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VMC Left Turn Curved Approaches

Test Results

Rosanne M. Weiss

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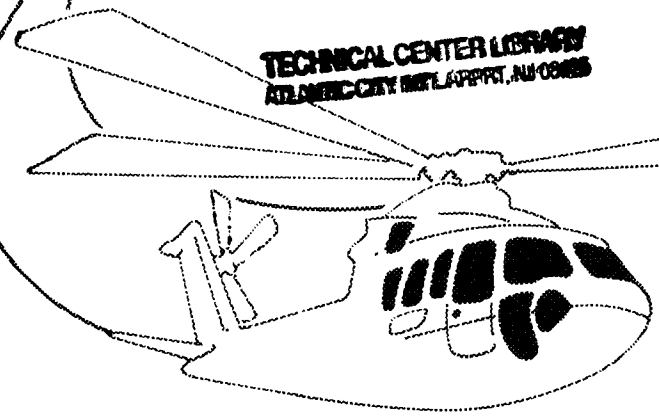

July 1993

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16. Abstract

Flight tests were conducted at the Federal Aviation Administration (FAA) Technical Center in 1989 and 1990 to aid in answering questions concerning curved approaches to a heliport under visual meteorological conditions (VMC). These questions include protected airspace within the curved segment of the approach, the most feasible angle of turn and minimum final approach segment. The FAA's Sikorsky S-76 and UH-1H were used for these tests. Data were collected from approaches using turn angles of 45-, 90-, and 180-degrees, each with three different final segments, 800, 1200, and 1600 feet (ft). Due to airspace restrictions at the time of these tests, left turns to final were flown. All maneuvers were tracked by ground-based tracking systems.
This report documents the results of these flights. The test procedures, evaluation methodology, and technical and operational issues are described. Analysis of pilot performance, as well as pilot subjective input, are provided. Conclusions are presented that address the airspace, turn angle, and final segment issues. The results will be considered in future modifications of the FAA Heliport Design Advisory Circular, AC 150/5390-2.
All appendixes can be found in Research Directorate for Aviation Technology Division Report DOT/FAA/CT-ACD33093/6, "Appendixes for TN92/46 VMC Left Turn Curved Approaches, Test Results."

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All appendixes referenced in this report are contained in Directorate for Aviation Technology Division Report DOT/FAA/CT-ACD33093/6, "Appendixes for TN92/46, VMC Left Turn Curved Approaches, Test Results."

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EXECUTIVE SUMMARY

From late fall 1989 through the summer of 1990, flight tests were conducted at the Federal Aviation Administration (FAA) Technical Center to aid in answering questions concerning curved approaches to a heliport under visual meteorological conditions (VMC). These questions deal with the dimensions of airspace that must be protected within the curved segment of the approach, the most feasible angle of entry and minimum final approach segment.

Flights were conducted at the Technical Center using both the FAA's Sikorsky S-76 and the UH-1H. A total of 630 approaches were completed. Each approach evaluated one of three turn angles: 45, 90, and 180 degrees, and one of three final segments: 800, 1200, and 1600 feet (ft). Due to construction at the Technical Center's Concepts Development and Demonstration Heliport/Vertiport, these flights were conducted at an alternate landing area. Airspace restrictions at this site required left turns to final. All maneuvers were tracked by ground based tracking systems to provide accurate objective three-dimensional position information. Subjective data were also collected via in-flight pilot questions and a post-flight questionnaire. The in-flight answers were based on the pilot's immediate recall of what occurred during the approach. The post-flight questionnaire gathered the pilot's overall opinion of the procedures. All appendixes referenced in this report are contained in Directorate for Aviation Technology Division Report DOT/FAA/CT-ACD33093/6, "Appendixes for TN92/46, VMC Left Turn Curved Approaches, Test Results."

Results indicate that the 45- and 90-degree turns are more practical than the 180-degree turns. Pilot input indicates that the 90-degree turns offered an advantage in area and landing pad reconnaissance opportunities. In addition, the pilots indicated that they felt more comfortable with the 1200- and 1600-ft final segments than with the 800-ft final, particularly for passenger-carrying operations.

However, since this flight test required left turns to final, a worst case scenario, it is suggested that a limited number of additional curved-approach flights be conducted using right turns to final.

INTRODUCTION

BACKGROUND.

In 1986, the Vertical Flight Program Office, ARD-30, requested the Federal Aviation Administration (FAA) Technical Center's Airborne Systems Technology Branch, ACD-330, to examine the airspace and obstacle protection requirements for visual approaches and departures to heliports.

The current Federal Aviation Advisory Circular (AC) 150/5390-2, which reflects Federal Air Regulation (FAR) Part 77 requirements, states:

"The approach surface begins at the end of the heliport primary surface with the same width as the primary surface, and extends outward and upward for a horizontal distance of 4000 feet (ft) where its width is 500 ft. The slope of the approach surface is 8 to 1 for civil heliports."

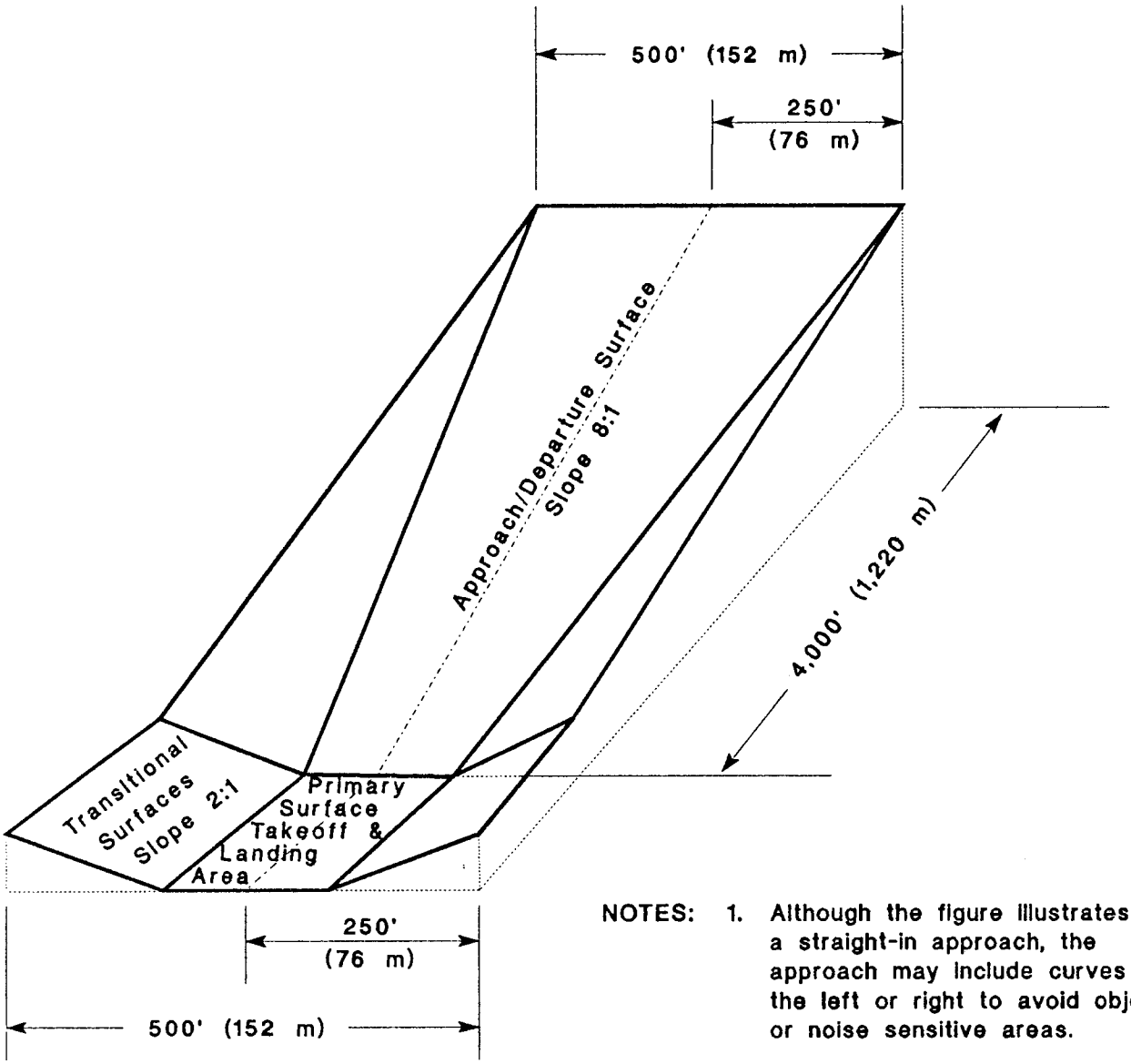
The term primary surface, as defined in the AC, is an imaginary surface which overlies the designated takeoff and landing area. Figure 1 shows these areas as they are depicted in AC150/5390-2.

Testing occurred in 1987 that focused on the issues of approach and departure airspace requirements. The test results are reported in "Heliport Visual Approach and Departure Airspace Tests," DOT/FAA/CT-TN87/40, Volume I, dated August 1988. The conclusions from that test state that curved path approaches and departures to and from heliports are viable alternative procedures to heliports. As seen in figure 1, note 1, curved approaches are now permitted when necessary.

The flight tests conducted in 1987 were not structured to address specific aspects of curved procedures, such as turn angle and length of the final straight segment. In addition, since there were no controls placed on how the pilot was to accomplish the turn, the dispersions of the flightpaths during the curved portion of the procedures in both the vertical and lateral dimensions were not examined.

The FAA Technical Center conducted flight tests in late fall 1989 through the summer 1990 to answer these additional concerns. The Office of Airports Safety and Standards, Design and Operations Criteria Division, AAS-100, will use the test flight data to define the dimensions of the airspace to be protected within the curved portion of the approach. The data will be used to further define curved approach parameters, such as, angle of the turn to final, and the minimum final approach segment.

All appendixes referenced in this report are contained in Directorate for Aviation Technology Division Report DOT/FAA/CT-ACD33093/6, "Appendixes for TN92/46, VMC Left Turn Curved Approaches, Test Results."



NOTES:

1. Although the figure illustrates a straight-in approach, the approach may include curves to the left or right to avoid objects or noise sensitive areas.

2. The primary surface is physically identical to the takeoff and landing area.

Figure 1. HELIPORT APPROACH/DEPARTURE SURFACES

OBJECTIVES.

The flight test objectives addressed were to determine:

1. The airspace consumed in the curved portion of these Visual Flight Rules (VFR) approaches to heliports.

2. The most practical angle of entry into the final segment.

3. The minimum acceptable final straight segment following the curved portion of the approach.

4. The dispersions in flightpaths in both lateral and vertical dimensions throughout the entire curved VFR approach.

These objectives were studied using both objective methods (statistical analysis) and subjective methods (pilot questionnaires).

METHODOLOGY

TEST LOCATION.

The flights were conducted at the FAA Technical Center from November 1989 to July 1990. Since the Technical Center's heliport was being upgraded during this flight test period, these flights were flown to an alternate landing area located abeam runway 31 and approximately 565 ft to the north of the runway's threshold. All approaches remained within a two-nautical mile (nmi) radius of the landing area. Due to air traffic constraints, the glideslope for each approach was maintained at ten degrees and each approach was flown using left turns to the final approach path.

FACILITIES AND INSTRUMENTATION.

AIRCRAFT. Two FAA owned and operated helicopters, a Sikorsky S-76A and a Bell 205A-2 (UH-1H), were used for the flight tests.

Sikorsky S-76A. The FAA's S-76A is a twin engine, single main rotor helicopter designed to carry a pilot and up to five passengers. It is capable of speeds up to 155 knots (kt), has a maximum takeoff weight of 10,300 pounds (lbs), and a main rotor diameter of 44 ft. This aircraft is certified for single pilot Instrument Flight Rules (IFR) operations and is representative of IFR-certified transport helicopters currently in use. During the test flights, it was flown under VFR. The helicopter's gross weight was maintained between 9,000 and 10,000 lbs during the test flights.

Bell 205A-2. The Bell 205A-2 is a single turbine engine, single-rotor helicopter equipped with electromechanical displays representative of civil IFR-certified helicopters. The FAA's Bell 205A-2 was designed to carry a pilot, a copilot, and up to nine passengers. It is capable of flying at speeds up to 120 kt

and has a main rotor diameter of 48 ft. During the flight tests, its gross weight was maintained between 8,000 and 9,000 lbs.

GROUND TRACKING. Two different ground based radar tracking systems were used to provide the aircraft's track position during the approaches. The two systems were the GTE Sylvania Precision Automated Tracking System (PATS) and the Vitro RIR778 Tracking Radar.

GTE Sylvania PATS. This system measures azimuth (AZ), elevation (EL), and range automatically by transmitting a laser pulse to a target on the aircraft and measuring the angle of return and round trip time. The angle coverage for the AZ is 540 degrees, and for EL it is 0.5 to 85 degrees. The angle accuracy or maximum error for both AZ and EL is 20 arc seconds at all ranges. The maximum reliable range coverage is 25 nmi. Accuracies are 1 ft for target ranges up to 5 nmi, 2 ft for target ranges of 5 to 10 nmi, and 3 ft for target ranges of 10 to 25 nmi. The system is capable of tracking an aircraft from takeoff through touchdown. However, because of visibility conditions, the operational range is limited at the Technical Center to ranges of 7 to 10 nmi.

