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AUG 79 D ELDREDGE, W G CROOK, B D DEBARYSHE

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SIMULATION STUDY OF THE OPERATIONAL CHARACTERISTICS OF A TWO/THREE-DIMENSIONAL MULTIWAYPOINT AREA NAVIGATION (RNAV) SYSTEM

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AUGUST 1979

FINAL REPORT

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16. Abstract

The purpose of this report is to evaluate pilot capability to fly air traffic control offsets and vertical profiles for both two- and three-dimensional area navigation (RNAV) modes both with and without the use of a flight director. Flight pilot subjects participated in simulation tests conducted at the National Aviation Facilities Experimental Center. Performance was measured for two variables: total system crosstrack error (TSCT) and flight technical error (FTE); and assessment was made of pilot performance on horizontal tracking, vertical tracking, and turns. The major findings were: (1) 2-sigma and 2-RMS steady state tracking data for centerline and offset tracking were within ±1.5 nautical miles of the course being flown, (2) summary data for centerline turns never exceeded a ±2 nautical miles error range, (3) centerline tracking was less variable than offset tracking, (4) the use of 3D RNAV mode to arrive at a specified altitude at a specific location increased pilot workload along the route segment leading to that location, (5) lag times for pilot response to ATC RNAV clearances were found to be a function of the situation complexity, and (6) the calculated RSS statistic proved to be an overconservative estimator of TSCT errors.

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

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METRIC CONVERSION FACTORS

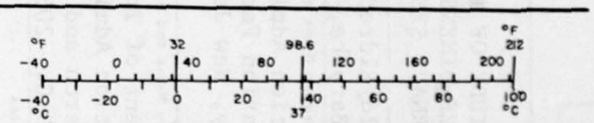
Approximate Conversions to Metric Measures

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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INTRODUCTION

PURPOSE.

The purpose of this report is to evaluate pilot capability to fly air traffic control (ATC) offsets and vertical profiles for both two- and three-dimensional (2D/3D) area navigation (RNAV) modes both with and without the use of a flight director.

BACKGROUND.

A Federal Aviation Administration (FAA)/Industry Task Force was established to define how to implement RNAV in the National Airspace System (NAS). Their report of February 1973 (reference 1) detailed an action plan which included substantial research and development efforts. This report covers two of several studies conducted by the FAA which are directed toward the orderly introduction of RNAV into the NAS.

The two phases of this experiment were conducted at the National Aviation Facilities Experimental Center (NAFEC) and were reported as data and interim reports (references 2 and 3). Both studies were conducted in a simulated 2D/3D RNAV environment, and both studied pilot ability to fly various horizontal offsets and vertical profiles, the main difference being that a flight director system was used in Phase I, whereas it was not in Phase II.

DISCUSSION

EQUIPMENT DESCRIPTION.

For these experiments, the NAFEC General Aviation Trainer (GAT)-2B/XDS-530 flight simulation facility was used. It was equipped with a Collins Radio Co. FD-109 (V) integrated flight director system and a EDO Commercial Corp. TCE-71A (Aeronautical Radio Inc. (ARINC) Mark 13) 3D RNAV system. Refer to appendix A, "Equipment Used in the RNAV Simulation Study," for a detailed description of equipment.

As compared to a general aviation type RNAV unit, which was tested in another simulation (reference 4), the EDO RNAV system is a commercial-type unit. It operates by converting navigational aid (NAVAID) signals, toward which aircraft normally fly for guidance, into a "phantom" very high frequency omnirange (VOR) location called a waypoint toward which the pilots fly for guidance. The advantage of using RNAV is that since RNAV can create its own waypoints, the pilot can fly directly to destination, thus effecting fuel economy and shorter flying times.

Two modes of RNAV operation were evaluated: 3D RNAV (VNAV) and 2D RNAV. Use of the 3D mode required the pilot to insert the planned waypoint crossing altitudes for climb and descent route segments. The RNAV system computed required flight-path angle (FPA). The pilot derived his primary vertical flight profile commands from the pitch command bars of the attitude deviation indicator (ADI), and referenced vertical flightpath deviations by use of the glide slope pointers on the ADI and horizontal situation indicator (HSI). In the 2D mode, the VNAV (3D) button of the RNAV system was not activated, which precluded altitude and FPA entries for RNAV-computed vertical flight profile. However, the pilot could make use of the pitch command control of the flight director and manually position the command bars of the ADI to establish a desired climb or descent pitch altitude. When the desired altitude was attained, the pilot could engage the "altitude hold" function of the flight director.

ROUTE STRUCTURE.

A single route structure used in both phases of this study is illustrated in figure 1. From this route structure four different combinations of offset routes were devised (figure 2). Also common to both phases of the study were the approach plates which are depicted in figures 3 and 4.

PSEUDO WAYPOINT PROCEDURE.

A pseudo waypoint is located on the wayline of the parent waypoint at a distance equal to the amount of the offset (figure 5). The wayline is a line passing through the waypoint at 90° to the course being flown and represents the zero-distance-to-go point as displayed on the distance readout on the HSI. The "potential error" distance, as indicated, must be estimated and taken into consideration by the pilot in establishing a more accurate turn point. Pilots making turns at waypoints while on an offset must be able to visualize the offset pseudo waypoint location in order to more accurately maintain the offset around the turn. This is especially true for a turn in the same direction as the offset and for large-angle turns.

Associated with the turn functions is the "HALRT" light which is set to illuminate and flash at 0.9 minutes prior to the waypoint. The "HALRT" light is a function of airspeed and distance and is also measured with respect to the wayline. It alerts the pilot that he is approaching the waypoint/wayline and signifies that turn preparations should be started. This "HALRT" light has significant value to the pilot when he is flying on the parent course, but cannot be relied upon in every respect when flying offsets. For certain combinations of turn angle, airspeed, and offset, the "HALRT" light will not signal an alert prior to the turn, making the pilot's capability to visualize the pseudo waypoint doubly important.

EXPERIMENTAL DESIGN.

The experiment was conducted in two phases:

Phase I--2D/3D RNAV With flight director, and
Phase II--2D/3D RNAV Without flight director.

These phases are discussed in separate sections in this report.

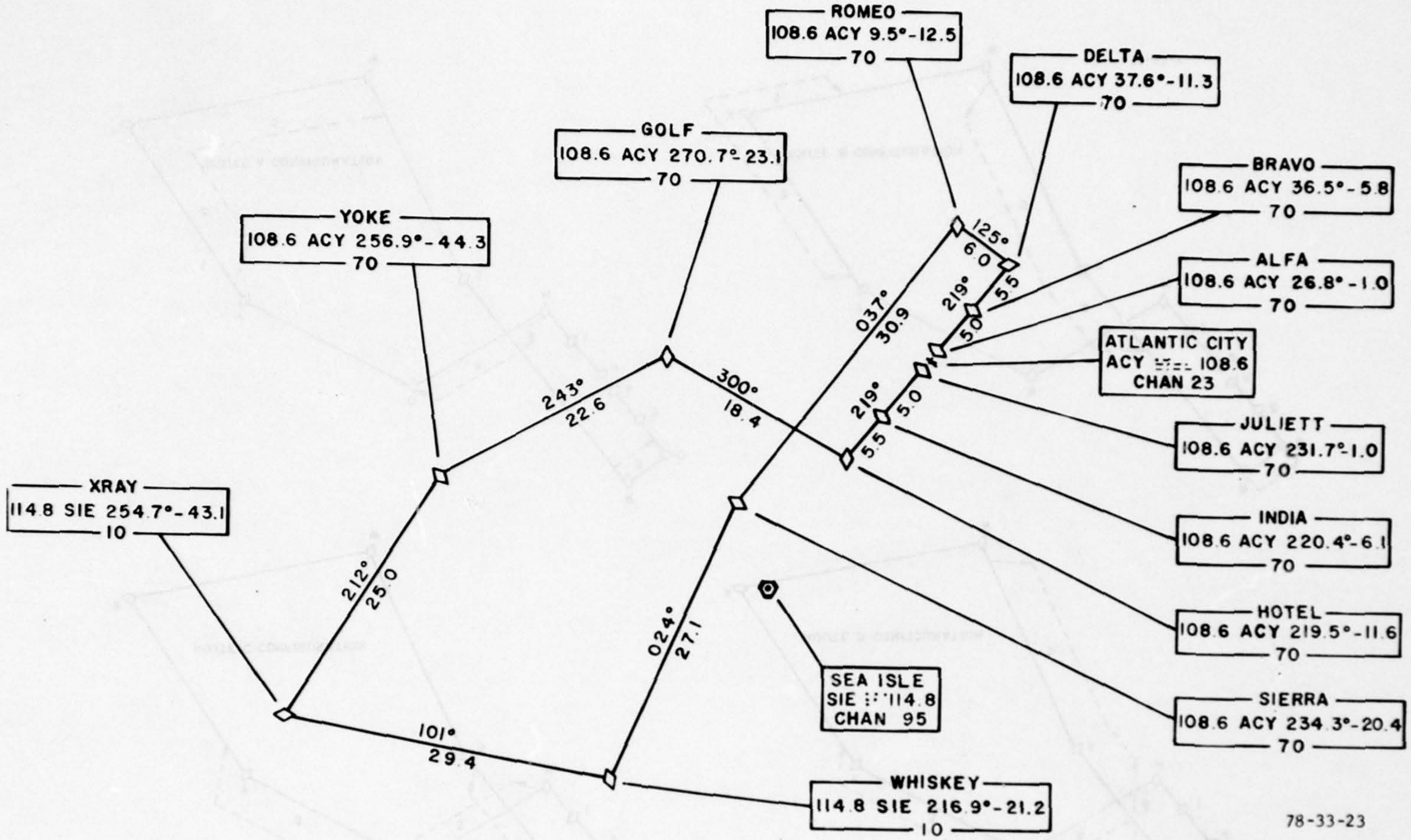

FIGURE 1. BASELINE DATA ROUTE CONFIGURATION

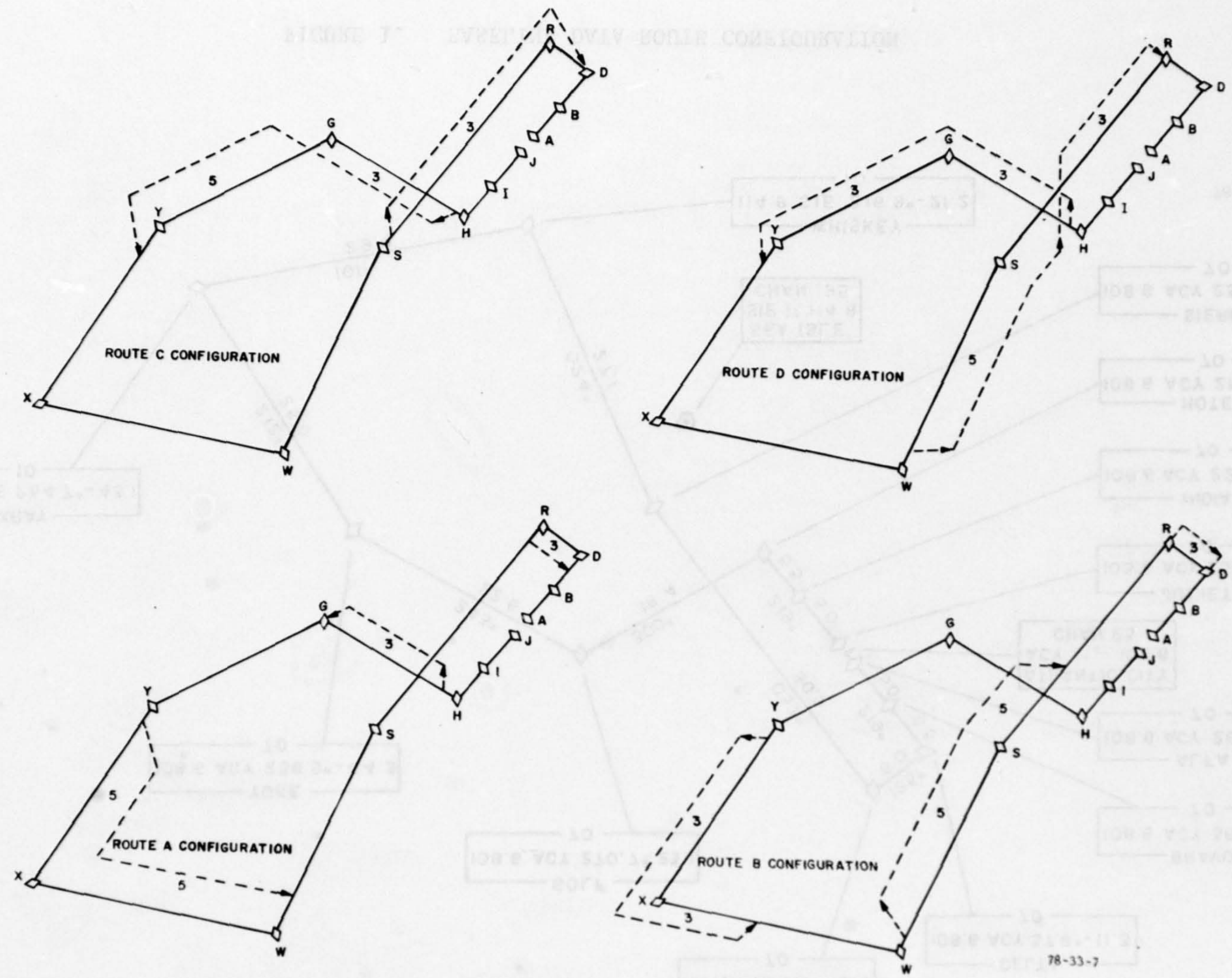

FIGURE 2. THE FOUR OFFSET ROUTE STRUCTURES EVALUATED IN THIS EXPERIMENT

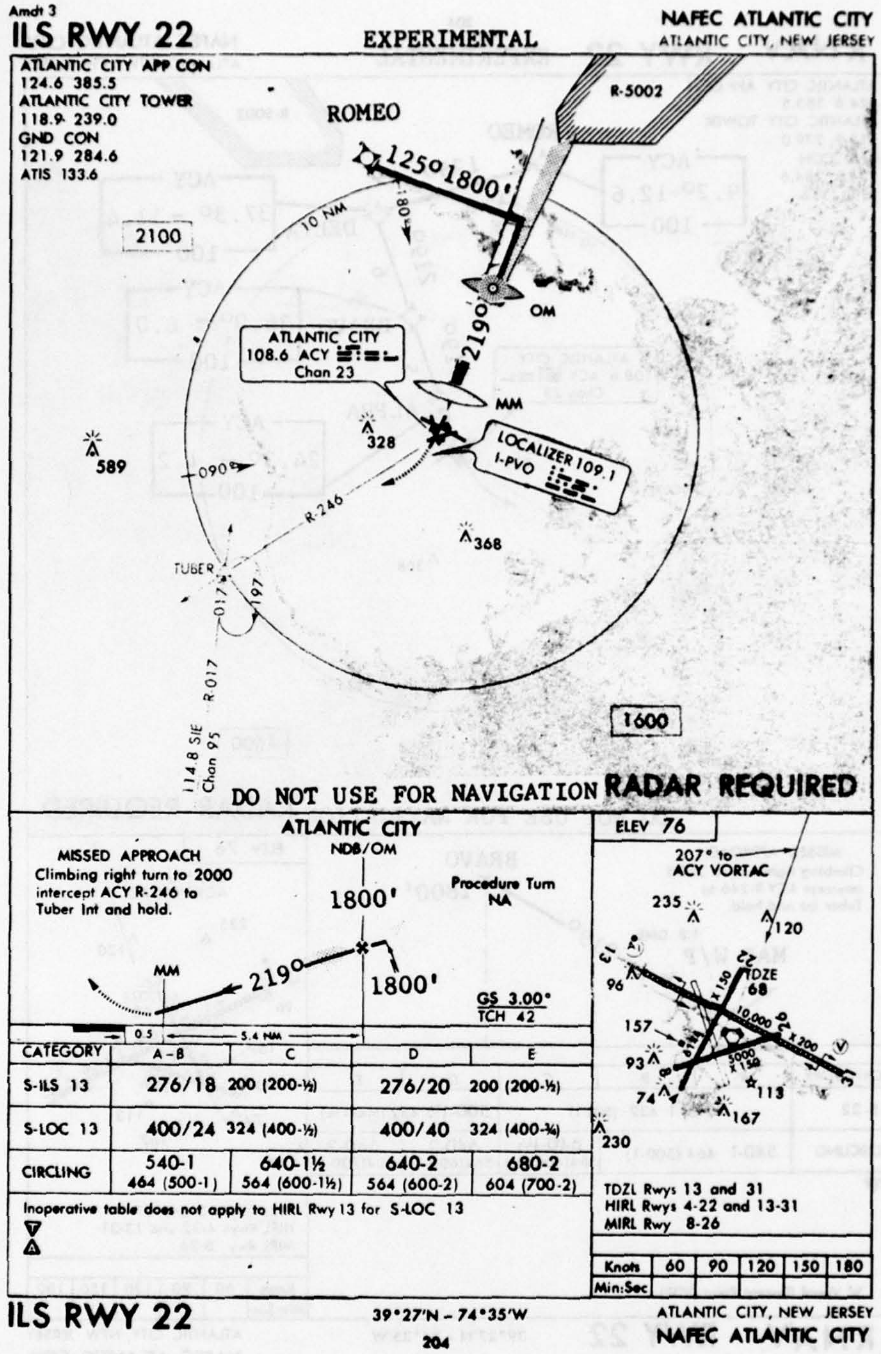

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FIGURE 3. ILS APPROACH PLATE--RUNWAY 22

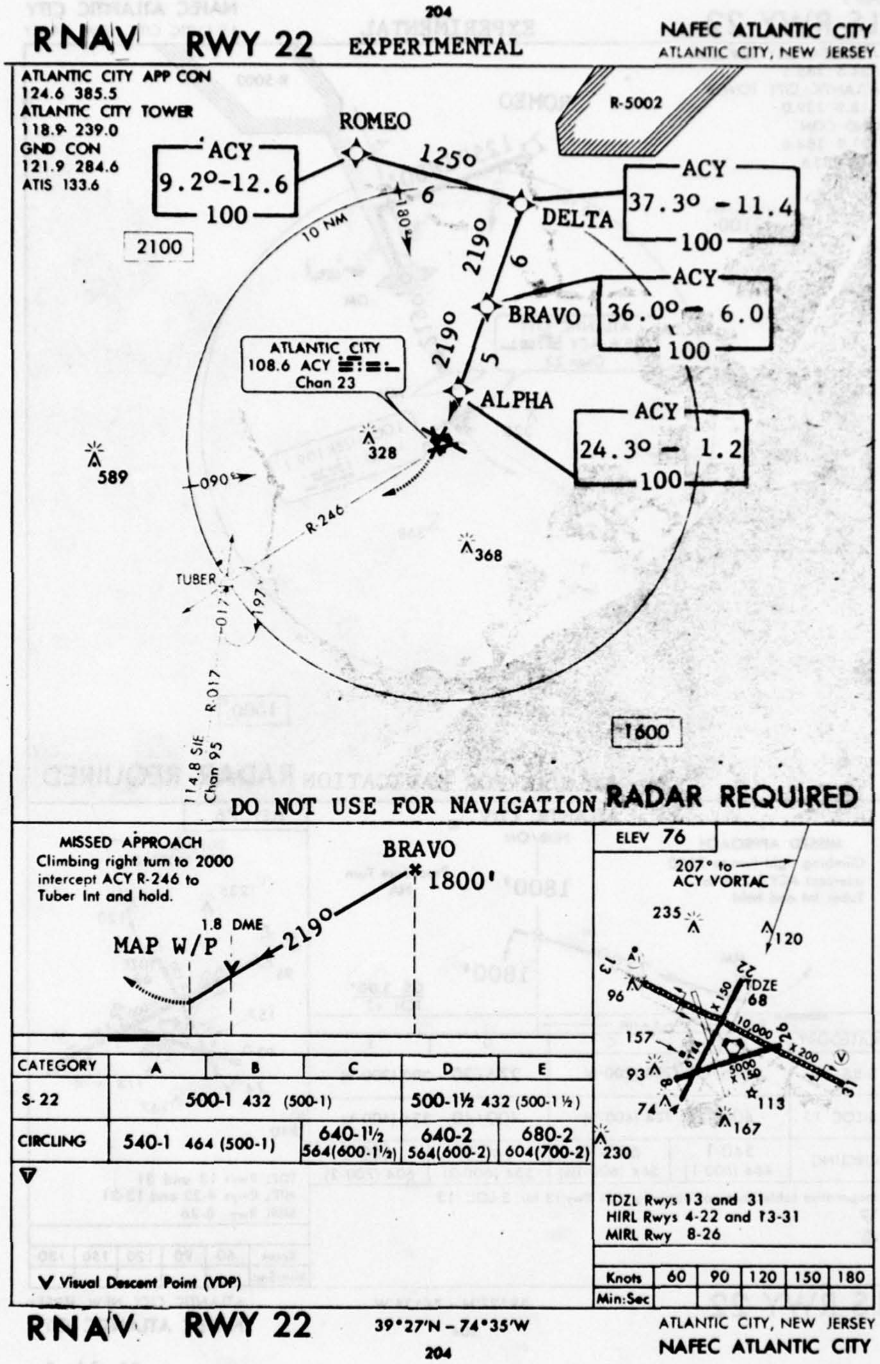

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FIGURE 4. RNAV APPROACH PLATE--RUNWAY 22

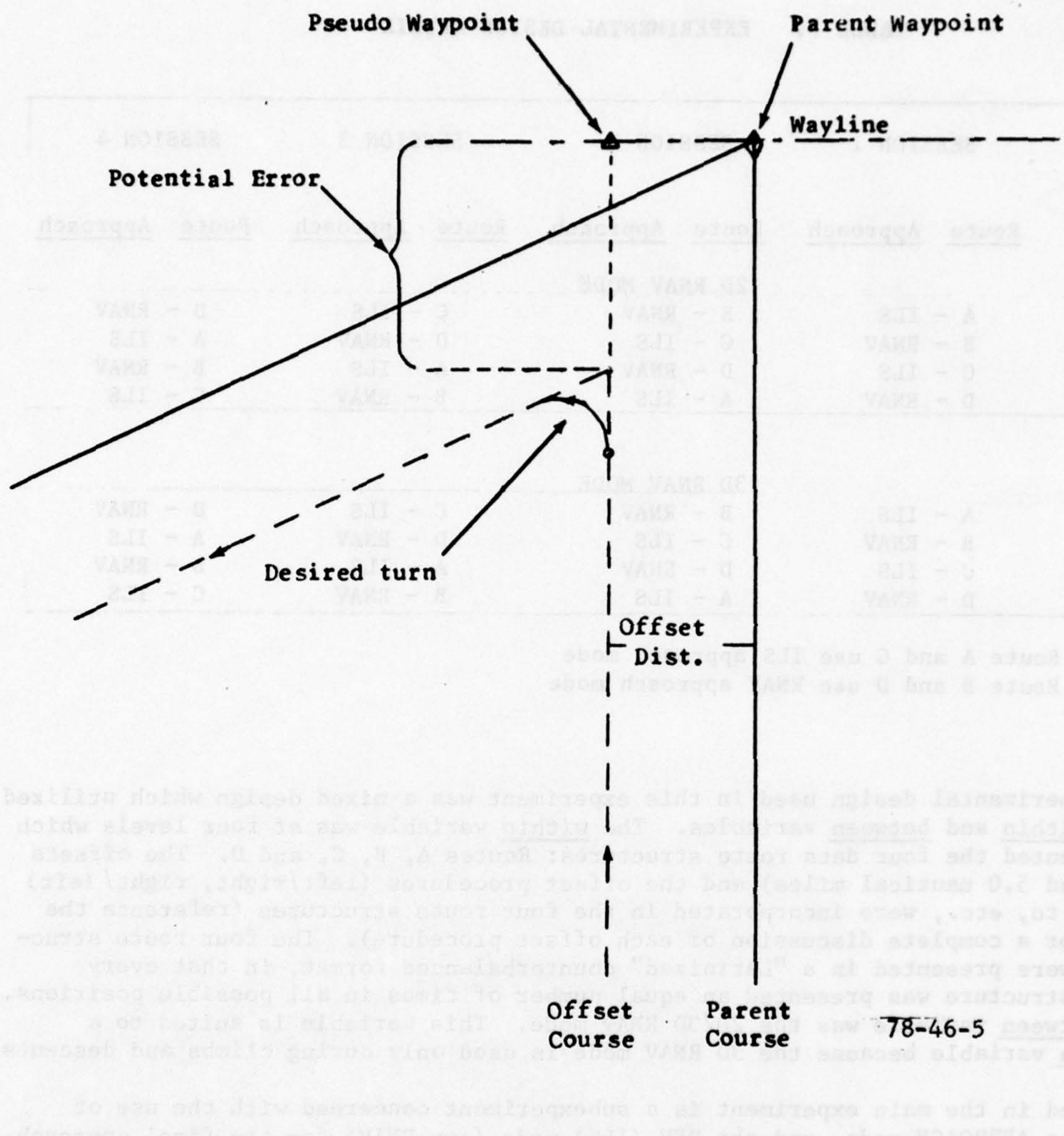


FIGURE 5. WAYPOINT/WAYLINE RELATIONSHIP

The experimental design was developed for the purpose of determing if operational differences occurred when an ARINC Mark 13 RNAV system was used under various experimental offset and offset procedure conditions with and without the use of a flight director command function. Eight subject pilots were each given four data runs, as outlined in table 1.

