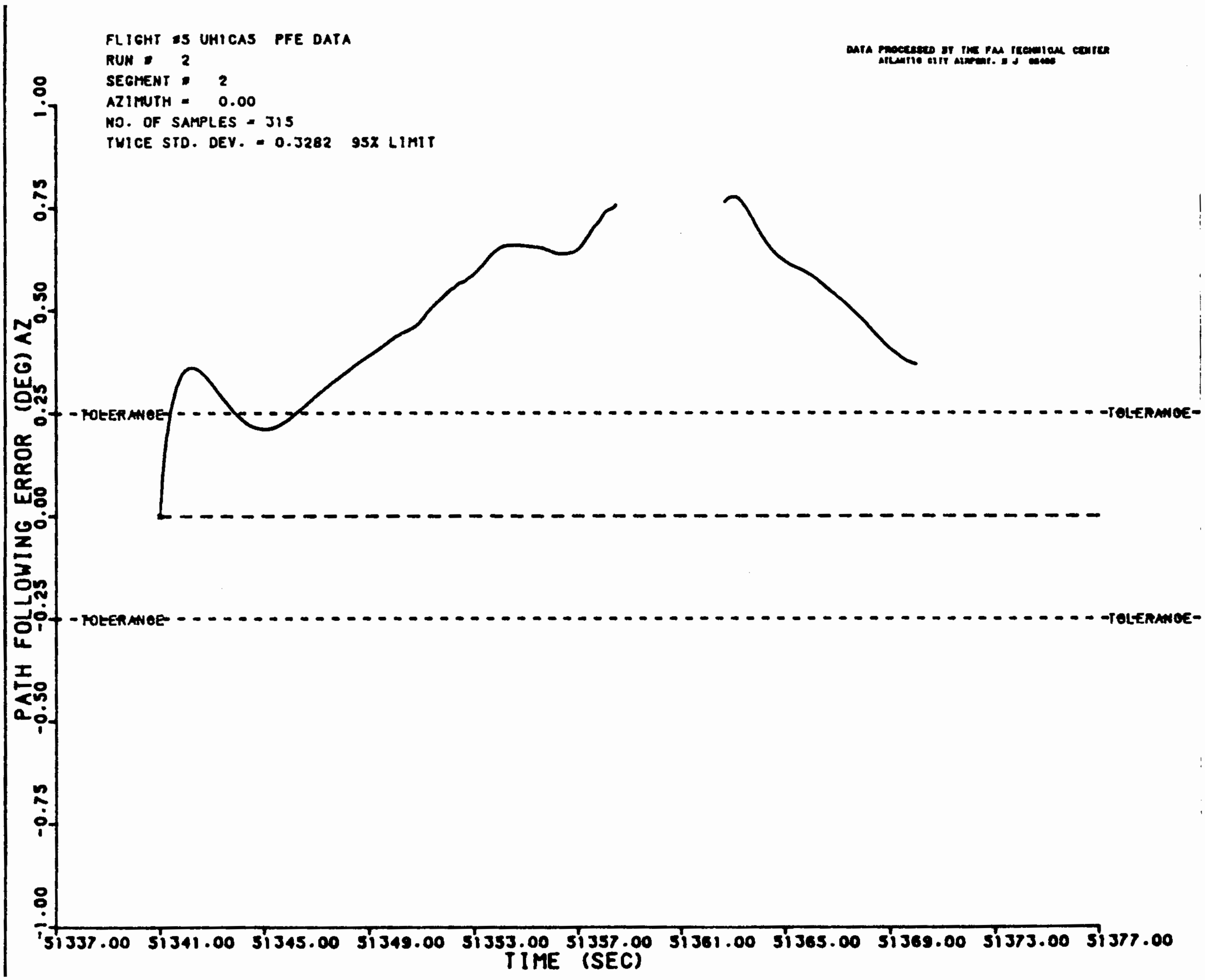


FIGURE 54. POOR AZIMUTH PFE RESULTS OBTAINED WHEN THE INTERDICTOR WAS HOVERING NEAR THE MONITOR POLE

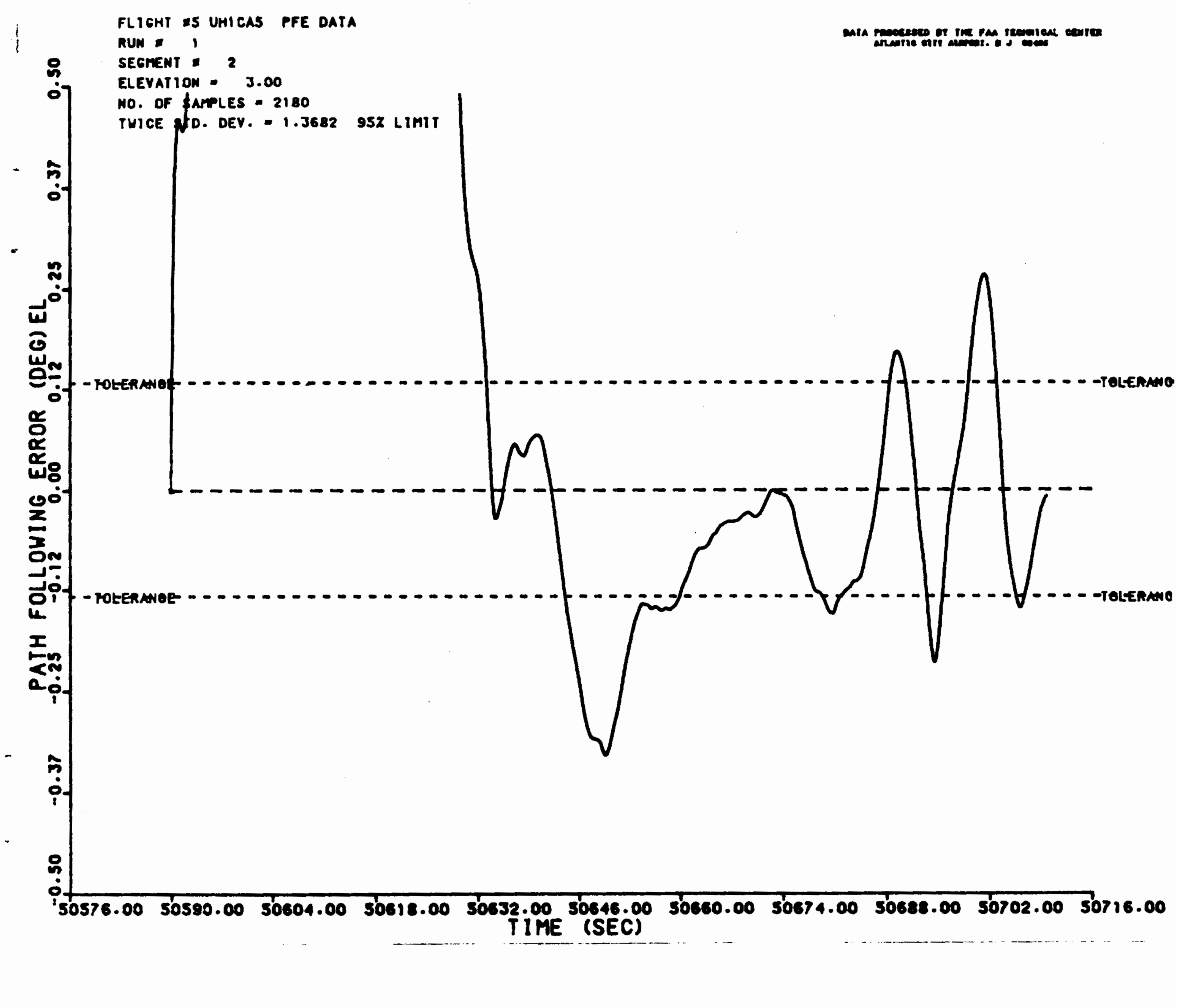


FIGURE 55. POOR ELEVATION PFE RESULTS OBTAINED WHEN THE INTERDICTOR WAS HOVERING NEAR THE MONITOR POLE

TABLE 7. FLIGHT 6, AZ AND EL FRAMING FLAG RESULTS

Run No.	EL Results Maximum %	EL Results Location (ft)	AZ Results Maximum %	AZ Results Location (ft)
1	0.47	200	0.28	300
2	0.34	300	0.64	100
3	0.57	200	0.40	100
4	0.00	-	0.40	100
5	0.00	-	0.18	200
6	0.04	100	0.64	300
7	0.14	100	0.35	100
8	0.00	-	0.37	200
9	34.04	100	0.26	200
10	0.00	-	0.67	200
11	0.00	-	0.40	100
12	0.21	200	0.32	400

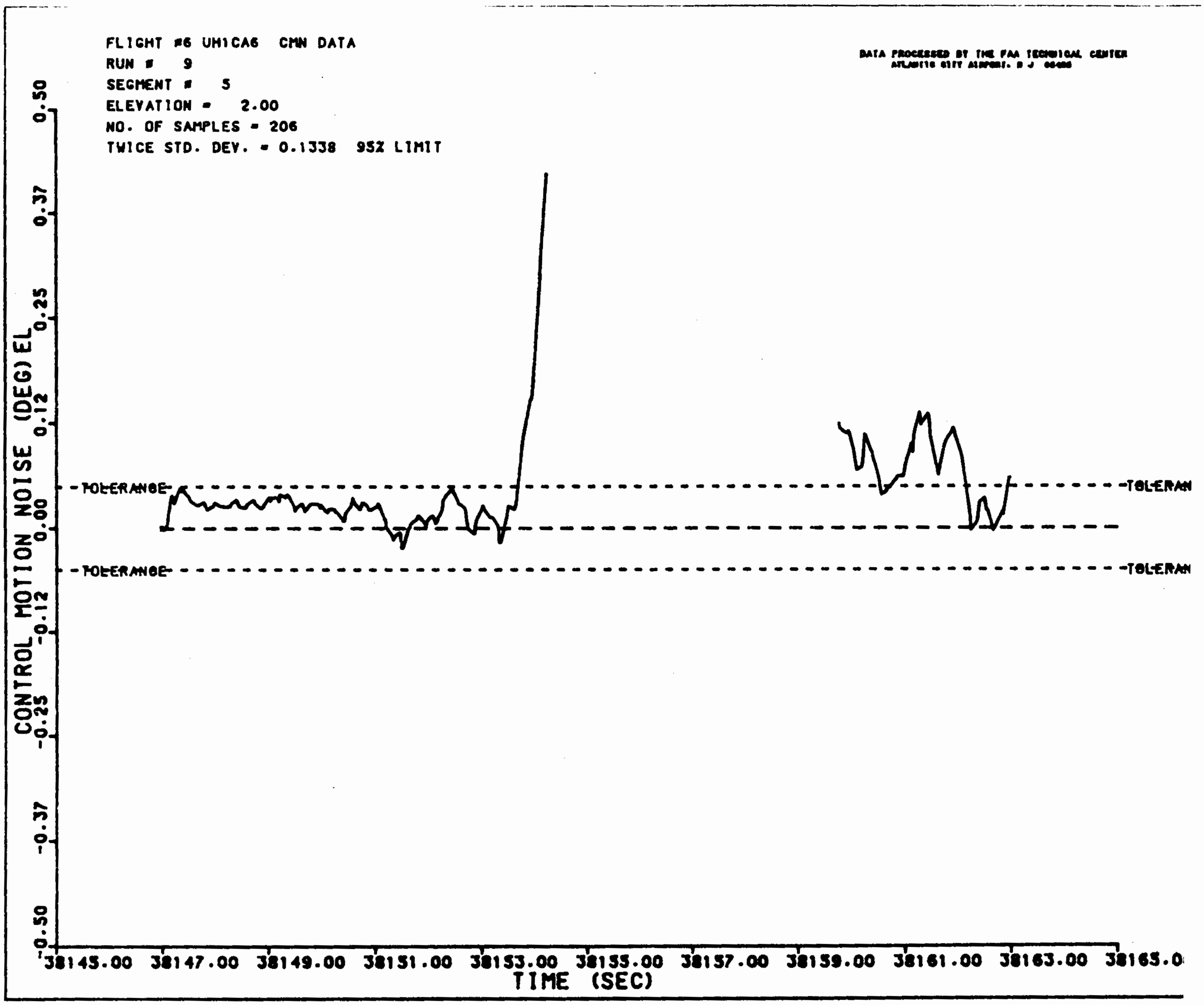


FIGURE 56. POOR ELEVATION CMN RESULTS COINCIDENT WITH A HIGH ELEVATION FRAMING FLAG COUNT

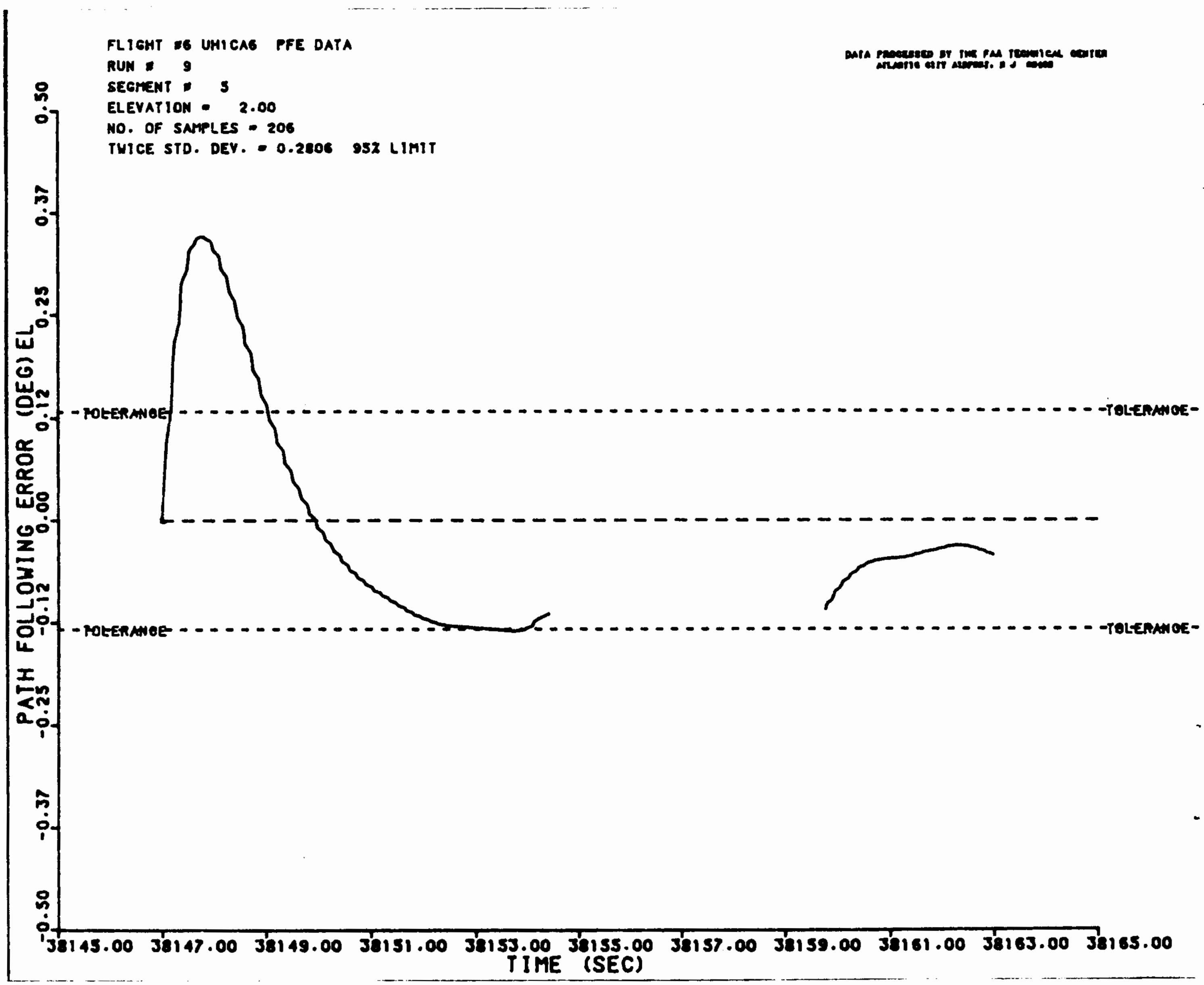


FIGURE 57. POOR ELEVATION PFE RESULTS COINCIDENT WITH A HIGH ELEVATION FRAMING FLAG COUNT

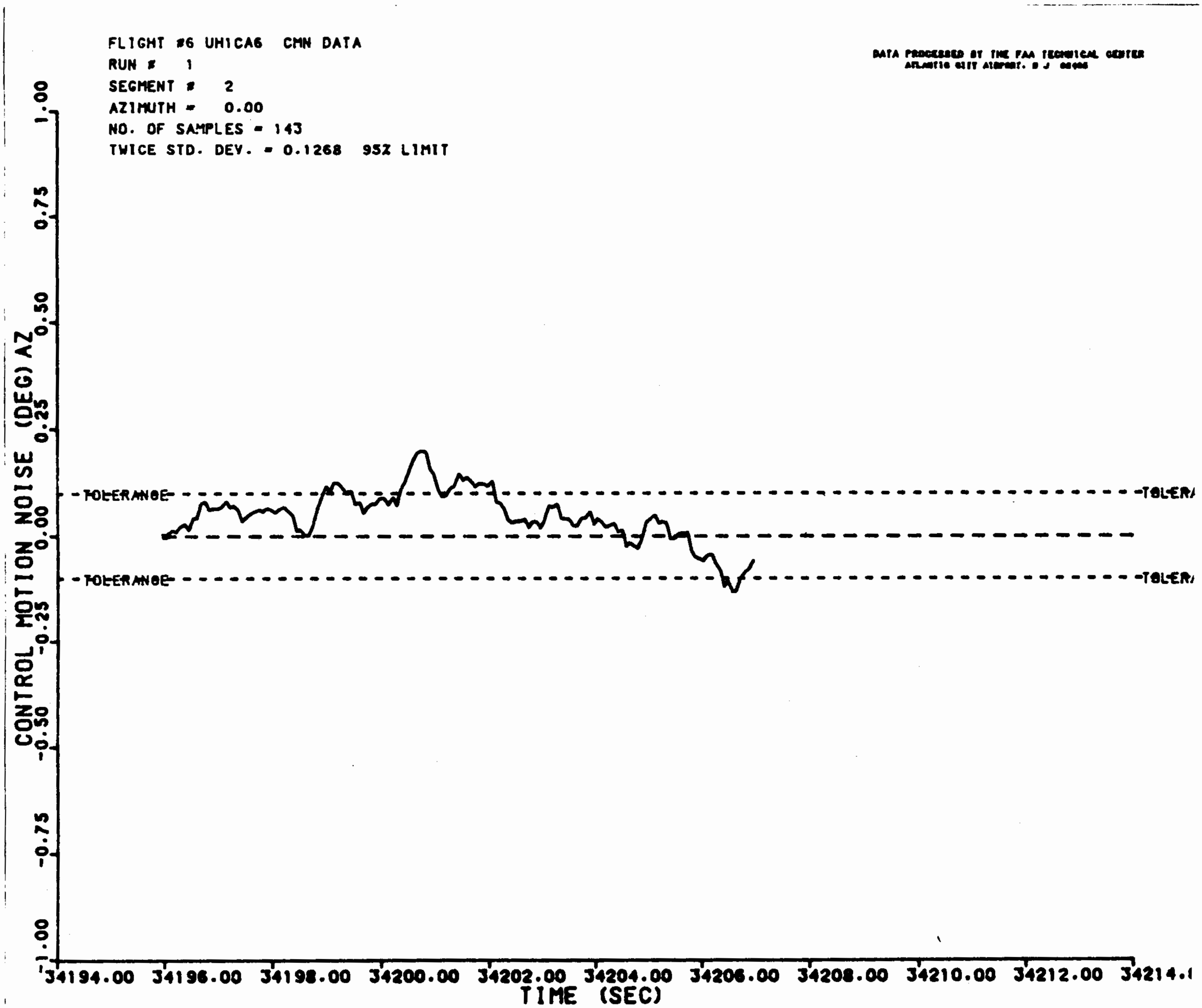


FIGURE 58. EXCELLENT AZIMUTH CMN RESULTS ON PATTERN SEGMENT WHERE NO FRAMING FLAGS OCCURRED

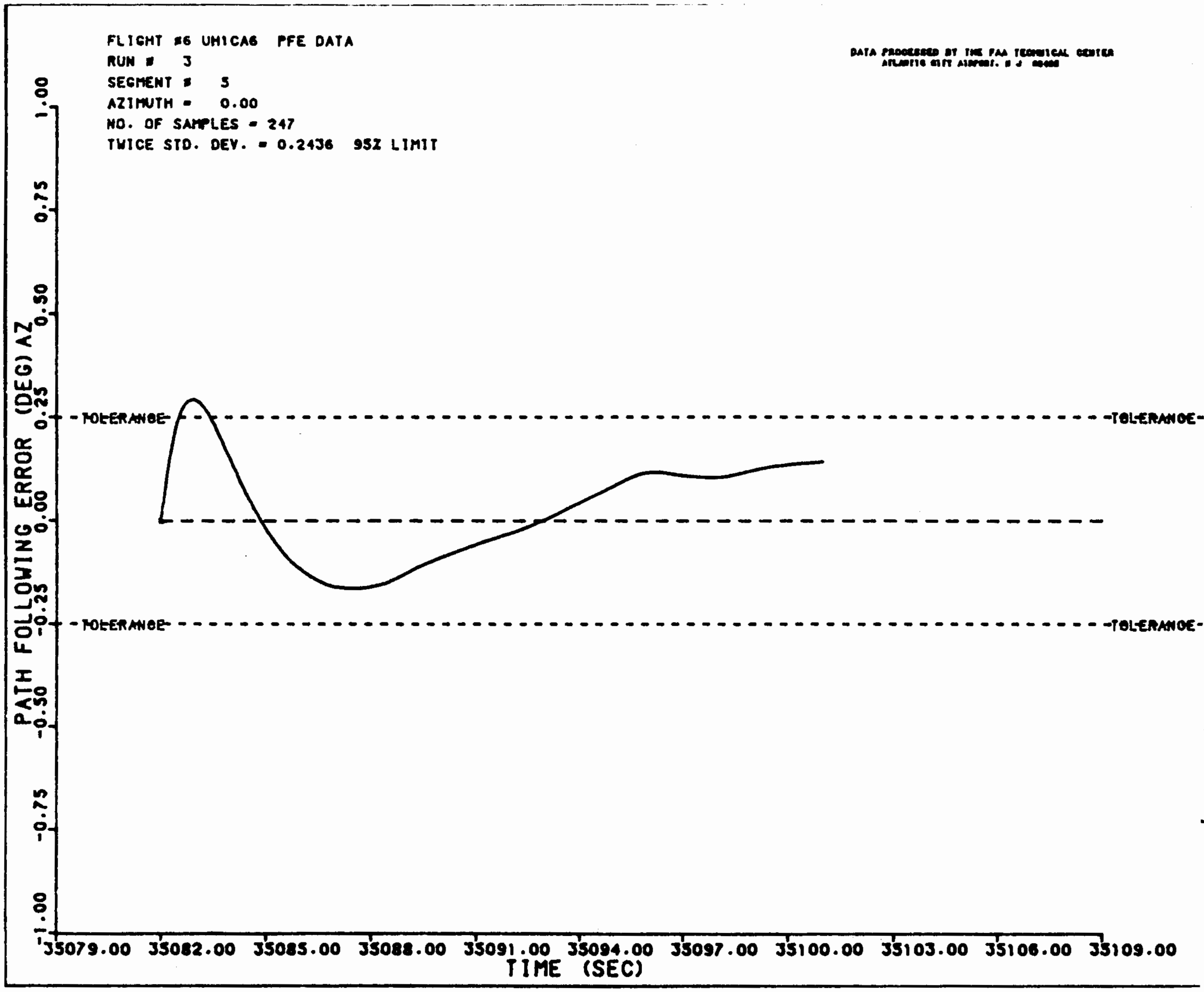


FIGURE 59. EXCELLENT AZIMUTH PFE RESULTS ON PATTERN SEGMENT WHERE NO FRAMING FLAGS OCCURRED

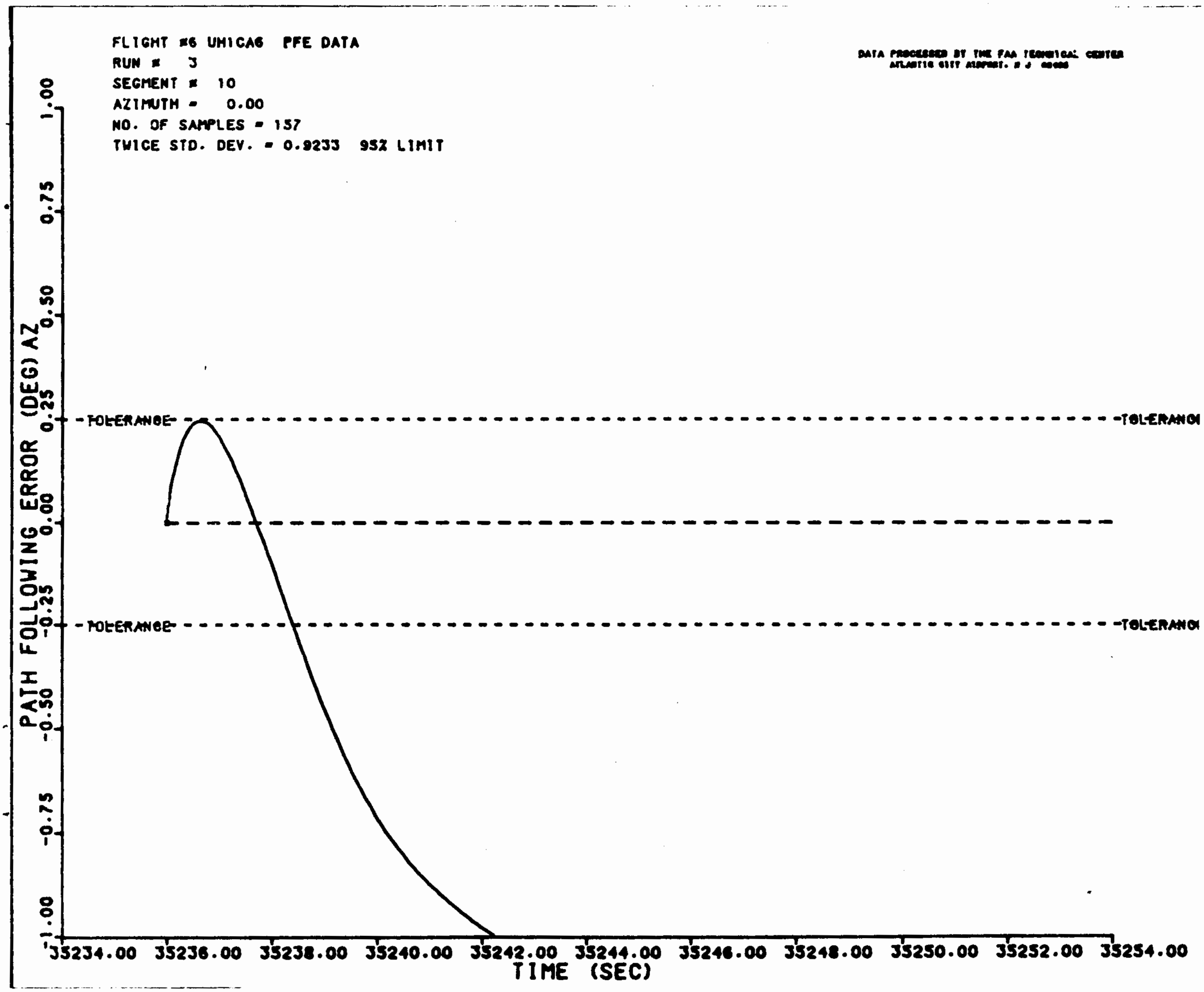


FIGURE 60. POOR AZIMUTH PFE RESULTS WHICH OCCURRED WHEN THE INTERDICTOR WAS IN THE VICINITY OF THE MONITOR POLE

FLIGHT 7, PERPENDICULAR "S" PATTERN RESULTS. On the final test flight, the interdictor perpendicular "S" patten was repeated. Previously, on flight 3 the entire test matrix consisting of 12 different combinations of interdictor hover height and receiving MLS aircraft DH position was not totally completed. Table 8 presents the maximum percentage of framing flags for each test run and the pattern segment on which they occurred. The location of the segment is expressed as a distance from the antenna.

TABLE 8. FLIGHT 7, AZ AND EL FRAMING FLAG RESULTS

Run	EL Results		AZ Results	
No.	Maximum %	Location (ft)	Maximum %	Location (ft)
1	0.37	300	6.15	150
2	0.00	-	0.51	150
3	0.00	-	0.45	400
4	0.51	200	0.43	400
5	10.70	200	0.60	400
6	0.51	400	0.54	150
7	0.00	-	0.00	-
8	0.00	-	0.00	-
9	49.28	100	0.00	-
10	0.21	600	0.53	300
11	0.28	700	0.55	200
12	0.80	400	0.40	300

Based on the framing flag occurrence, the interdictor's position had the most effect when the interdictor was 200 feet or less from the antennas. The framing flag percentages never exceeded 1 percent when the interdictor was more than 200 feet from the antennas. When the interdictor was more than 200 feet from the AZ antenna, the received AZ signal quality was excellent. However, poorer signal quality was observed when the interdictor was within 200 feet of the AZ antenna. The error components in these cases exceeded tolerance limits. The CMN and PFE results shown in figures 61 and 62 occurred when the interdictor was within 200 feet of the AZ antenna.

EL signal quality was excellent when the interdictor was more than 200 feet from the EL antenna. An example of the excellent EL signal quality is presented in figures 63 and 64. The interdictor was 400 feet from the antenna and no framing flags occurred for the example data shown in figures 63 and 64. Poor EL signal quality associated with an interdictor position 200 feet in front of the antenna is presented in figures 65 and 66. EL Framing Flag occurance exceeded 10 percent for plotted data.