VITRO RIR778 Tracking Radar. This system uses a NIKE Hercules radar antenna. It is capable of operating either in beacon (cooperative) mode or in skin paint mode. It is calibrated to a 1-sigma bias error of uncertainty envelope of 0.014 degrees in AZ and EL. 1-sigma range errors are 3.3 meters for the beacon mode and 6.0 meters for the skin paint mode. The standard deviation of short term variations or jitter is within 0.009 degrees for both AZ and EL and within 3.0 meters for range. The beacon mode was used for these flights.

TEST PROCEDURES.

FLIGHT PROCEDURES. Each flight consisted of 18 approaches. Each approach evaluated one of three turn angles of 45, 90, and 180 degrees and one of three final segments of 800, 1200, and 1600 ft. Thus, nine run profiles were established and each was flown twice on a flight. Figure 2 shows each profile. Each approach began at 500 ft above ground level (AGL). In order to maintain a constant 10-degree final descent angle on each of the three final segments, each final segment began at a different altitude. Table 1 provides, for each run, a listing of each turn angle and the final segment length and the altitude following the turn. Pilots flew either one or two flights, depending on time and weather constraints.

A safety pilot vectored the subject pilot to a position that set up one of the nine types of runs. The position at which the curved portion began was determined by surveyed ground locations. This aircraft position was either on the downwind or base leg of the approach. Using these surveyed ground points the subject pilot was instructed by the safety pilot when to start the turn

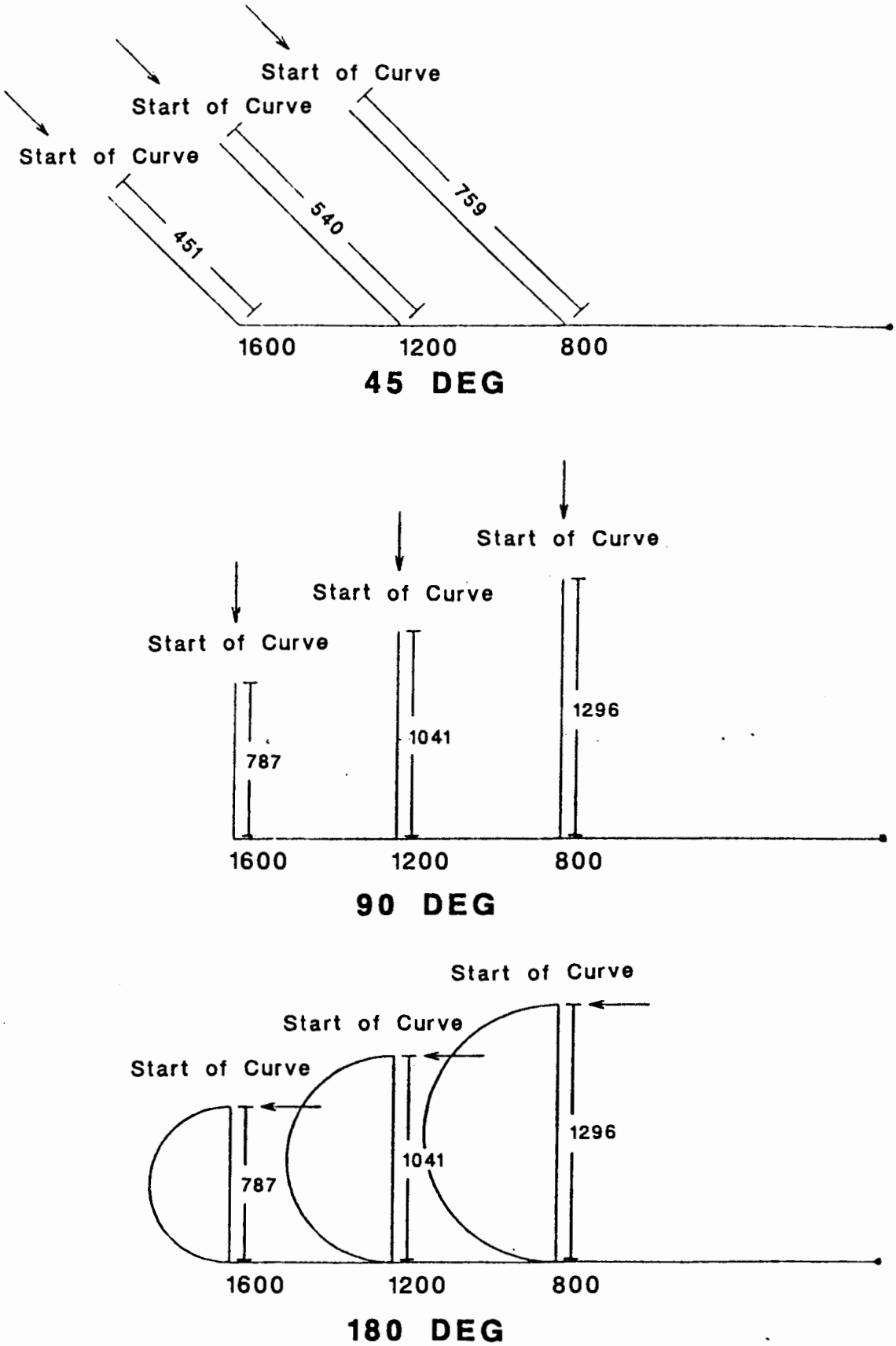


Figure 2. Flight Profiles

TABLE 1. FLIGHT TEST MATRIX

Run Number at Final Segment	Lateral Intercept Angle	Final Segment Length (ft)	Altitude at Start of Turn
1,10	45	1600	282
2,11	45	1200	216
3,12	45	800	141
4,13	90	1600	282
5,14	90	1200	216
6,15	90	800	141
7,16	180	1600	282
8,17	180	1200	216
9,18	180	800	141

to the final approach segment. The subject pilot flew the approach from the beginning of the turn to touchdown via visual references only.

The safety pilot called out maximum bank angles during the turn, and the altitude upon final segment fix rollout for data collection purposes only.

Following each curved approach, the subject pilot was asked to rate the maneuver in terms of safety, workload, and controllability, using the Modified Cooper-Harper Rating Scale. A copy of this scale is found in figure 3.

SUBJECT PILOT BRIEFING.

The objectives of the flight tests and the flight procedures were explained to each subject pilot during a preflight briefing. Also, during this briefing, the use of the Cooper-Harper Rating Scale for the inflight post-maneuver questions was explained to the subject. In addition, the responsibilities of each crew member: subject pilot, safety pilot, and technician, were described and local area conditions and aircraft information were discussed. Following the briefing, each subject pilot was familiarized with the curved approach routes.

SUBJECT PILOTS.

Twenty-six pilots with diverse rotorcraft operations background from the private sector, military, and the FAA, participated in these tests. This diversity of experience is representative of the rotorcraft industry at large. Nine of the pilots flew the procedures in both aircraft. Table 2 presents a listing of the experience of the subject pilots. The flight experience for both the S-76 and UH-1H subject pilots is shown in table 3. The S-76 subject pilot helicopter experience ranged from 150 to 6900 total hours (hrs), from 2 to 1650 hrs in type, and from 8 to 350 hrs in the past 6 months. The median number of total helicopter hours was 2600 hrs. The median number of time-in-type hrs was 350, and for time over the past 6 months, the median was 75 hrs.

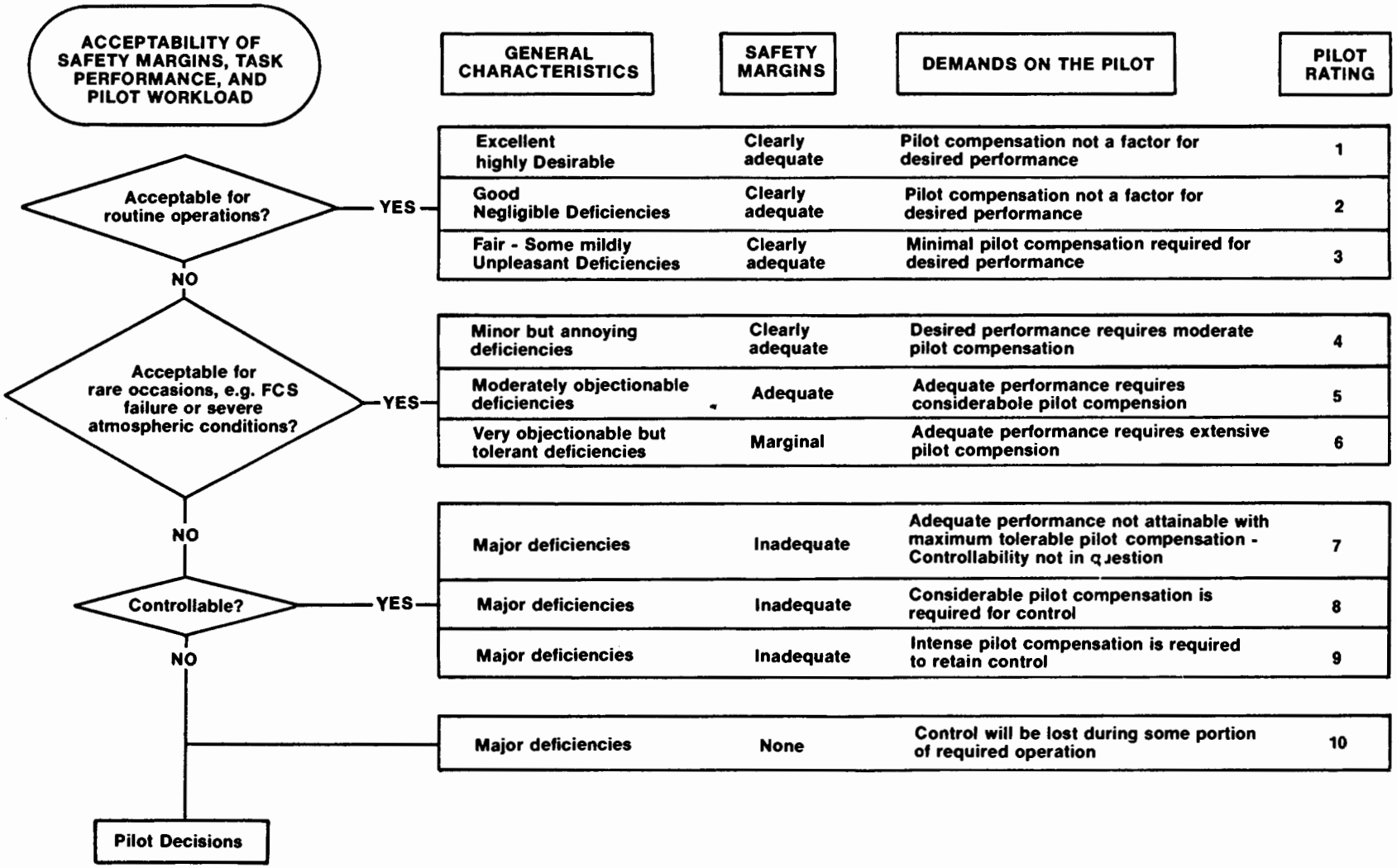


FIGURE 3. MODIFIED COOPER-HARPER RATING SCALE

TABLE 2. SUBJECT PILOT BY EXPERIENCE AND AFFILIATION

S-76

Number of Pilots	Affiliation	Experience
1	FAA	FAA
1	FAA	FAA + Industry
2	FAA	FAA + Military
2	Military	Military
2	Military	Military + Industry
5	State Government	State Government
1	State Government	State Government + Military
4	Industry	Industry
1	Industry	Industry + Military

UH-1H

Number of Pilots	Affiliation	Experience
1	FAA	FAA + Industry
2	FAA	FAA + Military
5	Military	Military
2	Military	Military + Industry
1	Military	Military + Industry + FAA
3	State Government	State Government
1	State Government	State Government + Military
1	Private	Private

TABLE 3. SUBJECT PILOT FLIGHT EXPERIENCE

S-76 Subjects

Total Flight Hours	Number of Pilots
0-500	0
501-1500	3
1501-3000	2
> 3000	13

Total Helicopter Hours	Number of Pilots
0-500	1
501-1500	5
1501-3000	7
> 3000	5

Total Time in Type	Number of Pilots
0-500	11
501-1500	6
1501-3000	1
> 3000	0

Total Helicopter Hours Last 6 Months	Number of Pilots
< 10	0
10-50	5
> 50	13

UH-1H Subjects

Total Flight Hours	Number of Pilots
0-500	0
501-1500	3
1501-3000	2
> 3000	11

Total Helicopter Hours	Number of Pilots
0-500	1
501-1500	3
1501-3000	3
> 3000	9

Total Time in Type	Number of Pilots
0-500	7
501-1500	1
1501-3000	4
> 3000	4

Total Helicopter Hours Last 6 Months	Number of Pilots
< 10	1
10-50	6
> 50	9

The UH-1H subject pilot experience ranged from 55 to 8300 total helicopter hrs with a median of 3300 hrs, from 2.8 to 5755 hrs in type with a median of 1900 hrs, and from 5.9 to 300 hrs over the past 6 months with a median of 100 hrs.

