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AN EVALUATION OF MODIFIED RNAV TERMINAL PROCEDURES USING A SING--ETC(U)
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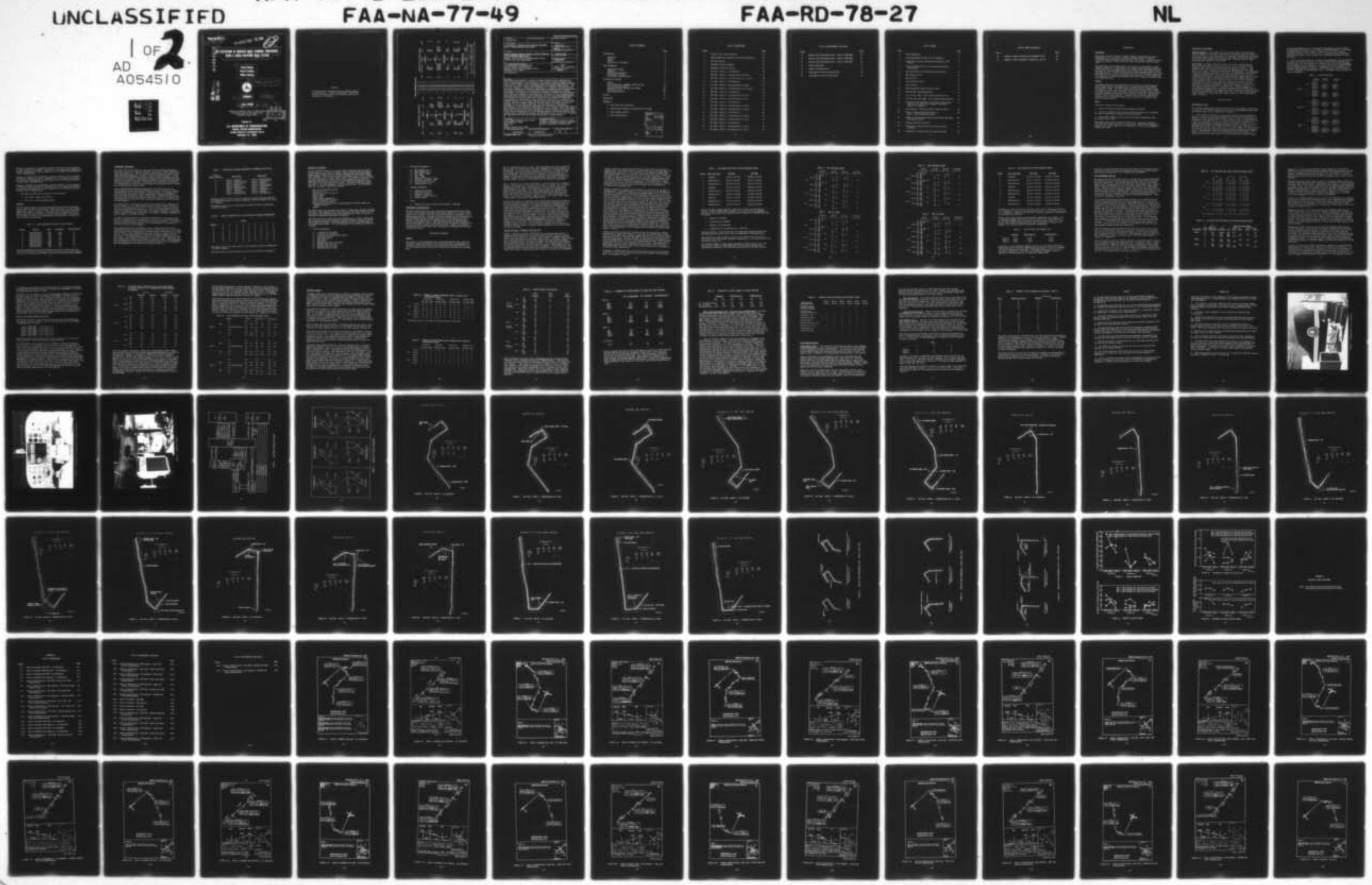

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FOR FURTHER TRAN

AD A054510

AN EVALUATION OF MODIFIED RNAV TERMINAL PROCEDURES USING A SINGLE-WAYPOINT RNAV SYSTEM.

Donald Eldredge,
Bernard Goldberg
William Crimbring

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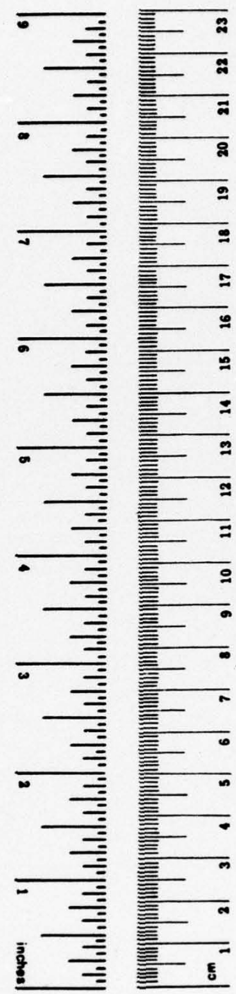
NOTICE

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

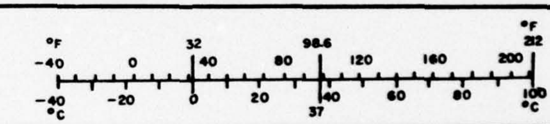
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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16. Abstract

Nine pilots participated in a series of flight simulation tests employing solo pilot techniques which were conducted at the National Aviation Facilities Experimental Center (NAFEC) in order to measure Total System Crosstrack (TSCT) and Flight Technical Error (FTE) using a single-waypoint area navigation (RNAV) system. The tests were designed to assess pilot performance as a function of routes and route structures (consisting of different combinations of waypoints and/or intersections). Performance was measured on the variables: horizontal tracking and procedural performance. The horizontal tracking data included both steady state and transition data. The major findings of this study were: (1) that 10 of the 14 intersections exhibited more variability during transitions than did the corresponding waypoints, (2) the RMS TSCT and FTE steady state statistical data produced no significant trends among the combinations of nine route/route structures, (3) procedural performance (accuracy of data inputs) was affected by the route/route structure combinations, and pilot comments indicated that the design of the RNAV head and its placement in the instrument panel were contributing factors to procedural performance, (4) the procedural requirement for a two-waypoint terminal RNAV instrument procedure which defines the final approach course is valid, (5) an intersection should not be used for an initial approach fix, and (6) distance to waypoint (DTW) fixes should be designated in lieu of waypoints whenever the distance between fixes is less than 5.0 nautical miles (nmi) and the DTW fix is not a turn point. Primarily, DTW fixes should be used for altitude restrictions on final approach.

17. Key Words Total System Crosstrack Error (TSCT) Area Navigation (RNAV) Simulation GAT-2 Flight Technical Error (FTE)		18. Distribution Statement Document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161	
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INTRODUCTION

BACKGROUND.

This study is one of a series of flight simulation experiments designed to investigate 2D, 3D, and 4D area navigation (RNAV) concepts in order to establish minimum operational characteristics (MOC's) and to determine certain operational aspects of RNAV interaction within the National Airspace System (NAS).

This experiment was developed based on the results of a preliminary cockpit simulator evaluation of "simplified versus standard RNAV procedures" performed by the University of Illinois (Report No. FAA-RD-74-148) which demonstrated an advantage for replacing RNAV waypoints with intersections when using a two waypoint RNAV system. In addition, observations during previous RNAV flight tests indicated that pilots did not necessarily input and use all charted waypoints for navigation, but substituted intersections and/or distance to waypoint (DTW) fixes when applicable.

PURPOSE.

The primary purpose of this experiment was to measure pilot performance on modified RNAV terminal procedures using a single-waypoint analog, general aviation RNAV system. The NAFEC Cockpit Simulation Facility (CSF) provided the testbed to collect data concerning Total System Crosstrack Error (TSCT) and Flight Technical Error (FTE) while simulating flight over terminal routes including Standard Instrument Departures (SID's), transitions, and Standard Terminal Arrival Routes (STAR's). A General Aviation Trainer (GAT-2A) was configured with a King KNC-610 RNAV system coupled with a standard Course Deviation Indicator (CDI).

SCOPE.

These tests included the following:

1. The use of three different routes between the airports.

2. The use of different route structures within the same route consisting of various combinations of waypoints and intersections.

3. Two different STAR's and final approaches (North Philadelphia (PNE) and Atlantic City (ACY)).

Nine subject pilots were utilized in these tests. Each pilot completed a 1-1/2 hour data flight over each of the nine route combinations designed as a typical cross country flight for this simulation. A total of 81 simulator flights were flown.

DESCRIPTION OF EQUIPMENT.

COCKPIT SIMULATOR. All testing was done using the Singer-Link GAT-2A/Xerox XDS-530A computer facility which represents a twin-engine, general aviation aircraft (figure 1). For these tests, the GAT-2A was equipped with conventional instruments, dual Navigation/Communication (NAV/COM), King KNC-610 single-waypoint analog RNAV computer, and a standard CDI. Figure 2 shows how these equipments were installed in the GAT-2A.

RNAV SYSTEM. The RNAV system used in these tests was a single-waypoint, station-oriented computer which, in effect, moves the very high frequency omnirange (VOR) position to a phantom location called a "waypoint." The desired course to the waypoint is set with the Omnibearing Selector (OBS) control on the CDI, as is done in conventional VOR navigation. A corresponding course error signal is then shown on the CDI. The magnitude of the deviation is shown in nautical miles (nmi) rather than degrees as is the case with conventional VOR systems. The CDI's noncentered needle swings through a range of ±5 dots (±5/8 inch). When operating in the enroute ("RNAV") mode, the distance between each dot (1/8 inch) represents 1 mile of course deviation. In the approach ("APPR") mode, each dot is equal to a quarter of a mile. A sine/cosine resolution potentiometer was incorporated into the CDI which permitted the accurate measurement of OBS settings made by the pilots. Aircraft DTW is displayed directly on the RNAV unit. Waypoint selection is accomplished by tuning the No. 2 navigation communication (NAV/COM) unit to the proper VOR frequency and entering the proper range (rho) and bearing (theta) for the desired waypoint on the RNAV control head. The GAT-2A, RNAV computer, flight instruments, and the XDS-530A computer (figure 3) were interfaced as shown in figure 4.

DATA COLLECTION

EXPERIMENTAL DESIGN.

The following experimental design was developed for the purpose of determining if operational differences existed when an analog, single-waypoint RNAV system was employed under various experimental conditions.

1. Three different routes, A, B, and C, were utilized and are presented in figure 5. Route A was considered the baseline route and was comprised of six waypoints for both the PNE and ACY STAR's. Routes B and C were considered as variations of the baseline route. An examination of figure 5 reveals that the flight task complexity for the route B and C variations was lowered by the reduction in the number of waypoints defining the STAR's. Routes B and C were characterized by fairly long segments between E and H, and E and R for the PNE STAR, and between P and V, and P and S for the ACY STAR. The total distance of these four legs was always less than the distance required by the standard Route A configurations. The route configurations were established as "mirror image" courses in that the ACY to PNE course was duplicated as nearly as possible for the PNE to ACY course. The only differences in segment lengths

and course headings were due to the angular displacement of the two runway configurations and the use of two different VOR/TACAN (VORTAC's). The reason for establishing the "mirror image" courses was to be able to obtain a replication for each of the route structure combinations and to establish a sufficient data base in order to make valid conclusions regarding the route variations.

2. Each of the three routes (A, B, and C) were established with three different route structures consisting of different combinations of waypoints and intersections. The first combination (number 1) was considered the <u>standard</u> and was composed of all waypoints (i.e., subject pilots were required to tune in each waypoint without exception). Combinations 2 and 3 consisted of the different configurations of waypoints and intersections outlined in table 1, and were considered as modifications 1 and 2. Individual route structures are found in appendix A.

TABLE 1. ROUTE DEFINITIONS

		Route A Definitions	Route B Definitions	Route C Definitions
Standard	PNE	Waypoint F	---	---
		Waypoint G	---	---
		Waypoint H	Waypoint H	Waypoint R
		Waypoint I	Waypoint I	Waypoint I
		Waypoint J	Waypoint J	Waypoint J
		Waypoint K	Waypoint K	Waypoint K
	ACY	Waypoint T	---	---
		Waypoint U	---	---
		Waypoint V	Waypoint V	Waypoint S
		Waypoint W	Waypoint W	Waypoint W
		Waypoint X	Waypoint X	Waypoint X
		Waypoint Y	Waypoint Y	Waypoint Y
Modification No. 1	PNE	Waypoint F	---	---
		Waypoint G	---	---
		Intersection H	Intersection H	Intersection R
		Waypoint I	Waypoint I	Waypoint I
		Intersection J	Intersection J	Intersection J
		Waypoint K	Waypoint K	Waypoint K
	ACY	Waypoint T	---	---
		Waypoint U	---	---
		Intersection V	Intersection V	Intersection S
		Waypoint W	Waypoint W	Waypoint W
		Intersection X	Intersection X	Intersection X
		Waypoint Y	Waypoint Y	Waypoint Y
Modification No. 2	PNE	Waypoint F	---	---
		Intersection G	---	---
		Waypoint H	Waypoint H	Waypoint R
		Intersection I	Intersection I	Intersection I
		Intersection J	Intersection J	Intersection J
		Waypoint K	Waypoint K	Waypoint K
	ACY	Waypoint T	---	---
		Intersection U	---	---
		Waypoint V	Waypoint V	Waypoint S
		Intersection W	Intersection W	Intersection W
		Intersection X	Intersection X	Intersection X
		Waypoint Y	Waypoint Y	Waypoint Y

Figures A-1 through A-12 of appendix A present the Route A route structures for both the PNE and ACY STAR's. Figures A-1 to A-4 compose the standard (all waypoint configuration), whereas figures A-5 to A-12 make up the modification 1 and 2 configurations.

Figures A-13 through A-24 of appendix A present the Route B route structures for both the PNE and ACY STAR's. Figures A-13 to A-16 compose the standard (all waypoint configuration), whereas figures A-17 to A-24 make up the modification 1 and 2 configurations.

Figures A-25 through A-36 of appendix A present the Route C route structures for both the PNE and ACY STAR's. Figures A-25 to A-28 compose the standard (all waypoint configuration), whereas figures A-29 to A-36 make up the modification 1 and 2 configurations.

3. Two different STAR's were utilized in this experiment:

a. ACY to PNE - Medford One arrival.

b. PNE to ACY - NAFEC One RNAV arrival.

SUBJECTS.

The nine subjects used in this experiment were selected from the available active, general-aviation-type pilots at NAFEC (see table 2 for their range of experience). Three of the nine subjects had limited experience flying with RNAV in the NAFEC Aero Commander. The subject pilots' experience with the GAT-2A ranged from 0 to 50 hours on projects other than RNAV. All subjects were required to complete two preexperimental familiarization flights prior to the actual data collection.

TABLE 2. FLIGHT EXPERIENCE IN HOURS OF PILOT SUBJECTS

Subject	License	Total	Instrument	Previous GAT-2A
1	Comm/Inst/Multi	1800	300	0
2	Comm/Inst/Multi	4000	1000	50
3	Comm/Inst/Multi	402	77	1
4	Comm/Inst/Multi	1500	175	20
5	Comm/Inst/Multi	450	120	15
6	Comm/Inst/Multi	2500	275	25
7	Comm/Inst/Multi	2900	190	35
8	Comm/Inst/Multi	3000	700	35
9	Comm/Inst/Multi	1500	122	0

The familiarization flights were designed to acquaint the pilots with the route structure and the procedures to be used in the data collection flights, as well as to familiarize the subjects with the GAT-2A and the RNAV equipment.

EXPERIMENTAL PROCEDURES.

All pilots were given written and oral instructions regarding experimental objectives, use of the navigation equipment, and specific flight task requirements (see appendix B). The instructions stressed adherence to specific airspeeds which were designated for climb, cruise, and final approach. In addition, the route geometry was discussed, and route charts and approach plates were given to the pilots. The pilots were instructed to anticipate the turns; however, no particular turn anticipation technique or procedure was specified. This task was left to the pilot. Furthermore, the pilots were instructed to fly the particular route/route structure exactly as specified and not to modify any procedure during a given flight.

After completing the preliminary instructions, each pilot was given two familiarization flights (each approximately 1 hour in duration) on a specific familiarization route which included a missed approach. To complement both the familiarization and data flights, instrument clearances were given to direct the pilots throughout their intended course. Moderate values of wind velocities were initiated and changed at specific points in the routings, and mild turbulence was introduced after takeoff and withdrawn just prior to turn on final approach.

The flight courses for the baseline route A and routes B and C variations are shown in figure 5. The flight courses shown were "mirror image" courses in that the route between ACY and PNE for a given route/route structure combination was duplicated between PNE and ACY. One can see from figure 5 that the flight task complexity for routes B and C was reduced, relative to the baseline route A, primarily through a reduction in the number of waypoints defining the routes (STAR's) to both PNE and ACY.

The order of presentation of the different combinations of route/route structure was counterbalanced across subjects for each of the nine possible combinations of waypoints and/or intersections as depicted in table 3. In this study intersections were defined as either (a) the intersection of two radials or (b) a DTW fix along a route segment.

These combinations were established in order to control the effects due to learning since each pilot was required to fly the same route (A, B, or C) three times under different combinations of waypoints and/or intersections for a total of nine flights. These combinations were used in order to avoid a bias in the data due to increasing degrees of learning for subsequent flights over the same course. All flights originated from ACY and flew to PNE (where the pilots were issued a missed approach procedure) and then back to ACY. Therefore, the nine combinations of route/route structure presented in table 3 were established. The nine combinations of route/route structure and their order of presentation were counterbalanced across subjects as outlined in table 4.

TABLE 3. ROUTE/ROUTE STRUCTURE COMBINATIONS PRESENTED TO THE PILOTS

Route/ Route Structure	ACY To PNE	PNE to ACY
1	Route A Standard*	Route B Modification 1
2	Route A Modification 1**	Route B Modification 2
3	Route A Modification 2	Route B Standard
4	Route B Standard	Route C Modification 1
5	Route B Modification 1	Route C Modification 2
6	Route B Modification 2	Route C Standard
7	Route C Standard	Route A Modification 2
8	Route C Modification 1	Route A Standard
9	Route C Modification 2	Route A Modification 1

*Standard refers to the fact that all waypoint locations along the STAR and final approach course were treated as waypoints, and were required to be input for navigation.

**The modifications were the combinations of waypoints and/or intersections outlined in table 1.

TABLE 4. ORDER OF PRESENTATION OF THE ROUTE/ROUTE STRUCTURE COMBINATIONS

	Trials								
Subject	1	2	3	4	5	6	7	8	9
1	1*	2	3	4	5	6	7	8	9
2	3	1	2	6	4	5	9	7	8
3	2	3	1	5	6	4	8	9	7
4	7	8	9	1	2	3	4	5	6
5	9	7	8	3	1	2	6	4	5
6	8	9	7	2	3	1	5	6	4
7	4	5	6	7	8	9	1	2	3
8	6	4	5	9	7	8	3	1	2
9	5	6	4	8	9	7	2	3	1

*The numbers within this table refer to the route/route structure combinations outlined in table 3.

The route charts for each route/route structure are presented in appendix A.

STATISTICAL TREATMENT.

The Xerox XDS-530A (figure 3) computer software interfaced with the GAT-2A cockpit simulator and read into computer memory analog and digital signals using analog-to-digital (A/D) conversion equipment and direct input/output (DIO) equipment. The data were collected on magnetic tape, with a 1-second clock interrupt used to control system timing. The format on the data collection tape consisted of a header record at the beginning of the tape and sequential data records; one record for each second of simulation run time. Both record types were 180 words in length. The header record was created from card input at the beginning of each GAT-2A data run. The information input via the header record was as follows:

Type of test identifying label
Date (Mo: D: Yr)
Problem start time (H: Min: S)
Subject number
Subject name
Flight number (sequential)
Aircraft identification (ACID)
Subject replication number
Experimentation design matrix interexperimental variable number and number of levels
Comments

The header record had an easy-to-use, specific format which served to identify the data at data reduction time, since these data were output directly to the data tapes. The remainder of the record contained zero data, but could be modified for additional information as desired.

Each data item within a data record was represented by a 16-bit, fixed-point word recorded from raw-form analog and digital voltages as acquired from the GAT-2A interface devices. Provisions were made for up to 180 data items to be recorded every second. For this experiment, the following data items were recorded:

1. Aircraft parameters:

   a. X position of the GAT-2A
   b. Y position of the GAT-2A
   c. Z position (altitude) of the GAT-2A
   d. Indicated airspeed
   e. Wind velocity
   f. Wind angle
   g. Heading (earth axis yaw angle)
   h. Aircraft axis roll rate
   i. Aircraft axis pitch rate
   j. Indicated rate of climb

2. Navigation parameters:

   a. NAV frequency No. 1
   b. NAV frequency No. 2
   c. Mode switch - RNAV
   d. Rho - RNAV
   e. Theta - RNAV
   f. Distance to waypoint - RNAV
   g. OBS course set knob - CDI
   h. Course deviation - CDI
   i. To/from arrow - CDI

3. Computed parameters:

   a. Crosstrack deviation
   b. Along-track deviation
   c. Distance to wayline
   d. Distance to angle bisector
   e. Segment number

4. Time:

   a. Elapsed time from 1-second clock interrupt - XDS-530A

EXPERIMENTAL CONSIDERATIONS.

The ACY to PNE and the PNE to ACY courses were constructed as mirror images in terms of turn angles, headings, and segment lengths, and, as such, it was expected that the data on one part of the course would be equivalent to the data on the other part. The major difference between the two courses was that the ARD VORTAC which was located 12 nmi NE of the PNE airport was used for approach to PNE, whereas the ACY VORTAC (used for the ACY approach) was located on the airport itself. DME signal processing problems associated with the ARD VORTAC as well as other GAT-2A facility problems introduced into the data precluded a complex statistical analysis. However, the analysis conducted in this report takes into consideration any problems that may have occurred in the data.

DISCUSSION OF RESULTS

GENERAL.

The results of these simulation tests, using the baseline route A and route variations B and C and procedures in the terminal area, are presented for horizontal (crosstrack) control, both steady state and transition data, and for the procedural tasks involved with entering the waypoints into the RNAV unit.

FTE is a contributing factor to TSCT. TSCT represesents the actual deviations left or right of a course centerline while navigating to or from a waypoint or intersection. For the purpose of analysis, deviations to the right of course are indicated as positive, whereas deviations to the left of course are indicated as negative. Deviation values are expressed in nautical miles and represent the aircraft's position as it would have been tracked during actual flight. Although in actual flight VOR/DME signal errors would contribute to the TSCT budget, they were not introduced into the simulation environment.

FTE is a measure of the actual displacement of the CDI needle left or right of course. Its accuracy is affected by the precision of the OBS, rho, and theta settings made by the pilot. Displacements of the CDI needle to the right (indicating that the aircraft is acually left of course) are expressed as positive values in the data. Left needle displacements are negative values. These values represent the amount in nautical miles by which the pilot must correct his actual position in the direction of the needle displacement in order to be on course. Therefore, when the pilot is off course, there exists a high, negative correlation between TSCT and FTE.

The time series data for horizontal error TSCT and FTE were edited in order to delete all erroneous data due to electrical spikes and transients as well as for data which was erroneous due to tuning new waypoints (including OBS, rho, theta, and frequency changes). The edited data were then separated into steady-state tracking data and transition (or turning) data. Initially the turning data were extracted using a "window" width of 2.0 nmi prior to and after each turn point (waypoint or intersection). The angle bisector of the turn angle was used to determine when the aircraft had passed the waypoint or intersection. As a secondary measure, in order to insure that the turn data were indeed within the ±2.0 nmi window, the actual turn data were determined manually by using <u>rate of change of heading data</u> as the key parameter. As a result, it was found that a ±4.0 nmi "window" was required to adequately encompass all the turn data. The steady-state data were then used to calculate summary statistics for the individual segments and the extracted transition data were used to calculate summary statistics for the turns within the SID's and STAR's.

<u>STEADY-STATE DATA - SEGMENTS (TSCT AND FTE)</u>.

Figures 6 through 23 present the RMS TSCT error statistical data and the composite plots (showing the total system crosstrack error data for all nine subjects) for all routes (A, B, and C), route structures (standard, modification 1, and modification 2), and STAR's (PNE and ACY). Included in these figures are the RMS total system crosstrack statistics associated with each segment within the STAR and each turn within the STAR. Also included in these figures are the RMS total system crosstrack statistics for the entire STAR as well as the base leg segments and the final approach segments. The RMS TSCT error data is presented in these figures because it is indicative of the variability associated with flying a single-waypoint RNAV system in a terminal area environment.

Figures 6 through 11 present the statistical data and plots for the Route A configurations. From these figures, it can be seen that for the PNE STAR, the standard route structure (i.e., all waypoints), the individual segment RMS TSCT ranged between 0.251 to 0.338 nmi. The modifications 1 and 2 resulted in RMS TSCT of 0.216 to 0.466 nmi and 0.220 to 0.417 nmi, respectively. For the ACY STAR, the RMS TSCT for the standard route structure ranged between 0.098 to 0.633 nmi, whereas modifications 1 and 2 resulted in RMS TSCT of 0.142 to 0.370 nmi and 0.123 to 0.442 nmi, respectively. From these data, it would appear that the overall 2 RMS TSCT tracking data for both the Route A PNE and ACY STAR's were well within the $\pm$2.0 nmi allowable error established in AC 90-45A for the terminal area.

Figures 12 through 17 present the statistical data and plots for the Route B configurations. From these figures, it can be seen that for the PNE STAR, the RMS TSCT for the standard route structures ranged between 0.155 to 0.317 nmi, whereas modifications 1 and 2 resulted in RMS TSCT of 0.154 to 0.271 nmi and 0.218 to 0.326 nmi, respectively. For the ACY STAR, the RMS TSCT for the standard route structure ranged between 0.129 to 0.471 nmi, whereas modifications 1 and 2 resulted in RMS TSCT of 0.140 to 0.764 nmi and 0.338 to 0.799 nmi, respectively. From these data it would appear, except for two cases, that the overall 2 RMS TSCT data for both the Route B PNE and ACY STAR's were well within the $\pm$2.0 nmi allowable error established in AC 90-45A for the terminal area. The two exceptions occurred within the ACY STAR, for modifications 1 and 2. The modification 1 exception occurred within the V-W segment and was the direct result of the dispersion of tracking data at or near the "V" intersection (figure 16). The dispersion of data around this intersection was influenced by a problem with the rho (DME) distance calculation in the GAT-2, and as such caused the relatively short V-W segment to have an inflated amount of RMS variability. The second exception occurred for modification 2 and once again involved an intersection. The intersection at "W" had an inflated amount of RMS variability due to an excessive number of pilot errors and blunders. This variability in turn influenced the steady state variability for the segment between the "W" and "X" intersections (reference figure 11). From this data it may be argued that intersections can have an adverse influence on the pilot's tracking capability in the terminal area and should be used with some degree of caution.

Figures 18 through 20 present the statistical data and plots for the Route C configurations. From these figures it can be seen for the PNE STAR, the RMS TSCT for the standard route structure ranged between 0.275 to 0.479 nmi, whereas modifications 1 and 2 resulted in RMS TSCT of 0.212 to 0.415 nmi and 0.240 to 0.543 nmi respectively. For the ACY STAR, the RMS TSCT for the standard route structure ranged between 0.156 to 0.449, whereas modifications 1 and 2 resulted in RMS TSCT of 0.149 to 0.401 nmi and 0.102 to 0.405 nmi. From these data, it would appear that the overall 2 RMS TSCT tracking data for both the Route C PNE and ACY STAR's were well within the $\pm$2.0 nmi allowable error established in AC 90-45A for the terminal area.

In summary, the RMS steady-state total system crosstrack errors for the three routes (A, B, and C) and the three route structures (standard, modifications 1 and 2) are presented in table 5.

TABLE 5. RMS STEADY-STATE TOTAL SYSTEM CROSSTRACK ERRORS

Route	Route Structure	PNE STAR	ACY STAR
A	Standard	±0.251 to ±0.338	±0.098 to ±0.633
A	Modification 1	±0.216 to ±0.466	±0.142 to ±0.370
A	Modification 2	±0.220 to ±0.417	±0.123 to ±0.442
B	Standard	±0.155 to ±0.317	±0.129 to ±0.471
B	Modification 1	±0.154 to ±0.271	±0.140 to ±0.764
B	Modification 2	±0.218 to ±0.326	±0.338 to ±0.799
C	Standard	±0.275 to ±0.479	±0.156 to ±0.449
C	Modification 1	±0.212 to ±0.415	±0.149 to ±0.401
C	Modification 2	±0.240 to ±0.543	±0.102 to ±0.405

Tables 6 through 9 present RMS TSCT, RMS FTE, mean TSCT, and mean FTE as a function of the interexperimental variables for each of the route segments. The data in these tables are categorized based on whether the segment was flown as follows:

1. Waypoint to waypoint
2. Intersection to waypoint
3. Waypoint to intersection
4. Intersection to intersection (i.e., DTW fix)

From these tables, it can be seen that the steady-state tracking task was not systematically affected by any of the four combinations listed previously.

RMS steady-state flight technical errors for the three routes (A, B, and C) and the three route structures (standard, modification 1, and modification 2) are presented in table 10.

Even though a number of these values exceeded the 2 RMS criteria of ±1.0 nmi (12 out of 84, table 7), established by AC 90-45A for the terminal area environment, 86 percent of the FTE values were within the ±1.0 nmi criteria.

TABLE 6. RMS CROSSTRACK ERROR

			Wpt to Wpt			Int to Wpt			Wpt to Int			Int to DTW Fix		
			Std	Mod 1	Mod 2	Std	Mod 1	Mod 2	Std	Mod 1	Mod 2	Std	Mod 1	Mod 2
Route A	PNE STAR	E-F	.338	.280	.373									
		F-G	.251	.373							.417			
		G-H	.288					.258		.265				
		H-I	.277				.466				.408			
		I-J	.301							.420				.392
		J-K	.326				.216	.220						
	ACY STAR	P-T	.425	.370	.363									
		T-U	.228	.172							.268			
		U-V	.469					.389		.289				
		V-W	.633				.348				.442			
		W-X	.273							.275				.375
		X-Y	.098				.142	.123						
Route B	PNE STAR	E-H	.214		.326					.271				
		H-I	.289				.221				.299			
		I-J	.317							.212				.312
		J-K	.155				.154	.218						
	ACY STAR	P-V	.471		.384					.493				
		V-W	.467				.764				.348			
		W-X	.400							.320				.799
		X-Y	.129				.140	.338						
Route C	PNE STAR	E-R	.280		.240					.415				
		R-I	.479				.304				.255			
		I-J	.309							.308				.543
		J-K	.275				.212	.522						
	ACY STAR	P-S	.449		.405					.354				
		S-W	.314				.166				.226			
		W-X	.206							.401				.372
		X-Y	.156				.149	.102						

TABLE 7. RMS FTE ERROR

			Wpt to Wpt			Int to Wpt			Wpt to Int			Int to DTW Fix		
			Std	Mod 1	Mod 2	Std	Mod 1	Mod 2	Std	Mod 1	Mod 2	Std	Mod 1	Mod 2
Route A	PNE STAR	E-F	.369	.301	.341									
		G-F	.237	.367							.423			
		G-H	.351					.593		.320				
		H-I	.386				.576				.317			
		I-J	.343							.487				.395
		J-K	.363				.277	.218						
	ACY STAR	P-T	.429	.345	.316									
		T-U	.257	.238							.368			
		U-V	.926					.868		.266				
		V-W	.433				.324				.478			
		W-X	.309							.284				.617
		X-Y	.134				.209	.113						
Route B	PNE STAR	E-H	.288		.394					.284				
		H-I	.415				.264				.446			
		I-J	.553							.258				.287
		J-K	.220				.358	.240						
	ACY STAR	P-V	.315		.324					.271				
		V-W	.310				.707				.304			
		W-X	.434							.393				1.269
		X-Y	.172				.153	.391						
Route C	PNE STAR	E-R	.412		.286					.348				
		R-I	.581				.416				.660			
		I-J	.343							.358				.872
		J-K	.275				.330	.342						
	ACY STAR	P-S	.305		.253					.288				
		S-W	.302				.253				.296			
		W-X	.196							.404				.605
		X-Y	.173				.149	.118						

TABLE 8. MEAN CROSSTRACK ERROR

			Wpt to Wpt			Int to Wpt			Wpt to Int			Int to DTW Fix		
			Std	Mod 1	Mod 2	Std	Mod 1	Mod 2	Std	Mod 1	Mod 2	Std	Mod 1	Mod 2
		E-F	.105	.069	.134									
		F-G	.173	.215							.268			
		G-H	-.047					-.083		.178				
	PNE STAR	H-I	-.004				-.177				.076			
		I-J	.032							-.324				.249
		J-K	.050				.037	.115						
Route A														
		P-T	-.135	-.126	-.090									
		T-U	.032	.018							.138			
		U-V	-.248					.004		-.058				
	ACY STAR	V-W	-.486				-.017				-.140			
		W-X	-.060							-.146				-.151
		X-Y	.052				.037	-.033						
		E-H	.070		.072					-.130				
	PNE STAR	H-I	-.197				-.103				.019			
		I-J	-.054							.013				.177
		J-K	.041				.038	.071						
Route B														
		P-V	-.220		-.111					.184				
	ACY STAR	V-W	-.447				.237				-.294			
		W-X	.089							-.011				-.170
		X-Y	.052				.011	-.122						
		E-R	.029		-.087					.313				
	PNE STAR	R-I	-.310				-.032				-.039			
		I-J	-.163							-.158				-.157
		J-K	.054				.023	.327						
Route C														
		P-S	-.177		-.262					-.191				
	ACY STAR	S-W	-.005				-.037				-.037			
		W-X	-.042											-.002
		X-Y	.101				.061	.015						

TABLE 9. MEAN FTE ERROR

			Wpt to Wpt			Int to Wpt			Wpt to Int			Int to DTW Fix		
			Std	Mod 1	Mod 2	Std	Mod 1	Mod 2	Std	Mod 1	Mod 2	Std	Mod 1	Mod 2
		E-F	.054	-.026	-.015									
		F-G	-.036	-.126							.005			
		G-H	-.213					-.037		-.192				
	PNE STAR	H-I	.069				.088				.114			
		I-J	.171							.416				-.183
		J-K	.250				.030	-.010						
Route A														
		P-T	.035	.166	.132									
		T-U	-.058	.037							.183			
		U-V	.521					.330		.158				
	ACY STAR	V-W	.172				-.165				.068			
		W-X	-.008							.049				-.197
		X-Y	-.052				-.035	.027						
		E-H	.077		.140					.075				
	PNE STAR	H-I	.322				.217				.331			
		I-J	.370							.158				-.039
		J-K	.098				.113	.012						
Route B														
		P-V	-.011		-.016					.100				
	ACY STAR	V-W	.056				-.570				.078			
		W-X	-.129							-.044				-.351
		X-Y	-.044				.031	.148						
		E-R	.077							061				
	PNE STAR	R-1	.480				.179				-.013			
		I-J	.278							.266				.759
		J-K	.125				.156	.043						
Route C														
		P-S	.037		.071					.155				
	ACY STAR	S-W	-.098				-.099				-.017			
		W-X	.128							-.154				-.129
		X-Y	-.047				-.013	.008						

TABLE 10. RMS STEADY-STATE FLIGHT TECHNICAL ERRORS

Route	Route Structure	PNE STAR	ACY STAR
A	Standard	±0.237 to ±0.386	±0.134 to ±0.926
A	Modification 1	±0.277 to ±0.576	±0.209 to ±0.345
A	Modification 2	±0.218 to ±0.593	±0.113 to ±0.868
B	Standard	±0.220 to ±0.553	±0.172 to ±0.434
B	Modification 1	±0.258 to ±0.358	±0.153 to ±0.707
B	Modification 2	±0.240 to ±0.446	±0.304 to ±1.269
C	Standard	±0.275 to ±0.581	±0.173 to ±0.305
C	Modification 1	±0.330 to ±0.416	±0.149 to ±0.404
C	Modification 2	±0.286 to ±0.872	±0.118 to ±0.605

In summary, for both the TSCT and FTE data, there were no significant differences between the four different configurations in which the segments were flown (i.e., waypoint to waypoint, intersection to waypoint, waypoint to intersection, and intersection to DTW fix).

However, some trends, while not statistically significant, are notable. Due to equipment problems noted earlier, the ACY data was put aside temporarily, and the super-segment data for the TSCT for PNE is shown in table 11. It can be seen that the pilots generally did a more accurate job of flying the all waypoint case than the intersection/waypoint combinations.

TABLE 11. TSCT PNE RMS SUPER-SEGMENT DATA

	Standard	Modification 1	Modification 2
Route A	0.272	0.337	0.333
Route B	0.282	0.356	0.334
Route C	0.388	0.489	0.357

In addition to the individual segments, the data for the entire PNE and ACY STAR's were used to calculate "super-segment" statistics in order to determine the overall operational performance of the RNAV system in each of the route structure combinations. These data are presented in appendix C and are analyzed in the same manner as the individual segment data.

Therefore, the remaining data analysis in this report will concentrate on the turn data in order to determine if significant differences do exist between intersections and waypoints in the terminal area environment.

TURN PERFORMANCE ANALYSIS.

As stated in the data collection section, turn data were reduced and analyzed for both ±2.0 nmi and ±4.0 nmi along track distance either side of each waypoint and intersection. This section deals with the impact of replacing a waypoint with an intersection at various points along an RNAV route. Table 12 shows the mean and RMS TSCT error for the turns involved in the PNE and ACY routes. The data in this table are computed based on the time series data starting 2.0 nmi before the waypoint (and/or intersection) and ending 2.0 nmi after the waypoint (and/or intersection). From the data in this table, it can be seen that 10 of the 14 cases involving intersections demonstrated more variability (in terms of RMS error) than the corresponding waypoints. These 10 cases are underlined in table 12.

The increased variability associated with flying to an intersection is the result of increased workload and is probably equivalent to the variability associated with flying IFR and using a single-VOR receiver to navigate to an intersection. The workload increases as the pilot approaches the intersection because, in order to determine when he is over the intersection, the pilot, in advance, must tune in the next waypoint, set the OBS to the next course, and wait for the CDI needle to center. During this time period no crosstrack guidance is availible to the pilot. He maintains his last heading until the CDI needle approaches the center, at this point the pilot should initiate a turn to the next course since he is approximatly at the intersection. An alternative to this method would be to use DTW distance. If the distance from a waypoint to an intersection is known (e.g., from a chart), the pilot can fly a set DTW distance and initiate the turn to the next course at that distance. In this study, even though the DTW distances were depicted on the charts the pilots rarely used them, and treated an intersection in the same manner as single station VOR intersection.

Table 13 presents the RMS crosstrack error data for the three routes (A, B, and C) for the PNE STAR using data 4 nmi prior to and after the turn point. The data in this table is organized by waypoint and intersection categories for the applicable turns on each route. Turn magnitude, turn direction, and RMS variability are shown. A similar table for the ACY STAR is shown in table A-1 of appendix A.

The data in table 13 must be examined carefully to determine specific effects due to waypoints being used as intersections. In order to do this, a figure has been prepared (figure 24) which shows the corresponding composite track data for route A. Figure 24 shows the standard, modification 1, and modification 2 turn data for route A. Figure 25 shows the standard, modification 1, and modification 2 turn data for route B. Figure 26 shows the standard, modification 1, and modification 2 turn data for route C.

TABLE 12. ±2.0 NMI TURN DATA--TOTAL SYSTEM CROSSTRACK ERROR

			Standard		Modification-1		Modification-2	
			Mean	RMS	Mean	RMS	Mean	RMS
Route A	PNE	G	.218	(45°) .308 WPT	.241	(45°) .320 WPT	.196	(45°) .345 INT
		H	-.101	(90°) .300 WPT	-.051	(80°) .409 INT	-.091	(90°) .310 WPT
		I	-.003	(90°) .303 WPT	-.212	(90°) .410 WPT	.212	(90°) .505 INT
	ACY	U	-.253	(45°) .390 WPT	-.103	(45°) .260 WPT	.288	(45°) .362 INT
		V	-.404	(90°) .531 WPT	.136	(90°) .354 INT	-.171	(90°) .364 WPT
		W	-.099	(90°) .395 WPT	-.047	(90°) .340 WPT	-.064	(90°) .419 INT
Route B	PNE	H	-.031	(30°) .186 WPT	-.156	(30°) .327 INT	.020	(30°) .222 WPT
		I	-.012	(90°) .311 WPT	.022	(90°) .265 WPT	.114	(90°) .362 INT
	ACY	V	-.522	(30°) .549 WPT	1.026	(30°) 1.157 INT	-.315	(30°) .383 WPT
		W	-0.52	(90°) .486 WPT	.038	(90°) .517 WPT	-.100	(90°) .564 INT
Route C	PNE	R	-.052	(90°) .428 WPT	.408	(90°) .654 INT	.008	(90°) .281 WPT
		I	-.183	(45°) .404 WPT	-.102	(45°) .293 WPT	-.152	(45°) .534 INT
	ACY	S	.293	(90°) .422 WPT	-.027	(90°) .304 INT	-.163	(90°) .281 WPT
		W	.031	(45°) .240 WPT	.145	(45°) .427 WPT	.208	(45°) .347 INT

NOTE: Underlined numbers in table indicate intersection RMS data which exceeded waypoint variability.

TABLE 13. ±4.0 NMI TURN DATA (PNE)-TOTAL SYSTEM CROSSTRACK ERROR

				RMS Crosstrack (nmi)				
		Turn			Waypoint		Intersection	
Route/STAR	Turn Point	Magnitude (Degrees)	Turn Direction	Std	Mod 1	Mod 2	Mod 1	Mod 2
A/PNE	G	≈45	Right	.281	.297	-	-	.357
	H	90	Left	.296	-	.357	.375	-
	I	90	Left	.288	.423	-	-	.454
B/PNE	H	≈30	Left	.247	-	.247	.254	-
	I	90	Left	.297	.194	-	-	.336
C/PNE	R	≈80	Left	.383	-	.340	.620	-
	I	45	Left	.451	.280	-	-	.542

Figures 24, 25, and 26 are presented as typical examples of the relative difference in turn performance between waypoints and intersections at the same points. The examples shown here are actual composite tracks from the base leg/final approach portion of the PNE Route A, B, and C STAR's. Further comparisons may be made by examining the data and composites which can be found in appendix C.