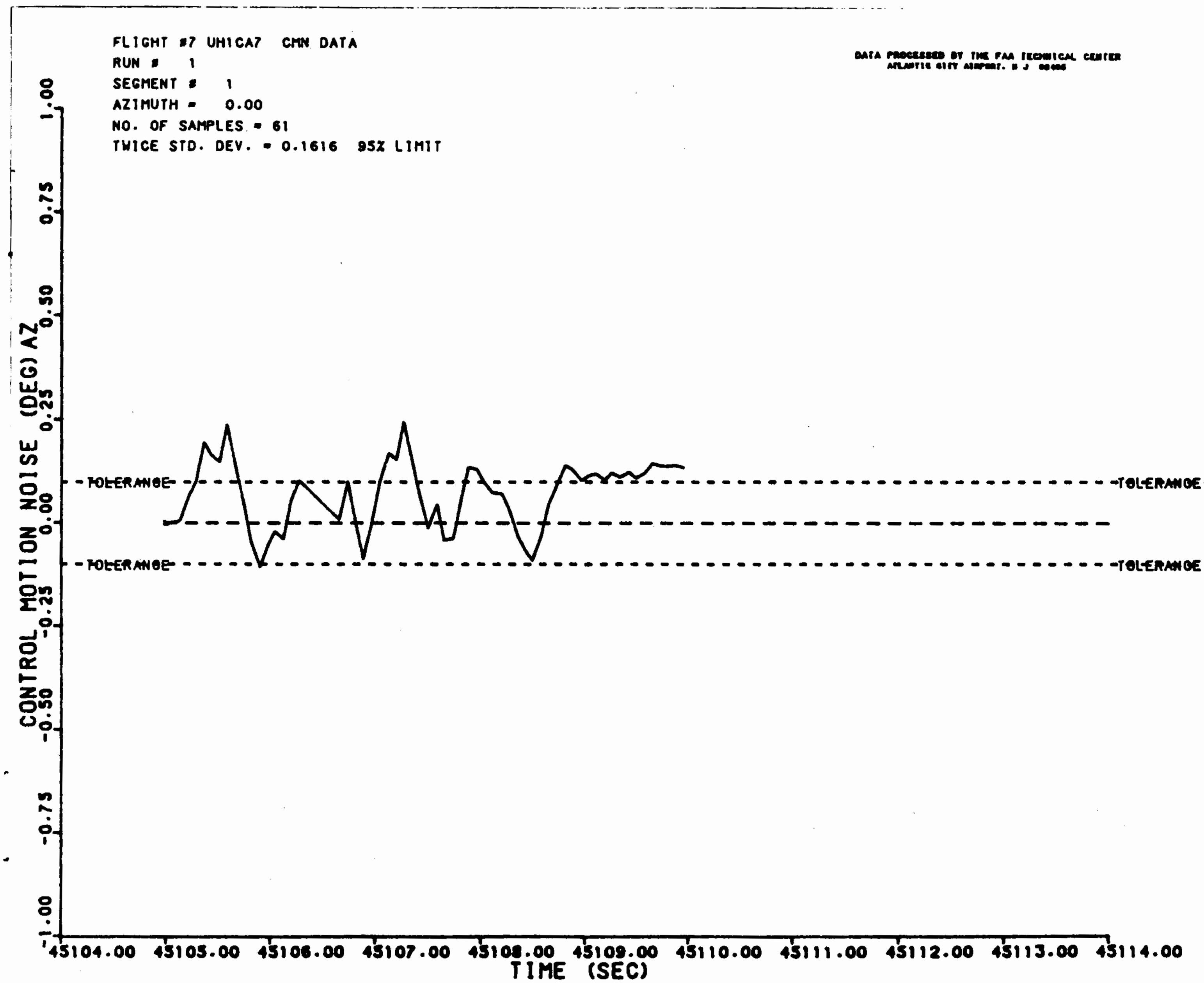


FIGURE 61. POOR AZIMUTH CMN RESULTS WHEN THE INTERDICTOR WAS 150 FEET FROM THE AZIMUTH ANTENNA

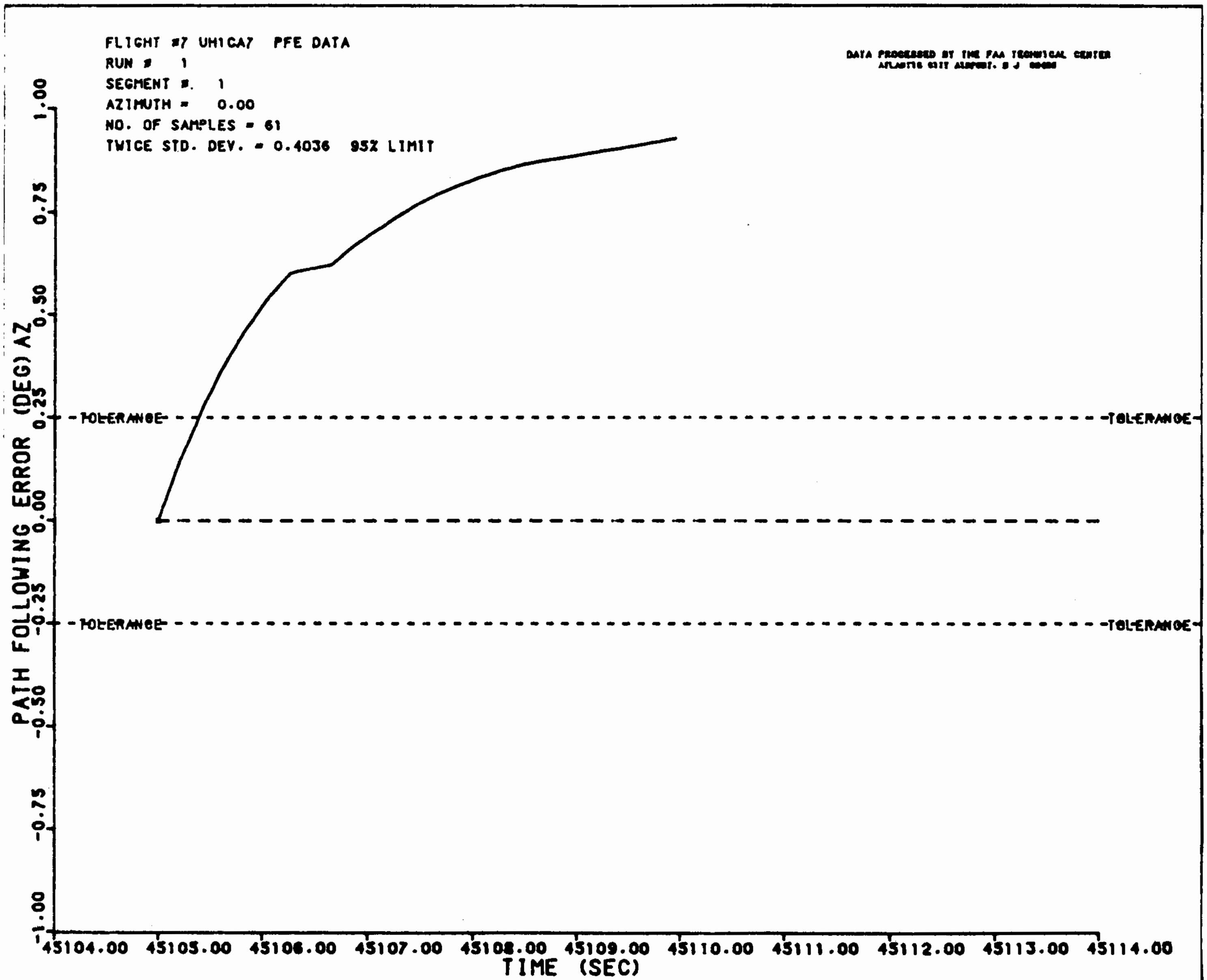


FIGURE 62. POOR AZIMUTH PFE RESULTS WHEN THE INTERDICTOR WAS 150 FEET FROM THE AZIMUTH ANTENNA

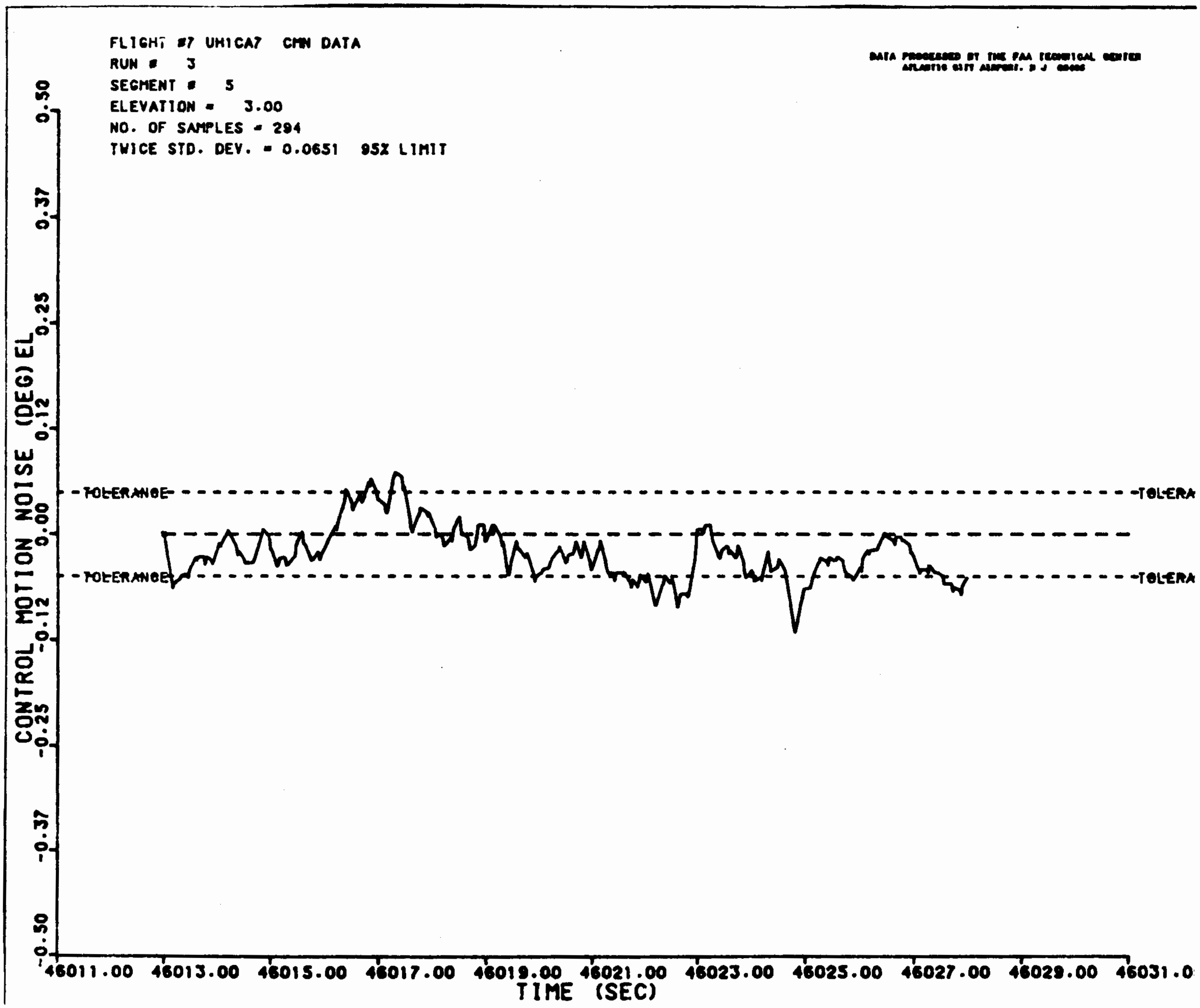


FIGURE 63. EXCELLENT ELEVATION SIGNAL QUALITY WHEN INTERDICTOR WAS NOT IN VICINITY OF ELEVATION MONITOR POLE (CMN)

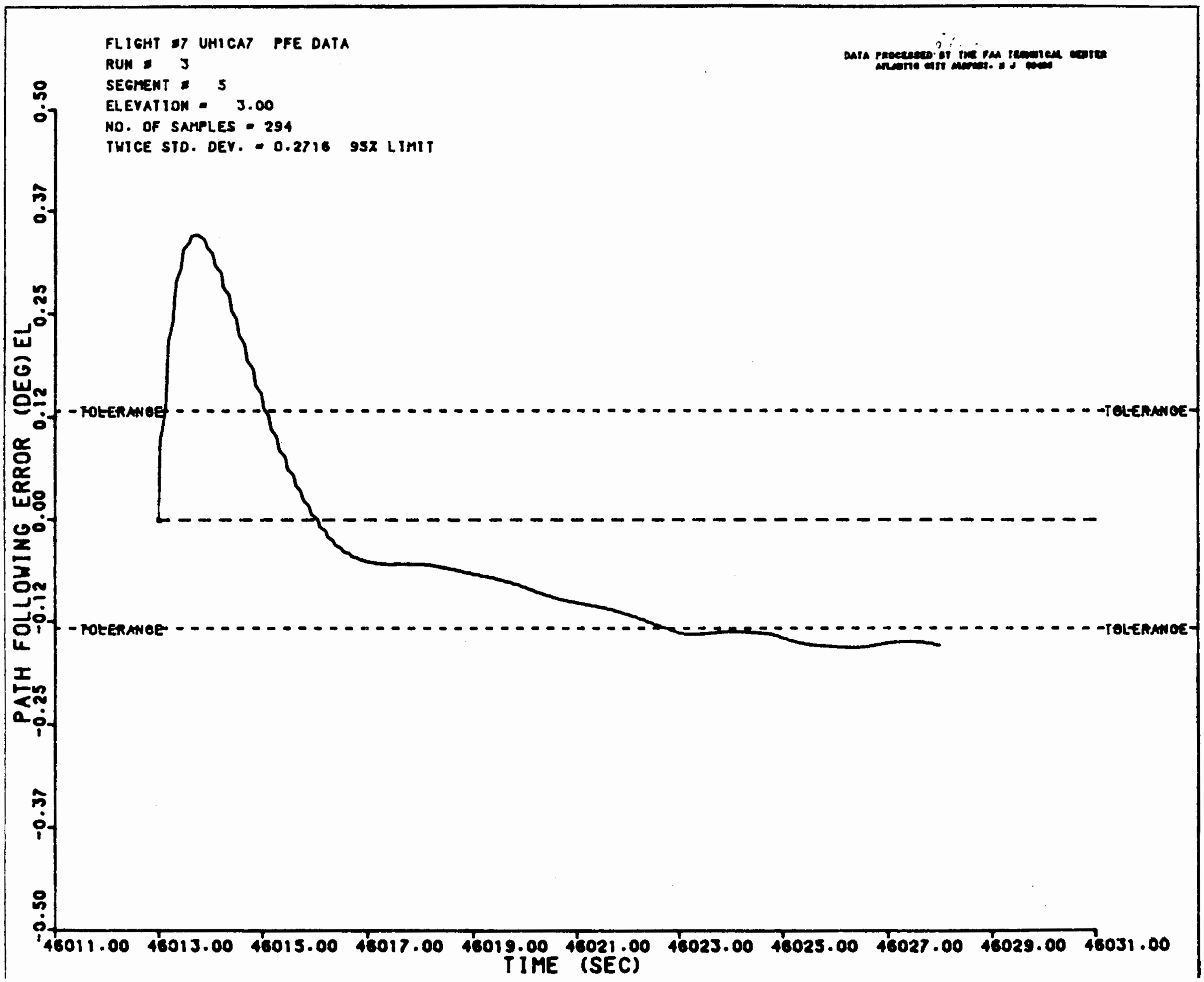


FIGURE 64. EXCELLENT ELEVATION SIGNAL QUALITY WHEN INTERDICTOR WAS NOT IN VICINITY OF ELEVATION MONITOR POLE (PFE)

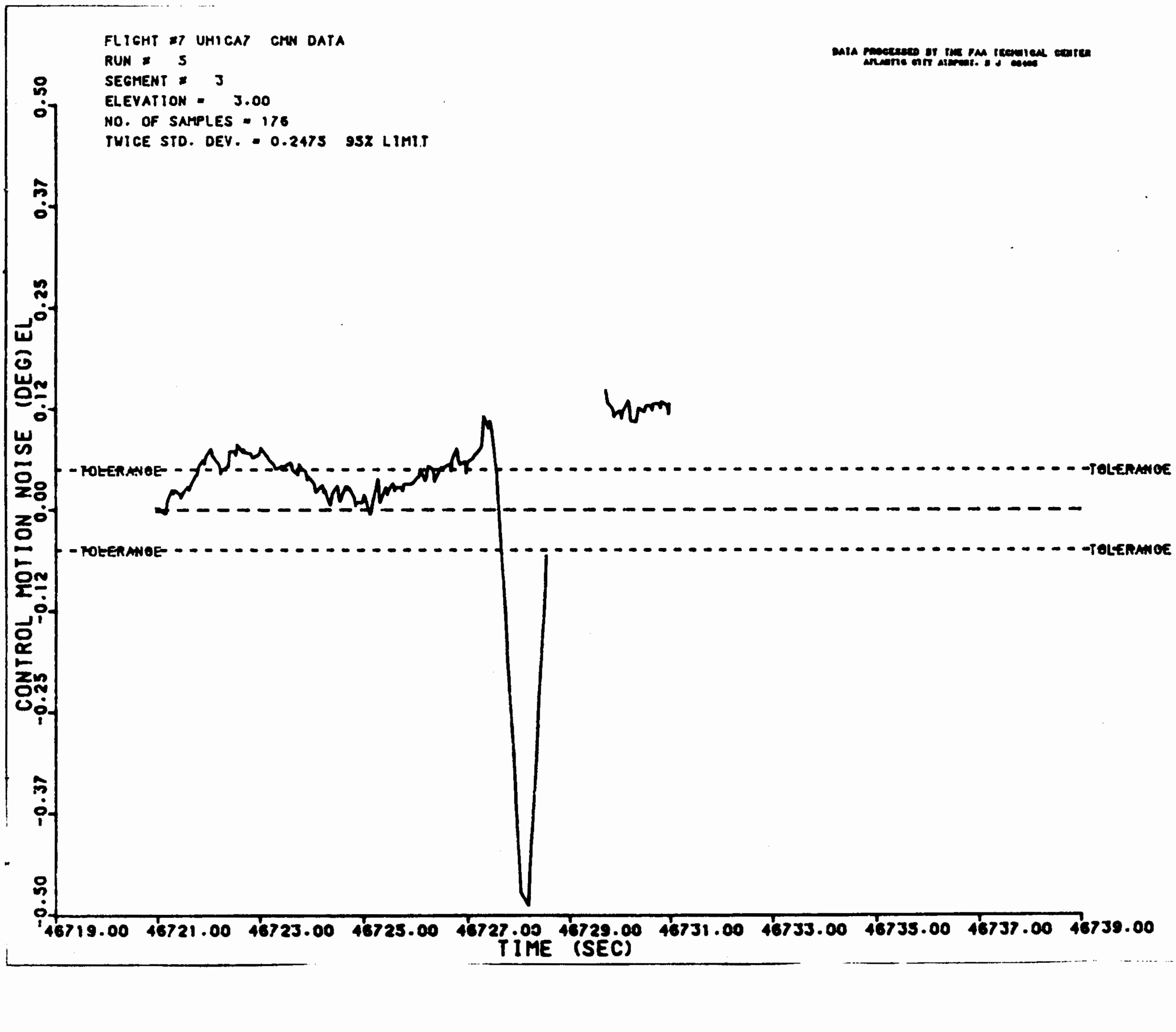


FIGURE 65. POOR ELEVATION HIGH FREQUENCY ERROR COMPONENT RESULTS

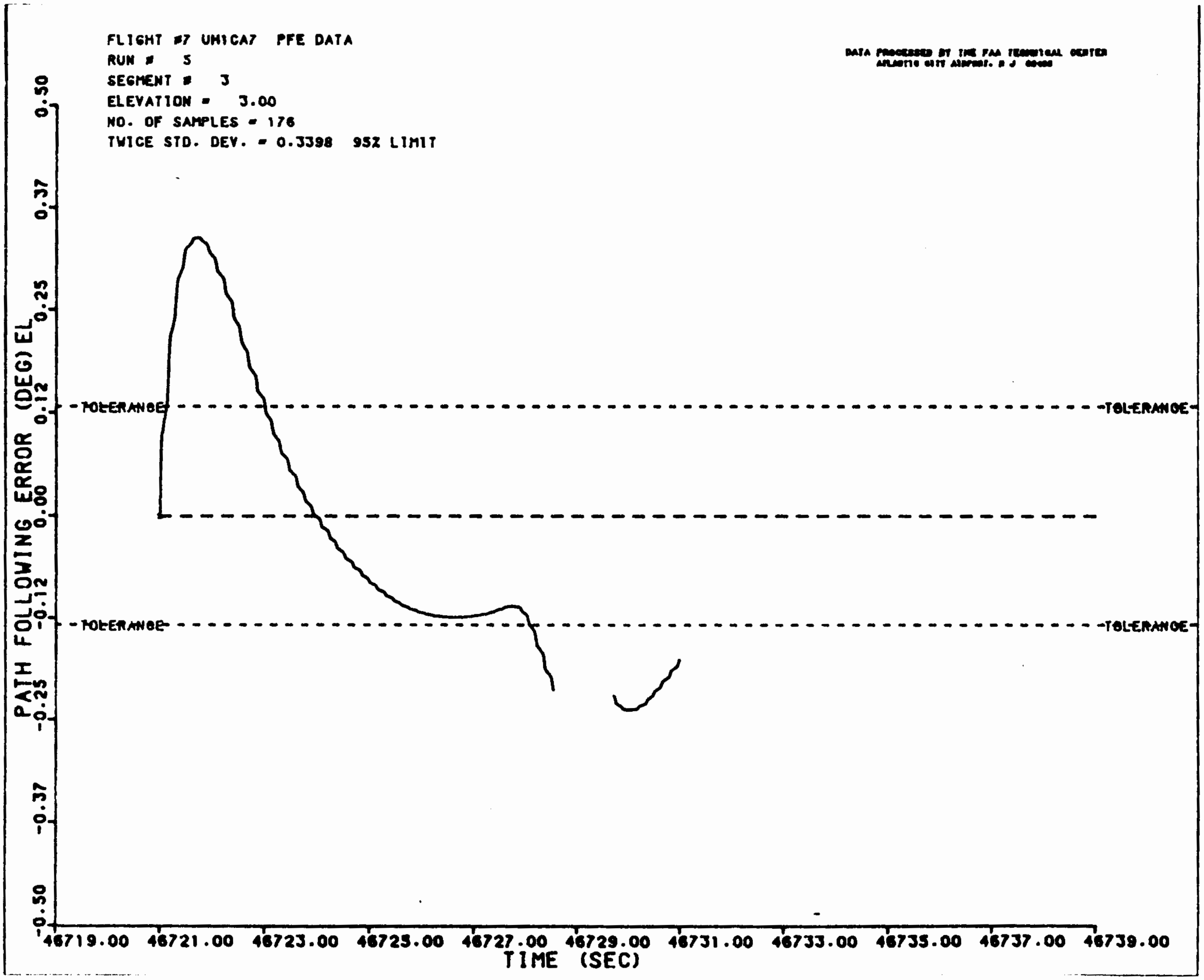


FIGURE 66. POOR ELEVATION LOW FREQUENCY ERROR COMPONENT RESULTS

CONCLUSIONS

Based on the test flight data presented in this report, several specific conclusions have resulted.

1. The region between the microwave landing system (MLS) antennas and signal monitor pole locations must be protected to prevent signal interdiction by either ground vehicles or helicopters.

2. Beyond the location of the monitor poles, neither signal coverage nor quality was influenced by interdictor. This result held for both the hovering helicopter and the ground vehicle. At various respresentative decision height's (DH's), signal coverage and quality met Federal Aviation Administration (FAA) Standard 022C despite the interdictor's presence.

3. Although flight tests have shown little effect on the received MLS signal when two aircraft are flown in close proximity to each other during MLS approaches, normal air traffic control (ATC) operational procedures should be applied to separate aircraft. This includes helicopters hovering in the vicinity of the takeoff and landing area when an instrument approach is in progress and ATC services are available.

4. These results were obtained with a wide beam width MLS system (3.5° azimuth and 2.4° elevation). Results may not apply to narrower beam width systems.

5. The interdicting aircraft and ground vehicle used were representative of traffic that can be found at off airport heliports. Aircraft considerably larger than the UH-1 may cause a greater impact on signal coverage and quality.

RECOMMENDATIONS

Based on the results presented in this report, two specific recommendations are made.

1. A three-dimensional critical region exists about the microwave landing system (MLS) antennas and monitor poles which must be protected. This region has lateral boundaries which encompass both the antenna and monitor poles. The length of the region should encompass both the antenna and monitor poles. The width of the region should encompass the approach reference azimuth plus or minus the azimuth beam width.

Due to the helicopter's ability to hover over obstacles, the critical region must be three-dimensional and extend from the surface to a height exceeding the maximum monitor pole to antenna distance times the tangent at 15°. This will protect the full range of elevation coverage. The recommended critical region is shown in figure 67.

2. If other than wide beam width systems are collocated at heliports, a subset of flight tests described in this report should be performed. The purpose would be to determine if beam width influenced the results of the tests outlined in this report.

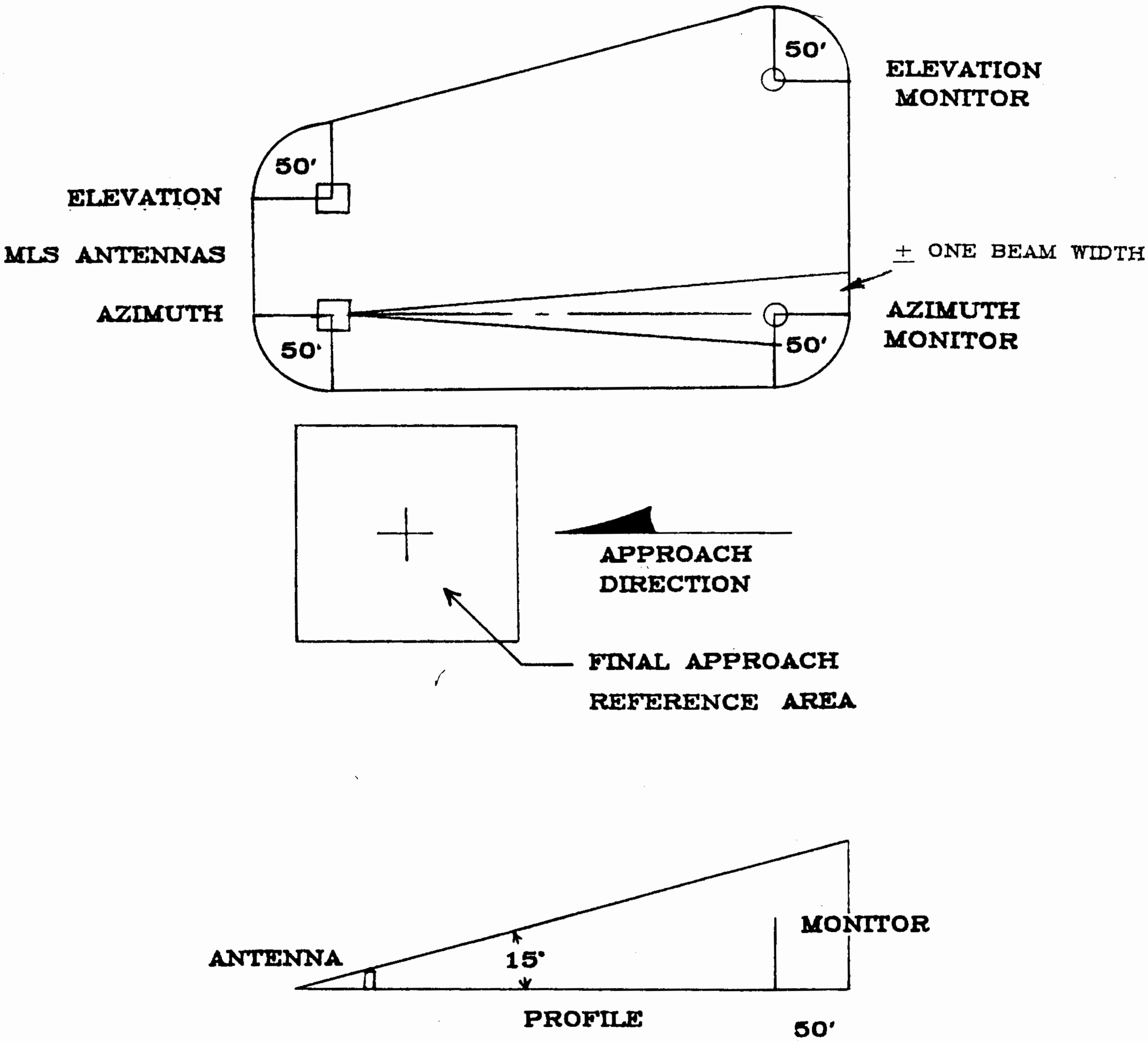


FIGURE 67. HELIPORT MLS CRITICAL REGION

1. Microwave Landing System (MLS) Interoperabiity and Performance Requirements, FAA-STD-022c, DOT/FAA, October 1983.

2. Billmann, Barry R., et al., Signal Coverage and Characteristics of the Atlantic City Heliport MLS, DOT/FAA/CT-TN86/40, October 1986.

3. Shollenberger, Scott B. and Billmann, Barry R., Heliport MLS Flight Inspection Project, DOT/FAA/CT-86/14, April 1986.

GLOSSARY OF TERMS

AZ - Refers to Azimuth Portion of the Microwave Landing System

CDI - Course Deviation Indication

CMN - Control Motion Noise

DH - Decision Height

EL - Refers to Elevation Portion of the Microwave Landing System

FTE - Flight Technical Error

IFR - Instrument Flight Rules

MLS - Microwave Landing System

PFE - Path Following Error

STEP - System Test and Evaluation Program

TRSB - Time Reference Scanning Beam

VDI - Vertical Deviation Indicator 86

APPENDIX A

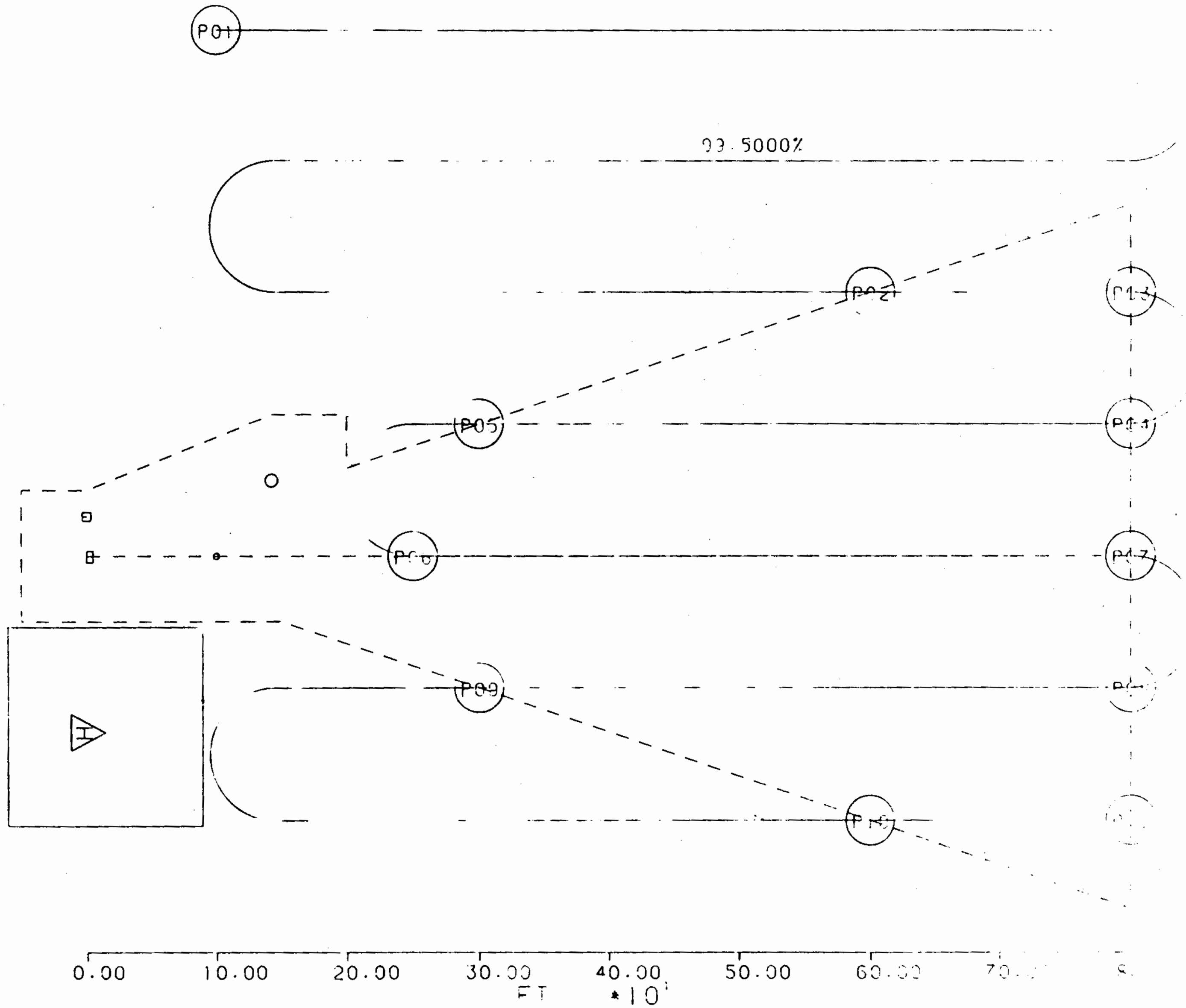
STATISTICAL DIFFERENCE PLOTS FOR DIGITAL AZIMUTH

DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N.J.