DATA PROCESSING AND ANALYSIS

SOURCE OF DATA.

Test data came from four sources: in-flight subject-pilot Cooper-Harper ratings of each procedure, the data technician's log, post-flight subject pilot questionnaire and ratings, and Laser and/or NIKE tracking tapes.

IN-FLIGHT PILOT RATINGS. Immediately following each approach, the subject pilot was asked to rate the maneuver in terms of safety, workload, and controllability. This questionnaire was designed to provide immediate subject response. These ratings were recorded on the flight log by the flight data technician.

DATA TECHNICIAN'S LOG. The flight data technician was responsible for filling in a log during each flight. The subject pilot's name, flight date, start time for the run, start/stop times for each curve, and time of touchdown were recorded. Additional information recorded included: subject pilot comments, wind conditions, angle of bank during the turn, and altitude upon beginning the final segment. A sample flight log can be found in appendix A.

POST-FLIGHT QUESTIONNAIRE. At the conclusion of the second flight, or the first if only one flight was flown, the subject pilot was asked to complete a post-flight questionnaire.

Appendix B contains a sample post-flight questionnaire. Unlike the in-flight questionnaire, this questionnaire was designed to provide comparative subject pilot measures across all test profiles. It required the subject pilot to provide an overall rating for each type curve, as well as a rating for each curve in terms of safety, control margin, and pilot workload and desirability. In addition, each subject pilot was asked to rate each final segment length in terms of safety, control, workload, and desirability. Finally, the post-flight questionnaire required a rating for each combination of turn angle and final segment. Pilot background information, such as number of flight hours and aircraft experience, was also collected. The subject pilots were encouraged to include any comments they might have about the procedures.

TRACKER DATA. The NIKE and Laser tracker tapes contained data that had been converted from slant range, AZ, and EL to X, Y, and Z coordinates (using the Tracking Coordinate System) by the Technical Center's Honeywell 66/60 facility. The tapes were then converted from Honeywell format to VAX/VMS format. The origin of the tracker data was translated to the center of the landing area with the X and Y axis running through the landing areas's center

point. The X-axis is in-line and positive on the approach side of the landing point and negative beyond the landing area. The Y-axis is perpendicular to the X-axis through the landing point and within the plane of the landing area. The Y-axis is positive to the right of the approach and negative to its left. The Z-axis is drawn perpendicular to the X-Y plane at the landing point of intercept, positive above and negative below the landing point (see figure 4). Ground tracking data were used to generate plots depicting both plan and profile views of each flight test procedure relating to the desired curved approach.

Tracking of each approach began prior to the curved portion and continued through termination at the helipad.

ANALYSIS PROCEDURES.

FLIGHT DATA. Flight data were provided from two possible sources: the Laser and/or NIKE tracker tapes, and the data technician's flight logs. The data technician's logs chronologically listed specific events that occurred during the various procedures, along with other supporting information as previously discussed.

DATA PARTITIONING. In order to perform the required statistical analysis it was necessary to partition, or bin, the data. Data along the straight and curved segments of the flight test paths were projected onto related three-dimensional axes. The data were partitioned or binned along these projected paths.

All horizontal and vertical binning for the straight segment was begun with the leading edge of the helipad as the first bin or bin zero. Bin ranges for other bins along the straight segment were calculated as follows:

$$BRn = BRo + (100 \times COS(10) \times BNn)$$

where BRn is the nth bin range in feet, BRo is the bin range for the initial bin, bin zero in feet, 100 is the partition interval in feet, COS(10) is the cosine of the 10-degree approach path, and BNn is the nth bin number.

Along the straight segment, this procedure was performed for altitude, along track velocity, altitude error, and crosstrack error. The altitude and radial errors were computed by subtracting the aircraft's planned position from its actual position.

The binning of the curved segments began from the end of the curved paths. These bins were calculated as follows:

$$BRAn = BRAo + \frac{(100 \times COS(10) \times BNRAn)}{R}$$

where BRAn is the nth bin portion of the curved path segment in degrees, BRAo is the bin angle for bin zero in degrees, BNRAn is

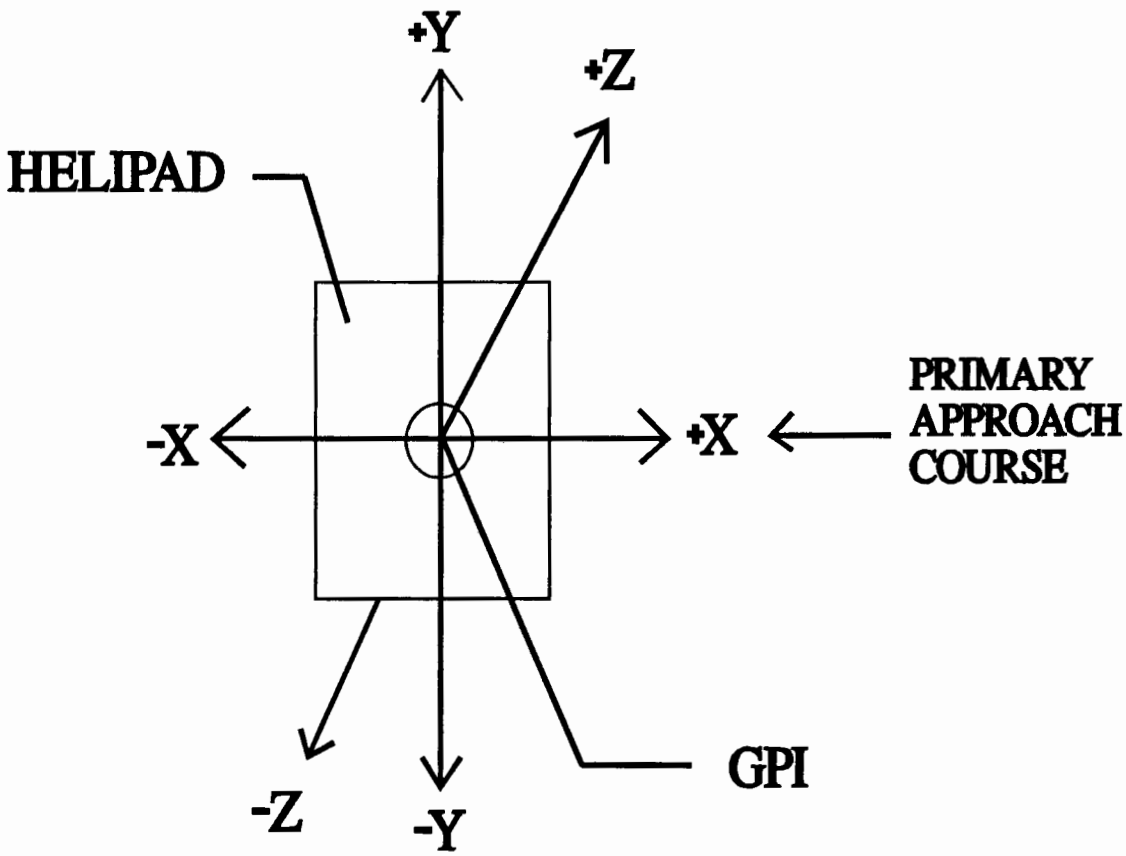


Figure 4. Rectangular Coordinate Reference System

the nth bin number for the radial, 100 is the arc partition distance or interval on the curved path in feet, COS(10) is the cosine of the 10-degree approach path, and R is the radius of the appropriate curve in feet.

Along the curved segment, this procedure was performed for altitude, vertical velocity, along path speed, altitude error, and radial error.

STATISTICS. Statistical calculations were performed on the binned data. For each bin, the parameters of interest were the number of data points (N), the arithmetic mean, and the unbiased estimates of standard deviation, skewness, and kurtosis. The first four moments about zero were calculated to aid in the computations of skewness and kurtosis. The formulas for skewness and kurtosis are as follows:

Third moment (skewness)

$$a_3 = 1/N \; \Sigma \; f(\; (x-\bar{x})/s \;)^3$$

Fourth moment (kurtosis)

$$a_4 = 1/N \; \Sigma \; f(\; (x-\bar{x})/s \;)^4$$

Further discussion of these statistics can be found in Elements of Statistics by Elmer B. Mode, Prentice Hall, Inc., NJ, 1961. Listings of these statistics can be found in appendix C.

PLOTTING. All plotting for this project was accomplished using a California Computer's Calcomp 1051 plotter using Calcomp 907 software for the VAX 11/750 computer. The plots generated fall into three categories: flight data plots, statistical data plots, and subjective pilot response plots.

FLIGHT DATA PLOTS. Two classes of plots were prepared from the tracker data. The first graphically depicts lateral deviations versus range from the heliport. The second depicts vertical deviations versus range. These plots were prepared in two ways: individual and composite.

Individual Plots. The individual plots were prepared on a per run basis for both the curved and final segments. Individual X-Y plots for the straight-in segment were generated for crosstrack in feet versus range in feet, and Z-Y plots for altitude versus range in feet. For the curved portion they were produced for crosstrack and altitude versus radial angular position. Velocity plots were also produced. The individual plots were used to determine if individual runs were acceptable for use in further analysis procedures. Figure 5 presents a sample of these plots.

Composite Data Plots. Subject pilot group performance is shown in the composite approach plots. These plots show the desired path as a dotted line. Nine lateral view composite plots

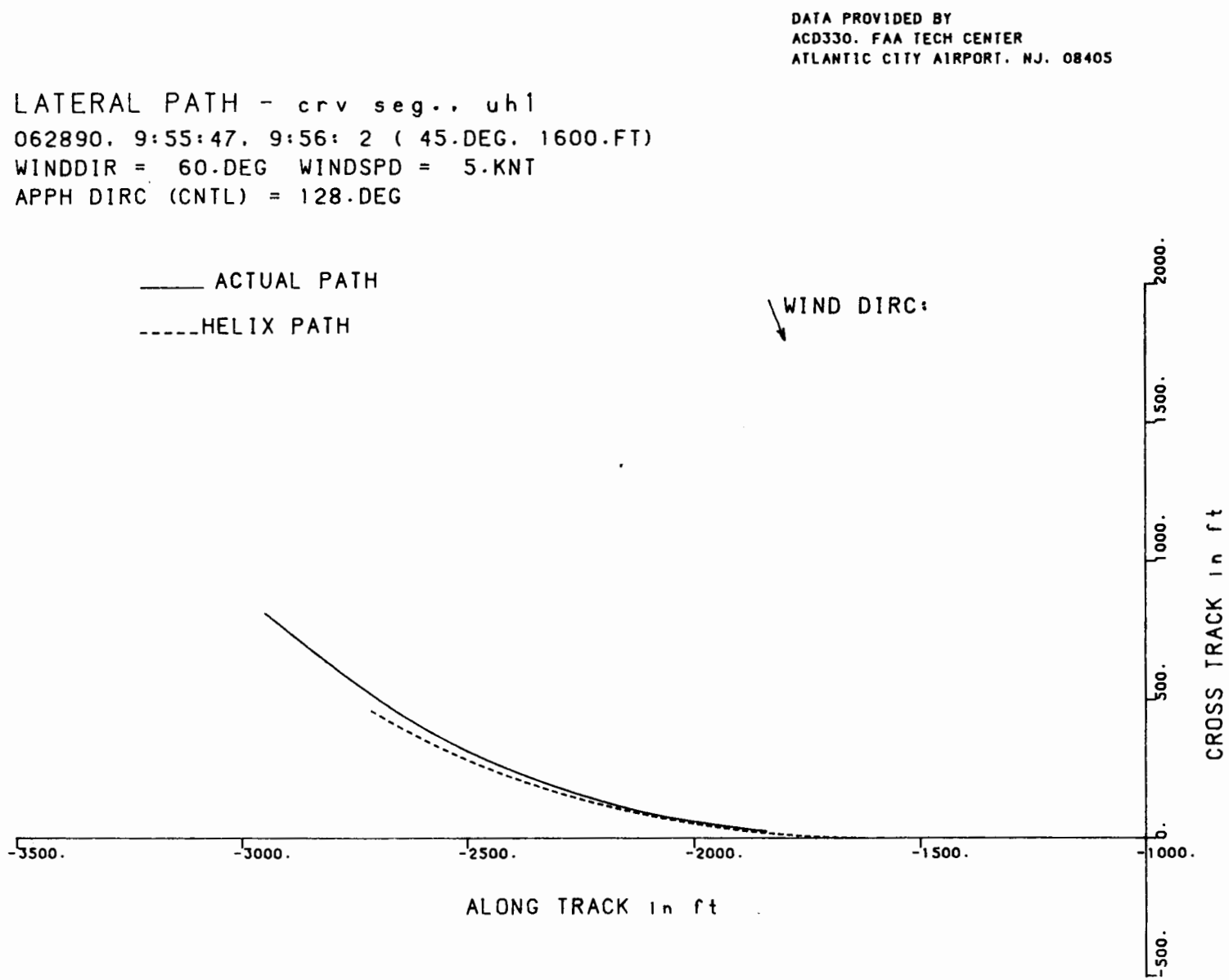


FIGURE 5. SAMPLE INDIVIDUAL PLOT (SHEET 1 OF 7)