TABLE 1. EXPERIMENTAL DESIGN MATRIX

	SESSION 1	SESSION 2	SESSION 3	SESSION 4
PILOT	Route Approach	Route Approach	Route Approach	Route Approach
		2D RNAV MODE		
1	A - ILS	B - RNAV	C - ILS	D - RNAV
2	B - RNAV	C - ILS	D - RNAV	A - ILS
3	C - ILS	D - RNAV	A - ILS	B - RNAV
4	D - RNAV	A - ILS	B - RNAV	C - ILS
		3D RNAV MODE		
5	A - ILS	B - RNAV	C - ILS	D - RNAV
6	B - RNAV	C - ILS	D - RNAV	A - ILS
7	C - ILS	D - RNAV	A - ILS	B - RNAV
8	D - RNAV	A - ILS	B - RNAV	C - ILS

NOTE: Route A and C use ILS approach mode
Route B and D use RNAV approach mode

The experimental design used in this experiment was a mixed design which utilized both <u>within</u> and <u>between</u> variables. The <u>within</u> variable was at four levels which represented the four data route structures: Routes A, B, C, and D. The offsets (3.0 and 5.0 nautical miles) and the offset procedures (left/right, right/left) direct to, etc., were incorporated in the four route structures (reference the text for a complete discussion of each offset procedure). The four route structures were presented in a "Latinized" counterbalanced format, in that every route structure was presented an equal number of times in all possible positions. The <u>between</u> variable was the 2D/3D RNAV mode. This variable is suited to a <u>between</u> variable because the 3D RNAV mode is used only during climbs and descents.

Imbedded in the main experiment is a subexperiment concerned with the use of both the APPROACH mode, and the REV (ILS) mode (non-RNAV) for the final approach. One-half of the data runs used the APPROACH mode and the other half used the REV mode. The APPROACH mode was used for all runs on data Routes B and D. The REV mode was used for all runs on data Routes A and C. The data from this subexperiment were analyzed independently from the main experiment data. Reference table 1 for the experimental design matrix used in this evaluation.

PHASE I: WITH FLIGHT DIRECTOR

PHASE I PROCEDURES.

SUBJECTS. Eight subjects were chosen from the Flight Operations Branch (ANA-640) at NAFEC. The subjects were randomly utilized, based on their availability from their assigned duties. All subjects were active professional pilots for the FAA. Some subjects had prior experience with area navigation both in the GAT-2B/XDS-530 facility and in FAA RNAV-equipped aircraft. All subjects were required to complete four familiarization flights designed to acquaint the pilots with route structures and procedures similar to those used in the data collection flights. None of the subjects indicated a need for additional familiarization flights. Table 2 is a summary of the subjects' qualifications.

TABLE 2. PHASE I SUBJECT QUALIFICATIONS

Subject	Group	License	Total Hrs.	Instr. Time	Prev. GAT-2 Time	Prev. RNAV Time
1	1	ATR*	19,521	900	25	40
2	1	ATR	8,742	1,328	10	10
3	1	ATR	2,388	210	15	15
4	1	Comm**	5,000	300	20	0
5	2	ATR	10,600	700	10	20
6	2	ATR	15,800	700	20	80
7	2	ATR	22,093	1,300	20	15
8	2	ATR	16,827	1,250	25	20

* Air Transport Rating
** Commercial Rating

PROCEDURES. All pilots were given instructions regarding experimental objectives, use of the navigational equipment, and specific flight task requirements. The eight subject pilots were divided into two groups of four. Group 1 flew the route structures using the 3D RNAV mode, while group 2 flew the route structures using the 2D mode.

Instructions stressed adherence to specific airspeeds which were designated for climb, cruise, descent, and final approach. These airspeeds were also placarded on the instrument panel of the simulator. In addition, the route geometry was discussed, and route charts and approach charts were given to the pilots. The pilots were also instructed to perform turn anticipation. One method of turn anticipation was suggested, but specific techniques were left to the pilots' discretion.

After completing the preliminary instructions, each pilot was given four familiarization flights on a route similar to the data route. To complement both the familiarization and data flights, prepared voice scenarios 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. Familiarization and data flights were flown in a solo mode, without a copilot.

EXPERIMENTAL LIMITATIONS WITH FLIGHT DIRECTOR. The output of the RNAV unit was not directly compatible with the input requirements of the flight director. It was necessary to furnish interface control by designing and building a coupling unit. A perfect match of the two subsystems, flight director and RNAV, was not possible because of certain equipment constraints. It was necessary to make tradeoffs or compromises. The integrated system could be adjusted to optimize performance in only one of the four operating modes:

1. Tracking of parent (centerline) courses
2. Tracking of offset courses
3. Turns, or
4. The transitions, at a nominal 45° intercept, between parent and offset courses.

It was possible to obtain satisfactory performance for several, but not all, of these modes with one set of adjustments. The decision was made to accept degraded turn performance in favor of obtaining good operation in steady state tracking of parent and offset courses, and the desired 45° transitions.

This compromise did, at times, result in large (up to 2.4 nautical mile) overshoots in turns, but no more satisfactory solution was apparent.

Turn data obtained during these experiments, therefore, were not considered to be representative of RNAV performance obtainable under actual flight conditions, where the flight director interface would have been optimized for the particular aircraft installation. Therefore, the turn data were omitted from the analysis which follows. Multiple regression analyses were computed only on steady state centerline and offset tracking data in order to obtain an estimate of RNAV tracking performance with a digital RNAV unit in a terminal area environment. Data were analyzed within an operational context. A turn region was defined as the area 2.0 nautical miles prior to and 2.0 nautical miles after the point where the RNAV route changed direction.

Vertical (3D) performance data were not considered for analysis because of the same system integration problems that influenced turn data.

DATA REDUCTION AND ANALYSIS. The results of the 32 data runs (four routes times four pilots 2D and four pilots 3D) were recorded. For the purpose of this study, blunders were defined as cases where total system crosstrack error (TSCT) exceeded 2 nautical miles. Procedural errors were defined as cases where TSCT exceeded 1.0, but were less than 2.0 nautical miles. The on-track data, including regions of procedural error, were analyzed using the time series measurements of the selected variables collected during this study.

The primary analytical tool was a computerized, stepwise multiple linear regression program (references 2, 3, and 4). This program was used to determine the relation of TSCT to eight independent variables:

1. Flight technical error (FTE), a measure of horizontal tracking accuracy of the RNAV/pilot system. It has been assumed that, since there is an absence of ground station signal errors in simulation, the course direction indicator (CDI) variations represent the only significant component of FTE. The sign convention used in the GAT-2B data reduction is that a "fly left" CDI command is negative, a "fly right" command is positive. When the GAT is left of course, FTE would be negative, but the CDI would command "fly right." Hence, we take CDI=-FTE. CDI error is measured in nautical miles.

2. Omni bearing selector (OBS) setting error, a measure of analog data inaccuracies. This measure was converted to linear distance in nautical miles.

3. Bank steering bar (BSB) commands, a measure of instrument bank output to the pilots, and of the flight director coupling to the RNAV system. This measurement was expressed in degrees.

4. Vertical direction indicator (VDI) reading (for 3D only), a measure of how closely the pilots tracked their instruments in terms of vertical flight-path profile. This measure was in feet.

5. Pitch steering bar (PSB) commands, a measure of instrument pitch output to the pilots, and of the flight director system coupling to the RNAV system. This measurement was expressed in degrees.

6. Indicated airspeed (KIAS), a potential measure of pilot workload, expressed in knots.

7. Navigation system error (NSE), defined as TSCT minus FTE (nautical miles).

An eighth independent variable was created in order to determine if horizontal tracking under the 2D RNAV mode was different than under the 3D RNAV mode. This variable consisted of a vector of 1's and 0's. The value of 0 was assigned to the 3D RNAV mode condition, and the value of 1 was assigned to the 2D RNAV mode. These values acted as "flags" during the calculation of the regression equation.

The stepwise regression program first determines the degree of correlation between the dependent and the independent variables, selects the most correlated independent variable, and then computes the regression between the dependent variable and the selected independent variable. The next most correlated value is then selected and the regression model is recalculated. The procedure is iterated for all remaining variables, both those previously selected and those not yet entered. The process stops when either the inclusion of the remaining candidate variable with the highest correlation causes the test statistic to fall below a preset minimum, or when all independent variables are utilized. The test statistic is the F ratio obtained from an analysis of variance conducted for the equation: sum of squares (about the means) = sum of squares (about regression) + sum of squares (due to regression). This F ratio is then evaluated on the basis of the number of degrees of freedom in the numerator and the denominator. When the F ratio is significant for the sum of squares due to regression, the variable is accepted as being a valid predictor, and the residual sum of squares is minimized. The technique of checking all variables and reevaluating the obtained partial F criterion against the present F value (α =0.001) (α is the minimum acceptable F value) for each variable in the regression at any stage of calculation is automatic. Therefore, a variable which may have been the best single variable to enter at an early stage may be rejected at a later stage. As a result of this iterative procedure, only those variables that best characterize the regression between the dependent variable and the independent variables will be selected for inclusion in the final linear model which will be of the form: y = Intercept + Coefficient (Beta Weights) + Error.

The data of interest to be extracted from the derived regression model include the intercept, the partial regression coefficients, obtained R^2 value (which measures the amount of variation explained by the model), and the percentage sum of squares reduced by the model (which also measures the degree of fit of the model). In addition, the means and variances for the dependent variable and for each of the independent variables are also calculated and listed.

Initially, 36 cases were analyzed. Each data route (A, B, C, and D) was broken down into base course and offset segments. Each route was analyzed in terms of 2D or 3D guidance. Therefore, each of the four routes was analyzed in terms of nine different combinations, (2D, 3D, or 2D plus 3D) times (base, offset, or base plus offset).

The thirty-seventh case is the grand total. It consists of all segments, centerline and offset, for all pilots, for all four routes.

The computer program depends on a matrix inversion technique. There are instances when the variables are not amenable to this treatment, and the matrix is termed "singular;" that is, the inverse is nonexistent, usually because two or more variables are too closely correlated, or because of lack of accuracy (word length) in the computer. In these situations, essentially an attempt to divide by zero, the program does not function, and execution is terminated.

<u>RNAV SYSTEM OPERATION</u>. An RNAV system and its interfaces with the other aircraft navigational systems have characteristics which are discussed in this section. The problem of assuring system matching and interface control of the RNAV and flight director systems has been discussed above and will not be treated herein.

<u>LOCATION OF THE PSEUDO WAYPOINT IN OFFSET MODE</u>. While flying offsets, pilots must be able to visualize the pseudo waypoint location in order to judge their turn point accurately and maintain their offset while transitioning. When the offset turn required is greater than 90°, the problem is most serious. The potential error distance (figure 5) must be estimated and taken into account by the pilot in order to establish a more accurate turn point without overshooting. The pilots usually allowed about 1-mile lead distance for their turns at a cruise airspeed of approximately 160 knots. This worked quite satisfactorily for flying the centerline track, but when the pilots followed this turn logic while flying acute offset turns, it resulted in large overshoots, since they allowed the amount of the offset plus 1 mile to turn. The pilots failed to realize that this logic was valid only for turns of 90° or less. Had they set their OBS to the next course much earlier than normal, they might have detected the error.

Normally, the "HALRT" light would aid the pilot in preparation for his turn. The route used in this experiment has waypoints at each turning point. The "HALRT" light operation is a function of airspeed and distance to the wayline and is designed to alert the pilot that the waypoint is being approached. Hence, it warns that turn preparations should be started by the pilot. This alert light has significant value to the pilot when flying on the parent course, but cannot be consistently relied upon when flying offsets. On certain combinations of turn angle, airspeed, and offset, the "HALRT" light will not signal an alert prior to the turn, which makes the pilot's capability to visualize the position of the pseudo waypoint and its relation to turn angle doubly important.

Flight director warning flags and appropriate corrective actions are discussed in detail in appendix A, section A-3.

PILOT/FLIGHT DIRECTOR INTERACTION. Of the eight pilots who used this particular flight director system, six required a brief refresher on its operational characteristics. Two pilots required a more thorough indoctrination. Piloting technique varied somewhat in the use of the flight director/RNAV equipment between the 2D (RNAV) and 3D (VNAV) modes, especially when changing altitude.

Pilots who used the 2D RNAV mode climbed and descended manually at various vertical rates. These rates always exceeded the vertical rate which resulted from the VNAV-computed FPA. Two-dimensional RNAV flights invariably arrived at their prescribed altitude much sooner than the 3D RNAV flights. For VNAV flights, the FPA is calculated so that the flight arrives at altitude and the waypoint simultaneously. The pilots were critical of these shallow flightpath angles of 1.0° to 1.5° during RNAV climbs and descents.

At certain points of Routes A and C, pilots using the 3D mode were required to reach altitude at an assigned along-track point (ATK). Compliance with such clearance would necessitate a climbing/descending turn around a waypoint. Occasionally, the pilots erroneously updated to the next waypoint and lost 3D RNAV guidance. They were then forced to fly the remainder of the climb/descent profile manually (usually 10 nautical miles or less).

In a previous RNAV experiment, when the pilots had the option of entering their own desired path angles, they usually selected a 3° FPA.

PHASE I RESULTS.

LAG TIMES. An estimate of the delay between the issuance of an RNAV clearance and the moment that the pilot responds to that command is useful for planning RNAV procedures. To satisfy the objectives of this experiment, quantitative measurements of this delay or lag were obtained. The data-recording system for the GAT-2B allowed a technician to record the time an offset-related RNAV clearance was started and when the delivery of the clearance was concluded.

There is a problem in terminology. Engineering psychologists use the term "response time." Response time has a specific and incompatible definition in ATC usage where response time is defined as the interval between the conclusion of a clearance and the initiation of a measurable response. The following factors cause this definition to be unusable in this study:

1. Occasionally, the operator or the recording system omitted the end-of-clearance event marker.

2. Some clearances are long, and pilot response may be initiated during transmission of the clearance; i.e., the subject may respond to the initial portion of the clearance as much as 5 to 10 seconds before the clearance ends.

Negative delay times are an unpleasant anomaly; for example, they cannot be fitted to a log-normal distribution.

The measure of choice is lag time, which is defined, for this study, as the interval between the start of an ATC clearance and the initiation of a specific recognizable response. Mathematically, it would be expressed as the time of response minus the time of the start of the clearance.

For each route, there were several RNAV clearances which were timed by use of an event marker. Data Route A had three such events, Routes B and C had four events each, and Route D had five events. In table 3, lag times are listed by route and by event within a route for each of the eight pilots. Lag times are listed both for the first responses by the pilots and for initiation of turns. The data of table 3 were processed by grouping the lags into 5-second classes. This information is shown in table 4. The results of the delay of first responses are plotted in a histogram in figure 6. Figure 7 is a histogram of grouped lag times to initiation of a turn.

Inspection of the grouped data indicates:

Lag times to first recognizable response are trimodal with modes of 7.5, 20, and 37.5 seconds.

Lag times to initiate a turn are not quite as sharply separated, but there are apparent modes of 12.5, 35, and 50 seconds.

Lag times may be separated into three cases in relation to which type of clearances the pilot was given and what he was doing when it was given:

1. Short response, on the order of 6 to 10 seconds, such as "cancel offset" or "fly direct to."

2. Intermediate response, on the order of 16 to 25 seconds. The aircraft was in a relatively steady state, the pilot had low workload and was issued a simple offset command.

3. Long response, on the order of 30 to 50 seconds. The pilot was busy, trying to complete a turn, get to an offset or a parent course, or perform some other high-priority task. He noted and acknowledged the clearance, finished his previous task, and then responded.

Lag times, to first response, could be predicted from the scenarios. The situation and the RNAV clearance determined the response in a relatively simple manner:

TABLE 3. LAG TIMES IN SECONDS FROM START OF CLEARANCE

ROUTE A

	Waypoint H First Response	Waypoint H Turn Initiation	Waypoint G First Response	Waypoint G Turn Initiation	Waypoint Y First Response	Waypoint Y Turn Initiation
	41	41	13	13	40	46
3D	19	32	5	14	42	61
RNAV	30	32	3	9	50	53
	42	51	17	23	62	62
	31	31	6	15	37	37
2D	37	81	6	6	50	50
RNAV	18	–	14	19	43	73
	39	42	19	24	53	53

ROUTE B

	Past Waypoint Y First Response	Past Waypoint Y Turn Initiation	Past Waypoint X First Response	Past Waypoint X Turn Initiation	Past Waypoint W First Response	Past Waypoint W Turn Initiation	Past Waypoint S First Response	Past Waypoint S Turn Initiation
	40	–	12	14	85	90	18	19
3D	52	58	14	14	36	36	4	12
RNAV	55	64	9	15	16	16	3	11
	26	108	4	13	38	38	4	9
	8	8	5	5	48	53	5	14
2D	–	–	13	13	82(?)	–	27	31
RNAV	28	33	12	14	–	–	4	6
	28	62	22	22	79	79	5	10

TABLE 3. LAG TIMES IN SECONDS FROM START OF CLEARANCE (Continued)

ROUTE C

	Waypoint H		Waypoint Y		Waypoint S		Waypoint R	
	First Response	Turn Initiation	First Response	Turn Initiation	First Response	Turn Initiation	First Response	Turn Initiation
	20	32	24	24	21	22	7	13
3D	17	27	28	-	36	46	5	11
RNAV	43	53	9	9	36	46	14	-
	23	24	5	29	22	26	3	4
	22	30	-	-	24	24	4	8
2D	21	21	25	27	48	52	36	37
RNAV	19	27	4	-	22	34	5	-
	23	23	19	50	36	39	9	-

ROUTE D

	Past Waypoint H		AT Waypoint Y		Past Waypoint W		Past Waypoint S		Before Waypoint R	
	First Response	Turn Initiation	First Response	Turn Initiation	First Response	Turn Initiation	First Response	Turn Intiation	First Response	Turn Initiation
	22	51	21	21	42	64	20	20	6	8
3D	36	37	8	11	35	35	38	38	-	-
RNAV	32	46	19	35	43	51	32	36	9	17
	36	39	8	20	46	74	42	45	4	7
	53	57	5	14	49	52	22	22	9	14
2D	40	49	17	17	70	72	69	70	19	19
RNAV	25	27	4	5	33	57	38	38	11	20
	32	47	17	18	58	69	19	22	7	21

Note: (-) indicates missing date

TABLE 4. RANKED LAG TIMES

Class Interval Seconds	No., to First Response	No., to Initiation of Turn	Class
1-5	19	3	1
6-10	13	11	2
11-15	8	16	3
16-20	16	10	4
21-25	15	13	5
26-30	6	7	6
31-35	6	9	7
36-40	16	10	8
41-45	8	3	9
46-50	6	8	10
51-55	4	9	11
56-60	1	3	12
61-65	1	5	13
66-70	2	2	14
71-75	0	3	15
76-80	1	1	16
81-85	2	1	17
86-90	0	1	18
91-95	0	0	19
96-100	0	0	20
101-105	0	0	21
106-110	0	1	22

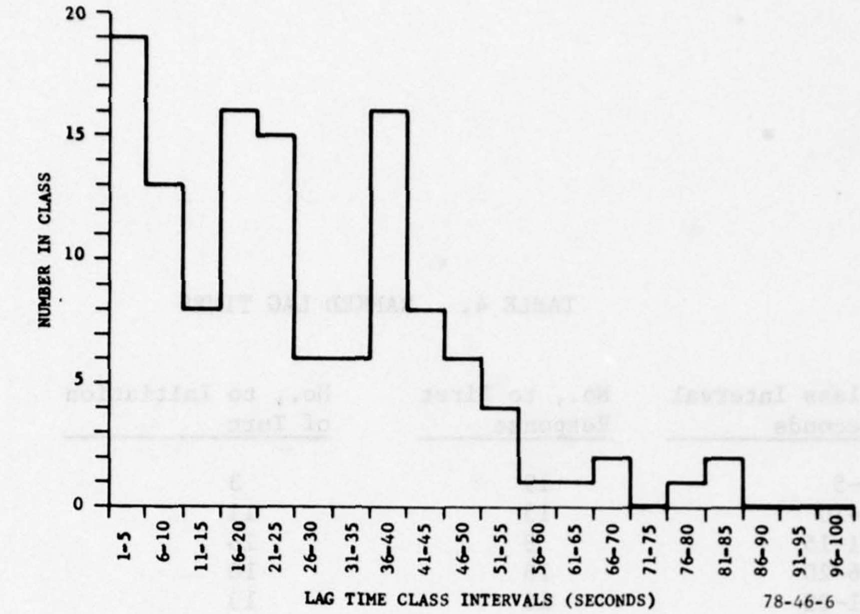


FIGURE 6. LAG OF PILOT ACKNOWLEDGMENTS TO RNAV CLEARANCES

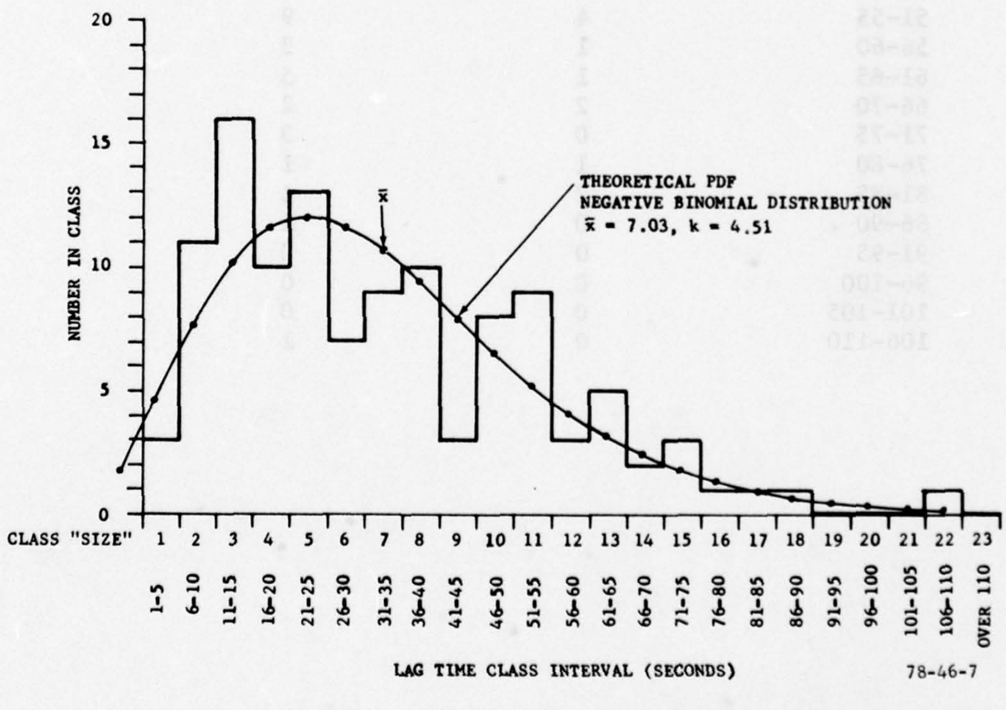


FIGURE 7. LAG BETWEEN CLEARANCE INITIATION AND TURN INITIATION

- "Cancel offset" or "direct to" commands resulted in short (5 to 10 second) lags.