Examination of table 13 and figure 24 shows the following trends. First, for the route A/PNE configuration (all waypoints), the RMS data is always less than 0.300 nmi (0.281, 0.296, 0.288). When waypoint H is changed to an intersection, two results occur. As would be expected from the workload analysis previously discussed, the RMS error at H increases to 0.375 nmi (Mod 1--intersection at H). Second, the intersection at H and the increased variability during this turn are also reflected in the increased RMS error at waypoint I (0.423 versus 0.288) due to the fact that this is only a 5-nmi segment (H to I) and the ±4 nmi data aggregation correctly shows this variability.

Similarly, in comparing modification 2 on the route A/PNE STAR to the standard route, it can be seen that the intersection at G and I signficiantly increased RMS variability (0.357 versus 0.281 and 0.454 versus 0.288) over the standard route where these were waypoints. Once again, the intersection at G also caused an increase in RMS variability at waypoint H (0.357 versus 0.296) as was discussed for modification 1.

Examination of table 13 and figure 25 shows the following trends for the route B (PNE) data. First, for the all waypoint configuration, the RMS data are less than 0.300 nmi (0.247, 0.297). For the modification 1 configuration, in which H was an intersection and I was a waypoint, the RMS values were also less than 0.300 nmi (0.254, 0.194). However, for the modification 2 configuration, when I was designated as an intersection, the variability increased (0.336). This increase in variability points out the necessity of the initial approach fix being a waypoint in order to insure that the final approach tracking is accurate.

Examination of table 13 and figure 26 shows the following trends for the route C (PNE) data. First, for the all waypoint configuration, the RMS data are more variable than that obtained for either the route A or route B data (0.383 nmi and 0.451 nmi as opposed to other values all being less than 0.300 nmi). The different results obtained for the route C configuration are due to the fact that two of the subject pilots forgot to tune in the rho/theta settings and used R as an intersection which caused an increased amount of variability to exist. In addition, another subject pilot set the rho/theta and initiated the turn to the next segment at a point that resulted in a large TSCT error.

Secondly, for the route C (PNE) configuration, whenever an intersection was substituted for a waypoint, the result was an increase in variability. For the modification 1 configuration, the RMS value was 0.620 nmi (as opposed to 0.383 nmi for the standard and 0.340 nmi for modification 2) and for the modification 2 configuration, the RMS value was 0.542 nmi (as opposed to 0.451 for the standard and 0.280 nmi for modification 1). The resultant increase in variability would indicate that intersections are not adequate replacements for waypoints and should not be used in terminal area environment for the base leg/final approach portion of a STAR.

In general, for the routes A, B, and C configurations, whenever an intersection was used in lieu of a waypoint (within the PNE STAR's), the result was an increase in RMS TSCT error. This increased variability in TSCT error would suggest that intersections should be avoided in the terminal area environment. Furthermore, for the route C configuration, it is apparent that the RMS TSCT values for the intersections are much larger than any of the route A or B values. This increased variability may have resulted from either: (1) the extra length of the steady state segment, or (2) the different transition angles. It was not possible, from the data, to determine the exact causes or reasons for these differences; however, the differences are consistent and do show the same trends and differences between intersections and waypoints as found for the routes A and B configurations.

BASE LEG AND FINAL APPROACH DATA (TSCT).

The purpose of table 14 is to present the base leg and final approach data for both the PNE and ACY STAR's. The base leg data cons sts of two segments of unedited data as follows:

.Route A (PNE STAR) - G to H and H to I
.Route B (PNE STAR) - E to H and H to I
.Route C (PNE STAR) - E to R and R to I
.Route A (ACY STAR) - U to V and V to W
.Route B (ACY STAR) - P to V and V to W
.Route C (ACY STAR) - P to S and S to W

The base leg data includes both steady state and turn data in that the two legs contain all of the data between the angle bisectors.

The final approach data consists of three segments including the base leg (H to I and R to I for the PNE STAR; V to W and S to W for the ACY STAR) as well as the two final segments (I to J and J to K for the PNE STAR; W to X and X to Y for the ACY STAR). The reason for including these data in the report is that the data should be indicative of total performance in terms of workload on the various route/route structure combinations, providing the means to evaluate how well the pilots are able to use a single-waypoint RNAV system in the terminal area. The data being analyzed are continuous time series data, and should reflect the difficulties and/or problems associated with making RNAV approaches to a terminal facility. From table 14 it can be seen that the base leg RMS total system crosstrack error data for the PNE STAR ranged between 0.254 and 0.582 nmi and the base leg data for the ACY STAR ranged between 0.363 and 0.834 nmi. The final approach RMS TSCT error data demonstrated the same trend as the base leg data. The PNE STAR ranged between 0.244 and 0.553 nmi and the ACY STAR ranged between 0.317 and 0.768 nmi.

TABLE 14. CROSSTRACK ERROR (UNEDITED FOR ALL DATA BETWEEN ANGLE BISECTORS) FOR BASE LEG (2 SEGMENTS) AND FINAL APPROACH (3 SEGMENTS)

			Base Leg		Final Approach	
			Mean (nmi)	RMS (nmi)	Mean (nmi)	RMS (nmi)
Route A	STD	PNE	-0.034	0.364	-0.014	0.367
		ACY	.240	.834	.206	.768
	MOD 1	PNE	.045	.359	.045	.332
		ACY	-.154	.470	-.151	.487
	MOD 2	PNE	.011	.393	.038	.363
		ACY	-.259	.525	-.211	.485
Route B	STD	PNE	.035	.254	.035	.244
		ACY	-.174	.402	-.140	.378
	MOD 1	PNE	-.074	.363	-.058	.345
		ACY	-.274	.470	-.230	.436
	MOD 2	PNE	.038	.409	.042	.392
		ACY	-.158	.457	-.118	.426
Route C	STD	PNE	-.037	.374	-.025	.367
		ACY	.030	.518	.010	.432
	MOD 1	PNE	.304	.582	.273	.553
		ACY	-.317	.570	-.195	.472
	MOD 2	PNE	.048	.314	.077	.448
		ACY	-.037	.363	-.016	.317

These data indicate that pilots, flying with a single-waypoint RNAV system, do not exceed the ± 2.0 nmi turn airspace when making approaches (to a terminal facility) that consists of waypoints or combinations of waypoints and/or intersections. However, the steady state data (as analyzed in figures 6 through 23) for the two final approach segments (I to J and J to K for the PNE STAR; W to X and X to Y for the ACY STAR) indicate that except for two cases, both of which involved an intersection at the initial approach fix (IAF) followed by a DTW distance at the outer marker, the 2 RMS total system crosstrack error data did not exceed the value specified in AC 90-45A (appendix D, table A-4). The ACY value of ± 0.9 was based on an alongtrack distance of approximately 10 nmi and on a tangent point distance of less than 1 nmi for the ACY VORTAC and the PNE value of 1.0 nmi was based on an alongtrack distance of approximately 10 nmi and a tangent point distance of approximately 10 nmi for the ARD VORTAC.

The PNE STAR was executed as a missed approach, whereas for the ACY STAR the pilots actually landed the aircraft. Therefore, it would be expected that the ACY STAR would result in a lower RMS TSCT. The data in table 15 substantiates this fact in that for the PNE STAR, the RMS TSCT data in the J to K segment ranged between 0.154 and 0.522 nmi, while the RMS TSCT data for the ACY STAR ranged between 0.098 and 0.338 nmi for the X to Y segment.

From the data in table 15 it can be seen that the waypoint-waypoint-waypoint combination produced nearly identical results in terms of tracking proficiency, whereas the intersection-DTW fix-waypoint combination resulted, for the most part, in larger RMS TSCT errors. This data tends to reinforce the AC 90-45A argument (appendix D, part 1, section H) that simplified terminal RNAV instrument procedures should be constructed such that the transition to the final approach course is specified as a waypoint, and the runway threshold is specified as a waypoint. From the data in table 15, the final approach data does not seem to be affected by whether the outer marker is a waypoint or a DTW fix.

TABLE 15. FINAL APPROACH--RMS TOTAL SYSTEM CROSSTRACK ERROR

		Segment	Standard		Modification 1		Modification 2	
		H-I	(W)		(W)		(I)	
	PNE	I-J	(W)	.301	(I)	.420	(I)	.392
Route A		J-K (Missed Approach)	(W)	.326	(W)	.216	(W)	.220
		V-W	(W)		(W)		(I)	
	ACY	W-X	(W)	.273	(I)	.275	(I)	.375
		X-Y	(W)	.098	(W)	.142	(W)	.123
		H-I	(W)		(W)		(I)	
	PNE	I-J	(W)	.317	(I)	.212	(I)	.312
Route B		J-K (Missed Approach)	(W)	.155	(W)	.154	(W)	.218
		V-W	(W)		(W)		(I)	
	ACY	W-X	(W)	.400	(I)	.320	(I)	.799
		X-Y	(W)	.129	(W)	.140	(W)	.338
		R-I	(W)		(W)		(I)	
	PNE	I-J	(W)	.309	(I)	.308	(I)	.543
Route C		J-K (Missed Approach)	(W)	.275	(W)	.212	(W)	.522
		S-W	(W)		(W)		(I)	
	ACY	W-X	(W)	.206	(I)	.401	(I)	.372
		X-Y	(W)	.156	(W)	.149	(W)	.102

PROCEDURAL ERRORS.

Procedural errors were counted whenever an incorrect navigation control setting or inappropriate aircraft control operation would have resulted in a significant deviation from course (or intended route of flight) if allowed to continue uncorrected. Table 16 summarizes the number of observed operations input for each of the four basic types of input operations. Table 17 presents the number of setting errors which occurred while inputting the required course (OBS), waypoint distance (RHO), waypoint theta (theta), and VOR frequency (FREQ). These data are plotted in later figures.

From table 16 and figure 27, it can be seen that the total number of required operations for routes B and C were significantly less then that required for route A. The numbers in this table are the totals for all subjects and all runs. The reduction in observed workload was, of course, influenced by the fact that the route A configuration was constructed with the greatest number of waypoints and/or intersections. Within the routes B and C configurations, it appears that modification 1 results in considerably less rho/theta settings than either of the other two options.

Table 16 shows that the total number of observed operations for routes B and C were less than that observed for route A. The numbers in this table are the totals for all nine subjects except in the two cases footnoted in table 16.

From table 17 and figure 28, it can be seen that the total number of setting errors is least for route C (45) whereas the greatest number of errors appear to occur for route A (72). Once again, route A contained the greatest number of waypoint locations and required the greatest number of input operations (1253), as opposed to Route B which had 954 and route C which had 956 operations, and as such constituted a greater workload with more chance for making setting errors.

From table 18 and figures 29 and 30, it can be seen that there is a nearly constant percentage of error for all routes and configurations of waypoints and/or intersections; however, the route A configuration appears to have a larger percentage of error. This would indicate that the percentage of setting errors may be related to the complexity of the route structures, as well as to the design of the RNAV unit or its placement in the instrument panel. The rho/theta setting errors are possibly due to the parallax angle (between the pilot and the control head) as well as to the relatively coarse setting accuracy of the RNAV unit. The pilots, in using the RNAV unit, must interpolate between dashed lines that represent 0.2 nmi or 0.2°. These lines are spaced fairly close to each other, and when coupled with the existing parallax angle could be a source of setting error. It is assumed that if the face of the RNAV unit were angled appropriately to eliminate the parallax problem, the number of rho/theta setting errors would decrease since the face of the unit would be in a more direct line with the pilot's vision.

TABLE 16. NUMBER OF OBSERVED OPERATIONS INPUT IN ORDER TO FLY THE REQUIRED COURSE

		OBS Setting			RHO Setting			THETA Setting			Frequency Change		
		Std	Mod 1	Mod 2	Std	Mod 1	Mod 2	Std	Mod 1	Mod 2	Std	Mod 1	Mod 2
	Route A	66	72	71	75	69	63	75	69	63	9	9	9
PNE	Route B	55	47	54	65	46	53	65	46	53	9	8*	9
	Route C	59	60	57	65	49	53	65	49	53	9	9	9
	Route A	61	61	60	80	63	54	80	63	54	9	9	9
ACY	Route B	44	40	43	60	40	45	60	40	45	9	9	9
	Route C	47	43	37	48	42	43	48	42	43	9	9	8*

*One subject's data were not recorded, and is therefore missing from this analysis.

TABLE 17. NUMBER OF SETTING ERRORS WHICH OCCURRED WHILE INPUTTING THE REQUIRED COURSE

		OBS Errors			RHO Errors			Theta Errors			Frequency Errors		
		Std	Mod 1	Mod 2	Std	Mod 1	Mod 2	Std	Mod 1	Mod 2	Std	Mod 1	Mod 2
	Route A	1	3	0	7	9	4	9	6	4	0	0	0
PNE	Route B	0	1	1	4	6	1	1	2	1	0	0	0
	Route C	1	3	2	0	1	1	2	1	4	1	0	0
	Route A	3	5	2	3	2	4	6	2	2	0	0	0
ACY	Route B	2	1	2	5	5	6	5	2	3	0	0	0
	Route C	1	5	3	5	3	4	2	3	4	0	0	0

TABLE 18. SETTING ERRORS PER OPERATION

			Number of Operations	Number of Errors	Errors per Operation
ROUTE A (PNE and ACY STAR's)	STD	OBS	127	4	.03
		Rho	155	10	.06
		Theta	155	15	.10
		Freq	18	0	.00
	MOD 1	OBS	133	8	.06
		RHO	132	11	.08
		Theta	132	8	.06
		Freq	18	0	.00
	MOD 2	OBS	131	2	.02
		Rho	117	8	.07
		Theta	117	6	.05
		Freq	18	0	.00
ROUTE B (PNE and ACY STAR's	STD	OBS	99	2	.02
		Rho	125	9	.07
		Theta	125	6	.05
		Freq	18	0	.00
	MOD 1	OBS	87	2	.02
		RHO	86	11	.13
		Theta	86	4	.05
		Freq	17	0	.00
	MOD 2	OBS	97	3	.03
		Rho	98	7	.07
		Theta	98	4	.04
		Freq	18	0	.00
ROUTE C (PNE and ACY STAR's)	STD	OBS	106	2	.02
		Rho	113	5	.04
		Theta	113	4	.04
		Freq	18	0	.00
	MOD 1	OBS	103	8	.08
		Rho	91	4	.04
		Theta	91	4	.04
		Freq	18	0	.00
	MOD 2	OBS	94	5	.05
		Rho	96	5	.05
		Theta	96	8	.08
		Freq	17	0	.00

Table 19 presents the overall error percentage across all routes and route structures for all equipment setting errors (OBS/rho/theta). From table 19, it can be seen that the overall percentage setting error was 5.22 percent for this experiment. From table 19, it can also be seen that route A configuration resulted in the largest percentage error setting (5.75 percent versus 5.03 percent for the route B configuation, and 4.71 percent for the route C configuration). These data indicate that as the number of input operations increases, the percentage of errors also increases, which in turn indicates that the route structures should be established using the minimum number of waypoints.

TABLE 19. PERCENTAGE OF SETTING ERRORS--BY ROUTE AND ROUTE STRUCTURE

	No. of Operations	No. of Errors	Percentage Error
Route A			
STD	455	29	6.37
MOD-1	415	27	6.51
MOD-2	383	16	4.18
Total	(1253)	(72)	(5.75)
Route B			
STD	367	17	4.63
MOD-1	276	17	6.16
MOD-2	311	14	4.50
Total	(954)	(48)	(5.03)
Route C			
STD	350	11	3.14
MOD-1	303	16	5.28
MOD-2	303	18	5.94
Total	(956)	(45)	(4.71)
All Routes			
Total	3163	165	5.22

Table 20 presents the overall error percentage as a function of route structure and STAR (PNE and ACY) for all equipment setting errors. From table 20 it can be seen that the PNE STAR resulted in a lower percentage of equipment setting errors than did the ACY STAR. This finding was consistent for all route structure conditions (standard, modification 1, and modification 2). Table 20 shows that the PNE STAR for modification 2 resulted in a significantly lower percentage of error than all of the other route structure/STAR combinations.

TABLE 20. PERCENTAGE OF SETTING ERRORS--BY ROUTE STRUCTURE

	Standard		Modification 1		Modification 2	
	PNE	ACY	PNE	ACY	PNE	ACY
No. of Operations	617	555	533	461	547	450
No. of Errors	25	33	32	28	18	30
Percentage Error	4.5%	5.9%	6.0%	6.1%	3.3%	6.7%

Total System Crosstrack Error--Procedural and Equipment Errors. For both the PNE and ACY STAR's there were a number of cases in which TSCT error deviated significantly from the centerline track. These deviations, however, do affect the data and are reflected in the statistical calculations. The major causes of these deviations were either a combination of GAT-2 and/or RNAV computer malfunctions or procedural errors which resulted in tracking errors. These deviations have been annotated on the STAR plots and are presented in figures 6 through 23. The tracking data in figures 6 through 23, depicted over routes with boundaries 1 1/2 nmi either side of centerline, are the actual TSCT position data which were used in the "steady state" and "turn" statistical data. From figures 6 through 23, it can be seen that almost all of the procedural errors occurred at or near the waypoints and/or intersections and affected primarily the turn data ($\pm$2.0 nmi around the waypoint/intersection), although the number and magnitude of these procedural errors were sufficient to affect the initial and/or final steady state tracking data.

Table 21 presents a summary of the major procedural or equipment errors which appeared to have affected or influenced the tracking capability of the pilots in this experiment. From table 21 it can be seen that the hardware malfunctions accounted for 10 of the disturbances in the data, whereas procedural errors accounted for 45 of the disturbances in the data. The 45 procedural errors were further broken down to reflect the fact that 12 of the deviations in tracking were due to pilot inattention and heading drift, 16 of the deviations were due to OBS and rho/theta setting errors and 17 of the deviations were due to untimely setting of OBS and rho/theta. The larger number of setting errors and untimely settings of the OBS and rho/theta parameters were, in part, influenced by the fact that the pilots in this study were not instructed in any form of turn anticipation procedure or technique. In fact, they were told to fly the RNAV route in the manner that they used for flying IFR-VOR navigation. The results of the data in figures 6 through 23 and table 21 indicate that it is necessary to establish a procedural method of turn anticipation which can be used with the single-waypoint RNAV system, and to train the pilots to use the procedure or technique. It is assumed that, if a standard procedure were available and used by the pilots, the incidences of early or late OBS and rho/theta setting would decrease, and the pilots would decrease the amount of variability associated with tracking to a waypoint and transitioning to the next course segment.

TABLE 21. SUMMARY OF MAJOR PROCEDURAL AND EQUIPMENT ERRORS

Type of Procedural and Equipment Error	Route A PNE STAR	Route A ACY STAR	Route B PNE STAR	Route B ACY STAR	Route C PNE STAR	Route C ACY STAR
RNAV Malfunctions-DTW Sticking or Excessive CDI Motion (left/right)	-	2	1	-	1	-
GAT-2 Malfunction (artificial horizon roll)	-	-	1	-	1	4
Heading Drift - FTE	2	2	2	3	2	1
Rho/Theta Setting Error	2	1	-	2	2	1
OBS Setting Error	1	4	1	-	-	-
Rho/Theta tuned early or late	-	3	-	2	2	-
OBS tuned early or late	-	-	1	3	1	5
Wrong waypoint input	1	-	-	-	-	-
Wrong frequency input	-	-	-	1	-	-

QUESTIONNAIRE RESULTS.

QUESTIONNAIRE PART I. After each pilot completed his series of data flights, he was administered a two-part questionnaire. The first part dealt with RNAV cockpit equipment, workload, and procedures. The second part was concerned with the RNAV routings and procedures used during this series of tests. The subject pilots' responses to the questionnaire are presented in this section.

From the first part of the questionnaire we can see that there was some dissatisfaction with the RNAV equipment used. Most pilots felt that the digital numbers on the RNAV display would have been easier to read if they were larger. All pilots found the means of entering waypoint information less than satisfactory while they felt that the output display was adequate. Inability to dial through zero for theta selection, parallax problems, and knob sensitivity were the major complaints.

Generally, the pilots replied that they only occasionally used the "test" button feature or reset rho, theta, or OBS. They were equally divided about spending too much time looking at the RNAV display to verify the accuracy of the waypoint information which they had inserted. Eight of the nine pilots used the approach mode feature for final approach while only one pilot neglected to switch to approach mode on final. Seven of the nine pilots were correct in their assessment of the value of one-dot displacement being equal to 1 nmi while two were unsure of the actual values.

Turn Anticipation. Six pilots anticipated their turns by starting to turn when their DTW read some value which they felt would provide ample time to complete the turn without overshooting. These values varied from 3/4 to 3 nmi based on the size of the turn. The other three pilots set their OBS to the next leg heading and waited for the needle to begin to center prior to startin the turn. All nine pilots reset their OBS 1 mile or more prior to the waypoint.

Waypoints/Intersections. Seven of the nine pilots indicated they felt that the designation of intersection fixes in lieu of waypoints did not tend to simplify flying the routes, nor did they consider them to be very practical except where the distance between two waypoints was small (i.e., 5 nmi or less).

QUESTIONNAIRE PART II. This part of the questionnaire was concerned with the RNAV routings and route structures used during this series of tests and was specifically directed toward determining the pilots preference for the waypoint and/or intersection combinations that they encountered in the test series. It was determined, prior to administering the test series, that since the route structure was a mirror image course, it was only necessary to concentrate on evaluating the PNE STAR and that the responses would extrapolate to the ACY STAR.

The results from the questionnaire indicated that the pilots preferred the Route C configuration for the PNE STAR. Their rankings were based on a scale of 1 to 3, with 1 being the most desirable and 3 being the least desirable, and were as follows:

	Rank		
	1	2	3
Route A	1	2	6
Route B	3	4	2
Route C	5	3	1

In general, the Route C configuration was preferred due to the fact that it did not require a 90° turn onto the final approach. The objective data (RMS TSCT) for the Route C PNE STAR, however, indicated that the angular change may have increased the complexity of the Route C configuration which resulted in a higher overall RMS TSCT error.

This questionnaire also required the pilots to indicate which of the waypoints within the PNE STAR's (Routes A, B, and C) they would prefer to have as an intersection or DTW fix. The responses were as follows and are presented in table 22.

TABLE 22. SUMMARY OF PILOT RESPONSES TO QUESTION 2, PART II

Route	Waypoint Location	Preference: Waypoint	Preference: Intersection
A	E	7	2
A	F	6	3
A	G	7	2
A	H	6	3
A	I	3	6
A	J	4	5
B	E	7	2
B	H	7	2
B	I	5	4
B	J	4	5
B	K	7	2
C	E	7	2
C	R	5	4
C	I	7	2
C	J	4	5
C	K	7	2

The results from question 2 indicated that the pilots preferred that the Route A waypoint I be an intersection (6 to 3), and that the Routes A, B, and C waypoint J be either an intersection or a DTW fix. The objective data, however, indicated that waypoint I, which provides the transition to the final approach course. results in higher RMS TSCT error during the transition when it is used as an intersection. The objective data for waypoint J supported the fact that it did not matter whether J was a waypoint or a DTW fix. In fact, the pilots in their comments indicated that they either favored J as a DTW fix or wanted it omitted altogether.

The rationale that the pilots used for making the waypoint/intersection/DTW fix distinction was based on distance between fixes. In general, the pilots commented that they designated a fix as a waypoint when there was sufficient distance between fixes or when accuracy was critical.

RESULTS

1. The RMS TSCT statistical data for the intersection-DTW fix-waypoint configuration final approach segments was significantly greater than that for the waypoint-intersection-waypoint and the waypoint-waypoint-waypoint configurations.

2. The RMS TSCT statistical data for 10 of the 14 intersection cases exhibited more variability during turns than did the data for the corresponding waypoints.

3. Turns of 90° (baseleg to final approach) exhibited a significant increase in the RMS TSCT for intersections versus waypoints.

4. The pilots indicated that they preferred the use of waypoints to intersections unless the distance between fixes was less than 5 nmi. Then they should be DTW fixes.

5. Routes with fewer waypoints and/or intersections produced generally fewer procedural errors and less pilot workload.

6. The RMS steady-state TSCT statistical data produced no significant differences among the combinations of the nine route/route structure variables. Overall errors were, for the most part, within the 2 RMS value of the $\pm$2.0-nmi criteria established by AC 90-45A for the terminal area environment.

7. The RMS steady-state FTE statistical data produced no significant differences among the combinations of the nine route/route structure variables.

8. With the exception of one intersection, the 2 RMS TSCT statistical data in turns did not exceed $\pm$2.0-nmi.

9. The 2 RMS TSCT statistical data for the turns to base leg and final approach did not exceed $\pm$2.0-nmi.

10. The 2 RMS steady-state TSCT statistical data for the final approach segments did not exceed the value specified in AC 90-45A (appendix D, table D-4).

11. The use of standard procedures for turn anticipation by the pilots would reduce the incidence of early or late OBS, of variability associated with tracking to a waypoint and transitioning to the next course segment.

CONCLUSIONS

Based upon the results of this simulation, the following conclusions are made concerning useability of a single-waypoint area navigation system in a terminal area environment:

1. It is possible to construct functional RNAV routes by judicious designation of waypoints and DTW fixes. DTW fixes for short distances result in less workload; however, they produce less accurate tracking performance than waypoints.

2. Transition (turn) navigation is more accurate over waypoints than intersections.

3. Intersections should not be used to establish RNAV route structures for the terminal area when such structures will be used with a single waypoint RNAV system.

4. DTW fixes should be designated in lieu of waypoints only when the distance between fixes is less than 5 nmi and the DTW fix is not at a turn point. Under these conditions, DTW fixes may be used for altitude restrictions.

5. The use of less complex routes (less waypoints/intersections) will reduce procedural errors and pilot workload.

6. The error budget tolerances for steady state TSCT and FTE, specified by AC 90-45A, are not affected by different route/route structures combinations.

7. Procedural errors per input operation are related to the complexity of the route structure. Routes with fewer waypoints, and/or intersections, will produce fewer procedural errors and will reduce pilot workload in terms of input requirements. In addition, procedural errors in inputting the required data are inherent in the design of the RNAV control head and its position on the instrument panel.

8. RNAV final approaches may be expected not to exceed the 2 RMS TSCT criteria specified in appendix D, table 4 of AC 90-45A.

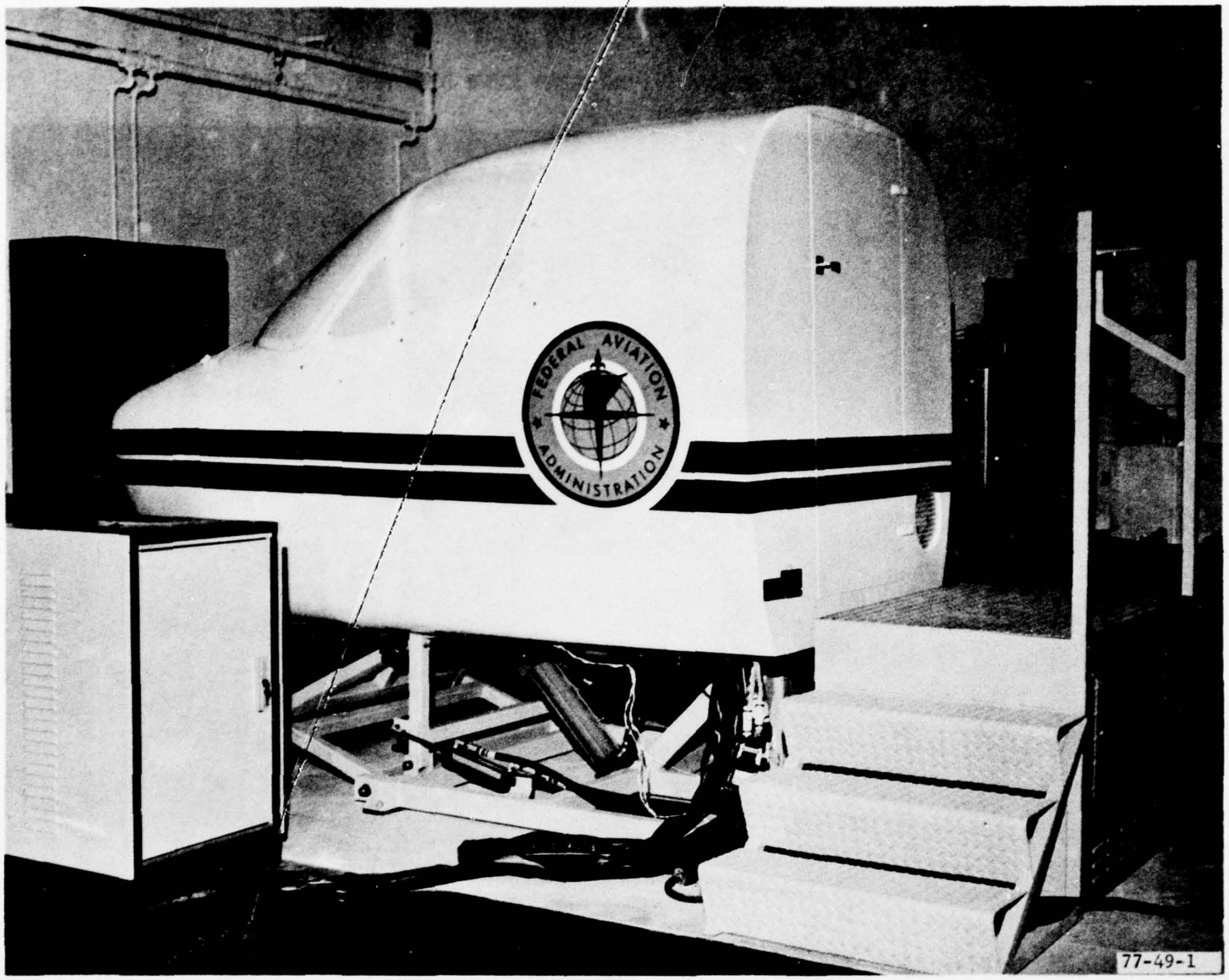


FIGURE 1. EXTERIOR VIEW - GAT-2 SIMULATOR

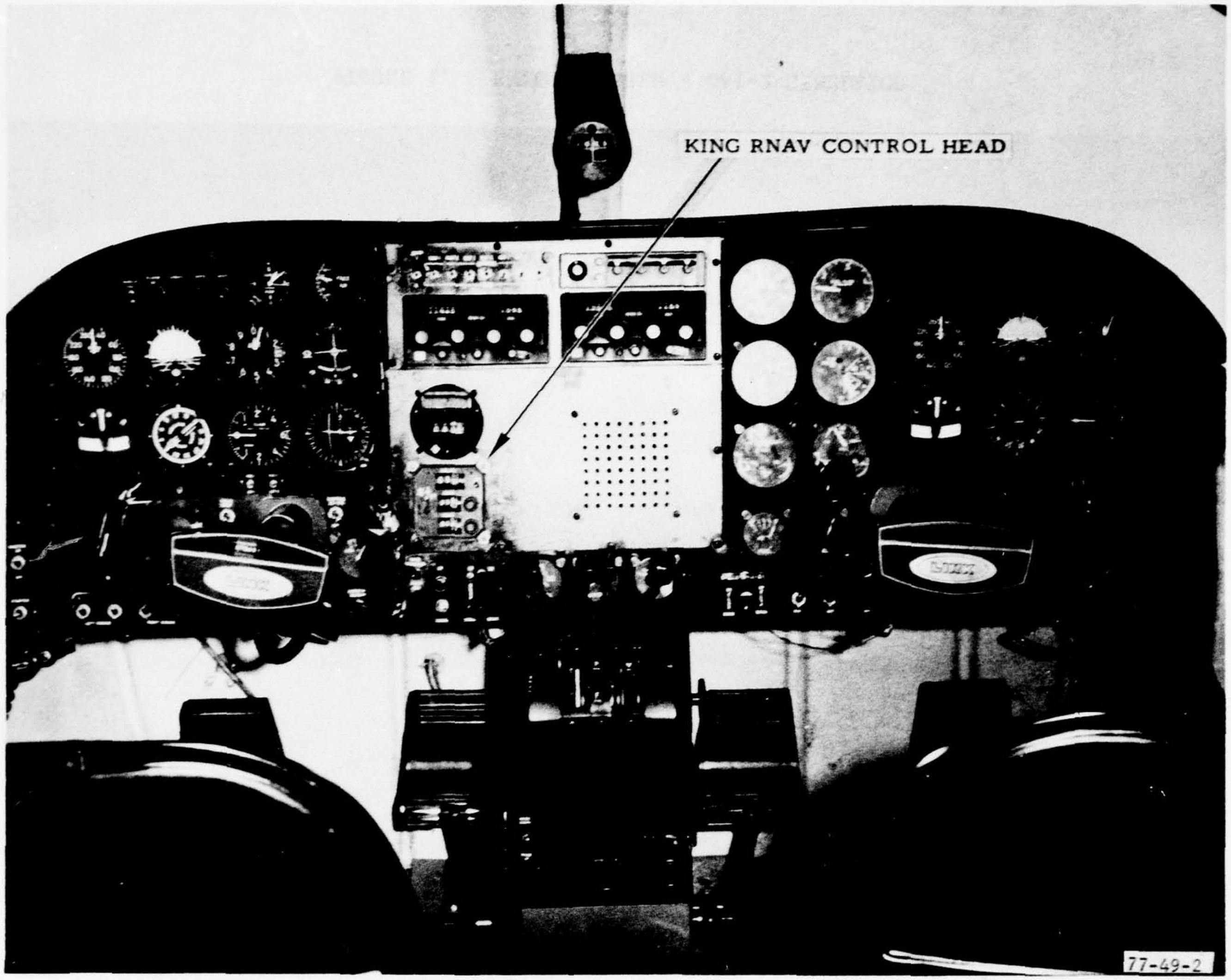


FIGURE 2. KNC-610 RNAV UNIT INSTALLED IN THE GAT-2A SIMULATOR

FIGURE 3. XDS-530A COMPUTER

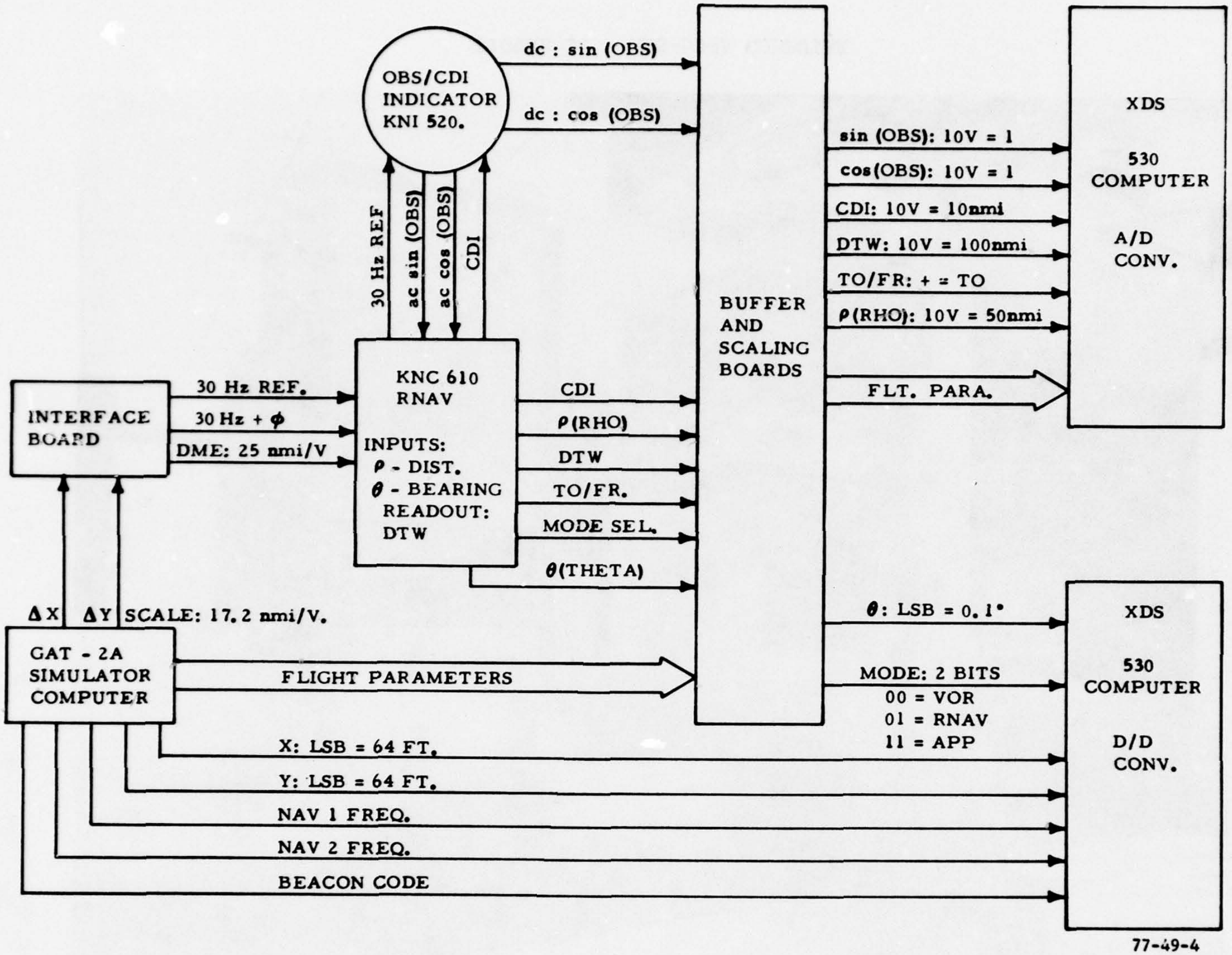


FIGURE 4. EQUIPMENT INTERFACE DIAGRAM

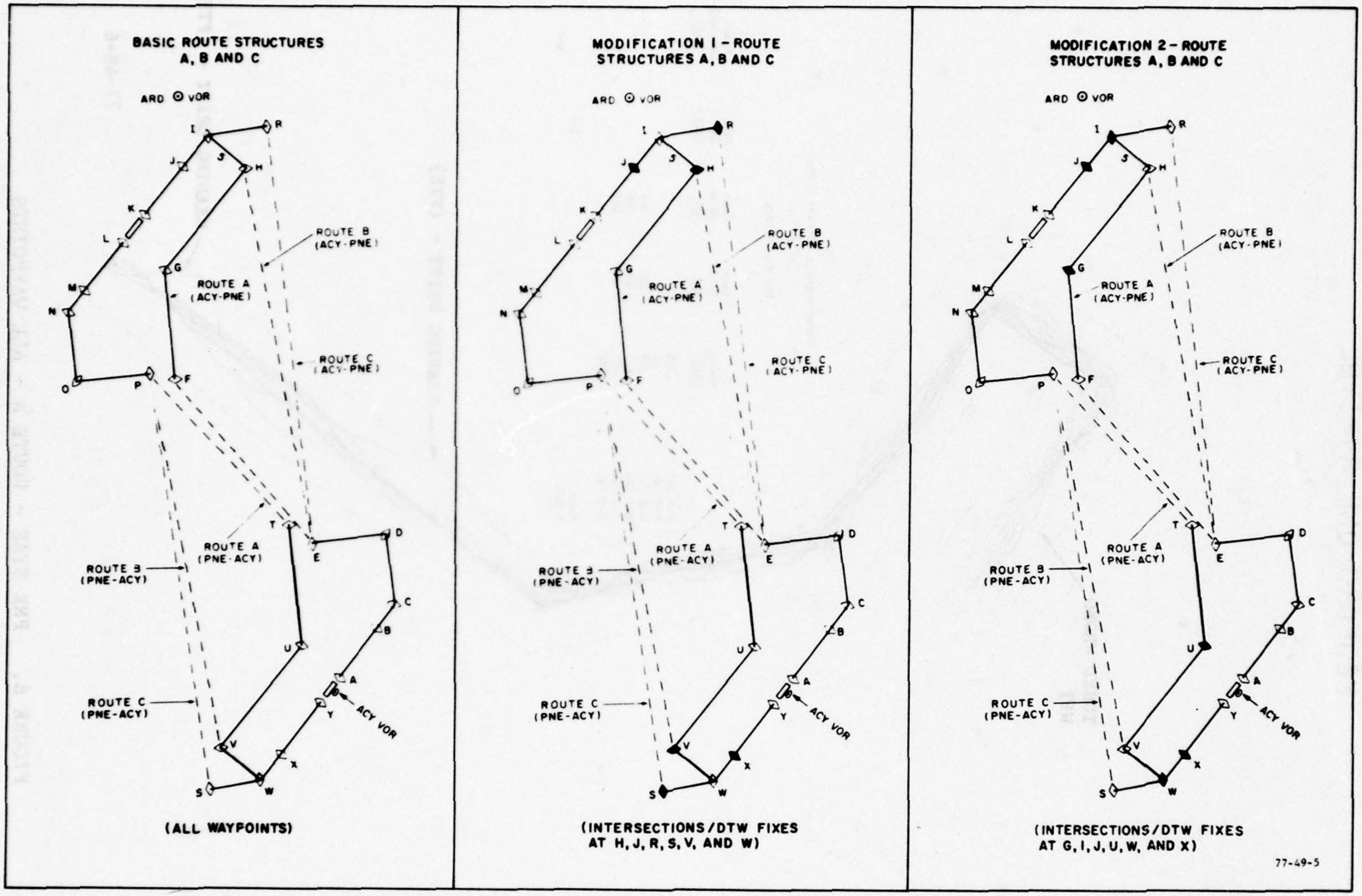
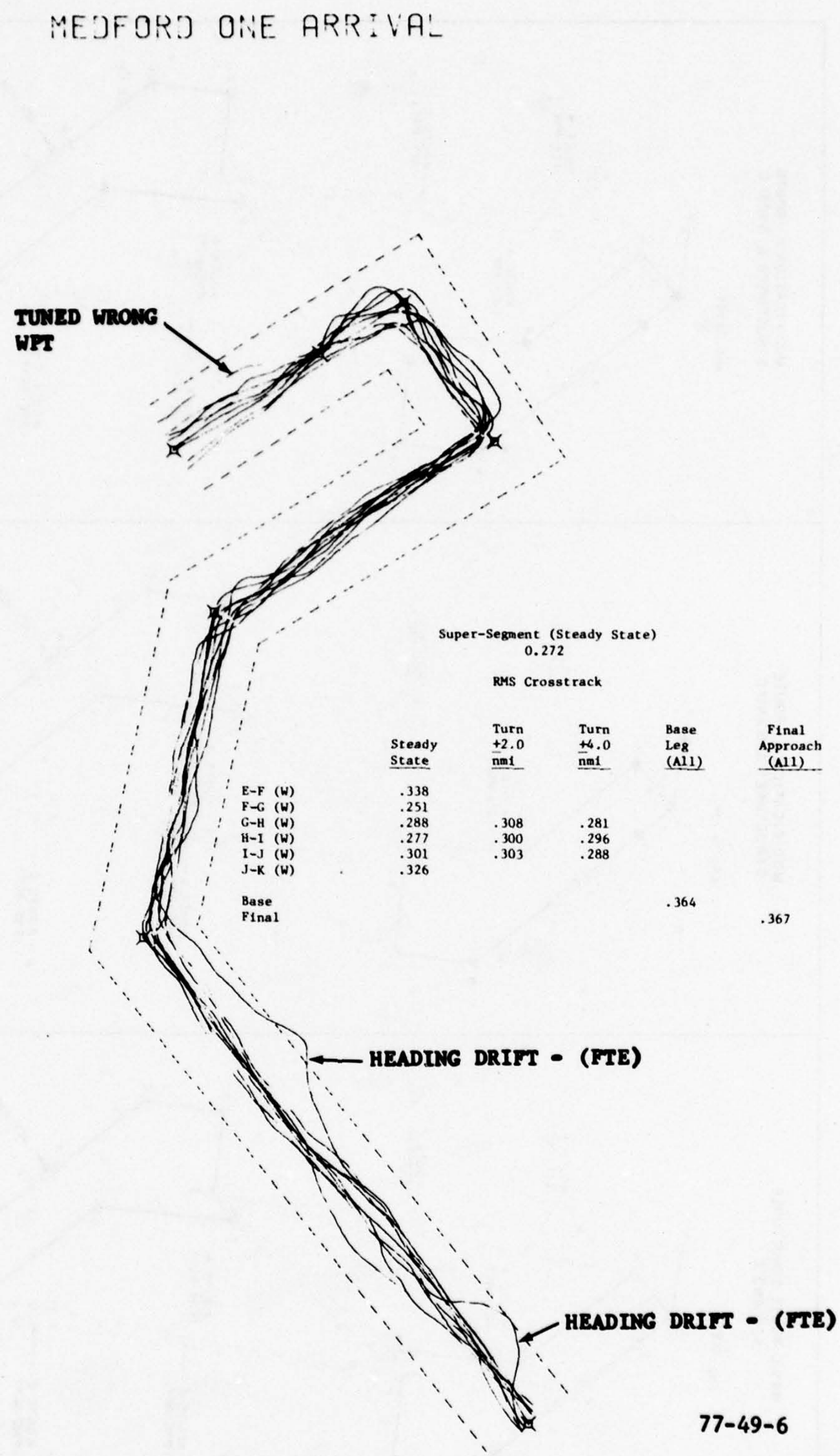