DATA PROVIDED BY
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RADIAL ERROR - crv seg., uh1
062890, 9:55:47, 9:56: 2 (45.DEG, 1600.FT)
WINDDIR = 60.DEG WINDSPD = 5.KNT

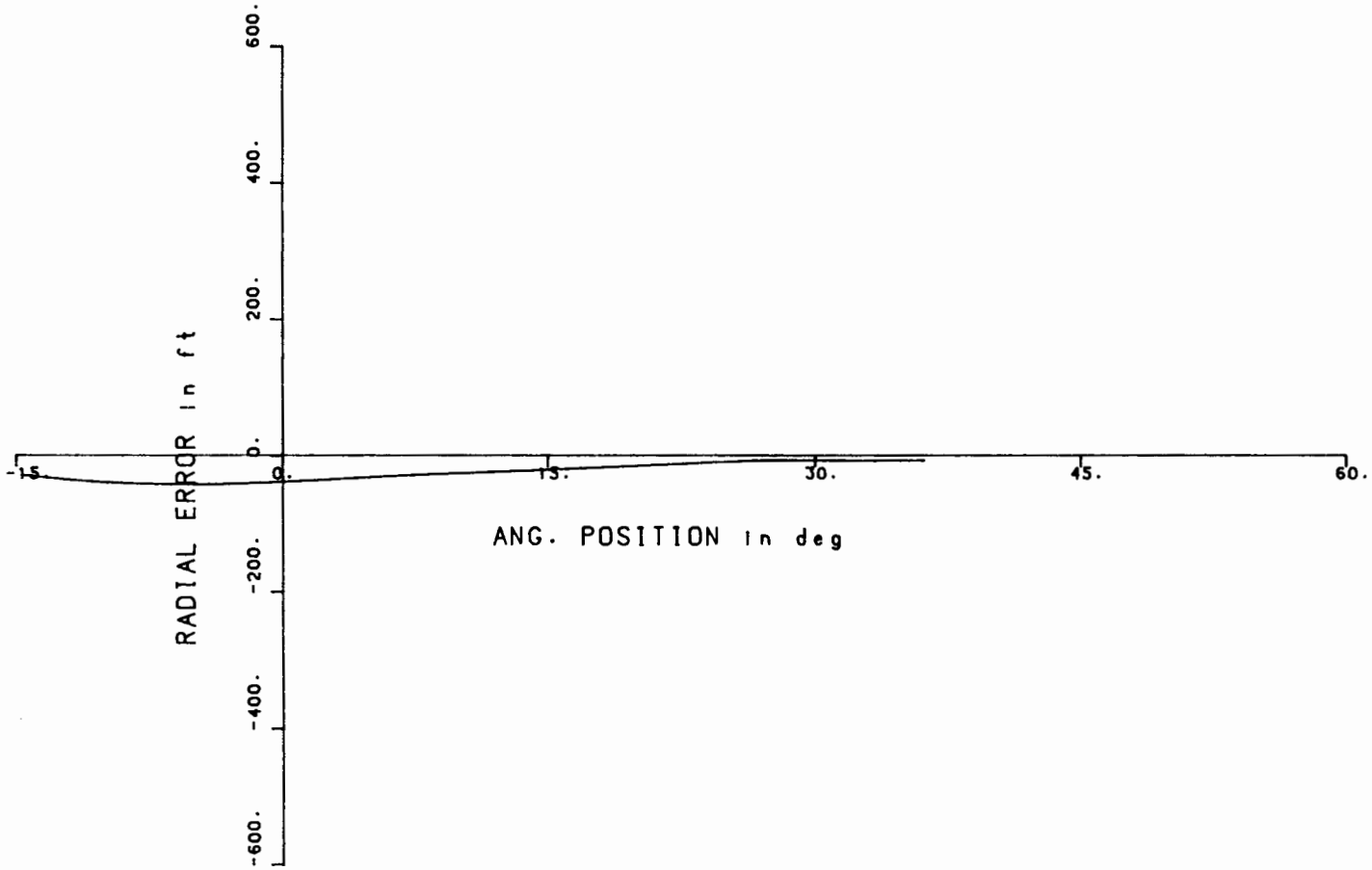

FIGURE 5. SAMPLE INDIVIDUAL PLOT (SHEET 2 OF 7)

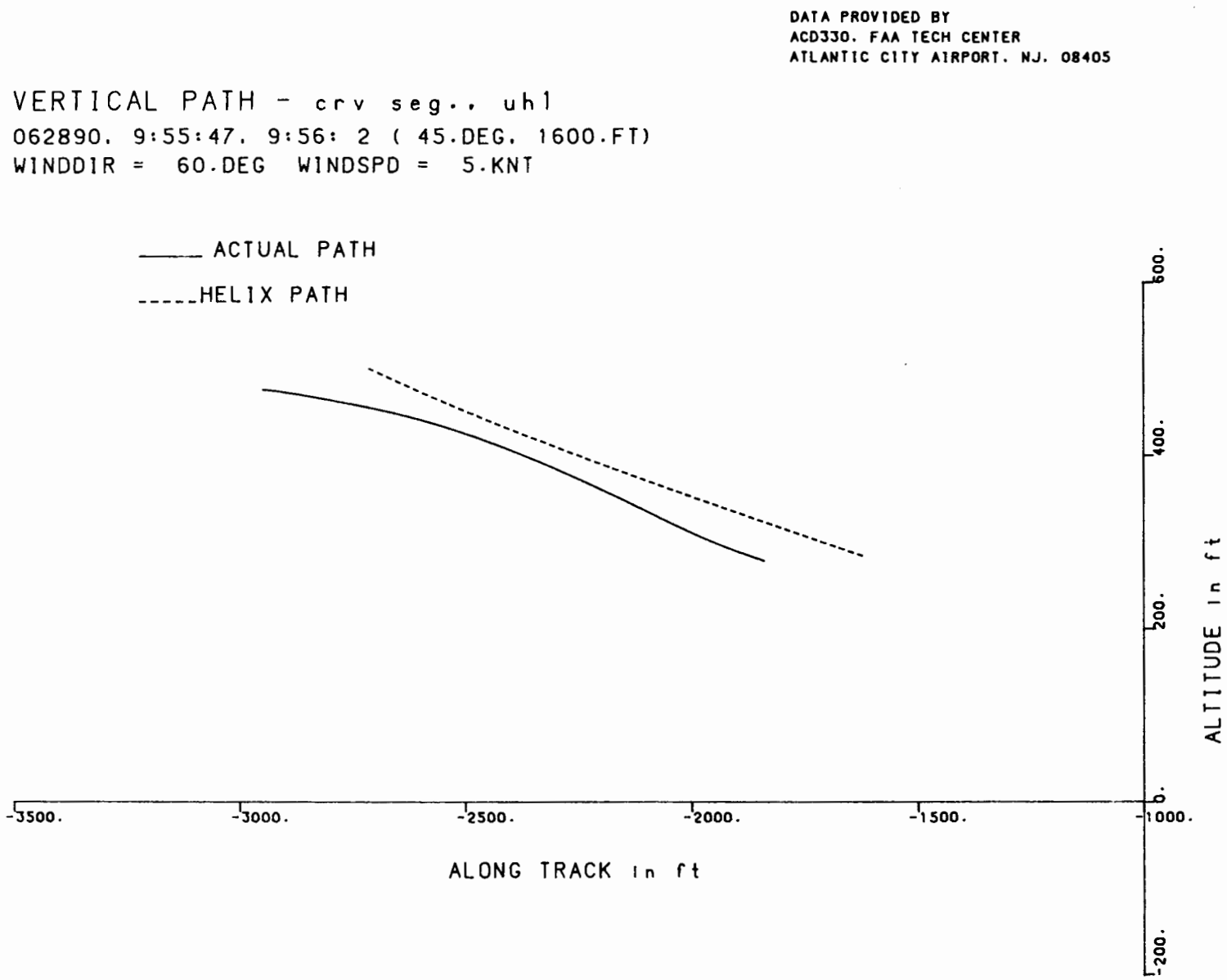

FIGURE 5. SAMPLE INDIVIDUAL PLOT (SHEET 3 OF 7)

DATA PROVIDED BY
ACD330. FAA TECH CENTER
ATLANTIC CITY AIRPORT. NJ. 08405

VERT.POST. ERR - crv seg., uh1
062890. 9:55:47. 9:56: 2 (45.DEG. 1600.FT)
WINDDIR = 60.DEG WINDSPD = 5.KNT

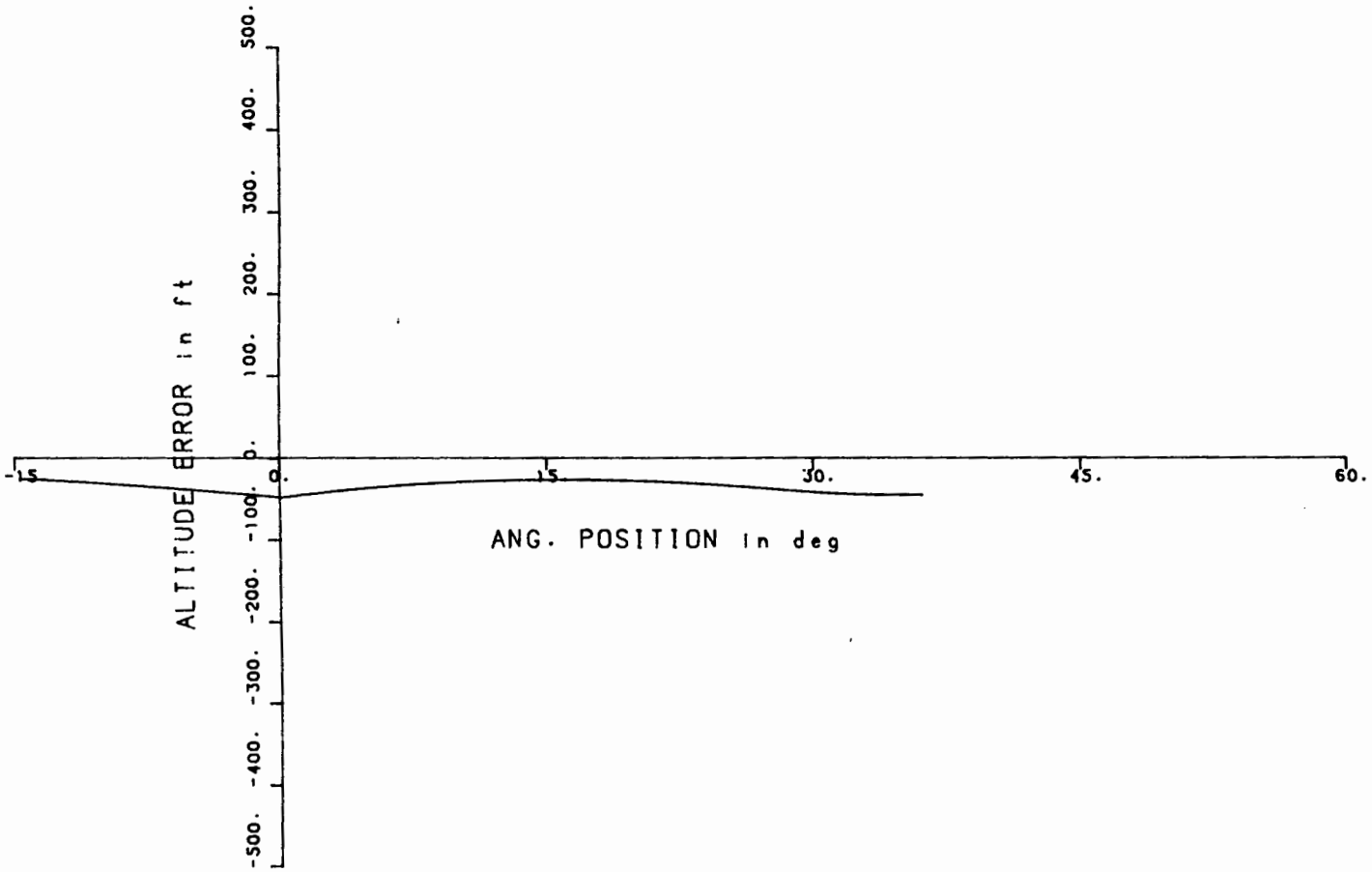

FIGURE 5. SAMPLE INDIVIDUAL PLOT (SHEET 4 OF 7)

DATA PROVIDED BY
ACD330, FAA TECH CENTER
ATLANTIC CITY AIRPORT, NJ. 08405

LATERAL PATH - str.seg., uh1
062890, 9:56: 2, 9:56:42 (45.DEG, 1600.FT)
WINDDIR = 60.DEG WINDSPD = 5.KNT
APPH DIRC (CNTL) = 128.DEG