CRITICAL AREA FLIGHT 6: F STATISTICS DIGITAL AZ

RUN # 1

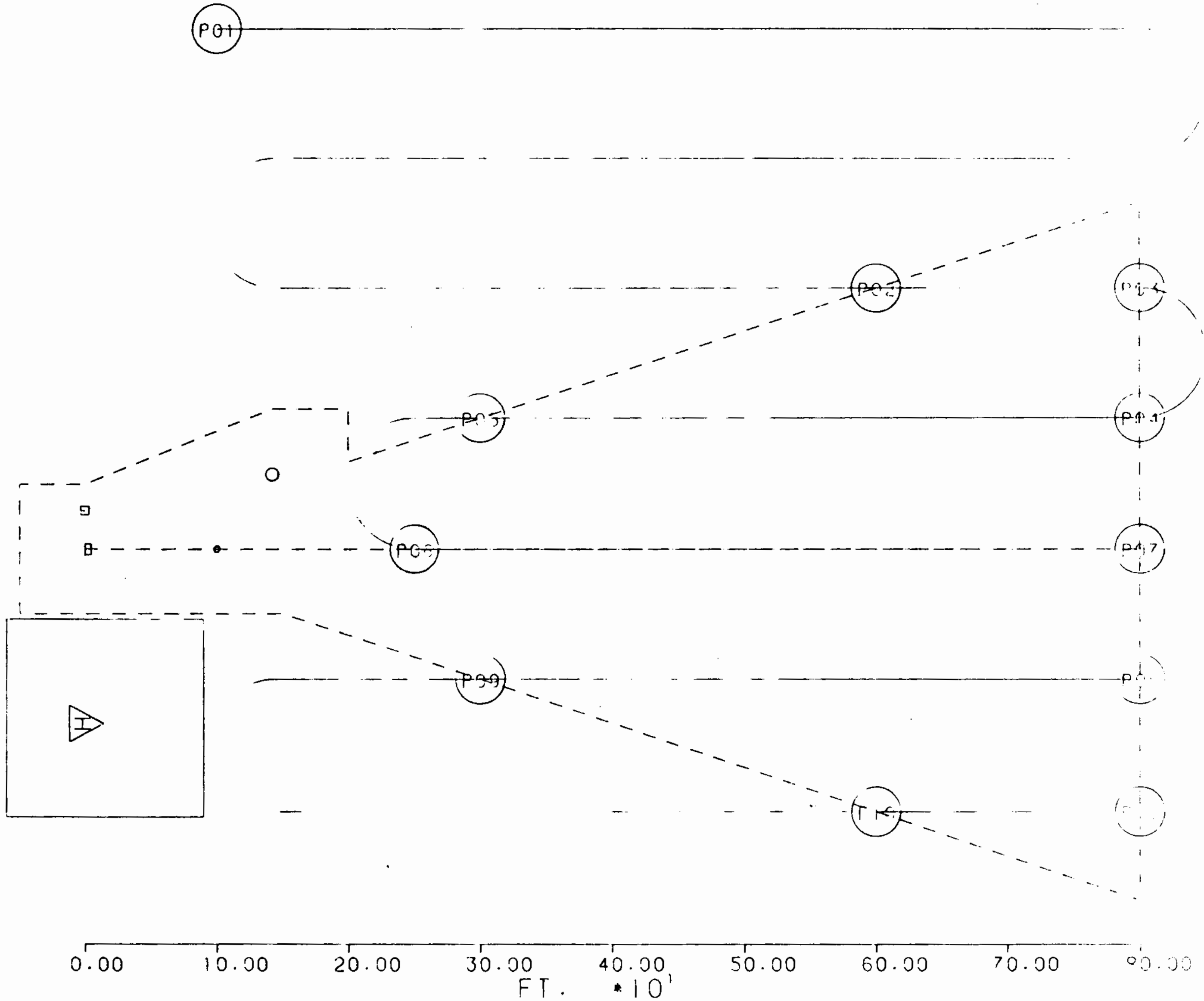
AZIMUTH RUN



CRITICAL AREA FLIGHT 6: F STATISTICS DIGITAL AZ

RUN # 2

AZIMUTH RUN

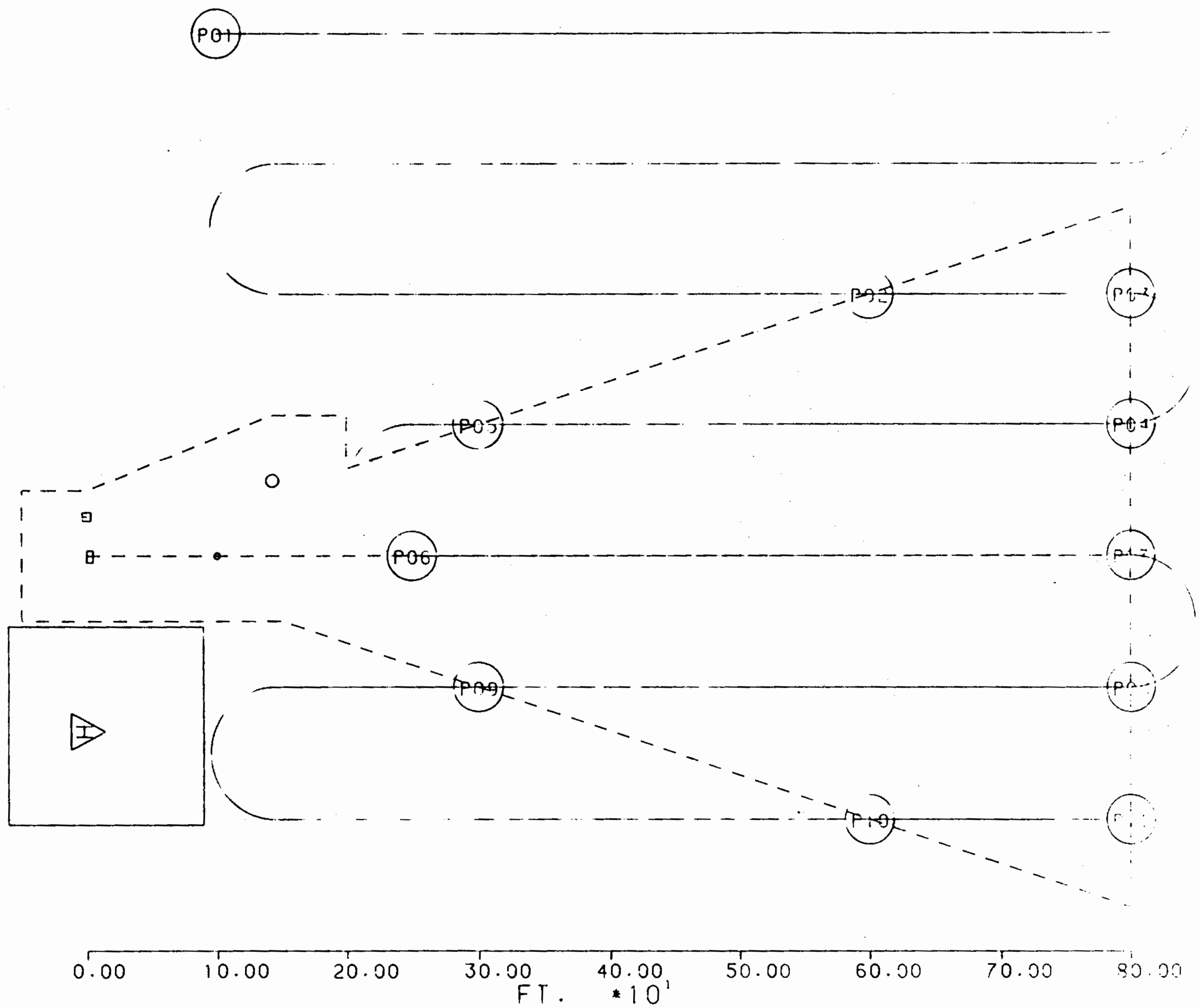


DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N.J. 08405

CRITICAL AREA FLIGHT 6. F STATISTICS DIGITAL AZ

RUN # 3

AZIMUTH RUN

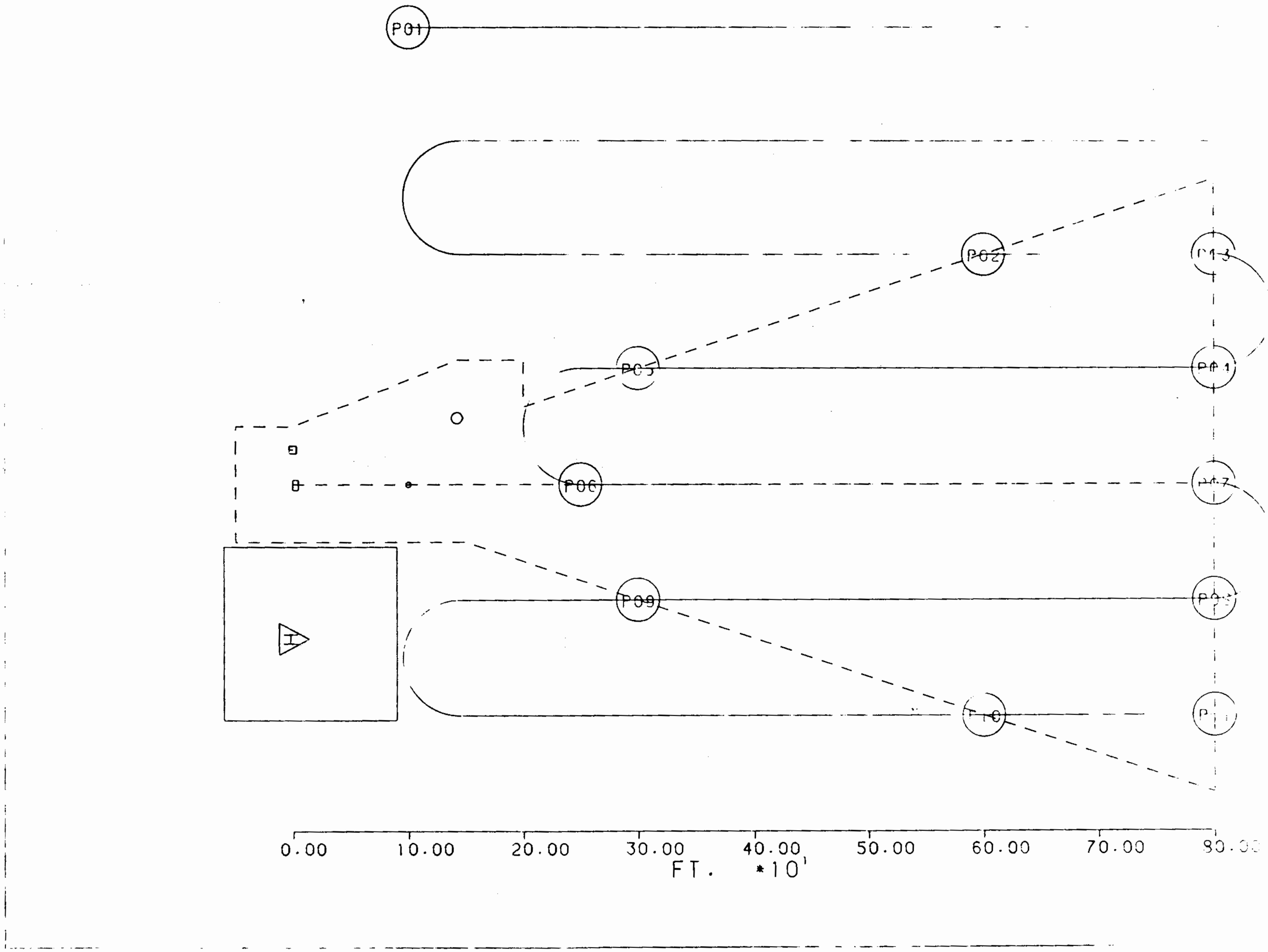


DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N.J. 08405

CRITICAL AREA FLIGHT 6: F STATISTICS DIGITAL AZ

RUN # 4

AZIMUTH RUN

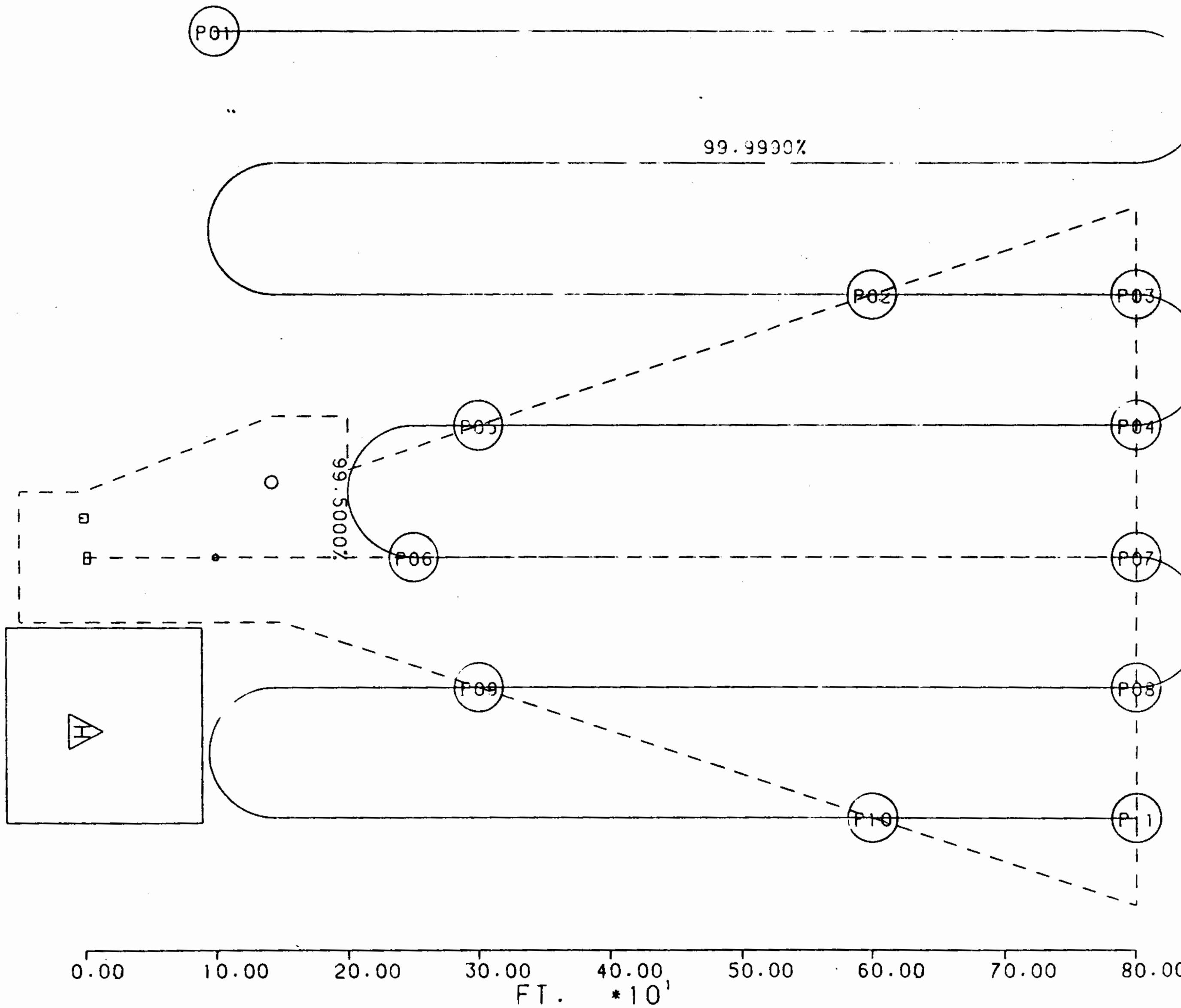


DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N.J. 08405

CRITICAL AREA FLIGHT 6: F STATISTICS DIGITAL AZ

RUN # 7

AZIMUTH RUN

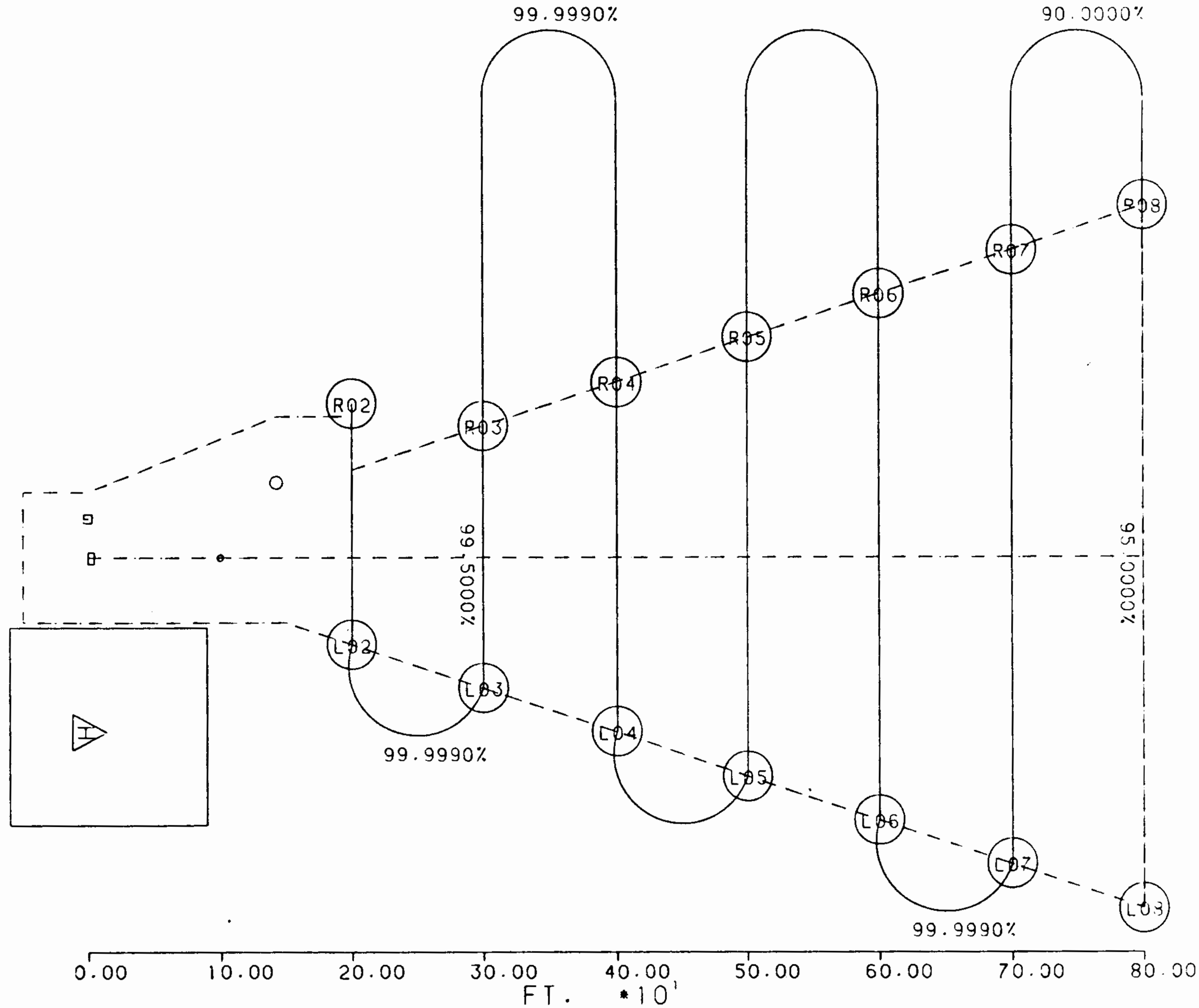


DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N.J. 08405

CRITICAL AREA FLIGHT 7: F STATISTICS DIGITAL AZ

RUN # 1

AZIMUTH RUN

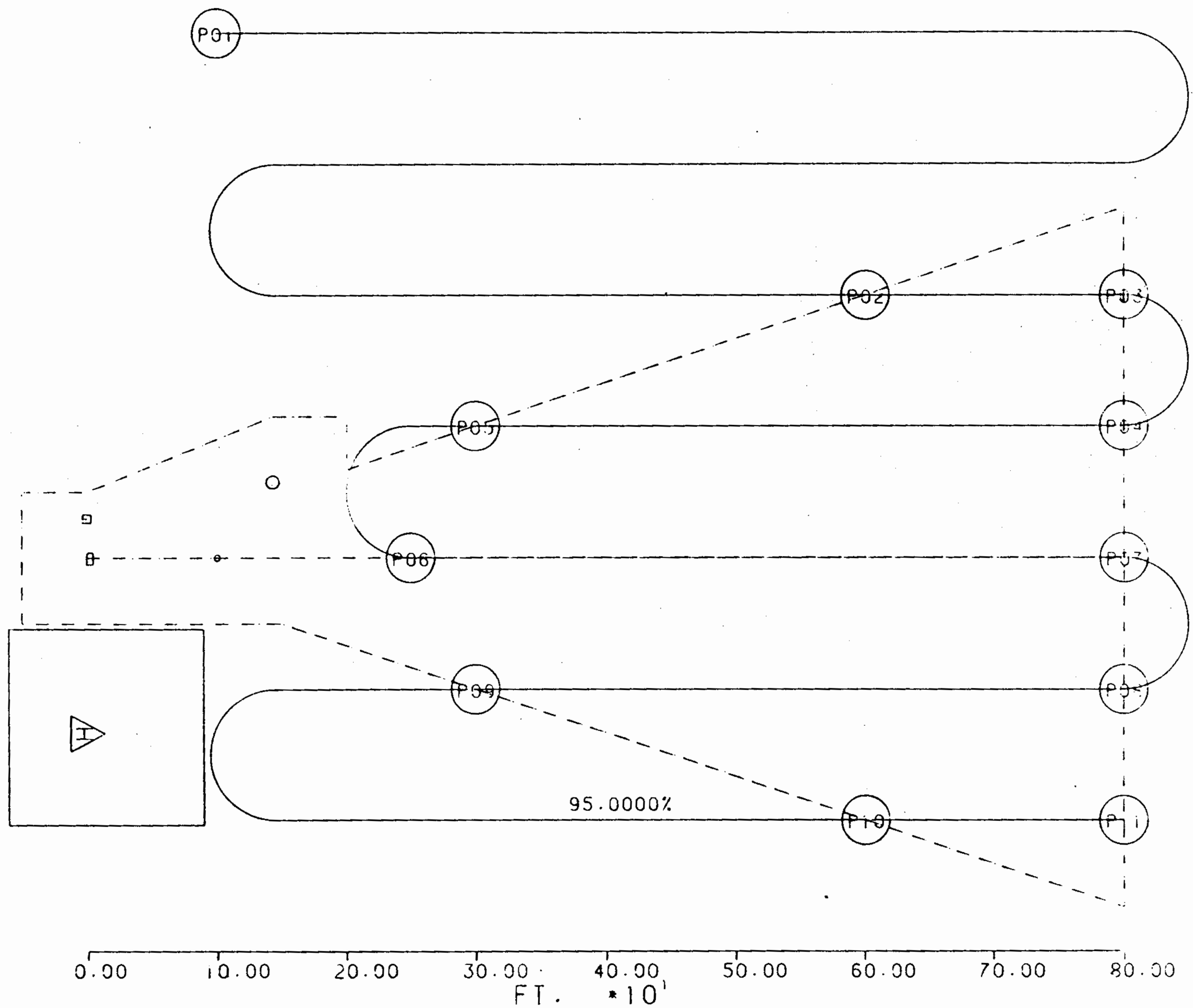


DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N J 08405

CRITICAL AREA FLIGHT 6 F STATISTICS DIGITAL E

RUN # .

ELEVATION RUN



APPENDIX B

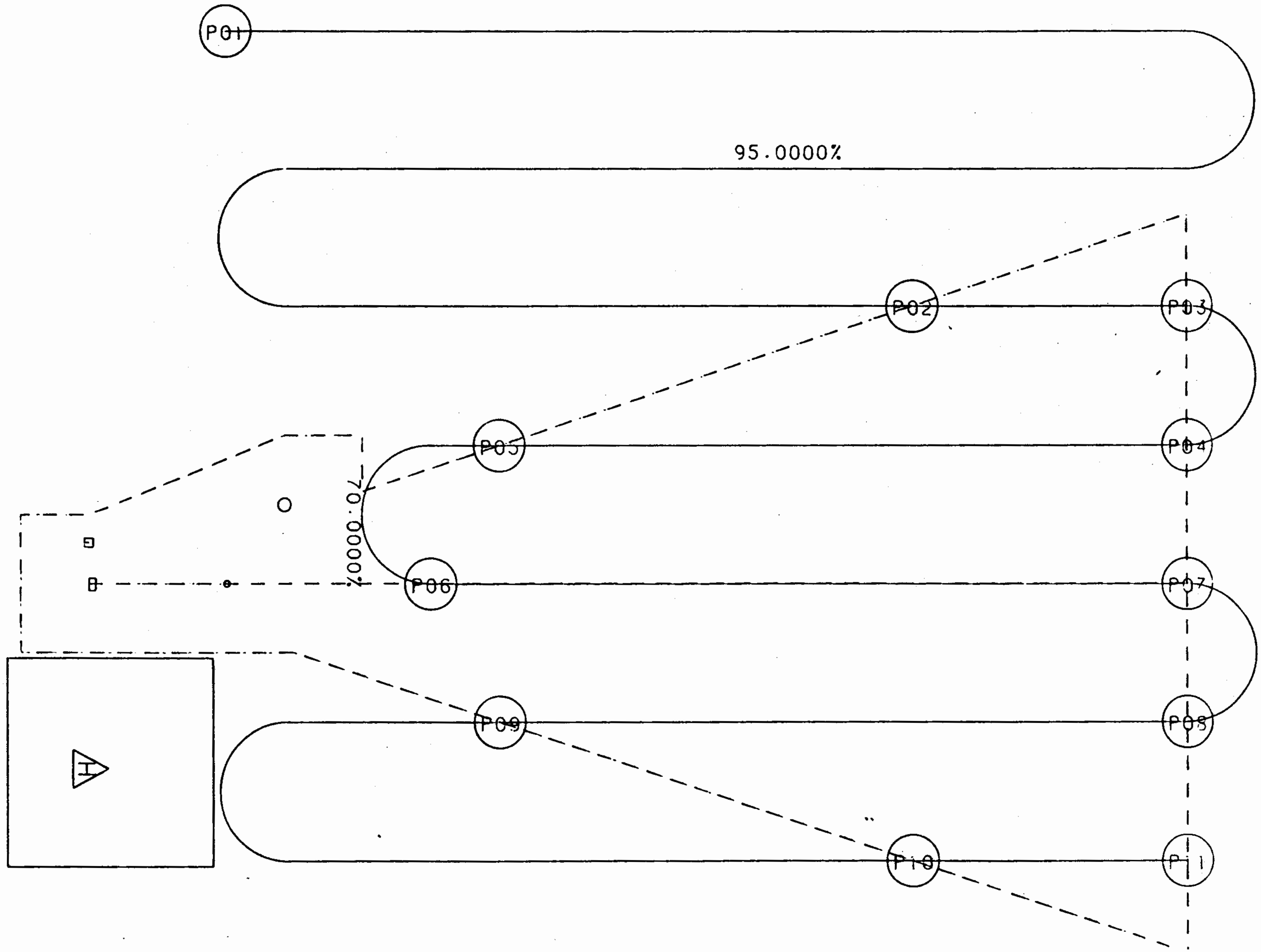
STATISTICAL DIFFERENCE PLOTS FOR DIGITAL ELEVATION

DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N J 08405

CRITICAL AREA FLIGHT 6: F STATISTICS DIGITAL EL

RUN # 4

ELEVATION RUN

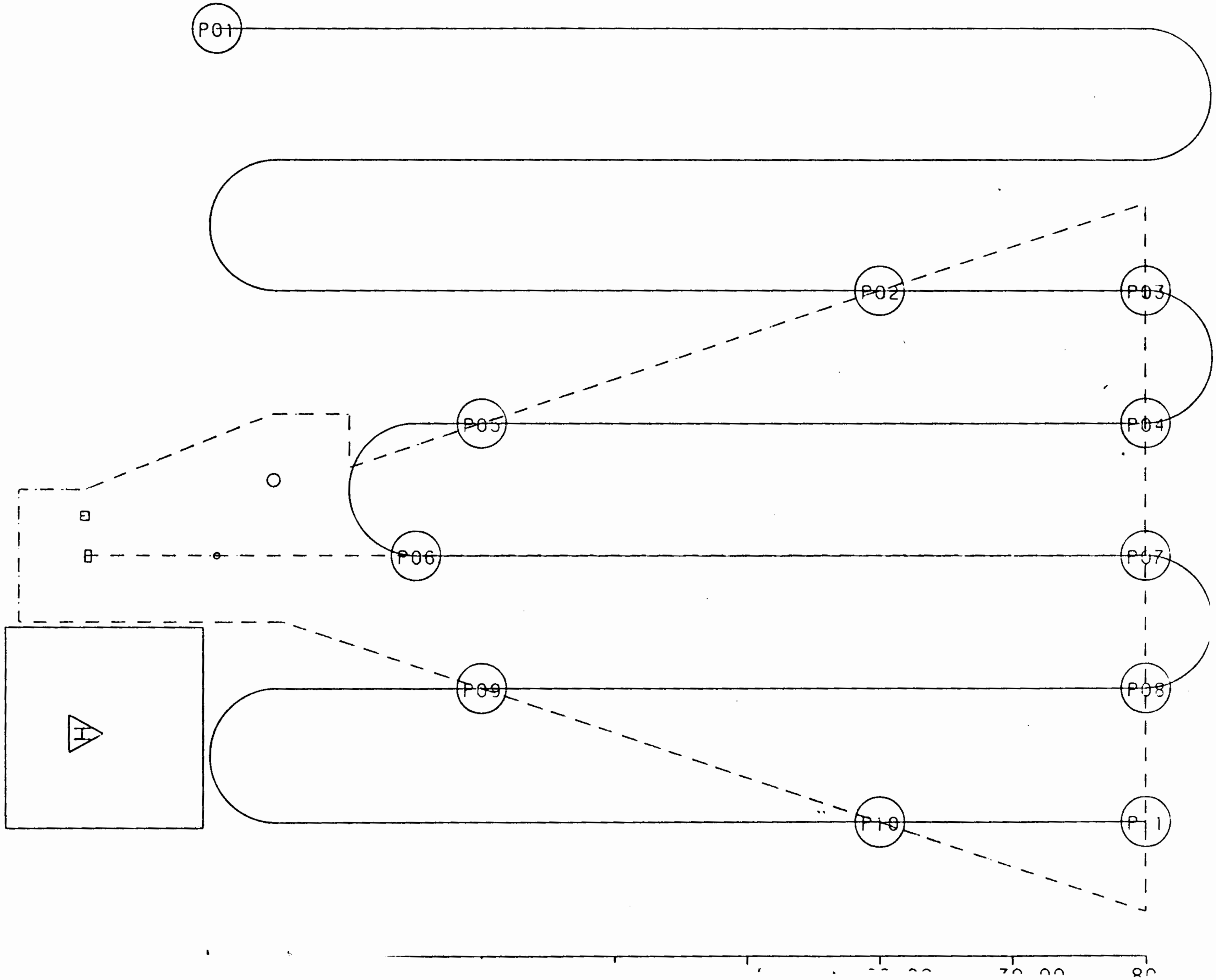


DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N J 08405

CRITICAL AREA FLIGHT 6: F STATISTICS DIGITAL.EL.