- Offset commands, without altitude assignments or with a simple altitude assignment and 2D guidance, resulted in intermediate (16 to 35 second) lags.

- Complex or lengthy commands, offsets plus altitudes, plus reporting commands, combined with the workload of a turn, resulted in long (35 to 100 second) lags.

The foregoing ground rules were applied to the four route scenarios. Part A of table 5 is a matrix of results. Compare this with part B of table 5, which is the matrix derived by inspection of the first recognizable responses listed in table 3, Lag Times.

TABLE 5. WAYPOINTS CLASSIFIED IN TERMS OF SHORT, INTERMEDIATE, OR LONG LAG TIMES

A: By Analysis of Scenarios (Expected Response Lag)			
Route	Short	Intermediate	Long
A	G	H	Y
B	X,S		Y*
C	Y,R	H,S	
D	Y,R	H,S	W
B: From Inspection of Results (at each Waypoint (table 3) (Actual Response Lag)			
Route	Short	Intermediate	Long
A	G	H	Y
B	X,S	Y(2D)	Y(3D)W
C	Y,R	H,S	
D	Y,R	H,S	W

NOTE: *Route B near Waypoint is different for 2D or 3D guidance. 2D may be intermediate rather than slow.

The lag data were processed with a series of computer programs (reference 5) in an attempt to fit them to standard probability density functions (PDF's): normal, long-normal, Poisson, and negative binomial. The data were treated both as individual points and grouped into classes. The normal and log-normal programs work only with grouped data. Table 6 is a matrix of results. Based on the chi-square test, the probability of match between a negative binomial PDF and test data lies between 10 and 50 percent. This is what is signified by the notation .5 .2 .1. The lags to start of turn are fitted reasonably well by a negative binomial distribution of mean 35.15 (class number 7.03) seconds and k=4.51 (figure 7).

TABLE 6. FIT OF LAG DATA TO PROBABILITY DISTRIBUTION FUNCTIONS

Statistic / PDF Model	Lag To Start of Turn, Ungrouped	Lag To Start of Turn, Grouped	Lag To First Response, Grouped	LAG TO FIRST RESPONSE SHORT Ungrouped	SHORT Grouped	INTERMEDIATE Ungrouped	INTERMEDIATE Grouped	LONG Ungrouped	LONG Grouped
Negative Binomial	Accept $.5>\alpha_{\chi^2}>.1$	Accept $.5>\alpha_{\chi^2}>.1$	Reject	Reject $.025>\alpha_{\chi^2}>.1$	? $.05>\alpha_{\chi^2}>.025$	Reject	Reject	Accept $.5>\alpha_{\chi^2}>.1$	Reject
Poisson	Reject	Reject	Reject	Reject	? $.1>\alpha_{\chi^2}>.05$	Reject	Accept $.5>\alpha_{\chi^2}>.1$	Reject	Accept $.957>\alpha_{\chi^2}>.9$
Normal	-	Reject	-	-	Reject	-	Reject	-	Accept $.5>\alpha_{\chi^2}>.1$
Log Normal	-	? $.1>\alpha_{\chi^2}>.05$	-	-	Reject	-	Reject	-	Accept $.5>\alpha_{\chi^2}>.1$

NOTE: (-) indicates missing data

There was no match of lag to first response (figure 6). When the three components of first response were separated, as discussed before, a Poisson PDF provided a questionable (probability of fit between 5 percent and 10 percent) fit to the fast component (mean = 12.9 seconds), a fair (probability of fit between 10 and 50 percent) fit to the intermediate component (mean = 32.8 seconds), and an excellent (probability of fit between 90 and 97.5 percent) fit to the slow component (mean = 50.4 seconds). This was for 5-second groupings of the data. The three components of first response could not be fitted to the ungrouped data. Neither normal nor log-normal PDF's could be fitted to the data, except in one case (slow, grouped lag to first response) where the Poisson PDF was clearly superior.

MAIN EXPERIMENT. Figures 8 through 15 are composite plots of the pilots' performance over each of the data routes. Each plot consists of four superimposed tracks, generated by the pilots of group 1 (3D RNAV) or group 2 (2D RNAV). There are separate plots for each of the four data routes, A, B, C, and D. The effects of the RNAV-Flight Director interface incompatibility are apparent at turns and transitions.

The stepwise multiple linear regression program was used to fit the experimental data to a linear model of TSCT as a function of eight variables.

When a model was constructed which regressed all eight variables on TSCT, the result was either TSCT = NSE + FTE (78 percent of runs), or the program was terminated because of the occurrence of a singularity (22 percent of runs). (See table 7.) This was to be expected. In effect, the computer was given a closed solution, since NSE was a calculated variable. If any other answer than TSCT = NSE + FTE resulted, the computer program would be suspect.

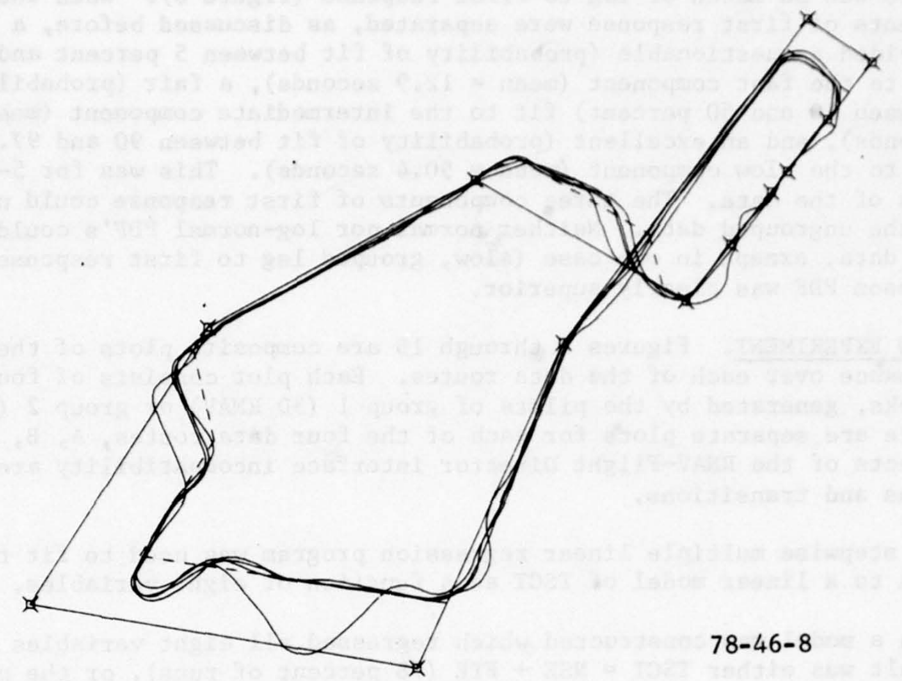
The regression program was also run for each case with NSE omitted from the set of candidate independent variables. Table 7 is a summary of the results of the regressions. Detailed breakdowns of the individual correlation matrices and other statistical data for each computer run can be found in appendix C. Table 8 contains the statistical data for the grand total of all the data sets analyzed in this experiment.

DETAILED RESULTS. The regression coefficient of the CDI needle displacement is approximately -1.0 nautical miles (mean = -1.000056 nautical miles, σ=0.06098 nautical miles). This is what one would expect if the RNAV system were performing properly, since CDI would then be minus TSCT.

The OBS setting error coefficient varies with route, type of course segment (centerline or offset), and with type of guidance (2D or 3D). Its contribution is always negative and ranges from -0.968 OBS error to -0.0563 OBS error.

The indicated airspeed (KIAS) coefficient makes a contribution to the linear model of TSCT error.

Only 3 of the 37 models include BSB as a variable in the final linear model; only 11 of the 37 models include PSB. In general, the BSB and PSB needle displacements do not constitute major components of the linear models.



78-46-8

FIGURE 8. COMPOSITE PLOT OF GROUND TRACK, ROUTE A, 2D GUIDANCE

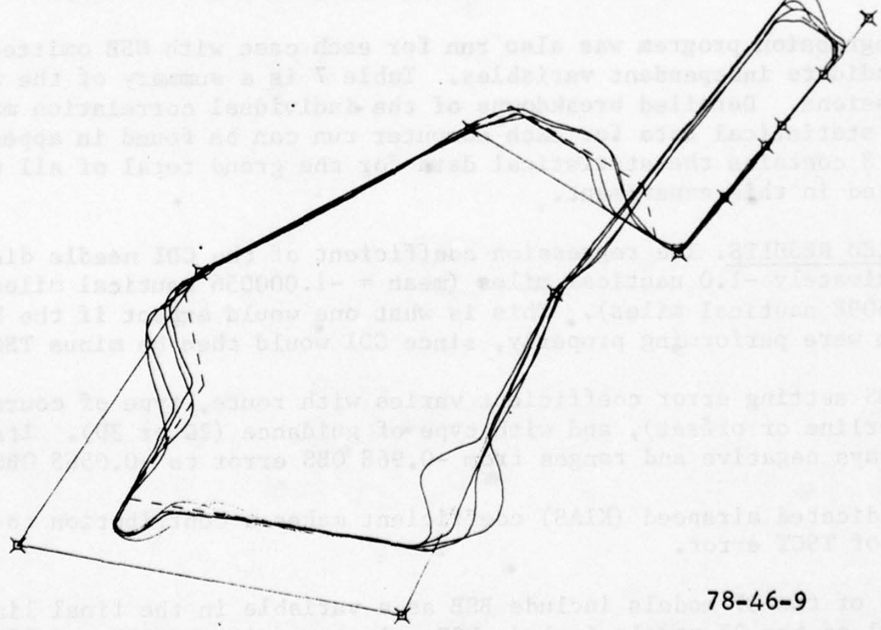


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FIGURE 9. COMPOSITE PLOT OF GROUND TRACK, ROUTE A, 3D GUIDANCE

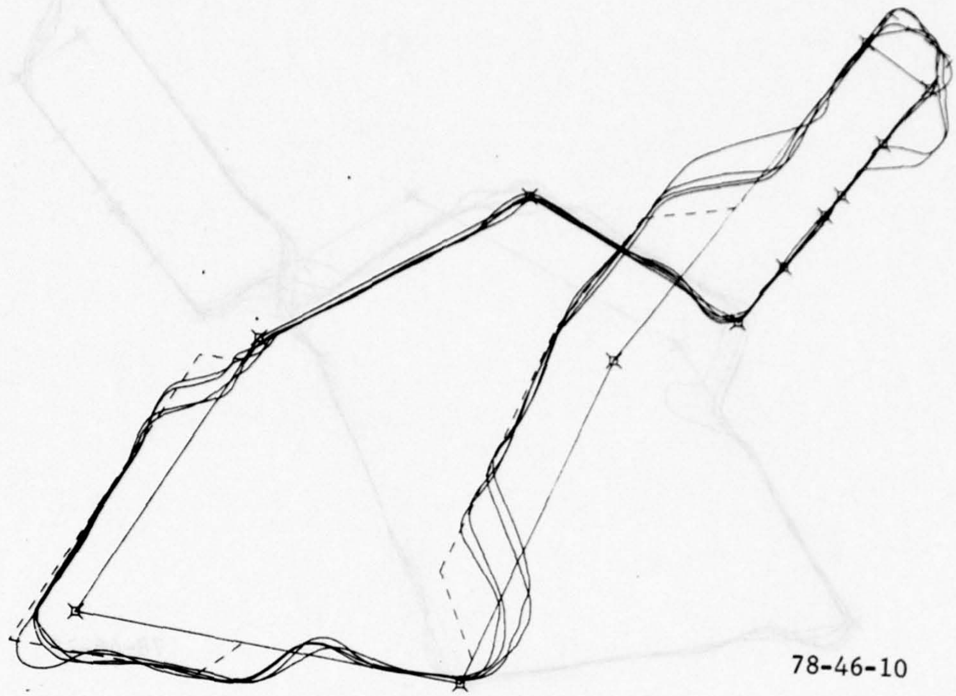

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FIGURE 10. COMPOSITE PLOT OF GROUND TRACK, ROUTE B, 2D GUIDANCE

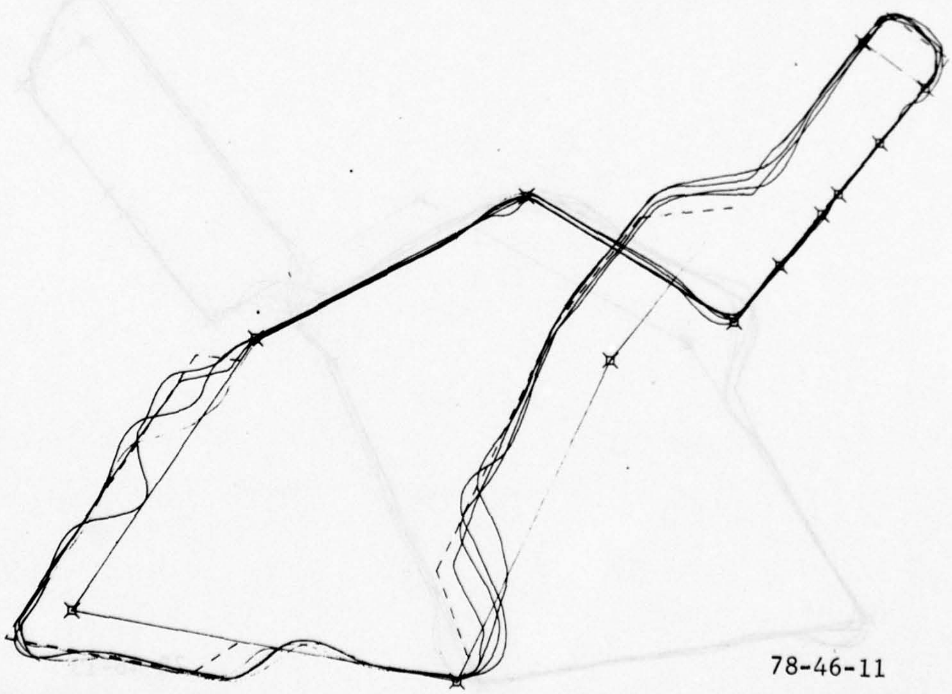

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FIGURE 11. COMPOSITE PLOT OF GROUND TRACK, ROUTE B, 3D GUIDANCE

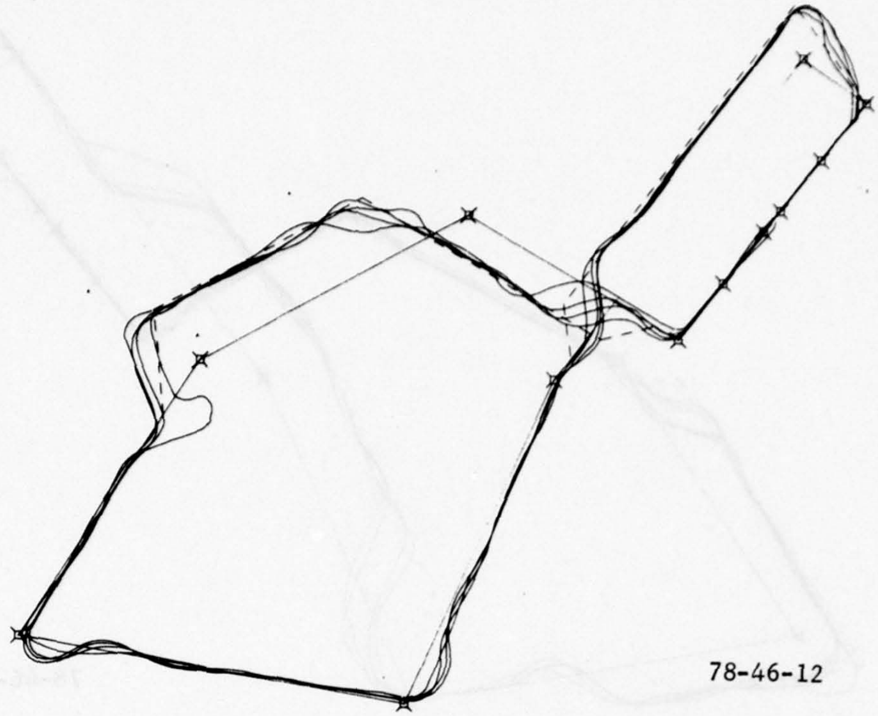


FIGURE 12. COMPOSITE PLOT OF GROUND TRACK, ROUTE C, 2D GUIDANCE

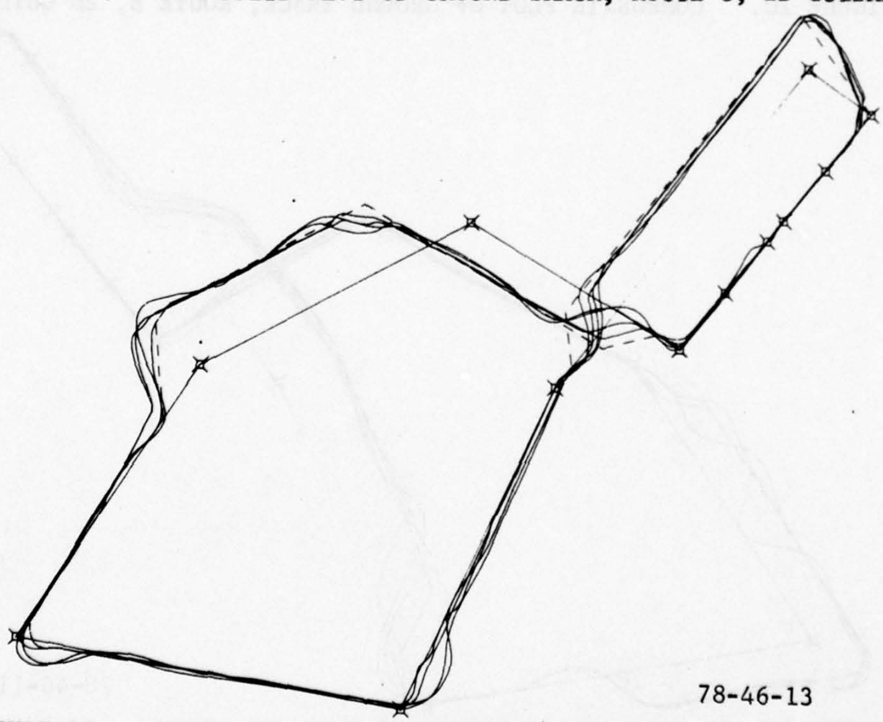
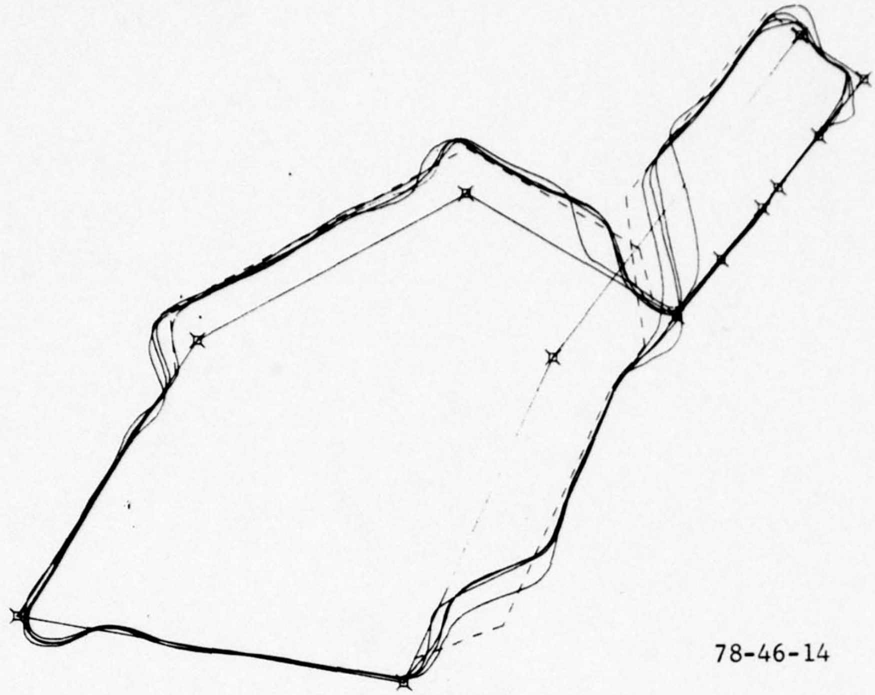