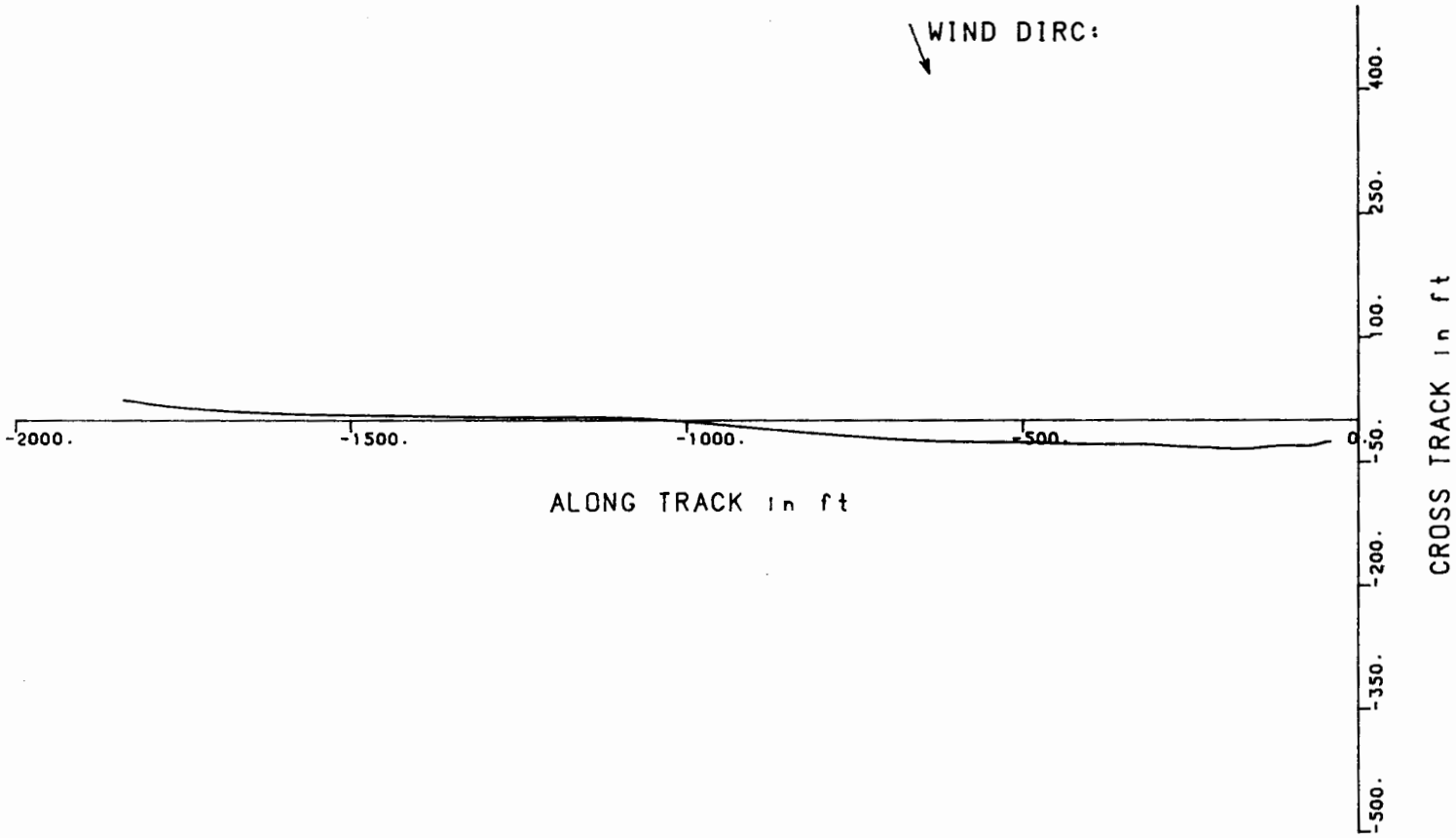

FIGURE 5. SAMPLE INDIVIDUAL PLOT (SHEET 5 OF 7)

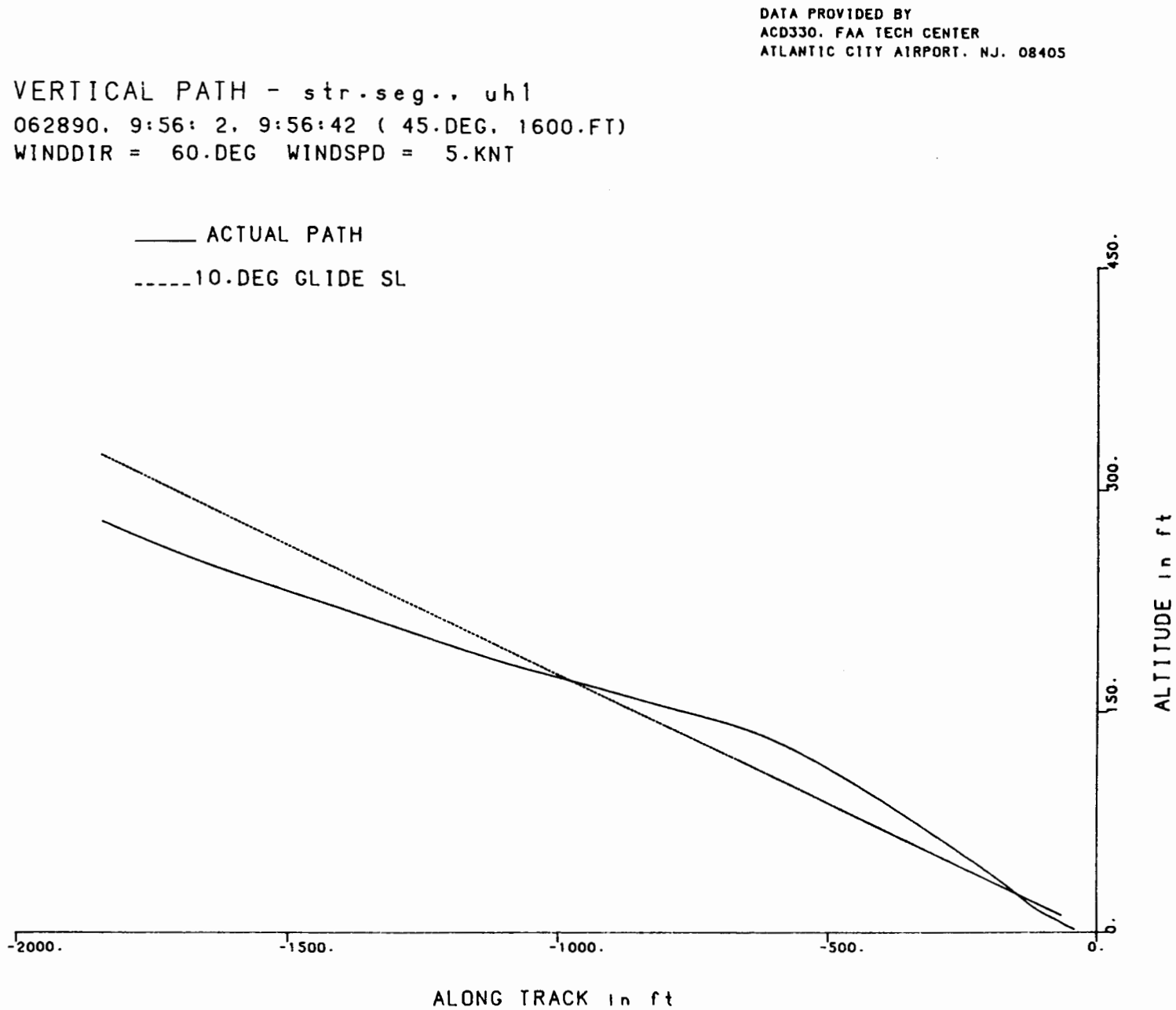

FIGURE 5. SAMPLE INDIVIDUAL PLOT (SHEET 6 OF 7)

DATA PROVIDED BY
ACD330. FAA TECH CENTER
ATLANTIC CITY AIRPORT. NJ. 08405

VERT.POST. ERR - str.seg., uhl
062890. 9:56: 2. 9:56:42 (45.DEG. 1600.FT)
WINDDIR = 60.DEG WINDSPD = 5.KNT

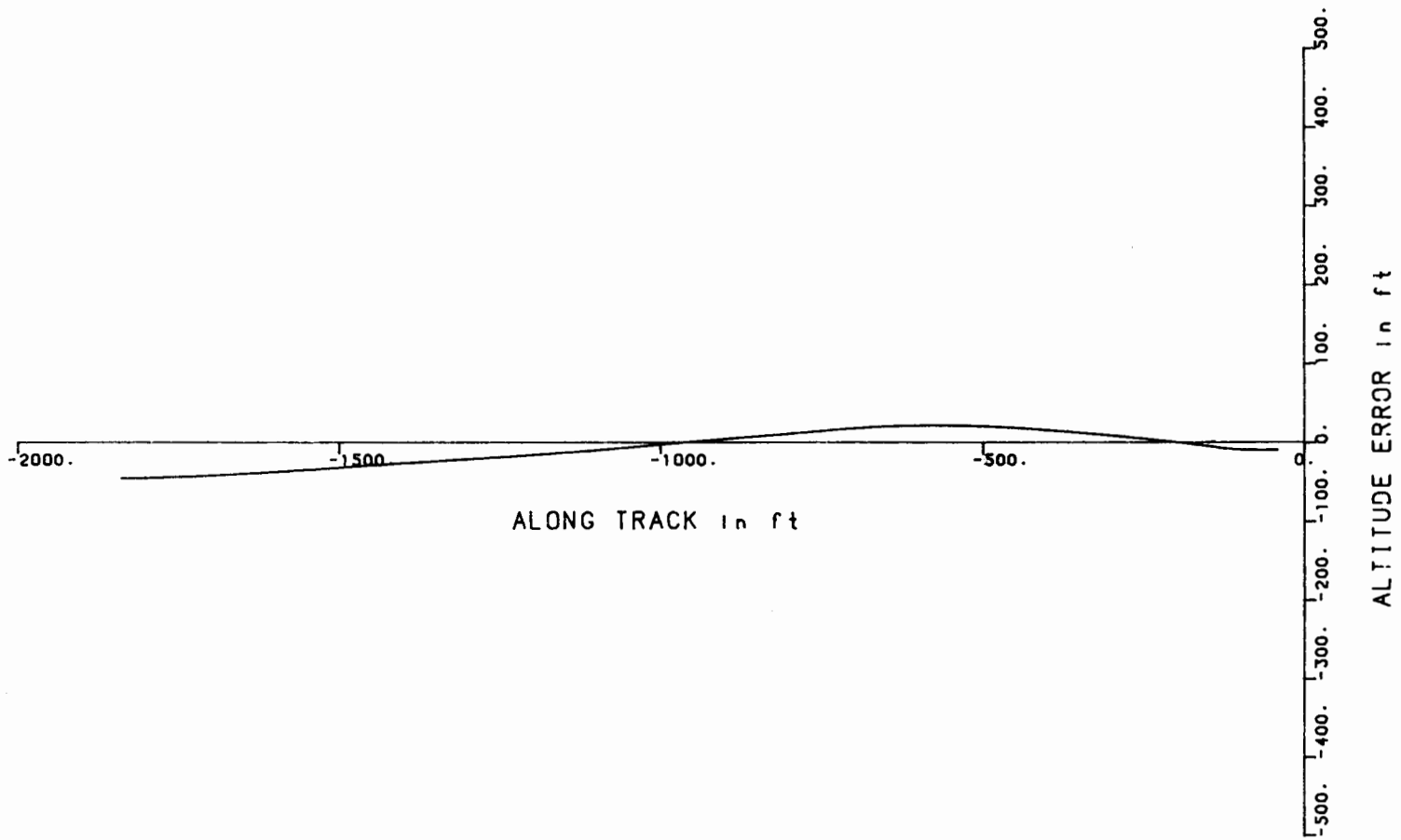

FIGURE 5. SAMPLE INDIVIDUAL PLOT (SHEET 7 OF 7)

and nine vertical composite plots were generated for both the curved and final segments. Figures 6 and 7 show a sample of the composite plots. All composite plots can be found in the Division Report ACD33093/6. S-76 composite plots can be found in appendix D, while those for the UH-1 can be found in appendix E.

STATISTICAL PLOTS. A graphical presentation of the results of the statistical analysis was produced using four and six sigma isoprobability contours. The statistics plot parameters plotted along the Y-axis, along the curved portion, were altitude, vertical velocity, along path speed, altitude error, and radial error. On the final segment, the parameters plotted were altitude, along track or straight-in velocity, crosstrack error, and altitude error.

The X-axis for the curved portion was the angular position or the position in the curve in degrees. For example, the angular bin position of 20 degrees indicates the pilot was 20 degrees into the turn; thus, a bin position of 90 degrees for a 180-degree turn indicates the pilot was half-way through the turn.

The X-axis for the final segment was distance from the heliport in feet.