RUN # 5

ELEVATION RUN

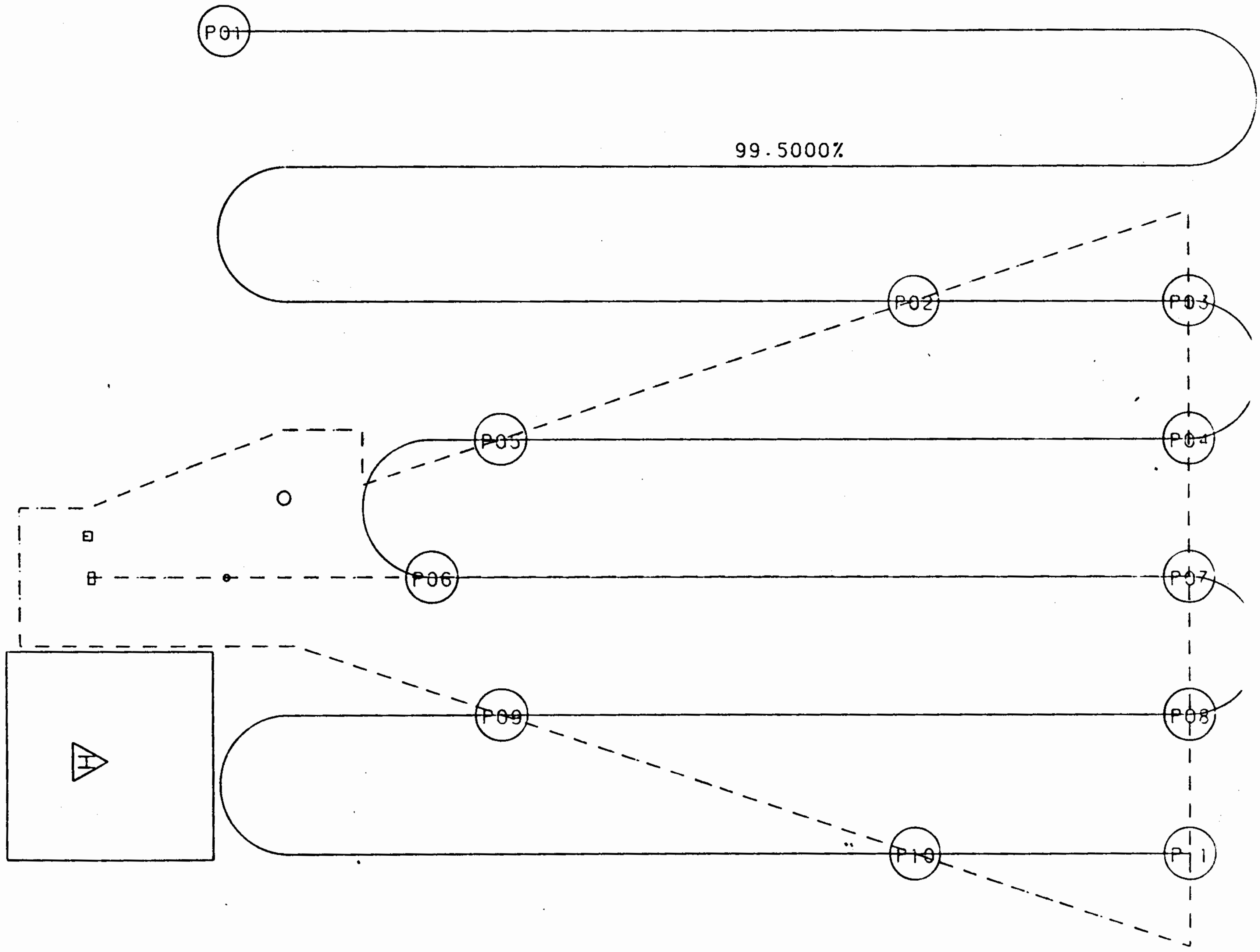


DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N J 08405

CRITICAL AREA FLIGHT 6: F STATISTICS DIGITAL EL

RUN # G

ELEVATION RUN

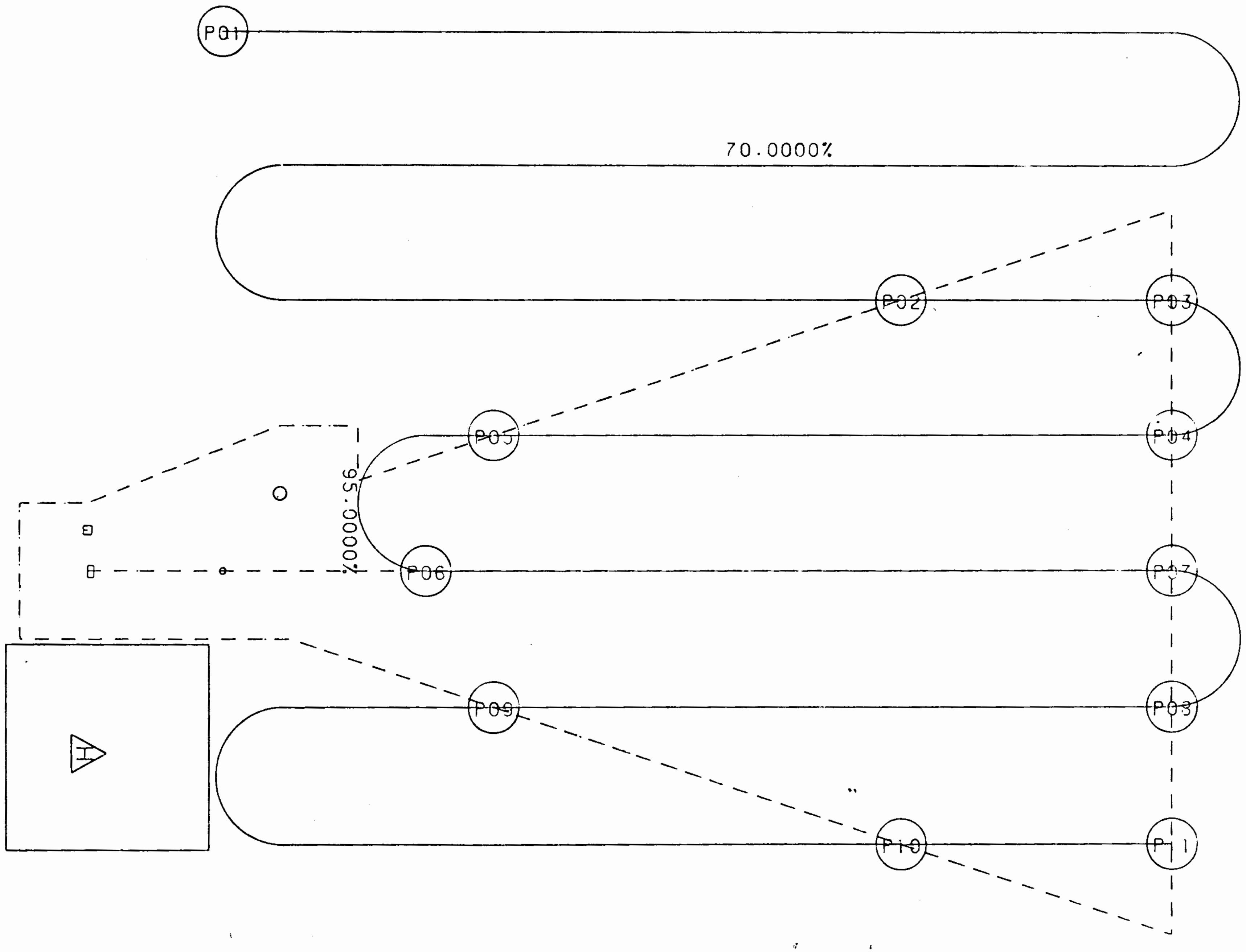


DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N J 08405

CRITICAL AREA FLIGHT 6: F STATISTICS DIGITAL EL

RUN # 8

ELEVATION RUN

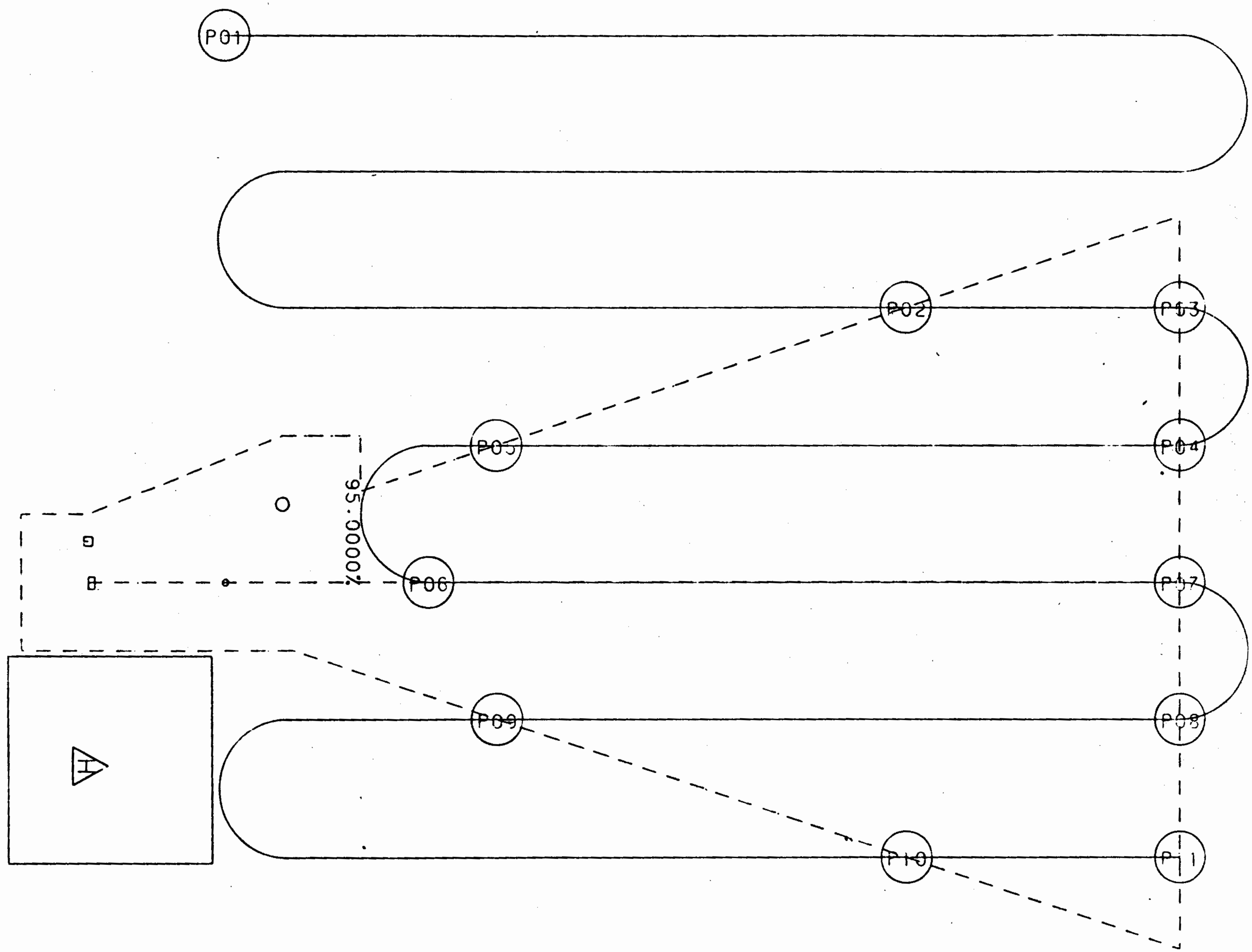


DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N J 08405

CRITICAL AREA FLIGHT 6: F STATISTICS DIGITAL EL

RUN # 9

ELEVATION RUN

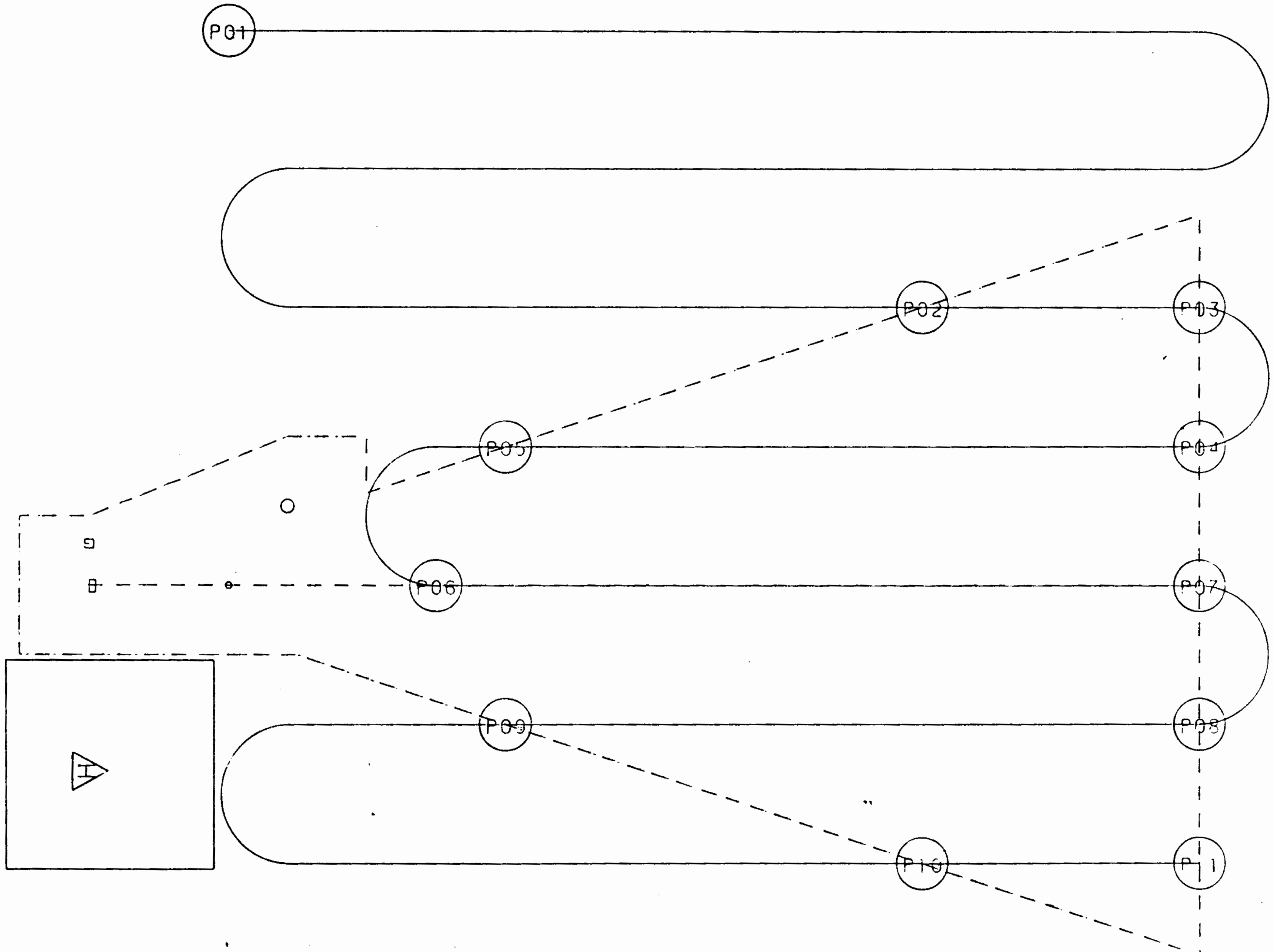


DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N J 08405

CRITICAL AREA FLIGHT 6: F STATISTICS DIGITAL EL

RUN # 10

ELEVATION RUN

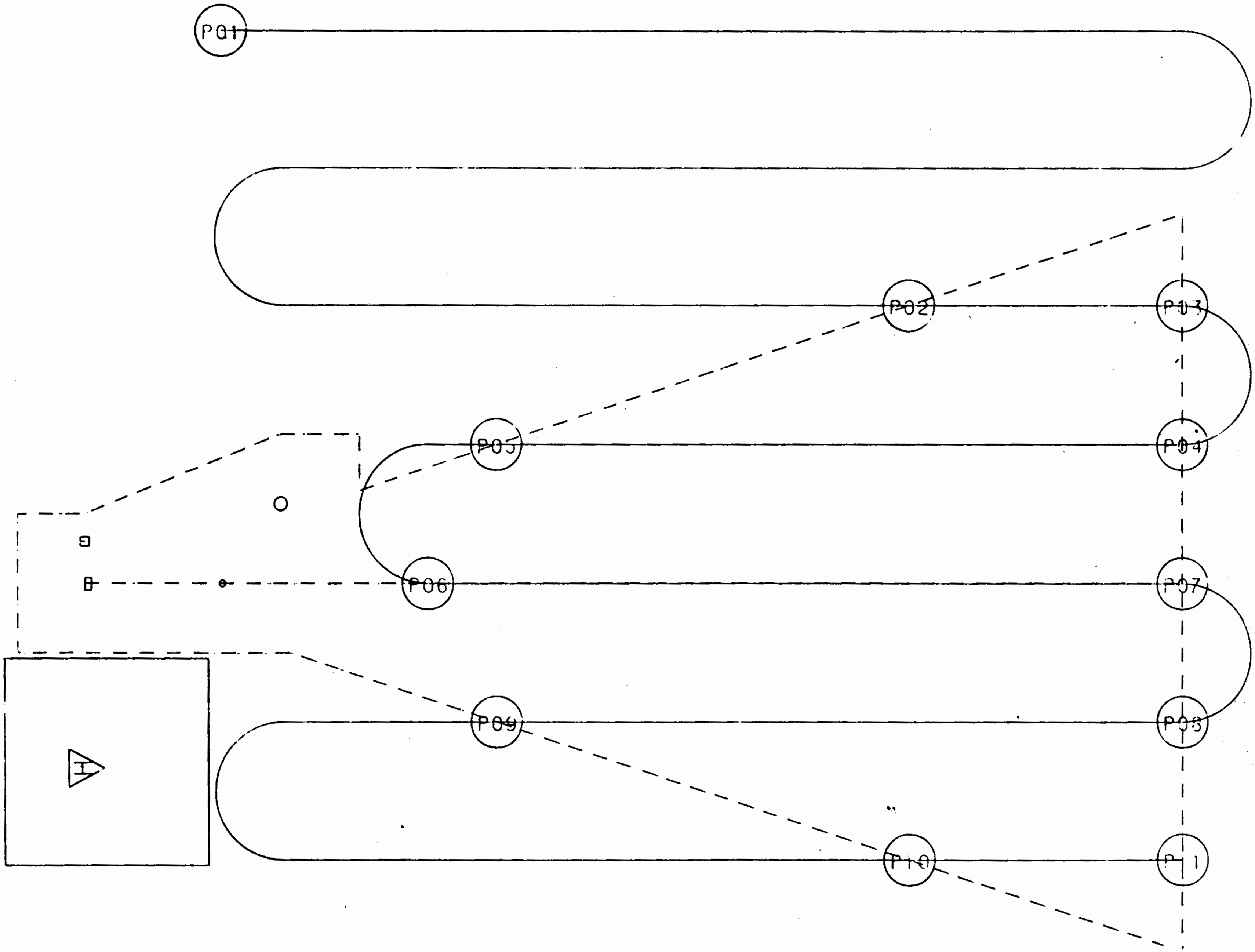


DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N J 08405

CRITICAL AREA FLIGHT 6 F STATISTICS DIGITAL EL

RUN # 11

ELEVATION RUN

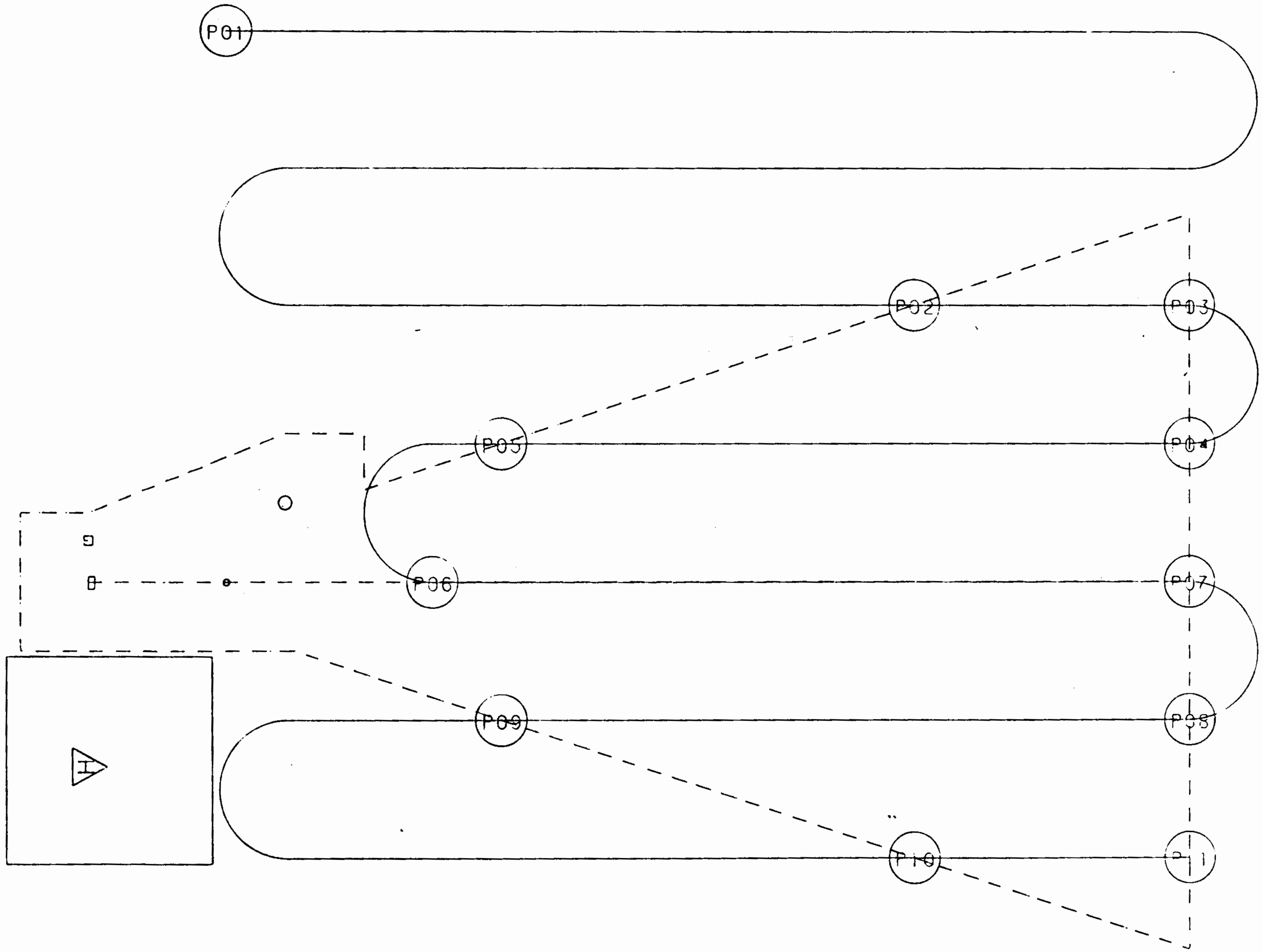


DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N J 08405

CRITICAL AREA FLIGHT 6 F STATISTICS DIGITAL EL

RUN # 12

ELEVATION RUN



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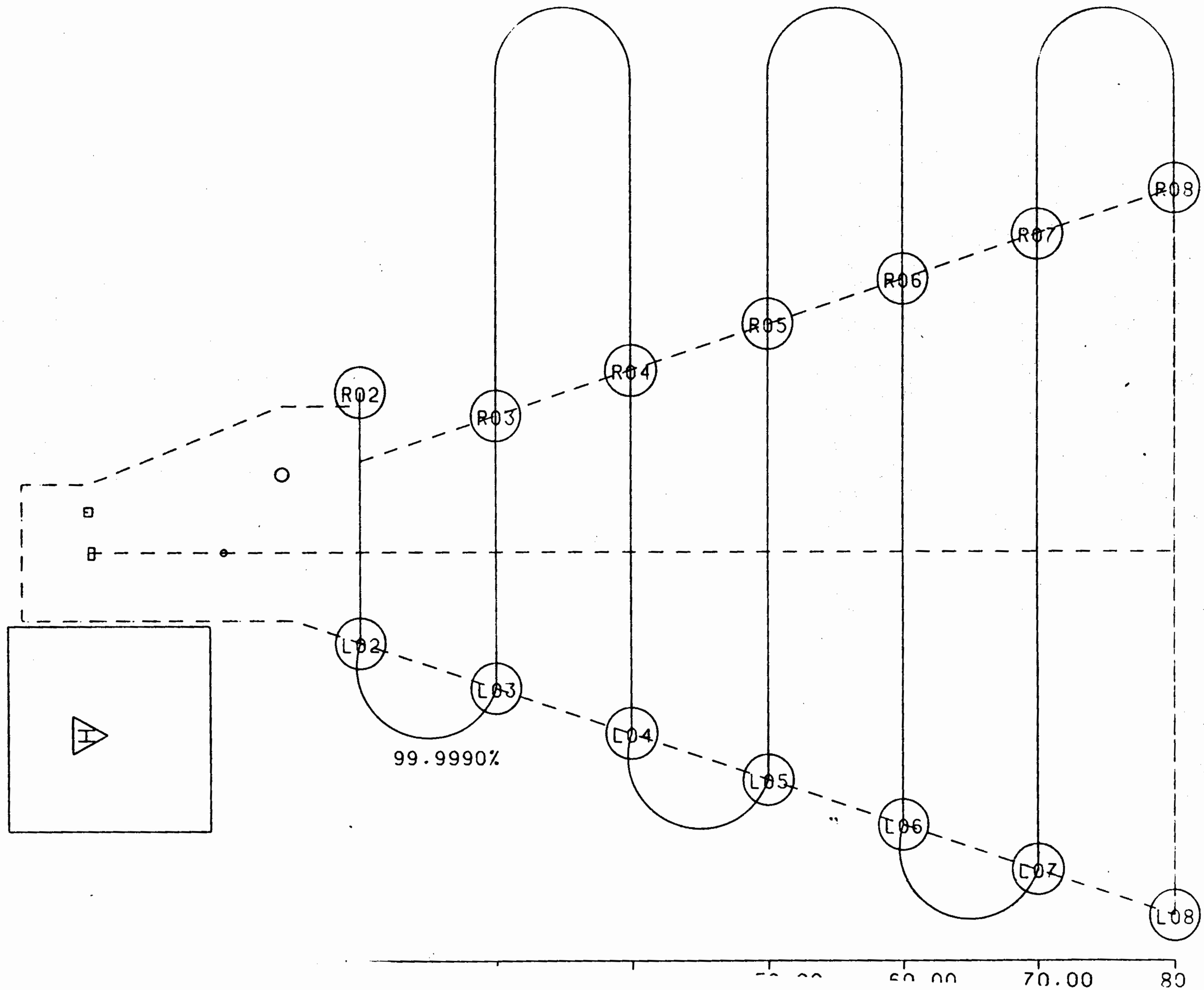
ATLANTIC CITY AIRPORT, N J 08405