FIGURE 5. COMPOSITE OF ROUTE STRUCTURES

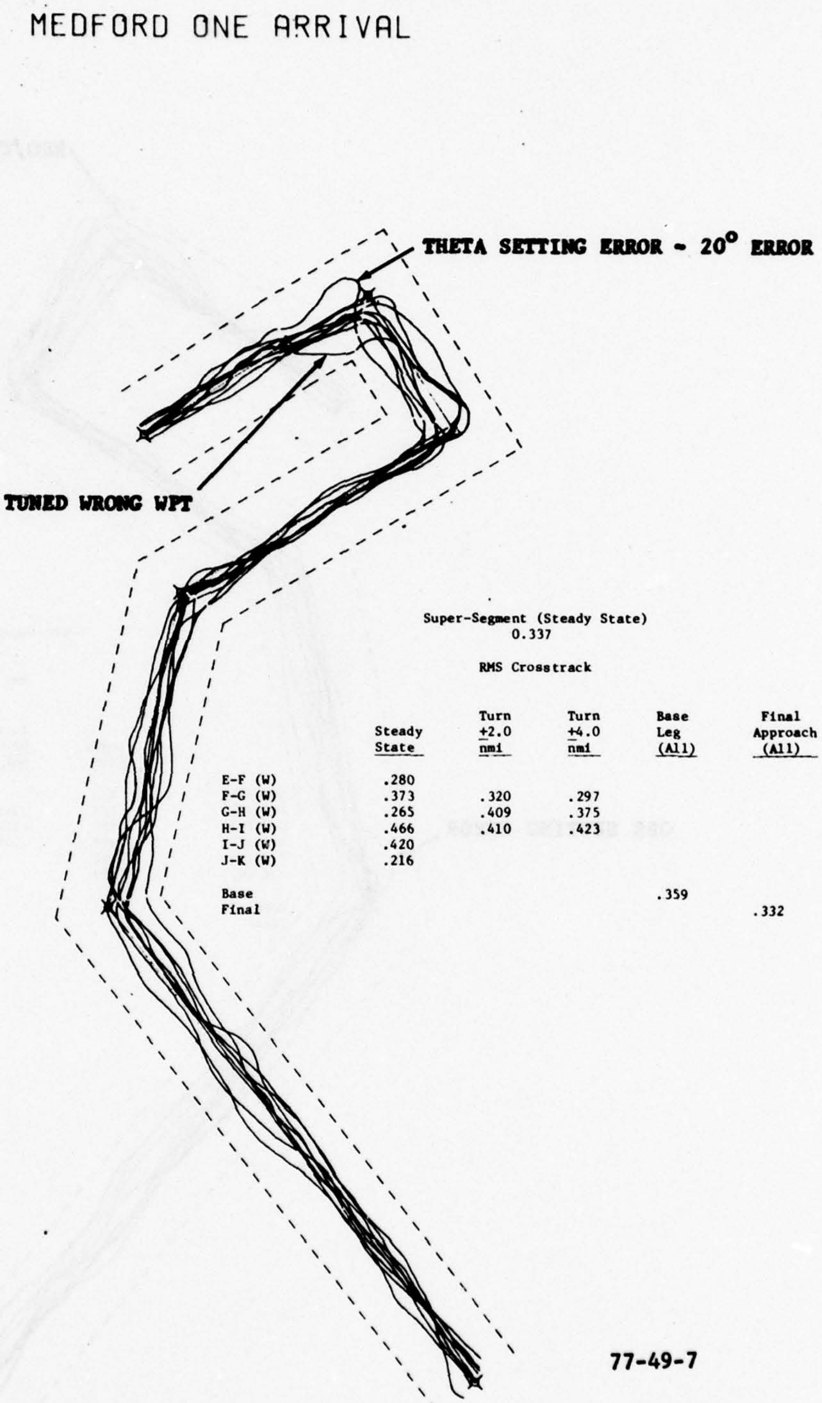


Super-Segment (Steady State)
0.272

RMS Crosstrack

	Steady State	Turn ±2.0 nmi	Turn ±4.0 nmi	Base Leg (All)	Final Approach (All)
E-F (W)	.338				
F-G (W)	.251				
G-H (W)	.288	.308	.281		
H-I (W)	.277	.300	.296		
I-J (W)	.301	.303	.288		
J-K (W)	.326				
Base				.364	
Final					.367

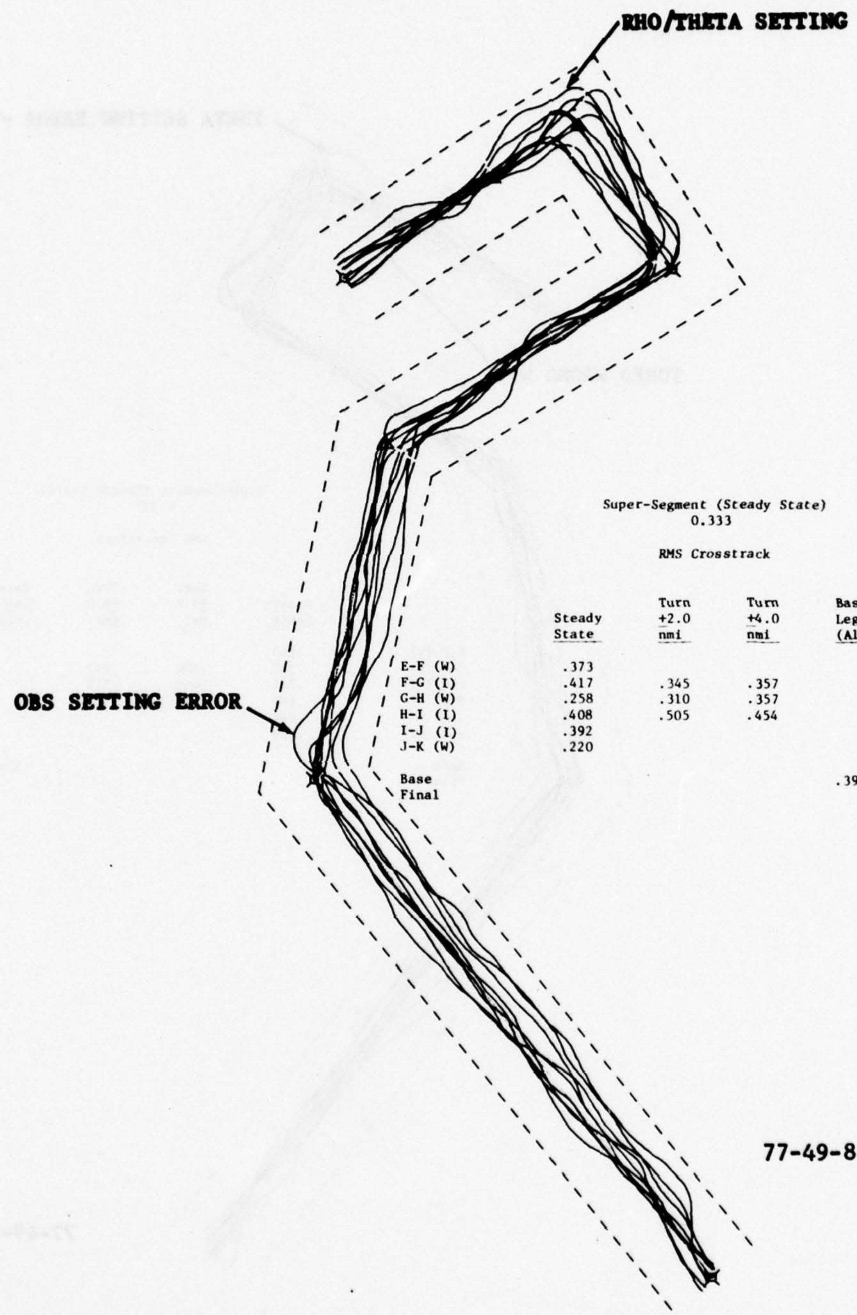
FIGURE 6. PNE STAR - ROUTE A - ALL WAYPOINTS



	Steady State	Turn ±2.0 nmi	Turn ±4.0 nmi	Base Leg (All)	Final Approach (All)
E-F (W)	.280				
F-G (W)	.373	.320	.297		
G-H (W)	.265	.409	.375		
H-I (W)	.466	.410	.423		
I-J (W)	.420				
J-K (W)	.216				
Base				.359	
Final					.332

FIGURE 7. PNE STAR - ROUTE A - INTERSECTIONS AT H AND J

MEDFORD ONE ARRIVAL

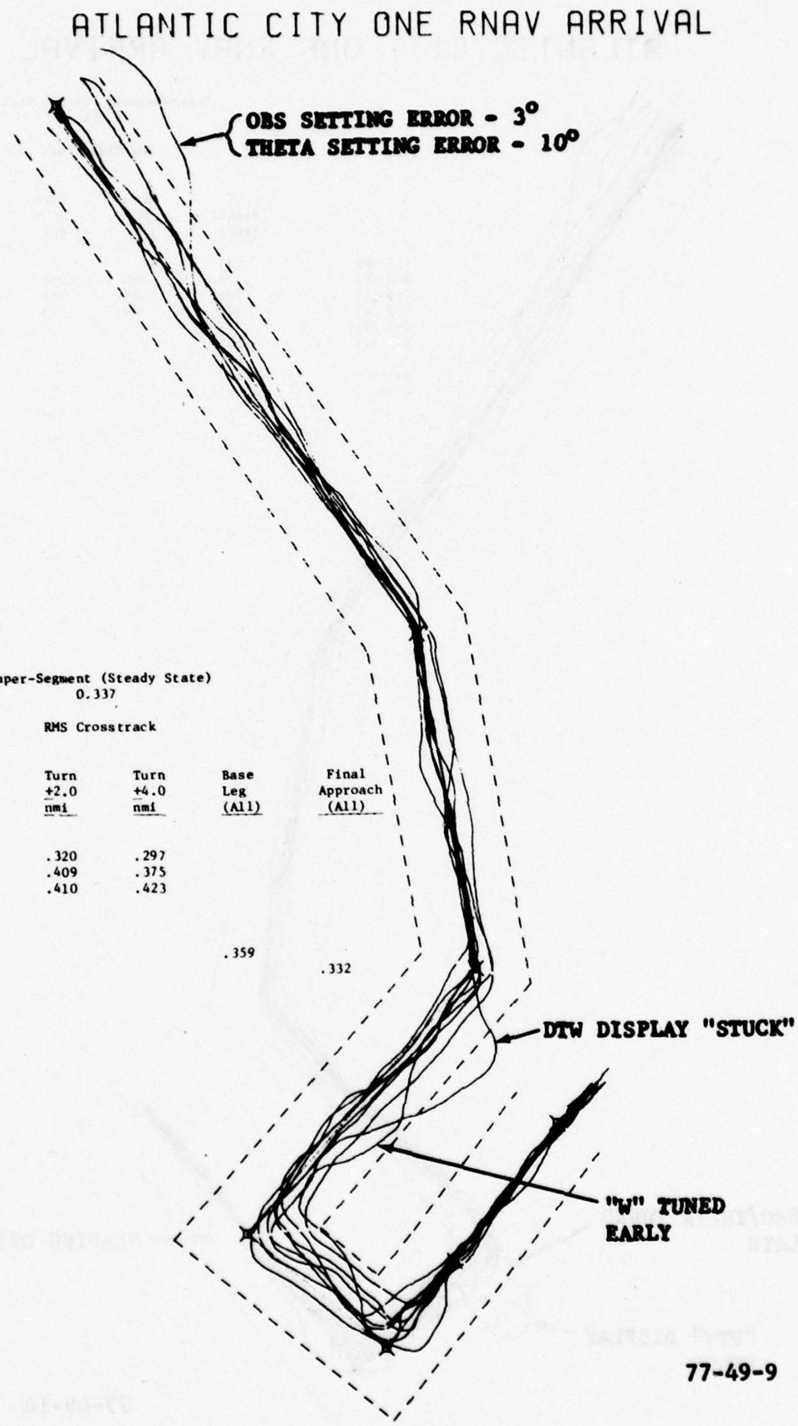


Super-Segment (Steady State)
0.333

RMS Crosstrack

	Steady State	Turn ±2.0 nmi	Turn ±4.0 nmi	Base Leg (All)	Final Approach (All)
E-F (W)	.373				
F-G (I)	.417	.345	.357		
G-H (W)	.258	.310	.357		
H-I (I)	.408	.505	.454		
I-J (I)	.392				
J-K (W)	.220				
Base				.393	
Final					.363

FIGURE 8. PNE STAR - ROUTE A - INTERSECTIONS AT G, H, AND J



Super-Segment (Steady State)
0.337

RMS Crosstrack

	Steady State	Turn +2.0 nmi	Turn +4.0 nmi	Base Leg (All)	Final Approach (All)
E-F (W)	.280				
F-G (W)	.373	.320	.297		
G-H (I)	.265	.409	.375		
H-I (W)	.466	.410	.423		
I-J (I)	.420				
J-K (W)	.216				
Base				.359	
Final					.332

FIGURE 9. ACY STAR - ROUTE A - ALL WAYPOINTS

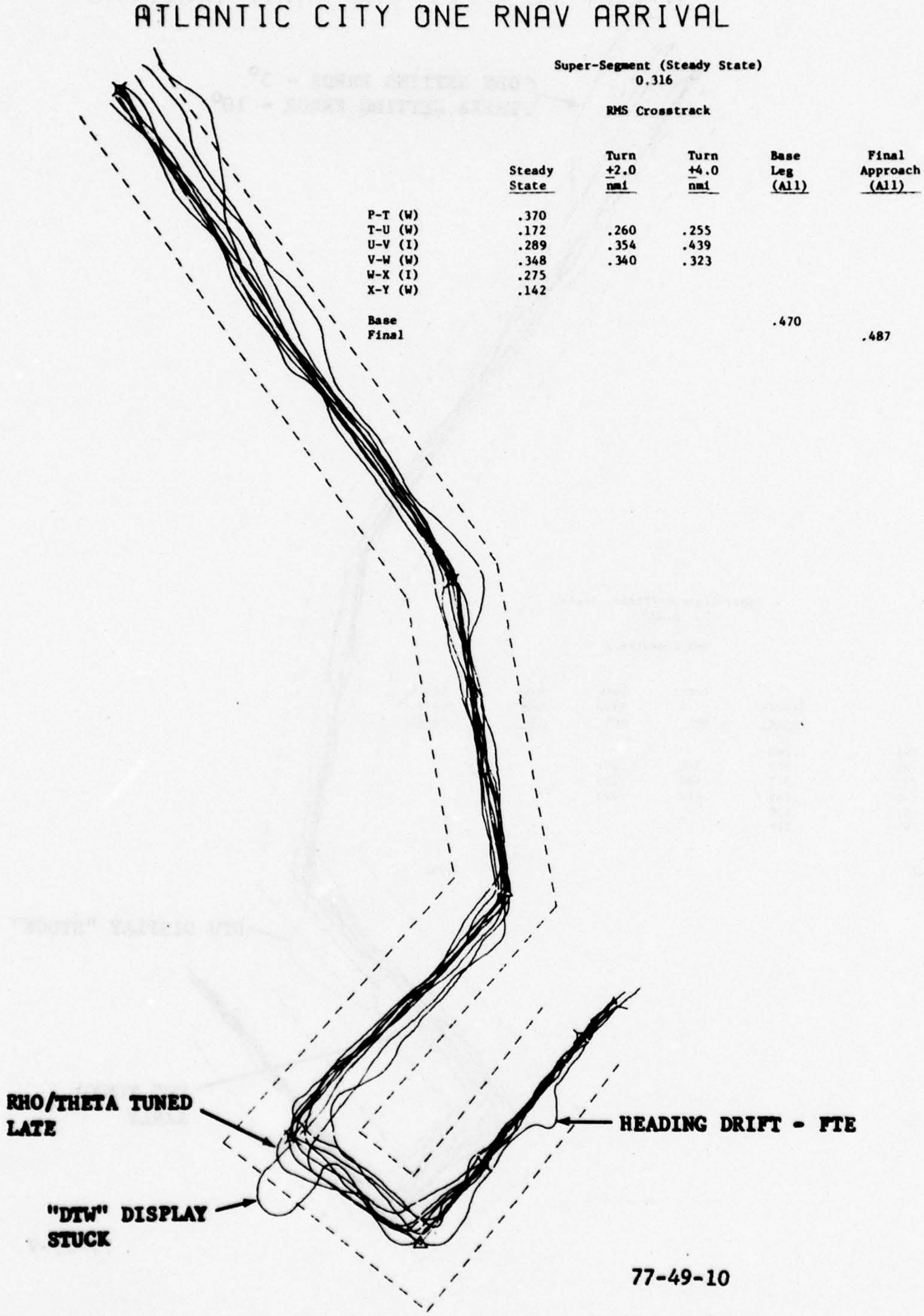
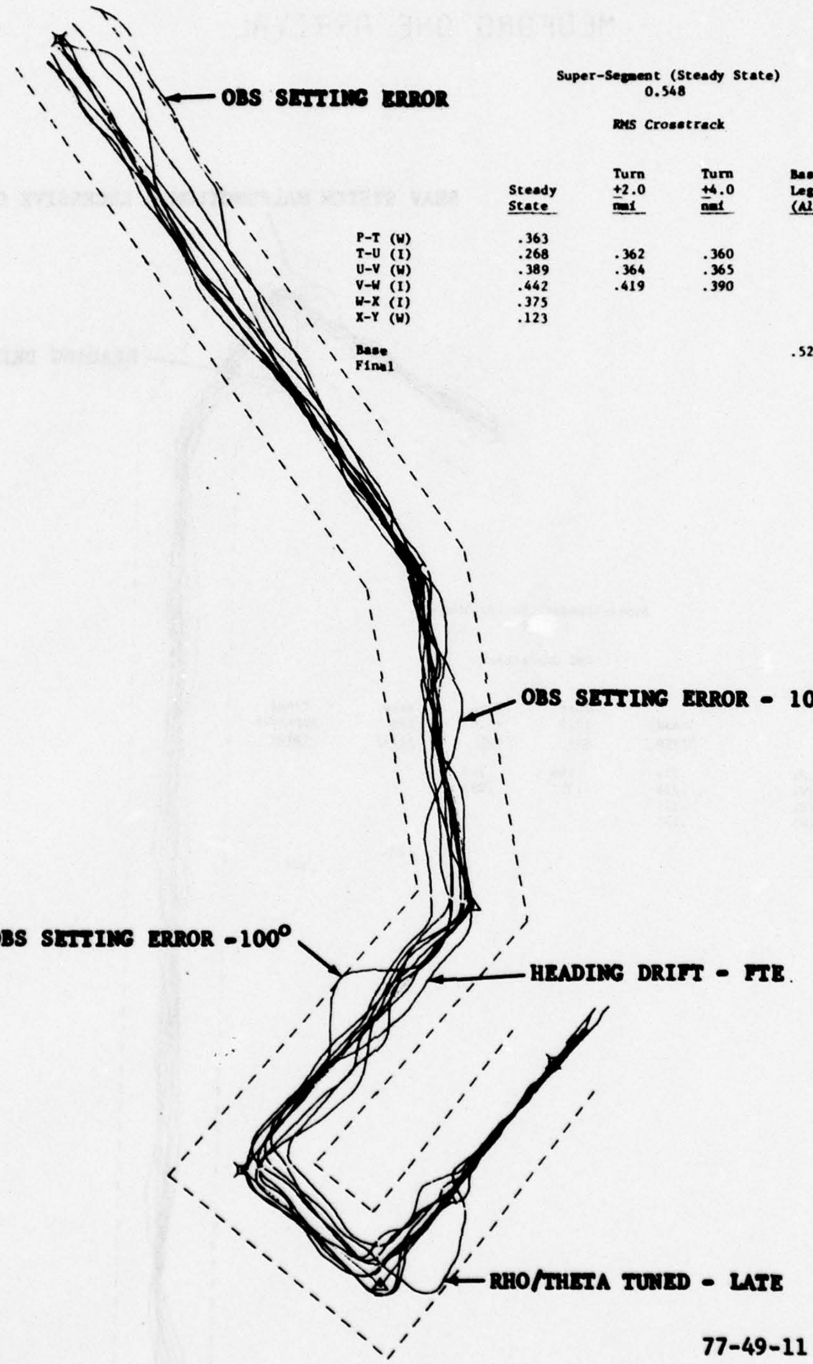


FIGURE 10. ACY STAR - ROUTE A - INTERSECTIONS AT V AND X

ATLANTIC CITY ONE RNAV ARRIVAL



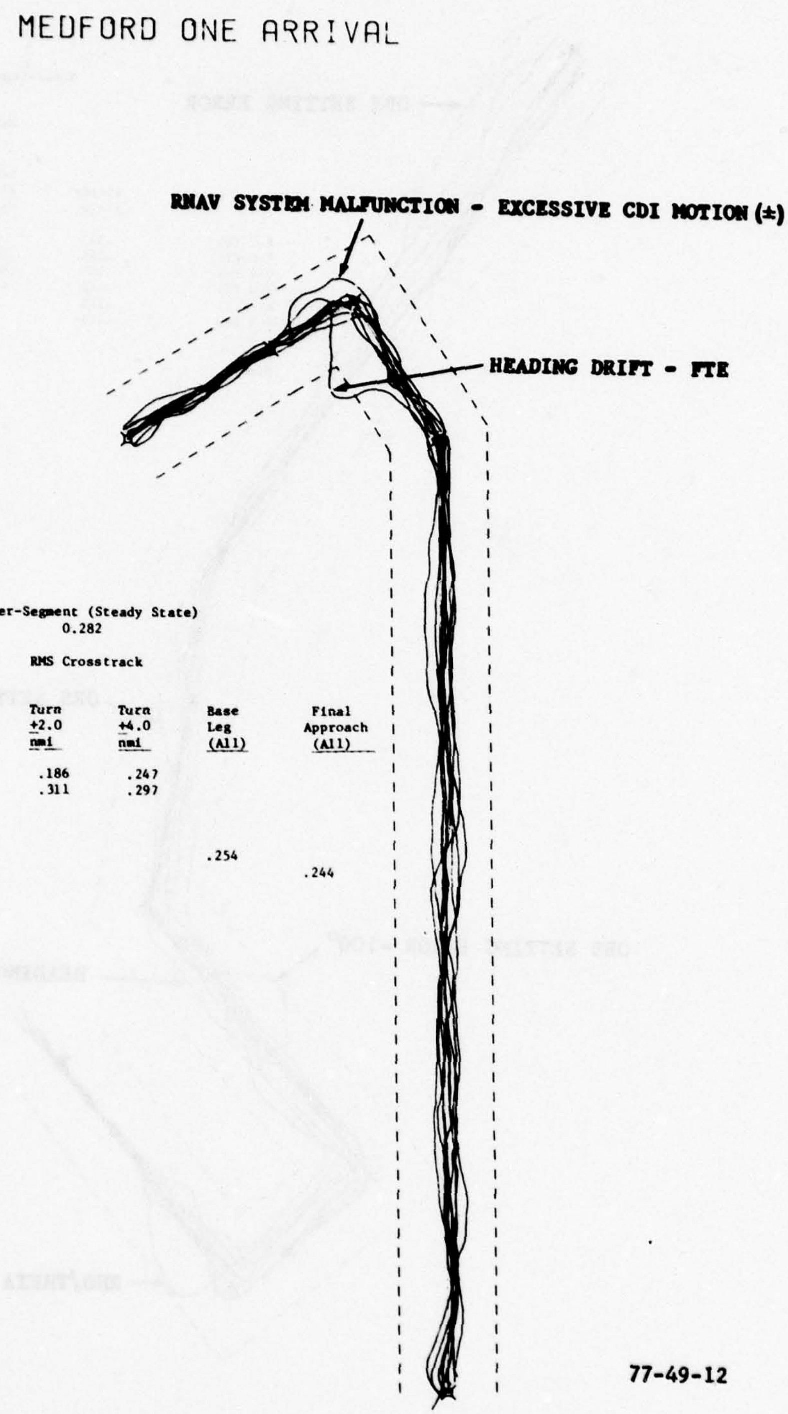
Super-Segment (Steady State)
0.548

RMS Crosstrack

	Steady State	Turn ±2.0 nmi	Turn ±4.0 nmi	Base Leg (All)	Final Approach (All)
P-T (W)	.363				
T-U (I)	.268	.362	.360		
U-V (W)	.389	.364	.365		
V-W (I)	.442	.419	.390		
W-X (I)	.375				
X-Y (W)	.123				
Base				.525	
Final					.485

77-49-11

FIGURE 11. ACY STAR - ROUTE A - INTERSECTIONS AT U, W, AND X



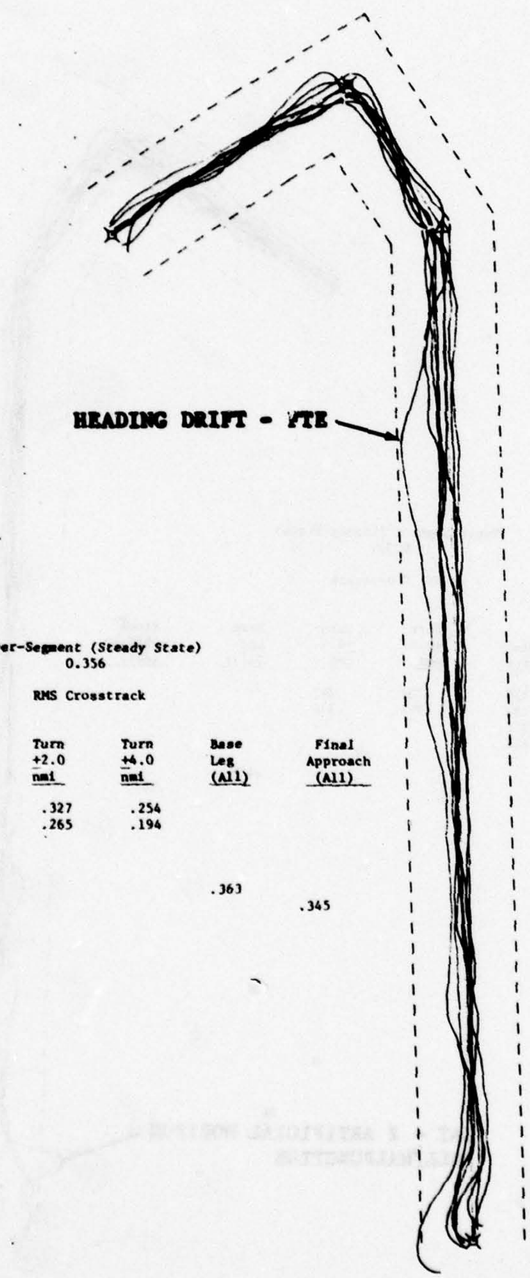
Super-Segment (Steady State)
0.282

RMS Crosstrack

	Steady State	Turn $\pm$2.0 nmi	Turn $\pm$4.0 nmi	Base Leg (All)	Final Approach (All)
E-H (W)	.214	.186	.247		
H-I (W)	.289	.311	.297		
I-J (W)	.317				
J-K (W)	.155				
Base				.254	
Final					.244

FIGURE 12. PNE STAR - ROUTE B - ALL WAYPOINTS

MEDFORD ONE ARRIVAL



Super-Segment (Steady State)
0.356

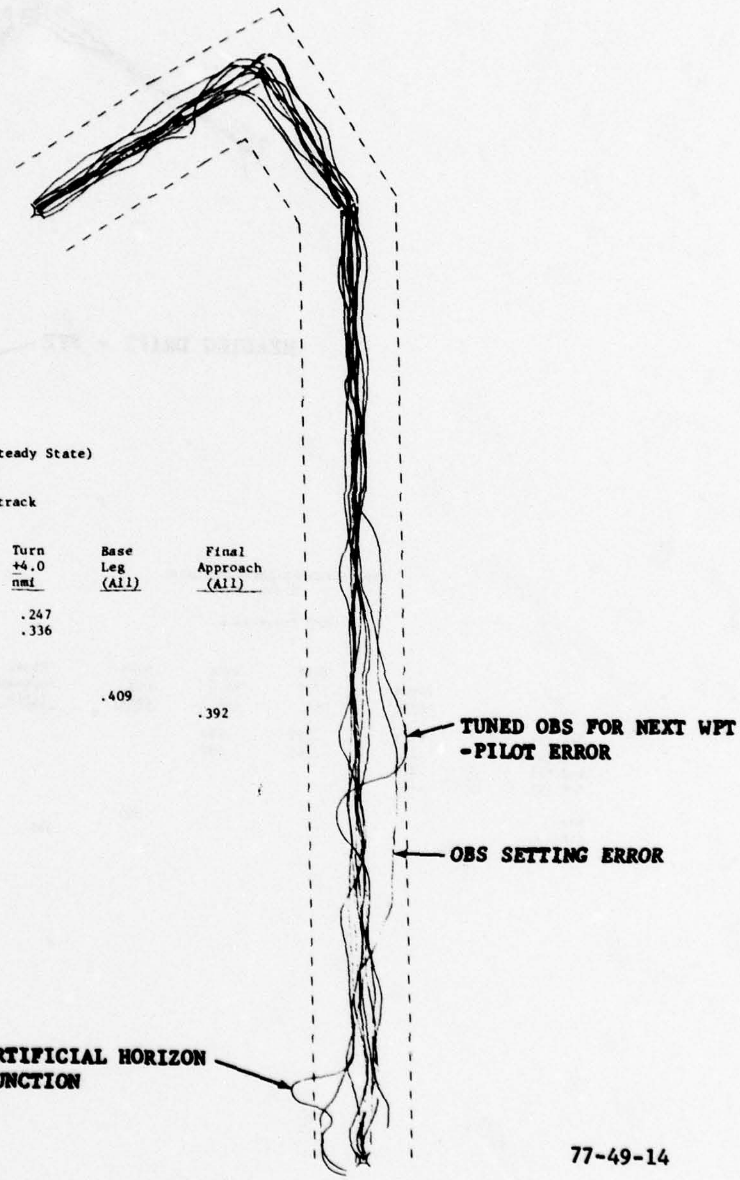
RMS Crosstrack

	Steady State	Turn ±2.0 nmi	Turn ±4.0 nmi	Base Leg (All)	Final Approach (All)
E-H (I)	.271	.327	.254		
H-I (W)	.221	.265	.194		
I-J (I)	.212				
J-K (W)	.154				
Base				.363	
Final					.345

77-49-13

FIGURE 13. PNE STAR - ROUTE B - INTERSECTIONS AT H AND J

MEDFORD ONE ARRIVAL



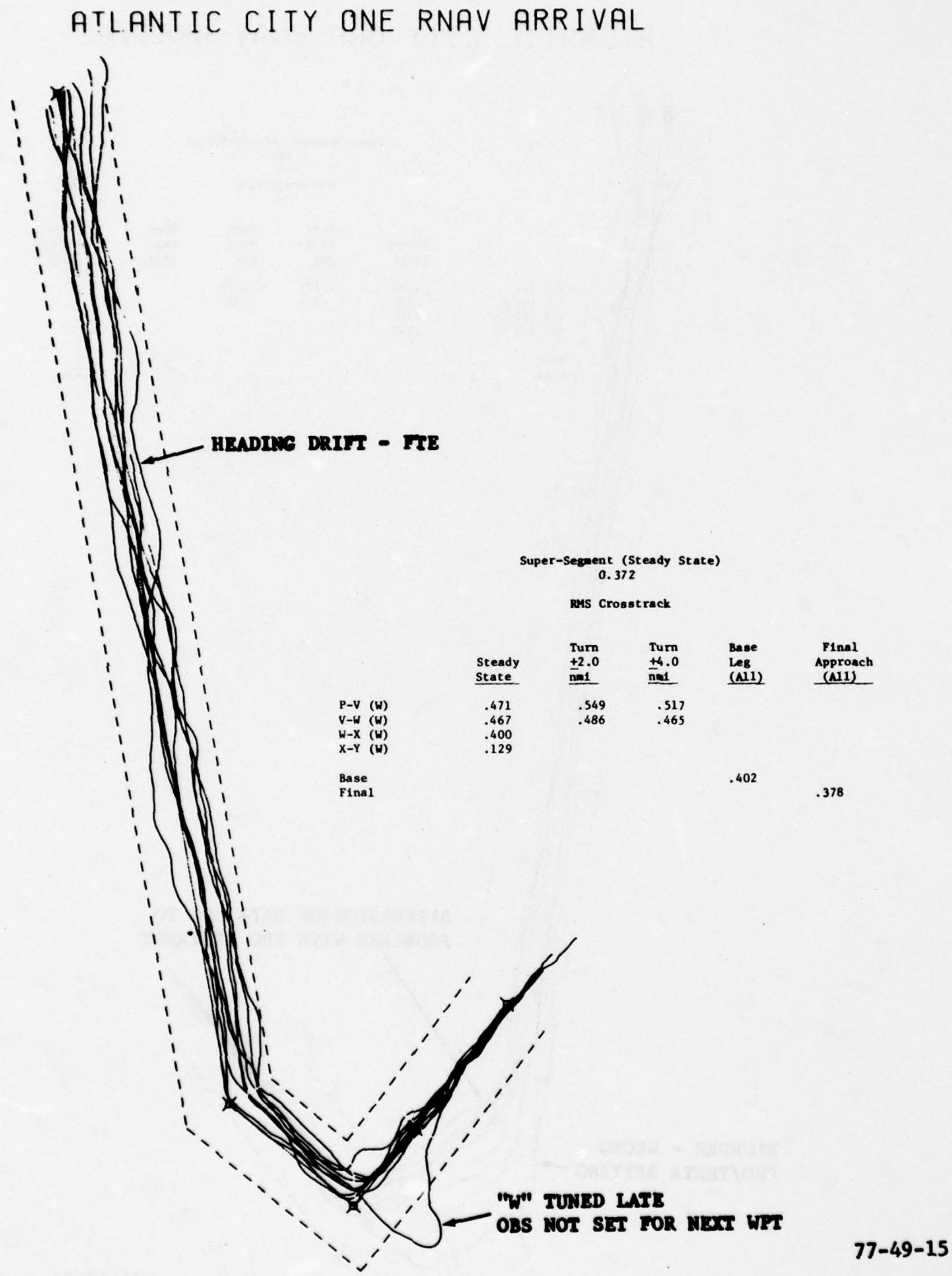
Super-Segment (Steady State)
0.334

RMS Crosstrack

	Steady State	Turn ±2.0 nmi	Turn ±4.0 nmi	Base Leg (All)	Final Approach (All)
E-H (W)	.326	.222	.247		
H-I (I)	.299	.362	.336		
I-J (I)	.312				
J-K (W)	.218				
Base				.409	
Final					.392

77-49-14

FIGURE 14. PNE STAR - ROUTE B - INTERSECTIONS AT I AND J

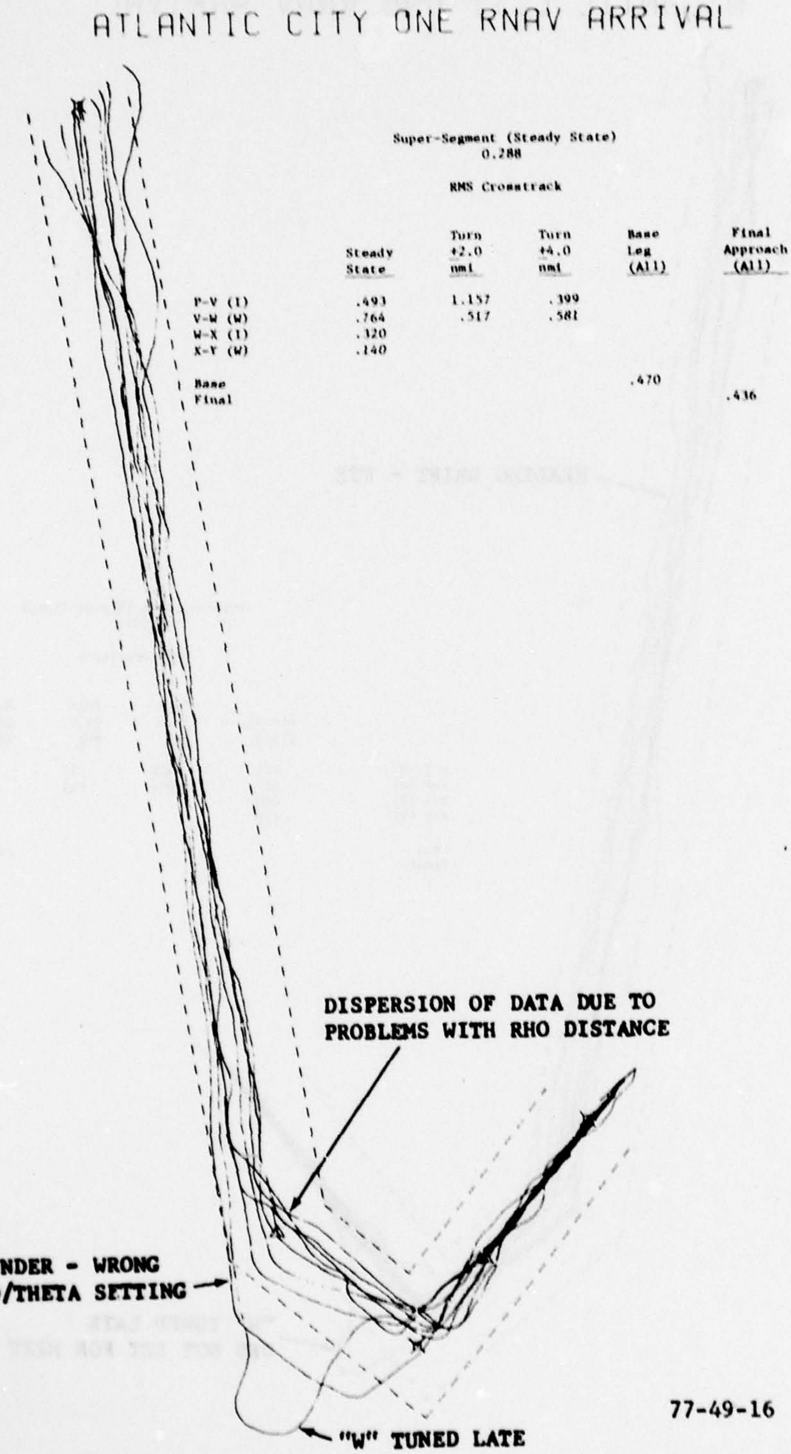


Super-Segment (Steady State)
0.372

RMS Crosstrack

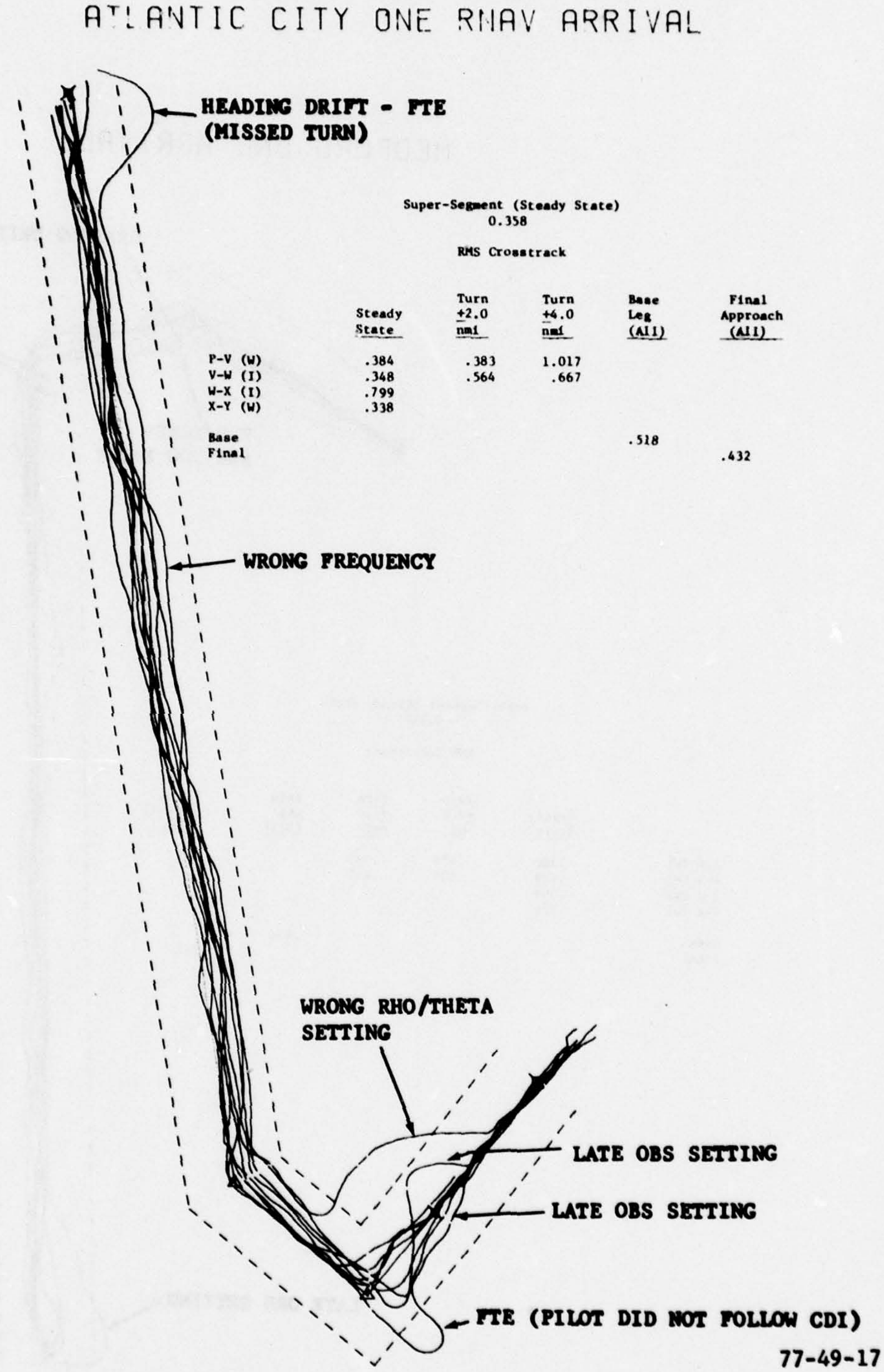
	Steady State	Turn ±2.0 nmi	Turn ±4.0 nmi	Base Leg (All)	Final Approach (All)
P-V (W)	.471	.549	.517		
V-W (W)	.467	.486	.465		
W-X (W)	.400				
X-Y (W)	.129				
Base				.402	
Final					.378