FIGURE 13. COMPOSITE PLOT OF GROUND TRACK, ROUTE C, 3D GUIDANCE



78-46-14

FIGURE 14. COMPOSITE PLOT OF GROUND TRACK, ROUTE D, 2D GUIDANCE

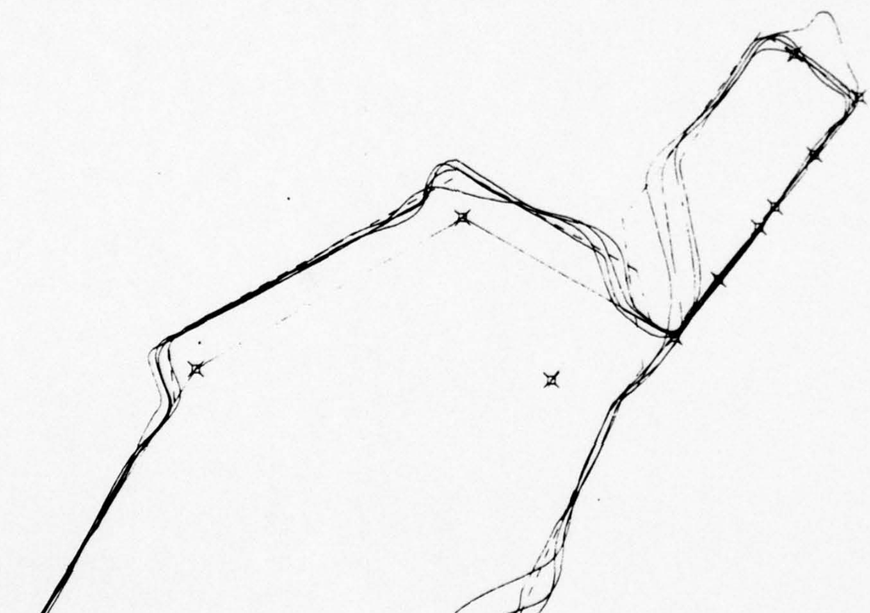


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FIGURE 15. COMPOSITE PLOT OF GROUND TRACK, ROUTE D, 3D GUIDANCE

TABLE 7. REGRESS

Data ROUTE	2 D	3 D	BASE	OFFSET	9-VARIABLES, TSCT=NSE+FTE	CDI (-FTE)	OBS ERR	COEFFICIENT VALUES, 8- BSB	VDI	F
A		X	X		Yes	-1.083	-0.705	-	-	
A		X		X	Yes	- .993	- .279	-	0.00020	
A		X	X	X	Yes	-1.049	- .667	-	-	
A	X		X		Yes	- .876	- .968	-	- .00027	
A	X			X	Yes	-1.047	- .364	-	-	-0.0
A	X		X	X	Yes	-1.046	- .806	-	- .00017	- .0
A	X	X	X		Yes	- .991	- .865	-	-	
A	X	X		X	Yes	-1.054	- .289	-	..00007	- .0
A	X	X	X	X	singularity	-1.054	- .739	-	-	
B		X	X	-	Yes	- .917	- .564	0.00175	-	
B		X		X	Yes	-1.022	- .111	.00410	-	
B		X	X	X	Yes	-1.003	- .357	.00436	-	
B	X		X		singularity	- .946	- .816	-	-	
B	X			X	singularity	- .938	- .194	-	..00031	.0
B	X		X	X	singularity	- .965	- .380	-	.00007	.0
B	X	X	X		Yes	- .936	- .713	-	-	
B	X	X		X	Yes	- .997	- .161	-	.00014	.0
B	X	X	X	X	Yes	- .981	- .372	-	.00009	
C		X	X		Yes	-1.105	- .440	-	.00023	
C		X		X	Yes	- .945	- .647	-	-	
C		X	X	X	Yes	-1.004	- .445	-	-	
C	X		X		Yes	-1.044	- .382	-	-	.0
C	X			X	Yes	- .954	- .817	-	.00014	
C	X		X	X	Yes	- .998	- .481	-	.00006	.0
C	X	X	X		Yes	-1.058	- .401	-	. -	.0
C	X	X		X	Yes	- .963	- .752	-	.00014	
C	X	X	X	X	singularity	-1.005	- .465	-	.00009	
D	X		X		singularity	- .965	-	-	-	.0
D	X			X	Yes	-1.174	- .899	-	.00017	
D	X		X	X	Yes	-1.015	- .402	-	.00006	
D		X	X		singularity	- .992	- .130	-	.00010	
D		X		X	singularity	- .919	- .561	-	.00030	
D		X	X	X	Yes	- .967	- .406	-	-	
D	X	X	X		Yes	- .974	- .056	-	-	
D	X	X		X	Yes	-1.031	- .754	-	-	
D	X	X	X	X	Yes	- .991	- .404	-	.00005	
A,B,C,D	X	X	X	X	Yes	-1.012	- .494	-	.00006	

SION RESULTS

3-VARIABLE PSB	IAS	2D TERM	CONS.	1 R^2	PERCENT REDUCED	e	COMMENT
-	0.00481		-0.675	0.963	92.6	0.114	
-	-	-	.0120	.950	90.3	.143	
-	-	-	.0644	.939	88.2	.148	
-	.00577	-	.693	.950	90.2	..153	
.0179	.0112	-	-1.854	.940	88.5	.189	
.0104	-	-	- .135	.908	82.5	.212	
-	-	-	.0499	.943	88.9	.152	
.0183	.00231	-	- .351	.940	88.4	.173	
-	.00212	-0.0498	- .260	.919	84.4	.185	
-	.00327	-	- .444	.889	79.1	.101	
-	00233	-	- .253	.879	80.4	.190	
-	.00382	-	- .540	.872	76.0	.165	
-	-	-	.0263	.921	84.9	.150	
.0150	.00613	-	- .672	.727	52.9	261	Poor match
.00627	.00218	-	- .293	.792	62.7	.239	Only fair match
-	.00132	- .0564	- .135	.903	81.5	.135	
0131	.00383	-	- .460	.829	68.7	.229	
-	.00298	-	- .398	.829	68.8	.205	
-	.0106	-	-1.57	.869	75.5	.183	
-	.00265	-	- .315	.964	92.9	.105	
-	.0081	-	-1.17	.899	80.8	.167	
0167	.00398	-	- .617	.788	62/0	.277	Only fair match
-	.00393	-	.815	.921	84.9	.165	
0116	.0019	-	- .219	.815	66.5	.258	
0107	.0082	- .108	-1.192	.818	66.9	.236	
-	-	.0735	.0914	.938	87.9	.143	
-	.0063	-	- .894	.849	72.1	.218	
0760	- .00210	-	.231	.893	79.8	.168	
-	- .00829	-	1.594	.919	84.5	.168	
-	.00140	-	- .190	.797	63.6	.240	Fair
-	-		- .0489	.883	78.0	.148	
-	.00778	-	-1.156	.955	91.3	.110	
-	.00426	-	- .640	.858	73.6	.174	
-	- .00154	-	.162	.885	78.4	.160	
-	-154	-	.067	.908	82.5	.168	
-	.00290	-	- .435	.821	67.3	.211	Fair
-	.00391	-	- .546	.852	72.5	.214	Grand Total

TABLE 8. SUMMARY STATISTICAL DATA

A. Statistical Data, 74,057 Samples

Variable	Mean	Std. Dev.
TSCT	0.0741	0.409
FTE(CDI)	-.0665	.295
NSE	.00801	.295
OBSE	.0451	.394
BSB	4.661	4.947
VDI	-434.2	516.2
PSB	.453	.734
KLAS	154.15	16.48
2D/3D Flag	.484	.500

B. Comparison of TSCT and RSC, 1 Value

TSCT	0.409
RSS_1	.417
BSS_2	.492
RCS_3	.499

Analysis of table 7 leads to the conclusion that the root sum square (RSS) of the standard deviations of the components of TSCT is an over-conservative estimator of the standard deviation of TSCT.

Three RSS measures were evaluated: RSS_1, the root of the sum of the squares of $\sigma_{FTE} + \sigma_{NSE}$ standard deviations; RSS_2, the root of the sum of the squares of CDI and OBS standard deviations; and RSS_3, the root of the sum of the squares of CDI, OBS, and VDI (converted to nautical mile deviations). In all 37 cases, RSS_2 and RSS_3 were greater than RSS_1. In 28 cases, RSS_1 was greater than TSCT; in 2 cases, they were equal; and in 7 cases, TSCT was greater than RSS_1.

When the null hypothesis, "The distributions of RSS_1 and TSCT are equal, hence RSS is a good estimator of TSCT," was subjected to the nonparametric sign test (reference 6), the "z" score of 3.39 led to rejection at the p=.0003 level. In other words, the standard deviation of TSCT is less than the RSS of the component standard deviations, with a confidence on the order of 99.97 percent.

The components of TSCT are usually assumed to be statistically independent. If this is true, the square root of the sum of the squares of the deviations of the components from their means (termed "root sum square" and symbolized by RSS) would be a conservative estimator of the standard deviation of TSCT. However, if the components were not independant, RSS would be an over-conservative estimator of the variability of TSCT.

We conclude that the parameters that make up TSCT are not independent.

PHASE II: WITHOUT FLIGHT DIRECTOR

PHASE II PROCEDURES.

SUBJECTS. Eight subjects were chosen from the Flight Inspection Field Office (FIFO) at NAFEC. The subjects were assigned to the tests based on their availability from their regular duties. All subjects were professional pilots for the FAA with current flight assignments. Some subjects had prior experience with this RNAV system either in the GAT-2B/XDS-530 facility or in FAA RNAV-equipped aircraft. All subjects were required to complete four familiarization flights designed to acquaint them with route structures and procedures similar to those to be used in the data collection flights. None of the subjects indicated a need for additional familiarization flights. Table 9 is a summary of the subjects' qualifications.

TABLE 9. SUMMARY OF PHASE II PILOT QUALIFICATIONS

Subject	Group	License	Total Hours	Instrument Time	Previous GAT-2 Time	Previous RNAV Time
1	1	ATR*	3,700	600	0	40
2	1	COMM.**	2,800	300	0	0
3	1	ATR	2,900	400	25	25
4	1	ATR	10,216	450	25	35
1	2	ATR	14,000	1,500	0	10
2	2	COMM.	2,200	300	0	0
3	2	COMM.	1,800	220	0	0
4	2	COMM.	1,600	320	0	0

* ATR - Air Transport Rating
** COMM. - Commercial Rating

All pilots were given instructions regarding experimental objectives, use of the navigational equipment, and specific flight task requirements. The eight subject pilots were divided into two groups of four. Group 1 flew the route structures using the 3D RNAV mode, while group 2 flew the route structures using 2D mode.

Instructions stressed adherence to specific airspeeds which were designated for climb, cruise, descent, and final approach. These airspeeds were also placarded on the instrument panel of the simulator. In addition, the route geometry was discussed, and route charts and approach plates were given to the pilots. The pilots were also instructed to perform turn anticipation. One method of turn anticipation was suggested, but the choice of method was left to each pilot's discretion.

After completing the preliminary instructions, each pilot was given four familiarization flights on a route similar to the data route. To complement both the familiarization and data flights, prepared voice scenarios were given to direct the pilots throughout the preplanned 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. Familiarization and data flights were flown in a solo mode, without a copilot. During the 2D mode of operation, the flight director mode switch was put in the "gyro" position, and the flight director provided only basic pitch and roll guidance. The VNAV button of the RNAV system was not activated, which precluded the insertion of altitude and FPA for flying a vertical flight profile. All maneuvering was performed manually by the pilot.

STATISTICAL TREATMENT. Steady state tracking data (i.e., data independent of turning at waypoint intersections and independent of tuning new waypoint locations) were extracted from the data base for each run. These data were defined by an envelope ±2 nautical miles before and after a waypoint. This envelope was sufficiently large that it encompassed all activities related to transitions from one segment to the next segment. These data were then edited for erroneous data (i.e., spikes in CDI deflection, electrical transients, RNAV computer failures, etc.). The data were then statistically processed to obtain means ($\overline{X}$) and standard deviations (σ) for each segment of the route structure flown. All data exceeding ±2 nautial miles about the centerline were treated as blunders and were rejected from the statistical processing.

It should be noted that there was no VOR/DME error model employed during these tests; therefore, there were no ground signal errors or airborne receiver errors transmitted to the RNAV system. Thus, all tracking errors can be attributed to the navigation equipment or FTE.

Horizontal (crosstrack) error is defined as TSCT. FTE is a contributing factor to TSCT. TSCT represents the actual deviations left or right of course while flying to a waypoint. For purposes of analysis, deviations to the right of course are indicated as positive, whereas deviations to the left of course are indicated as negative, and as such, represent the actual aircraft position as it would have been tracked in flight. FTE represents the actual displacement of the CDI needle left or right of course while flying to a waypoint, and is affected by the accuracy with which the pilot sets his OBS (as well as the VOR, DME, true airspeed (TAS), and altitude reference signals). Displacements of the CDI needle to the right (i.e., actual position left of course) are indicated in the data as positive, whereas displacements to the left (actual position right of course) are indicated in the data as negative (for analysis purposes only), and as such, represent the amount by which the pilot must correct his actual position in the direction of the needle displacement in order to be on course. Therefore, if the pilot is off course, there should exist a high negative correlation between TSCT and FTE.

DATA REDUCTION AND ANALYSIS. The analytic tool used for this evaluation was a computerized stepwise multiple linear regression program (references 7 and 8). This program was used to determine the dependence of TSCT on five parametric independent variables previously described in the section which contained the Data Reduction and Analysis plan for Phase I.

1. Flight Technical Error (FTE),
2. Navigation System Error (NSE),
3. OBS Setting Error (OBS SET),
4. Vertical Deviation Error (VDI),
5. Indicated Airspeed (KIAS).

A sixth independent variable was created in order to determine if horizontal tracking under the 2D RNAV mode was different than under the 3D RNAV mode. This variable consisted of a vector of 1's and 0's. The value of 0 was assigned to the 3D RNAV mode condition and the value of 1 was assigned to the 2D RNAV mode. These values acted as "flags" during the calculation of the regression equation.

The stepwise regression program described in Phase I was used to produce the regression models presented in Phase II.

PHASE II RESULTS.

Table 10 presents stepwise regression models evaluated in this section.

ROUTE A. Tables 11 through 14 present the statistical summary data for the Route A configuration. The data in these tables are divided into centerline tracking data, offset tracking data, and combined centerline/and offset tracking data. In addition, the data are presented for the 2D RNAV mode, the 3D RNAV mode, and combined 2D/3D RNAV modes. Figures 16 and 17 present a summary of the horizontal tracking patterns for all data runs in this configuration. Tables 11a, 12a, and 13a present the means and standard deviations for the centerline, offset, and combined centerline/offset configurations. Tables 11b, 12b, and 13b present RSS calculations and the comparative actual TSCT values for the same three configurations. Tables 11c, 12c, and 13c present the correlation matrices obtained from the data variables collected under the same three configurations. Table 14 presents the results of the stepwise regression analysis performed on each of the nine regression models for the Route A configuration. Figure 16 presents the TSCT data for the 2D RNAV mode and figure 17 presents the TSCT data for the 3D RNAV mode.

The data in tables 11, 12, and 13 indicate that the use of RNAV produced very accurate course following for both centerline and offset tracking. The overall TSCT (1σ) values (tables 11b and 12b) ranged between 0.326 and 0.389 nautical miles for the centerline tracking, between 0.476 and 0.553 nautical miles for the offset tracking, and between 0.404 and 0.413 nautical miles for the combined centerline/offset tracking. The overall FTE (1σ) values (tables 11a and 12a) ranged between 0.284 and 0.304 nautical miles for the centerline tracking, between 0.374 and 0.494 nautical miles for the offset tracking, and between 0.312 and 0.372 nautical miles for the combined centerline/offset tracking.

TABLE 10. STEPWISE REGRESSION MODELS

	ROUTE	RNAV MODE	TRACKING CONFIGURATION	Regression SET No.	SEGMENTS
1.	A	2D	Centerline	(1.)	1,2,4,7,8
2.	A	2D	Offset	(2.)	3(3R); 5(5L); 6(5L)
3.	A	2D	Centerline + Offset		(1.)+(2.)
4.	A	3D	Centerline	(3.)	1,2,4,7,8
5.	A	3D	Offset	(4.)	3(3R); 5(5L); 6(5L)
6.	A	3D	Centerline + Offset		(3.)+(4.)
7.	A	2D + 3D	Centerline		(1.)+(3.)
8.	A	2D + 3D	Offset		(2.)+(4.)
9.	A	2D + 3D	Centerline + Offset		(1.),(2.),(3.)+(4.)
10.	B	2D	Centerline	(5.)	1,2,3,4,6,8
11.	B	2D	Offset	(6.)	5(3R); 6(3R); 7(5L);8(5L);9(3L)
12.	B	2D	Centerline + Offset		(5.)+(6.)
13.	B	3D	Centerline	(7.)	1,2,3,4,6,8
14.	B	3D	Offset	(8.)	5(3R); 6(3R); 7(5L);8(5L);9(3L)
15.	B	3D	Centerline + Offset		(7.)+(8.)
16.	B	2D + 3D	Centerline		(5.)+(7.)
17.	B	2D + 3D	Offset		(6.)+(8.)
18.	B	2D + 3D	Centerline + Offset		(5.), (6.), (7.) + (8.)
19.	C	2D	Centerline	(9.)	1,2,5,6,7
20.	C	2D	Offset	(10.)	3(3L); 4(5R); 8(3L)
21.	C	2D	Centerline + Offset		(9.)+(10.)
22.	C	3D	Centerline	(11.)	1,2,5,6,7
23.	C	3D	Offset	(12.)	3(3L); 4(5R); 8(3L)
24.	C	3D	Centerline + Offset		(11.) + (12.)
25.	C	2D + 3D	Centerline		(9.) + (11.)
26.	C	2D + 3D	Offset		(10.) + (12.)
27.	C	2D + 3D	Centerline + Offset		(9.), (10.), (11.) + (12.)
28.	D	2D	Centerline	(13.)	1,2,5,6,9,10
29.	D	2D	Offset	(14.)	3(3R);4(3R); 7(5R); 8(3L)
30.	D	2D	Centerline + Offset		(13.) + (14.)
31.	D	3D	Centerline	(15.)	1,2,5,6,9,10
32.	D	3D	Offset	(16.)	3(3R); 4(3R); 7(5R); 8(3L)
33.	D	3D	Centerline + Offset		(15.) + (16.)
34.	D	2D + 3D	Centerline		(13.) + (15.)
35.	D	2D + 3D	Offset		(14.) + (16.)
36.	D	2D + 3D	Centerline + Offset		(13.), (14.), (15.)+(16.)

TABLE 11a. STATISTICAL DATA FOR ROUTE A CONFIGURATION--2D MODE

	BASE COURSE			OFFSET COURSE			BASE AND OFFSET COURSE		
	No. SAMPLES	MEAN	1 SIGMA	No. SAMPLES	MEAN	1 SIGMA	No. SAMPLES	MEAN	1 SIGMA
TSCT	5,979	0.254	0.382	2,243	0.148	0.476	8,222	0.225	0.413
FTE	5,979	-.176	.284	2,243	-.204	.375	8,222	-.183	.312
NSE	5,979	.078	.299	2,243	-.056	.312	8,222	.042	.308
OBS SET	5,979	-.069	.346	2,243	.088	.369	8,222	-.026	.358

TABLE 11b. COMPARATIVE 1-SIGMA RSS VALUES AND ACTUAL --ROUTE A--2D MODE

BASE COURSE		OFFSET COURSE		BASE AND OFFSET COURSE	
RSS[1] TOTAL ERROR	ACTUAL TSCT ERROR	RSS TOTAL ERROR	ACTUAL TSCT ERROR	RSS TOTAL ERROR	ACTUAL TSCT ERROR
0.412	0.382	0.487	0.476	0.438	0.413

1 RSS-$(\sigma^2_{FTE} + \sigma^2_{NSE})^{1/2}$

TABLE 11c. CORRELATION MATRIX--ROUTE A--2D MODE

	BASE COURSE			OFFSET COURSE			BASE AND OFFSET COURSE		
	FTE	NSE	OBS SET	FTE	NSE	OBS SET	FTE	NSE	OBS SET
TSCT	-0.633	0.677	-0.523	-0.757	0.616	-0.146	-0.670	0.660	-0.408
FTE		.141	-.136		.050	-.261		.115	-.183
NSE			-.798			-.537			-.731

Note: Negative values represent distances to the left of the centerline and positive values represent distances to the right of centerline measured in nautical miles.

TABLE 12a. STATISTICAL DATA FOR ROUTE A CONFIGURATION--3D MODE

	BASE COURSE			OFFSET COURSE			BASE AND OFFSET COURSE		
	No. SAMPLES	MEAN	1 SIGMA	No. SAMPLES	MEAN	1 SIGMA	No. SAMPLES	MEAN	1 SIGMA
TSCT	6,252	0.235	0.326	2,499	0.239	0.553	8,752	0.236	0.404
FTE	6,252	-.131	.304	2,499	-.204	.494	8,752	-.162	.372
NSE	6,252	.104	.228	2,499	-.001	.344	8,752	.074	.271
OBS SET	6,252	-.076	.298	2,499	-.015	.383	8,752	-.059	.326

TABLE 12b. COMPARATIVE 1-SIGMA RSS VALUES AND ACTUAL TSCT --ROUTE A--3D MODE

BASE COURSE		OFFSET COURSE		BASE AND OFFSET COURSE	
RSS[1] TOTAL ERROR	ACTUAL TSCT ERROR	RSS TOTAL ERROR	ACTUAL TSCT ERROR	RSS TOTAL ERROR	ACTUAL TSCT ERROR
0.380	0.326	0.602	0.553	0.460	0.404

1 RSS-$(\sigma^2_{FTE} + \sigma^2_{NSE})^{1/2}$

TABLE 12c. CORRELATION MATRIX--ROUTE A--3D MODE

	BASE COURSE			OFFSET COURSE			BASE AND OFFSET COURSE		
	FTE	NSE	OBS SET	FTE	NSE	OBS SET	FTE	NSE	OBS SET
TSCT	-0.739	0.442	-0.299	-0.790	0.473	-0.017	-0.759	0.449	-0.149
FTE		.277	-.196		.167	-.457		.240	-.320
NSE			-.688			-.629			-.662

Note: Negative values represent distances to the left of the centerline and positive values represent distances to the right of centerline measured in nautical miles.

TABLE 13a. STATISTICAL DATA FOR ROUTE A CONFIGURATION--2D/3D MODE

	BASE COURSE			OFFSET COURSE			BASE AND OFFSET COURSE		
	No. SAMPLES	MEAN	1 SIGMA	No. SAMPLES	MEAN	1 SIGMA	No. SAMPLES	MEAN	1 SIGMA
TSCT	12,231	0.244	0.355	4,741	0.195	0.520	16,973	0.231	0.408
FTE	12,231	-.153	.295	4,741	-.223	.442	16,973	-.173	.344
NSE	12,231	.091	.267	4,741	-.027	.330	16,973	.058	.291
OBS SET	12,231	-.073	.322	4,741	-.034	.380	16,973	-.043	.342

TABLE 13b. COMPARATIVE 1-SIGMA RSS VALUES AND ACTUAL TSCT--ROUTE A--2D/3D MODE

BASE COURSE		OFFSET COURSE		BASE AND OFFSET COURSE	
RSS[1] TOTAL ERROR	ACTUAL TSCT ERROR	RSS TOTAL ERROR	ACTUAL TSCT ERROR	RSS TOTAL ERROR	ACTUAL TSCT ERROR
0.398	0.355	0.552	0.520	0.451	0.408

1 RSS-$(\sigma^2_{FTE} + \sigma^2_{NSE})^{1/2}$

TABLE 13c. CORRELATION MATRIX--ROUTE A--2D/3D MODE

	BASE COURSE			OFFSET COURSE			BASE AND OFFSET COURSE		
	FTE	NSE	OBS SET	FTE	NSE	OBS SET	FTE	NSE	OBS SET
TSCT	-0.680	0.579	-0.425	-0.776	0.535	-0.063	-0.714	0.559	-0.283
FTE		.206	-.165		.118	-.367		.184	-.255
NSE			-.751			-.592			-.702

Note: Negative values represent distances to the left of the centerline and positive values represent distances to the right of centerline measured in nautical miles.

TABLE 14. STEPWISE REGRESSION ANALYSIS--ROUTE A

Data Route	2D	3D	Base	Offset	Intercept	CDI	OBS SET	VDI	Airspeed (mach)	NSE	R^2 (units)	Remarks
					Coefficients (Beta Weights)							
A	X		X		0.03674	-0.96509	-0.68885				0.882	(0.779 Reduced)
A	X			X	-3.41540	-1.10014	- .61045		.02128		.907	(.823 Reduced)
A	X		X	X	- .71236	-1.01644	- .63647		.00465		.868	(.753 Reduced)
A		X			- .50432	- .82314	- .41756		.00390		.875	(.765 Reduced)
A		X		X	-1.12341	-1.19889	- .68924		.00690		.897	(.804 Reduced)
A		X	X	X	- .35624	- .96481	- .50859		.00264		.868	(.754 Reduced)
A	X	X	X		.05833	- .92593	- .60882				.871	(.759 Reduced)
A	X			X	-1.34350	-1.16233	- .61855		.00831		.885	(.885 Reduced)
A	X	X	X	X	- .40160	- .99023	- .57977		.00280		.864	(.864 Reduced)

NOTE: Negative values represent distances to the left of the centerline and positive values represent distances to the right of centerline measured in nautical miles.