CRITICAL AREA FLIGHT 7: F STATISTICS DIGITAL EL

RUN # 4

ELEVATION RUN

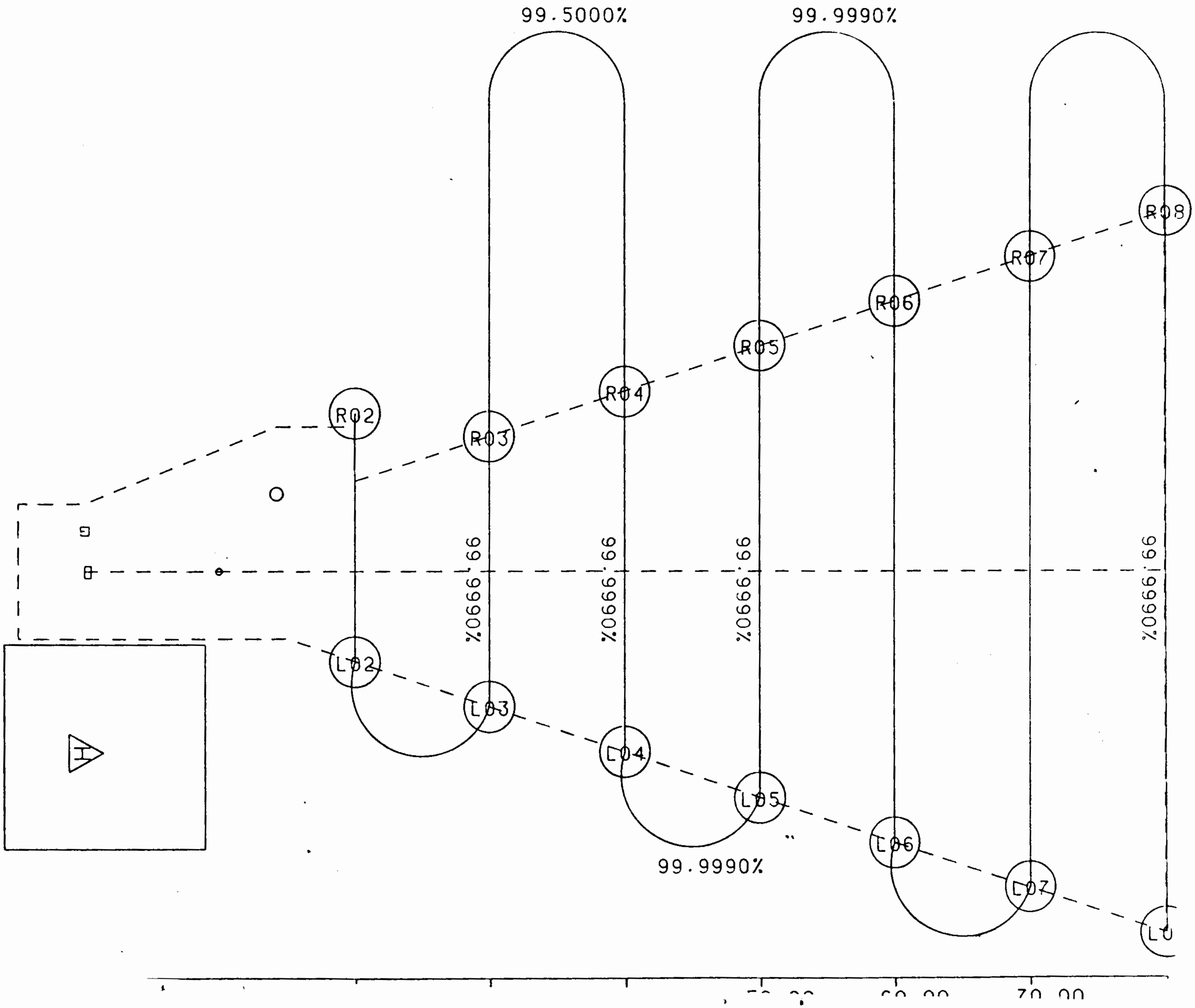


DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N J 08405

CRITICAL AREA FLIGHT 7: F STATISTICS DIGITAL EL

RUN # 6

ELEVATION RUN

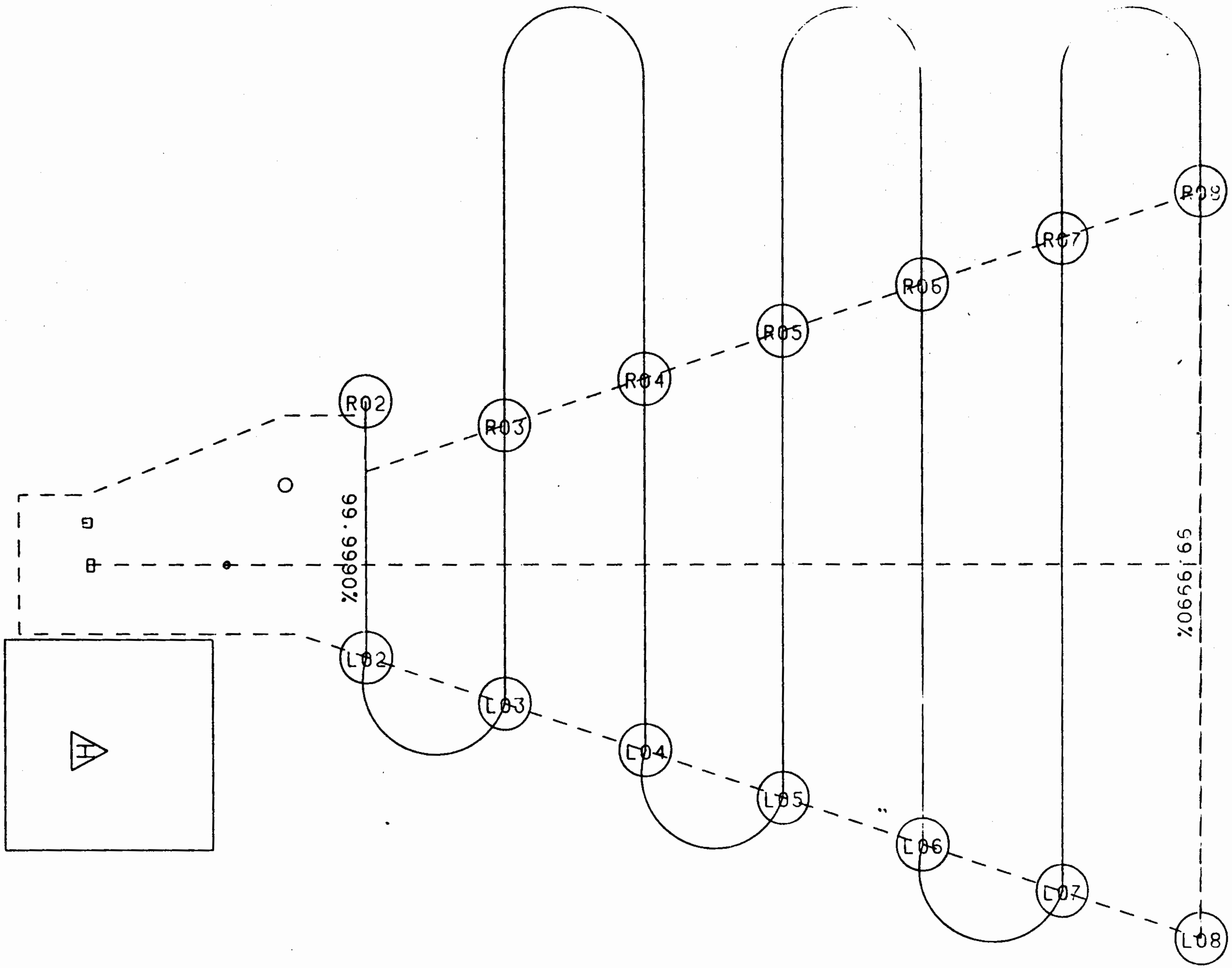


DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT. N J 08405

CRITICAL AREA FLIGHT 7: F STATISTICS DIGITAL EL

RUN # 9

ELEVATION RUN

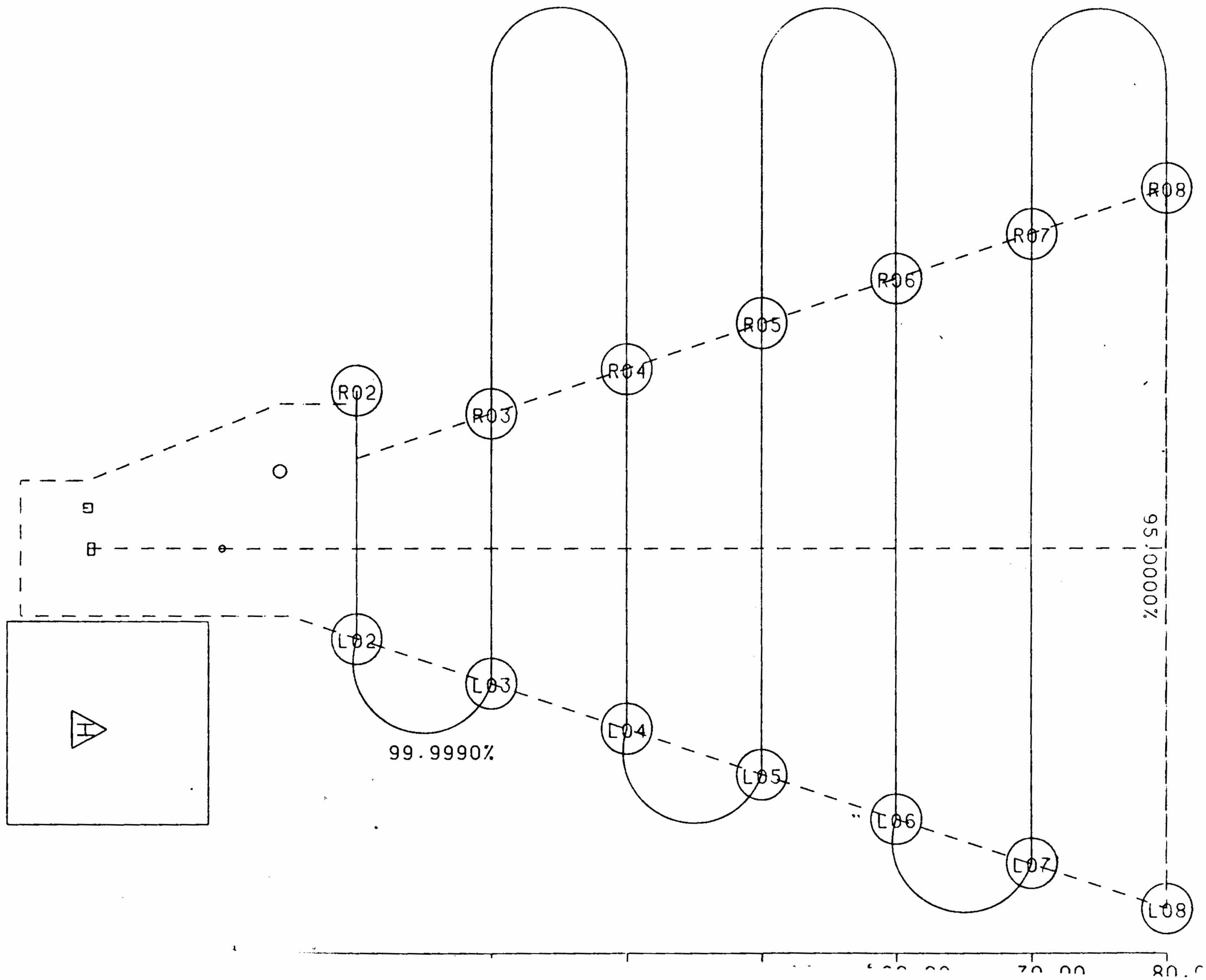


DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N J 08405

CRITICAL AREA FLIGHT 7: F STATISTICS DIGITAL EL

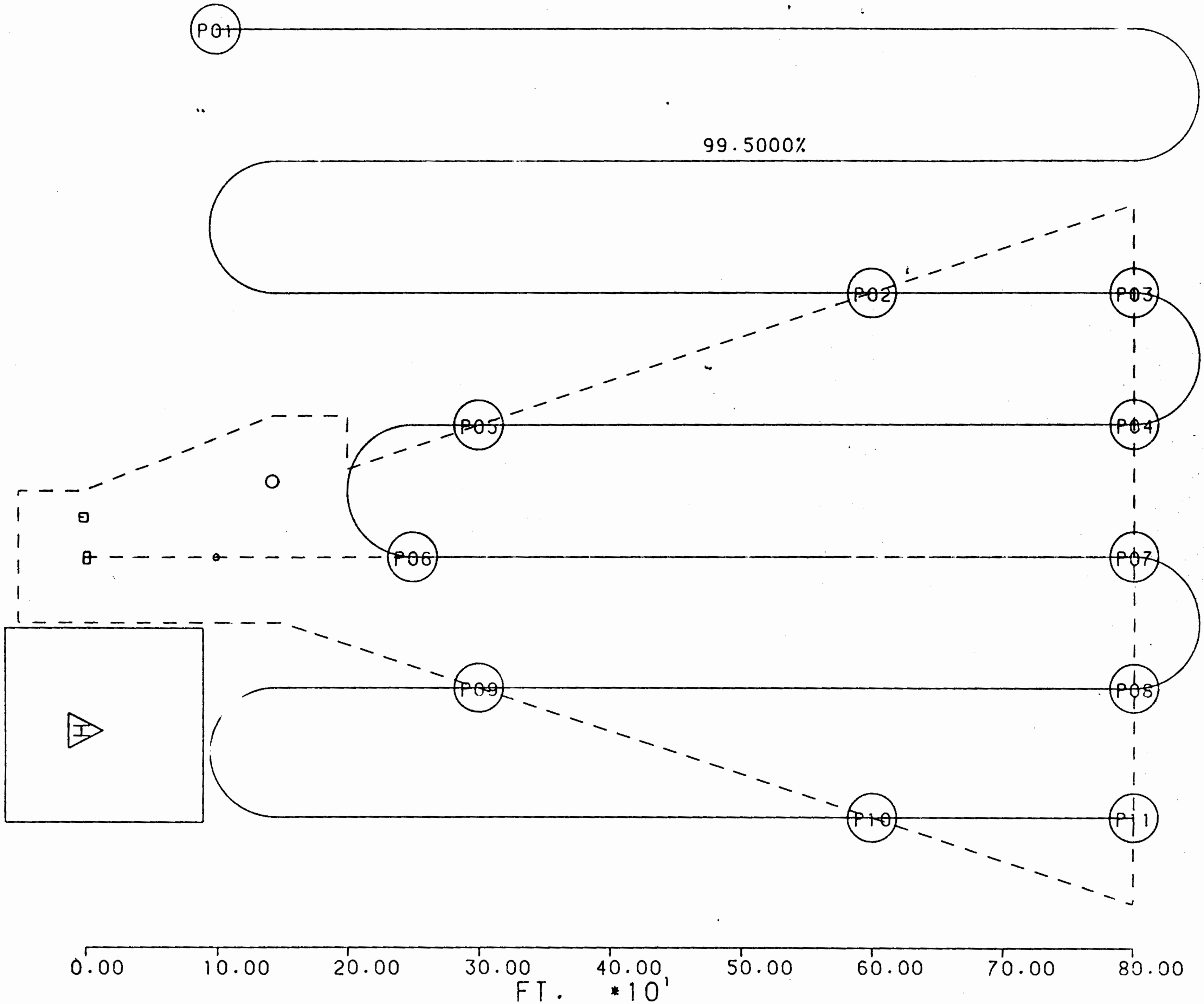
RUN # 11

ELEVATION RUN



APPENDIX C

STATISTICAL DIFFERENCE PLOTS FOR ANALOG AZIMUTH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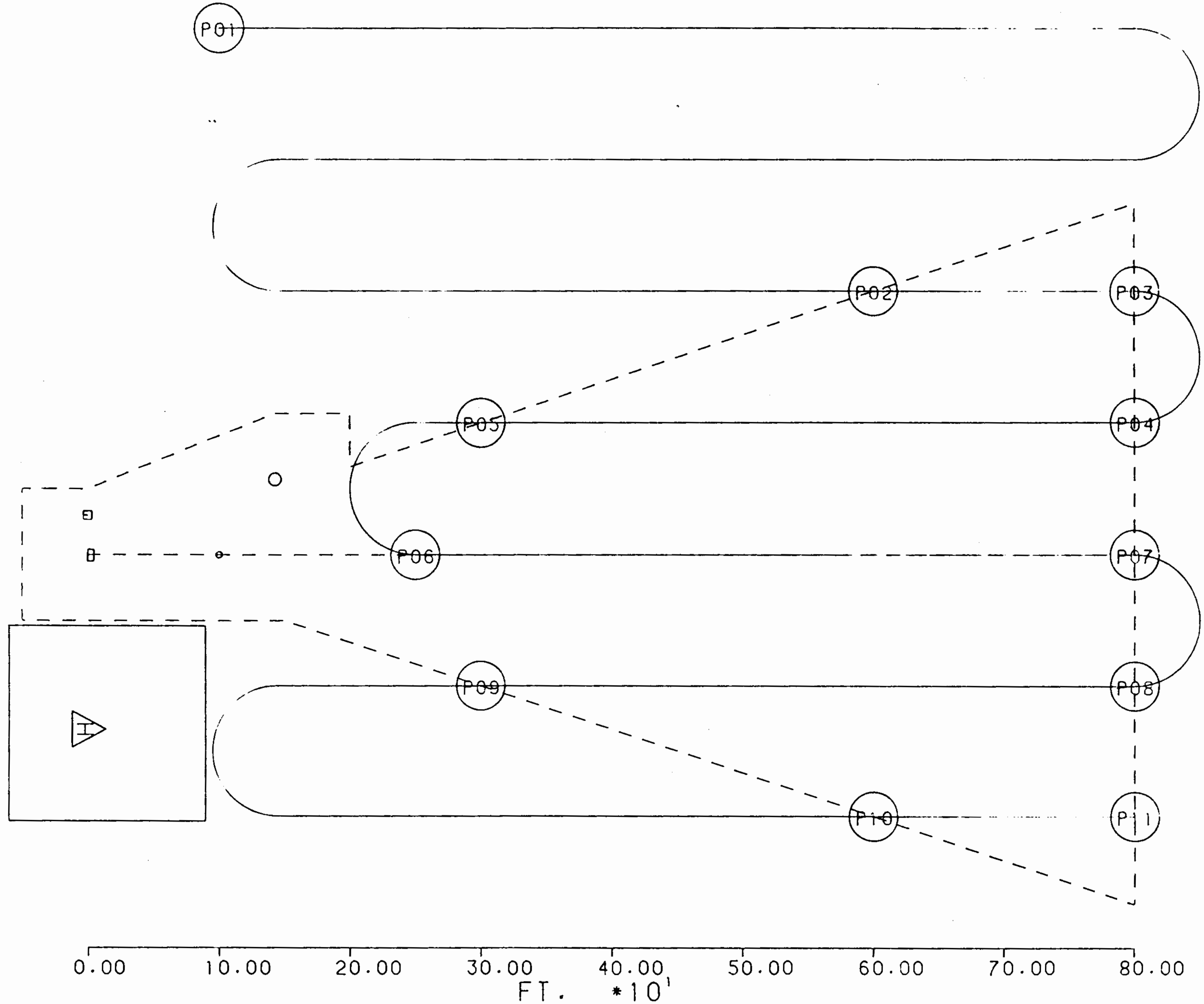
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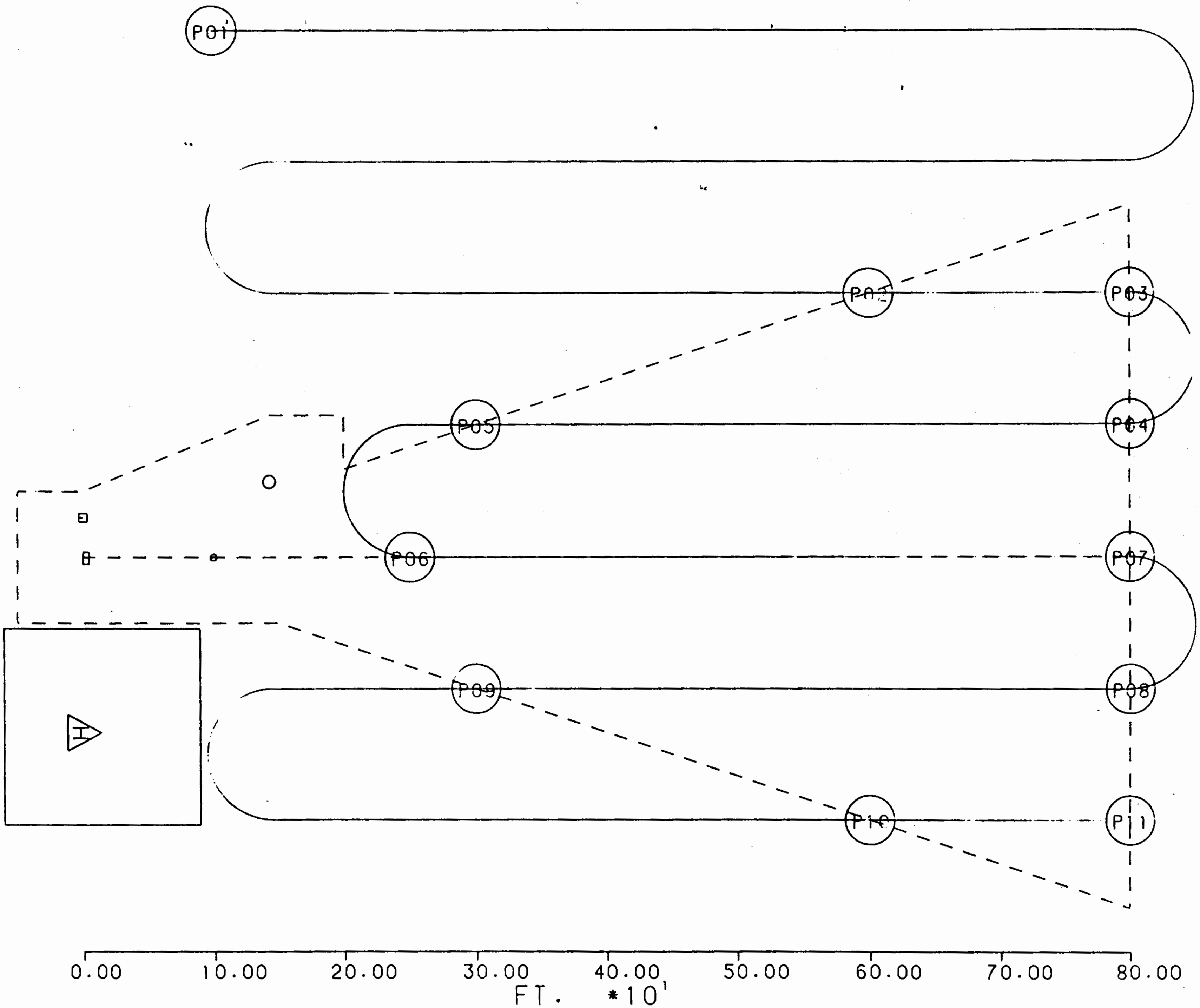
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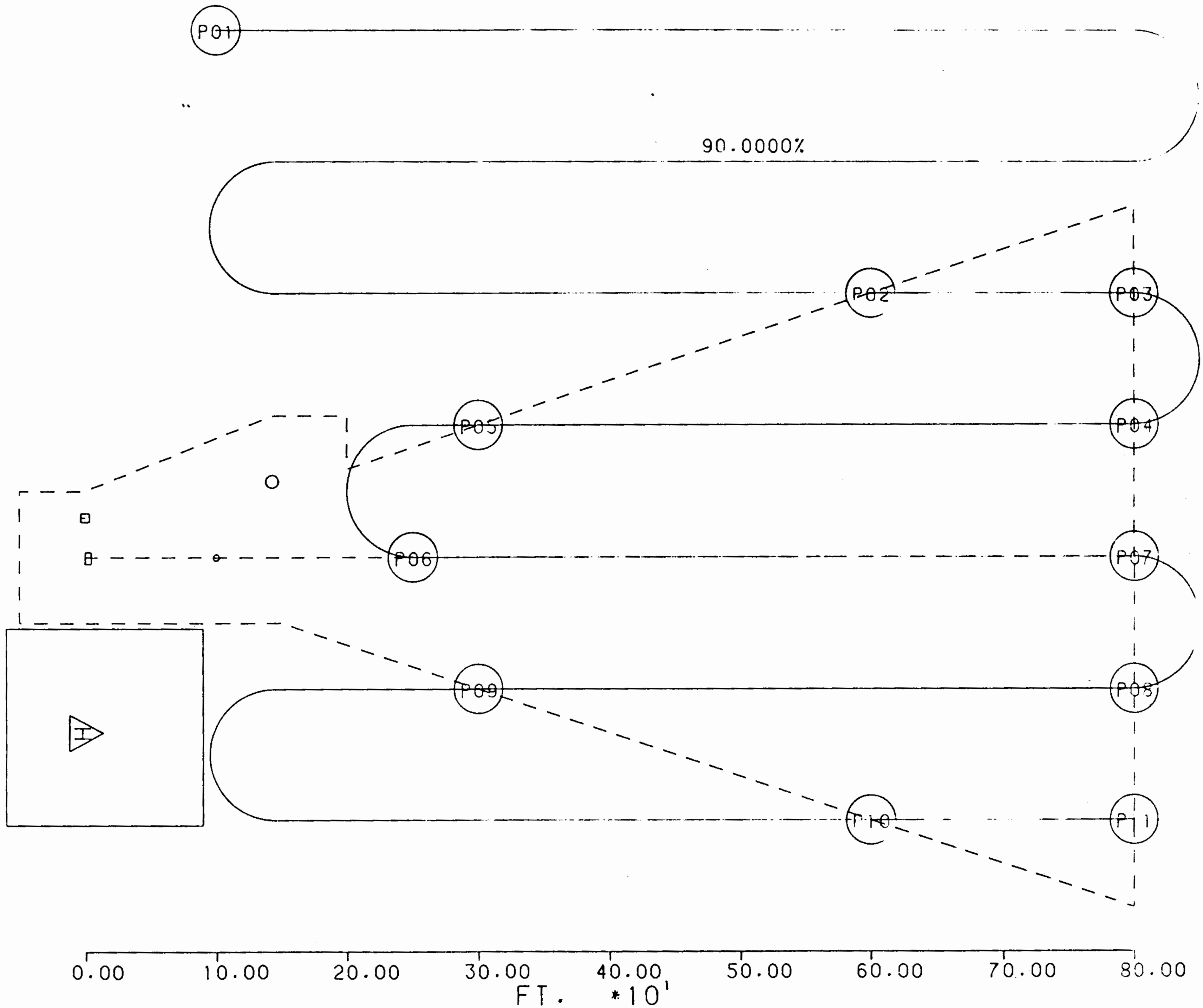
RUN # 4

AZIMUTH RUN



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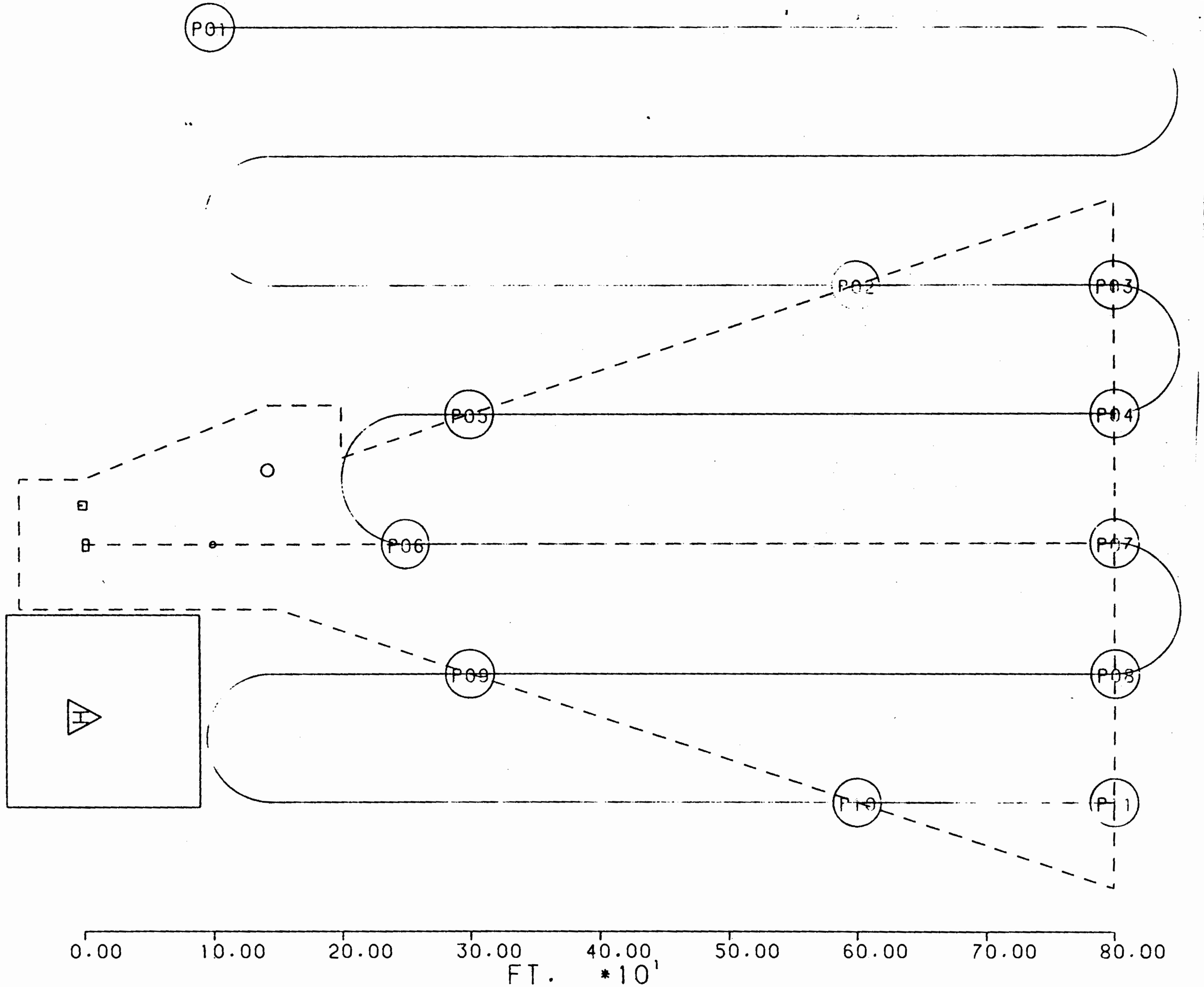
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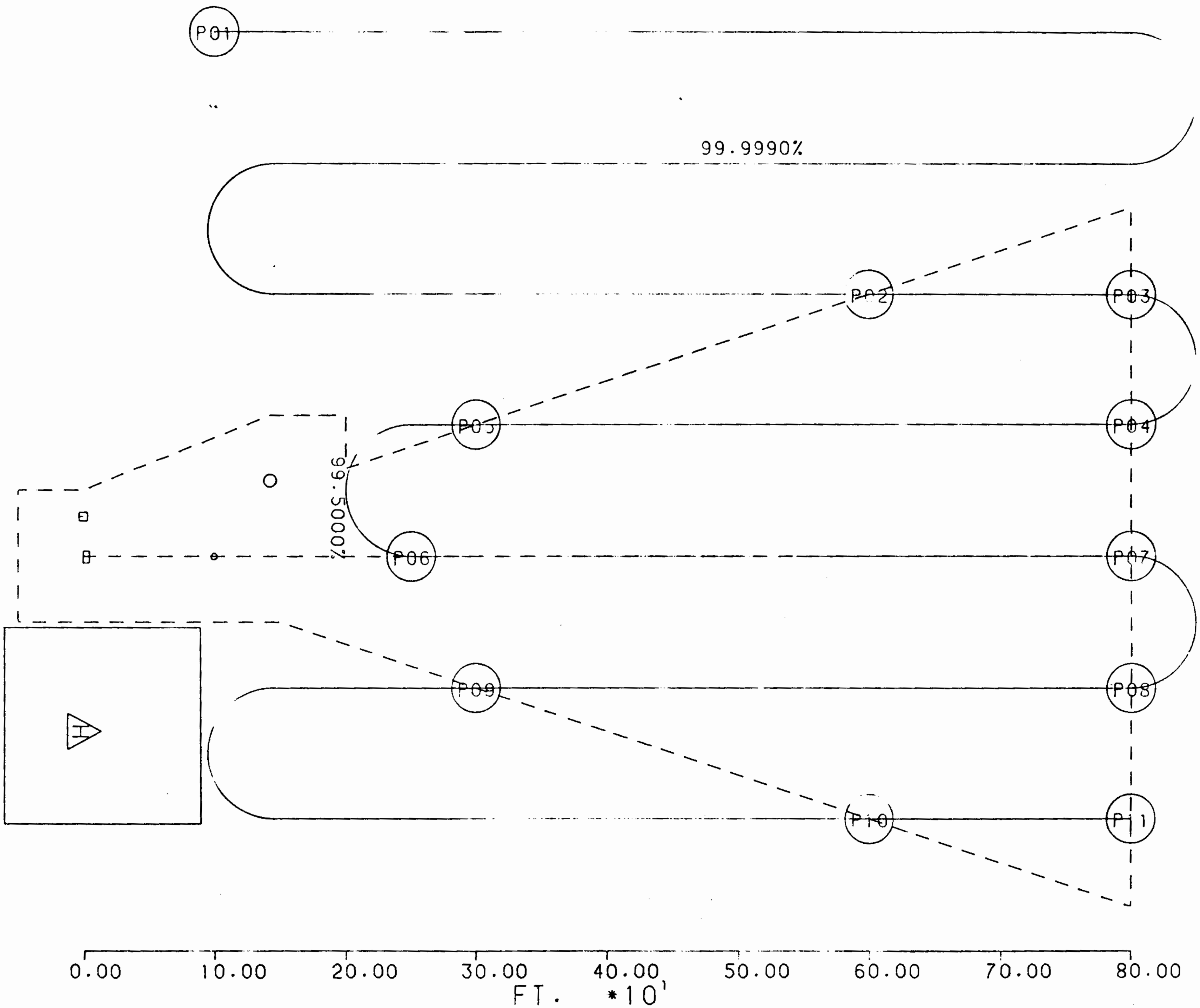
FT. *10