FIGURE 15. ACY STAR - ROUTE B - ALL WAYPOINTS



	Steady State	Turn +2.0 nmi	Turn +4.0 nmi	Base Leg (All)	Final Approach (All)
P-V (I)	.493	1.157	.399		
V-W (W)	.764	.517	.581		
W-X (I)	.320				
X-Y (W)	.140				
Base				.470	
Final					.436

FIGURE 16. ACY STAR - ROUTE B - INTERSECTIONS AT V AND X

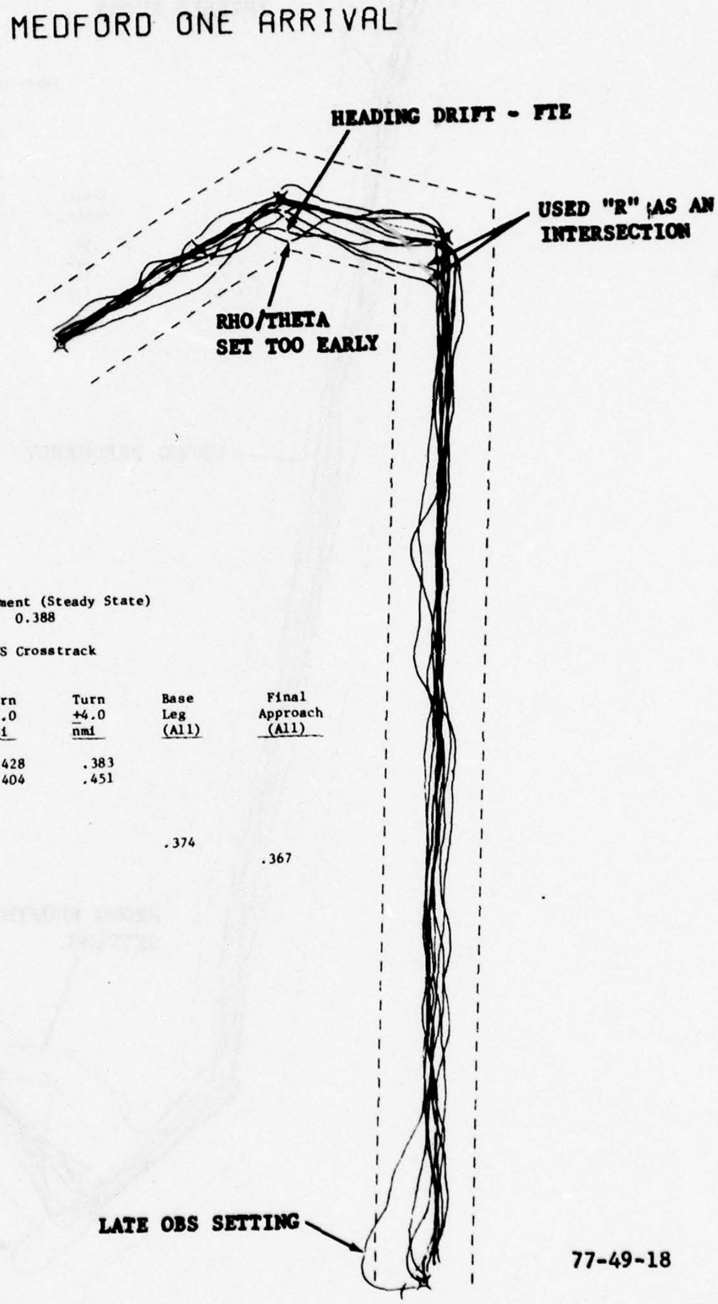


Super-Segment (Steady State)
0.358

RMS Crosstrack

	Steady State	Turn ± 2.0 nmi	Turn ± 4.0 nmi	Base Leg (All)	Final Approach (All)
P-V (W)	.384	.383	1.017		
V-W (I)	.348	.564	.667		
W-X (I)	.799				
X-Y (W)	.338				
Base				.518	
Final					.432

FIGURE 17. ACY STAR - ROUTE B - INTERSECTIONS AT W AND X



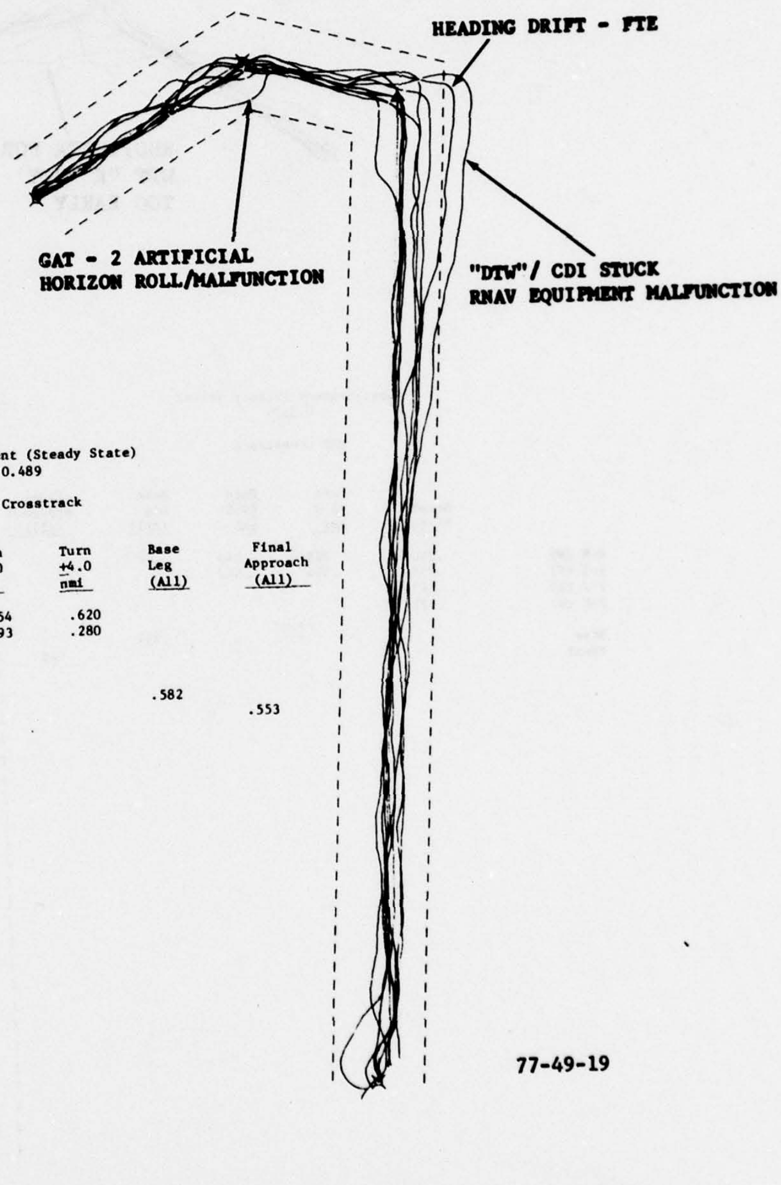
Super-Segment (Steady State)
0.388

RMS Crosstrack

	Steady State	Turn ±2.0 nmi	Turn ±4.0 nmi	Base Leg (All)	Final Approach (All)
E-R (W)	.280	.428	.383		
R-I (W)	.479	.404	.451		
I-J (W)	.309				
J-K (W)	.275				
Base				.374	
Final					.367

FIGURE 18. PNE STAR - ROUTE C - ALL WAYPOINTS

MEDFORD ONE ARRIVAL

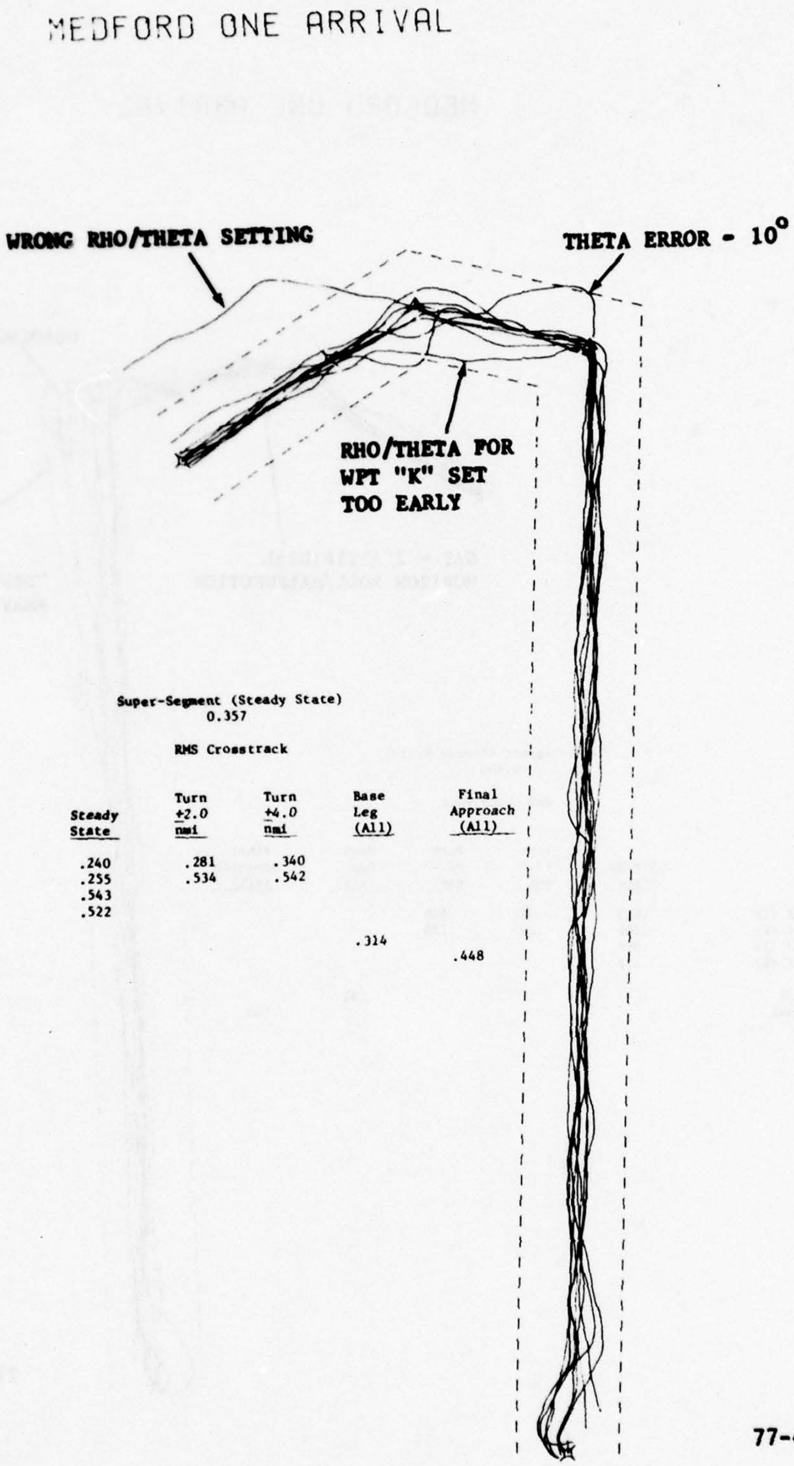


Super-Segment (Steady State)
0.489

RMS Crosstrack

	Steady State	Turn ±2.0 nmi	Turn ±4.0 nmi	Base Leg (All)	Final Approach (All)
E-R (I)	.415	.654	.620		
R-I (W)	.304	.293	.280		
I-J (I)	.308				
J-K (W)	.212				
Base				.582	
Final					.553

FIGURE 19. PNE STAR - ROUTE C - INTERSECTIONS AT R AND J



Super-Segment (Steady State)
0.357

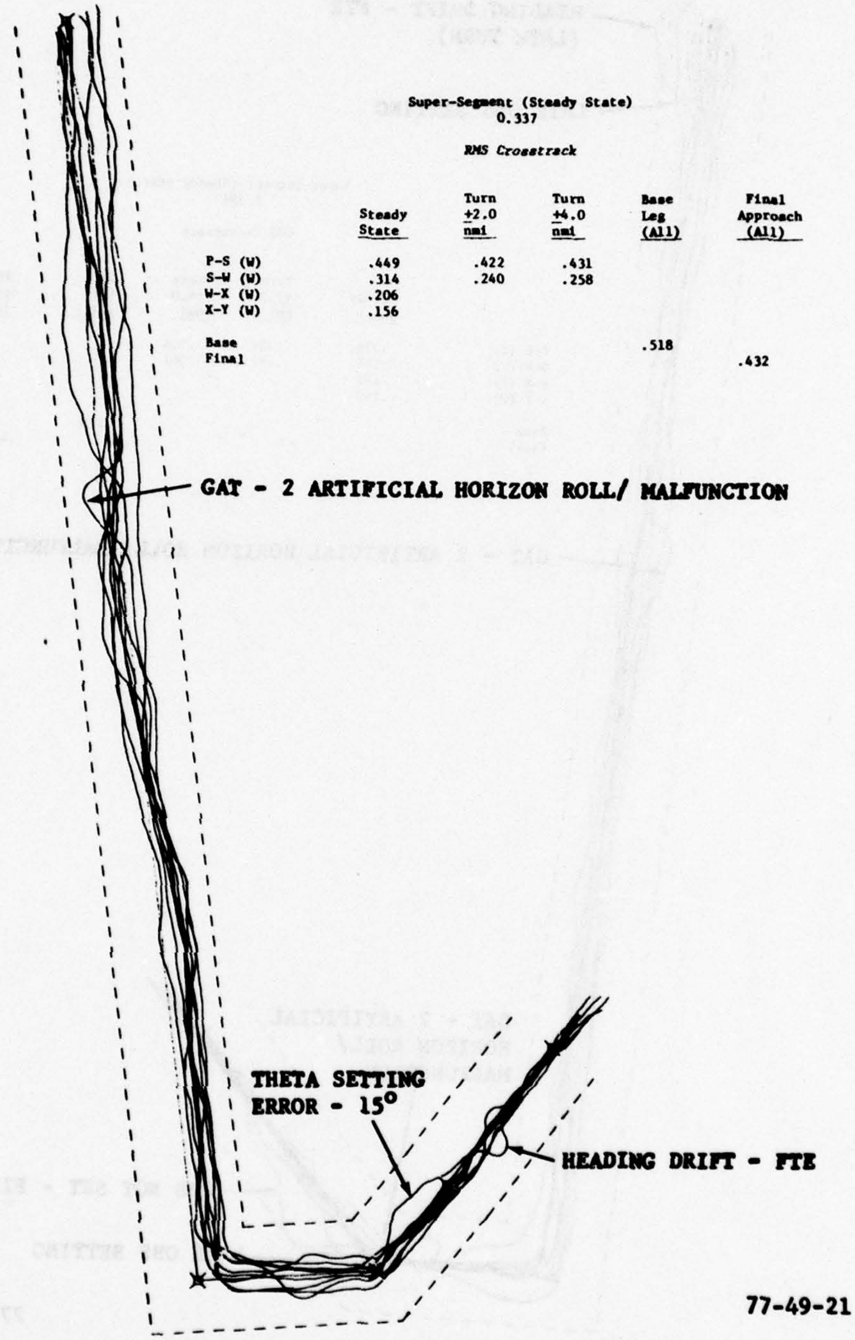
RMS Crosstrack

	Steady State	Turn ±2.0 nmi	Turn ±4.0 nmi	Base Leg (All)	Final Approach (All)
E-R (W)	.240	.281	.340		
R-I (I)	.255	.534	.542		
I-J (I)	.543				
J-K (W)	.522				
Base				.314	
Final					.448

77-49-20

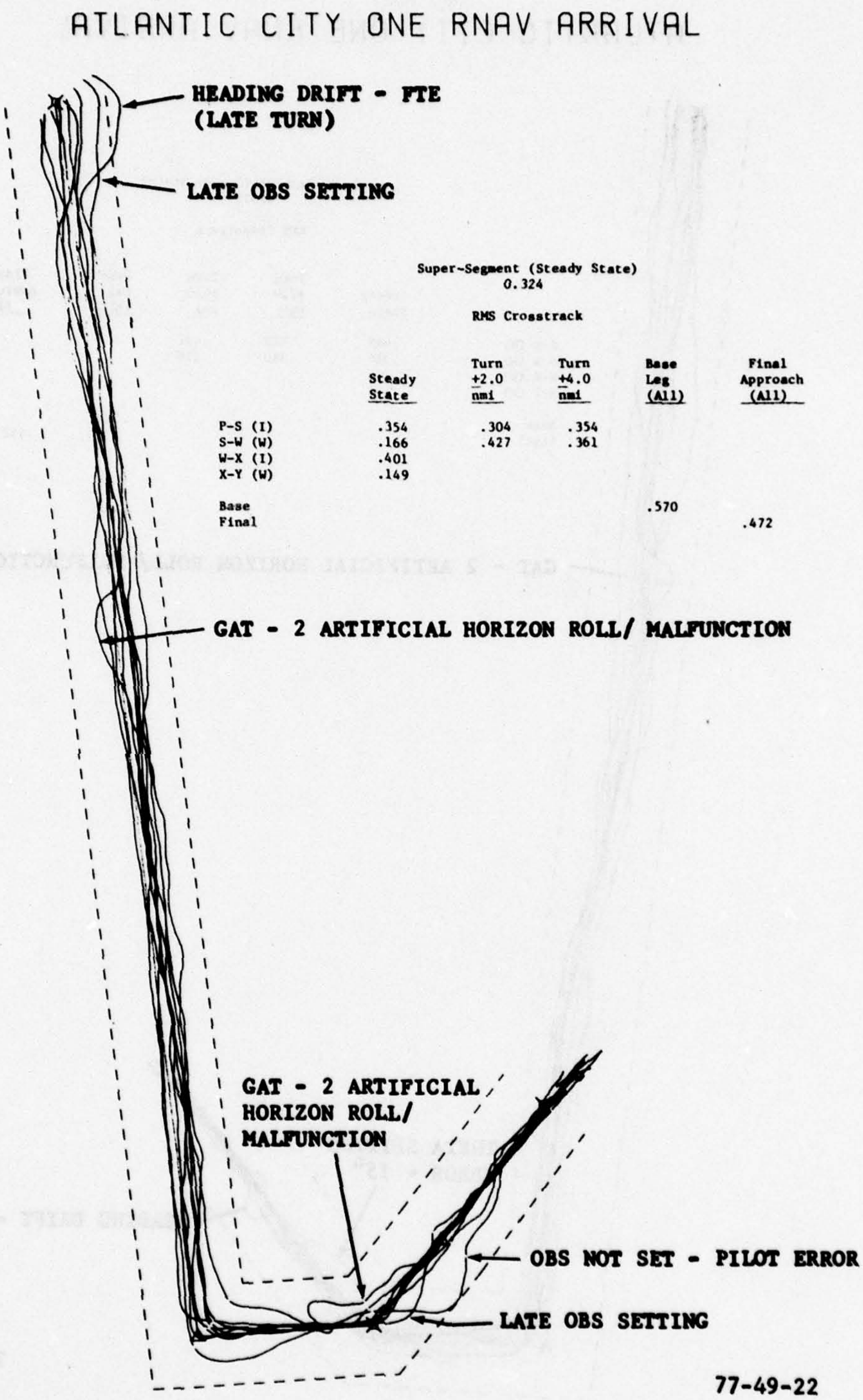
FIGURE 20. PNE STAR - ROUTE C - INTERSECTIONS AT I AND J

ATLANTIC CITY ONE RNAV ARRIVAL



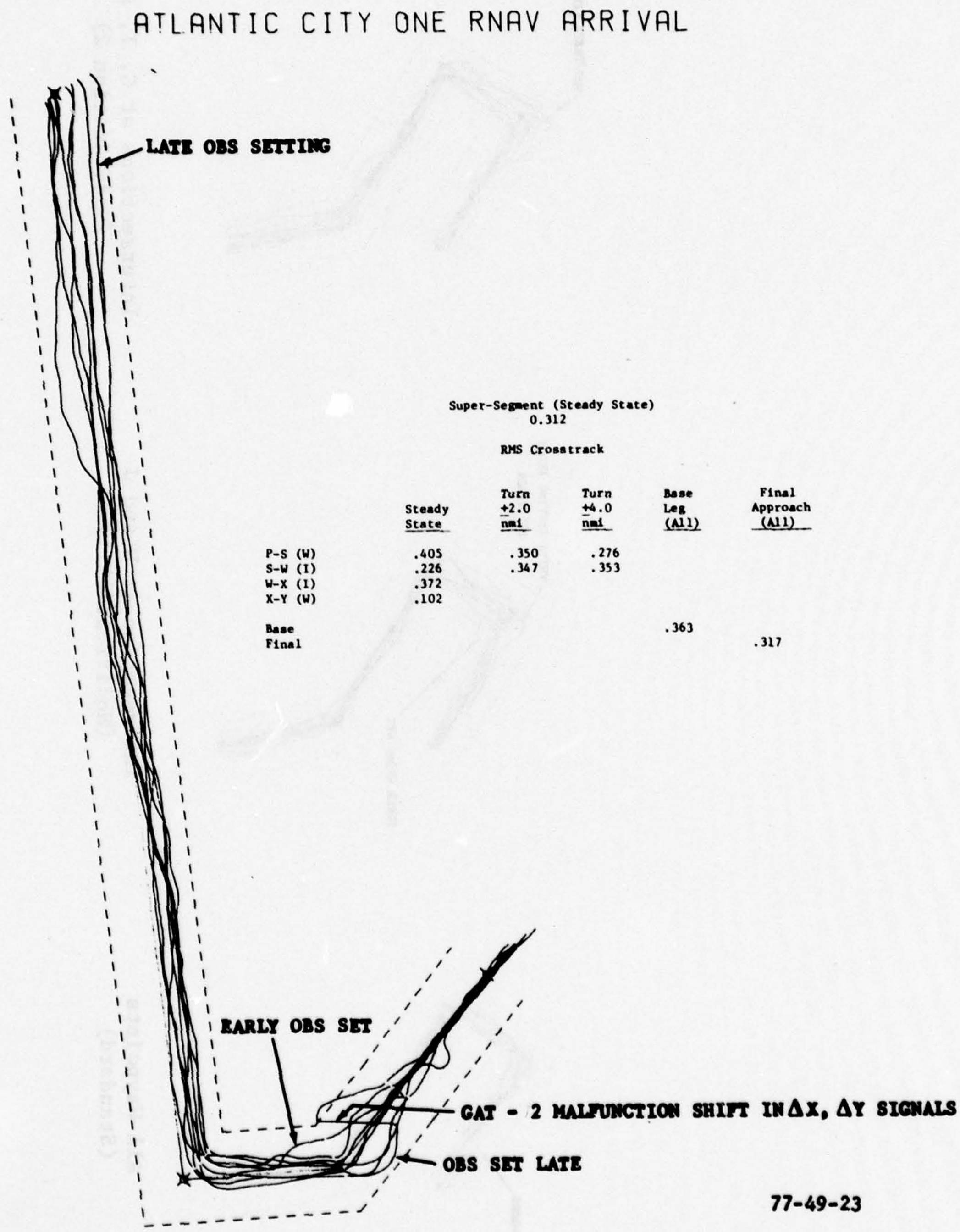
	Steady State	Turn ± 2.0 nmi	Turn ± 4.0 nmi	Base Leg (All)	Final Approach (All)
P-S (W)	.449	.422	.431		
S-W (W)	.314	.240	.258		
W-X (W)	.206				
X-Y (W)	.156				
Base				.518	
Final					.432

FIGURE 21. ACY STAR - ROUTE C - ALL WAYPOINTS



	Steady State	Turn +2.0 nmi	Turn +4.0 nmi	Base Leg (All)	Final Approach (All)
P-S (I)	.354	.304	.354		
S-W (W)	.166	.427	.361		
W-X (I)	.401				
X-Y (W)	.149				
Base				.570	
Final					.472

FIGURE 22. ACY STAR - ROUTE C - INTERSECTIONS AT S AND X

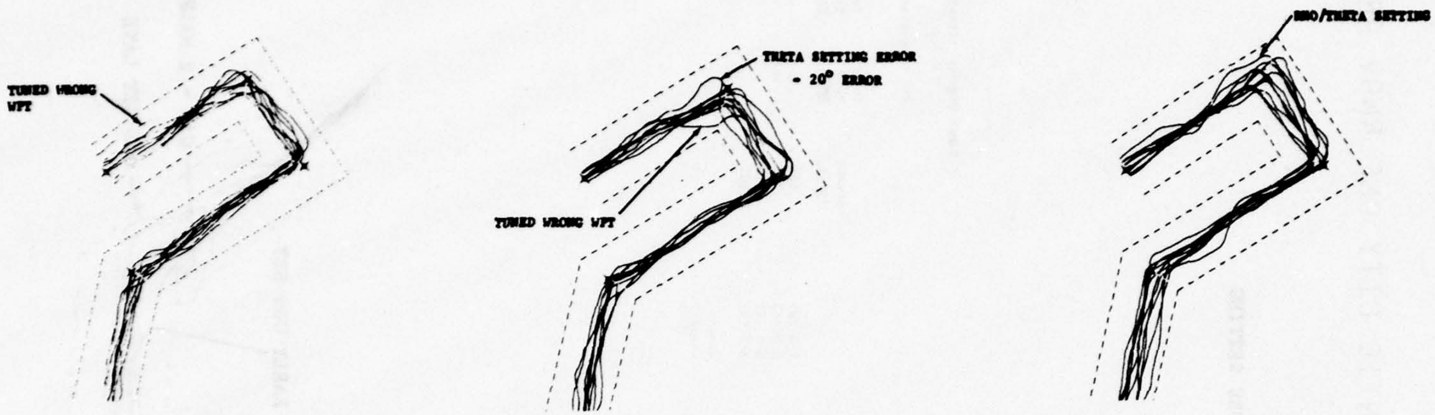


Super-Segment (Steady State)
0.312

RMS Crosstrack

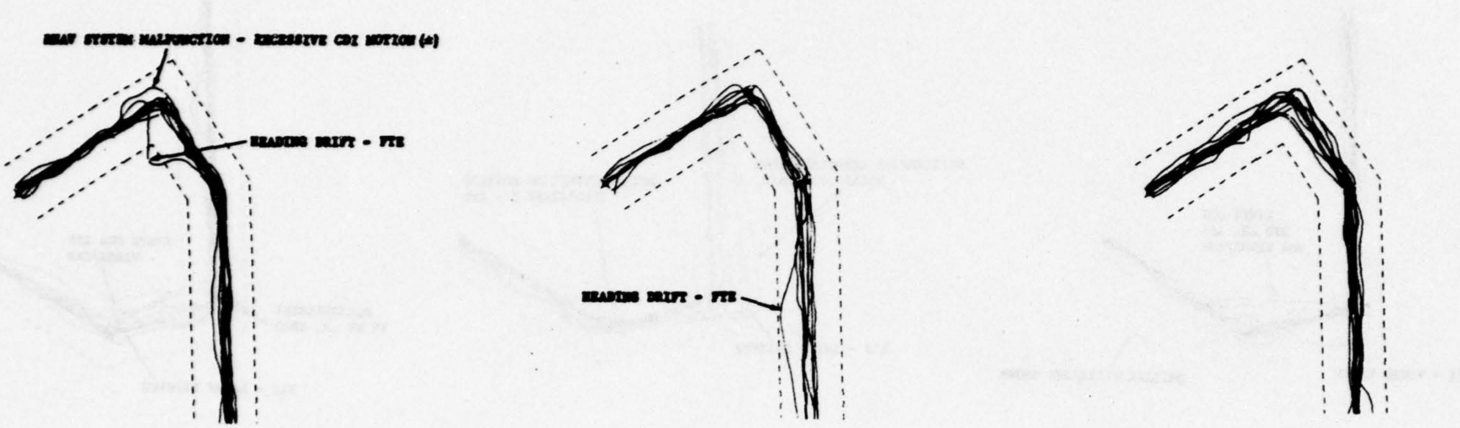
	Steady State	Turn ±2.0 nmi	Turn ±4.0 nmi	Base Leg (All)	Final Approach (All)
P-S (W)	.405	.350	.276		
S-W (I)	.226	.347	.353		
W-X (I)	.372				
X-Y (W)	.102				
Base				.363	
Final					.317

FIGURE 23. ACY STAR - ROUTE C - INTERSECTIONS AT W AND X



All Waypoints (Standard) | Intersection at H and J (Modification 1) | Intersections at G, I, and J (Modification 2)

FIGURE 24. RELATIVE TURN PERFORMANCE PLOTS - ROUTE A (PNE STAR)

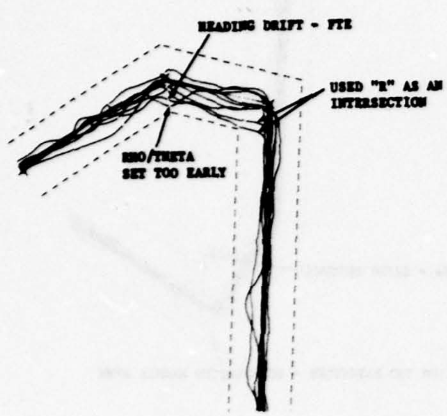


All Waypoints
(Standard)

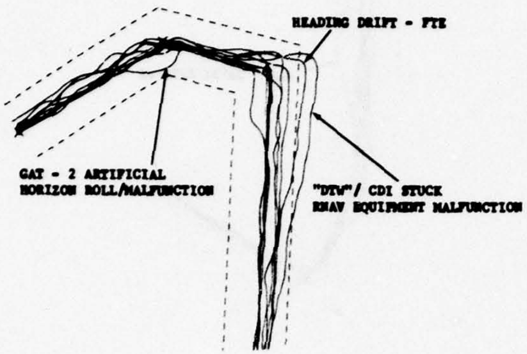
Intersection at H and J
(Modification 1)

Intersection at I and J
(Modification 2)

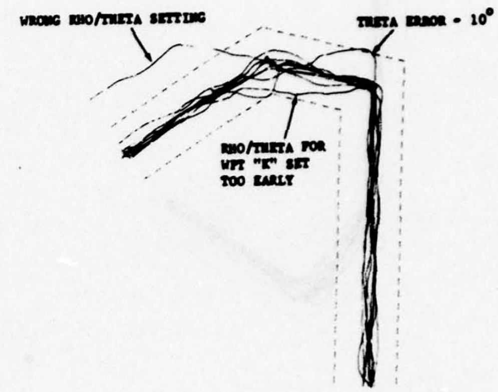
FIGURE 25. RELATIVE TURN PERFORMANCE - ROUTE B (PNE STAR)



All Waypoints
(Standard)



Intersection at R and J
(Modification 1)



Intersection at I and J
(Modification 2)

FIGURE 26. RELATIVE TURN PERFORMANCE PLOTS - ROUTE C (PNE STAR)

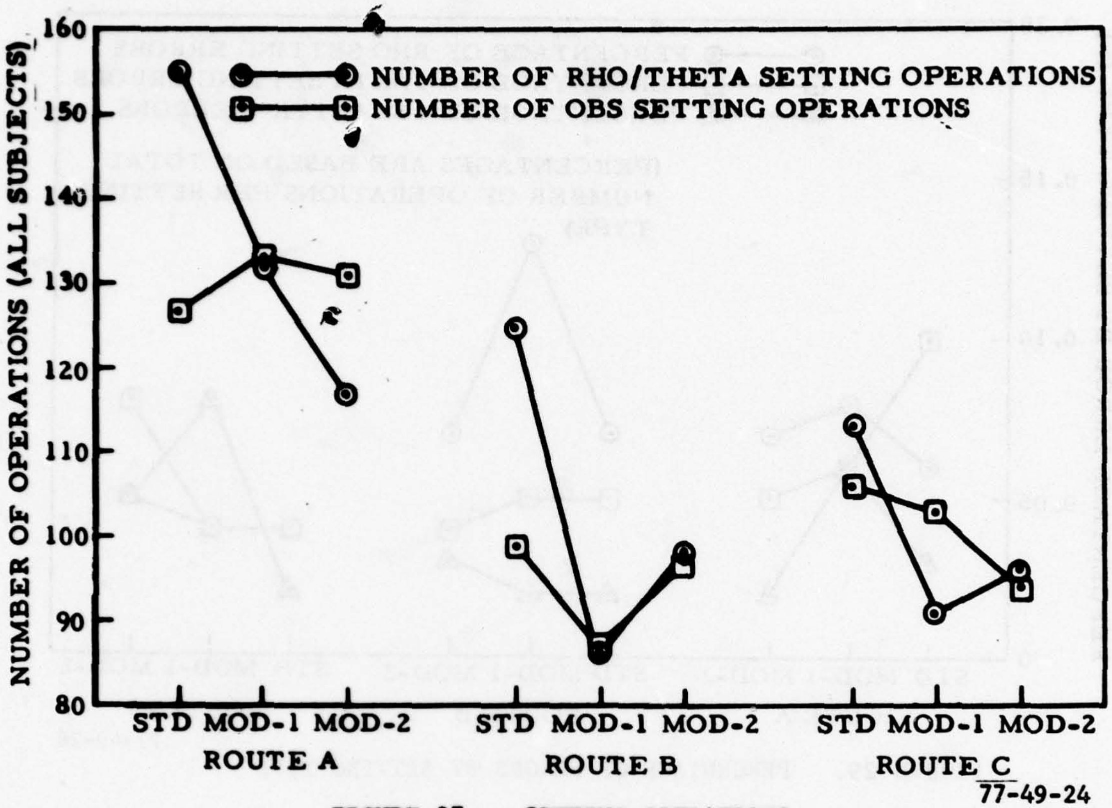


FIGURE 27. SETTING OPERATIONS

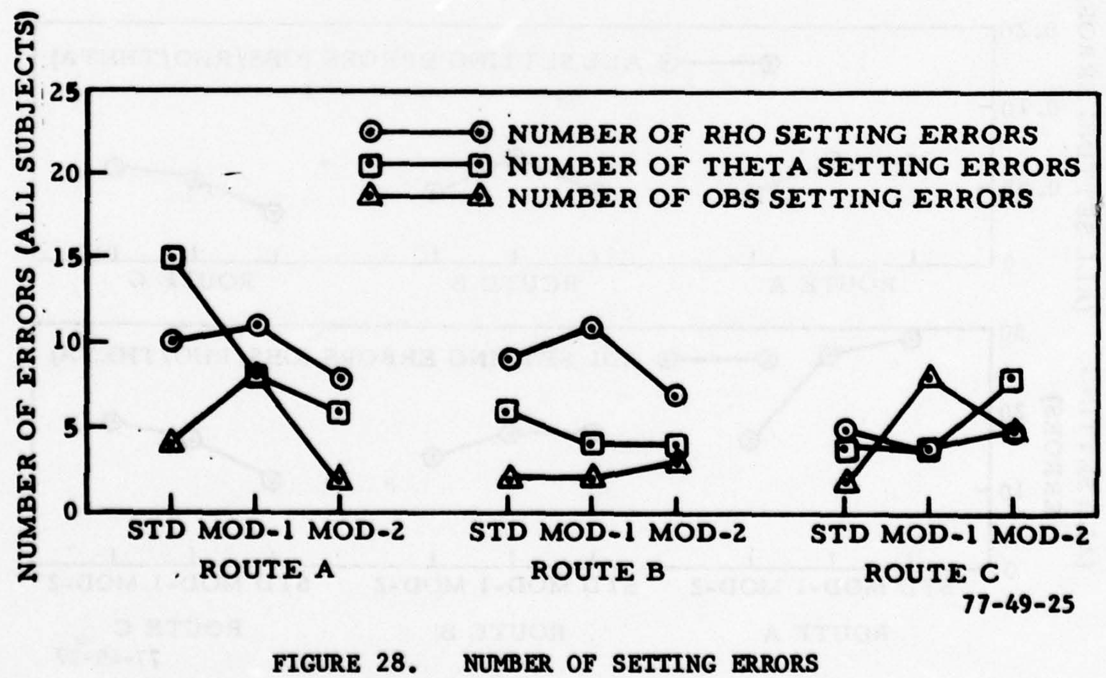


FIGURE 28. NUMBER OF SETTING ERRORS

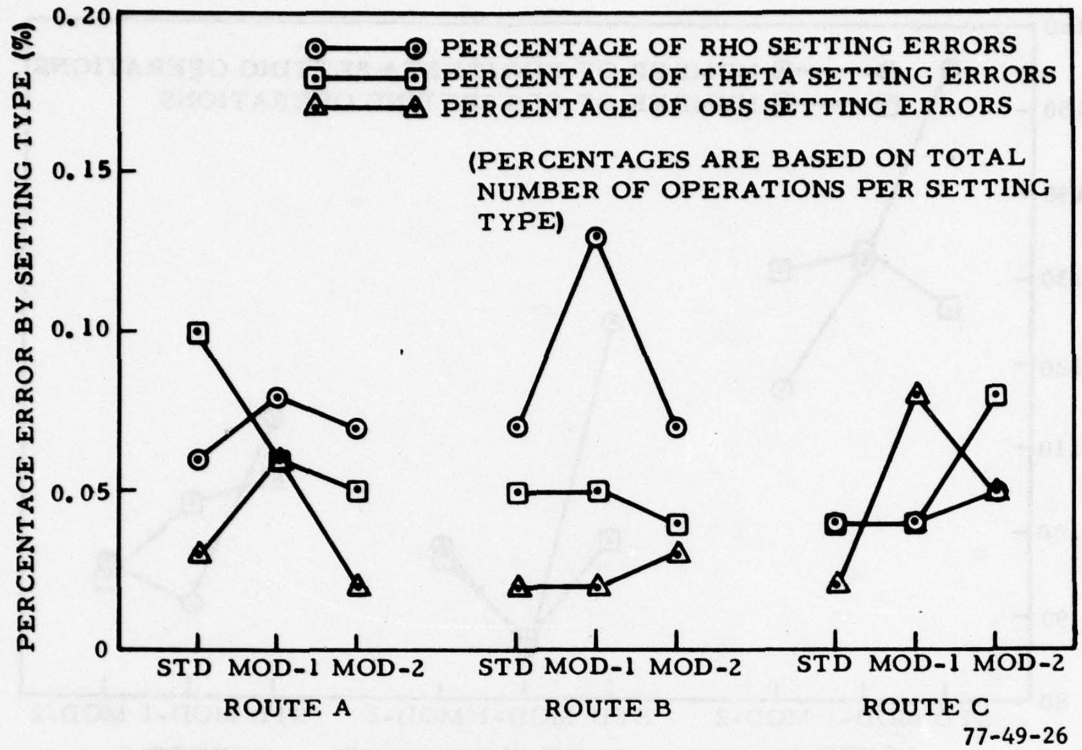


FIGURE 29. PERCENTAGE OF ERRORS BY SETTING TYPE

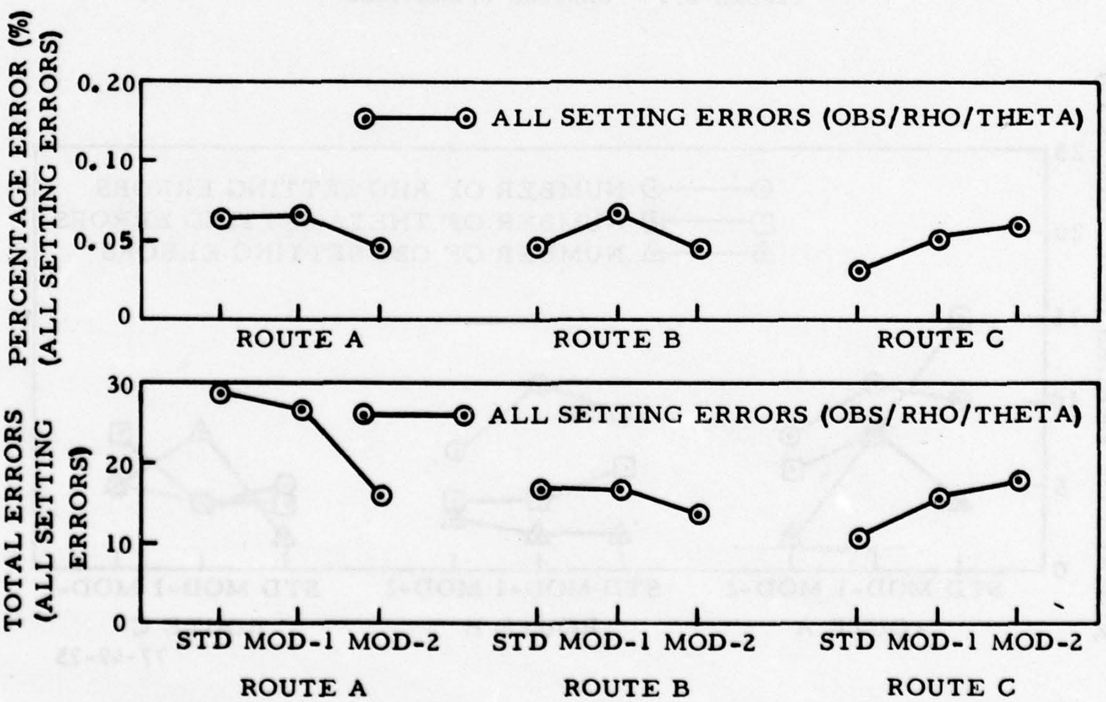


FIGURE 30. PERCENTAGE OF TOTAL SETTING ERRORS

APPENDIX A

INDIVIDUAL ROUTE STRUCTURES

NOTE: This appendix has been reproduced from the actual pilot records used during the flights.