One set of these plots show the mean value $\pm$ four standard deviations, while a second set shows mean $\pm$ six standard deviations. All points are plotted against their corresponding bin ranges or bin angles. All statistical plots are found in Division Report ACD33093/6. S-76 statistical plots can be found in appendix F, while UH-1H statistical plots are presented in appendix G.

PILOT RESPONSE PLOTS. Plots were also produced for the in-flight and post-flight ratings.

In-Flight Questionnaire Data Plots. Plots were produced showing the distribution of the Cooper-Harper in-flight ratings for safety, workload, and controllability. The S-76 and UH-1H in-flight plots can be seen in appendixes H and I, respectively.

Post-Flight Questionnaire Data Plots. These plots show the distribution of responses for each question. S-76 and UH-1H post-flight questionnaire results are found in appendixes J and K, respectively.

RESULTS

DATA PLOTS.

COMPOSITE PLOTS. The composite plots were produced for lateral as well as vertical views. They were analyzed by aircraft and type of turn.

S-76 Lateral View. When carrying out the 45-degree turns, regardless of the final segment length, the pilots tended to begin the curve on the inside of the desired curved path and

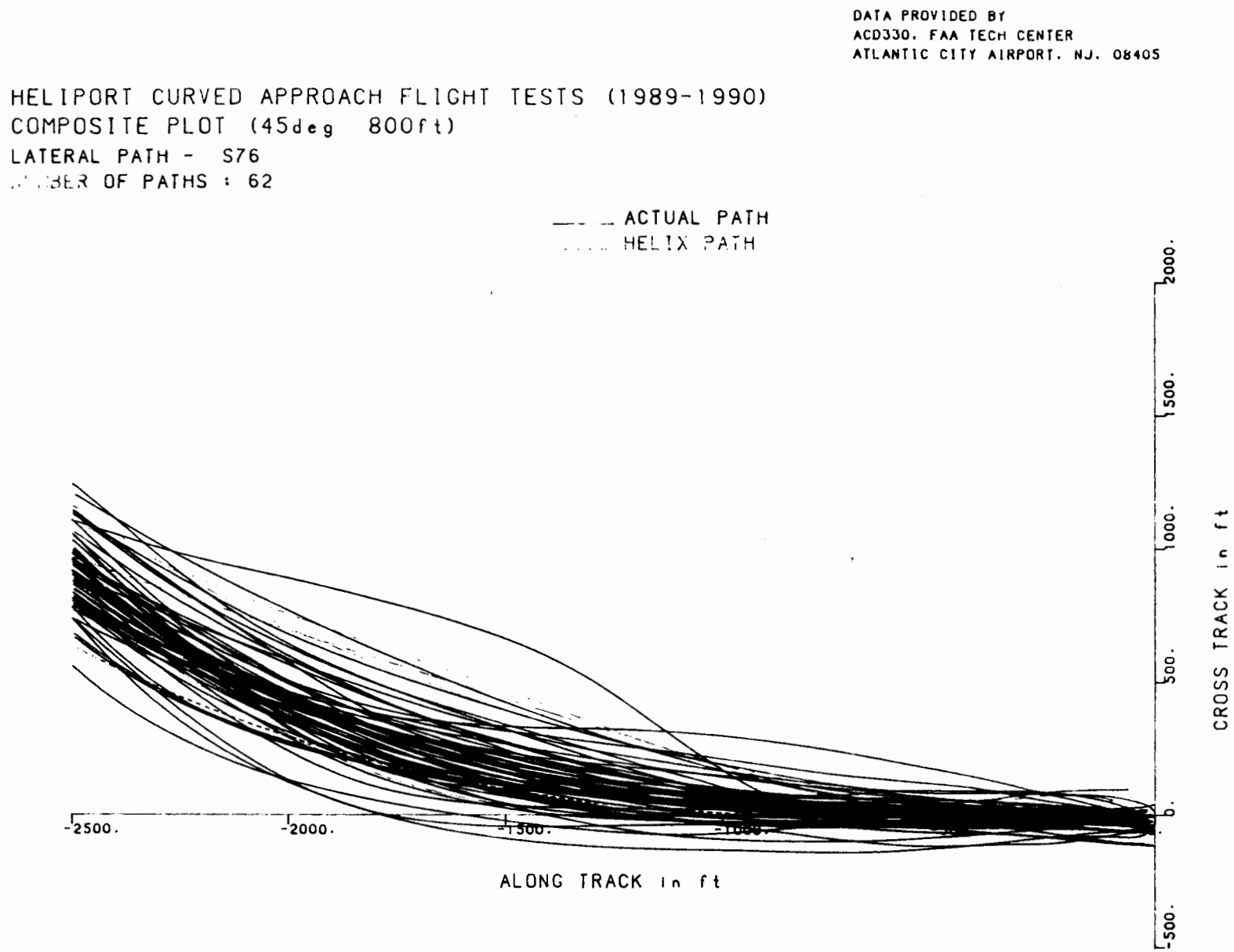

FIGURE 6. SAMPLE COMPOSITE PLOT, LATERAL VIEW

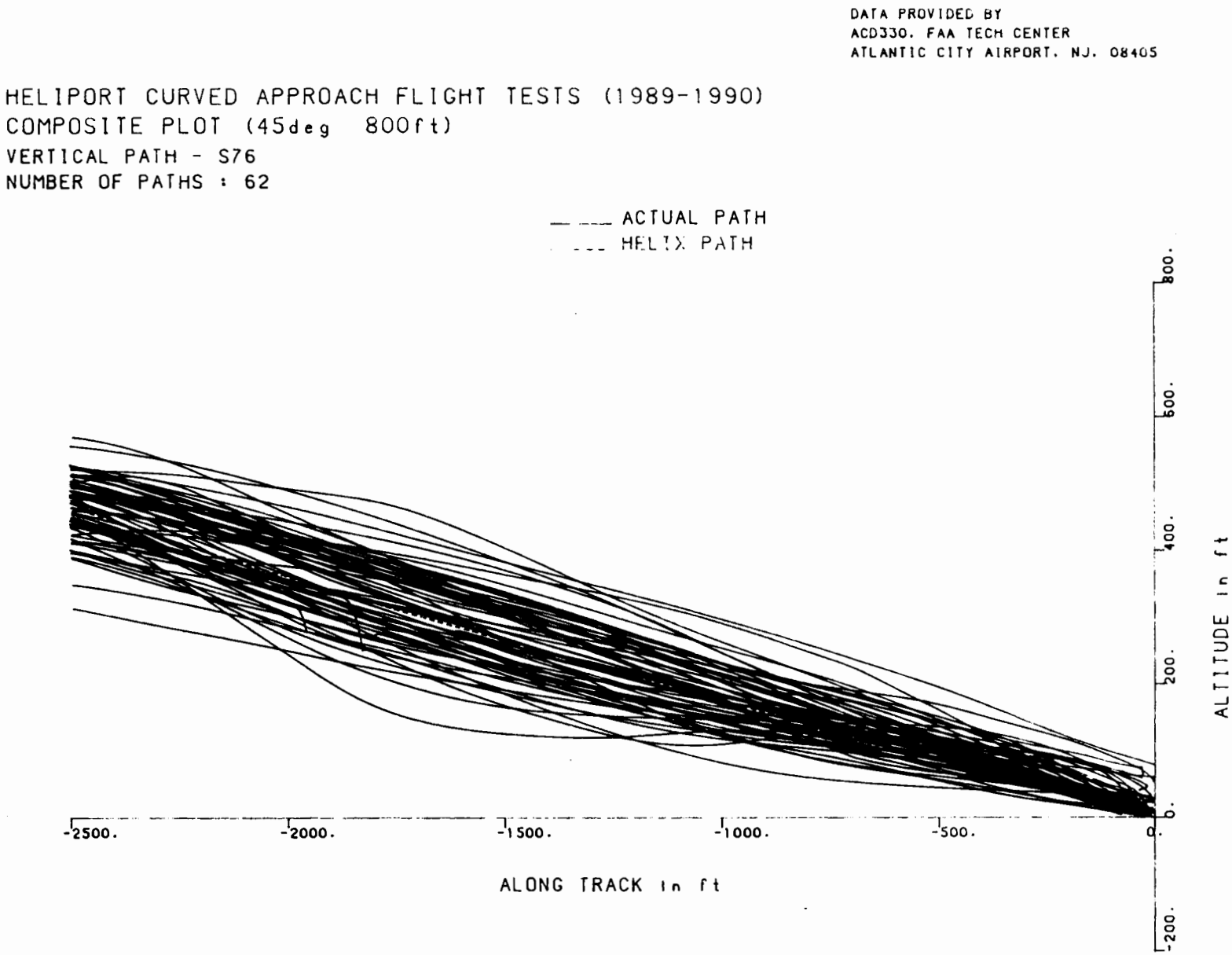

FIGURE 7. SAMPLE COMPOSITE PLOT, VERTICAL VIEW

remained on the inside during the entire approach. Examination of the composite plots for the 90-degree approaches revealed that the actual paths, regardless of final segment, tended to be centered around the desired path for the entire approach. With the 180-degree approaches, the pilots tended to begin the procedure outside the desired curved path and remained so for the entire run. These observed offsets are most likely due to the following:

1. On the 45-degree approaches, the path was just offset from a straight-in and there was a temptation to straighten out the approach to the inside.

2. On the 180-degree approaches, the pilot was caught by the abnormally higher bank angle to maintain track and, therefore, flew wide.

S-76 Vertical View. The examination of the vertical view plots indicates that the final segment length may be a factor in whether the pilot stays above the desired course or drops below. For the 45-degree turns with the 1600-ft final, the pilots began below the desired vertical track and stayed below throughout the approach. The paths for the 45-degree turn approaches, with both the 1200 and 800-ft final segments, were centered around the desired path. In the 90-degree turns with the 1600-ft final, the pilots tended to begin below the desired altitude, but they were on or above the desired surface from a distance of approximately 750 ft to touchdown. With both the 1200-ft and 800-ft final segments during the 90-degree turns, the paths tended to fluctuate around the desired vertical path. During the 180-degree turns, regardless of the final segment, the actual flightpaths were concentrated above the desired path at the beginning of the turn, then they fell below the desired path either during or just after the turn. It is important to note, however, that overall, the 10-degree approach was flyable.

UH-1H Lateral View. Most of the pilots tended to begin the 45-degree turns, regardless of the related final segment, on the inside of the desired path. However, they did tend to cluster more tightly around the desired path than the corresponding S-76 approaches. On the otherhand, the pilots tended to begin the 90- and 180-degree turns on the outside of the curve. In addition, regardless of final segment, the dispersion of actual paths during the 90- and 180-degree turns was wider. However, for all three turn angles, all paths during the final segment were grouped tightly around the expected path.

UH-1H Vertical View. The final segment length appears to be a factor in whether the pilot stays above the desired course or drops below. In the 45-degree turns with the 1600-ft final segment, the pilots began below the desired surface and tended to stay below throughout the curved portion. By the final segment, they tended to be back on course. The paths for the approaches, using a 45-degree turn with the 1200- and 800-ft final segments, were more centered around the desired path. With the 90-degree

turns, the paths for all three final segments tended to fluctuate around the desired course during the curved portion. Following the 90-degree turn, more of the paths on the 1200- and 800-ft final segments were above the desired course than for the 1600-ft final. At 500-800 ft from the touchdown area, most of the actual paths, except for a small number, were above the surface. The flightpaths during 180-degree turns for all three final segments were concentrated above the desired path both during the turn and during the final segment. Again, it is necessary to point out, the 10-degree approach was flyable.

Overall Observations. Further analysis revealed that, regardless of the turn angle and intended final segment, both the S-76 and UH-1H pilots tended to come out of the turn at a final approach point (FAP) that was approximately 1200 ft from and 200 ft above the touchdown point. Then, from the FAP, they flew a straight-in approach to touchdown.

Of the three turn angles, the 180-degree turns appear to take up the most airspace laterally, while the 45-degree turns had a much smaller lateral dispersion.

However, following the turn to final, the airspace consumed during the 90-degree approaches appears to be the least of all the three curved approaches.

For all three types of approaches, the airspace consumed vertically during the curved portion appears to be as large as 400 ft, and as large as 300 ft during the final segment.

STATISTICAL PLOTS. The statistical plots corresponding to the statistical data found in appendix C, were analyzed to determine the airspace consumed in the lateral and vertical perspective.

Lateral Variations. Both the four and six standard deviation plots of the lateral variation for the curved segment, or radial error, revealed much wider lateral clearances for the 180-degree curves for both aircraft than for the 45- and 90-degree curves. However, the wider lateral clearances were exhibited only during the middle third of the curve.