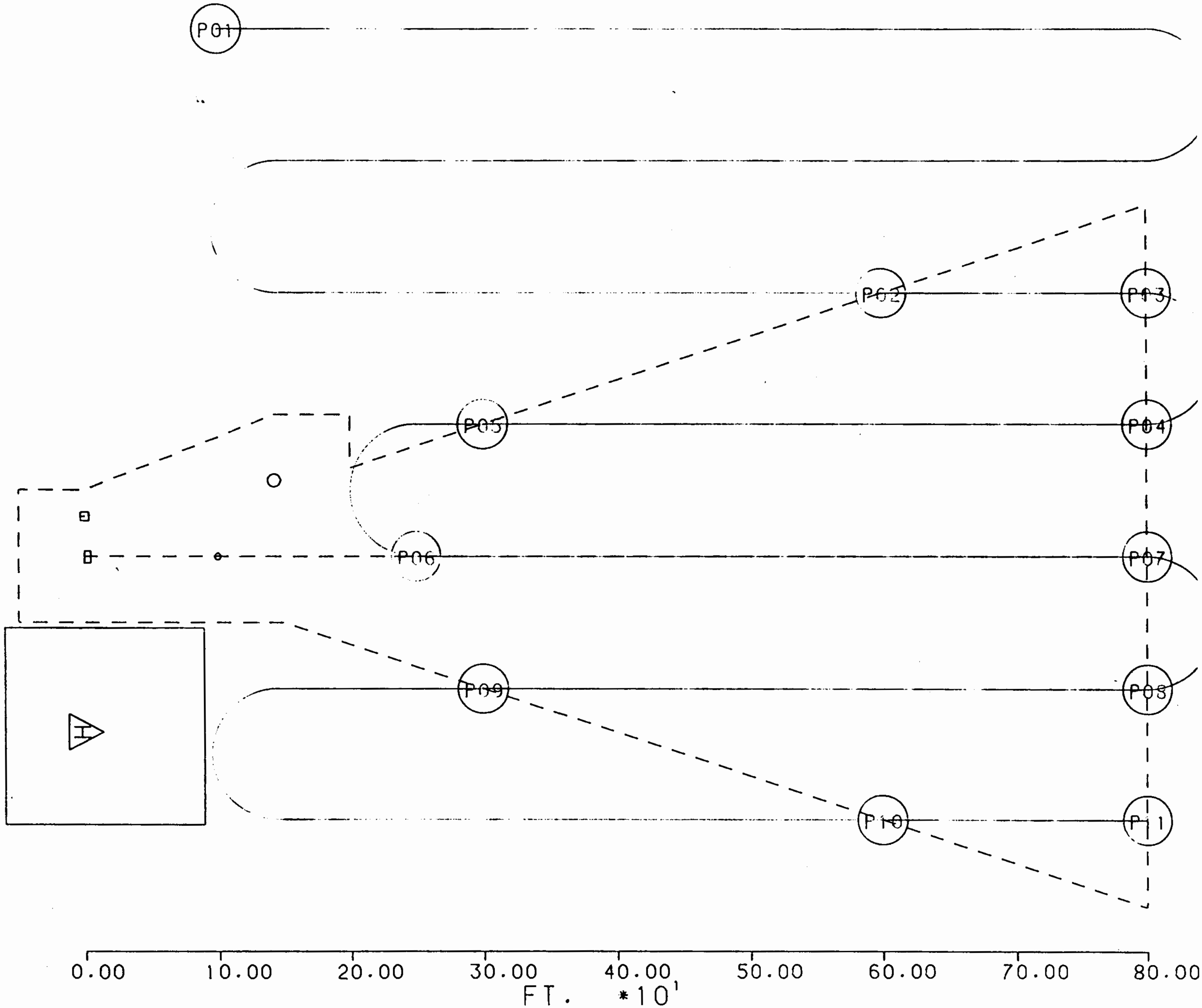
RUN # 7

AZIMUTH RUN



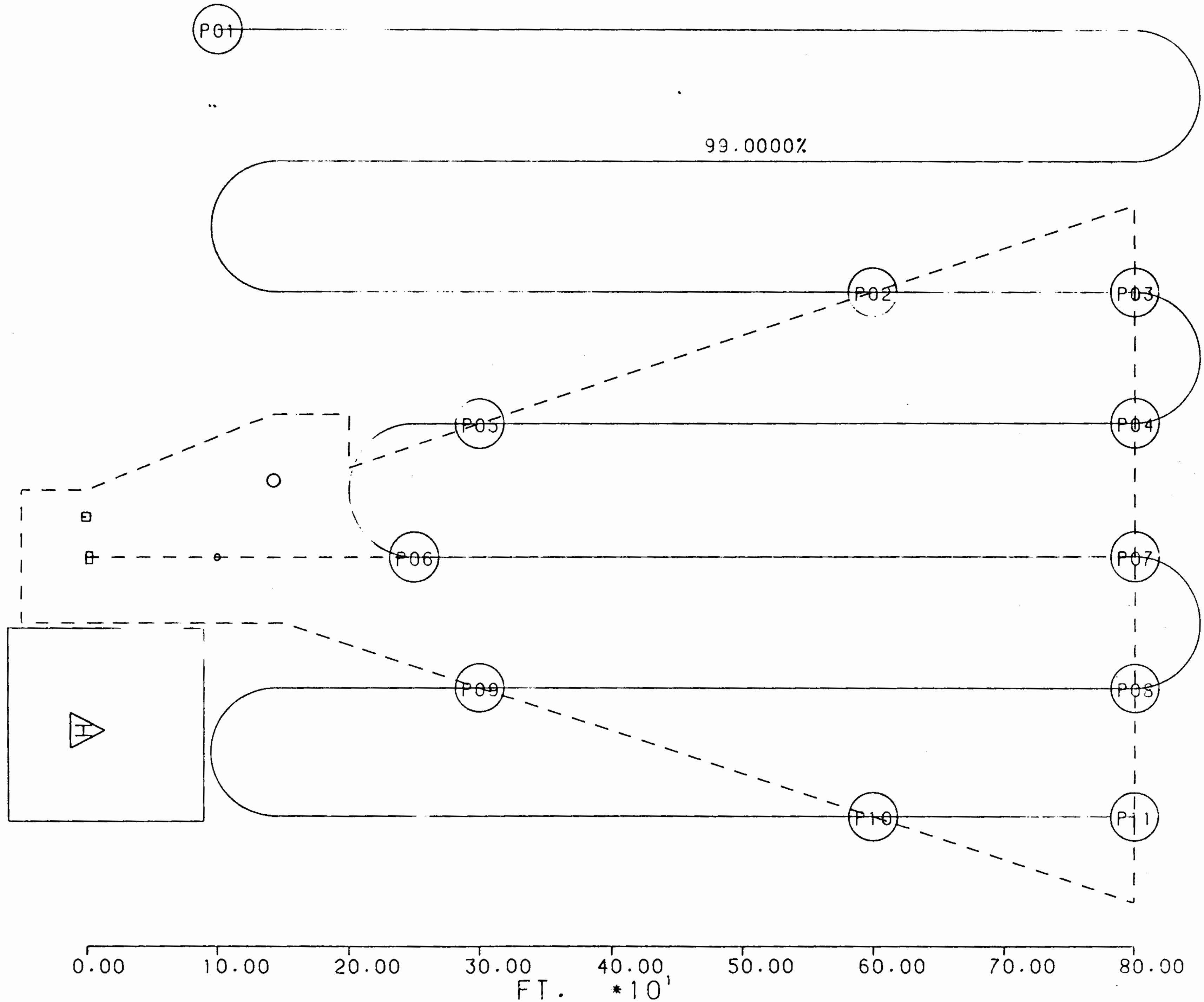
RUN # 9

AZIMUTH RUN



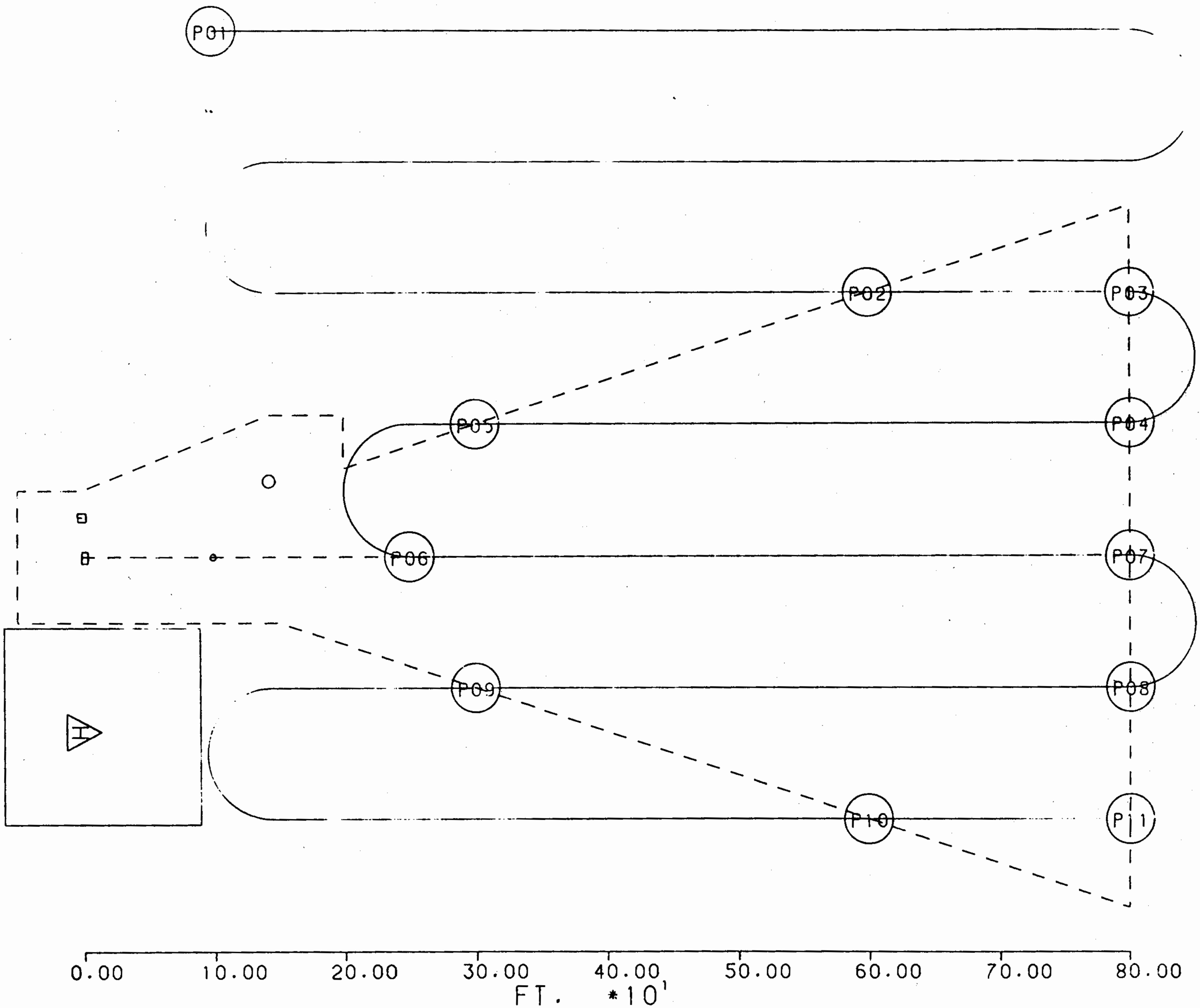
RUN # 10

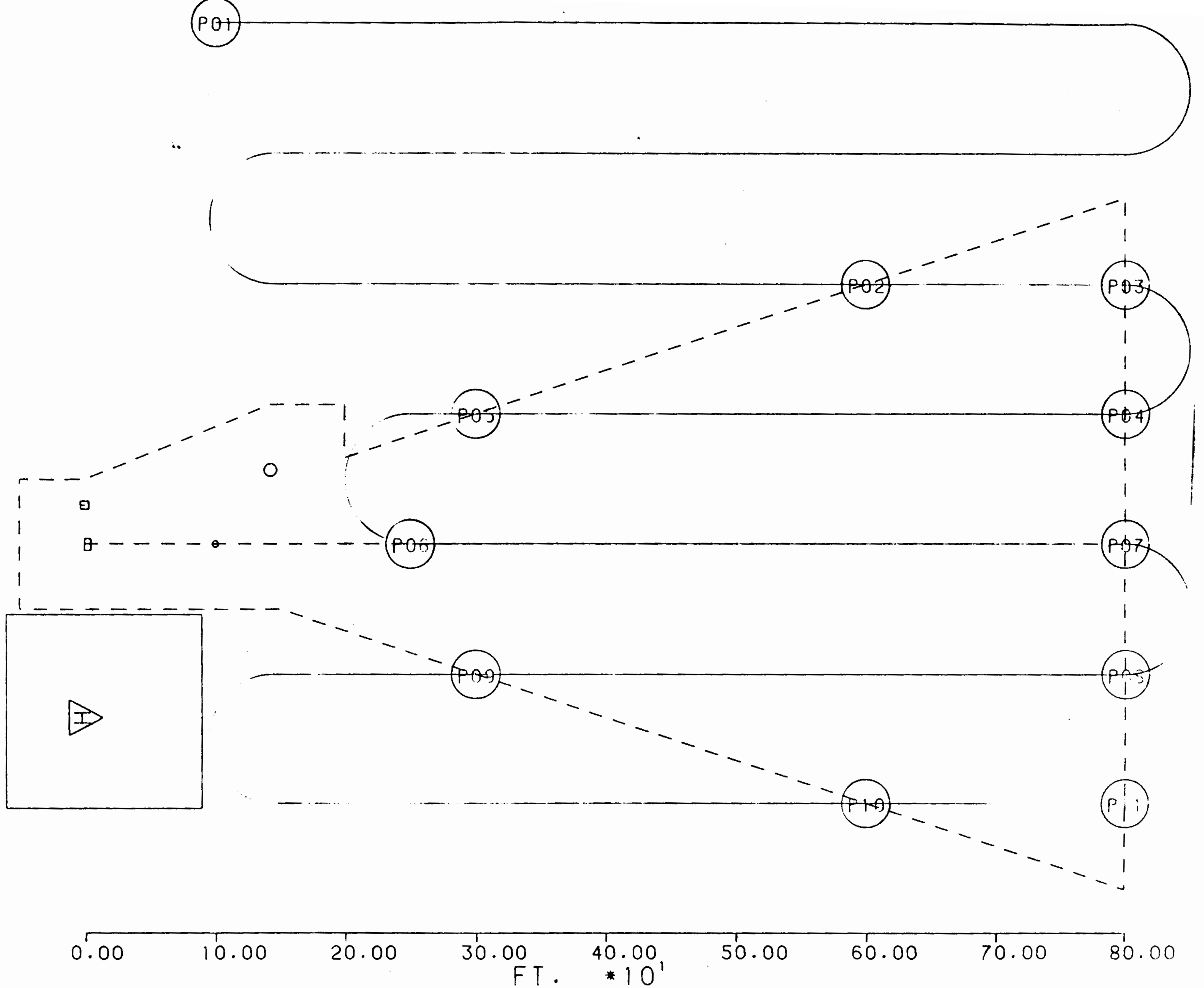
AZIMUTH RUN



RUN # 11

AZIMUTH RUN

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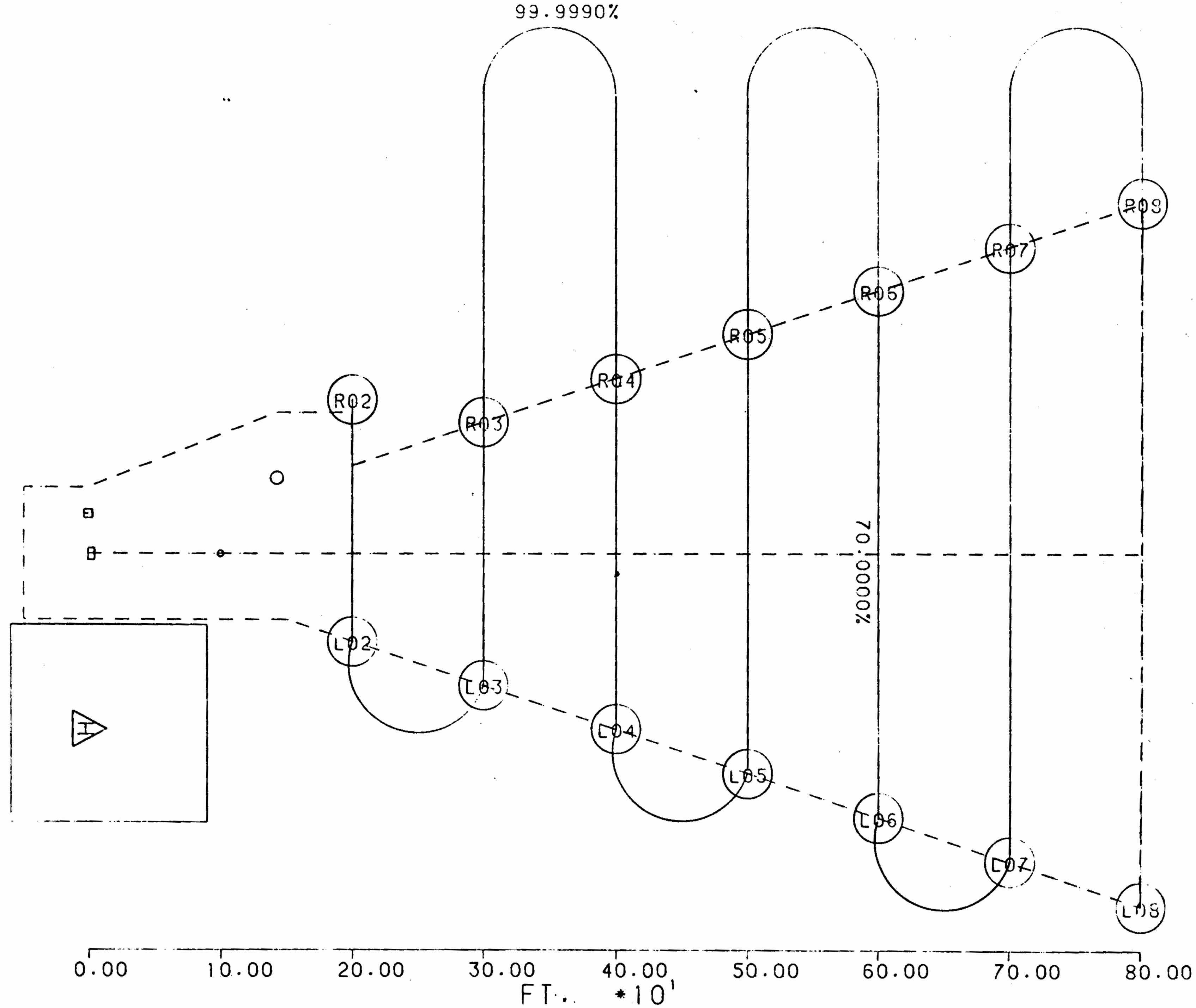
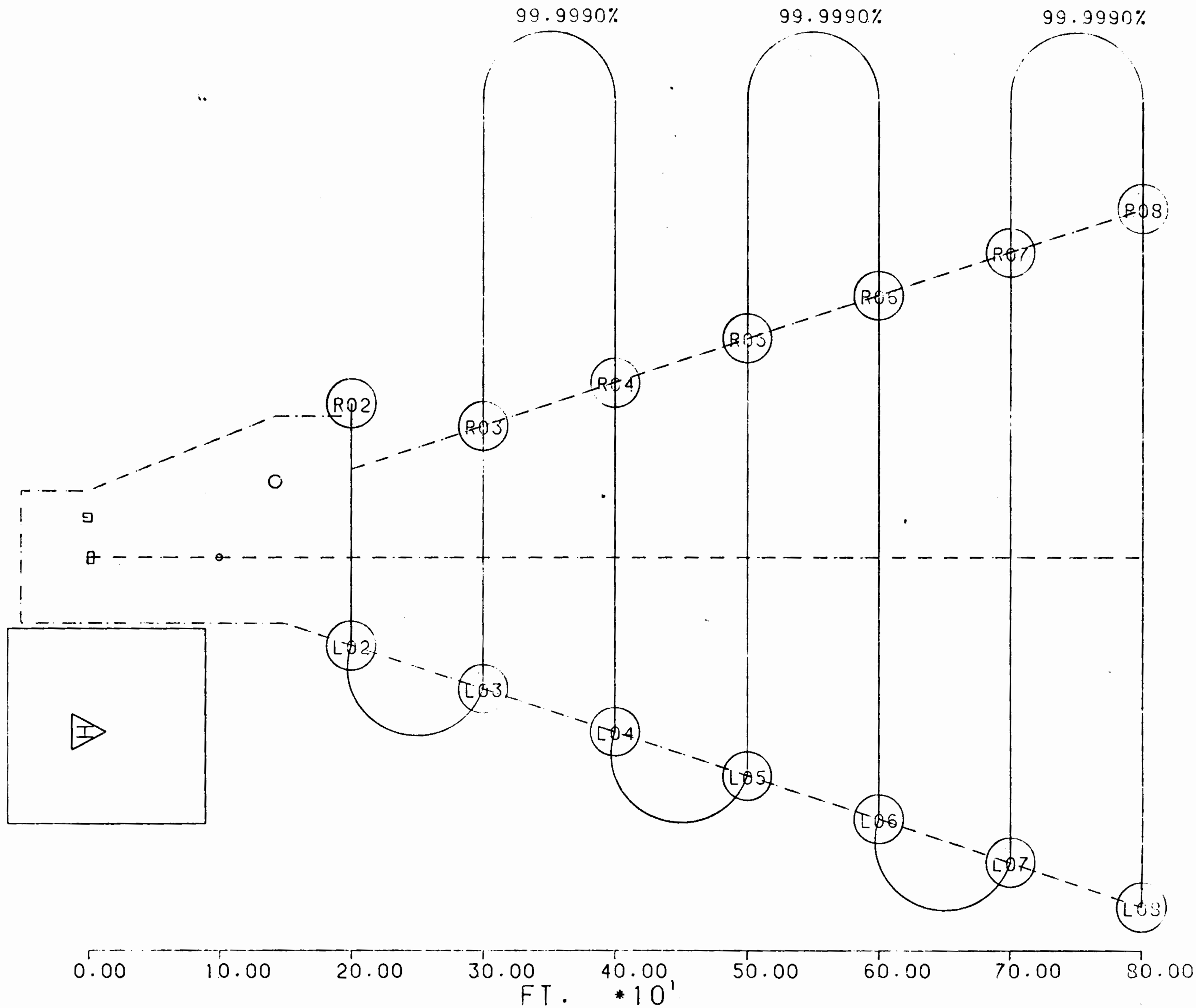
60.00
70.00
80.00
FT. *10¹

RUN # 2

AZIMUTH RUN



AZIMUTH RUN


99.9990%
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R04
R05
R06
R07
R08
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L03
L04
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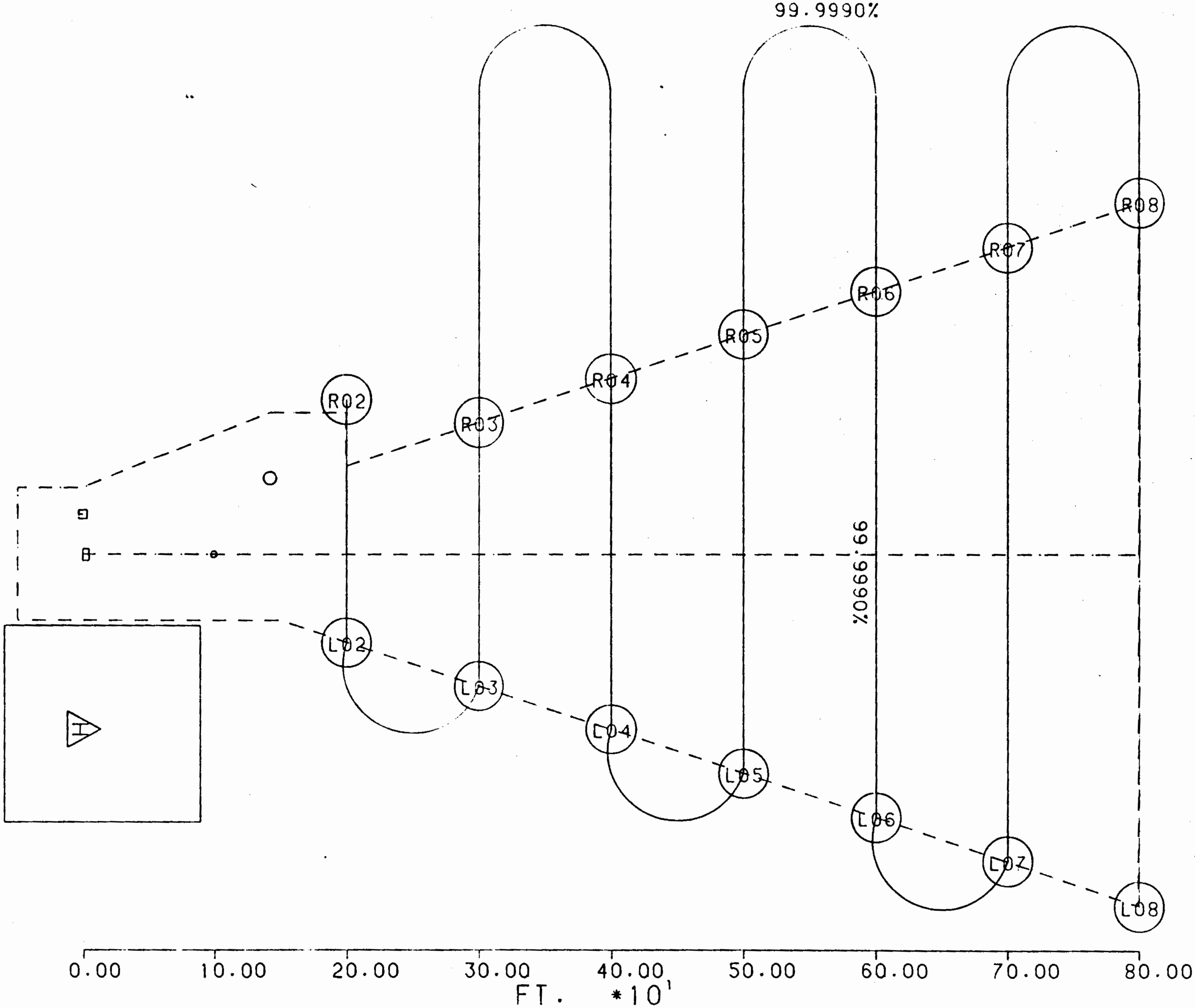
L06
L07
L08
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
FT. *10'