APPENDIX A

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Continued)

LIST OF ILLUSTRATIONS (Continued)

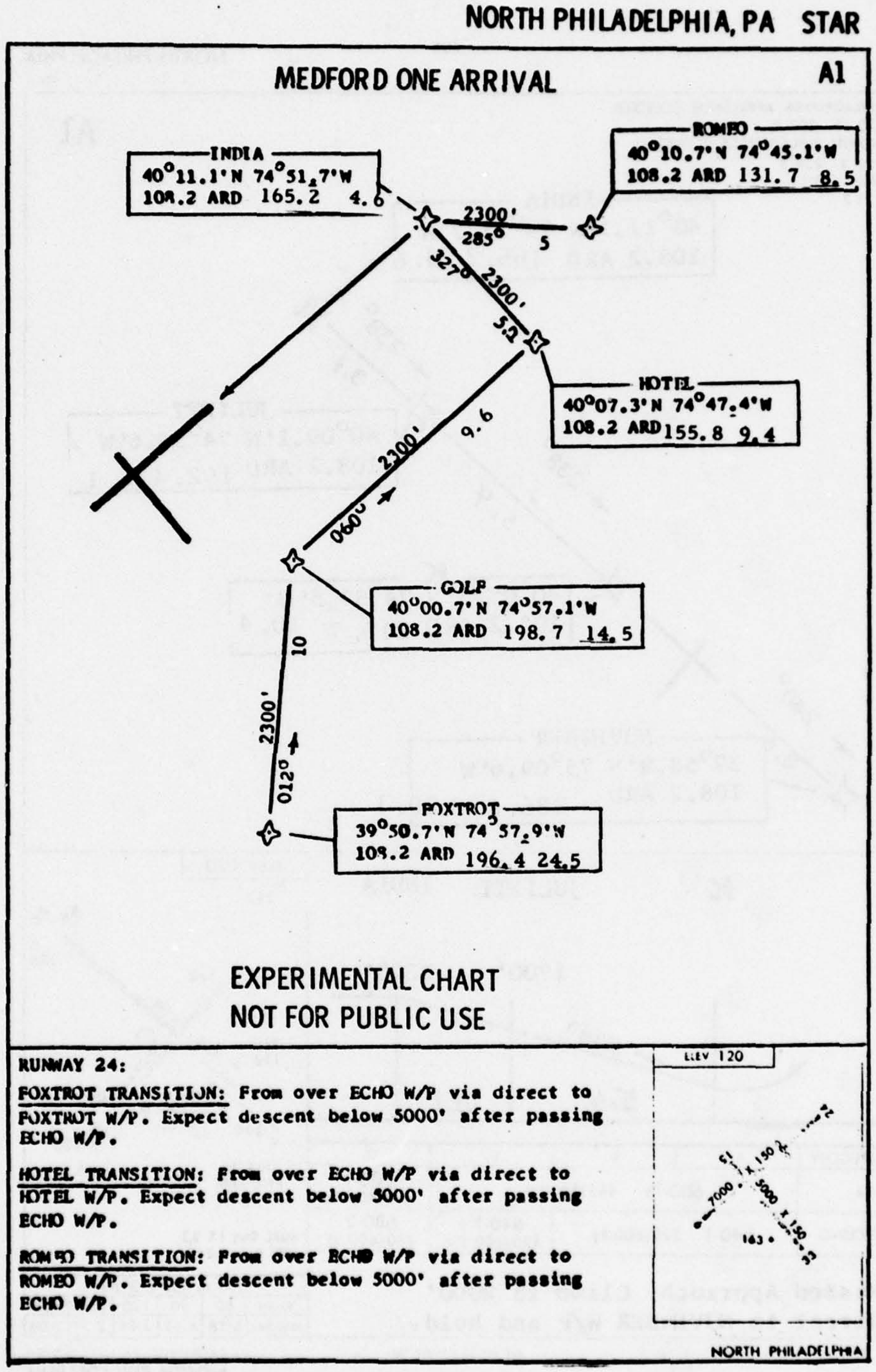


FIGURE A-1. ROUTE A--STANDARD (PNE STAR - ALL WAYPOINTS)

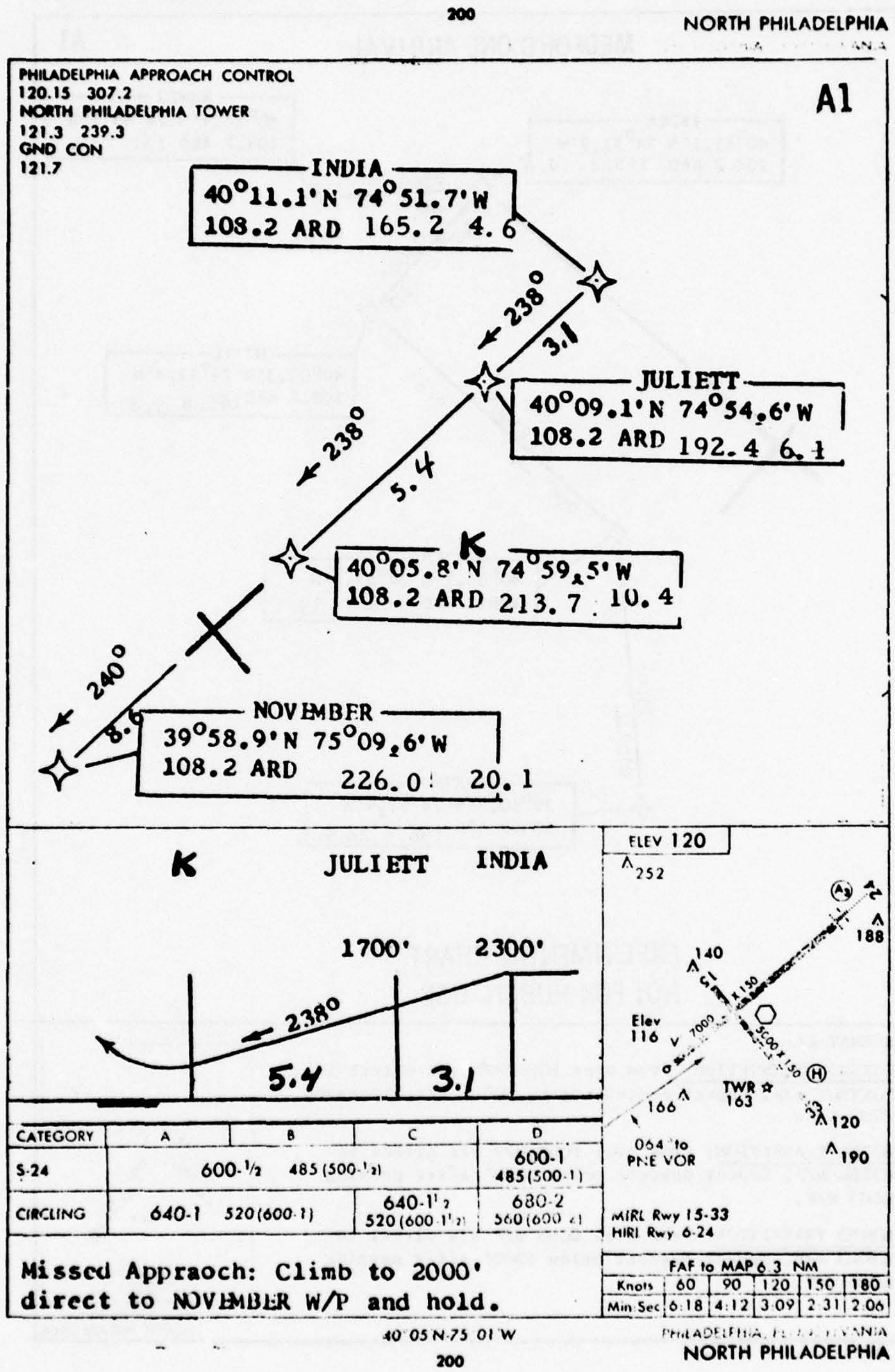


FIGURE A-2. ROUTE A--STANDARD (PNE APPROACH - ALL WAYPOINTS)

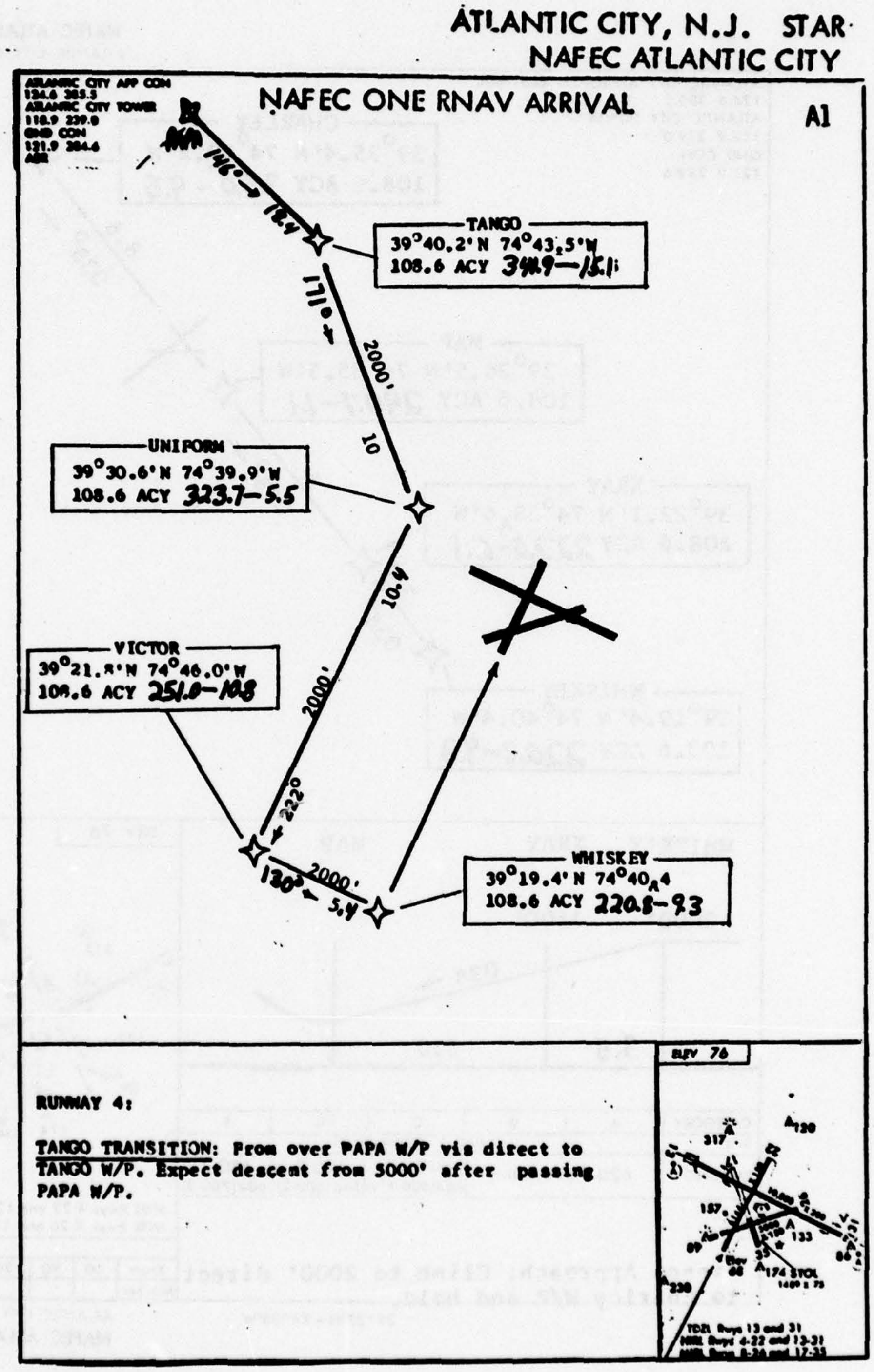


FIGURE A-3. ROUTE A--STANDARD (ACY STAR - ALL WAYPOINTS)

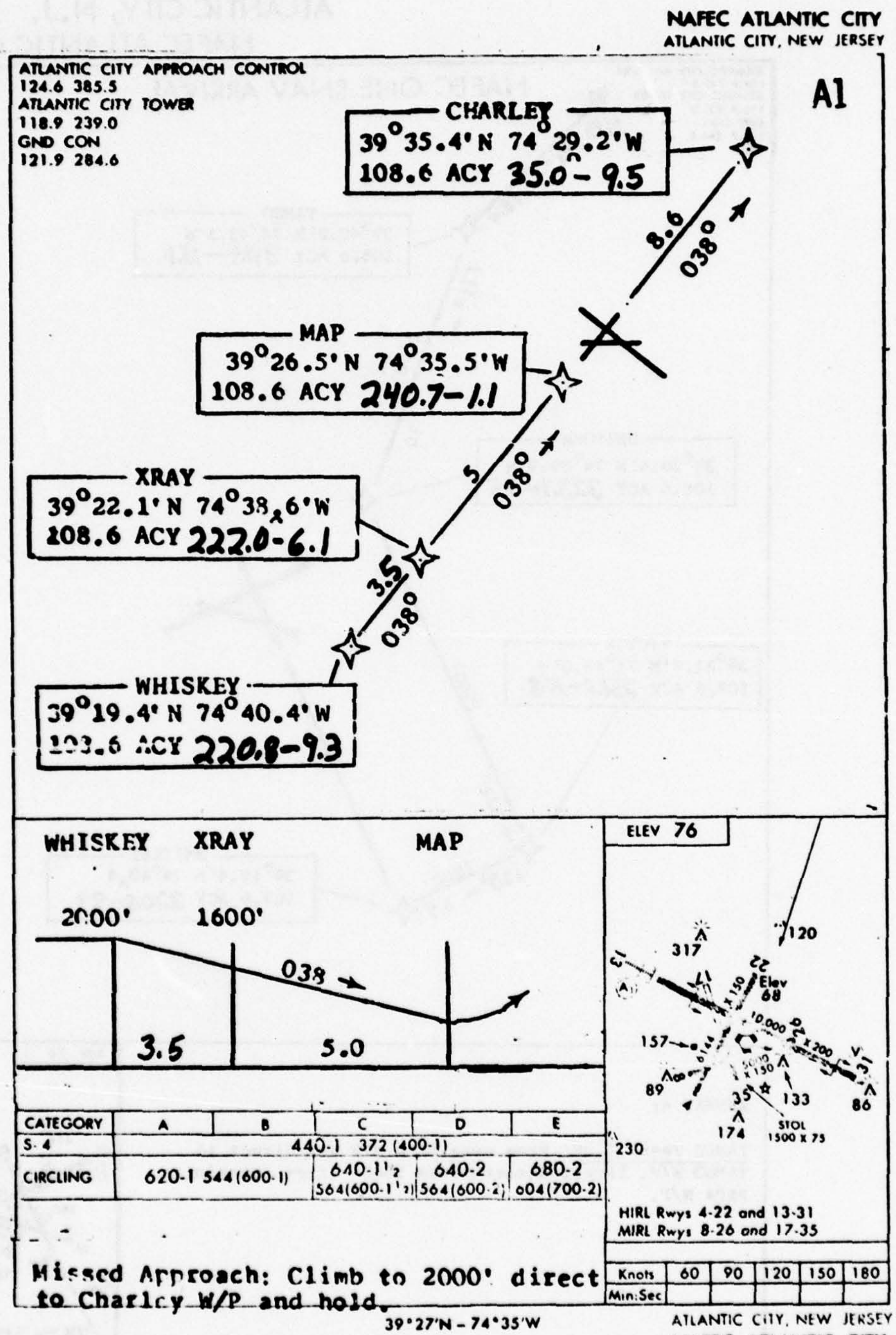


FIGURE A-4. ROUTE A--STANDARD (ACY APPROACH - ALL WAYPOINTS)

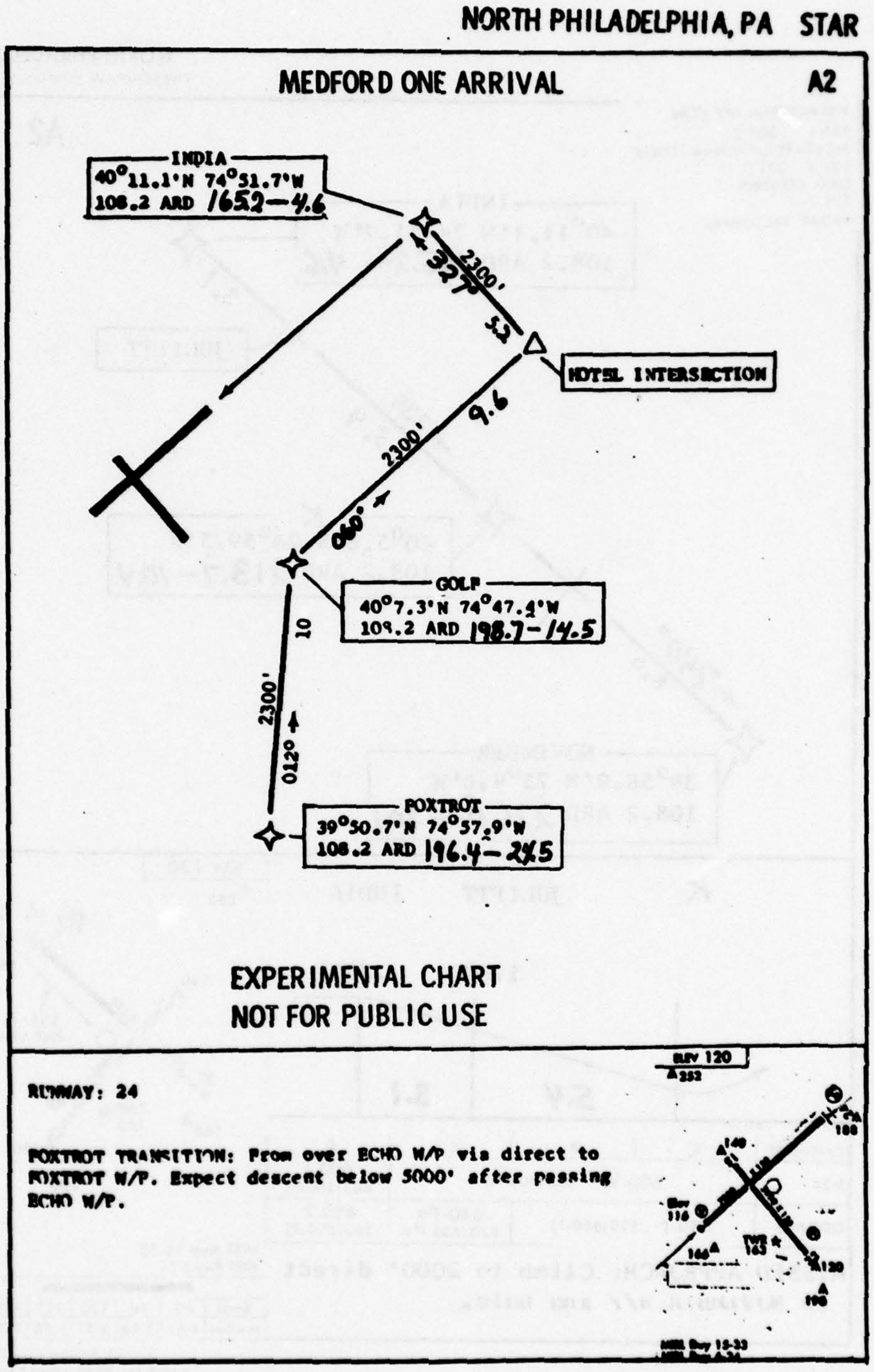


FIGURE A-5. ROUTE A--MODIFICATION 1 (PNE STAR - HOTEL AND JULIETT INTERSECTIONS)

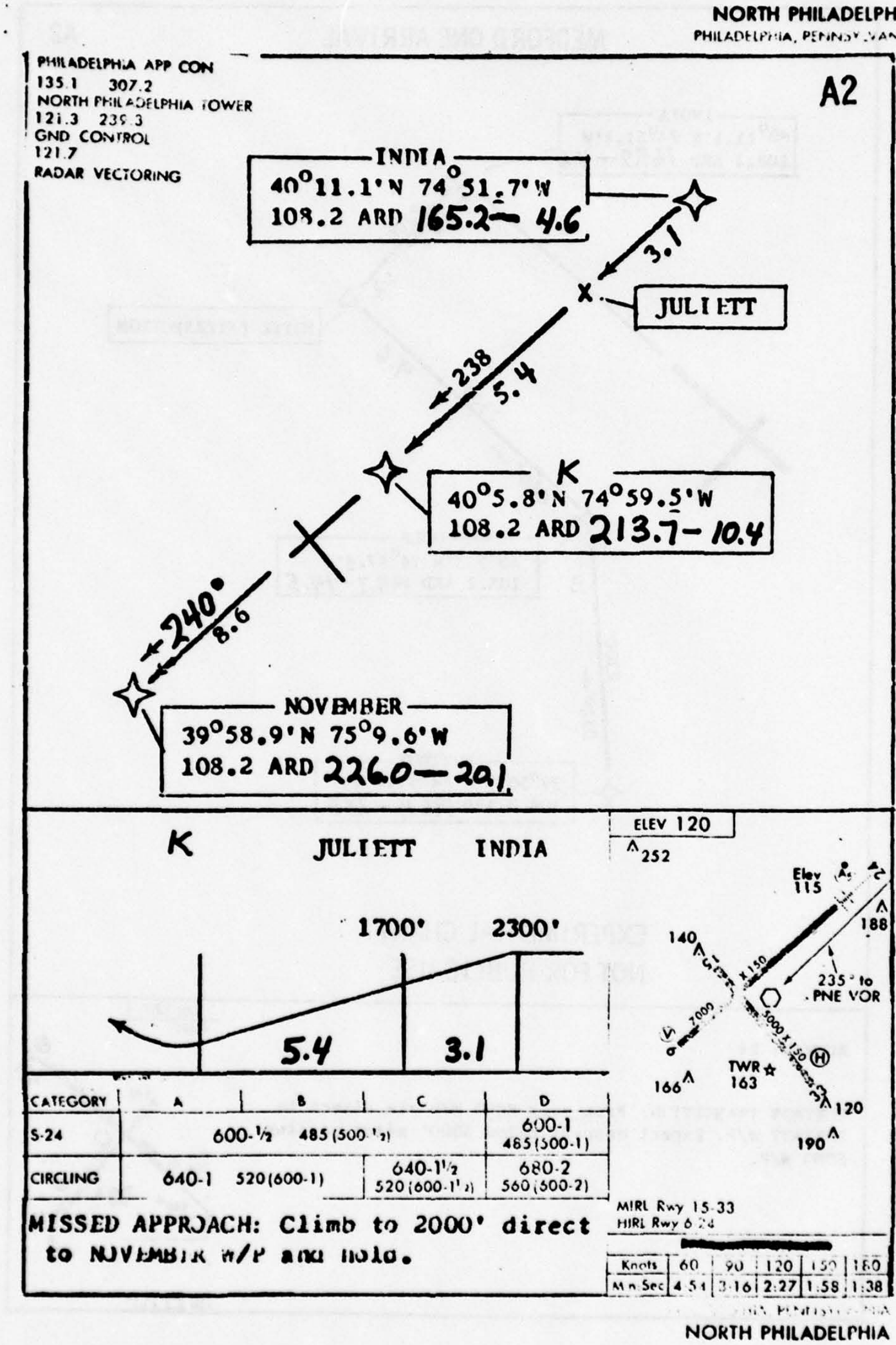


FIGURE A-6. ROUTE A--MODIFICATION 1 (PNE APPROACH - HOTEL AND JULIETT INTERSECTIONS)

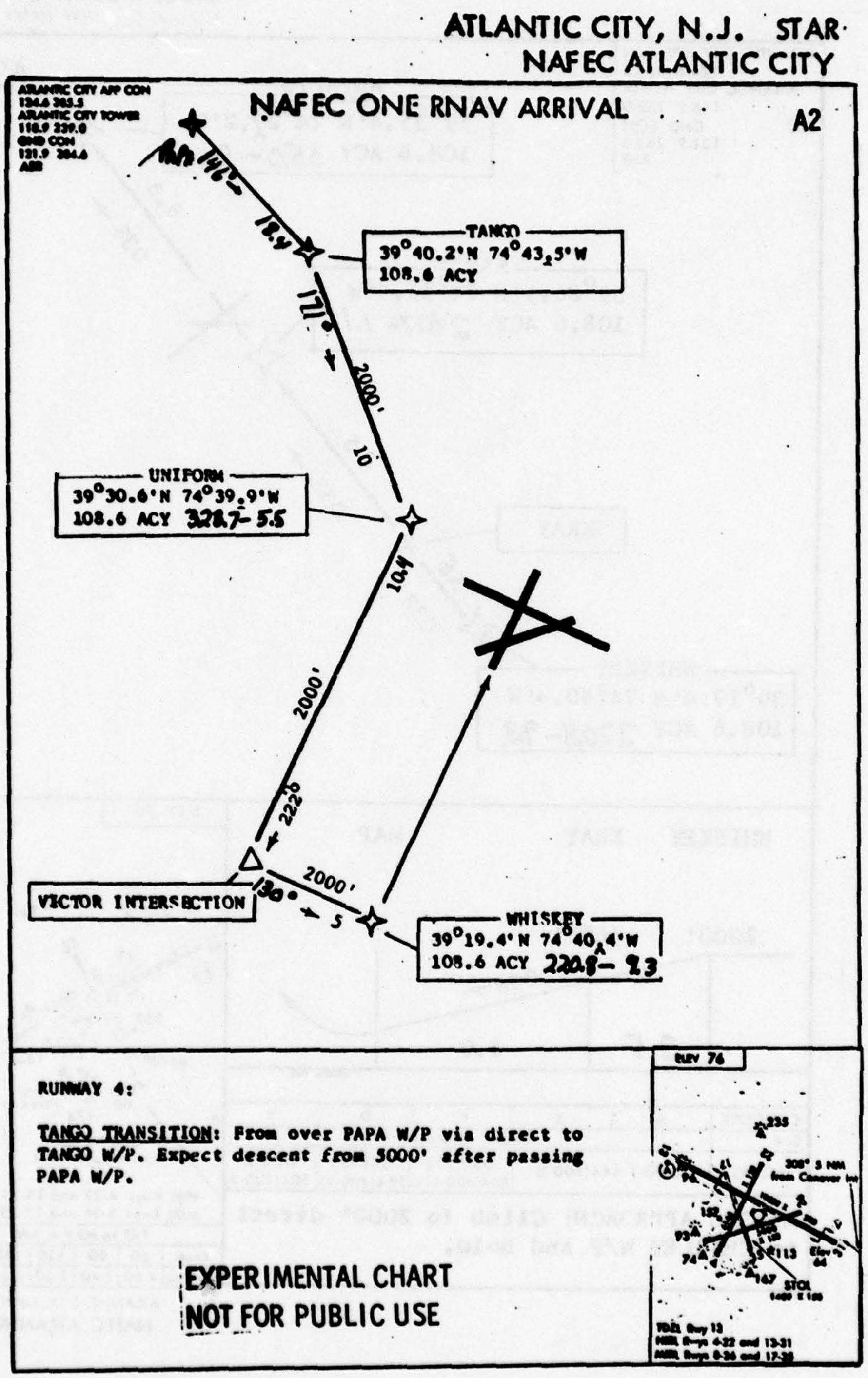


FIGURE A-7. ROUTE A--MODIFICATION 1 (ACY STAR - VICTOR AND X-RAY INTERSECTIONS)

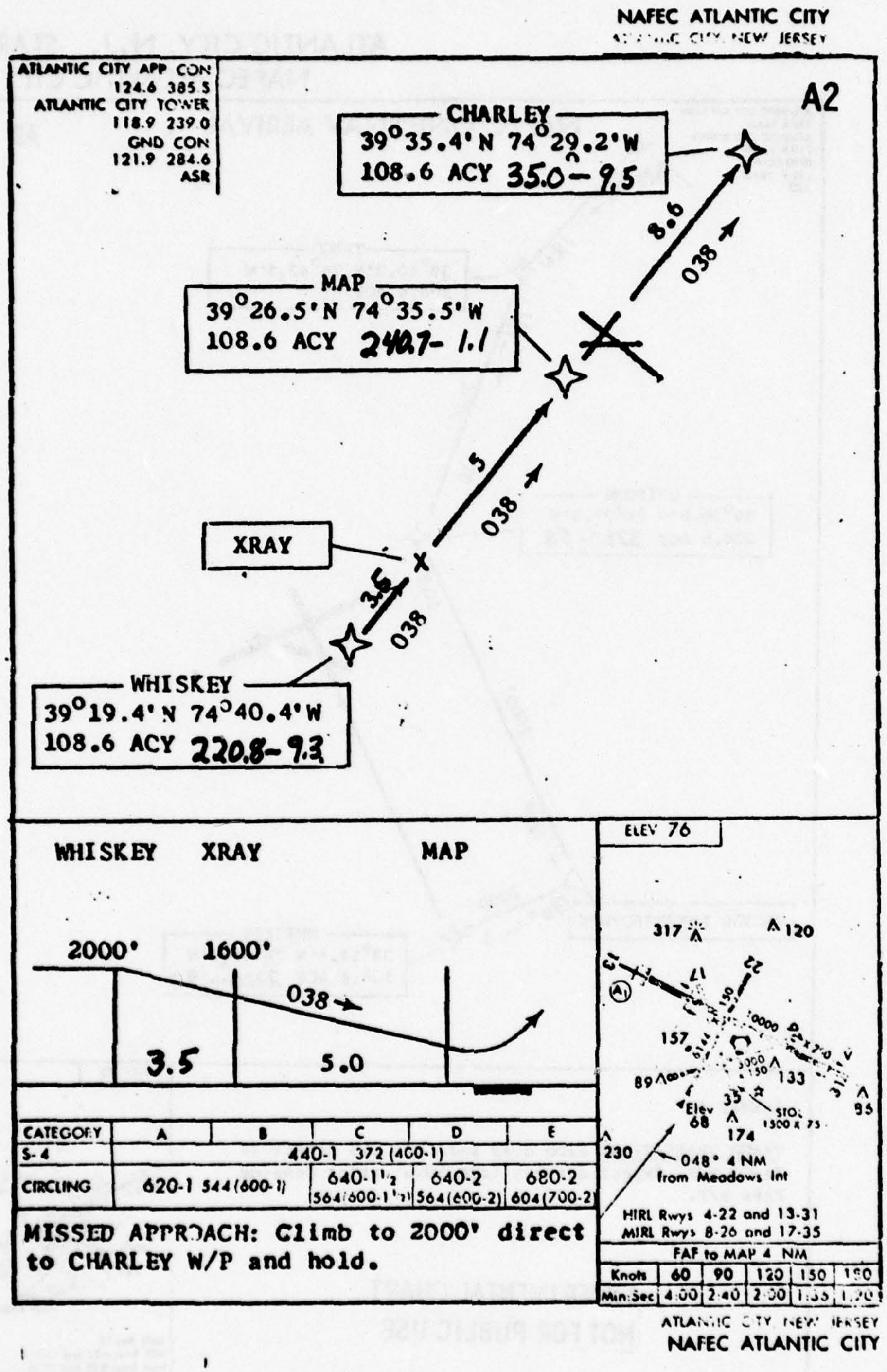


FIGURE A-8. ROUTE A--MODIFICATION 1 (ACY APPROACH - VICTOR AND X-RAY INTERSECTIONS)

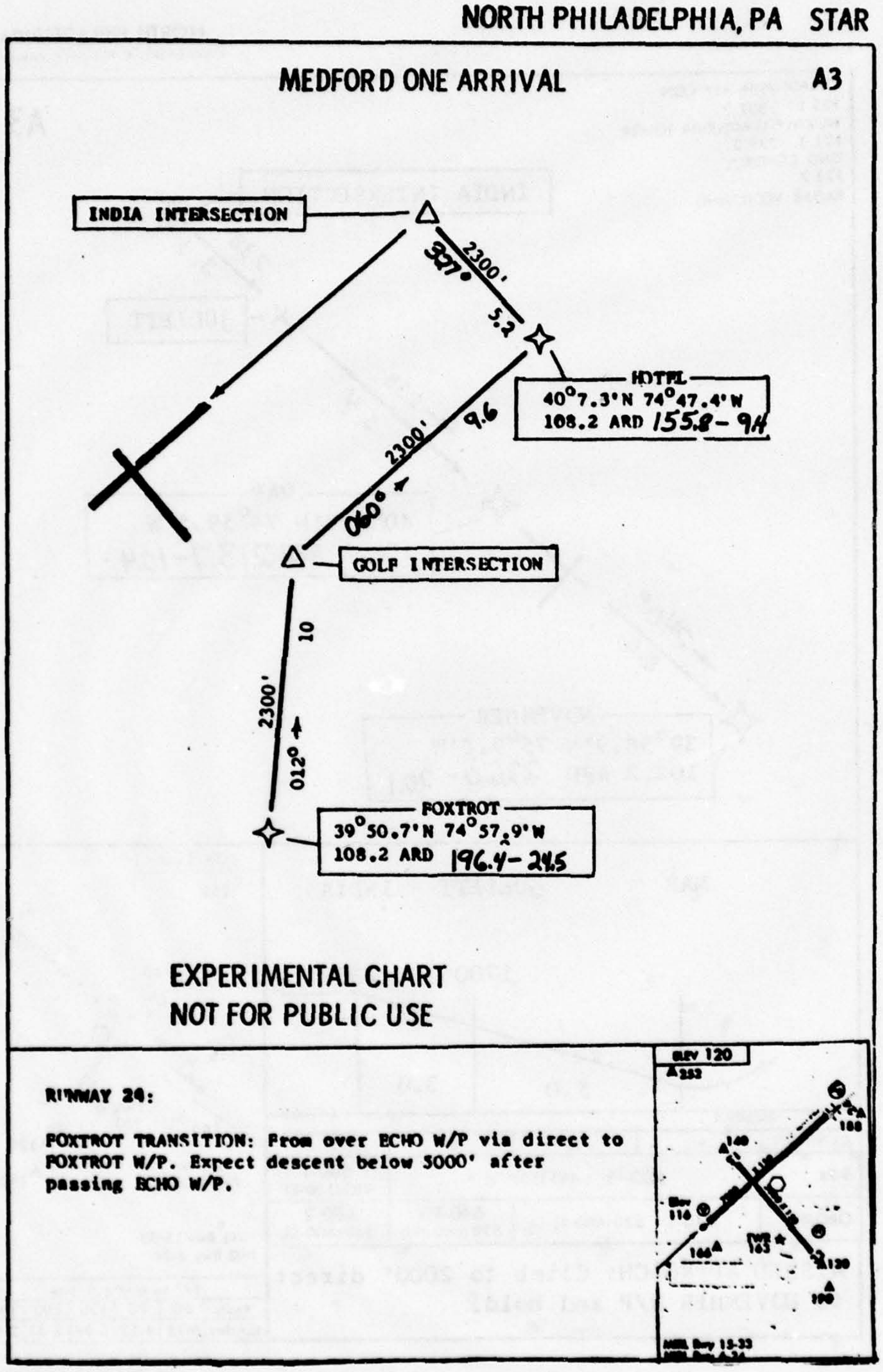


FIGURE A-9. ROUTE A--MODIFICATION 2 (PNE STAR - GOLF, INDIA, AND JULIETT INTERSECTIONS)

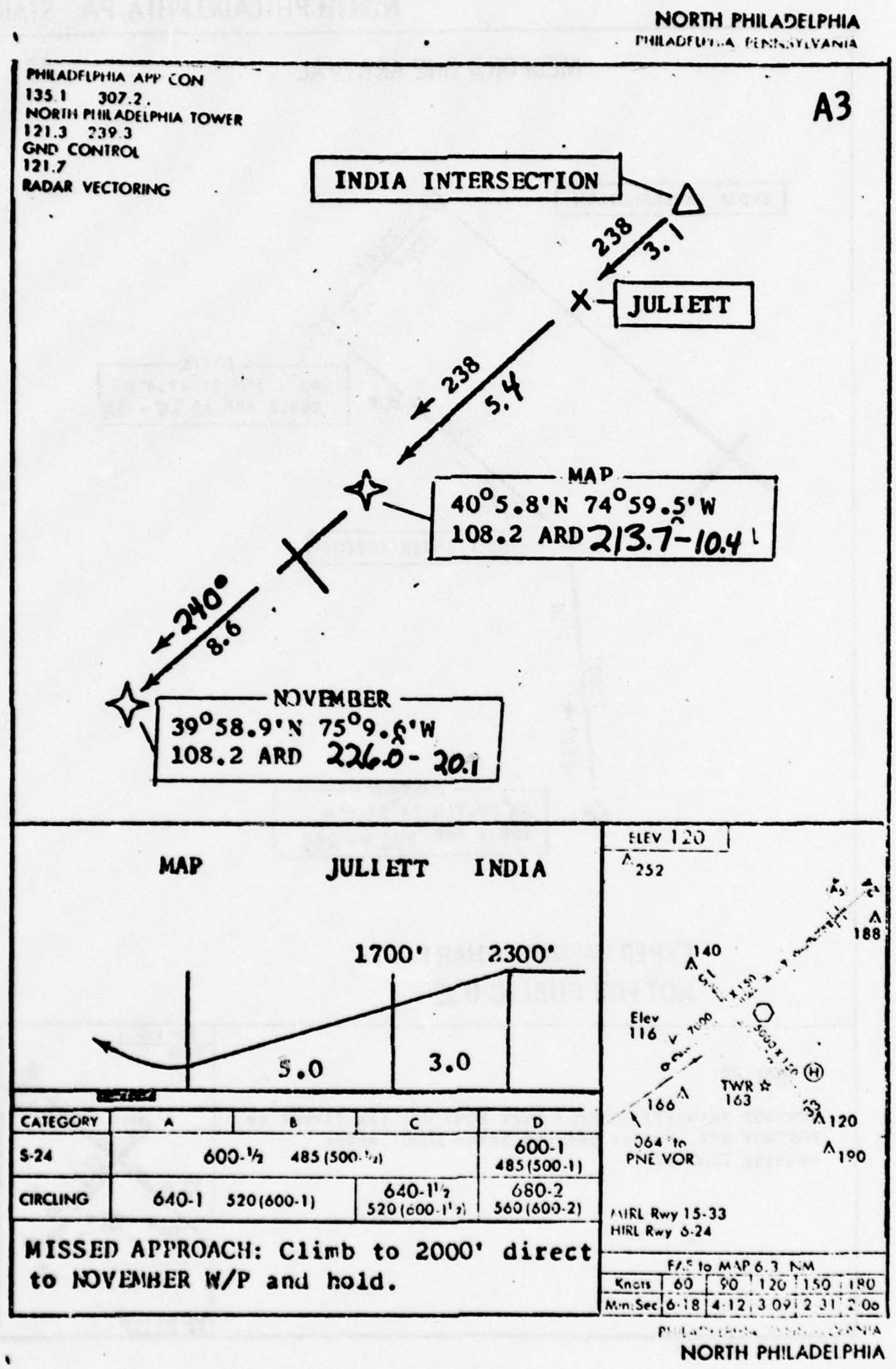


FIGURE A-10. ROUTE A--MODIFICATION 2 (PNE APPROACH - GOLF, INDIA, AND JULIETT INTERSECTIONS)