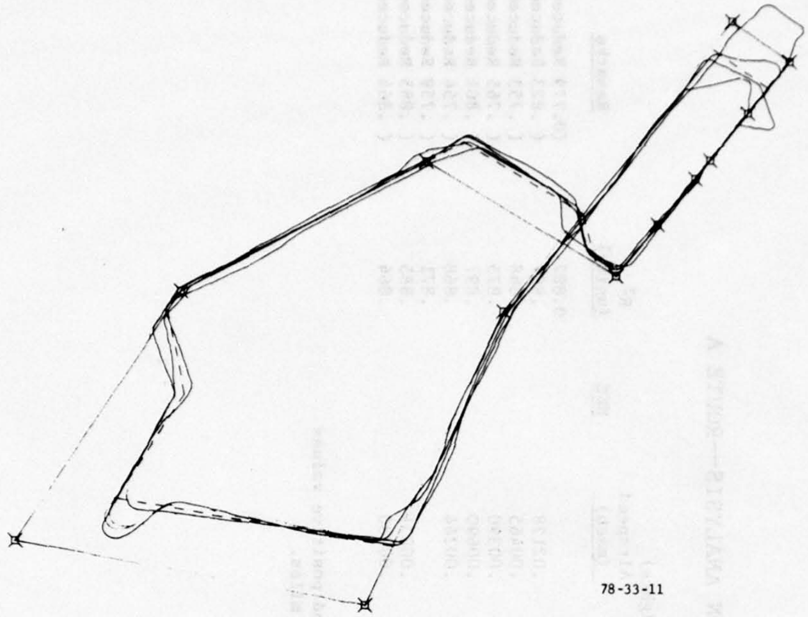

FIGURE 16. COMPOSITE PLOT OF GROUND TRACK, ROUTE A, 2D GUIDANCE

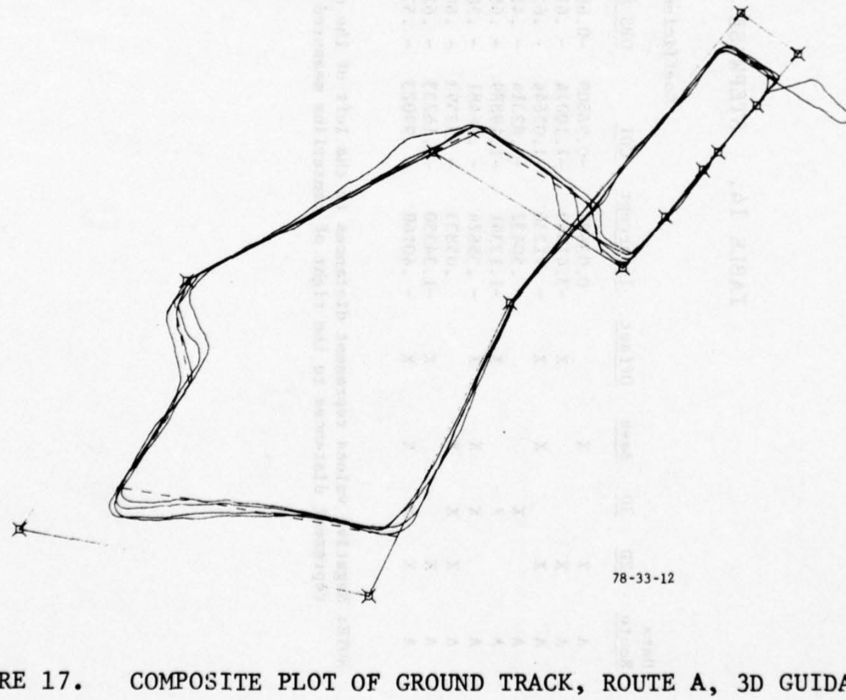

FIGURE 17. COMPOSITE PLOT OF GROUND TRACK, ROUTE A, 3D GUIDANCE

The RSS calculations (tables 11b and 12b) for the two-component model (σFTE + NSE) produced comparable TSCT error values.

The product moment correlation coefficients between the TSCT, FTE, NSE, and OBS SET time series data were calculated in order to determine if there was any consistent interaction among these parameters. These correlation coefficents are presented in tables 11c, 12c, and 13c. From these tables, it can be seen that the overall correlation coefficient between TSCT and FTE resulted in a high negative correlation ranging between -0.633 and -0.790. These high negative correlation coefficient values indicate that TSCT and FTE operated in the predicted manner. That is, as the aircraft proceeded further off course in one direction, the CDI needle moved in the opposite direction; and conversely, as the aircraft converged toward the course centerline, the CDI needle also converged to the center of the display. NSE, on the other hand, has a high positive correlation with TSCT. This correlation was expected because NSE is defined as the difference between TSCT and FTE.

The correlation matrices in the tables are the basic input to the stepwise regression program. Since the program selects the highest correlated variables first, the initial regression model was calculated to be TSCT = NSE + FTE, which produced a cumulative proportion (sum of squares) reduced of 0.999 and a multiple correlation coefficient (for the linear model) of 0.999. This model ignored any contribution of the other three (or four) variables in the model.

Since NSE was not a measured variable, it was decided to remove this variable from the regression model and to reevaluate the model once again. The results of these new models are presented in table 14. From table 14, it can be seen that for the nine models evaluated, the cumulative (sum of squares) proportion reduced ranged from 0.747 to 0.823 and the multiple correlation coefficient ranged from 0.864 to 0.907. Since both the cumulative proportion that is reduced and the multiple correlation coefficient are based on a scale from 0 to 1, the high values obtained indicate that the final linear models obtained from the regression represent a good fit to the data.

From table 14, it can be seen that two major variables can be used to predict TSCT error. These variables are (1) FTE and (2) OBS SET. A third variable, airspeed, enters as a minor variable; however, its importance has not been determined, and it may represent a workload item or may reflect the difficulty in performing a multi-axis tracking task. From the obtained regression model, it is apparent that OBS set does constitute an important variable for the horizontal tracking task, and, in fact, is nearly as important as the FTE parameter.

This type of setting error is inherent in analog OBS entry systems and is not unique to area navigation; it is present in VOR navigation systems as well. The causes of these errors are the approximations inherent in analog input and the system calibration tolerance for OBS alignment.

ROUTE B. Tables 15 through 18 present the statistical summary data for the Route B configuration. The data in tables 15, 16, and 17 indicate that the use of RNAV produced accurate course following for both centerline and offset tracking on this route structure. The overall TSCT (1σ) values ranged between

TABLE 15a. STATISTICAL DATA FOR ROUTE B CONFIGURATION--2D MODE

	BASE COURSE			OFFSET COURSE			BASE AND OFFSET COURSE		
	No. SAMPLES	MEAN	1 SIGMA	No. SAMPLES	MEAN	1 SIGMA	No. SAMPLES	MEAN	1 SIGMA
TSCT	7,080	0.069	0.335	3,601	-0.081	0.331	10,681	0.018	0.341
FTE	7,080	-.022	.196	3,601	-.071	.271	10,681	-.009	.228
NSE	7,080	.047	.253	3,601	-.010	.219	10,681	.027	.244
OBS SET	7,080	-.062	.218	3,601	-.013	.514	10,681	-.037	.349

TABLE 15b. COMPARATIVE 1-SIGMA RSS VALUES AND ACTUAL TSCT--ROUTE B--2D MODE

BASE COURSE		OFFSET COURSE		BASE AND OFFSET COURSE	
RSS[1] TOTAL ERROR	ACTUAL TSCT ERROR	RSS TOTAL ERROR	ACTUAL TSCT ERROR	RSS TOTAL ERROR	ACTUAL TSCT ERROR
0.320	0.335	0.348	0.331	0.334	0.341

1 RSS-$(\sigma^2_{FTE} + \sigma^2_{NSE})^{1/2}$

TABLE 15c. CORRELATION MATRIX--ROUTE B--2D MODE

	BASE COURSE			OFFSET COURSE			BASE AND OFFSET COURSE		
	FTE	NSE	OBS SET	FTE	NSE	OBS SET	FTE	NSE	OBS SET
TSCT	-0.662	0.813	-0.583	-0.751	0.580	-0.646	-0.700	0.742	-0.527
FTE		.102	.084		.102	-.295		-.042	.184
NSE			-.709			.609			.565

Note: Negative values represent distances to the left of the centerline and positive values represent distances to the right of centerline measured in nautical miles.

TABLE 16a. STATISTICAL DATA FOR ROUTE B CONFIGURATION--3D MODE

	BASE COURSE			OFFSET COURSE			BASE AND OFFSET COURSE		
	No. SAMPLES	MEAN	1 SIGMA	No SAMPLES	MEAN	1 SIGMA	No. SAMPLES	MEAN	1 SIGMA
TSCT	5,820	0.097	0.393	3,867	-0.057	0.333	9,687	0.035	0.378
FTE	5,820	-.064	.244	3,867	.010	.294	9,687	-.035	.257
NSE	5,820	.033	.289	3,867	-.047	.236	9,687	.001	.272
OBS SET	5,820	-.085	.259	3,867	-.176	.309	9,687	-.019	.308

TABLE 16b. COMPARATIVE 1-SIGMA RSS VALUES AND ACTUAL TSCT--ROUTE B--3D MODE

BASE COURSE		OFFSET COURSE		BASE AND OFFSET COURSE	
RSS[1] TOTAL ERROR	ACTUAL TSCT ERROR	RSS TOTAL ERROR	ACTUAL TSCT ERROR	RSS TOTAL ERROR	ACTUAL TSCT ERROR
0.366	0.393	0.377	0.333	0.374	0.378

1 $RSS=(\sigma^2 FTE + \sigma^2 NSE)1/2$

TABLE 16c. CORRELATION MATRIX--ROUTE B--3D MODE

	BASE COURSE			OFFSET COURSE			BASE AND OFFSET COURSE		
	FTE	NSE	OBS SET	FTE	NSE	OBS SET	FTE	NSE	OBS SET
TSCT	-0.688	0.827	-0.621	-0.724	0.507	0.186	-0.694	0.731	0.179
FTE		-.161	.099		.227	.017		-.018	-.007
NSE			-.769			.283			-.256

NOTE: Negative values represent distances to the left of the centerline and positive values represent distances to the right of center line measured in nautical miles.

TABLE 17a. STATISTICAL DATA FOR ROUTE B CONFIGURATION--2D/3D MODE

	BASE COURSE			OFFSET COURSE			BASE AND OFFSET COURSE		
	No. SAMPLES	MEAN	1 SIGMA	No. SAMPLES	MEAN	1 SIGMA	No. SAMPLES	MEAN	1 SIGMA
TSCT	12,900	0.082	0.363	7,468	-0.069	0.332	20,069	0.023	0.360
FTE	12,900	-.041	.211	7,468	.039	.285	20,069	-.013	.245
NSE	12,900	.040	.271	7,468	-.030	.229	20,069	.010	.256
OBS SET	12,900	.072	.238	7,468	-.087	.428	20,069	-.014	.332

TABLE 17b. COMPARATIVE 1-SIGMA RSS VALUES AND ACTUAL TSCT--ROUTE B--2D/3D MODE

BASE COURSE		OFFSET COURSE		BASE AND OFFSET COURSE	
RSS[1] TOTAL ERROR	ACTUAL TSCT ERROR	RSS TOTAL ERROR	ACTUAL TSCT ERROR	RSS TOTAL ERROR	ACTUAL TSCT ERROR
0.343	0.363	0.366	0.332	0.354	0.360

1 $RSS=(\sigma^2_{FTE} + \sigma^2_{NSE})^{1/2}$

TABLE 17c. CORRELATION MATRIX--ROUTE B--2D/3D MODE

	BASE COURSE			OFFSET COURSE			BASE AND OFFSET COURSE		
	FTE	NSE	OBS SET	FTE	NSE	OBS SET	FTE	NSE	OBS SET
TSCT	-0.673	0.816	0.601	-0.735	0.536	-0.310	-0.703	0.734	-0.357
FTE		-.119	.086		.178	.189		-.028	.105
NSE			-.739			-.214			-.404

NOTE: Negative values represent distances to the left of the centerline and positive values represent distances to the right of centerline measured in nautical miles.

TABLE 18. STEPWISE REGRESSION ANALYSIS--ROUTE B

Data Route	2D	3D	Base	Offset	Intercept	CDI	OBS SET	VDI	Airspeed (mach)	NSE	R^2 (units)	Remarks
					Coefficients (Beta Weights)							
B	X		X		-0.20769	-1.02489	-0.80088		0.00201		0.857	(0.735 Reduced)
B	X			X	- .41518	- .73196	- .30672		.00243		.876	(.767 Reduced)
B	X		X	X	- .27161	- .91730	- .40097		.00205		.817	(.817 Reduced)
B		X	X		- .18582	-1.09742	- .82236		.00180		.887	(.887 Reduced)
B		X		X	- .01159	- .82260	.21349				.751	(.751 Reduced)
B		X		X	- .63916	- .95677	- .22128		.00419		.732	(.536 Reduced)
B		X	X		- .19760	-1.05229	- .81408		.00192		.871	(.871 Reduced)
B		X		X	- .07493	- .82483	- .14759				.759	(.577 Reduced)
												(#7.05026) 2D/3D
B	X	X	X	X	- .41192	- .96420	- .31566		.00268		.770	(.592 Reduced)
												(#7.03610) 2D/3D

NOTE: Negative values represent distances to the left of the centerline and positive values represent distances to the right of centerline measured in nautical miles.

0.335 and 0.393 nautical miles for the centerline tracking, between 0.331 and 0.333 nautical miles for the offset tracking, and between 0.341 and 0.378 nautical miles for the combined centerline/offset tracking. The overall FTE (1σ) values ranged between 0.196 and 0.224 nautical miles for the centerline tracking, between 0.271 and 0.294 nautical miles for the offset tracking, and between 0.228 and 0.257 nautical miles for the combined centerline/offset tracking.

The RSS calculations for the two-component model (σFTE + σNSE) produced comparable TSCT error values.

The correlation coefficients are presented in tables 15c, 16c, and 17c. These tables show that the overall correlation coefficient between TSCT and FTE resulted in a high negative correlation ranging between -0.662 and -0.751. These high negative correlation coefficients indicated that TSCT and FTE operated in the predicted manner.

Table 18 presents the results of the stepwise regression analyses which show that for the nine models evaluated, the cumulative (sum of squares) proportion reduced ranged from 0.536 to 0.787, and the multiple correlation coefficient ranged 0.732 to 0.887. These values are somewhat lower than the Route A values (reference table 7), and, as such, indicate that the obtained linear model does not represent as good a fit to the data as did the Route A linear model. The difference is basically due to the 3D offset tracking data, in that for both sets of offsets, the pilots were required to reach a desired altitude (both descending and ascending) at a point 10 nautical miles along track and were given a clearance to cancel the offset upon reaching the desired altitude. The workload involved in implementing and following the altitude clearance (under the 3D RNAV mode) appears to have increased the amount of variability in the data and resulted in a less precise tracking model. (This problem will be discussed under the section dealing with the altitude data.) The combined 2D/3D RNAV mode for the offset tracking and the combined 2D/3D RNAV mode for the composite centerline/offset tracking linear models both included a regression coefficient term for the 2D/3D effect (independent variable number 6) which reinforced the RNAV mode difference for the offset tracking data.

Table 18 shows that two major variables can be used to predict TSCT error, (1) FTE and (2) OBS SET. A third variable, airspeed, also enters as a minor variable. These findings are the same as those for the Route A data.

Figure 18 presents the TSCT data for the 2D RNAV mode, and figure 19 presents the TSCT data for the 3D RNAV mode.

ROUTE C. Tables 19 through 22 present the statistical summary data for the Route C configuration. The data in tables 19, 20, and 21 indicate that the RNAV system produced accurate course following for both centerline and offset tracking on this route structure. The overall TSCT (1σ) values ranged between 0.345 and 0.409 nautical miles for the centerline tracking, between 0.445 and 0.448 nautical miles for the offset tracking, and between 0.399 and

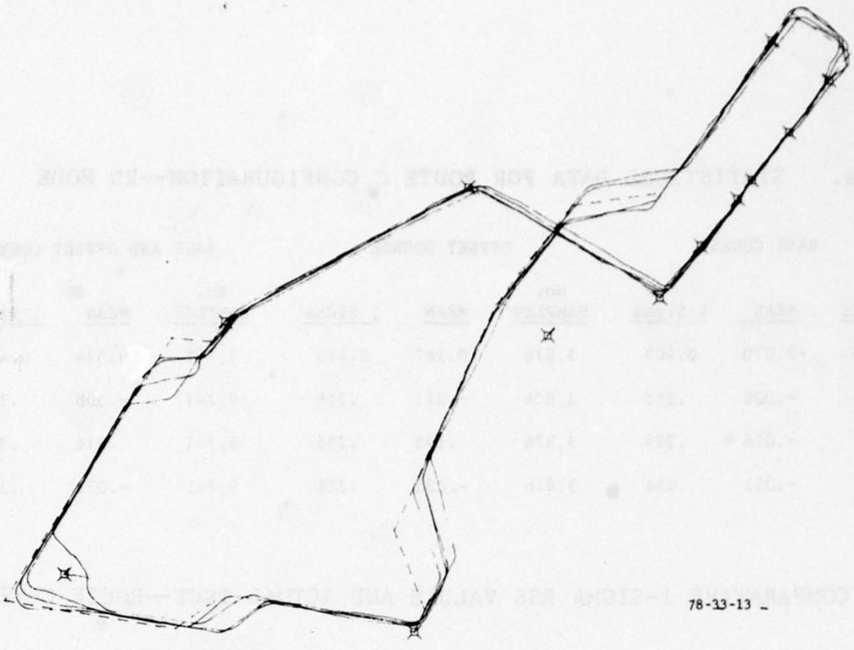

FIGURE 18. COMPOSITE PLOT OF GROUND TRACK, ROUTE B, 2D GUIDANCE

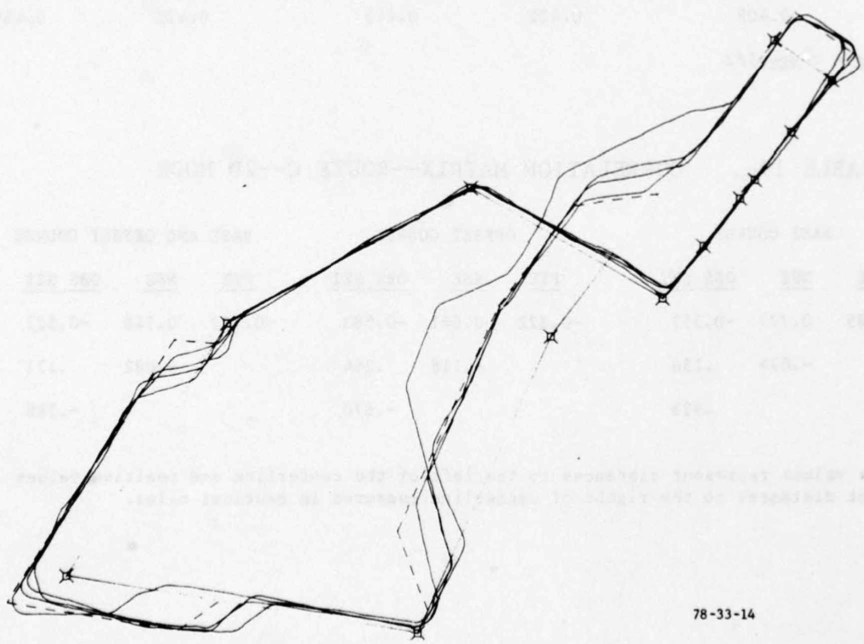

FIGURE 19. COMPOSITE PLOT OF GROUND TRACK, ROUTE B, 3D GUIDANCE

TABLE 19a. STATISTICAL DATA FOR ROUTE C CONFIGURATION--2D MODE

	BASE COURSE			OFFSET COURSE			BASE AND OFFSET COURSE		
	No. SAMPLES	MEAN	1 Sigma	No. SAMPLES	MEAN	1 SIGMA	No. SAMPLES	MEAN	1 SIGMA
TSCT	5,865	-0.070	0.409	3,876	0.167	0.445	9,741	0.024	0.439
FTE	5,865	-.006	.258	3,876	-.011	.336	9,741	-.008	.292
NSE	5,865	-.076	.299	3,876	.155	.255	9,741	.016	.305
OBS SET	5,865	-.011	.454	3,876	-.035	.226	9,741	-.021	.380

TABLE 19b. COMPARATIVE 1-SIGMA RSS VALUES AND ACTUAL TSCT--ROUTE C--2D MODE

BASE COURSE		OFFSET COURSE		BASE AND OFFSET COURSE	
RSS[1] TOTAL ERROR	ACTUAL TSCT ERROR	RSS TOTAL ERROR	ACTUAL TSCT ERROR	RSS TOTAL ERROR	ACTUAL TSCT ERROR
0.395	0.409	0.422	0.445	0.422	0.439

1 $RSS=(\sigma^2_{FTE} + \sigma^2_{NSE})^{1/2}$

TABLE 19c. CORRELATION MATRIX--ROUTE C--2D MODE

	BASE COURSE			OFFSET COURSE			BASE AND OFFSET COURSE		
	FTE	NSE	OBS SET	FTE	NSE	OBS SET	FTE	NSE	OBS SET
TSCT	-0.685	0.777	-0.557	-0.822	0.661	-0.583	-0.722	0.748	-0.521
FTE		-.074	.156		-.118	.264		-.082	.171
NSE			.628			-.670			-.588

NOTE: Negative values represent distances to the left of the centerline and positive values represent distances to the righbt of centerline measured in nautical miles.

TABLE 20a. STATISTICAL DATA FOR ROUTE C CONFIGURATION--3D MODE

	BASE COURSE			OFFSET COURSE			BASE AND OFFSET COURSE		
	No. SAMPLES	MEAN	1 SIGMA	No. SAMPLES	MEAN	1 SIGMA	No. SAMPLES	MEAN	1 SIGMA
TSCT	6,305	0.004	0.345	4,080	0.193	0.448	10,385	0.078	0.399
FTE	6,305	-.038	.224	4,080	-.036	.357	10,385	-.037	.284
NSE	6,305	-.034	.256	4,080	.157	.256	10,385	.041	.273
OBS SET	6,305	-.052	.432	4,080	-.036	.225	10,385	-.046	.365

TABLE 20b. COMPARATIVE 1-SIGMA RSS VALUES AND ACTUAL TSCT--ROUTE C--3D MODE

BASE COURSE		OFFSET COURSE		BASE AND OFFSET COURSE	
RSS TOTAL ERROR	ACTUAL TSCT ERROR	RSS TOTAL ERROR	ACTUAL TSCT ERROR	RSS TOTAL ERROR	ACTUAL TSCT ERROR
0.340	0.345	0.439	0.448	0.394	0.399

1 $RSS=(\sigma^2_{FTE} + \sigma^2_{NSE})^{1/2}$

TABLE 20c. CORRELATION MATRIX--ROUTE C--3D MODE

	BASE COURSE			OFFSET COURSE			BASE AND OFFSET COURSE		
	FTE	NSE	OBS SET	FTE	NSE	OBS SET	FTE	NSE	OBS SET
TSCT	-0.671	0.761	-0.571	-0.822	0.604	-0.491	-0.730	0.702	-0.483
FTE		-.029	.138		-.042	.101		-.027	.108
NSE			-.650			-.719			-.594

NOTE: Negative values represent distances to the left of the centerline and positive values represent distances to the right of centerline measured in nautical miles.