In contrast, constant envelopes were exhibited with both aircraft for the 45-degree curves and for the 90-degree curves with the S-76. The envelopes for the UH-1H data with a 90-degree curve were not as constant, but the width of the envelopes were similar for the two aircraft. The maximum widths of the envelopes for the 45- and 90-degree curves, with all three final segments, varied from a width of approximately 1300 ft to a width of 2000 ft for the S-76 data with six standard deviations. For the four standard deviation envelopes, the maximum widths for the S-76, 45- and 90-degree curves with all three final segments, varied from approximately 900 to 1300 ft. The maximum widths for the six standard deviation envelopes with the UH-1H were noticeably smaller for the 45-degree curves, from approximately 800 to 1000 ft wide. The maximum widths of the UH-1H envelopes for the four

standard deviation plots varied from approximately 600 to 700 ft with the 45-degree curves, while the envelopes were from 950 to 1200 ft wide for the 90-degree curves. The constant envelopes seen for the 45-degree turns are consistent with what would be expected during normal everyday operations.

Bear in mind that there were no obstacles in the testing area, therefore, the large lateral variations seen during the curved segment would most likely be much smaller if visual references were available.

The lateral variation plots for the straight segment, or crosstrack error, revealed that the 4 and 6 standard deviation envelopes are shaped like a cone laying on its side with widths at the widest end, the beginning of the straight segment, varying from approximately 500 to 1000 ft for the six standard deviation envelopes and from 300 to 650 ft for the four standard deviation envelopes for the S-76. With the UH-1H, the widest end had widths varying from 400 to 600 ft and from 300 to 400 ft for the six and four standard deviation envelopes, respectively. At the smallest end, the portion of the straight segment closest to touchdown, the widths of the envelopes varied from 400 to 500 ft and approximately 300 ft for the S-76 with six and four standard deviations, respectively, and from 200 to 300 ft and 150 to 200 ft for the UH-1H, six and four standard deviations, respectively. These numbers represent the widths from the center of the helicopter.

A summary of these envelope widths can be found in tables 4 through 7. Tables 4 and 5 present the largest observed deviation along with the position in the turn where that deviation occurred. Tables 6 and 7 present the largest observed deviations at the beginning and end of the straight segment.

Vertical Variations. As seen with the composite plots, the statistics plots for both aircraft show that, at the beginning of the turn for the majority of the 45- and 90-degree curves, the pilots tended to be below the requested 500 ft starting altitude. In contrast, with the 180-degree curves, pilots tended to be on, or just slightly above, the intended path. However, the plots of the mean paths for the 45- and 90-degree approaches revealed more of a constant descent during the turn than those for the 180-degree approaches.

The four and six standard deviation envelopes for the curved segment indicate that the airspace must be protected down to the ground.

The plots for the straight segment, for both aircraft and all three turn angles, show that at the beginning of the final segment the mean paths were at or just above the desired altitude and remained at or above through touchdown. As with the curved portion, the four and six standard deviation envelopes take in the airspace all the way to the ground or approximately 100 ft above the ground. As mentioned previously, if there had been an

TABLE 4. SUMMARY TABLE FOR S-76 RADIAL ERROR FOUR AND SIX STANDARD DEVIATION ENVELOPES

Estimated Largest Deviation (in ft)/Position in Turn (degrees)

Turn Angle	Final Segment 800	1200	1600
	± 4 Standard Deviations		
45	± 550/20	± 575/22	± 450/22
90	± 650/40	± 550/40	± 550/40
180	±1200/90	±1275/90	±1200/90
	± 6 Standard Deviations		
45	± 800/20	± 650/22	± 675/22
90	± 975/40	± 825/40	± 800/40
180	±1750/90	±1900/90	±1725/90

TABLE 5. SUMMARY TABLE FOR UH-1H RADIAL ERROR FOUR AND SIX STANDARD DEVIATION ENVELOPES

Estimated Largest Deviation (in ft)/Position in Turn (degrees)

Turn Angle	Final Segment 800	1200	1600
	± 4 Standard Deviations		
45	± 350/20	± 300/18	± 300/18
90	± 600/40	± 550/30	± 475/37
180	± 650/80	± 800/80	± 825/85
	± 6 Standard Deviations		
45	± 500/20	± 425/18	± 425/18
90	± 900/40	± 825/30	± 700/37
180	± 950/80	±1200/80	±1250/85

TABLE 6. SUMMARY TABLE FOR S-76 CROSSTRACK ERROR FOUR AND SIX STANDARD DEVIATION ENVELOPES

Estimated Maximum Deviation (in ft)
Widest Portion/Narrowest Portion

Turn Angle	Final Segment 800	1200	1600
	± 4 Standard Deviations		
45	±225/±150	±275/±150	±275/±150
90	±250/±150	±250/±150	±325/±150
180	±150/±150	±250/±150	±250/±150
	± 6 Standard Deviations		
45	±350/±250	±400/±200	±400/±200
90	±350/±225	±375/±225	±500/±225
180	±250/±225	±375/±200	±375/±200

TABLE 7. SUMMARY TABLE FOR UH-1H CROSSTRACK ERROR FOUR AND SIX STANDARD DEVIATION ENVELOPES

Estimated Maximum Deviation (in ft)
Widest Portion/Narrowest Portion

Turn Angle	Final Segment 800	1200	1600
	± 4 Standard Deviations		
45	±175/±100	±200/±100	±200/±75
90	±200/±100	±150/±75	±200/±75
180	±150/±100	±150/±75	±175/±100
	± 6 Standard Deviation		
45	±250/±150	±300/±150	±300/±100
90	±275/±150	±200/±125	±300/±100
180	±250/±150	±225/±125	±250/±125

obstacle in place during the approach, the envelopes would most likely have been much smaller.

VELOCITY PLOTS. Mean vertical velocities, as well as lateral speeds such as along path and track speeds, for both aircraft were well within the expected limits. During the curved segment, the mean descent rates were less than 800 feet per minute (ft/min), as would be seen in any approach. During the curved segment, the forward speeds averaged close to 70 kt, as requested. On the final segment, the pilots average closure rate was between 30 and 50 kt. These speeds indicate that no unusual velocity changes were needed to complete the maneuvers. The descent rates are consistent with good piloting technique, providing adequate controllability margin, passenger comfort, and airspeed in reserve for unplanned events. It should be noted that the test heliport presented no obstacles, thus, speeds may change under tighter, more restricted conditions. The plots are found in appendixes F and G.

ON-BOARD OBSERVATIONS.

Bank angles for each turn were recorded by the flight data technician. For the 45- and 90-degree turns, bank angles ranged from 10 to 30 degrees. These angles are considered to be acceptable for normal operations. However, with the 180-degree turns, (although most of the bank angles were between 20 to 35 degrees) angles as large as 45 degrees were observed on a few occasions. The large angles seen with the 180-degree turns were most likely due to the following: cross-cockpit maneuver, high angles due to tight turn radius, and occasional adverse crosswinds. With right turns, smaller bank angles would be expected.

IN-FLIGHT PILOT QUESTIONNAIRE.

The Cooper-Harper Pilot Rating Scale used for the in-flight questionnaire employs a one to ten scale. A rating of one to three indicates the maneuver is fully acceptable for routine operations. Ratings of four, five, or six indicate the pilot felt the maneuver would be acceptable only on occasion, as there were more deficiencies, and the safety margin deteriorated. A rating greater than six indicates the subject felt the maneuver should seldom, if ever, be attempted.

Overall, there were 68 maneuvers for each combination of turn angle and final segment for S-76 and 58 for the UH-1H.

To further aid in the analysis, the ratings were grouped into three major categories, from one to three, four to six, and greater than six. These groupings are based on the breakdowns given on the Cooper-Harper Rating Scale as seen in figure 3. Table 8 presents the break down of the number of ratings in each group for each factor.

TABLE 8. DISTRIBUTION OF S-76 IN-FLIGHT RATINGS

	Workload			Safety			Control		
	Group			Group			Group		
	1	2	3	1	2	3	1	2	3
Procedure	Number of Responses								
45°,1600′	65	3	0	63	5	0	64	4	0
45°,1200′	64	3	1	62	5	1	64	4	0
45°, 800′	61	7	0	61	6	1	62	6	0
90°,1600′	60	8	0	59	8	1	61	7	0
90°,1200′	59	9	0	60	7	1	62	6	0
90°, 800′	60	8	0	57	10	1	60	8	0
180°,1600′	59	9	0	56	12	0	56	12	0
180°,1200′	59	8	0	58	9	0	59	8	0
180°, 800′	60	7	0	57	9	1	59	8	0

Group 1 = acceptable procedure for routine operations (ratings of 1-3)
Group 2 = acceptable only on occasion (ratings of 4 to 6)
Group 3 = inadequate safety margin and major deficiencies (ratings >6)

Plots of the in-flight ratings are found in appendixes H and I.

S-76 DATA.

Safety Margin. The figures in appendix H, pages H1 through H9, of the Directorate for Aviation Technology Division Report DOT/FAA/CT-ACD33093/6 present S-76 results for safety margin for the 45-, 90-, and 180-degree turns for all three final segment lengths. As seen, the ratings for all three turn angles for each final segment tend to cluster in the acceptable category. However, one rating indicated inadequate safety margins for all of the 90-degree turn procedures, the 45-degree turn procedures with 1200- and 800-ft finals, and the 180-degree procedures with the 800-ft final segment. Additional examination of the safety ratings indicated that all of the inadequate safety ratings were given by the same pilot. The wind conditions, in excess of 15 kns, during that pilot's flight probably were the major contributing factor to the poor ratings.

The safety ratings, as grouped in table 8, also show the cluster of responses in the acceptable range. However, closer examination of the safety ratings does show a slight decrease in acceptability as the turn angle increased. This holds true when each final segment is compared for each angle, and when each angle is examined regardless of final segment.

Workload. The figures found in appendix H, on pages H10 through H18, present results for workload for the 45-, 90-, and 180-degree turns for all three final segments.

As seen with the safety margin ratings, these results also tended to cluster in the acceptable category for all three turn angles and each final segment. However, there were more ratings of two's and three's for workload than there were for safety. This trend was particularly noticeable with the 180- and 45-degree turns for all three final segments. The acceptable ratings for the 90-degree turn were more closely dispersed among the three acceptable ratings, one, two, or three. Only one pilot rated the workload as unacceptable for the 45-degree with a 1200 ft final.

In addition, that same pilot rated the 45-degree turn with an 800-ft final segment and the 90-degree turn with both a 1600- and 800-ft final segments as barely acceptable. Again, this was the pilot who flew under adverse wind conditions. Examination of the workload ratings, as grouped in table 8, also supports these clusters. As with the safety ratings, the workload ratings tend to show an increase in workload (decrease in acceptability) as the turn angle increased. However, within the 90- and 180-degree turn angle groupings, the ratings for each final segment were basically the same, while those ratings decreased noticeably within the 45-degree turn group for the 800-ft final segment.

Control. The figures found in appendix H, on pages H19 through H27, show the results for controllability for the 45-, 90-, and 180-degree turns for all three final segments. As seen with the safety margin and workload ratings, these ratings also tended to cluster in the acceptable category for all three turn angles and all final segments. However, there were more ratings of two's and three's for control than there were for safety and workload. There were noticeably more ratings of two's for the 45-degree turns with 1600- and 1200-ft final segments, but there were a smaller number of four, five, or six ratings for those two profiles than for any of the others. With the 180-degree turns for all final segments, there were noticeably more ratings falling in the "only on occasion" category. Examination of the control ratings, as grouped in table 8, supports these clusters. The control ratings tend to indicate that the pilots felt there was a decrease in acceptability as the turn angle increased.

UH-1H DATA.

Safety Margin. The figures in appendix I, on pages I1 through I9, present UH-1H results for safety margin during the 45-, 90-, and 180-degree turns for all three final segments.

As seen with the S-76 results, ratings during all three turn angles for each final segment tended to fall into the acceptable category. There were more one's with the 45- and 90-degree turns with a 1600-ft final than for the other procedures. However,

there were also more ratings of four or greater for all the 45- and 90-degree procedures than for the 180-degree procedures.

The safety ratings for the UH-1H, as grouped in table 9, also show that the responses tended to be grouped within the acceptable range.

Workload. The figures found in appendix I, on pages I10 through I18, present the UH-1H workload results for the 45-, 90-, and 180-degree turns for all three final segments.

As seen with the safety margin ratings, the workload ratings also tended to cluster in the acceptable category for all three turn angles and all final segments. However, there were more ratings of two's with the workload results. This trend was particularly noticeable with the 180- and 90-degree turns for all three final segments and with the 45-degree turns for the 1600- and 1200- ft final segments. Only one pilot rated the workload as unacceptable with the 45-degree turn for a 1200 ft final segment.

Examination of the workload ratings, as grouped in table 9, also supports these clusters. As with the safety ratings, the workload ratings tend to show that the workload decreased as the turn angle increased. This is the opposite of what was seen with the S-76 ratings. This difference may be due to the increased visibility in the UH-1H and the different handling qualities.

Control. The figures found in appendix I, on pages I9 through I27, show the UH-1H results for controllability during the 45-, 90-, and 180-degree turns for all three final segments.

These ratings also tended to cluster in the acceptable category for all three turn angles and each final segment. In addition, there was a closer dispersion of one's and two's for these ratings with no unacceptable ratings. As with the safety and workload ratings for the UH-1H, the pilots tended to rate the control issue for the 180-degree turns similarly, or slightly better than the other two turn angles. Examination of the control ratings, as grouped in table 9, supports these observations. This table indicates that the pilots felt there was a noticeable decrease in controllability with the 45-degree turn angle with an 800-ft final segment.