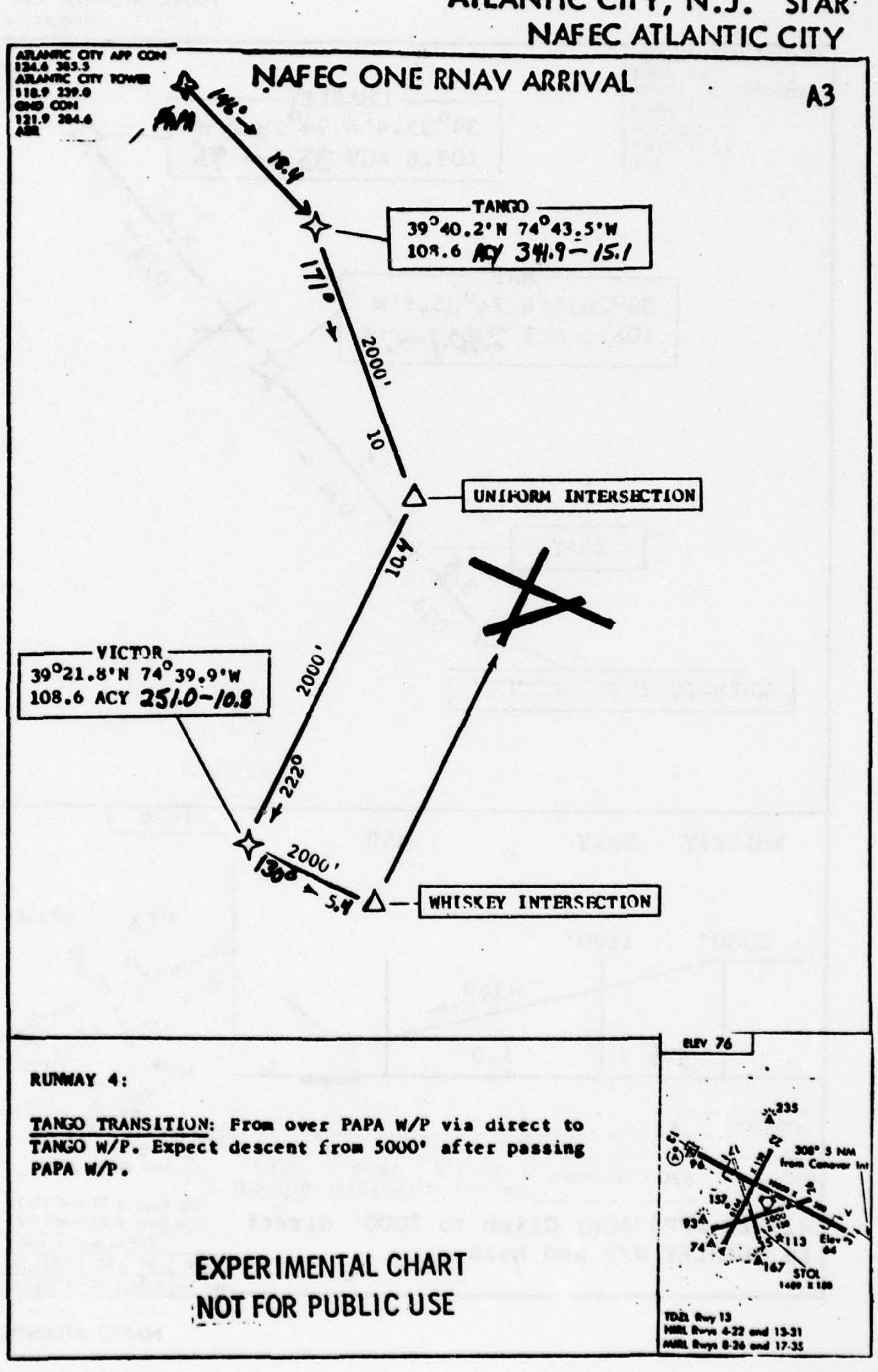


FIGURE A-11. ROUTE A--MODIFICATION 2 (ACY STAR - UNIFORM, WHISKEY, AND X-RAY INTERSECTIONS)

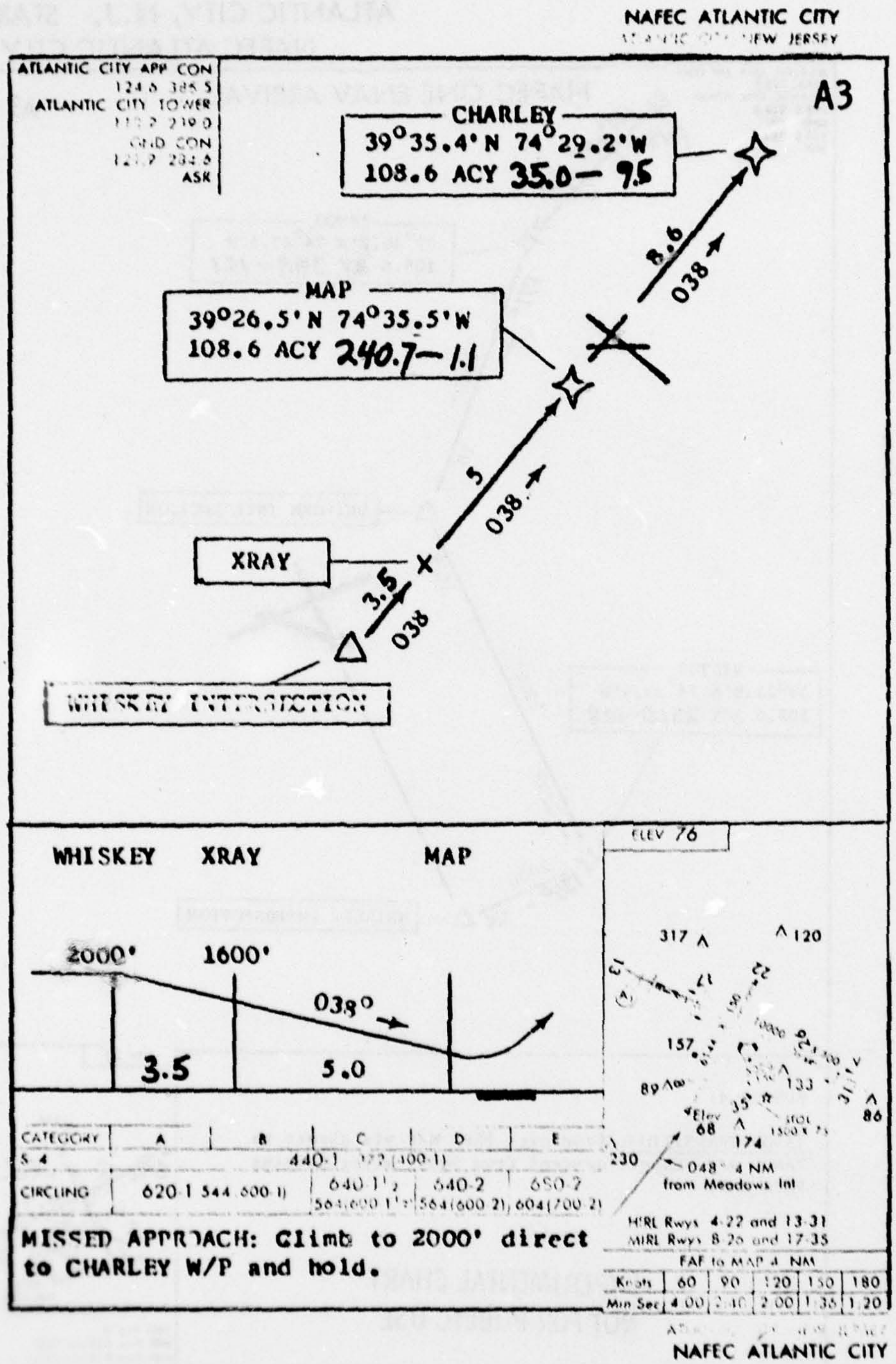


FIGURE A-12. ROUTE A--MODIFICATION 2 (ACY APPROACH - UNIFORM, WHISKEY, AND X-RAY INTERSECTIONS)

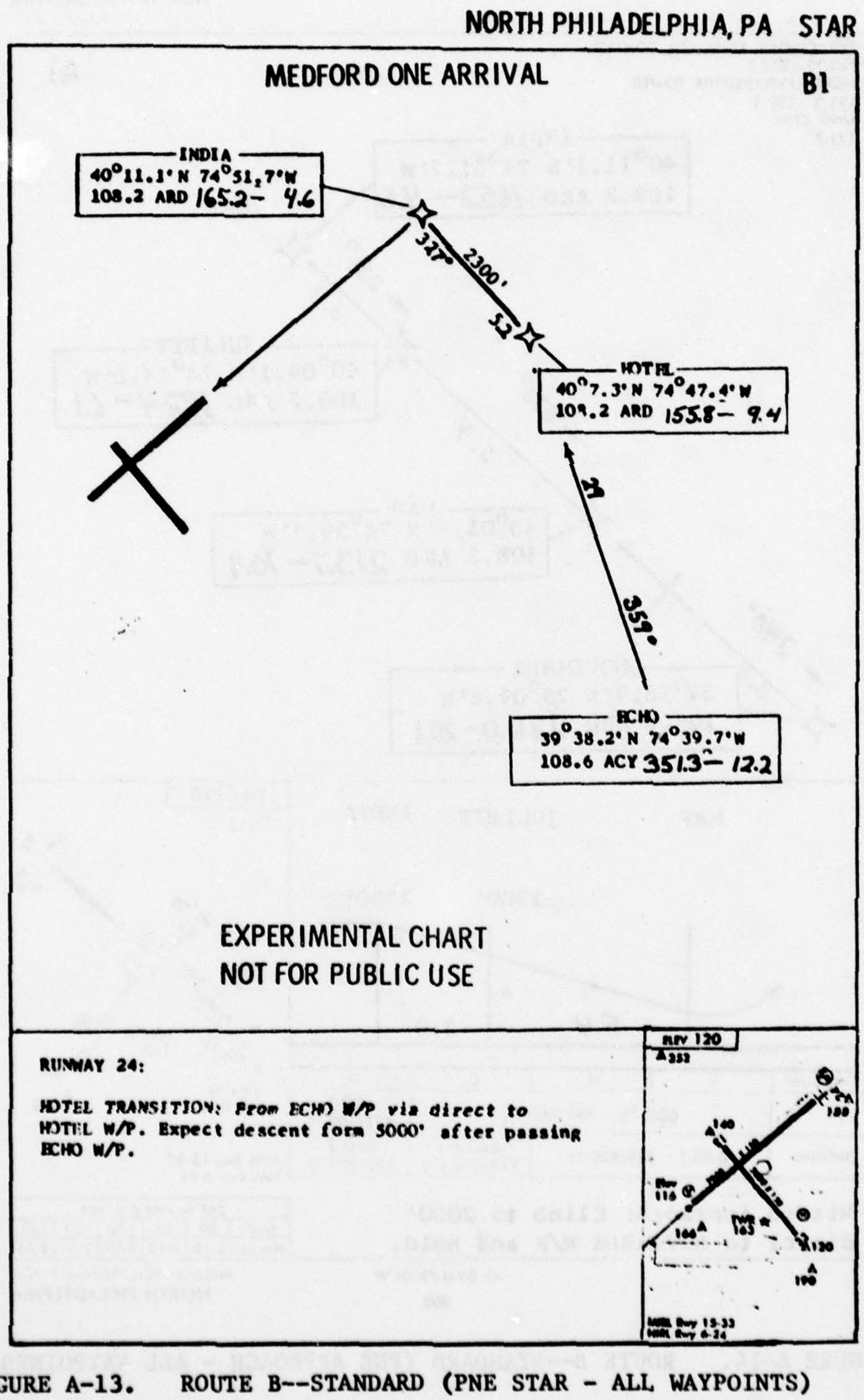


FIGURE A-13. ROUTE B--STANDARD (PNE STAR - ALL WAYPOINTS)

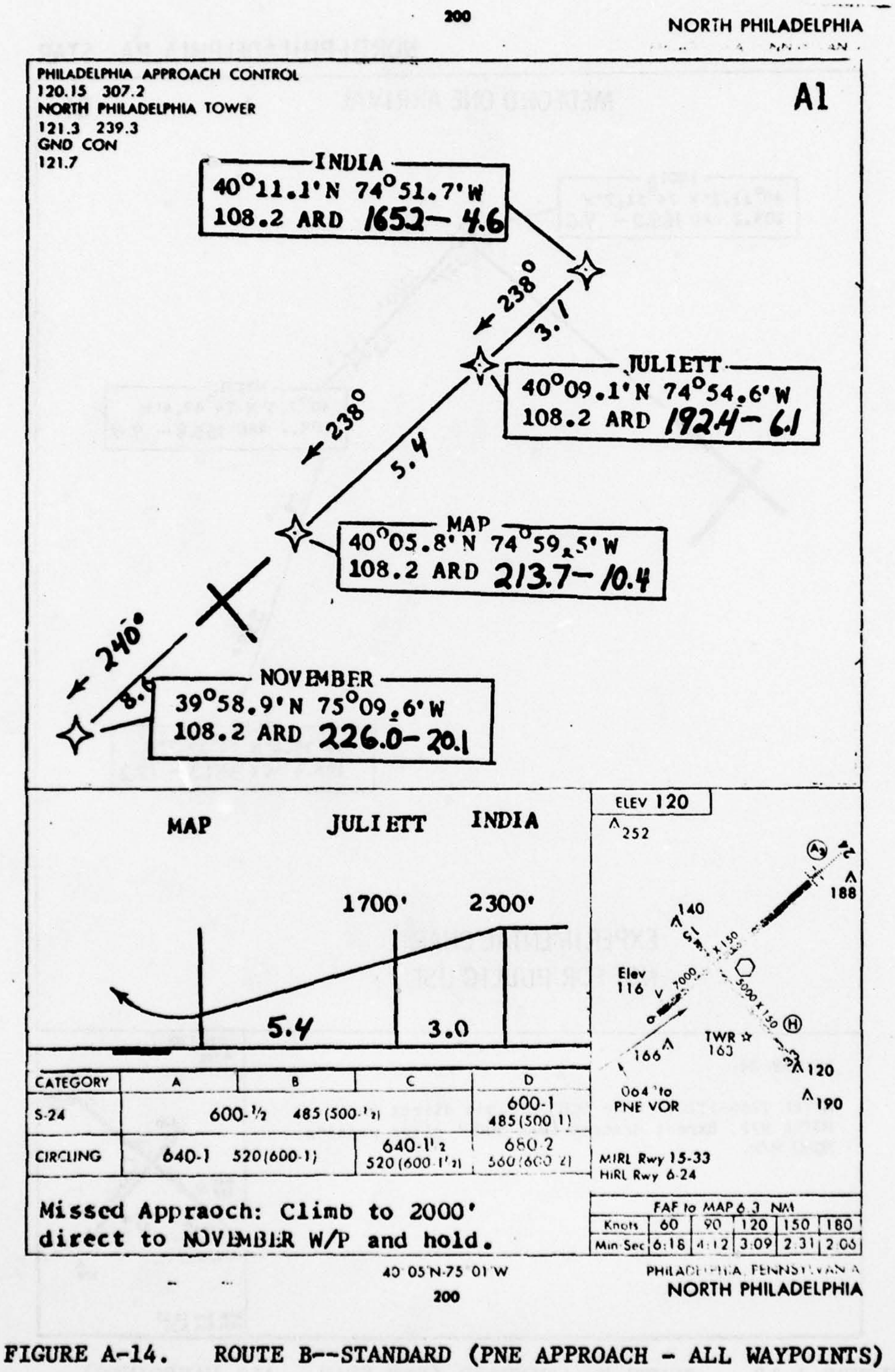


FIGURE A-14. ROUTE B--STANDARD (PNE APPROACH - ALL WAYPOINTS)

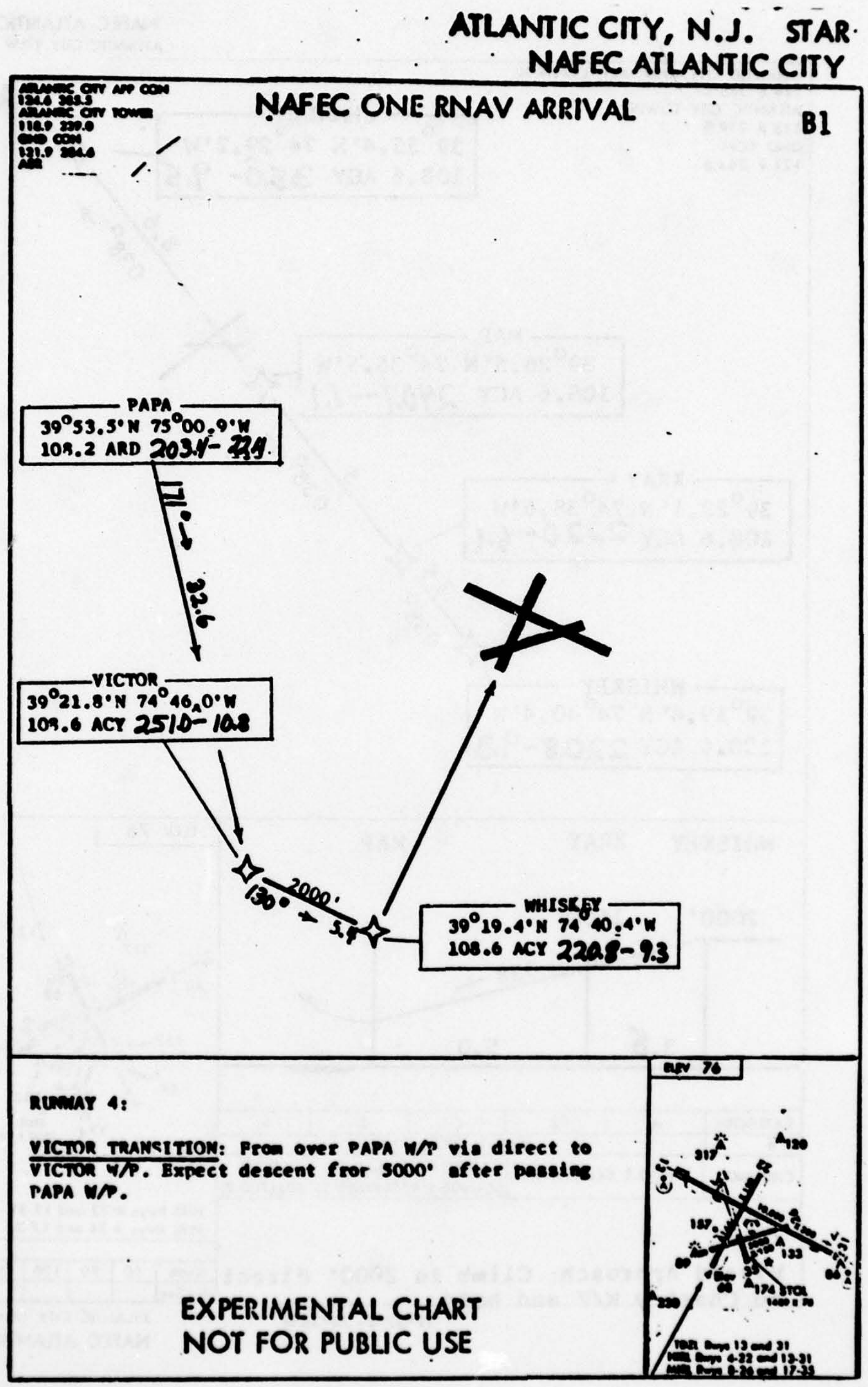


FIGURE A-15. ROUTE B--STANDARD (ACY STAR - ALL WAYPOINTS)

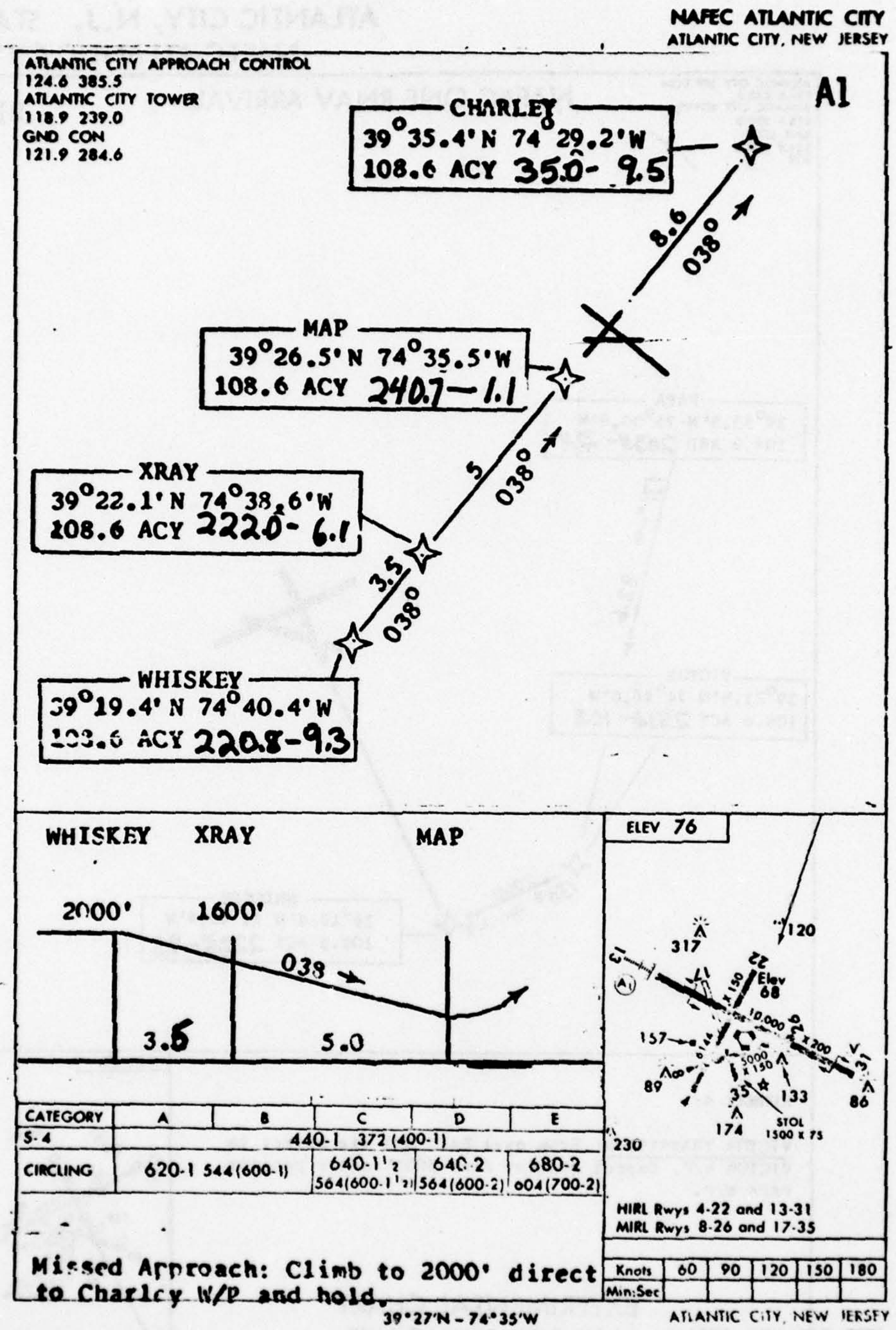


FIGURE A-16. ROUTE B--STANDARD (ACY APPROACH - ALL WAYPOINTS)

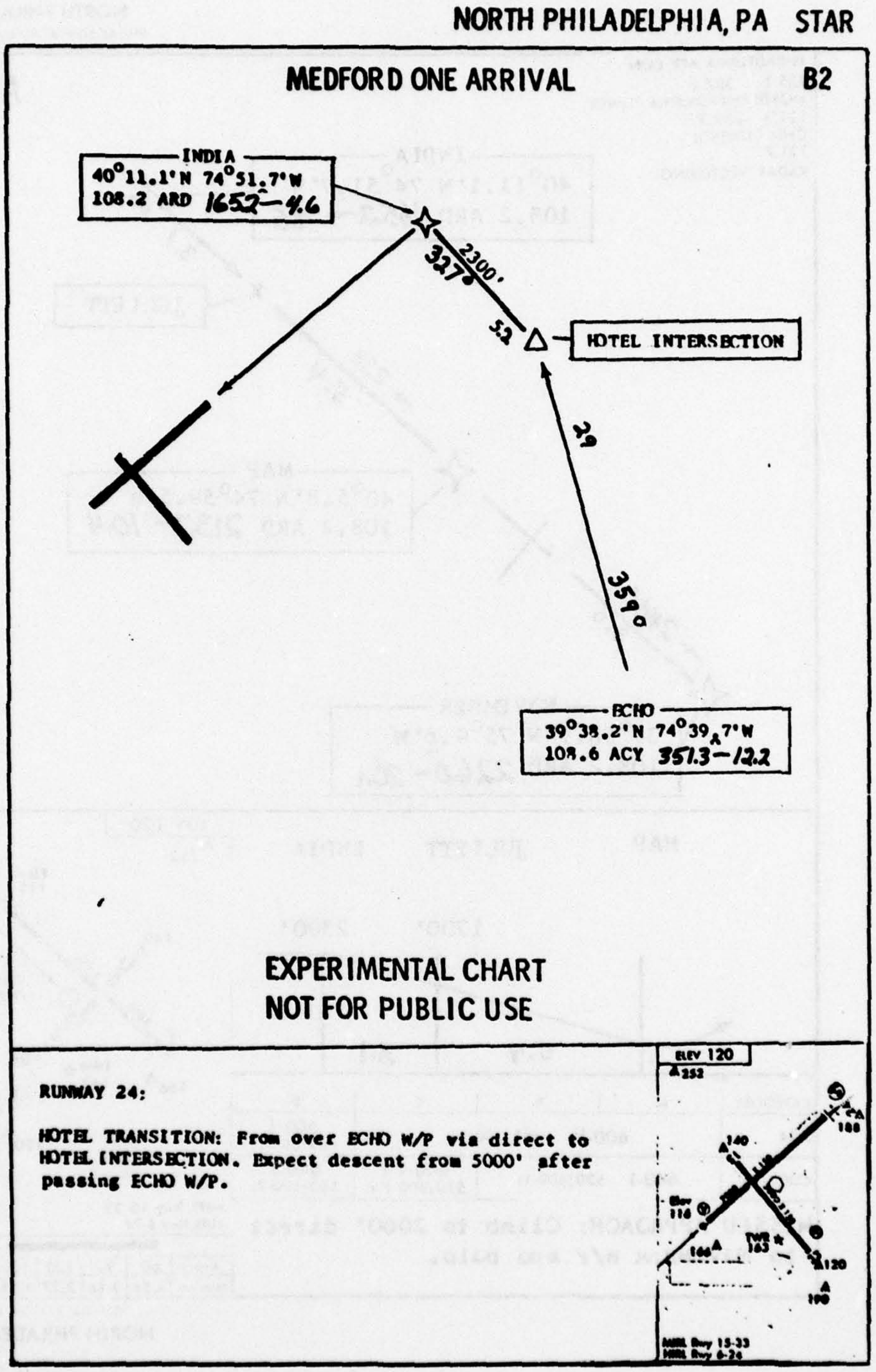


FIGURE A-17. ROUTE B--MODIFICATION 1 (PNE STAR - HOTEL AND JULIETT INTERSECTIONS)

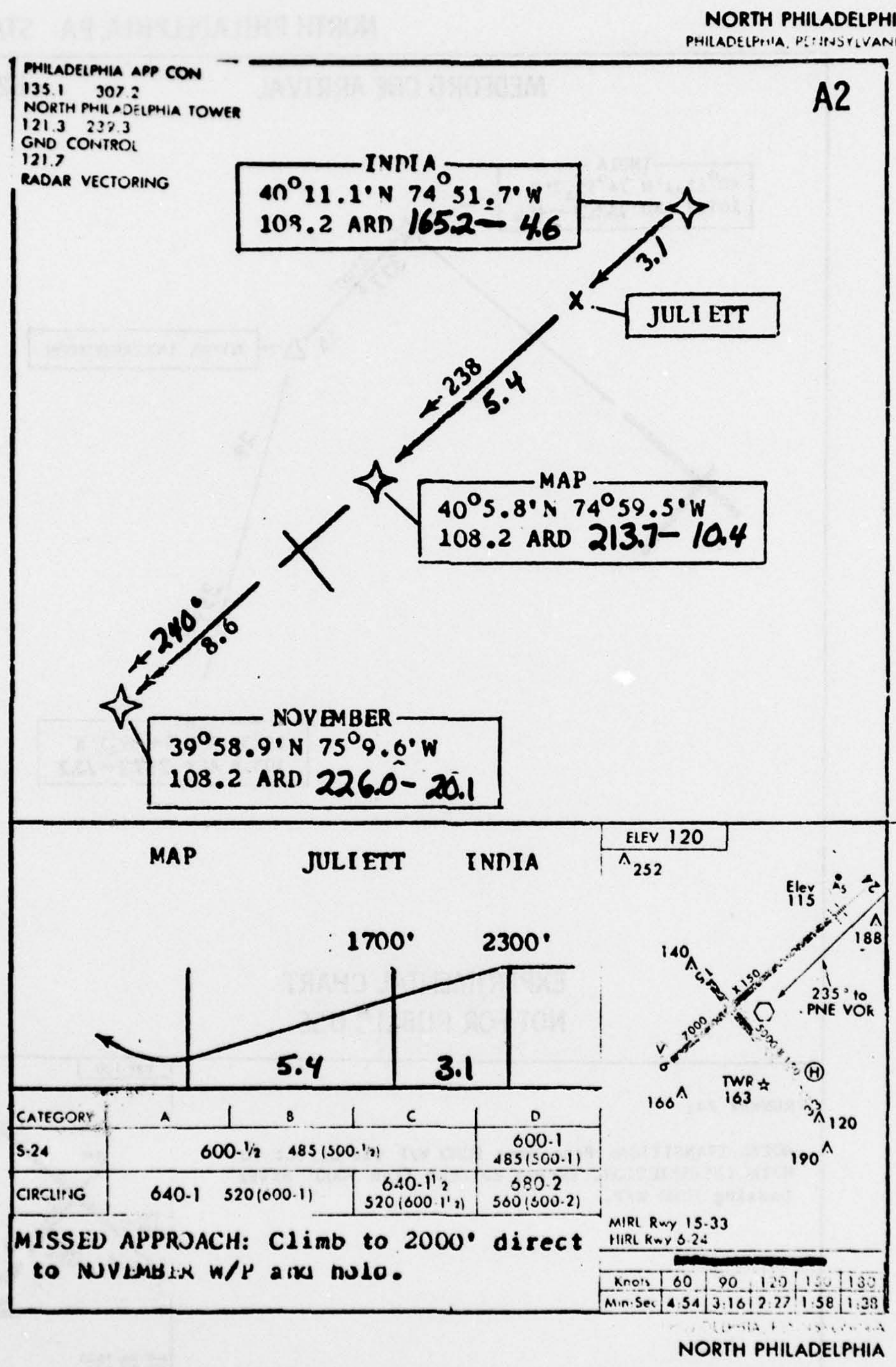


FIGURE A-18. ROUTE B--MODIFICATION 1 (PNE APPROACH - HOTEL AND JULIETT INTERSECTIONS)

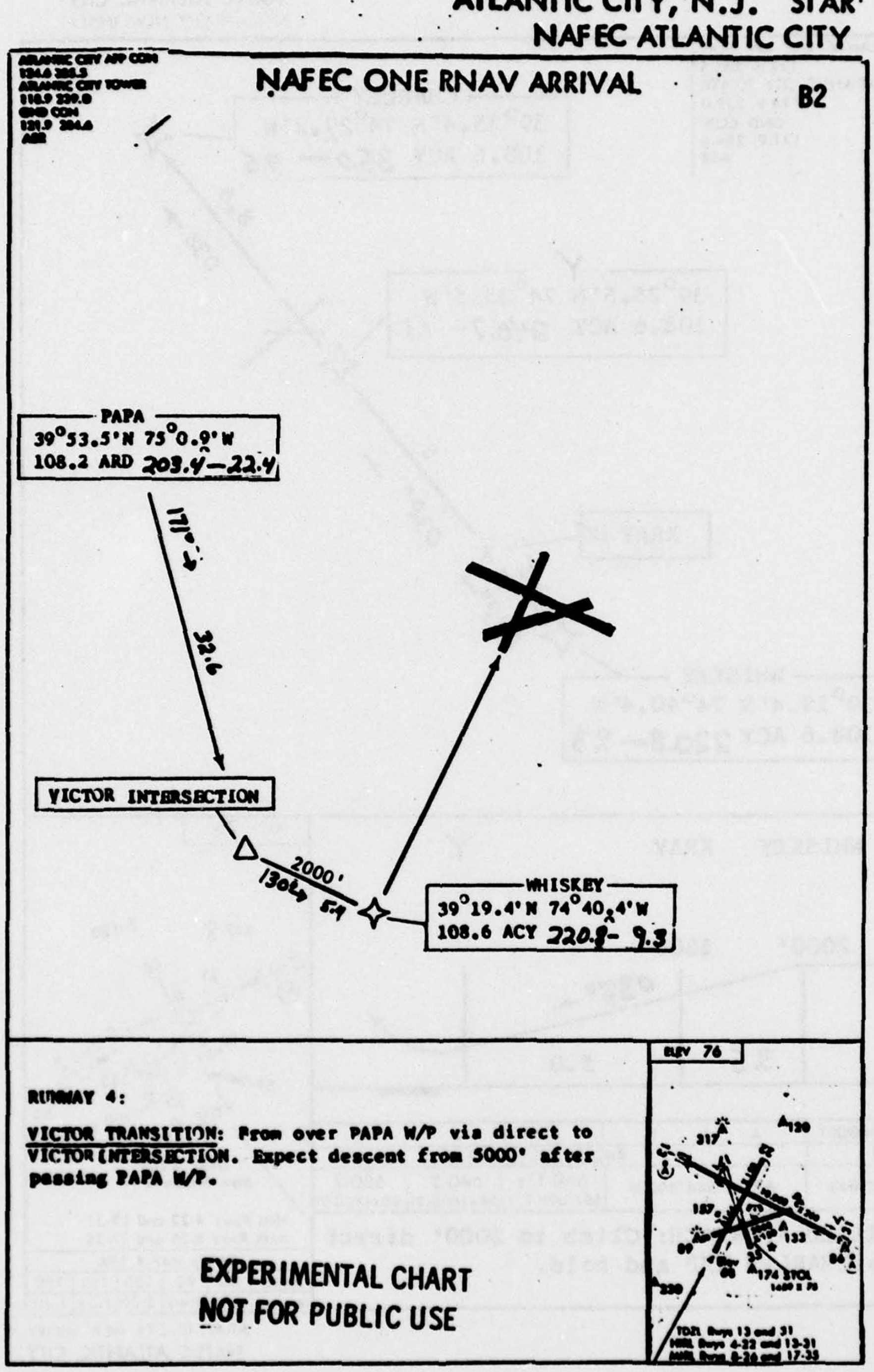
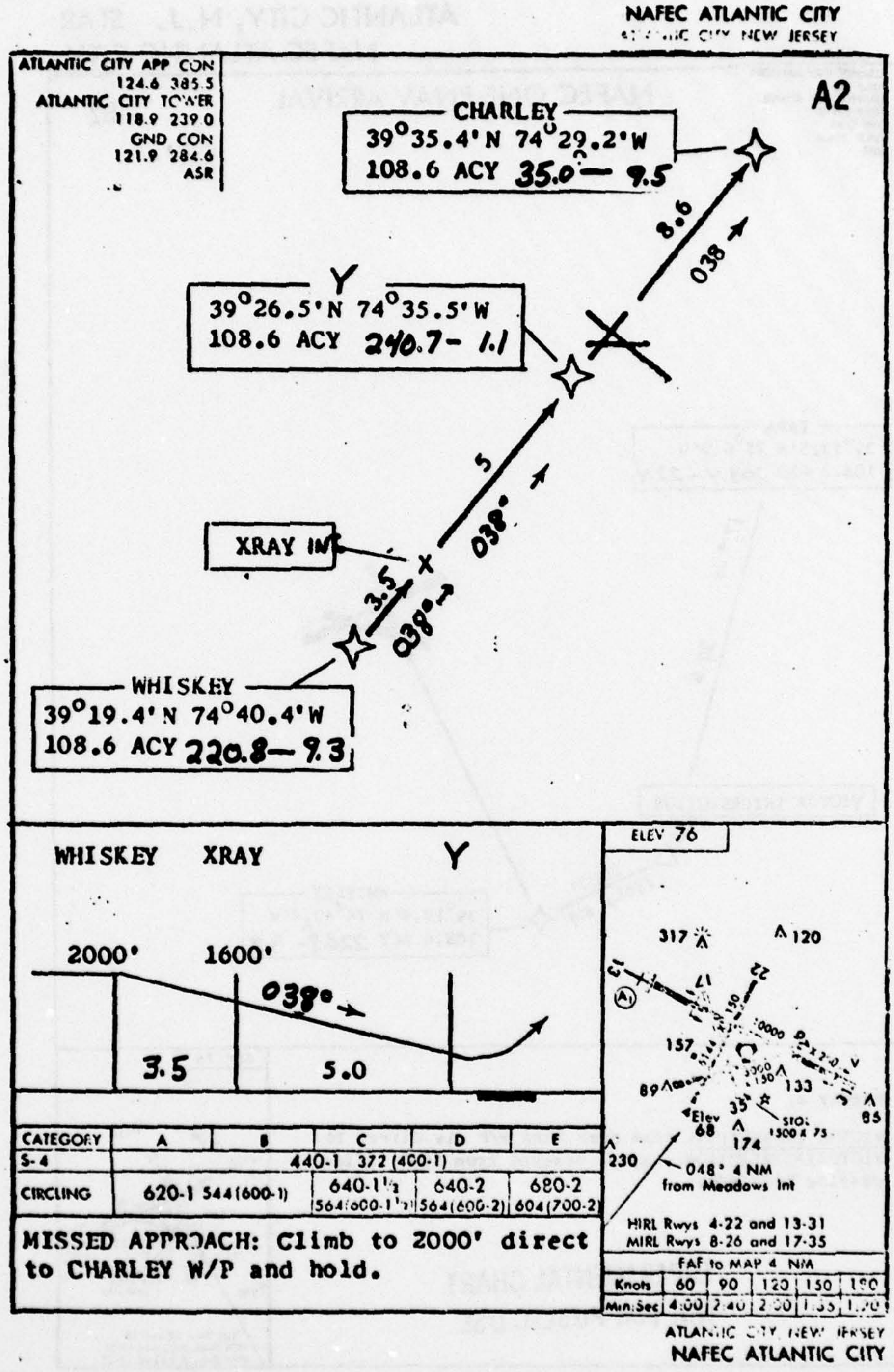


FIGURE A-19. ROUTE B--MODIFICATION 1 (ACY STAR - VICTOR AND X-RAY INTERSECTIONS)



CATEGORY	A	B	C	D	E
S-4	440-1 372 (400-1)				
CIRCLING	620-1 544 (600-1)		640-1½ 564 (600-1½)	640-2 564 (600-2)	680-2 604 (700-2)

FAF to MAP 4 NM					
Knots	60	90	120	150	180
Min:Sec	4:00	2:40	2:00	1:35	1:20

FIGURE A-20. ROUTE B--MODIFICATION 1 (ACY APPROACH - VICTOR AND X-RAY INTERSECTIONS)

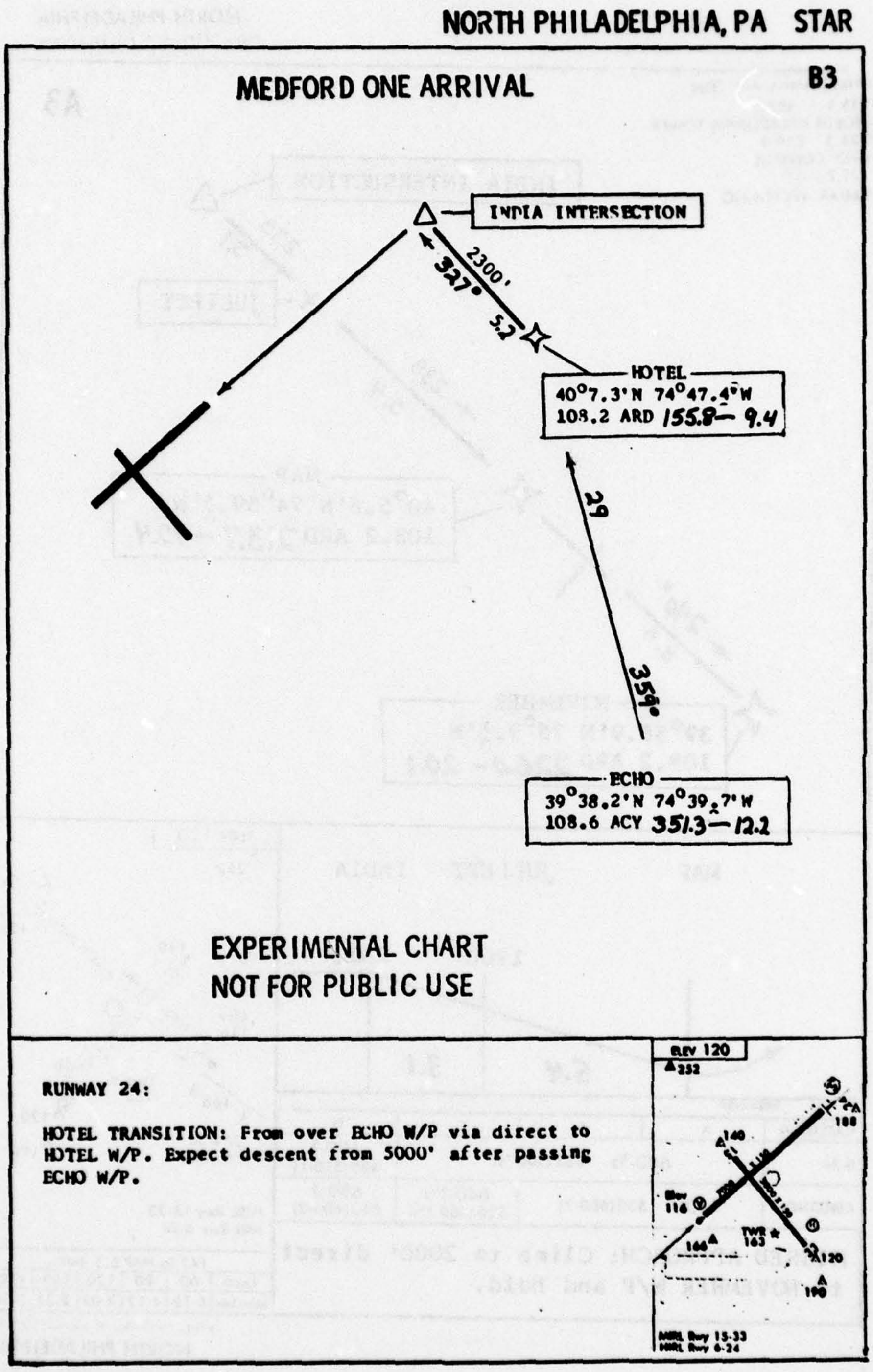


FIGURE A-21. ROUTE B--MODIFICATION 2 (PNE STAR - INDIA AND JULIETT INTERSECTIONS)