TABLE 21a. STATISTICAL DATA FOR ROUTE C CONFIGURATION--2D/3D MODE

	BASE COURSE			OFFSET COURSE			BASE AND OFFSET COURSE		
	No. SAMPLES	MEAN	1 SIGMA	No. SAMPLES	MEAN	1 SIGMA	No. SAMPLES	MEAN	1 SIGMA
TSCT	12,170	-0.032	0.379	7,955	0.180	0.447	20,126	0.052	0.420
FTE	12,170	-.023	.243	7,955	-.024	.347	20,126	-.023	.288
NSE	12,170	-.054	.279	7,955	.156	.255	20,126	.029	.289
OBS SET	12,170	-.032	.443	7,955	-.036	.226	20,126	-.034	.373

TABLE 21b. COMPARATIVE 1-SIGMA RSS VALUES AND ACTUAL TSCT--ROUTE C--2D/3D MODE

BASE COURSE		OFFSET COURSE		BASE AND OFFSET COURSE	
RSS[1] TOTAL ERROR	ACTUAL TSCT ERROR	RSS TOTAL ERROR	ACTUAL TSCT ERROR	RSS TOTAL ERROR	ACTUAL TSCT ERROR
0.370	0.379	0.431	0.447	0.408	0.420

1 $RSS=(\sigma^2_{FTE} + \sigma^2_{NSE})^{1/2}$

TABLE 21c. CORRELATION MATRIX--ROUTE C--2D/3D MODE

	BASE COURSE			OFFSET COURSE			BASE AND OFFSET COURSE		
	FTE	NSE	OBS SET	FTE	NSE	OBS SET	FTE	NSE	OBS SET
TSCT	-0.678	0.770	-0.564	-0.822	0.631	-0.535	-0.727	0.727	-0.503
FTE		-.054	.149		.077	.178		-.051	.140
NSE			-.638			-.695			-.593

NOTE: Negative values represent distances to the left of the centerline and positive values represent distances to the right of centerline measured in nautical miles.

TABLE 22. STEPWISE REGRESSION ANALYSIS--ROUTE C

Data Route	2D	3D	Base	Offset	Coefficients (Beta Weights) Intercept	CDI	OBS SET	VDI	Airspeed (mach)	NSE	R^2 (units)	Remarks
C	X		X		-0.62912	-0.98143	-0.41631		.00348		0.827	(0.684 Reduced)
C	X			X	- .43931	- .93799	- .77312		.00349		.908	(.908 Reduced)
C	X		X	X	- .99571	- .97585	- .47320		.00628		.838	(.703 Reduced)
C		X	X		- .05170	- .92908	- .38942				.827	(.684 Reduced)
C		X		X	- .63688	- .95469	- .75148		.00496		.926	(.858 Reduced)
C		X	X	X	- .47598	- .94248	- .46312		.00324		.841	(.708 Reduced)
C	X	X	X		- .25962	- .94390	- .40943		.00135		.826	(.682 Reduced)
C	X	X		X	- .52309	- .94773	- .76514		.00423		.917	(.840 Reduced)
C	X	X	X	X	- .65828	- .96010	- .47248		.00443		.841	(.707 Reduced)

NOTE: Negative values represent distances to the left of the centerline and positive values represent distances to the right of centerline measured in mautical miles.

0.439 nautical miles for the combined centerline/offset tracking. The overall FTE (1σ) values ranged between 0.224 and 0.258 nautical miles for the centerline tracking, between 0.336 and 0.357 nautical miles for the offset tracking, and between 0.284 and 0.292 nautical miles for the combined centerline/offset tracking.

The RSS calculations for the two-component model ($\sigma FTE + \sigma NSE$) produced comparable TSCT error values.

The correlation coefficients are presented in tables 19c, 20c, and 21c. These tables show that the overall correlation coefficient for TSCT and FTE ranged between -0.671 and -0.822. These high negative correlations indicate that TSCT and FTE operate in the predicted manner.

Table 22 presents the results of the stepwise regression analyses. From table 22, it can be seen that for the nine models evaluated, the cumulative (sum of squares) proportion reduced ranged from 0.682 to 0.858, and the multiple correlation coefficient ranged from 0.826 to 0.926. These high values indicate that the final linear models obtained from the regression represent a good fit to the data.

From table 22, it can be seen that two major variables can be used to predict TSCT error, FTE and OBS SET. A third variable, airspeed, also enters as a minor variable. These findings are the same as those found for the Route A data.

Figure 20 presents the TSCT data for the 2D RNAV mode, and figure 21 presents the TSCT data for the 3D RNAV mode.

ROUTE D. Tables 23 through 26 present the statistical summary data for the Route D configuration. The data in tables 23, 24, and 25 indicated that the RNAV systems produced accurate course following for both centerline and offset tracking on this route structure. The overall TSCT (1σ) values ranged between 0.280 and 0.329 nautical miles for the centerline tracking, between 0.367 and 0.408 nautical miles for offset tracking, and between 0.310 and 0.396 nautical miles for the combined centerline/offset tracking. The overall FTE (1σ) values ranged between 0.209 and 0.296 nautical miles for the centerline tracking, between 0.183 and 0.358 nautical miles for the offset tracking, and between 0.299 and 0.301 nautical miles for the combined centerline/offset tracking.

The RSS calculations for the two-component model ($\sigma_{FTE} + \sigma_{NSE}$) produced comparable TSCT error values.

The correlation coefficients are presented in tables 23c, 24c, and 25c. From these tables, it can be seen that the overall correlation coefficient for TSCT and FTE ranged between -0.416 and -0.791. These high correlations indicate that TSCT and FTE operate in the predicted manner.

Table 26 presents the results of the stepwise regression analyses which show that for the nine models evaluated, the cumulative (sum of squares) proportion

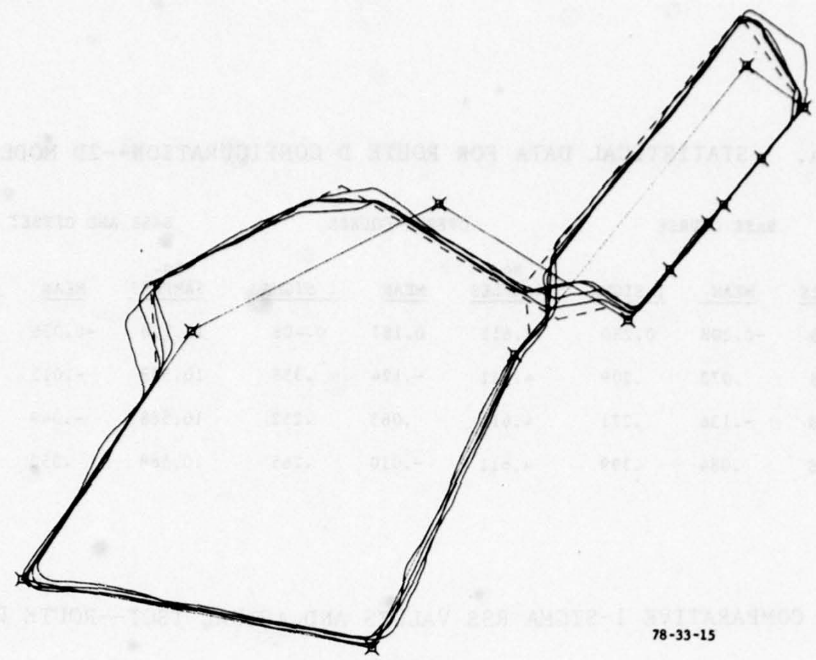

FIGURE 20. COMPOSITE PLOT OF GROUND TRACK, ROUTE C, 2D GUIDANCE

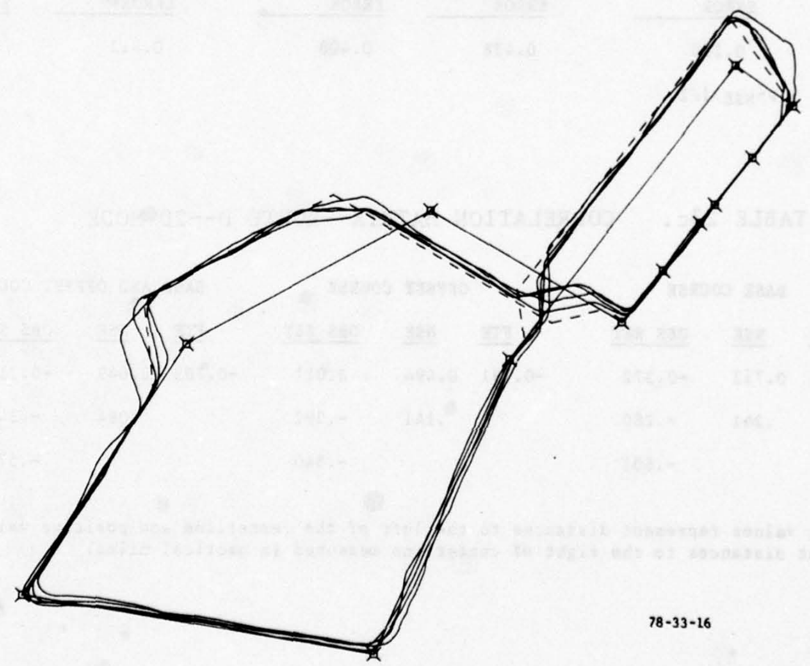

FIGURE 21. COMPOSITE PLOT OF GROUND TRACK, ROUTE C, 3D GUIDANCE

TABLE 23a. STATISTICAL DATA FOR ROUTE D CONFIGURATION--2D MODE

	BASE COURSE			OFFSET COURSE			BASE AND OFFSET COURSE		
	No. SAMPLES	MEAN	1 SIGMA	No. SAMPLES	MEAN	1 SIGMA	No. SAMPLES	MEAN	1 SIGMA
TSCT	5,948	-0.208	0.280	4,611	0.187	0.408	10,558	-0.036	0.394
FTE	5,948	.073	.209	4,611	-.124	.358	10,588	-.013	.301
NSE	5,948	-.136	.271	4,611	.063	.252	10,588	-.049	.281
OBS SET	5,948	.084	.399	4,611	-.010	.265	10,588	.052	.349

TABLE 23b. COMPARATIVE 1-SIGMA RSS VALUES AND ACTUAL TSCT--ROUTE D--2D MODE

BASE COURSE		OFFSET COURSE		BASE AND OFFSET COURSE	
RSS[1] TOTAL ERROR	ACTUAL TSCT ERROR	RSS TOTAL ERROR	ACTUAL TSCT ERROR	RSS TOTAL ERROR	ACTUAL TSCT ERROR
0.342	0.280	0.438	0.408	0.412	0.394

1 RSS=$(\sigma^2_{FTE} + \sigma^2_{NSE})^{1/2}$

TABLE 23c. CORRELATION MATRIX--ROUTE D--2D MODE

	BASE COURSE			OFFSET COURSE			BASE AND OFFSET COURSE		
	FTE	NSE	OBS SET	FTE	NSE	OBS SET	FTE	NSE	OBS SET
TSCT	-0.416	0.713	-0.372	-0.791	0.494	0.011	-0.703	0.649	-0.218
FTE		.341	-.280		.141	-.392		.084	-.247
NSE			-.601			-.540			-.570

NOTE: Negative values represent distances to the left of the centerline and positive values represent distances to the right of centerline measured in nautical miles.

TABLE 24a. STATISTICAL DATA FOR ROUTE D CONFIGURATION--3D MODE

	BASE COURSE			OFFSET COURSE			BASE AND OFFSET COURSE		
	No. SAMPLES	MEAN	1 SIGMA	No. SAMPLES	MEAN	1 SIGMA	No. SAMPLES	MEAN	1 SIGMA
TSCT	6,194	-0.200	0.329	4,309	0.270	0.310	10,503	-0.007	0.396
FTE	6,194	.114	.296	4,309	-.197	.183	10,503	-.013	.299
NSE	6,194	-.086	.261	4,309	.074	.257	10,503	-.020	.271
OBS SET	6,194	.053	.409	4,309	.008	.302	10,503	.028	.370

TABLE 24b. COMPARATIVE 1-SIGMA RSS VALUES AND ACTUAL TSCT--ROUTE D--3D MODE

BASE COURSE		OFFSET COURSE		BASE AND OFFSET COURSE	
RSS TOTAL ERROR	ACTUAL TSCT ERROR	RSS TOTAL ERROR	ACTUAL TSCT ERROR	RSS TOTAL ERROR	ACTUAL TSCT ERROR
0.395	0.329	0.315	0.310	0.404	0.396

1 $RSS=(\sigma^2_{FTE} + \sigma^2_{NSE})^{1/2}$

TABLE 24c. CORRELATION MATRIX--ROUTE D--3D MODE

	BASE COURSE			OFFSET COURSE			BASE AND OFFSET COURSE		
	FTE	NSE	OBS SET	FTE	NSE	OBS SET	FTE	NSE	OBS SET
TSCT	-0.656	0.518	-0.393	-0.560	0.808	-0.486	-0.727	0.658	-0.387
FTE		.308	-.164		.036	-.092		.036	-.083
NSE			-.680			-.652			-.657

NOTE: Negative values represent distances to the left of the centerline and positive values represent distances to the right of centerline measured in nautical miles.

TABLE 25a. STATISTICAL DATA FOR ROUTE D CONFIGURATION--2D/3D MODE

	BASE COURSE			OFFSET COURSE			BASE AND OFFSET COURSE		
	No. SAMPLES	MEAN	1 SIGMA	No. SAMPLES	MEAN	1 SIGMA	No. SAMPLES	MEAN	1 SIGMA
TSCT	12,142	-0.204	0.306	8,920	0.227	0.367	21,061	-0.021	0.395
FTE	12,142	.094	.258	8,920	-.159	.290	21,061	-.013	.299
NSE	12,142	-.110	.267	8,920	.068	.255	21,061	-.035	.277
OBS SET	12,142	.068	.405	8,920	.001	.283	21,061	.040	.360

TABLE 25b. COMPARATIVE 1-SIGMA RSS VALUES AND ACTUAL TSCT -- ROUTE D--2D/3D MODE

BASE COURSE		OFFSET COURSE		BASE AND OFFSET COURSE	
RSS TOTAL ERROR	ACTUAL TSCT ERROR	RSS TOTAL ERROR	ACTUAL TSCT ERROR	RSS TOTAL ERROR	ACTUAL TSCT ERROR
0.371	0.306	0.386	0.367	0.408	0.395

1 RSS=$(\sigma^2_{FTE} + \sigma^2_{NSE})^{1/2}$

TABLE 25c. CORRELATION MATRIX--ROUTE D--2D/3D MODE

	BASE COURSE			OFFSET COURSE			BASE AND OFFSET COURSE		
	FTE	NSE	OBS SET	FTE	NSE	OBS SET	FTE	NSE	OBS SET
TSCT	-0.563	0.603	-0.383	-0.722	0.617	-0.209	-0.71	0.652	-0.306
FTE		.324	-.210		.098	-.260		.068	-.164
NSE			-.641			-.597			-.614

NOTE: Negative values represent distances to the left of the centerline and positive values represent distances to the right of centerline measured in nautical miles.

TABLE 26.   STEPWISE REGRESSION ANALYSIS--ROUTE D

Data Route	2D	3D	Base	Offset	Coefficients (Beta Weights) Intercept	CDI	OBS SET	VDI	Airspeed (mach)	NSE	R^2 (units)	Remarks
D	X		X		0.46074	-0.66519	-0.32552		-0.00409		0.714	(0.510 Reduced)
D	X			X	.41886	-1.05798	- .55732		- .00220		.857	(.734 Reduced)
D	X		X	X	- .02542	-1.05540	- .47074				.811	(.657 Reduced)
D		X	X		.36361	- .79261	- .34884		- .00322		.846	(.717 Reduced)
D		X		X	-1.82821	- .78737	- .18024		.01242		.851	(.724 Reduced)
D		X	X	X	- .22020	- .99679	- .48935		.00145		.858	(.736 Reduced)
D	X	X	X		.40978	- .74936	- .33931		- .00364		.793	(.629 Reduced)
D	X	X		X	.50107	-1.03632	- .48196		.00354		.837	(.700 Reduced)
D	X	X	X	X	- .01624	-1.04071	- .47760				.835	(.698 Reduced)

NOTE: Negative values represent distances to the left of the centerline and positive values represent distances to the right of centerline measured in nautical miles.

reduced ranged from 0.510 to 0.736, and the multiple correlation coefficient ranged from 0.714 to 0.858. These values are lower than those for Routes A, B, and C and, as such, indicate that the obtained linear model does not represent as good a fit to the data as did the other linear models. The difference is primarily due to the fact that for the Route D configuration, approximately 50 percent of the route required offset tracking and, as such, constituted a higher workload for the pilots. This is especially true of the WHISKEY-SIERRA-ROMEO legs on which the pilot was directed to (1) fly a 5-mile right offset from WHISKEY to SIERRA, (2) maintain the offset while transitioning at SIERRA, and (3) cross over from a 5-mile right offset to a 3-mile left offset while maintaining the course between SIERRA and ROMEO.

From table 26, it can be seen that two major variables can be used to predict TSCT error. These two variables are FTE and OBS SET. A third variable, airspeed, also enters as a minor variable. These findings are the same as those found for the Route A data.

Figure 22 presents the TSCT data for the 2D RNAV mode, and figure 23 presents the TSCT data for the 3D mode.

<u>COMBINED STEADY STATE CENTERLINE AND OFFSET DATA (TSCT)</u>. The mean, 2 σ, and 2 RMS statistical summary steady state TSCT data are presented in tables 27a, 27b, and 27c. From these tables and the overall summary presented in table 28, it can be seen that there exists a difference between centerline tracking and offset tracking. The centerline tracking is more precise than the offset tracking.

<u>COMBINED STEADY STATE CENTERLINE AND OFFSET DATA (FTE)</u>. The mean, 2 σ, and 2 RMS statistical summary steady state FTE data are presented in tables 29a, 29b, and 29c. From these tables and the overall summary presented in table 30, it can be seen that there exists a difference between centerline tracking and offset tracking.

The TSCT and FTE summary data in tables 28 and 30 indicate that even though the CDI instrument used a centered needle presentation for both the centerline and offset tracking, there exists a difference between centerline and offset tracking in terms of variability. This difference must be attributed to the RNAV computation algorithm for the offset tracking mode.

Tables 31 and 32 present (by route) 2 σ and 2-RMS values for 2D and 3D TSCT and FTE, respectively. As indicated in these tables, there were no operational differences found in either TSCT or FTE measures between 2D and 3D flights.

In general, the 2 σ and 2 RMS data for the TSCT error in the terminal area were both within a ±2 nautical mile error range. Futhermore, only 8 of the 44 centerline tracking segments contained errors which exceeded a ±1 nautical mile error range. However, 10 of the 30 offset tracking segments contained errors with a ±1 nautical mile error range. The FTE data showed similar results, in that for the 2 σ and 2 RMS statistics, only 1 of the 44 centerline tracking segments and only 3 of the 30 offset tracking segments contained errors which exceeded a ±1 nautical mile error range. When the data were

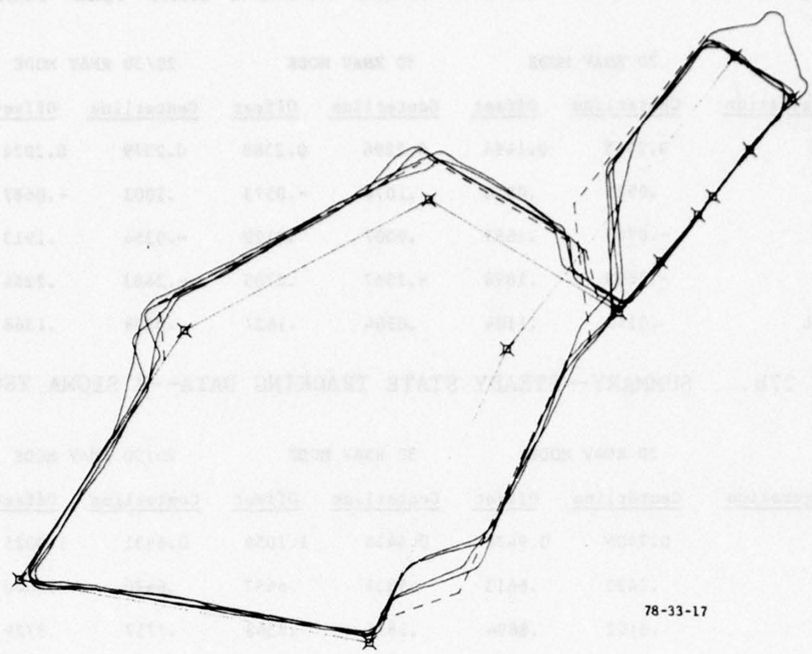

FIGURE 22. COMPOSITE PLOT OF GROUND TRACK, ROUTE D, 2D GUIDANCE

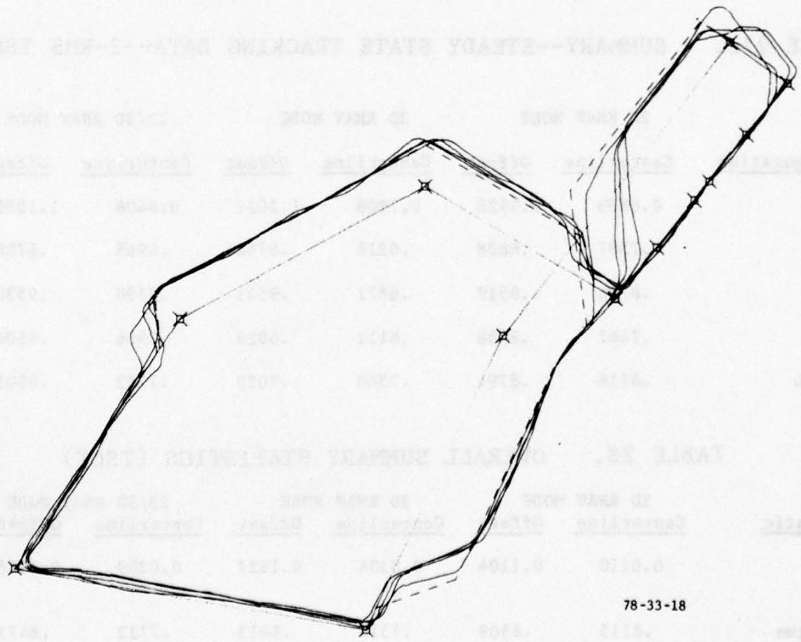

FIGURE 23. COMPOSITE PLOT OF GROUND TRACK, ROUTE D, 3D GUIDANCE

TABLE 27a. SUMMARY--STEADY STATE TRACKING DATA--MEAN TSCT

Route Configuration	2D RNAV MODE Centerline	2D RNAV MODE Offset	3D RNAV MODE Centerline	3D RNAV MODE Offset	2D/3D RNAV MODE Centerline	2D/3D RNAV MODE Offset
A	0.2465	0.1494	0.2296	0.2380	0.2379	0.2024
B	.0936	.0810	.1076	-.0573	.1003	-.0687
C	-.0743	.1697	.0007	.2120	-.0354	.1913
D	-.2609	.1898	-.2367	.2705	-.2483	.2284
ALL	.0110	.1104	.0304	.1627	.0209	.1368

TABLE 27b. SUMMARY--STEADY STATE TRACKING DATA--2 SIGMA TSCT

Route Configuration	2D RNAV MODE Centerline	2D RNAV MODE Offset	3D RNAV MODE Centerline	3D RNAV MODE Offset	2D/3D RNAV MODE Centerline	2D/3D RNAV MODE Offset
A	0.7406	0.9470	0.6438	1.1059	0.6931	1.0325
B	.7422	.6613	.5834	.6657	.6670	.6640
C	.8162	.8894	.6871	.8548	.7757	.8729
D	.5335	.8093	.6587	.6200	.6022	.7294
ALL	.8115	.8509	.7315	.8413	.7722	.8477