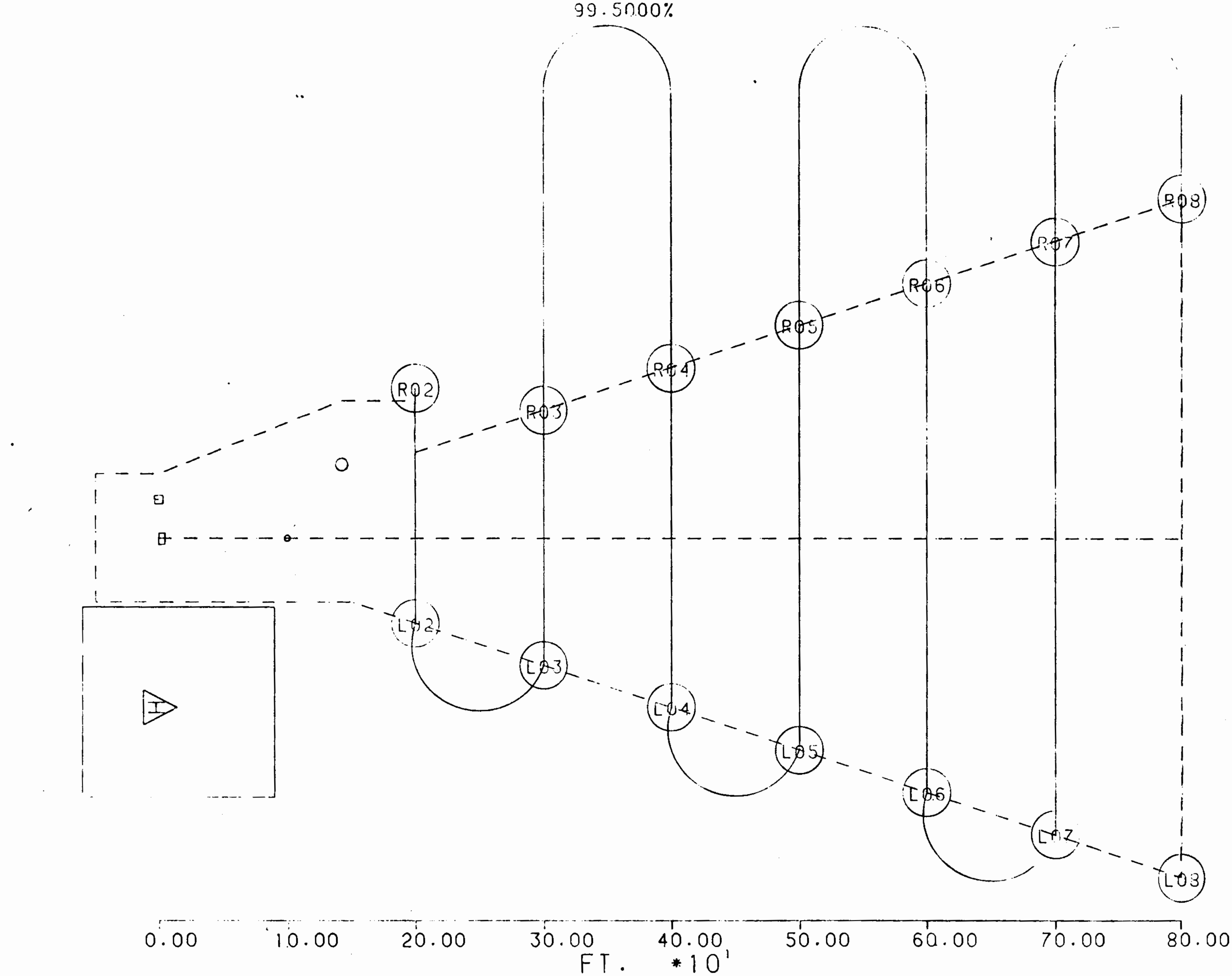
RUN # 6

AZIMUTH RUN



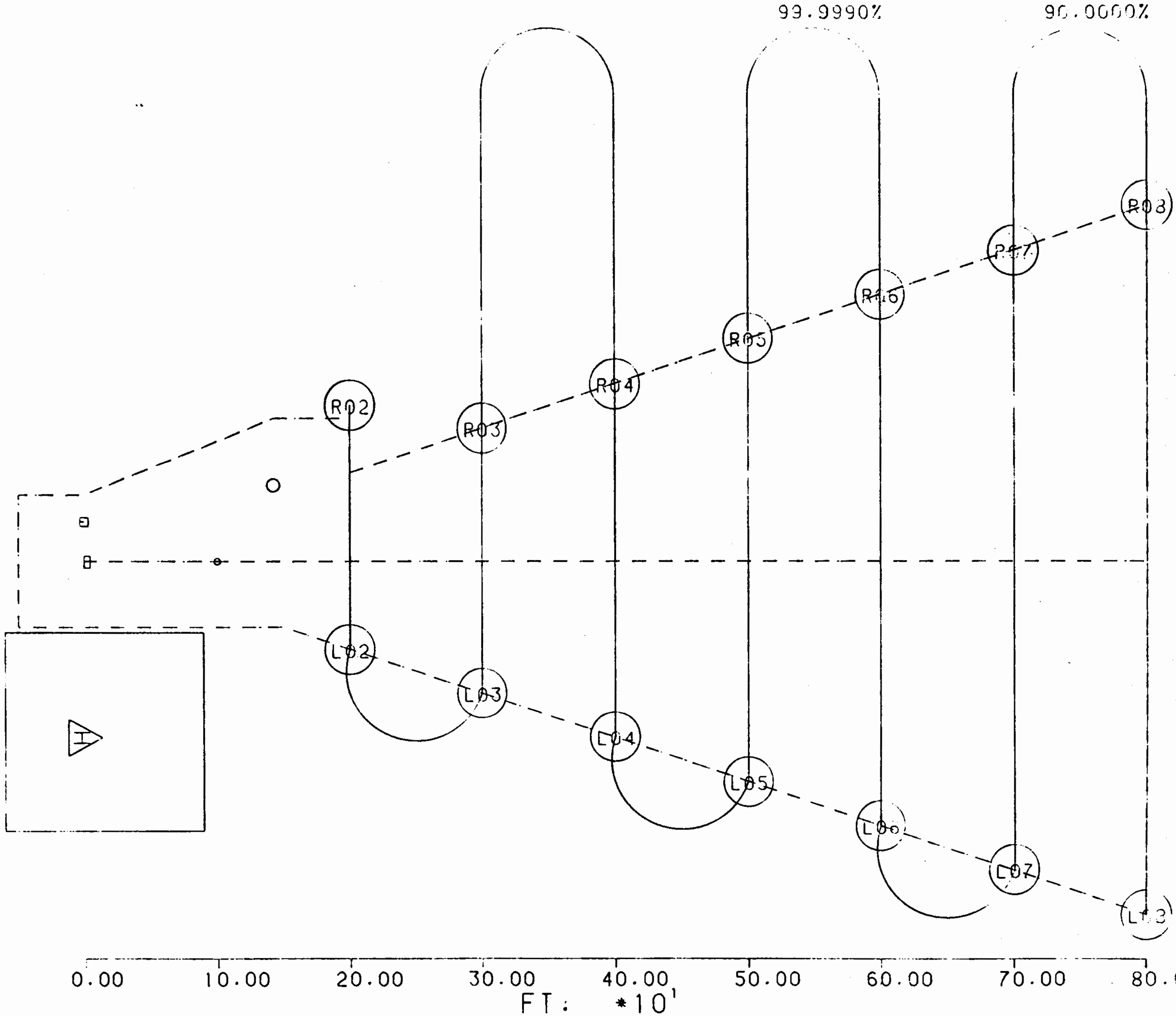
RUN # 9

AZIMUTH RUN



RUN # 10

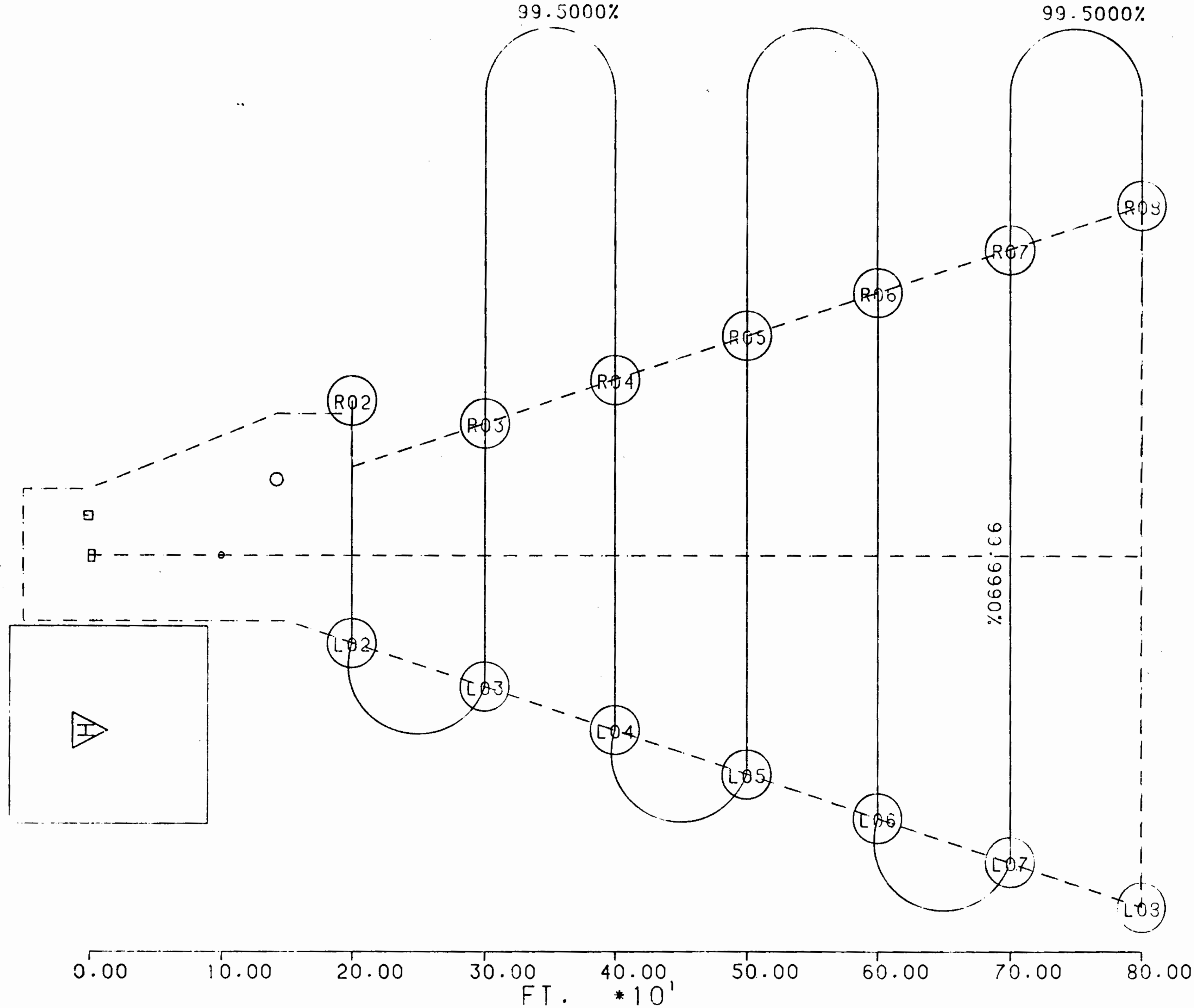
AZIMUTH RUN



C-15

RUN # 12

AZIMUTH RUN



APPENDIX D

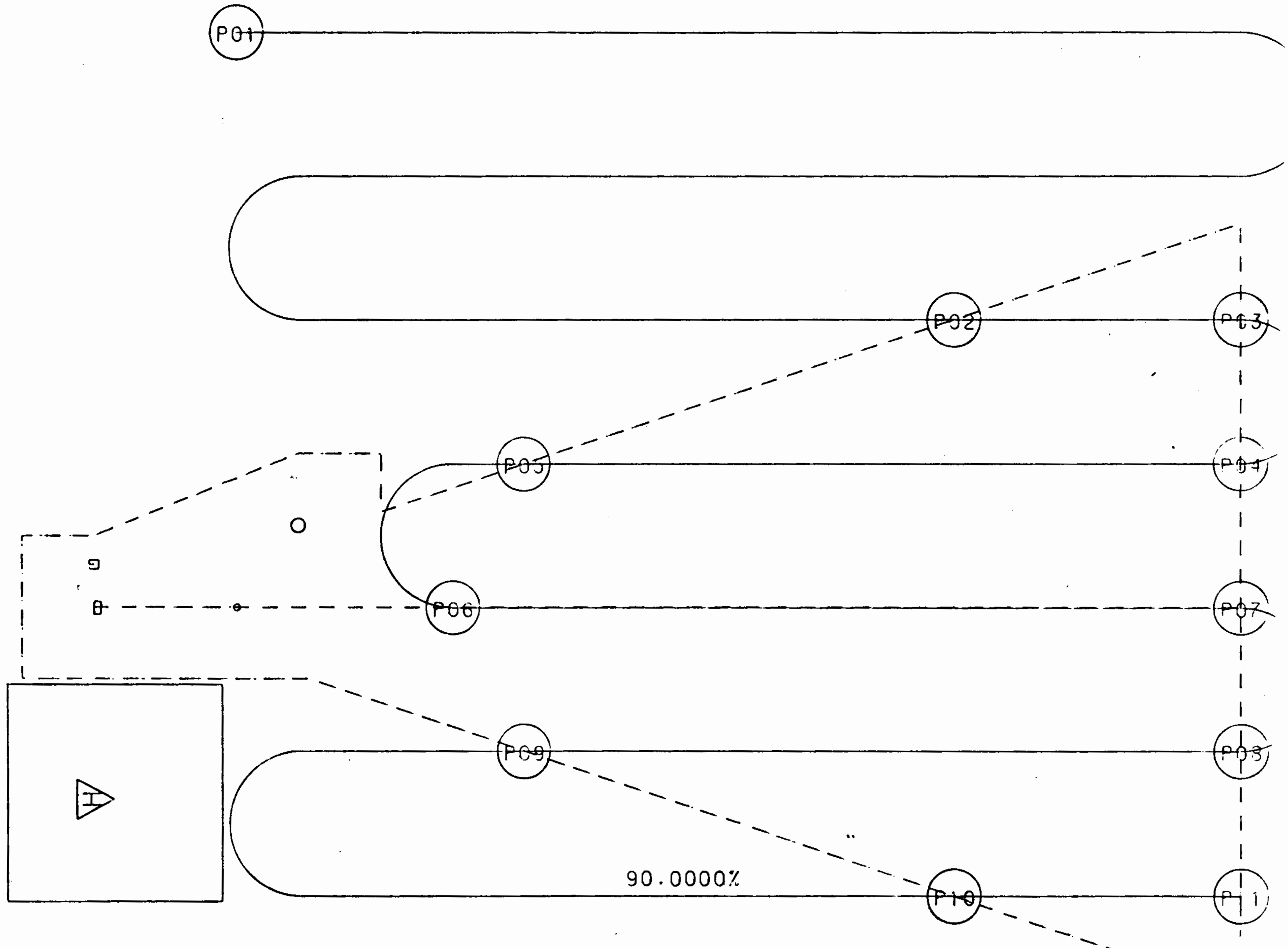
STATISTICAL DIFFERENCE PLOTS FOR ANALOG ELEVATION

DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N J 08405

CRITICAL AREA FLIGHT 6: F STATISTICS ANALOG EL

RUN # 1

ELEVATION RUN

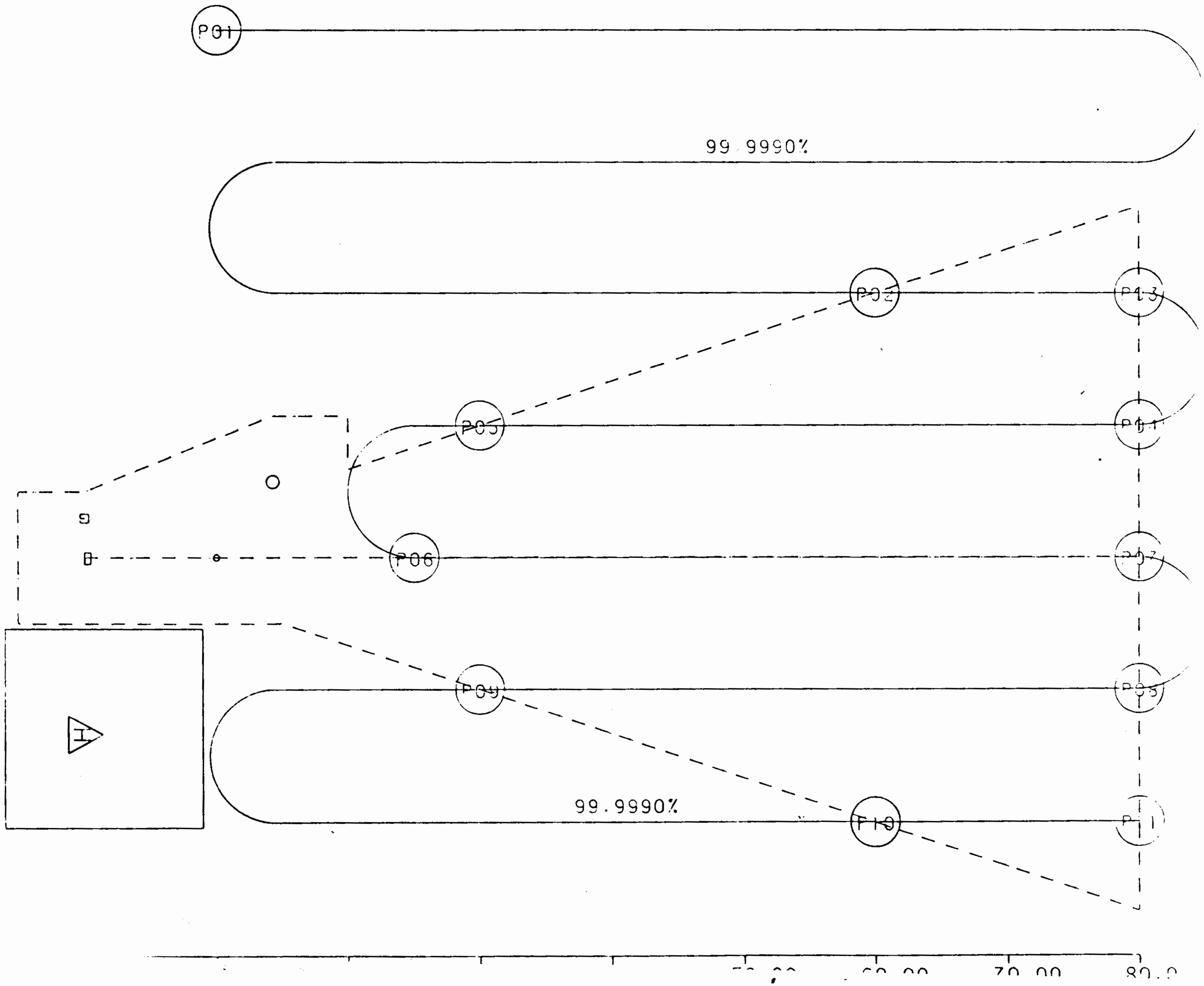


DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N J 08405

CRITICAL AREA FLIGHT 6 F STATISTICS ANALOG EL

RUN # 2

ELEVATION RUN

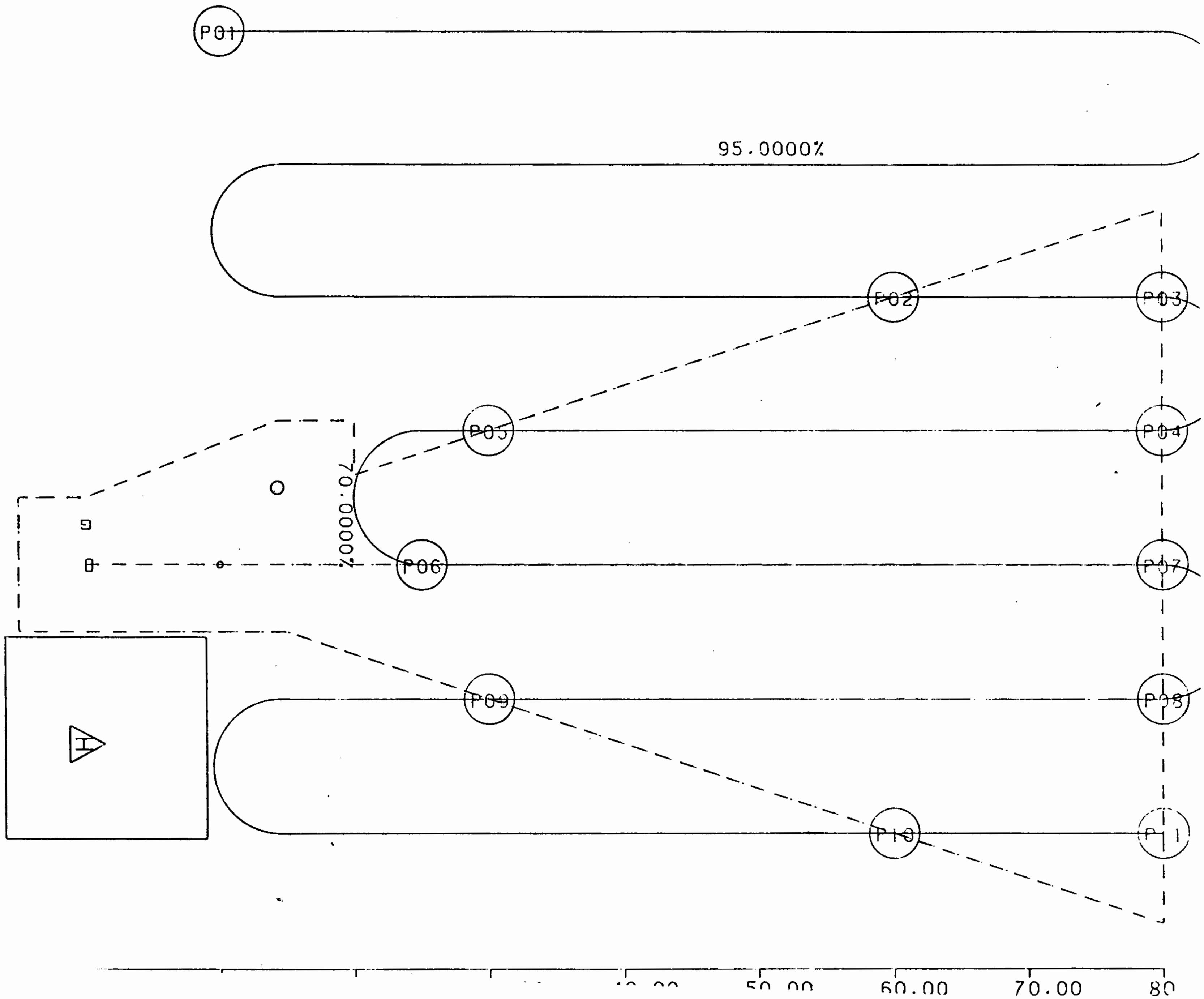


DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N J 08405

CRITICAL AREA FLIGHT 6: F STATISTICS ANALOG EL

RUN # 4

ELEVATION RUN

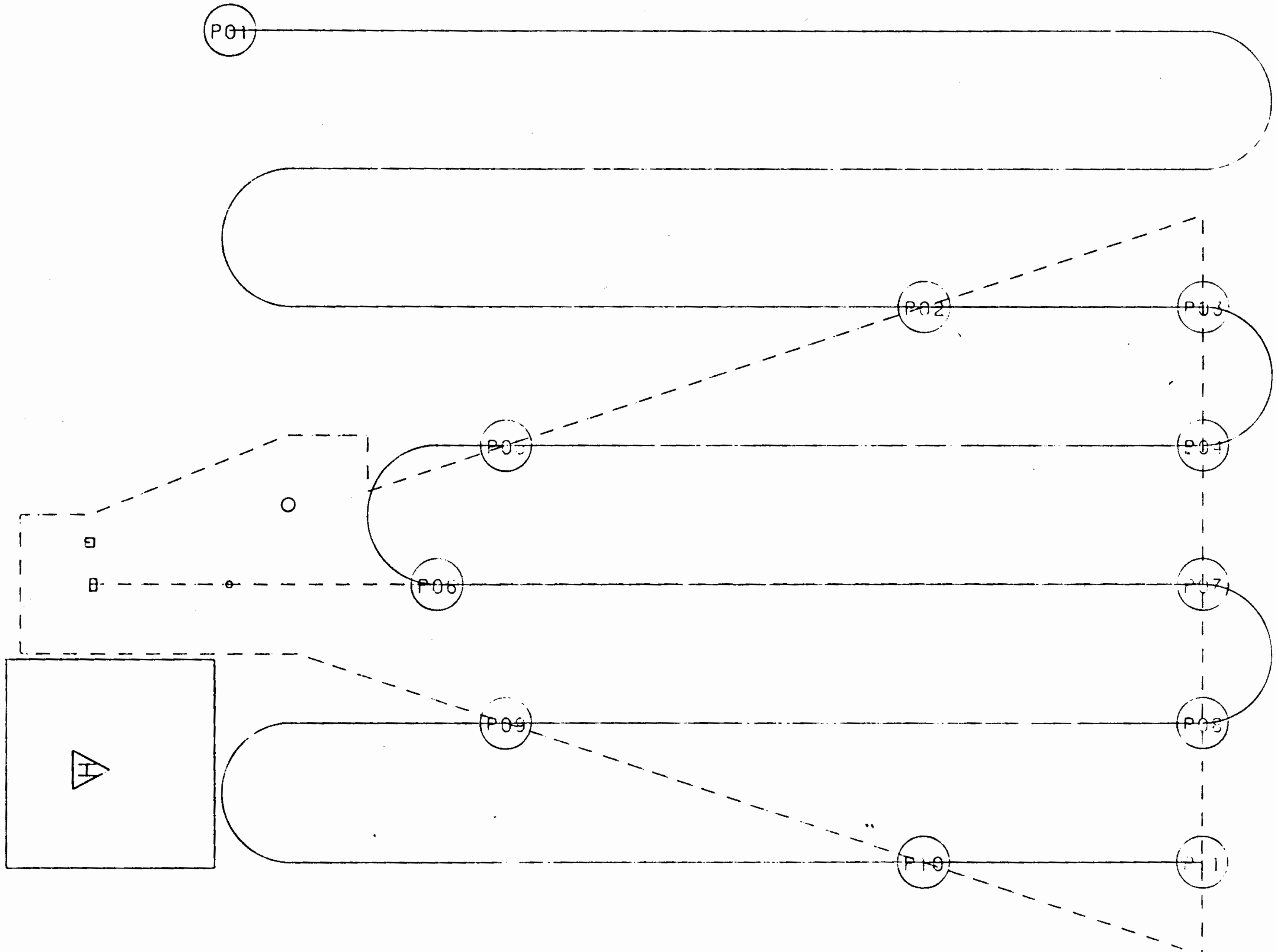


DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N J 08405

CRITICAL AREA FLIGHT 6: F STATISTICS ANALOG EL

RUN # 5

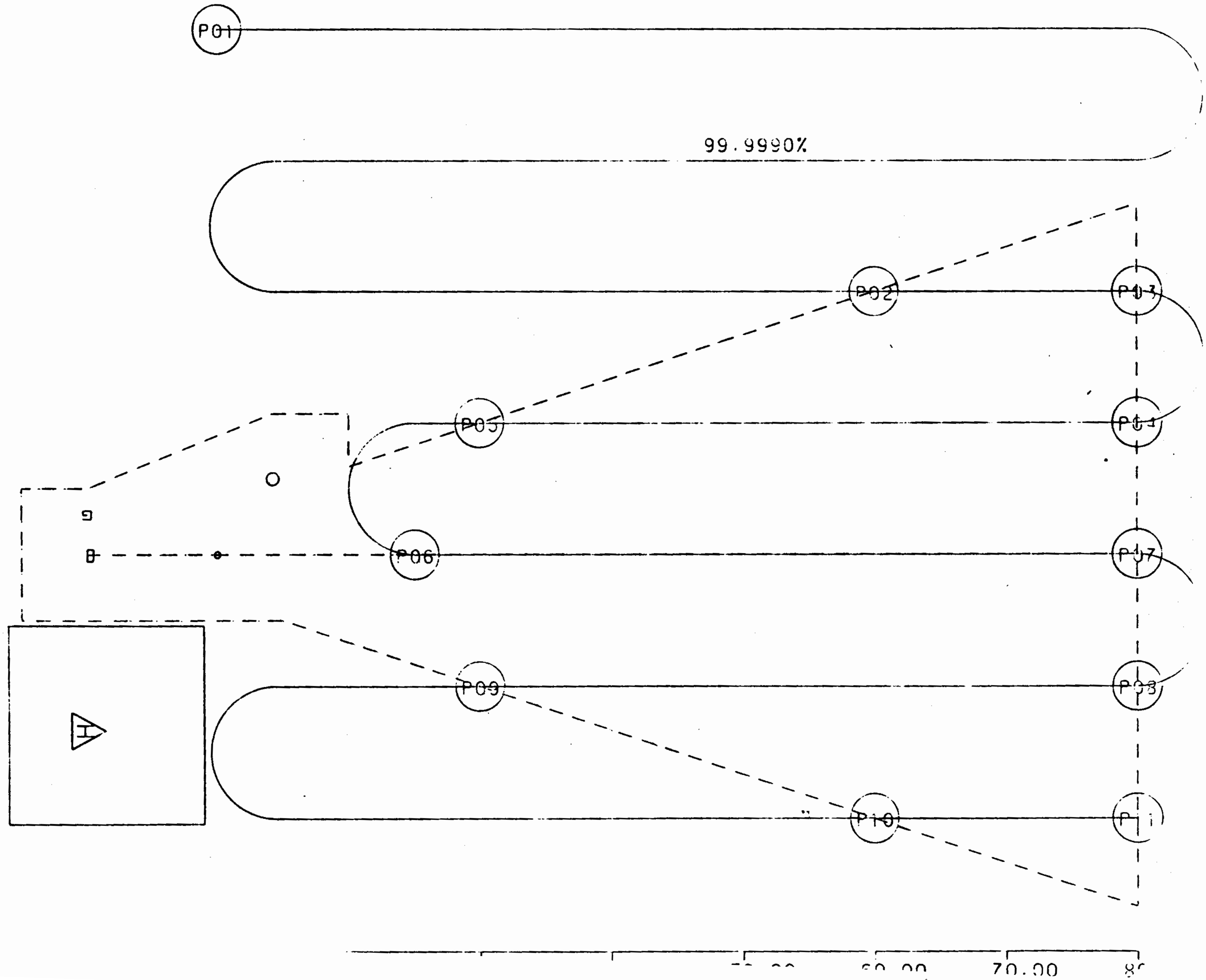
ELEVATION RUN



CRITICAL AREA FLIGHT 6 F STATISTICS ANALOG EL

RUN # 6

ELEVATION RUN

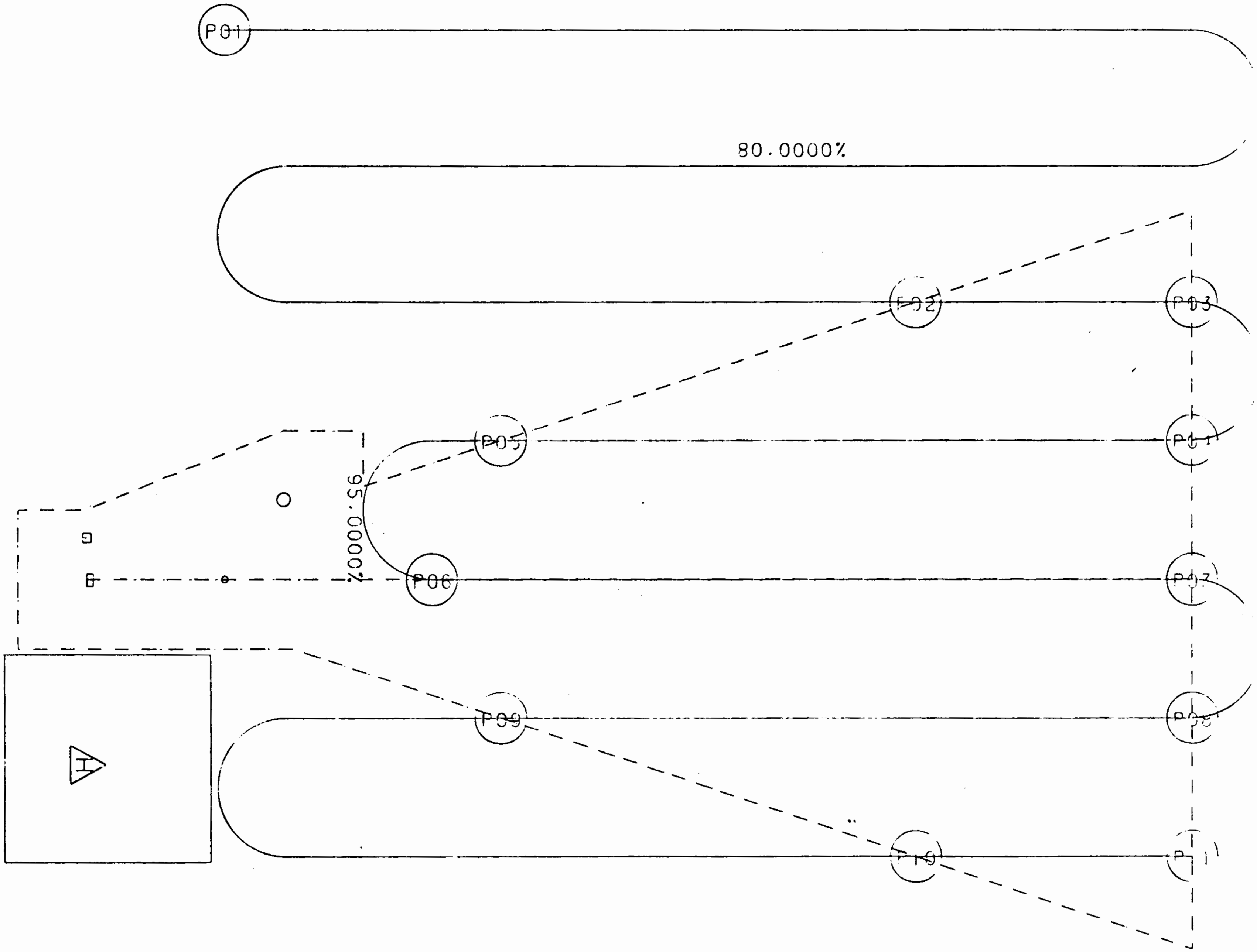


DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N.J. 08405

CRITICAL AREA FLIGHT 6. F STATISTICS ANALOG EL

RUN # 8

ELEVATION RUN



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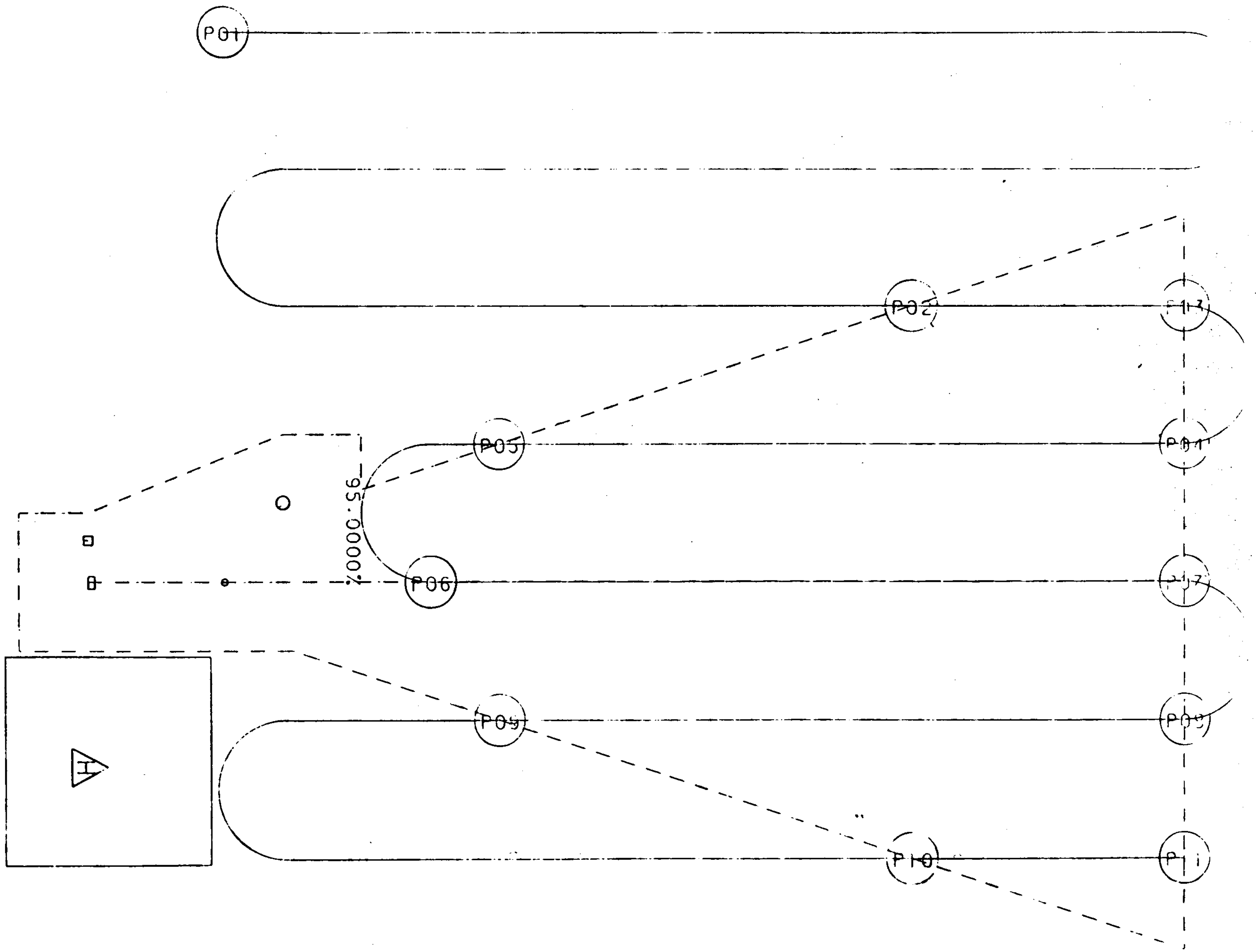
ATLANTIC CITY AIRPORT, N J 08405