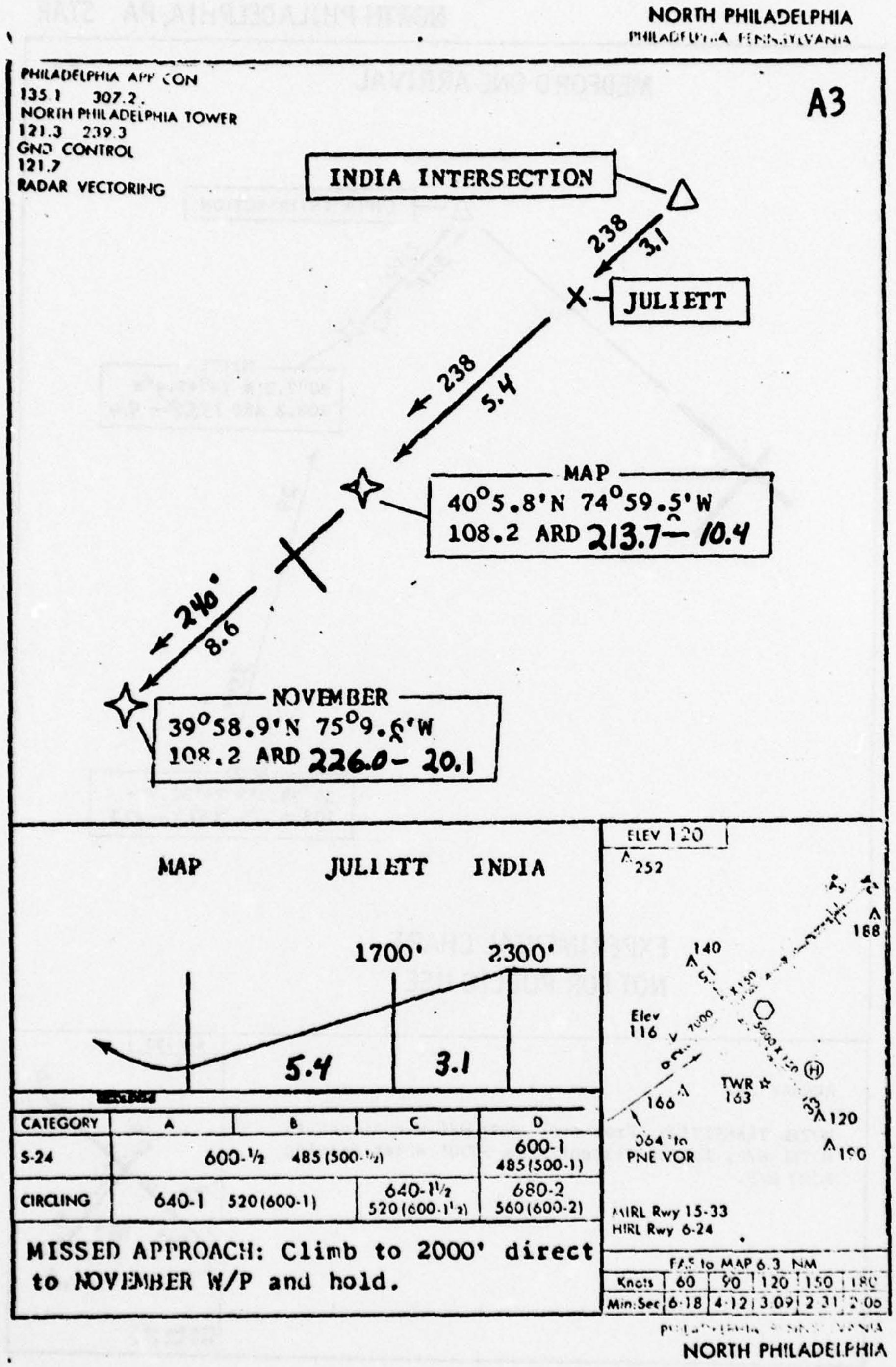


FIGURE A-22. ROUTE B--MODIFICATION 2 (PNE APPROACH - INDIA AND JULIETT INTERSECTIONS)

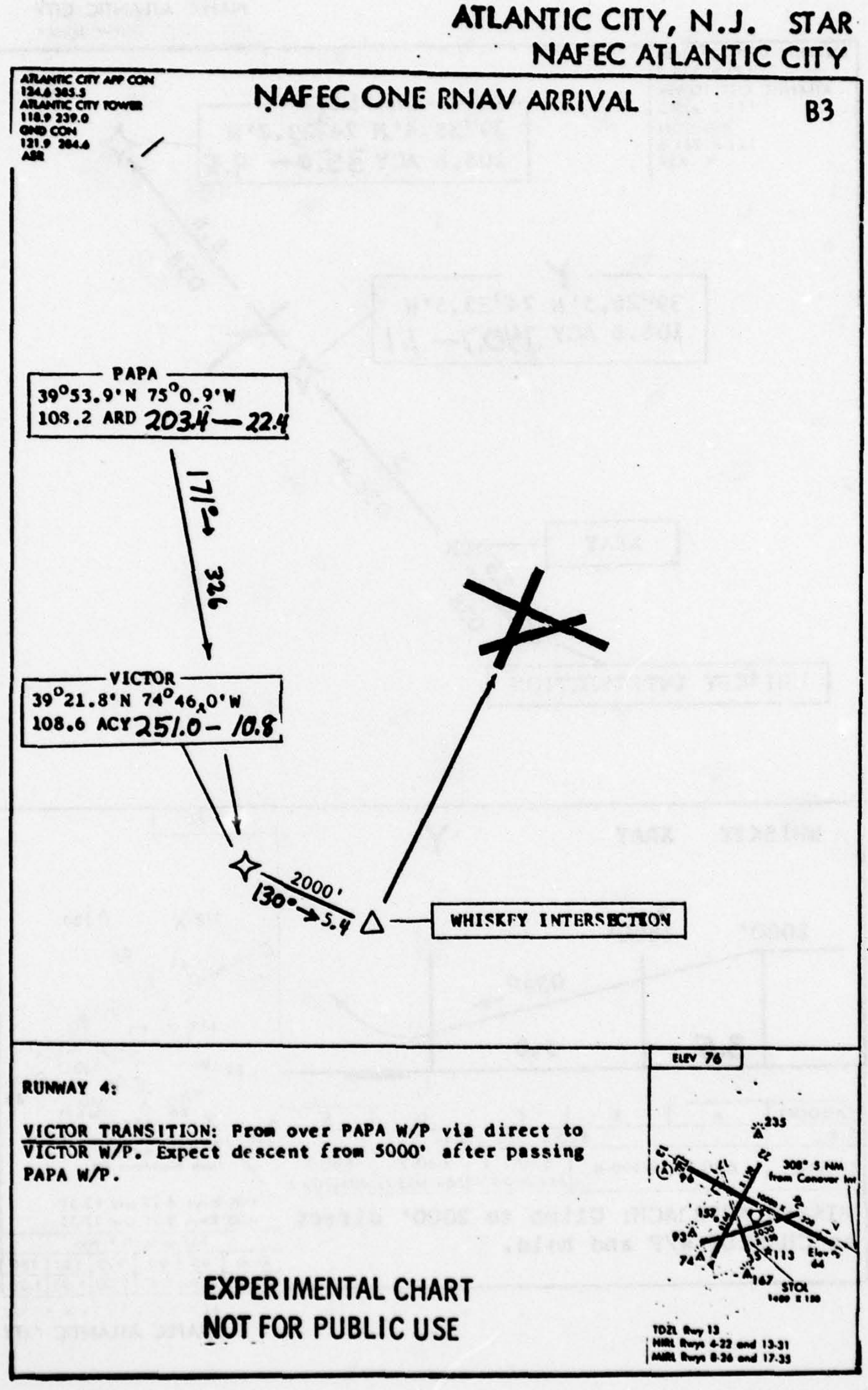


FIGURE A-23. ROUTE B--MODIFICATION 2 (ACY STAR - WHISKEY AND X-RAY INTERSECTIONS)

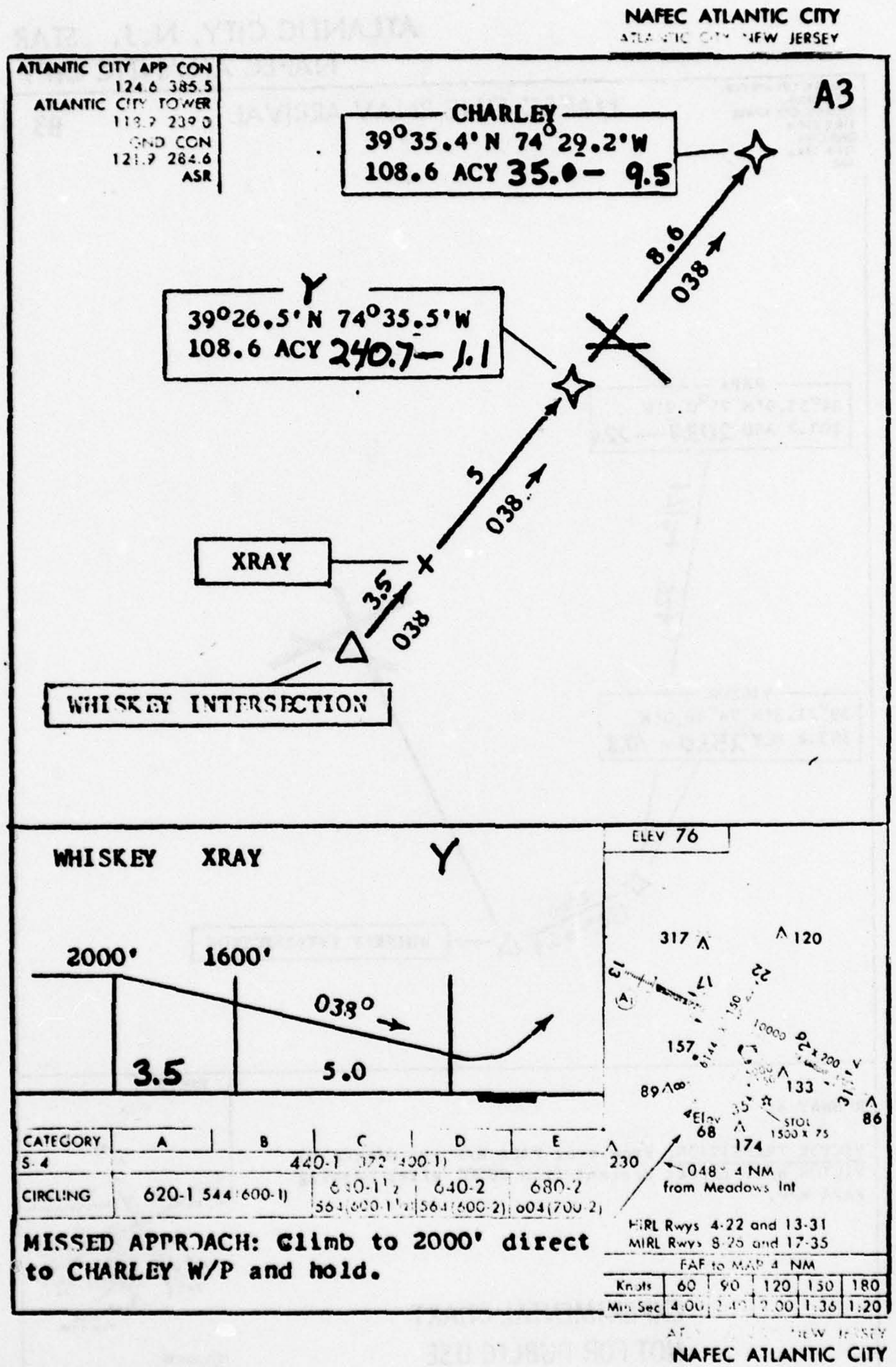


FIGURE A-24. ROUTE B--MODIFICATION 2 (ACY APPROACH - WHISKEY AND X-RAY INTERSECTIONS)

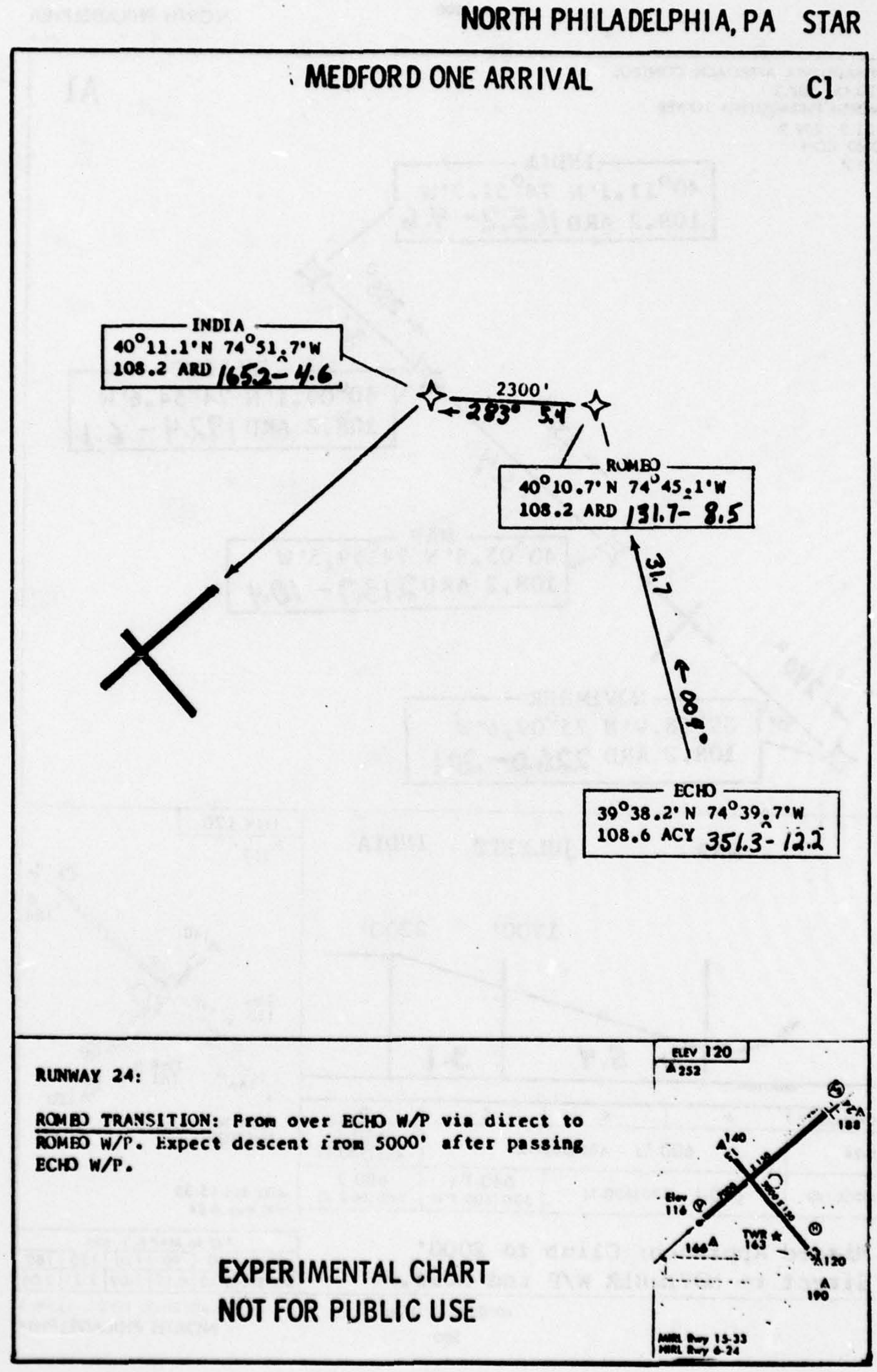


FIGURE A-25. ROUTE C--STANDARD - PNE STAR

AD-A054 510 NATIONAL AVIATION FACILITIES EXPERIMENTAL CENTER ATL--ETC F/G 17/7
AN EVALUATION OF MODIFIED RNAV TERMINAL PROCEDURES USING A SING--ETC(U)
APR 78 D ELDREDGE, B GOLDBERG, W CRIMBRING

UNCLASSIFIED FAA-NA-77-49 FAA-RD-78-27 NL

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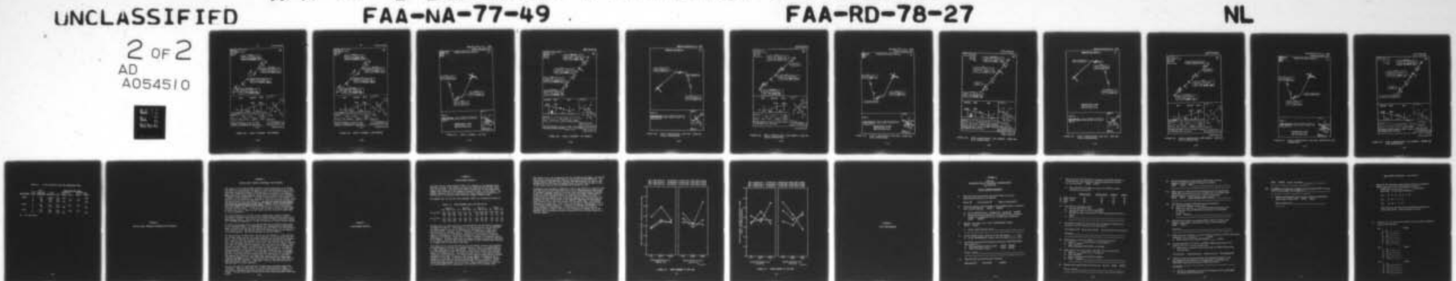

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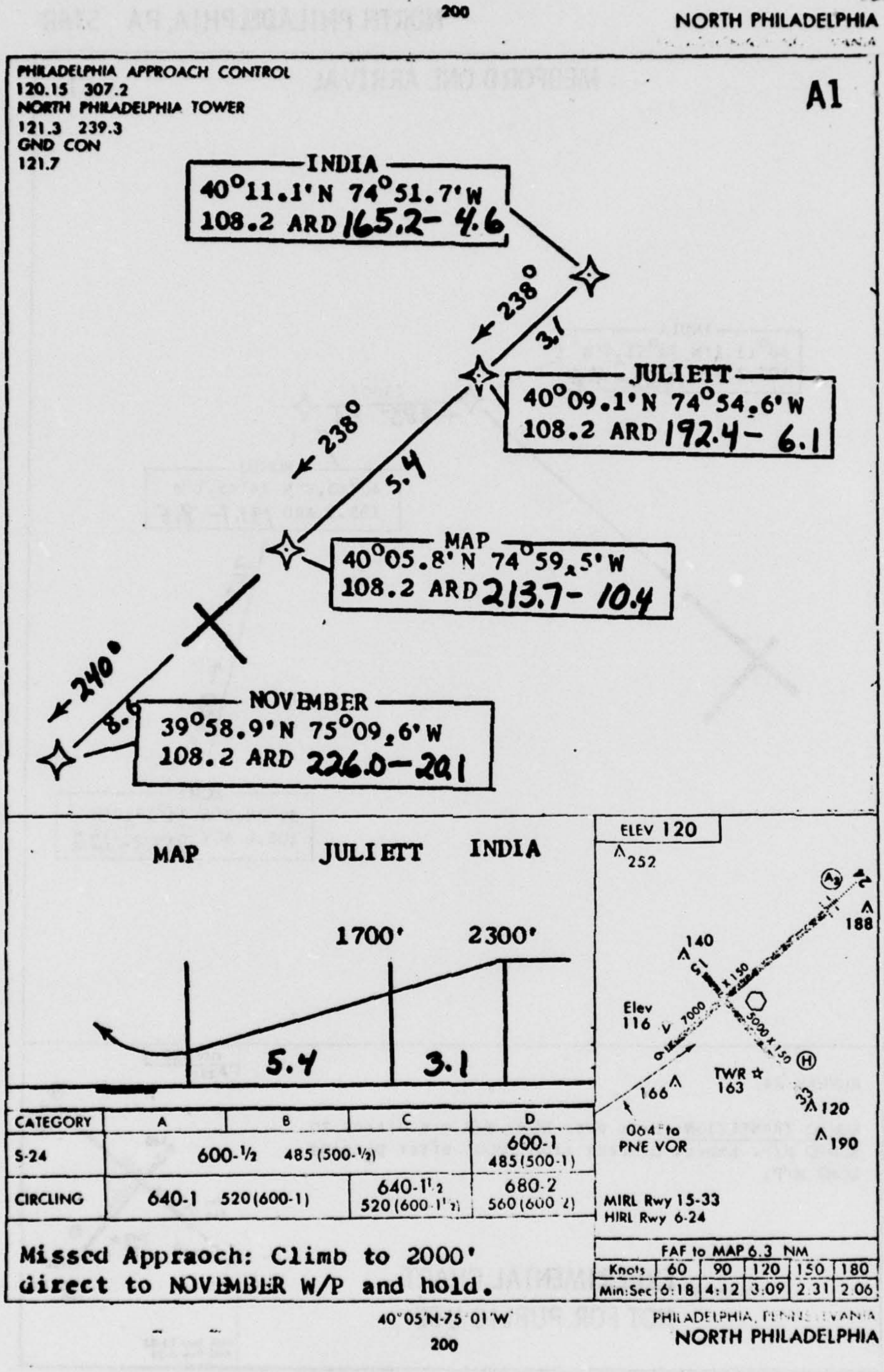


CATEGORY	A	B	C	D
S-24	600-½	485 (500-½)		600-1 485 (500-1)
CIRCLING	640-1	520 (600-1)	640-1½ 520 (600-1½)	680-2 560 (600-2)

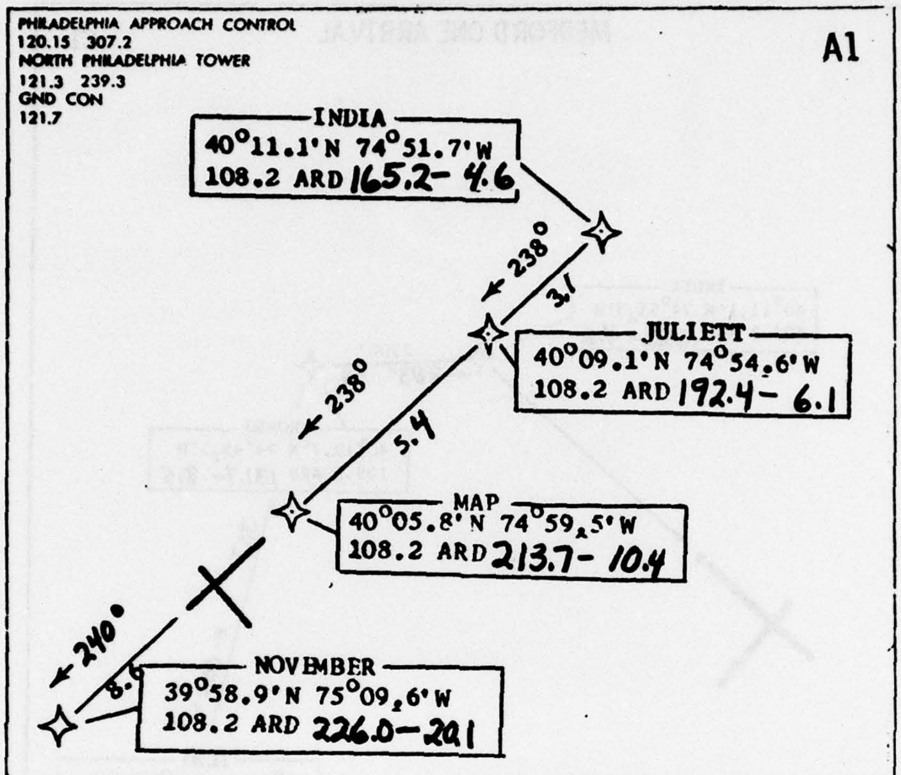
Missed Appraoch: Climb to 2000' direct to NOVEMBER W/P and hold.

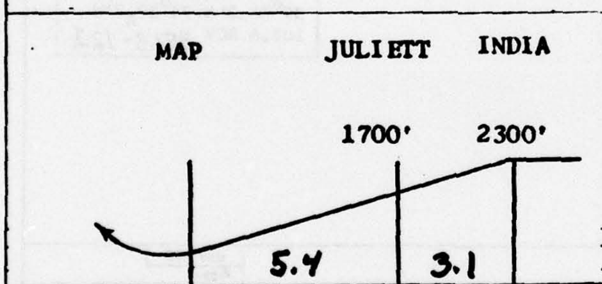
FAF to MAP 6.3 NM					
Knots	60	90	120	150	180
Min:Sec	6:18	4:12	3:09	2:31	2:06

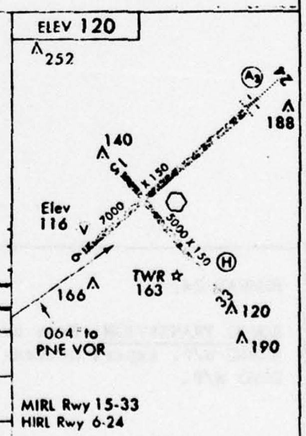
FIGURE A-26. ROUTE C--STANDARD - PNE APPROACH

PHILADELPHIA APPROACH CONTROL
120.15 307.2
NORTH PHILADELPHIA TOWER
121.3 239.3
GND CON
121.7

A1







CATEGORY	A	B	C	D
S-24	600-½	485 (500-½)		600-1 485 (500-1)
CIRCLING	640-1	520 (600-1)	640-1½ 520 (600-1½)	680-2 560 (600-2)

Missed Appraoch: Climb to 2000' direct to NOVEMBER W/P and hold.

FAF to MAP 6.3 NM

Knots	60	90	120	150	180
Min:Sec	6:18	4:12	3:09	2:31	2:06

40°05'N-75°01'W
200

PHILADELPHIA, PENNSYLVANIA
NORTH PHILADELPHIA

FIGURE A-26. ROUTE C--STANDARD - PNE APPROACH

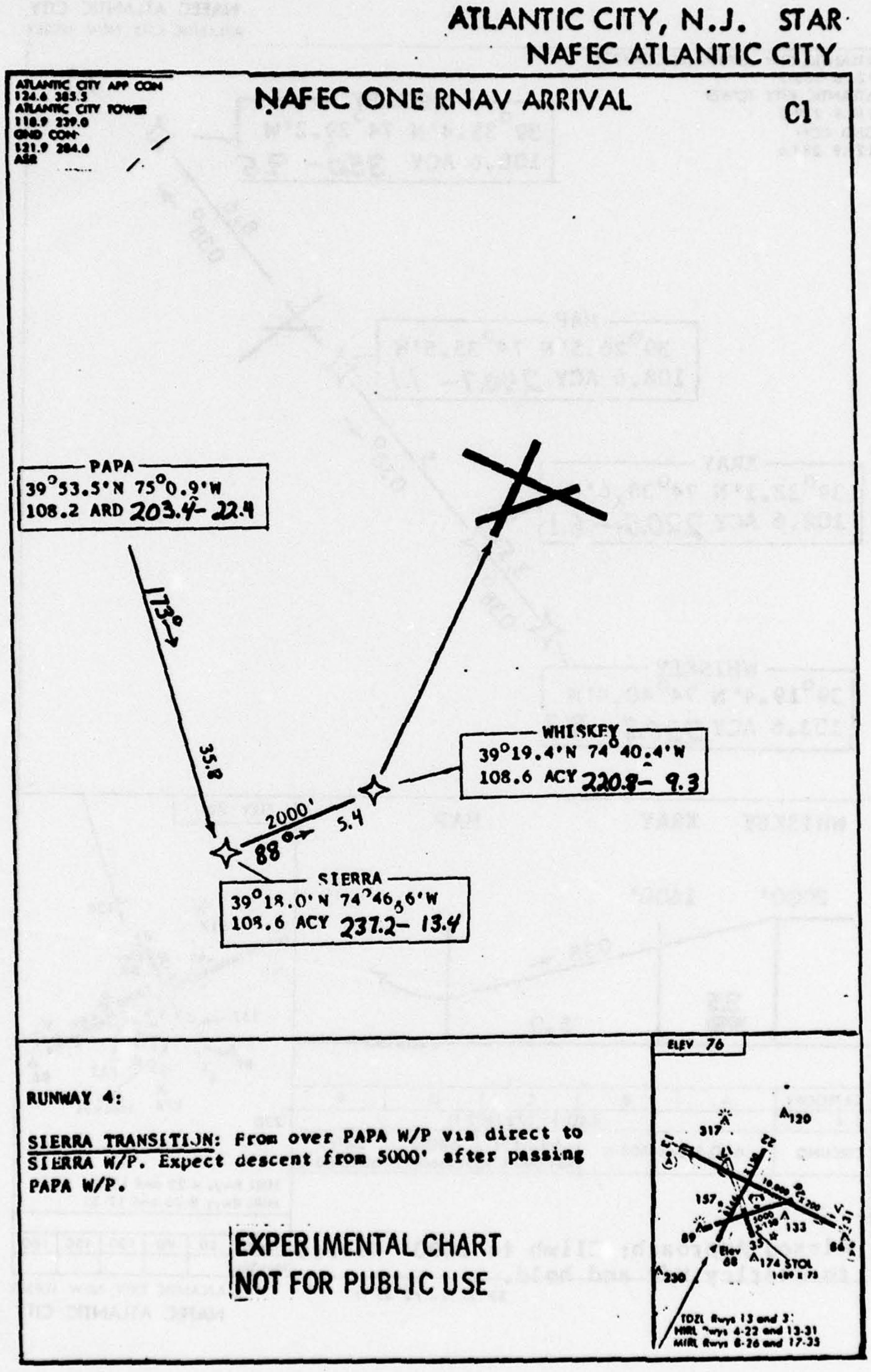


FIGURE A-27. ROUTE C--STANDARD - ACY STAR

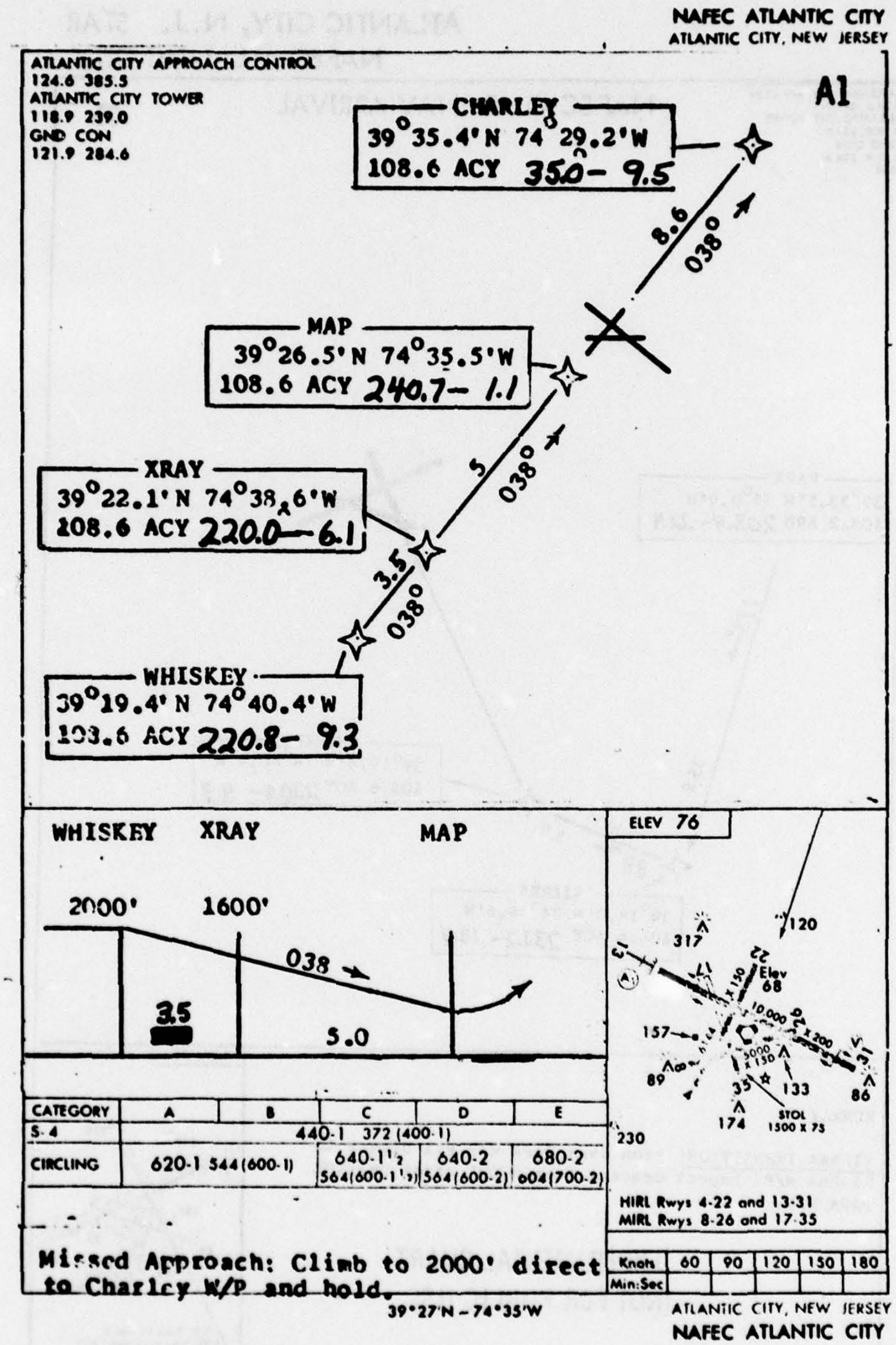


FIGURE A-28. ROUTE C--STANDARD - ACY APPROACH

NORTH PHILADELPHIA, PA STAR

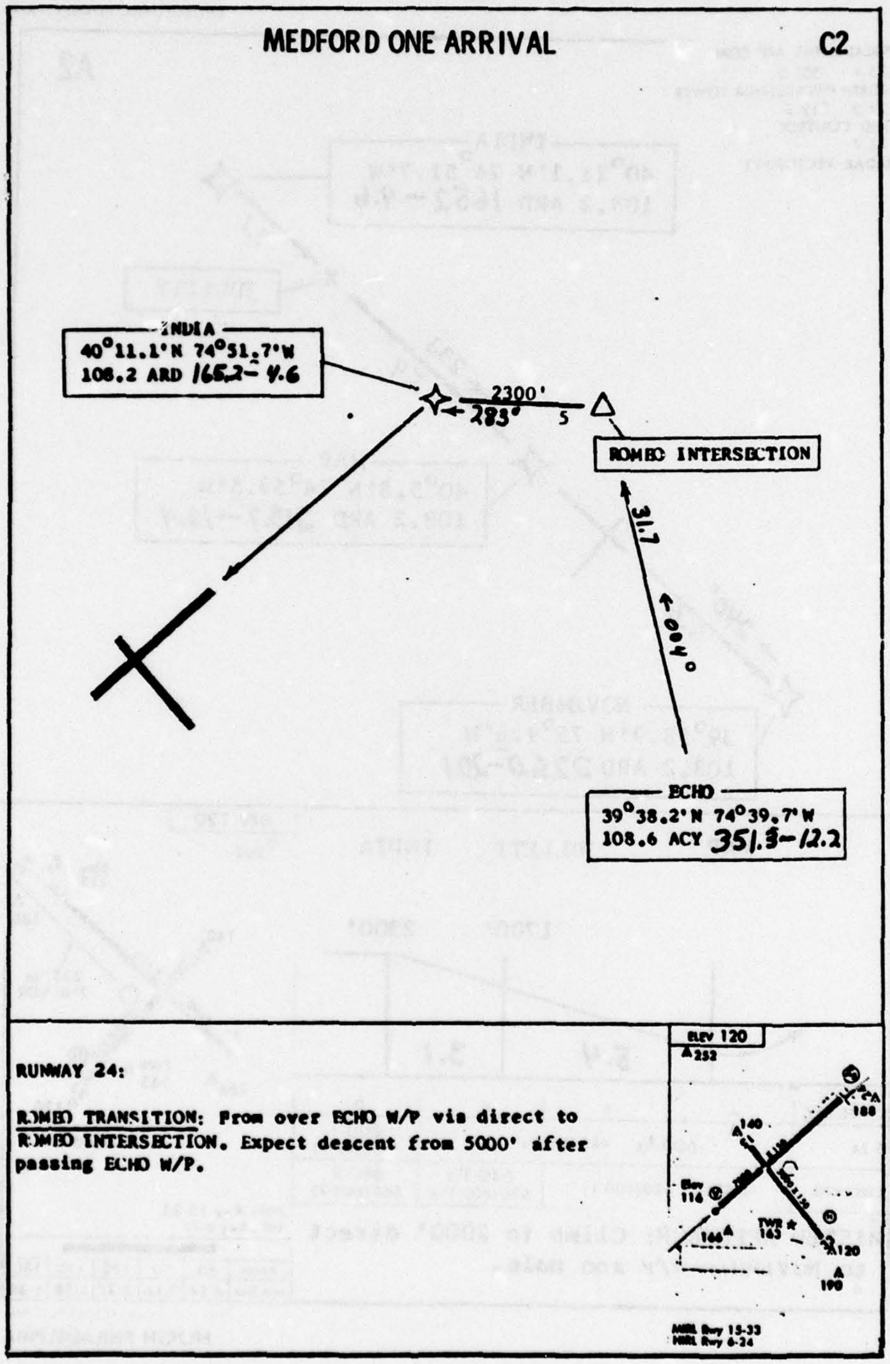


FIGURE A-29. ROUTE C--MODIFICATION 1 (PNE STAR - ROMEO AND JULIETT INTERSECTIONS)

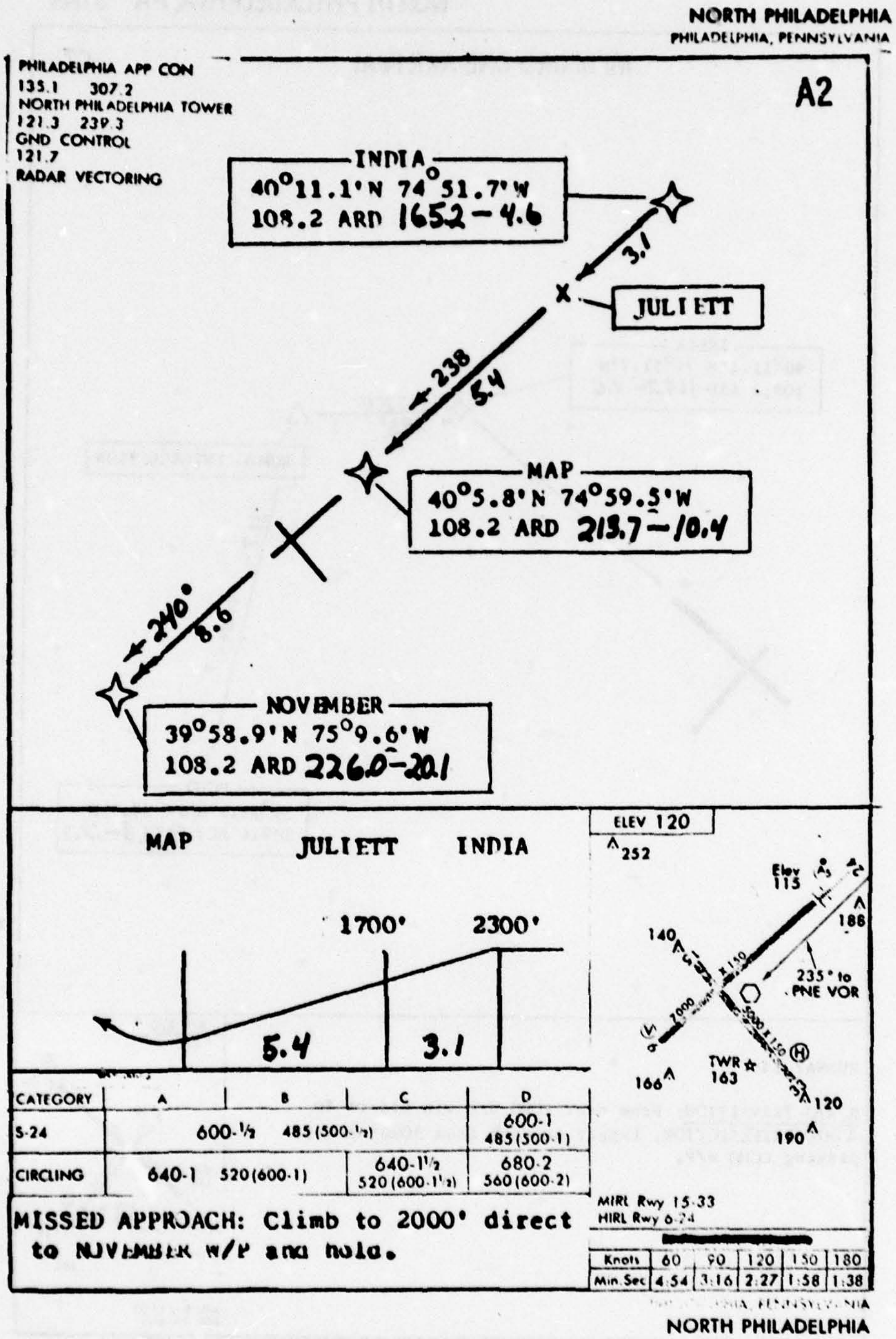


FIGURE A-30. ROUTE C--MODIFICATION 1 (PNE APPROACH - ROMEO AND JULIETT INTERSECTIONS)

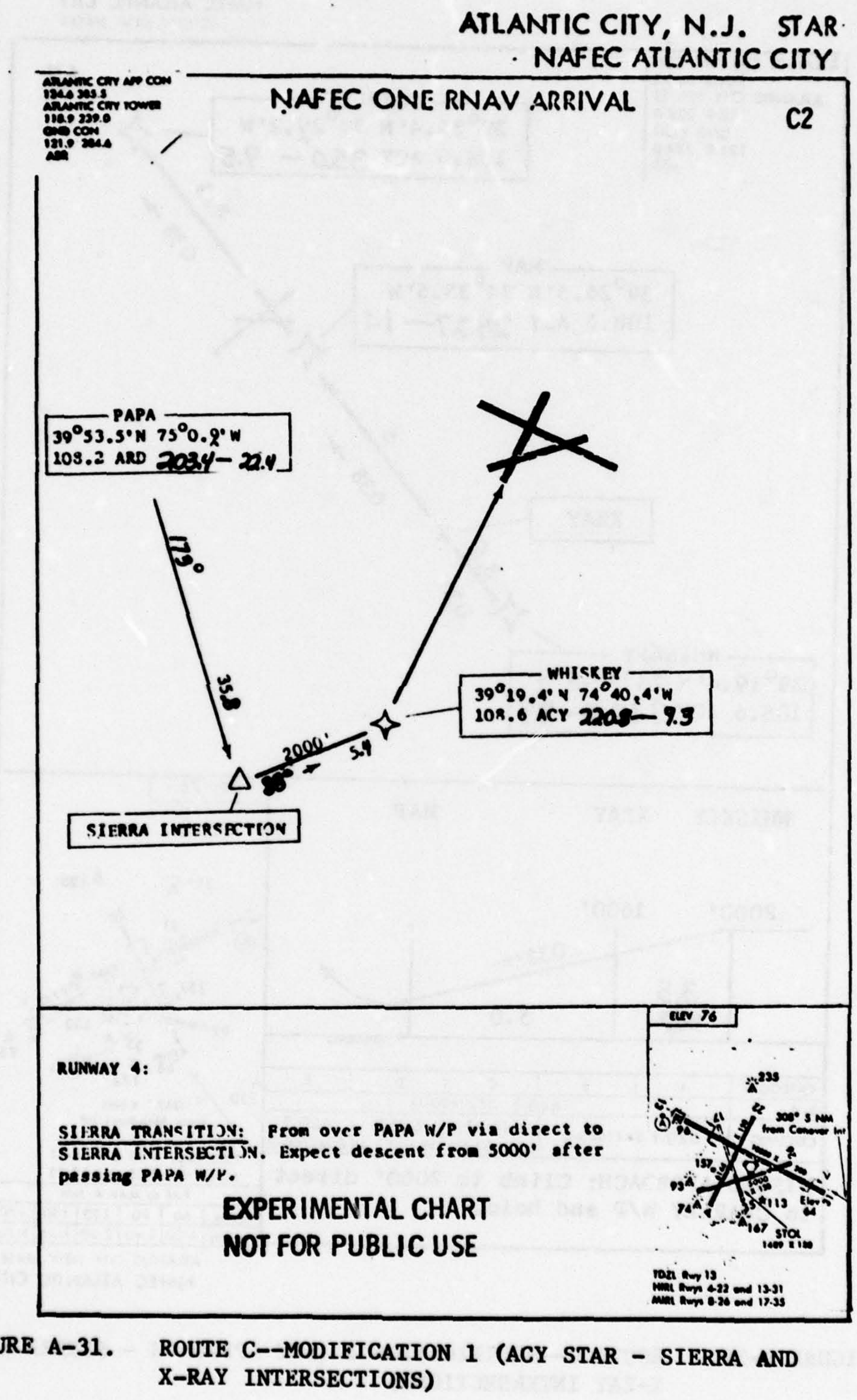
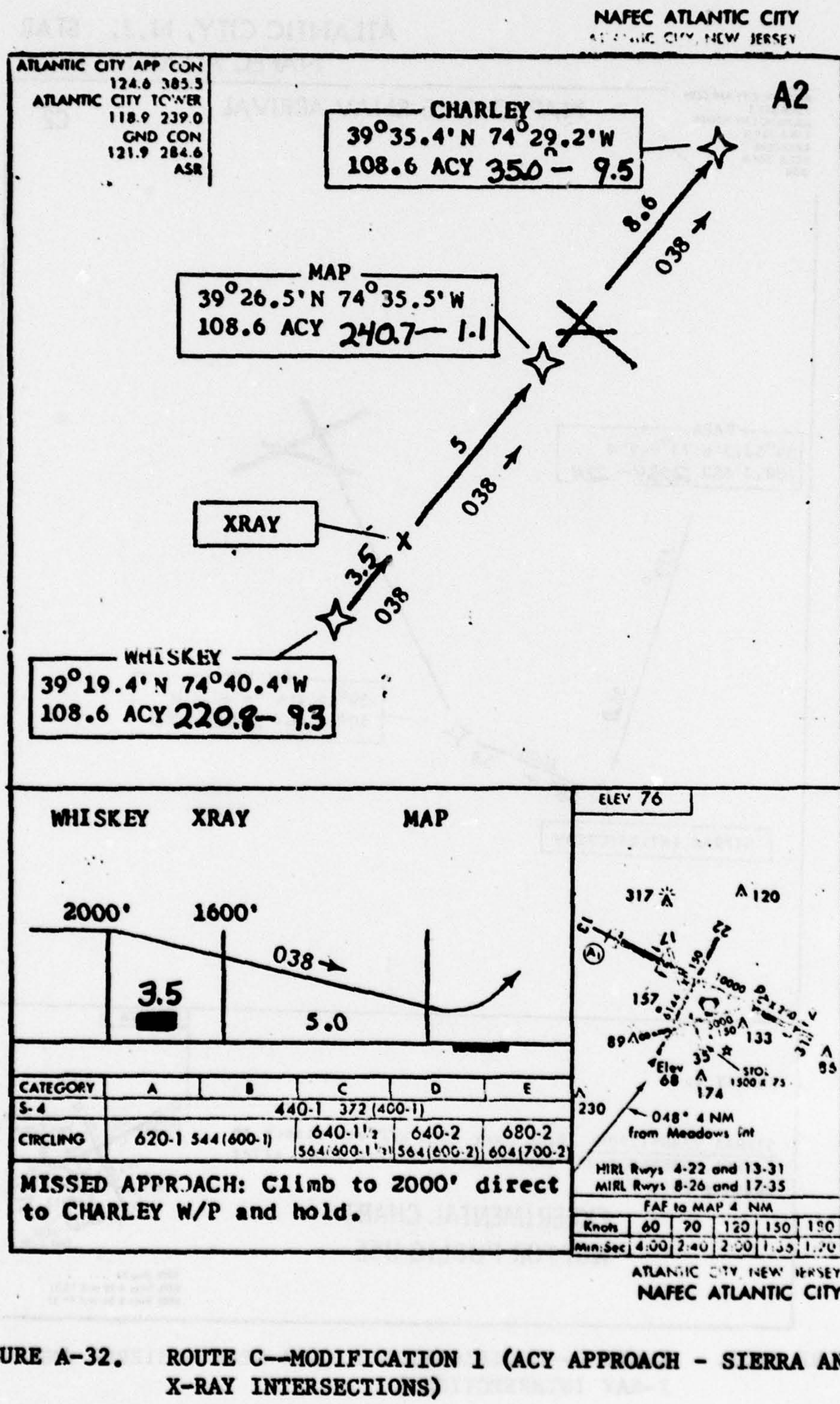


FIGURE A-31. ROUTE C--MODIFICATION 1 (ACY STAR - SIERRA AND X-RAY INTERSECTIONS)



CATEGORY	A	B	C	D	E
S-4	440-1 372 (400-1)				
CIRCLING	620-1 544 (600-1)		640-1½ 564 (600-1½)	640-2 564 (600-2)	680-2 604 (700-2)

MISSED APPROACH: Climb to 2000' direct to CHARLEY W/P and hold.