TABLE 27c. SUMMARY--STEADY STATE TRACKING DATA--2-RMS TSCT

Route Configuration	2D RNAV MODE Centerline	2D RNAV MODE Offset	3D RNAV MODE Centerline	3D RNAV MODE Offset	2D/3D RNAV MODE Centerline	2D/3D RNAV MODE Offset
A	0.8896	0.9928	0.7908	1.2037	0.8406	1.1089
B	.7587	.6808	.6218	.6754	.6965	.6780
C	.8296	.9519	.6871	.9541	.7590	.9530
D	.7462	.8938	.8111	.8829	.7806	.8606
ALL	.8118	.8791	.7340	.9020	.7733	.8907

TABLE 28. OVERALL SUMMARY STATISTICS (TSCT)

Statistic	2D RNAV MODE Centerline	2D RNAV MODE Offset	3D RNAV MODE Centerline	3D RNAV MODE Offset	2D/3D RNAV MODE Centerline	2D/3D RNAV MODE Offset
Mean	0.0110	0.1104	0.0304	0.1627	0.0209	0.1368
2 Sigma	.8115	.8509	.7315	.8413	.7722	.8477
2 RMS	.8118	.8791	.7340	.9020	.7773	.8907

TABLE 29a. SUMMARY--STEADY STATE TRACKING DATA--MEAN FTE

Route Configuration	2D RNAV MODE Centerline	Offset	3D RNAV MODE Centerline	Offset	2D/3D RNAV MODE Centerline	Offset
A	-0.1698	-0.2047	-0.0129	-0.2403	-0.1490	-0.2235
B	-.0363	.0705	-.0804	.0099	-.0575	.0391
C	-.0053	-.0153	-.0369	-.0573	-.0217	-.0368
D	.0779	-.1213	.1322	-.1968	.1061	-.1574
ALL	-.0384	-.0580	-.0317	-.1116	-.0350	-.0851

TABLE 29b. SUMMARY--STEADY STATE TRACKING DATA--2 SIGMA FTE

Route Configuration	2D RNAV MODE Centerline	Offset	3D RNAV MODE Centerline	Offset	2D/3D RNAV MODE Centerline	Offset
A	0.5404	0.7448	0.3674	0.9896	0.4622	0.8829
B	.4167	.5413	.4650	.5891	.4427	.5697
C	.5170	.6658	.4450	.6373	.4820	.6526
D	.4301	.7159	.6183	.3646	.5389	.5804
ALL	.5143	.6948	.5156	.6680	.5150	.6835

TABLE 29c. SUMMARY--STEADY STATE TRACKING DATA--2 RMS FTE

Route Configuration	2D RNAV MODE Centerline	Offset	3D RNAV MODE Centerline	Offset	2D/3D RNAV MODE Centerline	Offset
A	0.6383	0.8498	0.4490	1.1000	0.5499	0.9895
B	.4230	.5594	.4920	.5893	.4574	.5751
C	.5170	6664	.4511	.6474	.4840	.6568
D	.4574	.7559	.6725	.5365	.5791	.6602
ALL	.5199	.7044	.5195	.7043	.5197	.7043

TABLE 30. OVERALL SUMMARY STATISTICS (FTE)

Statistic	2D RNAV MODE Centerline	2D RNAV MODE Offset	3D RNAV MODE Centerline	3D RNAV MODE Offset	2D/3D RNAV MODE Centerline	2D/3D RNAV MODE Offset
Mean	-0.0384	-0.0580	-0.0317	-0.1116	-0.1116	-0.0851
2 Sigma	.5143	.6948	.5156	.6680	.5150	.6835
2 RMS	.5199	.7044	.5195	.7043	.5197	.7043

TABLE 31. TOTAL SYSTEM CROSS TRACK ERROR (TSCT) IN NAUTICAL MILES

ROUTE	CENTERLINE TRACKING				OFFSET TRACKING			
	2D RNAV MODE		3D RNAV MODE		2D RNAV MODE		3D RNAV MODE	
	2 Sigma	2 RMS	2 Sigma	2 RMS	2 Sigma	2 RMS	2 Sigma	2 RMS
A	0.7406	0.8896	0.6438	0.7908	0.9470	0.9928	1.1059	1.2037
B	.7422	.7587	.5834	.6218	.6613	.6808	.6657	.6754
C	.8162	.8296	.6871	.6871	.8894	.9519	.8548	.9541
D	.5335	.7462	.6587	.8111	.8093	.8938	.6200	.8829
All	(.8115)	(.8118)	(.7315)	(.7340)	(.8509)	(.8791)	(.8413)	(.9020)

TABLE 32. FLIGHT TECHNICAL ERROR (FTE) IN NAUTICAL MILES

ROUTE	CENTERLINE TRACKING				OFFSET TRACKING			
	2D RNAV MODE		3D RNAV MODE		2D RNAV MODE		3D RNAV MODE	
	2 Sigma	2 RMS	2 Sigma	2 RMS	2 Sigma	2 RMS	2 Sigma	2 RMS
A	0.5404	0.6383	0.3674	0.4490	0.7448	0.8498	0.9896	1.1000
B	.4167	.4230	.4650	.4920	.5413	.5594	.5891	.5893
C	.5170	.5170	.4450	.4511	.6658	.6664	.6373	.6474
D	.4301	.4574	.6183	.6725	.7159	.7559	.3646	.5365
All	(.5143)	(.5199)	(.5156)	(.5195)	(.6948)	(.7044)	(.6680)	(.7043)

evaluated using a ±1.5 nautical mile error range, it was found that only one case for centerline tracking and only one case for offset tracking exceeded this criterion.

TURN DATA (± 2.0 NAUTICAL MILE) FOR CENTERLINE AND MAINTAIN OFFSET TRANSITION. TSCT was measured during turns required to transition from one route segment to the next. The turn data for the centerline transition cases and the offset transition (while maintaining the selected offset) cases are presented in table 33. The mean and RMS TSCT statistics are presented as a function of route (A, B, C, and D) segment and RNAV mode (2D and 3D) for both the centerline and offset transitions and show that the offset transitions resulted in greater variability in terms of TSCT than did the centerline transition. Only two of the centerline transitions resulted in the 2 RMS TSCT values exceeding ±1.0 nautical mile, and none exceeded ±2.0 nautical miles. For the offset transitions, seven of the offset transitions resulted in the 2 RMS TSCT values exceeding ±1.0 nautical mile, five exceeded ±1.5 nautical miles, and four exceeded ±2.0 nautical miles. In the case of the four offset transitions which exceeded a 2 RMS TSCT value of ±2 nautical miles, the magnitude of the TSCT variability was due to (1) the fact that these cases had the additional task of reaching a desired altitude (either descending or climbing) at a point 10 nautical miles along track and therefore had additional workload, and (2) the peculiarities of the RNAV system's wayline logic. These peculiarities and the tracking results are discussed in detail in the section dealing with procedural errors. The Route D offset transitions did not have the along-track (ATK) clearance problem and resulted in lower variability even though two 2 RMS TSCT values exceeded ±1.0 nautical mile.

CLIMBS/DESCENTS. In this study, it was expected that flight techniques for changing altitudes would differ between the 2D and 3D pilots. The 3D pilots were limited to the experimental constraints of flying a computed FPA and referencing glide slope pointers to maintain relatively constant climb/descent rates to reach their prescribed altitude(s) at the assigned waypoint or clearance limit. The 2D pilots, on the other hand, had no such restraints and manually flew at climb/descent rates commensurate with the simulator performance characteristics. They invariably reached the assigned altitude prior to the waypoint or clearance limit and sooner than did the 3D pilots.

Climbs. The Route A configuration required the pilots to initiate a left offset from waypoint YOKE and commence climbing (starting altitude 7,000 feet) to reach 12,000 feet 10 miles past waypoint XRAY. The 3D pilots (flying their computed FPA) adhered to this requirement and arrived on altitude at the designated 10-mile clearance limit. By contrast, although given the same clearance, the 2D pilots arrived at the assigned altitude approximately 12 miles prior to waypoint XRAY.

The Route B configuration required the pilots to initiate a right offset climb from waypoint YOKE and commence climbing (starting altitude 7,000 feet) to reach 12,000 feet 10 miles past waypoint XRAY. The resulting climb profiles are a mirror image of the Route A profiles for both the 2D and 3D pilots.

TABLE 33. TURN DATA ($\pm$2.0 NAUTICAL MILES) FOR ON-COURSE AND OFFSET TRANSITION

Route/Waypoint	TRANSITION (ON COURSE) 2D RNAV MODE $\bar{X}$	TRANSITION (ON COURSE) 2D RNAV MODE RMS	TRANSITION (ON COURSE) 3D RNAV MODE $\bar{X}$	TRANSITION (ON COURSE) 3D RNAV MODE RMS	TRANSITION (MAINTAIN OFFSET) 2D RNAV MODE $\bar{X}$	TRANSITION (MAINTAIN OFFSET) 2D RNAV MODE RMS	TRANSITION (MAINTAIN OFFSET) 3D RNAV MODE $\bar{X}$	TRANSITION (MAINTAIN OFFSET) 3D RNAV MODE RMS
Data Route A								
HOTEL	0.291	0.405	0.459	0.640				
YYOKE	-.032	284	-.259	.361				
SIERRA	.440	.490	.221	.237				
XRAY (5L OFFSET)					1.195[1]	1.654	.066	2.035
Data Route B								
HOTEL	.271	.435	.315	.453				
GOLF	.031	.362	.205	.324				
YOKE	-.227	.105	-.332	.467				
WHISKEY	.300	.399	.172	.407				
XRAY (5L OFFSET)					-.879[1]	1.349	-0.468	.735
					.285[1]	.342	-0.618	1.570
Data Route C								
HOTEL	.253	.413	.189	.477				
XRAY	.017	.325	.019	.355				
WHISKEY	-.216	.459	.216	.430				
SIERRA	.194	.312	.178	.289				
Data Route D								
HOTEL	.336	.493	.443	.593				
XRAY	-.198	.352	-.242	.314				
WHISKEY	-.309	.438	-.167	.412				
ROMEO	.039	.316	-.245	.791				
GOLF (3R OFFSET)					.369	.658	.413	.531
SIERRA (5R OFFSET)					.114	.338	.068	.112

[1] Note: These three segments incorporated an additional task of reaching a desired altitude (either descending or climbing) at a point 10 nmi along track and therefore resulted in more variability than the two data route D cases.

The Route C configuration required the pilots to initiate an oncourse climb from waypoint YOKE (initial altitude 7,000 feet) to reach 12,000 feet at waypoint XRAY. The differences between the 2D and 3D climb profiles are the climb rates. The 2D pilots used climb rates approximately twice the magnitude of those used by the 3D pilots.

The Route D configuration required the pilots to initiate a climb from waypoint YOKE (initial altitude 7,000 feet) to reach 12,000 feet at waypoint XRAY. Once again, the results of these climb profiles are mirror images of the Route C climb profiles. Overall climb rates for the 3D pilots averaged about 415 feet per minute while the 2D pilots averaged about 1,160 feet per minute.

Descents. The results of the 2D and 3D climb profiles indicated that definite patterns existed regarding piloting technique used to climb, based on specific ATC clearances. The descents indicated a similar set of patterns.

Current FAA descent profile procedures for high-performance aircraft are based on a descent rate of 300 feet per mile from cruise altitude. This converts to about 800 feet per minute at the experimental speed of 160 knots. Actual descent rate, however, will vary depending on airspace requirements and aircraft characteristics that determine the most economical descent rate for a particular flight. The data indicate that the overall descent rate for the 3D pilots averaged approximately 560 feet per minute, while the 2D pilots averaged approximately 1,200 feet per minute, which is slightly over twice the 3D rate.

In general, we find that, as a precautionary measure to prevent waypoint overshoots, the 2D pilots, having no vertical guidance, preferred to reach their altitudes sooner by using vertical rates more commensurate with the climb/descent performance of the aircraft. In every case, they were able to reach the assigned altitudes 12 to 16 nautical miles prior to the fix, which allowed them time to stablize and avoid excessive workloads upon arrival at the fix.

Conversely, the 3D pilots, being required to fly a shallower flightpath angle, flew a longer climb/descent profile, arriving at the assigned altitude and the fix simultaneously. This can, and did, create the additional workload of leveling off, noting fix passage, setting in the new course, etc., in fairly rapid fashion. In addition, the pilots did not always use effectively turn anticipation procedures since they were still in a climb/descent attitude just prior to the fix.

These additional workloads quickly became apparent to the 3D pilots who expressed concern as to what the actual cost benefits would be, as well as the pilot impositions such a system/procedure demands. Pilot opinions with respect to this issue may be found in the "Summary of Responses to Pilot Questionnaire," in appendix D.

FINAL APPROACH DATA. In this experiment, one-half of the approaches to runway 22 were flown using the RNAV approach mode (one dot = 0.5 nautical mile), and the other half were flown using the ILS (one dot = 1 1/4°).

Data were collected during the final approaches to investigate the question of nonprecision approaches versus ILS approaches using a multi-waypoint, digital RNAV system in the terminal area enviroment. Specifically:

1. ILS approaches were made to runway 22 for Route A and Route C, and

2. RNAV approaches were made to runway 22 for Route B and Route D by using the RNAV system in the approach mode.

In this experiment, for the ILS approaches, the 2D/3D RNAV mode distinction has no meaning since under both conditions the pilots had both the glide slope and localizer deviations presented on the HSI. For the RNAV approaches, however, the 2D/3D distinction is real since, for the 3D approaches, the pilot enters the desired minimum descent altitude (MDA), whereas for the 2D approaches, the pilots had only horizontal guidance from the CDI needle.

From tables 34 and 35, it can be seen that only in two cases did the sigma and RMS data for TSCT exceed a 2σ or 2 RMS criterion of ±0.9 nautical mile. (The ±0.9 nautical mile criterion is based on table D-4 of appendix D (AC 90-45A) for an along-track distance of approximately 10 nautical miles and a tangent point distance of 1 mile or less.) Both of these cases were the result of blunders being committed at the transition between the ROMEO-DELTA and DELTA-BRAVO segments. Both of these blunders occurred under the ILS mode and may have resulted from the fact that the pilots were flying a 3-mile right offset on base leg which resulted in the intermediate final approach segment DELTA-BRAVO being only 2.5 miles in length. In addition, the added task of transitions from the RNAV mode to the ILS mode may have increased the workload required to complete this part of the approach. From the data in tables 33 and 34, it can be seen that the pilots flying the Route C configuration did not encounter the same difficulties and, in fact, had very little error on the final approach segments.

In general, except as noted above, the RNAV approach mode and the ILS final approach tracking resulted in equivalent error statistics for TSCT.

<u>PROCEDURAL ERRORS</u>. Procedural errors were defined as incorrect navigation control settings or inappropriate aircraft control operations which resulted in significant deviation from course (or intended route of flight) if allowed to continue uncorrected. Those procedural errors which resulted in deviations of greater than 2 nautical miles from the intended course were classified as "blunders." To supplement the above definition, it should be noted that procedural errors could be directly related to other than pilot mistakes in judgment. There are several categories of procedural errors, pilot errors, clearance delivery errors, equipment malfunction errors, and RNAV avionics system design induced errors. Examples of these potential type of errors are:

1. Pilot errors;

- Setting in the wrong waypoint coordinates.
- Setting the wrong course (OBS).
- Updating the waypoint at an incorrect time.
- Initiating transition to the next course too soon or too late.

TABLE 34. FINAL APPROACH DATA (2D RNAV MODE)

ROUTES A and C

Route	Run No.	Number Of Data Points	Mean TSCT	Mean ILS	1 Sigma TSCT	1 Sigma ILS	1 RMS TSCT	1 RMS ILS	Correlation Coefficient TSCT vs ILS
A	1	391	0.039	0.006	0.105	0.087	0.112	0.088	.95
A	2	-	-	-	-	-	-	-	- [2]
A	3	282	-.438	-.015	.656	.200	.787	.200	.01
A	4	237	.196	.057	.295	.136	.353	.147	.87
C	1	405	.031	-.001	.044	.047	.054	.047	.82
C	2	357	.076	.028	.160	.107	.176	.110	.95
C	3	344	.023	-.005	.036	.045	.043	.045	.80
C	4	365	.019	-.018	.024	.031	.031	.036	.56

ROUTES B and D

Route	Run No	Number Of Data Points	Mean TSCT	Mean FTE	2 Sigma TSCT	2 Sigma FTE	2 RMS TSCT	2 RMS FTE	Correlation Coefficient [1] TSCT vs FTE
B	1	409	0.026	-0.049	0.057	0.076	0.062	0.090	-.72
B	2	392	-.011	-.022	.050	.076	.051	.079	-.59
B	3	345	.016	.003	.088	.089	.089	.089	-.69
B	4	415	-.175	.139	.127	.086	.216	.164	-.89
D	1	432	-.023	.007	.132	.126	.134	.126	-.90
D	2	402	.010	-.032	.045	.077	.046	.083	-.66
D	3	359	-.016	.030	.063	.078	.065	.083	-.81
D	4	373	-.024	.028	.099	.141	.102	.144	-.85

NOTE: 1 The measured FTE was for the Approach Mode - (1 DOT = 1/2 nmi).
2 Subject failed to switch to Reversion/ILS mode and made approach using RNAV mode.
Values are shown in nautical miles.

TABLE 35. FINAL APPROACH DATA (3D RNAV MODE)

ROUTES A and C

Route	Run No.	Number Of Data Points	Mean TSCT	Mean ILS	1 Sigma TSCT	1 Sigma ILS	1 RMS TSCT	1 RMS ILS	Correlation Coefficient TSCT vs ILS
A	1	354	-0.259	0.110	0.560	0.189	0.616	0.218	.96
A	2	294	.127	.054	.211	.117	.246	.129	.77
A	3	354	.047	-.000	.121	.089	.129	.089	.72
A	4	293	.037	.001	.093	.076	.100	.076	.71
C	1	345	.053	.018	.117	.087	.128	.089	.94
C	2	380	.034	.007	.041	.048	.054	.049	.83
C	3	409	.026	.004	.020	.031	.033	.031	.49
C	4	338	.046	-.019	.051	.054	.068	.058	.86

ROUTES B and D

Route	Run No	Number Of Data Points	Mean TSCT	Mean FTE	2 Sigma TSCT	2 Sigma FTE	2 RMS TSCT	2 RMS FTE	Correlation Coefficient TSCT vs FTE[1]
B	1	352	-0.093	.101	0.250	0.283	0.266	0.300	-.98
B	2	382	-.075	-.040	.083	.078	.111	.087	-.72
B	3	355	.031	-.017	.042	.048	.052	.051	-.67
B	4	365	-.037	.020	.143	.122	.147	.124	-.81
D	1	334	-.062	.041	.299	.343	.305	.345	-.94
D	2	379	.015	-.046	.149	.166	.150	.172	-.94
D	3	408	.064	-.063	.049	.066	.081	.091	-.82
D	4	344	.012	-.033	.044	.048	.046	.058	-.54

NOTE: The measured FTE was for the Approach Mode - (1 DOT = 1/2 nmi). Values are shown in nautical miles.

2. Clearance delivery errors;

Wrong offset, either magnitude (i.e., "5 miles" instead of "3 miles"), or direction (i.e., "3 miles left" instead of "3 miles right"). Wrong waypoint (Proceed direct to waypoint "XRAY," instead of "WHISKEY").

3. RNAV equipment system design induced errors;

RNAV systems can and do vary in design logic with respect to offset (pseudo) waypoint location. Generally, while flying the parent course, RNAV systems with slant range correction will have distance-to-waypoint (DTW) countdown to zero miles when passing over the waypoint. Systems employing wayline logic will have DTW countdown to zero at the offset pseudo waypoint located on the wayline of the parent waypoint when flying offsets. Systems employing angle bisector logic will have DTW countdown to zero at the offset pseudo waypoint located on the angle bisector formed by the two legs of the parent routes.

Design philosophies can contribute to procedural and blunder errors in certain offset and turn angle configurations. Pilots using either system must be aware of the specific offset logic and utilize it properly to aid in determining their offset turn points.

If pilots flying an offset are required to cross through the next course to assume an offset on the opposite side of that course (see Route C, waypoint GOLF offset geometry), they should set the OBS for the new course, maintain their heading, and fly "from" the waypoint until the CDI needle approaches the center, then turn to intercept the desired offset.

Another potential problem exists when the pilot is flying an offset and is advised to maintain the offset and intercept the next course leg (see Route A, waypoint WHISKEY offset geometry). This situation is similar to the previous example (Route A, waypoint GOLF) inasmuch as the pseudo waypoints are displaced, and again requires that the pilots be aware of their locations and adjust their procedure in order to assure accurate transition to the next course.

DISCUSSION OF BLUNDERS AS RELATED TO ROUTE STRUCTURE.

Route A Blunders. On Route A there were three points where route design and RNAV system design interacted to contribute to the formation of procedural errors and/or blunders:

- The left offset turn at waypoint XRAY
- The transition to parent course at waypoint WHISKEY
- The offset base leg from waypoints ROMEO to DELTA

Blunders At Waypoint XRAY. Figure 24 illustrates the situation at waypoint XRAY. The particular RNAV unit used in this experiment placed its pseudo waypoint (X) on the wayline of XRAY at a distance greater than 7.5 nautical miles beyond the proper turn point, at X' (i.e., at the apex of the offset turn). Therefore, it was not surprising to find that all subject pilots overshot the turn, and that five out of eight blundered.