PILOT IN-FLIGHT COMMENTS.

Some of the in-flight comments pertained to safety and passenger comfort. One S-76 pilot felt he would be compromising safety with the right crab angle required to correct for winds with the 45- and 90-degree turns. Others felt the 45-degree turns were harder and required more concentration because of visibility problems with the S-76. The 90- and 180-degree turns brought pilot concern for the passengers. Specific pilot comments concerning passenger comfort with the 180-degree turns were: "passengers in the back wouldn't like it," "passengers would feel uncomfortable," and "with passengers I wouldn't attempt it."

TABLE 9. DISTRIBUTION OF UH-1H IN-FLIGHT RATINGS

	Workload			Safety			Control		
	Group			Group			Group		
	1	2	3	1	2	3	1	2	3
Procedure	Number of Responses								
45°,1600′	56	2	0	53	5	0	57	1	0
45°,1200′	54	3	1	52	5	1	56	2	0
45°, 800′	54	4	0	52	6	0	53	5	0
90°,1600′	55	3	0	55	3	0	56	2	0
90°,1200′	56	2	0	54	4	0	55	3	0
90°, 800′	57	1	0	51	7	0	57	1	0
180°,1600′	57	1	0	55	3	0	56	2	0
180°,1200′	58	0	0	55	3	0	58	0	0
180°, 800′	58	0	0	57	1	0	57	1	0

Group 1 = acceptable procedure for routine operations (ratings of 1-3)
Group 2 = acceptable only on occasion, ratings of 4 to 6
Group 3 = inadequate safety margin and major deficiencies, ratings >6

However, one pilot did feel that the 90- and 180-degree turns could be adjusted to help the passengers feel comfortable but he did not elaborate on this.

POST-FLIGHT QUESTIONNAIRES.

A tabular synopsis of the post-flight ratings for both the S-76 and the UH-1H is found in tables 10, 11, and 12.

S-76. All plots for the S-76 post-flight questionnaire responses can be found in appendix J.

Ratings for Each Turn Angle. Only three of the 18 pilots' overall ratings for the three turn angles, regardless of final segment, were given as marginal. The other 15 pilots appeared to approve of all three turn angles. The pilots did tend to rate the safety margin for the 90-degree turns as more acceptable than the other two turns. There were more bad marginal and inadequate safety ratings for the 180-degree turns. Although the pilots tended to rate the control margin as slightly better with the 90-degree turns than with the other two turn angles, the ratings for all three angles indicate acceptable control margins. In contrast, workload ratings for the 90- and 180-degree turns showed a wider spread, varying from inadequate to adequate. The workload ratings for the 45-degree turns had only three out of the 18 pilots indicating the workload was marginal. As for pilot desirability of each turn angle, at least one pilot rated all

TABLE 10. RANKINGS OF THE POST-FLIGHT TURN ANGLE RATINGS

A/C type	Rating Area	45°	90°	180°
S-76	Overall	1	1	1
	Control Margin	1	1	2
	Workload	1	2	2
	Safety Margin	2	1	2
	Desirability	1	2	2
UH-1H	Overall	3	2	1
	Control Margin	1	1	1
	Workload	3	2	1
	Safety Margin	3	2	1
	Desirability	2	2	1

Note: 1= Generally acceptable, 2= Neutral, 3= Not as acceptable

TABLE 11. RANKINGS OF THE POST-FLIGHT FINAL SEGMENT RATINGS

A/C Type	Rating Area	800 ft	1200 ft	1600 ft
S-76	Control Margin	2	1	1
	Workload	2	1	1
	Safety Margin	3	2	1
	Desirability	3	2	1
UH-1H	Control Margin	2	2	1
	Workload	1	1	1
	Safety Margin	1	1	2
	Desirability	2	1	2

Note: 1= Generally acceptable, 2= Neutral, 3= Not as acceptable

TABLE 12. RANKINGS OF THE POST-FLIGHT RATINGS FOR FINAL SEGMENT BY TURN ANGLE COMBINATIONS

A/C Type	180/ 800	90/ 800	45/ 800	180/ 1200	90/ 1200	45/ 1200	180/ 1600	90/ 1600	45/ 1600
S-76	5	4	3	3	3	2	2	1	3
UH-1H	2	4	4	2	3	4	1	3	4

where 1 = Most acceptable, 3 = Neutral, 5 = Least acceptable

three as less than marginal. The 45- and 90-degree turns did, however, appear to be more desirable than the 180-degree turns.

Ratings for Each Final Segment. All but one of the pilots felt the safety margin for the 1600- and 1200-ft final segments was better than marginal. With the 800-ft final, four pilots felt it was just marginal. The number of above-marginal to adequate ratings for control and workload were similar for all three final segments. However, the 1600- and 1200-ft final segments appear to be slightly more desirable than the 800-ft final segment.

Overall Rating for Turn Angle and Final Segment Combination. Of the combinations, the most desirable or adequate procedure appears to be the 90-degree turn with a 1600-ft final segment. The next most desirable or adequate procedure is the 180-degree turn with 1600-ft final followed by the 45-degree turn with a 1200-ft final segment. The least acceptable procedure is the 180-degree turn followed by the 800-ft final segment.

UH-1H. All post-flight questionnaire plots for the UH-1H can be found in appendix K.

Ratings for Each Turn Angle. At least one pilot gave an overall rating of less than marginal for all three turn angles. However, the plots indicate the UH-1H pilots felt the 180-degree turns were better overall. The overall ratings for the 45-degree turns were more dispersed from inadequate to adequate. Overall, the 90- and 180-degree turns were rated above marginal more than the 45-degree turns. The ratings for a safety margin for each angle also reflect this trend of a wider dispersion of ratings for the 45-degree turns. There were more ratings of four's and five's for the safety margins of the 90- and 180-degree turns. In addition, the ratings for workload were also more varied for the 45-degree turns, indicating the pilots felt more of a demand in performing those procedures. However, the ratings for control were similar for all three angles. Looking at the ratings of desirability for each turn angle, it can be seen that the 90- and 180-degree turn angles were the more acceptable procedures.

Ratings for Each Final Segment. There was at least one less-than-marginal rating for the safety factor for all three final segments. The 1200-ft final segment does appear to be the preferred final approach length as far as the safety issue is concerned. However, the ratings of the control margin were the same for all three final segment lengths. Although there was one workload rating of less-than-marginal for the 1600- and 1200-ft final segment, all three appear to be acceptable as far as the workload issue is concerned. As for the desirability factor of each final segment length, all had at least one below-marginal rating. A similar number of above-marginal desirability ratings were given for all three final segments.

Overall Rating for Turn Angle and Final Segment Combination. Of the combinations, the most desirable or adequate procedure appears to be the 180-degree turn with a 1600-ft final segment. This was followed by both of the other 180-degree turn combination flightpaths. As seen in the plots, appendix K, and from summary table 1, the 45-degree turn combination flightpaths do not appear to be as acceptable as the others.

General Post-Flight Questionnaire Observations. The responses indicate the S-76 pilots preferred the longer 1600-ft final segments, while the UH-1H pilots expressed a desire for the shorter final segments, 1200 or 800 ft. Both groups justified their preferences in terms of having adequate time to clearly re-acquire sight of the landing pad and to adjust the rate of descent and closure for a smooth, controlled approach and landing.

POST-FLIGHT PILOT COMMENTS.

The primary concern for both the S-76 and UH-1H pilots was general passenger comfort. Numerous comments were received concerning the effects of adverse wind conditions, such as a tailwind, on both the pilot and passengers. The following are examples of some of the comments received:

1. "...with the tighter turns and strong tailwind conditions the more the pilot has to compensate and the harder it is on the passengers";

2. "... not desirable for routine passenger carrying operations with tailwind. With headwind/no winds on final approach the three 45-degree maneuvers should be no problem; and the 90-degree procedure should be acceptable, with the shorter final straight segments being less desirable than the long one. For the 180-degree turns the shortest final with the largest turn radius is better than the narrow turn radius. The narrowest turn radius results in too steep a bank angle for routine passenger carrying operations. The middle selection (90-degree) is ok to marginal. The largest turn radius is ok.";

3. "[the 180-degree turns were] easier and less stressful, because you didn't have rapid collective adjustments to make in order to lose airspeed and altitude, however the bank angles would probably make the passengers uneasy";

4. "...while the 180-degree turns gave the best view...the 180-degree turns would be most uncomfortable to the passengers";

5. "...the 180-degree turns would present too much of a bank for the passengers... as a pilot the more the turn the more comfortable the approach...";

6. "...pilots will accept and feel comfortable with steeper bank angles [more] than passengers";

7. "The entry to the 800 foot final borders is unacceptable. Terminating at a confined area with the updrafts associated with urban heliports may make such an approach prohibitively unpleasant for high visibility passengers...";

8. "...the desirability of these type approaches is tempered by the tolerance of the passengers"; and

9. "The 180-degree turns would be of some discomfort for most of the passengers our company transports by helicopter."

Other comments and thoughts from UH-1H pilots included:

1. One pilot found each procedure satisfactory with no undesirable characteristics. He stated the following: "...in the UH-1 at least, the shorter approaches were no more demanding than the longer ones. The 180-degree turn was a tighter approach but did not seem overly demanding."

2. "The apprehension, caution and anxiety I would have under actual conditions would have caused me to terminate many of the approaches I flew today due to loss of visual cues + obstructions."

3. "...the larger turn angle the better the control."

Concerns and comments from S-76 pilots were:

1. "...concern with being out of the 'height-to-velocity' curve especially with tailwind conditions."

2. "...any of these combinations would be practical given normal wind conditions. Areas of above average sustained winds would require pilot techniques that in my opinion, would reach or surpass a normal safety margin."

3. "180- and 90-degree turns allow for altitude loss easier than did 45-degree turns."

4. The 45- and 90-degree approaches were deemed quite comfortable and common in the New York and Philadelphia heliports.

5. "Large tailwinds make it difficult to lose airspeed and maintain glide path w/o over arcing. .... The 180-degree intercept was easier to execute since you actually could increase your maneuver time by varying your angle bank."

CONCLUSIONS

1. At most, 500 feet (ft) of lateral airspace is consumed during the curved segment with the 45-degree turns, approximately 700 to 1000 ft during the 90-degree turns, and as much as 1500 ft during

the 180-degree turns. This is discussed in more detail in the Results section. Plots of this data can be found in appendixes D and E.

2. While the post-flight ratings with the UH-1 indicate the 180-degree turns are acceptable, the 45- and 90-degree curved approaches are more practical, and may be considered for use at a helipad that has certain restrictions, such as obstacles or noise abatement requirements. Pilots acknowledged that, despite the additional demands with flying the 90-degree approaches, 90-degree approaches offered an advantage in area- and landing-pad reconnaissance opportunities. Due to difficulties in performing the 180-degree left turns, and its larger airspace requirements, the 180-degree turns have very limited practical use.

3. While the plots show that all the pilots could adequately perform a landing with an 800-foot final segment, the post-flight and pilot-subjective data indicate the pilots were less comfortable with that final segment and they did not feel they were well established in a landing configuration for passenger-carrying operations. Therefore, for added safety, particularly when flying passengers, the 800-ft final segment would not be acceptable.

4. With four standard deviation envelopes, the lateral dispersions with the 45- and 90-degree turns were as large as ± 650 ft with the S-76, and as large as ± 600 ft with the UH-1H. With the six standard deviation envelopes, these dispersions were as large as ± 975 ft with the S-76 and ± 900 ft with the UH-1H. All dispersions were as much as ± 800 ft larger for the 180-degree turns. In the vertical plane, the dispersions cover all the way to the ground with both the four and six standard deviation envelopes. These dispersions in flightpaths, in both lateral and vertical dimensions, are discussed in depth in the Results section under the area of Statistical Plots. The actual plots can be found in appendixes F and G.

5. Since there were no obstacles in the testing area, the large airspace requirements would most likely be smaller if visual references were available.

6. The evaluated approaches are flyable up to a 10-degree approach angle.

7. Flight tests of curved visual approaches conducted to the left, away from the helicopter pilot-in-command, as these flights were, are most likely considered by helicopter pilots the worst case conditions (cross-cockpit sight picture). Thus, these conclusions are the most conservative, providing the greatest separation and airspace margins. Using right turns during the approach may decrease the lateral and vertical deviations, thereby reducing airspace requirements.

RECOMMENDATIONS

1. Curved approaches with any of the three turn angles (45, 90, 180) would be acceptable for areas that cannot meet the current airspace clearance requirements. However, the 45- and 90-degree turns are preferred. All approaches are flyable up to a 10-degree approach angle.

2. Based on subjective data in conjunction with the flight data, the straight segment following the turn should be no less than 1200 feet (ft).

3. Since these tests were done using left turns to final, differences in obstacle clearance and airspace requirements using right hand patterns are worthy of investigation. Therefore, it is recommended that a minimal number of flights be conducted using the same profiles with right hand turns to the final segment.

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