FAF to MAP 4 NM					
Knots	60	90	120	150	180
Min:Sec	4:00	2:40	2:00	1:35	1:20

FIGURE A-32. ROUTE C—MODIFICATION 1 (ACY APPROACH - SIERRA AND X-RAY INTERSECTIONS)

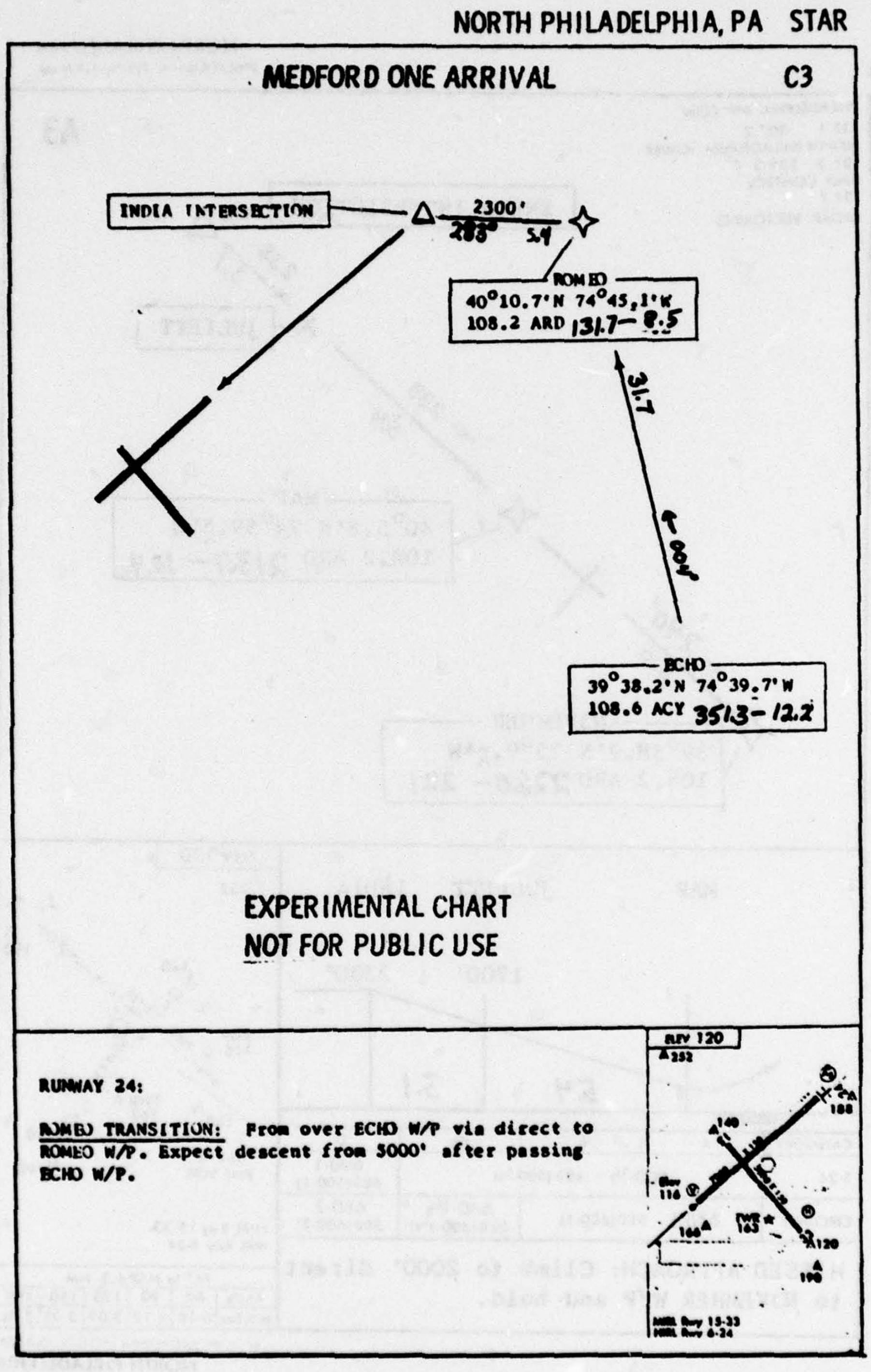


FIGURE A-33. ROUTE C--MODIFICATION 2 (PNE STAR - INDIA AND JULIETT INTERSECTIONS)

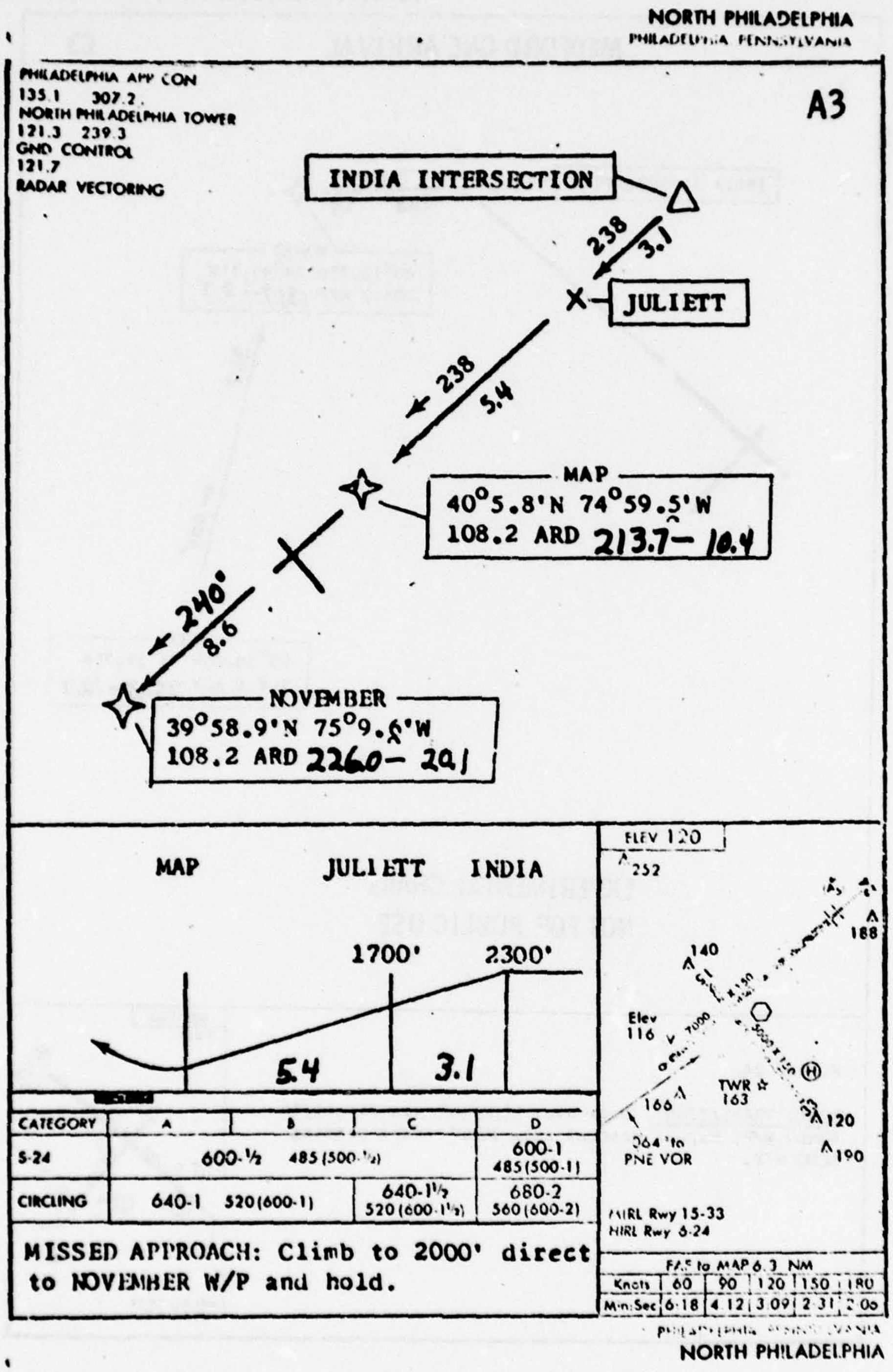


FIGURE A-34. ROUTE C--MODIFICATION 2 (PNE APPROACH - INDIA AND JULIETT INTERSECTIONS)

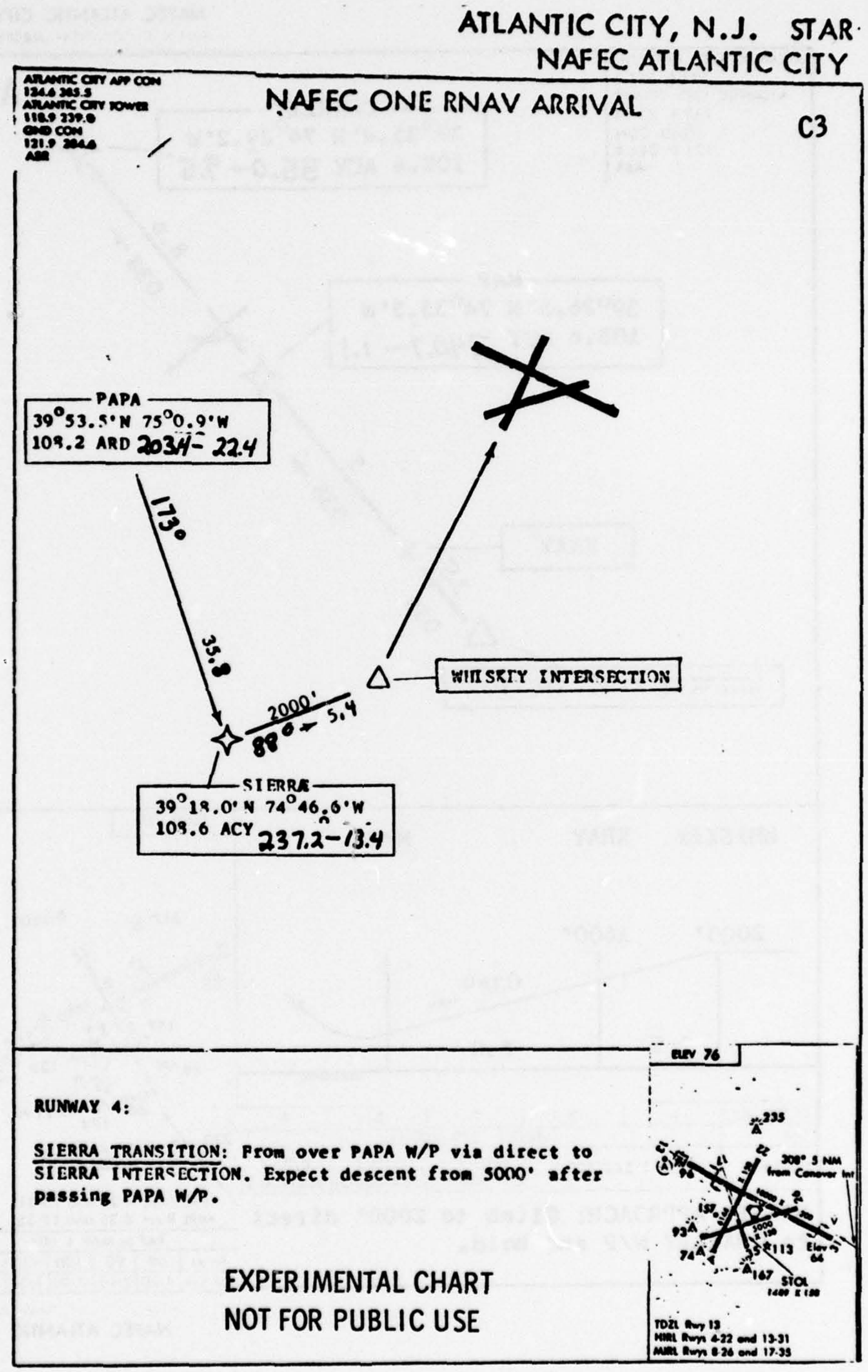


FIGURE A-35. ROUTE C--MODIFICATION 2 (ACY STAR - WHISKEY AND X-RAY INTERSECTIONS)

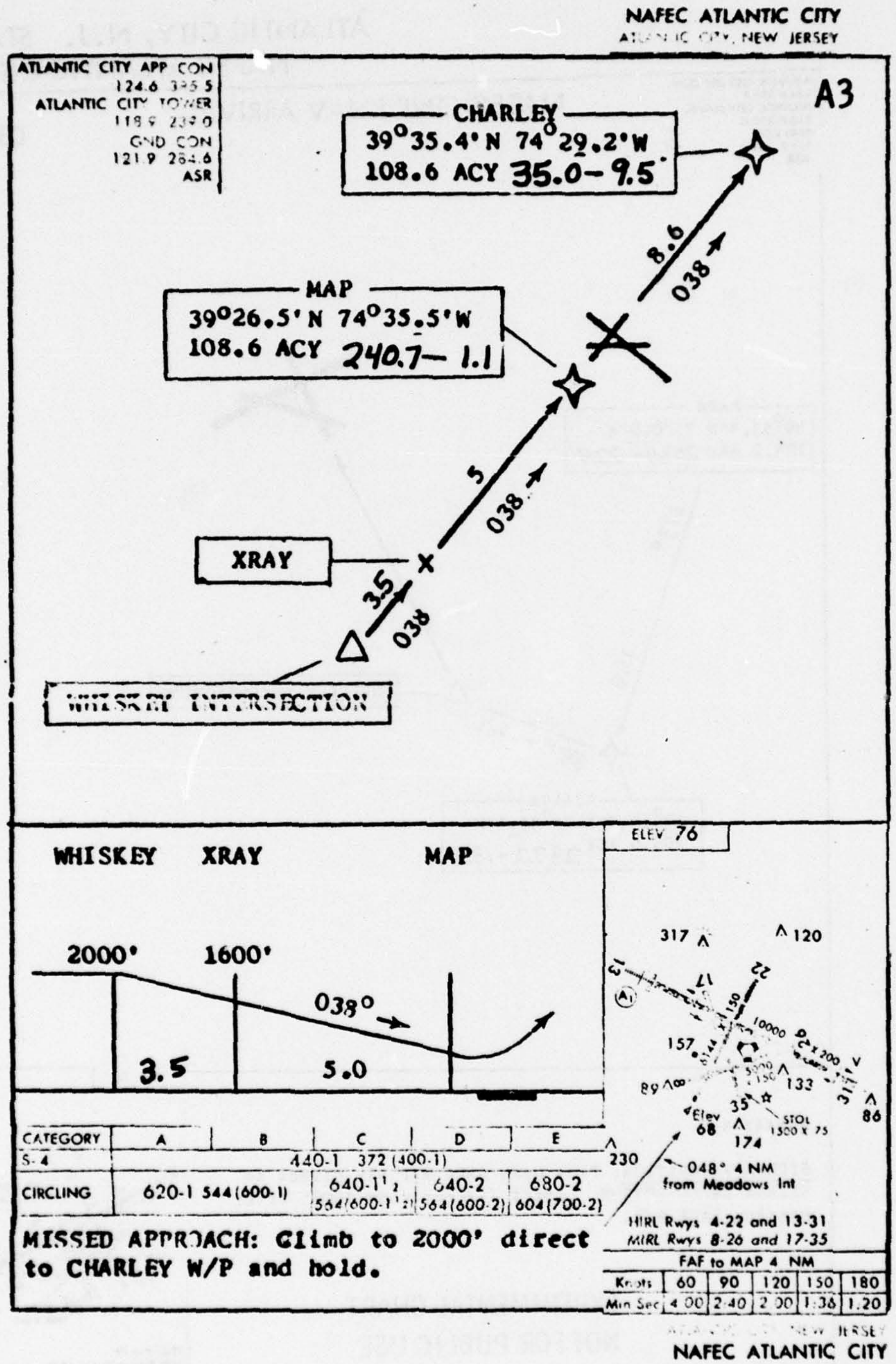


FIGURE A-36. ROUTE C--MODIFICATION 2 (ACY APPROACH - WHISKEY AND X-RAY INTERSECTIONS)

TABLE A-1. ±4 NMI TURN DATA (ACY) RMS CROSSTRACK (NMI)

Route/STAR	Turn Point	Turn Magnitude (Degrees)	Turn Direction	Std	RMS Crosstrack (nmi) Waypoint Mod 1	Waypoint Mod 2	Intersection Mod 1	Intersection Mod 2
A/PNE	U	≈45	Right	.376	.255	-	-	.360
	V	90	Left	.476	-	.365	.439	-
	W	90	Left	N/A	.323	-	-	.390
B/ACY	V	≈30	Left	.517	-	1.017	.399	-
	W	90	Left	.465	.581	-	-	.667
C/ACY	S	≈80	Left	.431	-	.296	.354	-
	W	≈45	Left	.258	.361	-	-	.353

N/A - not applicable

APPENDIX B

MODIFIED RNAV TERMINAL PROCEDURES-PILOT BRIEFING

APPENDIX B

MODIFIED RNAV TERMINAL PROCEDURES PILOT BRIEFING

The purpose of the Modified RNAV Terminal Procedure Experiment is to assess the effect of using specific procedures to reduce pilot workload and to minimize peak loading when making an RNAV approach. The modified procedure for a given route reduces the number of control settings required in the standard RNAV approach by changing waypoint designations to intersections or Distance-to-Waypoint (DTW) designations. By using an intersection or DTW instead of a waypoint, you can perform a turn maneuver or check your altitude without changing any settings on the King RNAV Unit. You will fly each route as given on the charts for the particular flight you are making. DO NOT in any instance modify any procedure during a given flight. After you have completed your nine test flights, you will be given an opportunity to specify any modified procedure you may prefer. If you feel that you have a procedure which might be better than any of those you have flown, you will be given an opportunity to fly your procedure.

The GAT-2A Simulator is a ground trainer representing a general aviation twin-engine, propeller-type aircraft with flight characteristics similar to a Beech Baron aircraft. The trainer has complete IFR flight capability, having dual NAV/COMM instrumentation. It has no autopilot or flight director system.

The GAT-2A is equipped with a King KNC-610 RNAV system mounted in the center of the instrument panel. The King KNC-610 is a single-waypoint RNAV system based on manually setting the Omni Bearing Selector (OBS) on the Course Deviation Indicator (CDI), and Bearing (Theta) and Distance (Rho) of the waypoint on the King KNC-610. The DTW is displayed on the King KNC-610.

The charts define the OBS, Theta, and Rho for each waypoint. After you have set the OBS, Theta, and Rho for a given waypoint, you are flying TO that waypoint. The TO flag will be displayed on the CDI and the DTW will be decreasing. When you reach the waypoint, the TO flag will disappear and the DTW will stop decreasing (DTW may not reach zero). When you are ready to initiate your turn, you should select the OBS for the next leg of your flight. After you pass the set waypoint, the FROM flag will appear on the CDI and DTW will start to increase. After setting the OBS, you may continue to fly FROM the previous waypoint for some distance or you may immediately set in the Theta and RHO for the next waypoint. In flying RNAV, it is important to remember that the route width is much narrower than that allowed in the conventional VOR routes, and, therefore, you should make an extra effort to fly with a centered CDI needle at all times (NOTE: The needle may become pegged when inserting new RNAV settings.) When starting your flight, make sure that the RNAV Mode Selector switch is in RNAV mode. The only time you may use the approach mode is on final approach.

You will be given two familiarization flights before starting actual data collection. Here are the charts for the first familiarization flight. You can expect to encounter some mild turbulence with winds aloft during your flight. You will be advised on wind and any other possible weather conditions by ATC.

APPENDIX C

SUPER-SEGMENT ANALYSIS

APPENDIX C

SUPER-SEGMENT ANALYSIS

The data from the "super-segment" STAR's are examined in this appendix since they were created by the route/route structure combinations which were evaluated in this study. The PNE and ACY STAR's included all of the steady-state segment data contained in the segments outlined in table 3 of the report. The summary statistics for the steady-state data were computed by training all of the data as if it existed as one continuous segment, without turns.

The summary data for the two "super-segment" STAR's are presented in table C-1.

TABLE C-1. SUPER-SEGMENTS STAR's FOR PNE AND ACY

	Mean TSCT			RMS TSCT			Mean FTE			RMS FTE		
	Std	Mod-1	Mod-2	Std	Mod-1	Mod-2	Std	Mod-1	Mod-2	Std	Mod-1	Mod-2
Route A (PNE)	0.054	0.061	0.076	0.272	0.337	0.333	-0.072	-0.012	0.016	0.348	0.382	0.369
B	-.086	.082	-.100	.282	.356	.334	.107	- .078	.169	.342	.475	.336
C	-.059	-.160	-.040	.388	.489	.357	- .126	- .036	.113	.413	.359	.553
Route A (ACY)	-.158	-.072	-.166	.424	.316	.548	.033	.087	.003	.359	.321	.455
B	.069	-.085	.028	.372	.288	.358	- .014	.140	-.011	.470	.379	.427
C	-.064	-.010	-.086	.337	.324	.312	- .009	.130	.117	.556	.428	.278

The RMS values for TSCT and FTE for the PNE STAR and the ACY STAR are presented in figures C-1 and C-2. From figure C-1 it can be seen that for the PNE STAR, all three routes (A, B, and C) exhibited the same behavior in terms of the plotted function. However, Route C evidenced a considerably higher TSCT error than did the two other routes. Routes A and B crossed H waypoint at angles of 90 degrees and 30 degrees respectively, whereas Route C crossed R waypoint at 81 degrees. Both A and B crossed I waypoint at 90 degrees, Route C at 45 degrees. It would appear that the angular change increased the complexity of the Route C structure and caused an increase in pilot workload which resulted in a higher TSCT for the Route C PNE STAR.

From figure C-1 it can be seen that for the ACY STAR's, Routes A and B exhibit the same behavior in terms of a v-shaped function. Route C is represented as a linear function for all combinations. These data are essentially reversals from the PNE STAR's in that the routes are reversed in terms of the resultant amount of crosstrack error. The shorter routes, B and C, have smaller overall crosstrack errors than Route A in terms of the number of waypoints and required distances to be flown. In general, the overall amount of crosstrack error appears to be the same for both the ACY and PNE STAR's. In summary, the RMS crosstrack error for both the PNE and ACY STAR's is constrained to a fairly narrow band approximately 0.27 to 0.55 nmi. These values are well within the ± 2.0 nmi allowable error established in AC 90-45A for the terminal area.

From figure C-2 it can be observed that for the PNE and ACY STAR's, the RMS FTE data did not exhibit the same clear-cut functions as the RMS TSCT data. The overall amount of RMS FTE error, however, was approximately the same as that exhibited by the TSCT data and ranged between 0.32 and 0.56 nmi and, as such, is well within the ± 2.0 nmi established by AC 90-45A for FTE.

In general, from the data in figures C-1 and C-2 and table C-1, it may be seen that the pilots in this study were able to use a single-waypoint RNAV system to traverse a complex series of route and route structures without violating either the 2-RMS TSCT requirements of ± 2.0 nmi error budget established by AC 90-45A for the terminal area or the 2-RMS FTE requirement of ± 2 nmi. A further detailed analysis of the individual segments and transition data was necessary in order to determine if the segments themselves may individually have a greater error than that reported for the entire STAR. The detailed analysis in the main part of the report concentrated on determining if any of the different segment types (i.e., waypoint to waypoint, intersection to waypoint, waypoint to intersection, or intersection to DTW fix) caused an increased amount of TSCT or FTE error for stead-state tracking, and if the waypoint and/or intersection caused increased TSCT error during transition to the next segment.

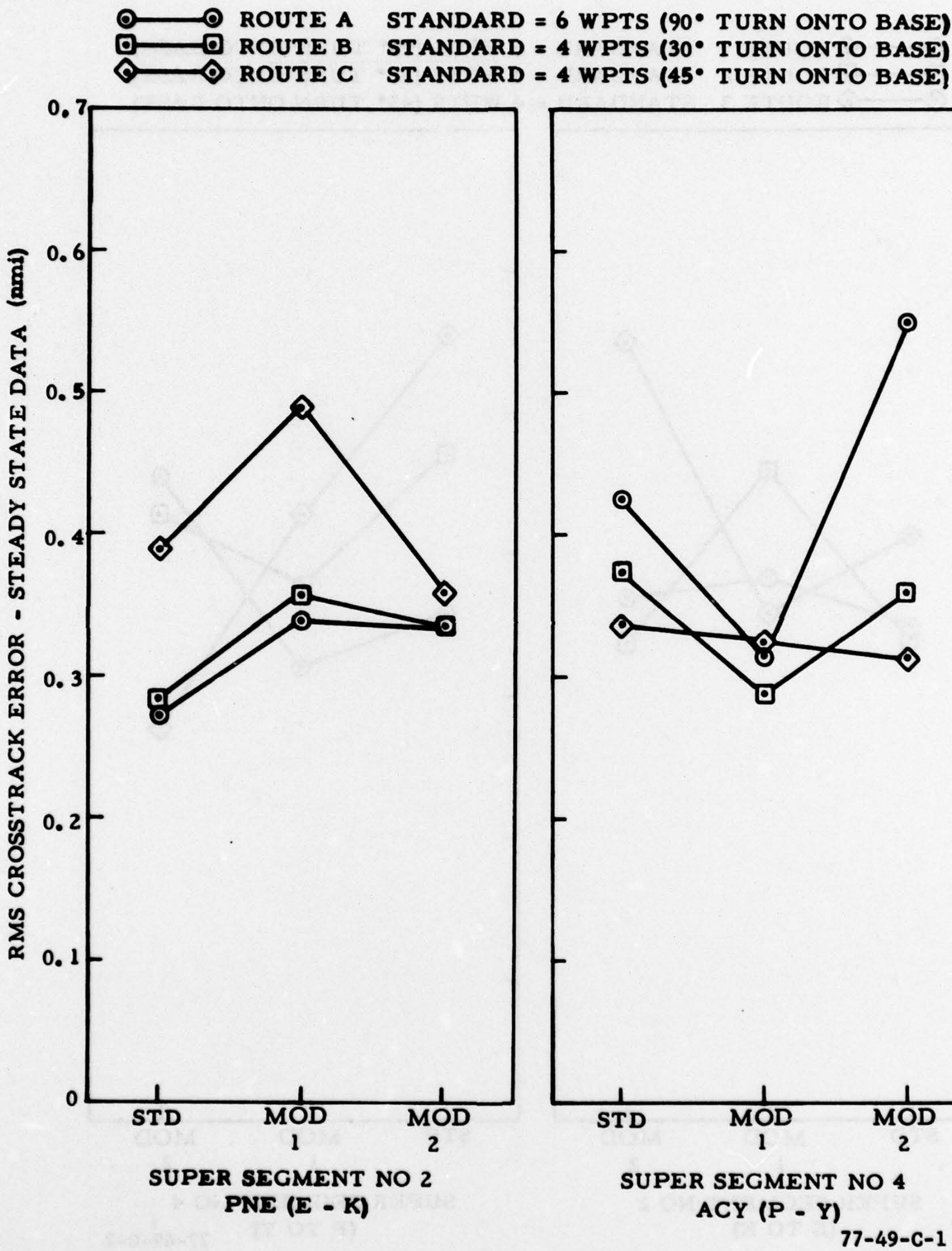


FIGURE C-1. SUPER SEGMENTS 2/4 RMS DATA

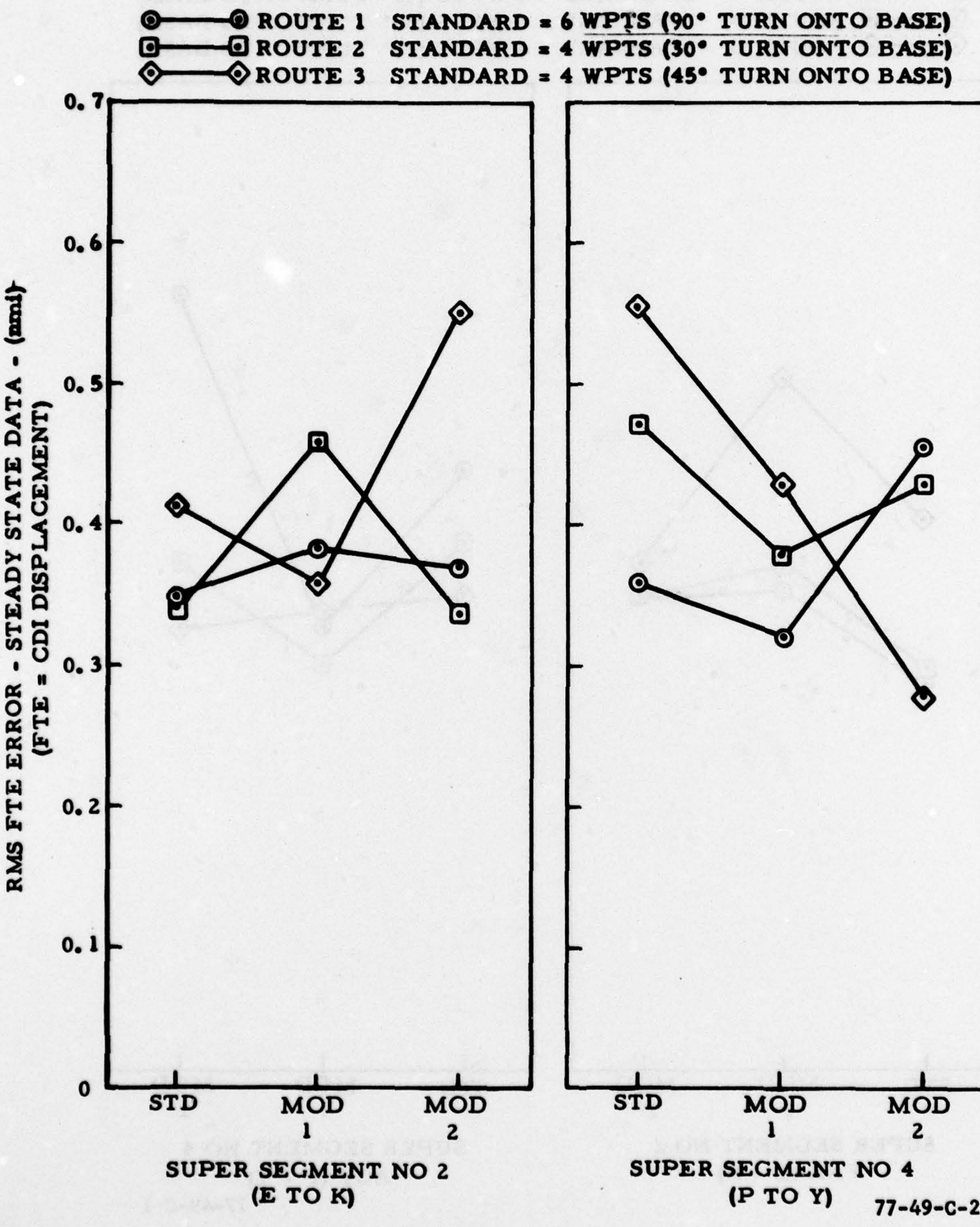


FIGURE C-2. SUPER SEGMENT 2/4 FTE DATA

APPENDIX D

PILOT QUESTIONNAIRE

APPENDIX D

GAT-2A
MODIFIED RNAV TERMINAL PROCEDURES
044-326-060

PILOT QUESTIONNAIRE

1. How often did you push the red "test" button to test the operational accuracy of the RNAV?

   Never ☐   Occasionally ☐   Quite Frequently ☐

2. Were the digital readout numbers on the RNAV easy to read with your cockpit lighting.   NO ☐   YES ☐

   a. If no, should they be: Brighter ☐   Larger ☐   Both ☒
   b. Should the internal lighting of the digital readout windows/numbers be adjustable to suit varying light conditions?
   NO ☐   YES ☐

3. Did you ever elect to fly in the "APPROACH" mode?
   NO ☐   YES ☐

   a. If yes, when and how often? ______________________________
   ____

4. In the "RNAV" mode, each dot on the CDI equals ________ nmi.
   a. In the "APPROACH" mode, each dot equals ________ nmi.

5. Are there any undesirable physical features of the King RNAV with respect to:
   1. Entering waypoint information?   NO ☐   YES ☐
   2. Output/Storage display?   NO ☐   YES ☐

   If yes, explain. ______________________________
   ____

6. Was the ATC communications workload:

   Excessive ☐   Normal ☐   Light ☐

7. Did you spend "too much time" looking at the RNAV displays to verify that you really had your desired waypoint information set in accurately? NO ☐ YES ☐

a. How often did you update or reset your RNAV to attain maximum accuracy of:

	Continuously	Occasionally	Seldom	Never
A. BRG. (Theta)	☐	☐	☐	☐
B. DIST. (Rho)	☐	☐	☐	☐
C. OBS	☐	☐	☐	☐

8. How did you anticipate turns?
a. Turned when DTW read ________ miles.
b. Waited for flag to go TO ——→ FROM.
c. Set OBS for next course prior to W/P and waited for CDI to center.
d. Other ____
____

9. All things considered, how would rate the degree of difficulty in flying the various routings of the experiment?

Very difficult ☐ Moderately diff. ☐ Fairly easy ☐ Very easy ☐

Comment ____
____

10. When did you reset your OBS for the next leg (course)?
a. Approx. ________ miles prior to the Waypoint.
b. Over the W/P.
c. After passing the W/P (TO → FROM).

11. When did you set in the BRG. and DIST. for the next W/P?
a. Approx. ______ miles prior to waypoint.
b. Over the W/P.
c. After passing the W/P (TO → FROM)
d. Other. Explain. ____________________________________
____

12. Did you have any problems with the nav. charts? NO ☐ YES ☐

If yes, explain. ______________________________________
____

13. Did the designation of intersection DTW fixes in lieu of waypoints tend to "simplify" flying the routing?
NO ☐ YES ☐ WHY ______________________________
____

14. With regard to reducing pilot workload and yet not sacrificing RNAV piloting accuracy, do you consider the use of DTW intersection fixes in a terminal area to be very practical?
NO ☐ YES ☐ Please explain either answer: ______________
____

15. How did you recognize DTW intersection locations?
   a. Used DTW mileage display only.
   b. When near (approx. ____ miles) the DTW intersection, set in the next course OBS value and waited for CDI needle to center.
   c. Other - Explain ______________________________
   ____

16. Did the panel location of the King RNAV adversely affect your ability to input BRG. and distance values of the waypoints?
NO ☐ YES ☐

Comment ______________________________________
____

17. What would you consider to be the maximum distance a DTW intersection should be from a waypoint? __________ Miles.
   a. What should be a minimum distance. ________ Miles.

18. On the King RNAV, the BRG. and DIST. dials are graduated into units of $.2^{o}$ and .2 miles respectively.
   a. What kind of consistent accuracy would you expect when using this scaling?

Very good ☐ Questionable ☐ Rather poor ☐ Unacceptable ☐

19. Using the attached approach plate for Bakersfield Airport, list the waypoints you probably would NOT enter in making a full IFR RNAV approach (starting at McKittrich W/P).
_______, _________, __________, __________, _________, _______,
or none ☐ .

   a. Would you designate any of the six waypoints as a usable DTW fix rather than a fixed W/P?

NO ☐ YES ☐ If yes, list them. ________, ________, ________, ________, ________, ________.

20. **If making your approach straight-in from Lamont W/P, list any W/P's you probably would NOT enter.** ________, ________, ________, ________, ________, ________.

a. Would you designate any of the four W/P's as DTW fixes rather than a fixed W/P? NO ☐ YES ☐

If yes, please list. ________, ________, ________, ________.

1. Which of the following routes did you prefer in making an RNAV approach to North Philadelphia Airport?
(Rank your choice from 1 to 3 - 1 is the most desirable, 3 is the least desirable.)

A.) E - F - G - H - I - J - K

B.) E - H - I - J - K

C.) E - R - I - J - K

Why was your #1 choice most desirable as opposed to choice #2 and #3? Please explain in detail.

2. In Routes A, B, and C above which would you make waypoints and/or intersections?

A.) Why?

1. E__________
2. F__________
3. G__________
4. H__________
5. I__________
6. J__________
7. K__________

B.) Why?

1. E__________
2. H__________
3. I__________
4. J__________
5. K__________

C.) Why?

1. E__________
2. R__________
3. I__________
4. J__________
5. K__________

3. In Route A above, which of the following procedures did you prefer?
(Rank your choice from 1 to 3 - 1 is the most desirable, 3 is the least desirable.)

A.) Waypoint at G followed by another waypoint at H and another waypoint at I.

B.) Waypoint at G followed by an intersection at H and another waypoint at I.

C.) Intersection at G followed by a waypoint at H and another intersection at I.

Why was your #1 choice most desirable as opposed to choice #2 and #3? Please explain in detail.

4. In departing Atlantic City Airport via Routes B, C, D, and E, which would you prefer as waypoints and/or intersections?

B. ___________

C. ___________

D. ___________

E. ___________

Why?