CRITICAL AREA FLIGHT 6: F STATISTICS ANALOG EL

RUN # 9

ELEVATION RUN

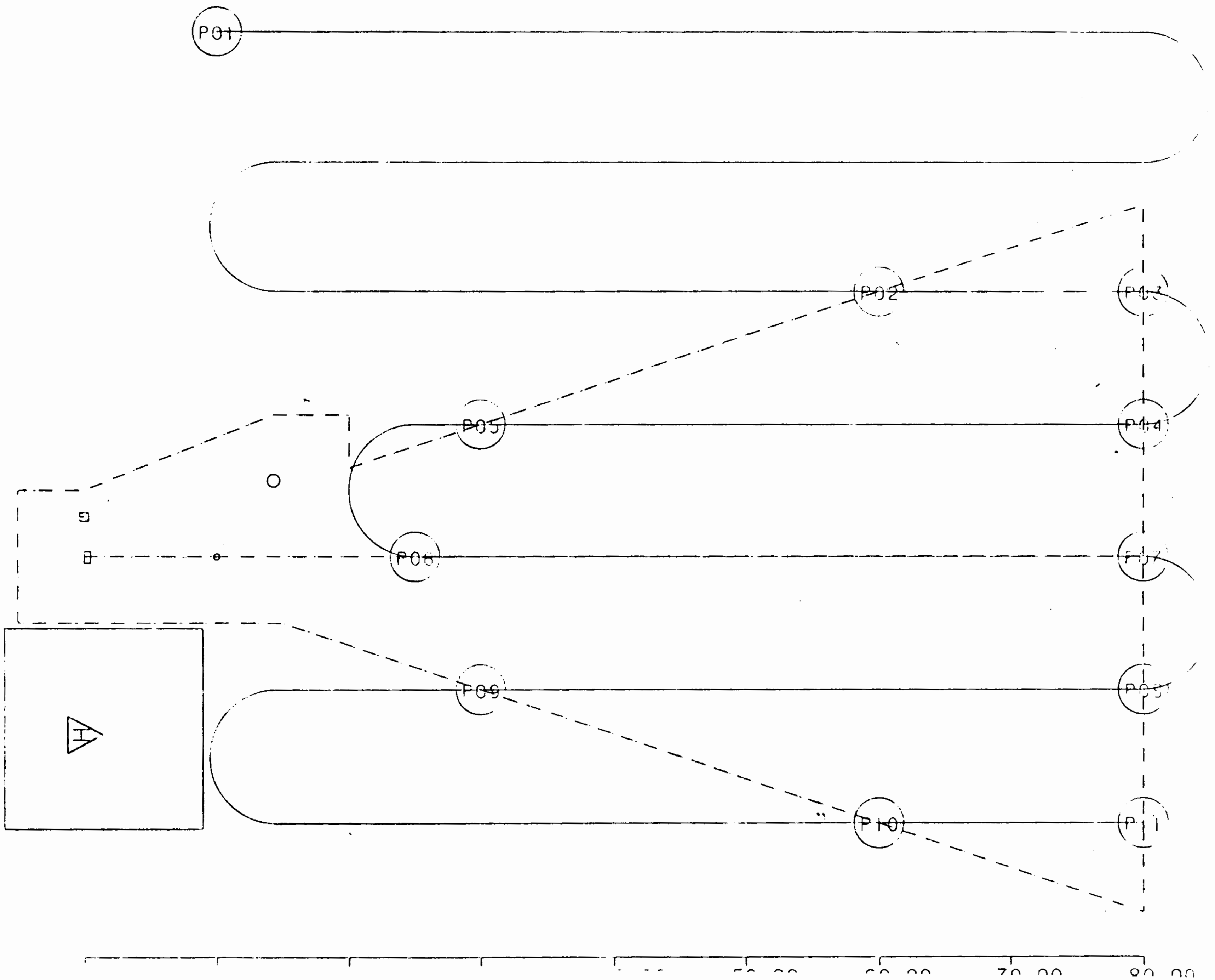


DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N J 08405

CRITICAL AREA FLIGHT 6: F STATISTICS ANALOG EL

RUN # 10

ELEVATION RUN

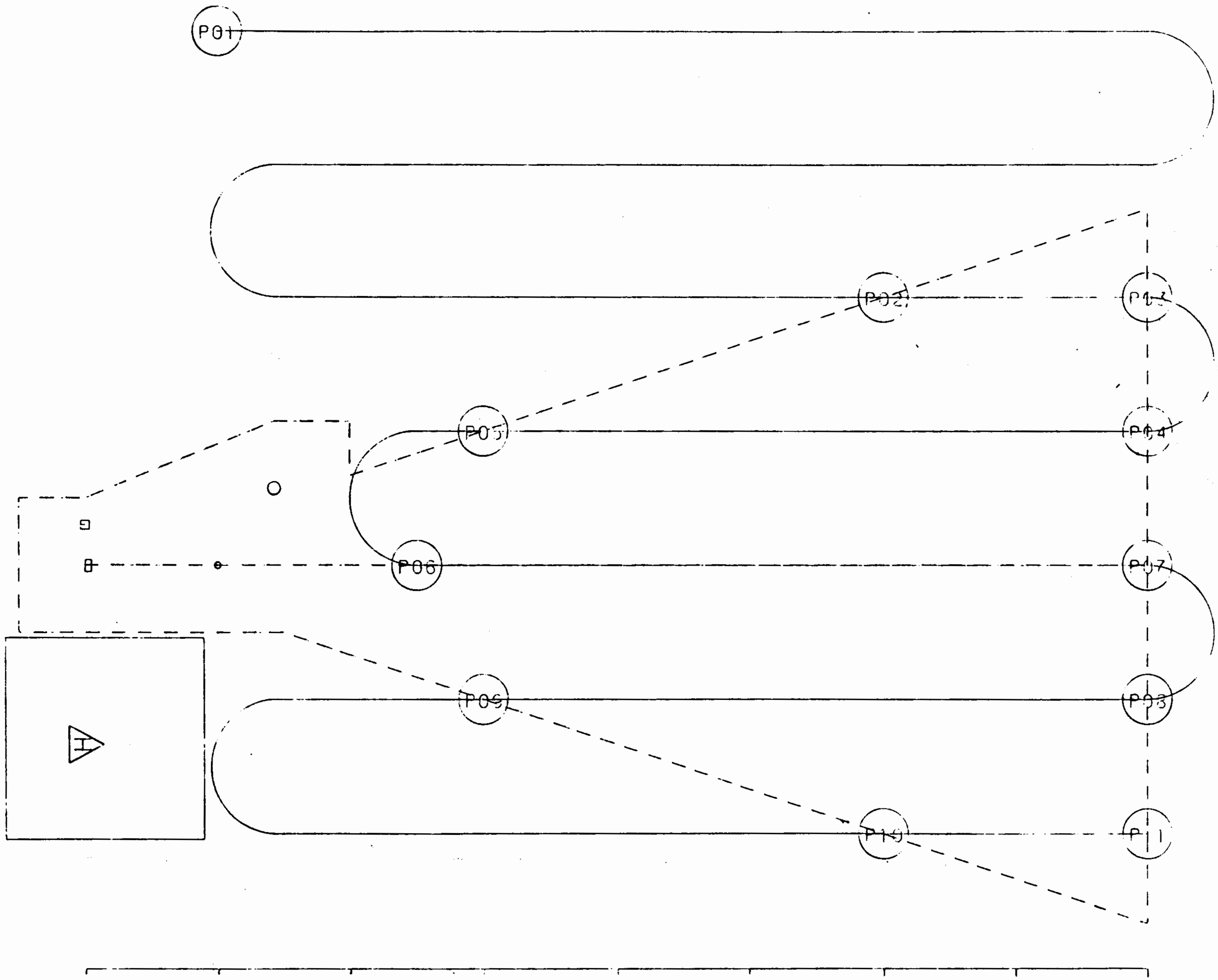


DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N J 08405

CRITICAL AREA FLIGHT 6 F STATISTICS ANALOG EL

RUN # 11

ELEVATION RUN

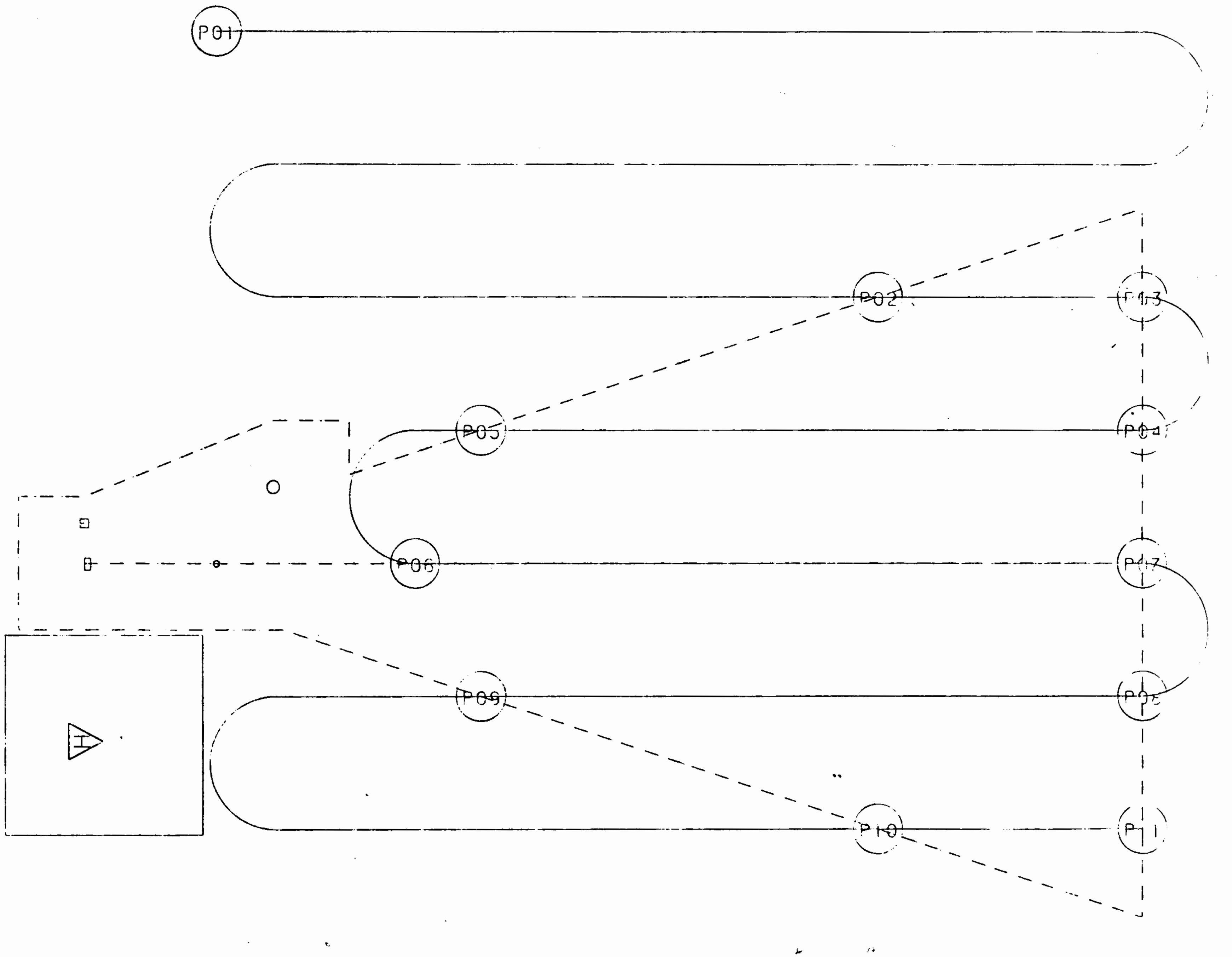


DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N J 08405

CRITICAL AREA FLIGHT 6: F STATISTICS ANALOG EL

RUN # 12

ELEVATION RUN

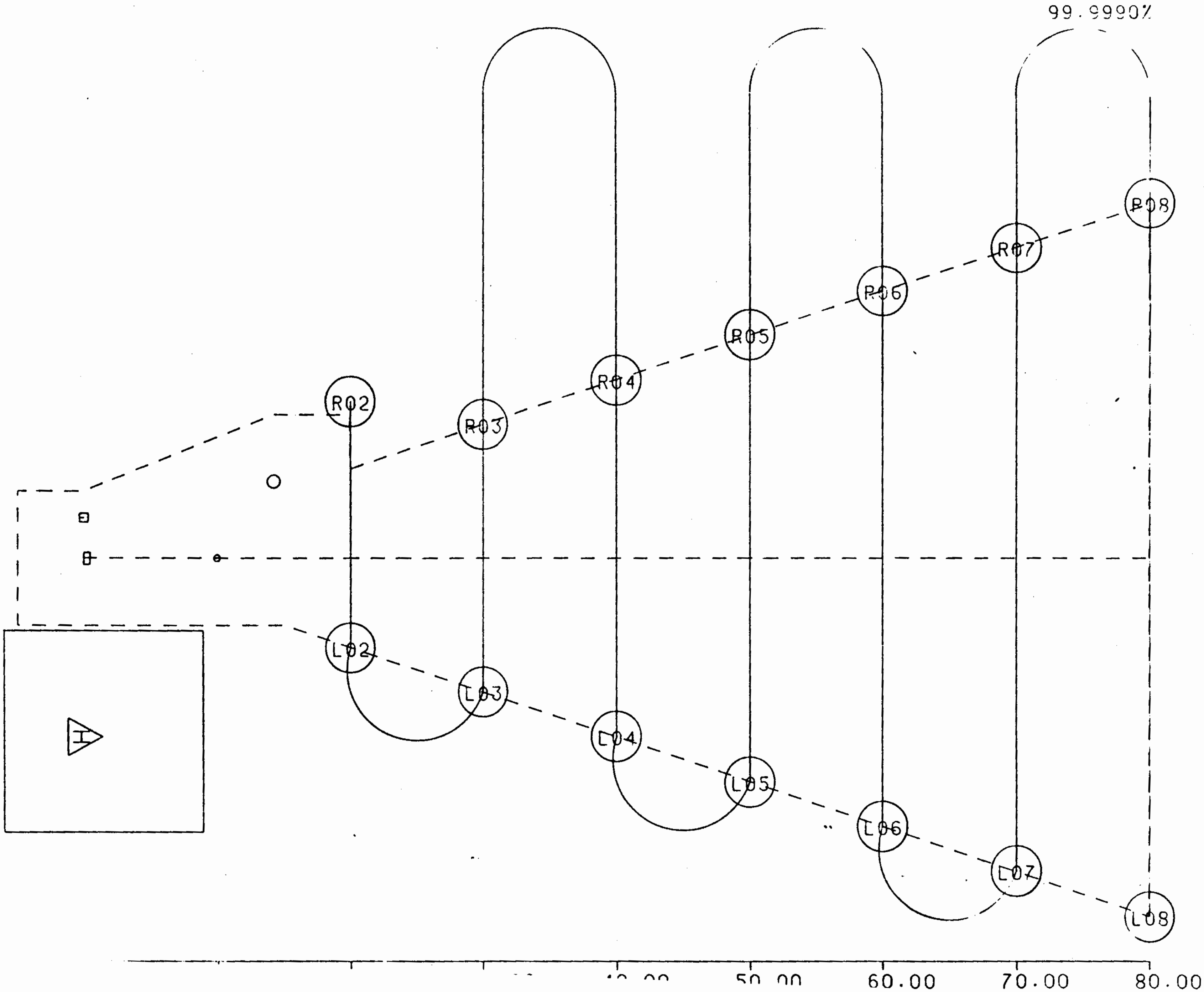


DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N J 08405

CRITICAL AREA FLIGHT 7: F STATISTICS ANALOG EL

RUN # 3

ELEVATION RUN

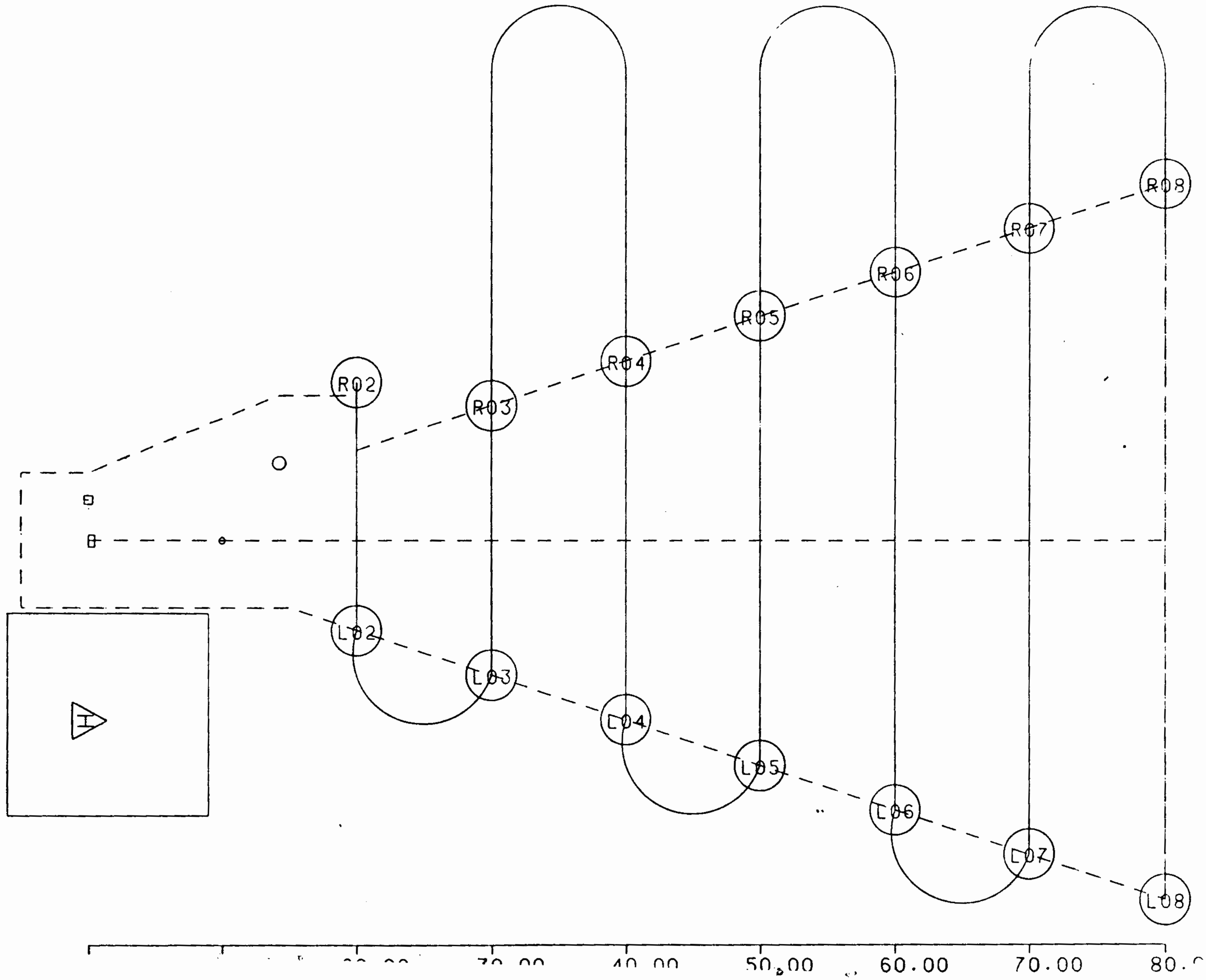


DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N J 08405

CRITICAL AREA FLIGHT 7: F STATISTICS ANALOG EL

RUN # 4

ELEVATION RUN

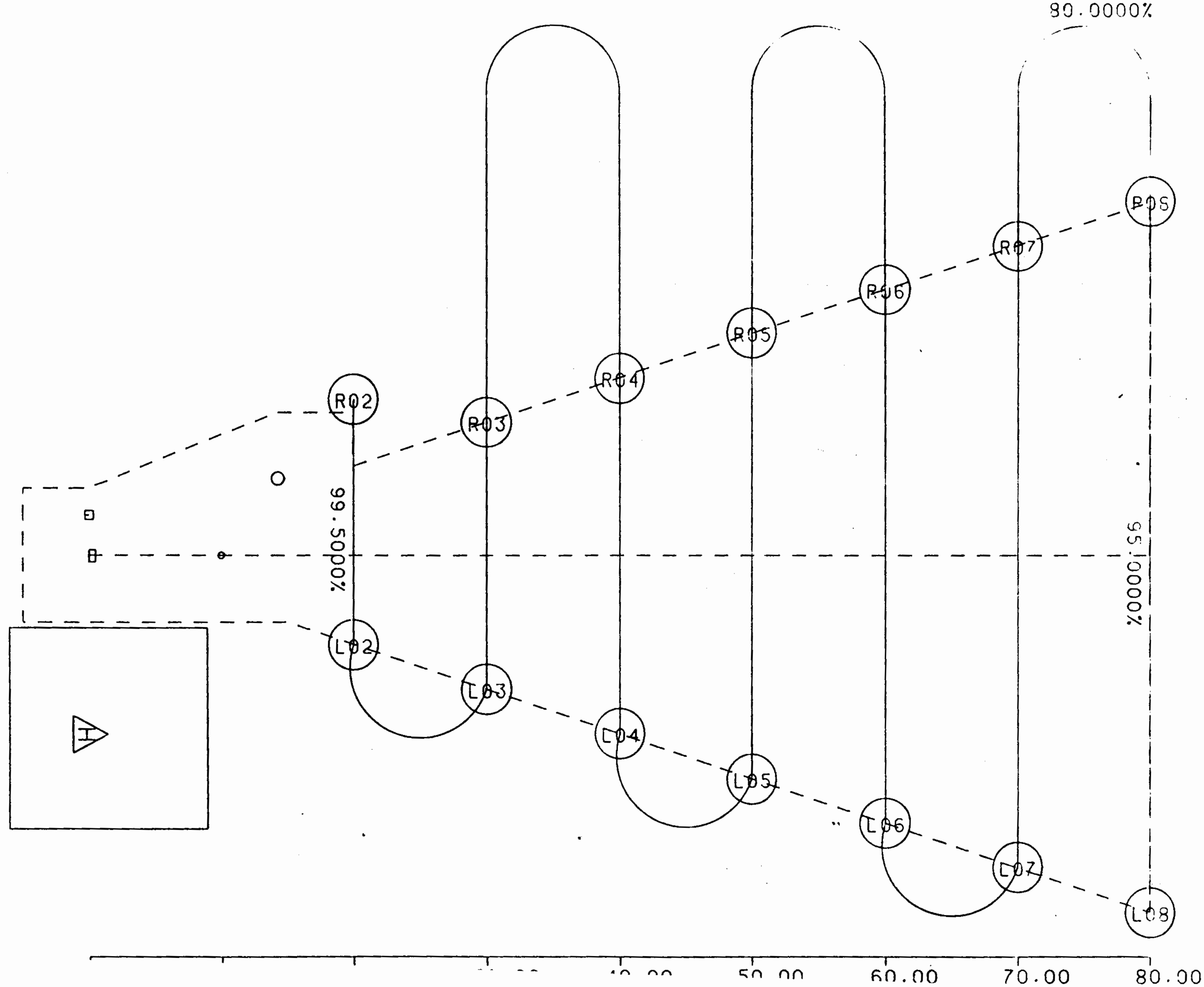


DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N J 08405

CRITICAL AREA FLIGHT 7: F STATISTICS ANALOG EL

RUN # 5

ELEVATION RUN

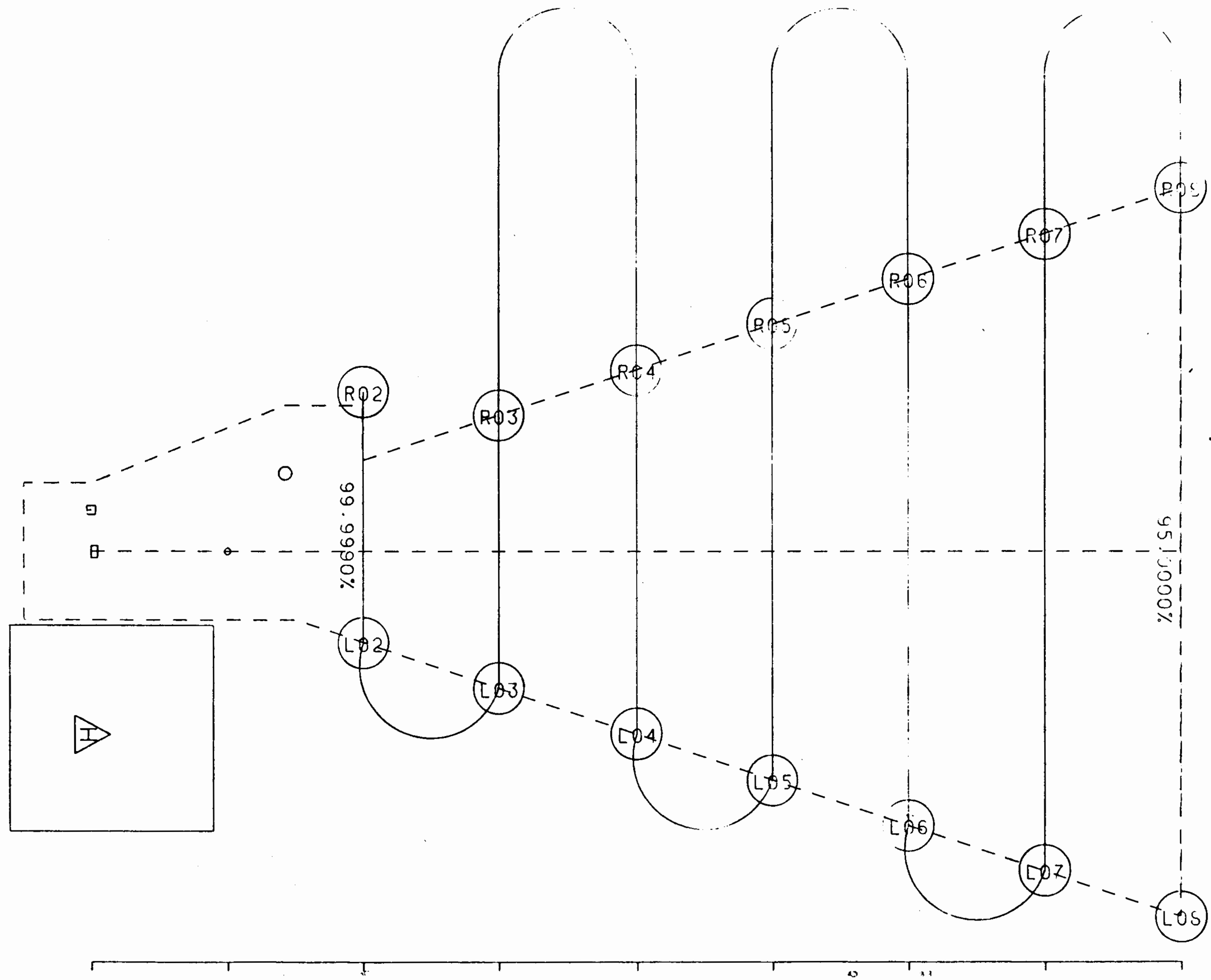


DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N J 08405

CRITICAL AREA FLIGHT 7: F STATISTICS ANALOG EL

RUN # 9

ELEVATION RUN

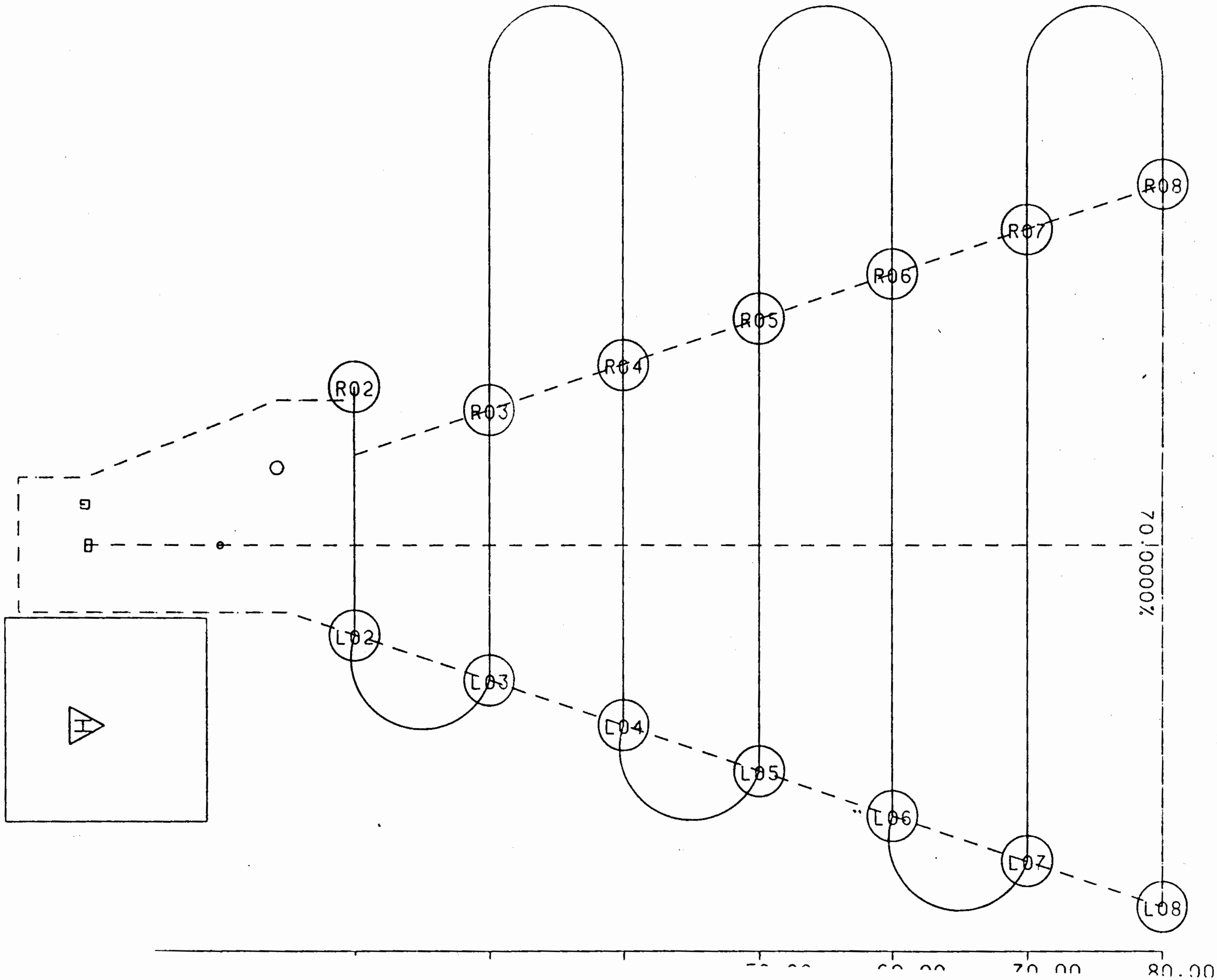


DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N J 08405

CRITICAL AREA FLIGHT 7: F STATISTICS ANALOG EL

RUN # 10

ELEVATION RUN

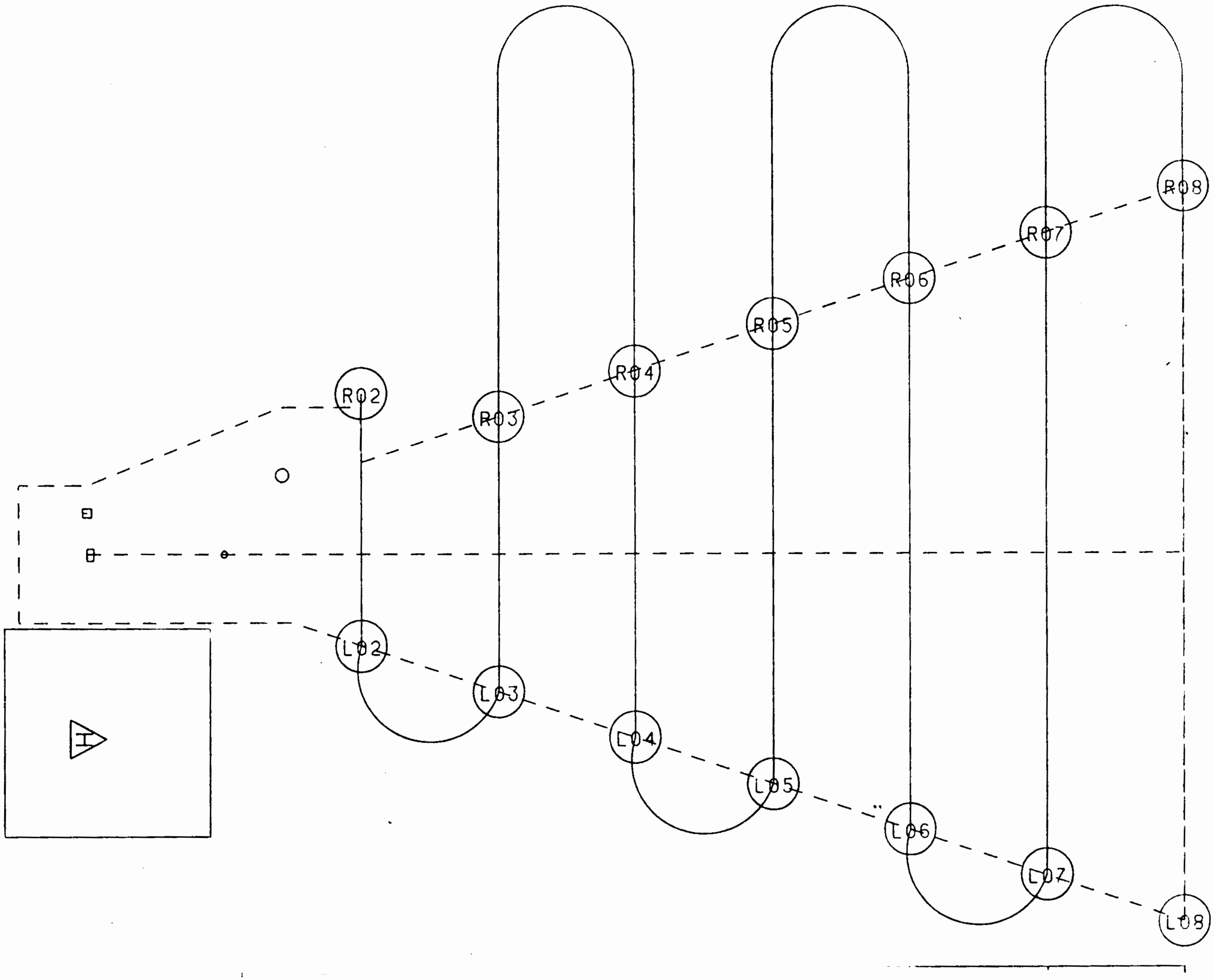


DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N J 08405

CRITICAL AREA FLIGHT 7: F STATISTICS ANALOG EL

RUN # 11

ELEVATION RUN



DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N J 08405

CRITICAL AREA FLIGHT 7: F STATISTICS ANALOG EL

RUN # 12

ELEVATION RUN