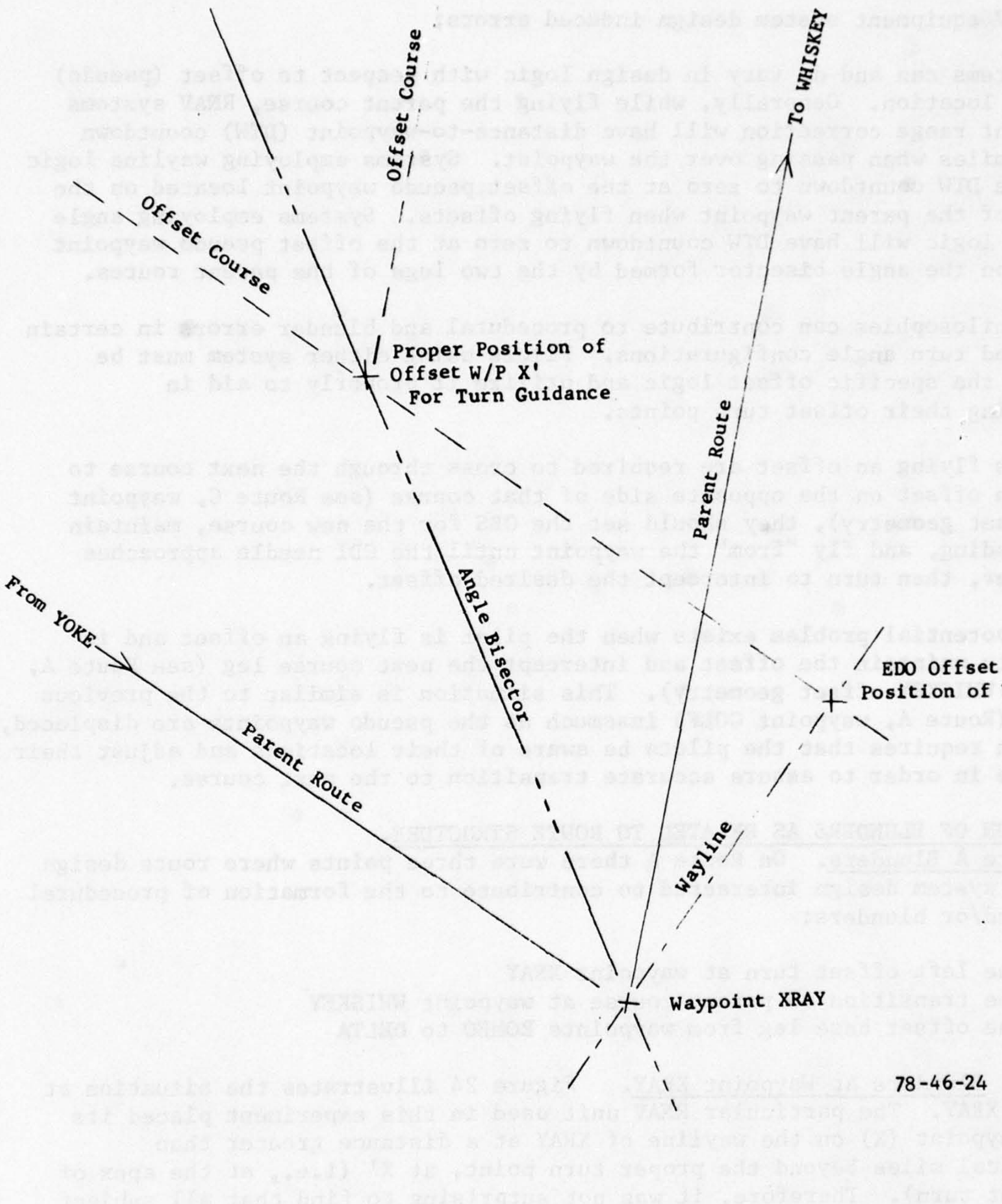

FIGURE 24. ROUTE A TRANSITIONS AT WAYPOINT XRAY

Procedures and Errors at Waypoint WHISKEY. Figure 25 presents the RNAV geometry for the transition at waypoint WHISKEY. The ATC clearance for this segment was "maintain present (offset) course to intercept flight plan route." The pilots were flying a 5-mile left offset between XRAY and WHISKEY and were expected to terminate the offset upon intercepting the WHISKEY to SIERRA segment. For the RNAV system being evaluated, the offset waypoint W was located on the wayline at a distance approximately 1.25 miles prior to the intersection of the offset course and the next course (WHISKEY to SIERRA). Since the pilots in this study made a practice of using a DTW distance of approximately 1 mile for turn anticipation, it was expected that the resultant turns would produce large undershoot distances at this point due to the RNAV system logic.

Table 36 contains a detailed description of the pilots' actions at waypoint WHISKEY. The data in table 36 show that the three pilots who elected to start their turns at the approximately 1-mile DTW distance did indeed incur large undershoot errors (two of which were greater than 1 mile). The other pilots (who used different procedures or techniques for turn anticipation) for the most part incurred overshoots; however, none were greater than 1 mile. These data indicate that the choice of turn anticipation procedure is subject to considerable variability because of the RNAV wayline system logic, and this particular logic must be taken into account.

It is interesting to note that an RNAV system which places the pseudo waypoint on the angle bisector at W' (reference figure 25) might lead to larger errors, since W occurs at a point almost 5 miles prior to the intersection of the offset course and the next leg parent track.

Blunders on Base Leg Offset. A detailed description of expected pilot actions for flying the test routings is shown in appendix B. The base leg of this course (waypoint ROMEO to waypoint DELTA) was 6 miles long and therefore resulted in a relatively high pilot workload when transitioning from the base leg to the final approach course when an offset shortened the final approach. (The 3-mile right offset procedure on the base leg created the problem. Figure 26 shows the route geometry.) For the eight pilots who flew this route, there were three blunders. One pilot forgot to activate the ILS for localizer capture, and overflew pseudo waypoint DELTA until he was returned by vectors. A second pilot set in the wrong ILS frequency. Finally, there was a clearance delivery error which cleared the pilot for a left offset instead of a right offset.

For a given flight, once a blunder has occurred, there is a significantly higher probability of further blunders during the flight. This is due, in part, by the increased workload caused by the earlier blunder(s), the confusion in the mind of the pilot from the previous blunder(s), and by the persistence of the problems which caused the original blunder(s).

Table 37 summarizes the blunders and procedural errors for Route A.

Data Route B Blunders. On data Route B there exists a region where route design and RNAV system design can combine to contribute to a potential

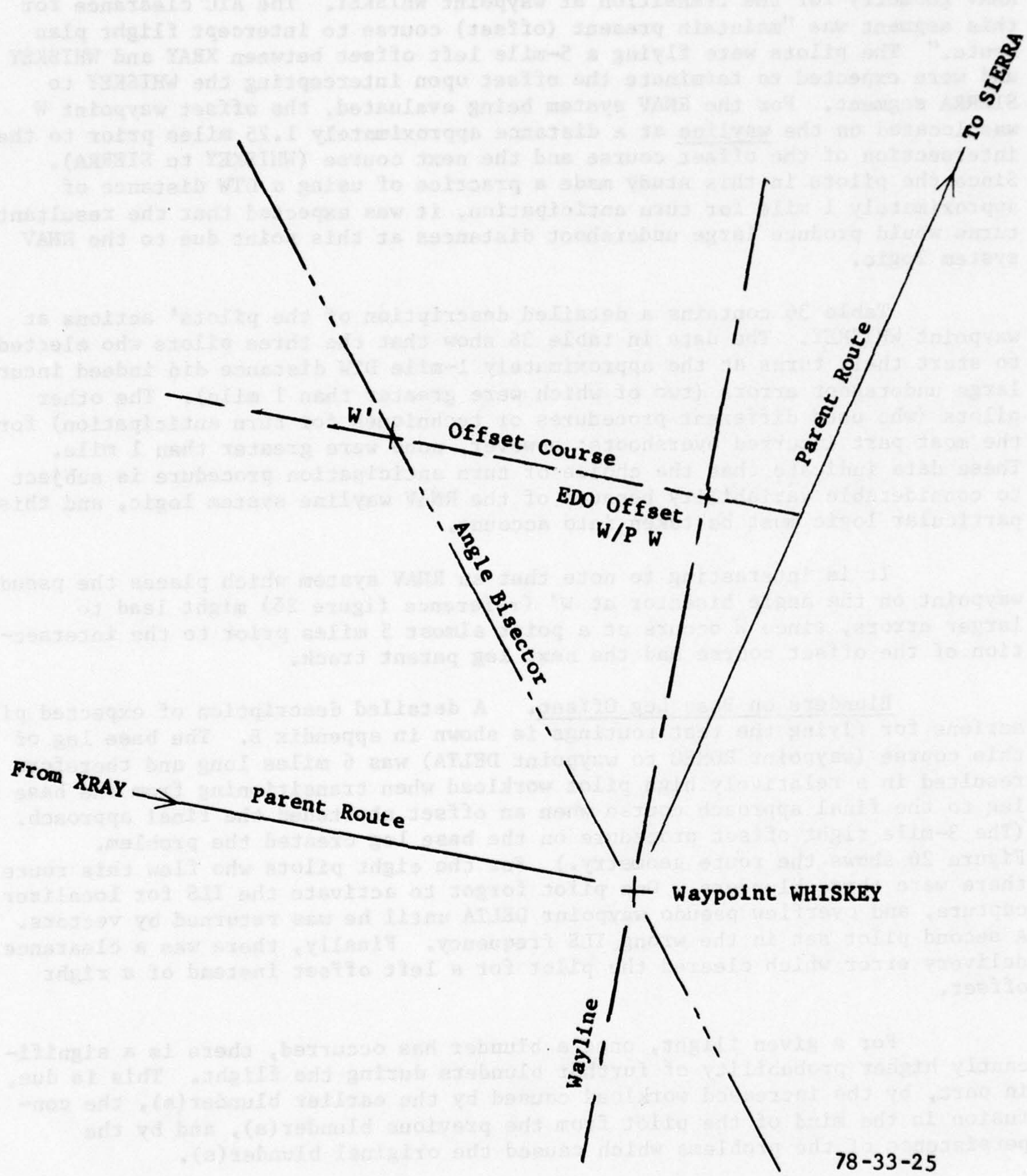

FIGURE 25. ROUTE A TRANSITIONS AT WAYPOINT WHISKEY

TABLE 36. DATA ROUTE A--PROCEDURES AND ERRORS AT WAYPOINT WHISKEY

CONDITION	RUN No.	INITIATE TRANSITION (DTW) DISTANCE (Nautical Miles)	MAXIMUM OVERSHOOT (feet)	MAXIMUM UNDERSHOOT (feet)	PROCEDURES
2D MODE	1	WPT update at 0.9		-3,247 left	(1) WPT update (2) OBS reset (3) canceled offset (4) left turn started
	2	offset canceled at 3.0	5,700 right		(1) offset canceled (2) WPT update (3) OBS reset (4) maintain heading (5) left turn started
	3	start turn at 0.9		-7,257 left	(1) left turn started (2) OBS reset (3) WPT update (4) offset canceled (time = 17 seconds)
	4	OBS reset at 2.8	5,443 right		(1) OBS reset (2) offset canceled (3) WPT update (4) maintained course (5) left turn started
3D MODE	1	start turn at 1.1		-6,443 left	(1) left turn started (2) offset canceled (3) OBS reset (4) WPT update (time = 18 seconds)
	2	OBS reset at 1.8	3,855 right		(1) reset OBS (2) offset canceled (3) WPT update (4) maintained course left turn started
	3	OBS reset at 1.5	3,547 right		(1) reset OBS (2) left turn started (3) offset canceled (4) WPT update (time = 25 seconds)
	4	start turn at 0.9		-5,203 left	(1) left turn started (2) offset canceled (3) OBS reset (4) WPT update (time = 17 seconds)

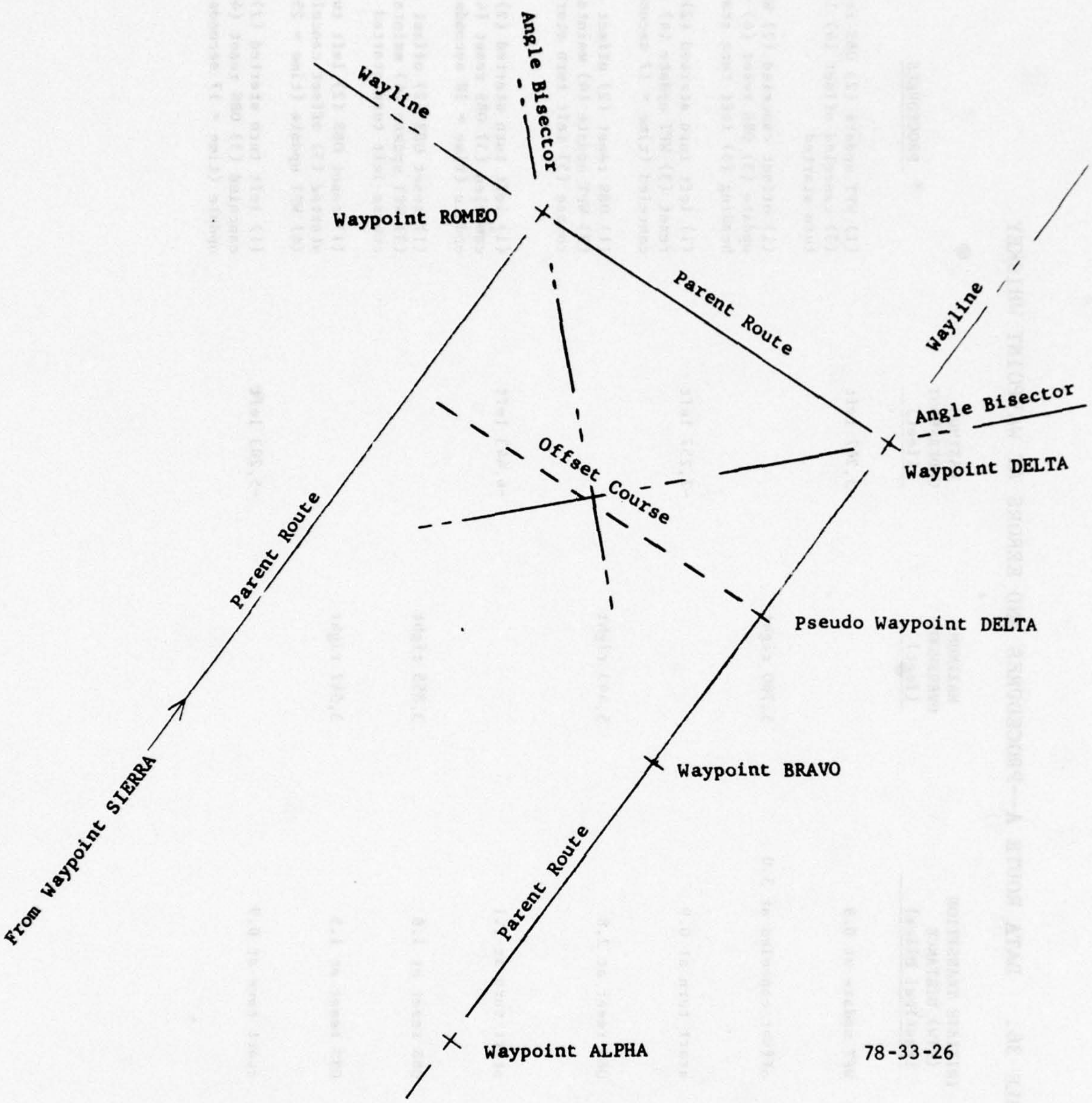

FIGURE 26. ROUTE A TRANSITIONS AT WAYPOINTS ROMEO AND DELTA

TABLE 37. DATA ROUTE A--ANALYSIS OF BLUNDERS AND PROCEDURAL ERRORS

SEGMENT OR WAYPOINT	No. OF ERRORS	No. OF BLUNDERS	COMMENT/CLASSIFICATION/PROBABLE CAUSE
1. HOTEL to GOLF	1	1	In this study the HOTEL to GOLF segment tended to have an approximately 4,000 foot northeast (right) bias for all subjects. In the case of the error, the NAV system error was approximately 3,300 feet and the pilot had an FTE of 0.7 miles. The resultant tracking error reached a maximum of 6,700 feet right of course.
2. GOLF	1	0	Pilot did not set OBS for "Direct To" flight from offset to waypoint GOLF, did not update waypoint to YOKE/flew course of 258° - resultant error was 11,700 feet right of course.
3. XRAY	2	5	Reference text discussion for five blunders. Of the procedural errors, one was 10,400 feet, the other was a 6,400 foot error. The 6,400 foot error was minimized because the pilot started his turn at 7.3 miles DTW (to XRAY) and turned at a rate greater than 3°/second.
4. WHISKEY	2	0	Reference table 1 for detail and test for discussion.
5. ROMEO	0	3	(A) At 7.9-miles DTW (to ROMEO) entered and enabled 3.0-nmi right offset. Took 45° cut to establish offset. Probable cause may have been due to not understanding ATC clearance. The phrase "on the base leg" probably not copied when clearance was given for offset. (B) Probable cause: 0.3-mile right offset instead of 3.0-mile offset. (C) Clearance delivery error 3.0 miles "left" instead of "right".
6. DELTA	0	2	(A) Overshot DELTA by 7.0 miles. Never reverted to ILS. Required radar vector. (B) Pilot set wrong ILS frequency. Overshot DELTA more than 2.0 miles.

blunder situation. This is the 3-mile right offset transition at waypoint XRAY. In addition to the above, the format of the offset clearance issued at waypoint WHISKEY, for the "WHISKEY to SIERRA" leg, can result in a potential blunder situation.

Errors and Blunders at Waypoint. Figure 27 illustrates the situation at waypoint XRAY. The RNAV system wayline logic placed the pseudo waypoint at X'. This was about 4.37 miles prior to the offset waypoint at X," which lay on the angle bisector. Most of the pilots tended to "cut the corner" at waypoint XRAY, starting their turn at a distance of 2 miles DTW past waypoint XRAY, and failing to account for the extra distance caused by the combination of offset distance and large turn angle. Had the pilots realized this, they could have started their turn at a distance of about 3.5 miles DTW past waypoint XRAY which would have resulted in a more accurate transition to the next course.

Only one pilot missed the offset transition region completely. He turned to the left of the parent waypoint XRAY. This was a result of a clearance delivery error. The pilot started to turn to a 3-mile left offset from a 5-mile right offset, then he corrected on his own, but he was too late to avoid the blunder.

Waypoints WHISKEY to SIERRA Leg Offset Problem. The ATC clearance issued at waypoint WHISKEY was "offset left 5 miles, descend to reach 7,000 feet 10 miles past waypoint SIERRA." One pilot experienced a blunder by entering the correct 5-mile left offset and then entered the 10-mile ATK but used the crosstrack (XTK) key instead of the ATK key to enter the command. This directed him to fly a 10-mile left offset. Once the blunder had been committed and recognized, the pilot finally corrected to the 5-mile offset, but forgot to change the OBS to 024° at waypoint SIERRA and continued to fly his old heading (037°). Eventually, the total system error exceeded 2 miles, and a second blunder ensued.

Table 38 summarizes the blunders and procedural errors for Route B.

Data Route C Blunders. There are two areas within data Route C where route design and RNAV system design could combine to contribute to blunder formation (1) the transition from a 3-mile left offset to a 5-mile right offset near waypoint GOLF, and (2) in the vicinity of waypoint YOKE, when offset cancellation was delayed or omitted.

Blunders Near Waypoint GOLF. Figure 28 shows the transition at waypoint GOLF. The pilot was given the following clearance: "Extend present course to offset right 5 miles next leg." The desired turning point is indicated on figure 28 by G". The RNAV installed in the GAT-2B has its pseudo waypoint at G'. The pilots had not been instructed to use a specific turn anticipation technique. However, for an offset turn of this sort, they were expected to use the following logic: "After passing waypoint GOLF, set the OBS to the new course, maintain heading, update to waypoint YOKE, enter the 5-mile right offset, and turn when the CDI needle is almost centered." On the contrary, most of the pilots seemed to have reasoned as follows: "Allow 1 mile for turn anticipation. Therefore, after passing waypoint GOLF, fly

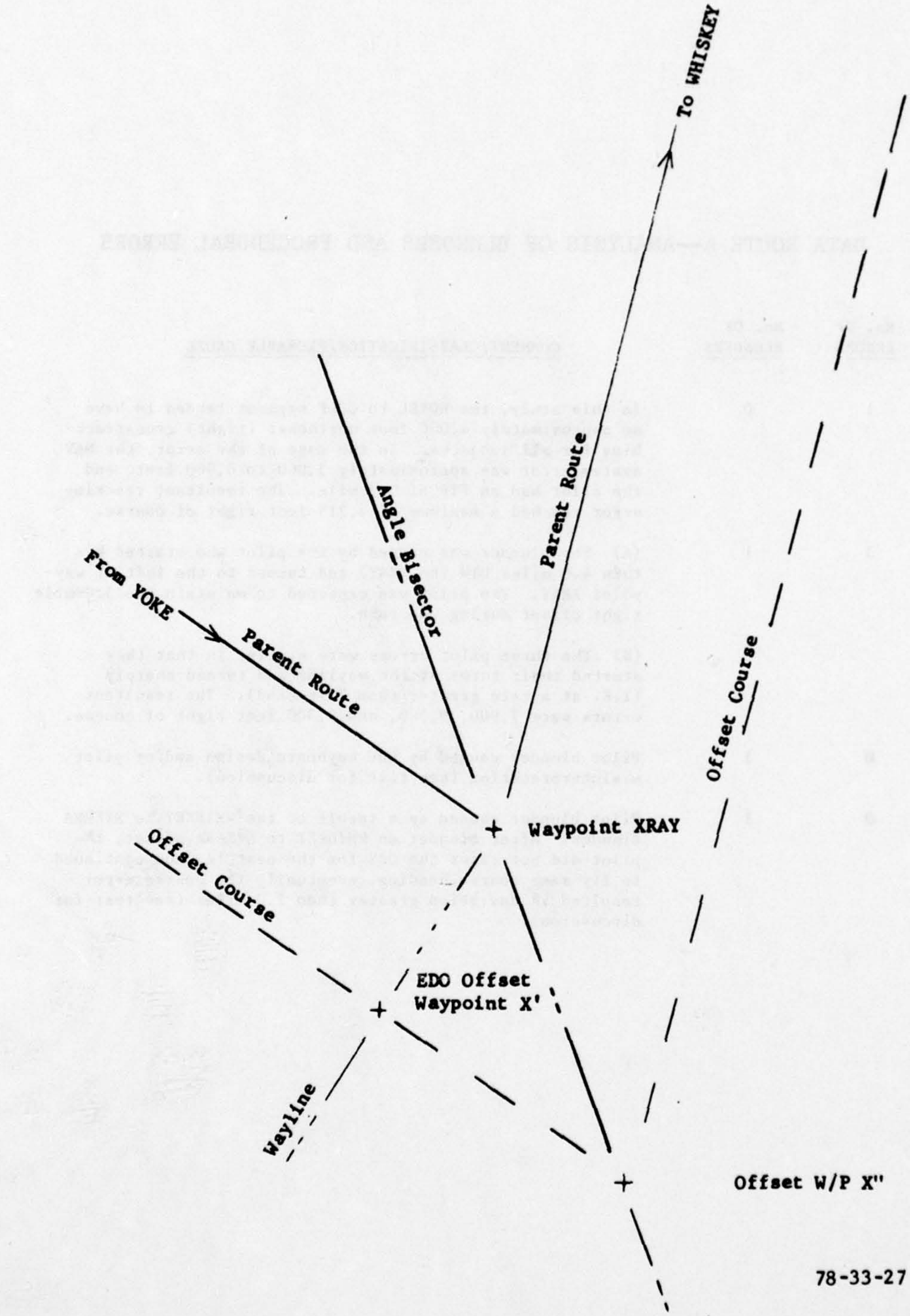

FIGURE 27. ROUTE B TRANSITIONS AT WAYPOINT XRAY

TABLE 38. DATA ROUTE A--ANALYSIS OF BLUNDERS AND PROCEDURAL ERRORS

SEGMENT OR WAYPOINT	No. OF ERRORS	No. OF BLUNDERS	COMMENT/CLASSIFICATION/PROBABLE CAUSE
1. HOTEL to GOLF	1	0	In this study, the HOTEL to GOLF segment tended to have an approximately 4,000 foot northeast (right) crosstrack bias for all subjects. In the case of the error, the NAV system error was approximately 3,000 to 4,000 feet, and the pilot had an FTE of 0.5 mile. The resultant tracking error reached a maximum of 6,215 feet right of course.
2. XRAY	3	1	(A) The blunder was caused by the pilot who started his turn 4.0 miles DTW (to XRAY) and turned to the left of waypoint XRAY. The pilot was expected to maintain the 3.0-mile right offset during the turn. (B) The three pilot errors were similar in that they started their turns at the wayline and turned sharply (I.E. at a rate greater than 3°/second). The resultant errors were 7,900, 8,300, and 9,300 feet right of course.
3. WHISKEY to SIERRA	0	1	Pilot blunder caused by CDU keyboard design and/or pilot misinterpretation (see text for discussion).
4. SIERRA to ROMEO	0	1	Pilot blunder caused as a result of the WHISKEY to SIERRA Blunder. After blunder on WHISKEY to SIERRA offset, the pilot did not reset the OBS for the next leg and continued to fly same course heading, eventually the course error resulted in deviation greater then 2.0 miles (see text for discussion).

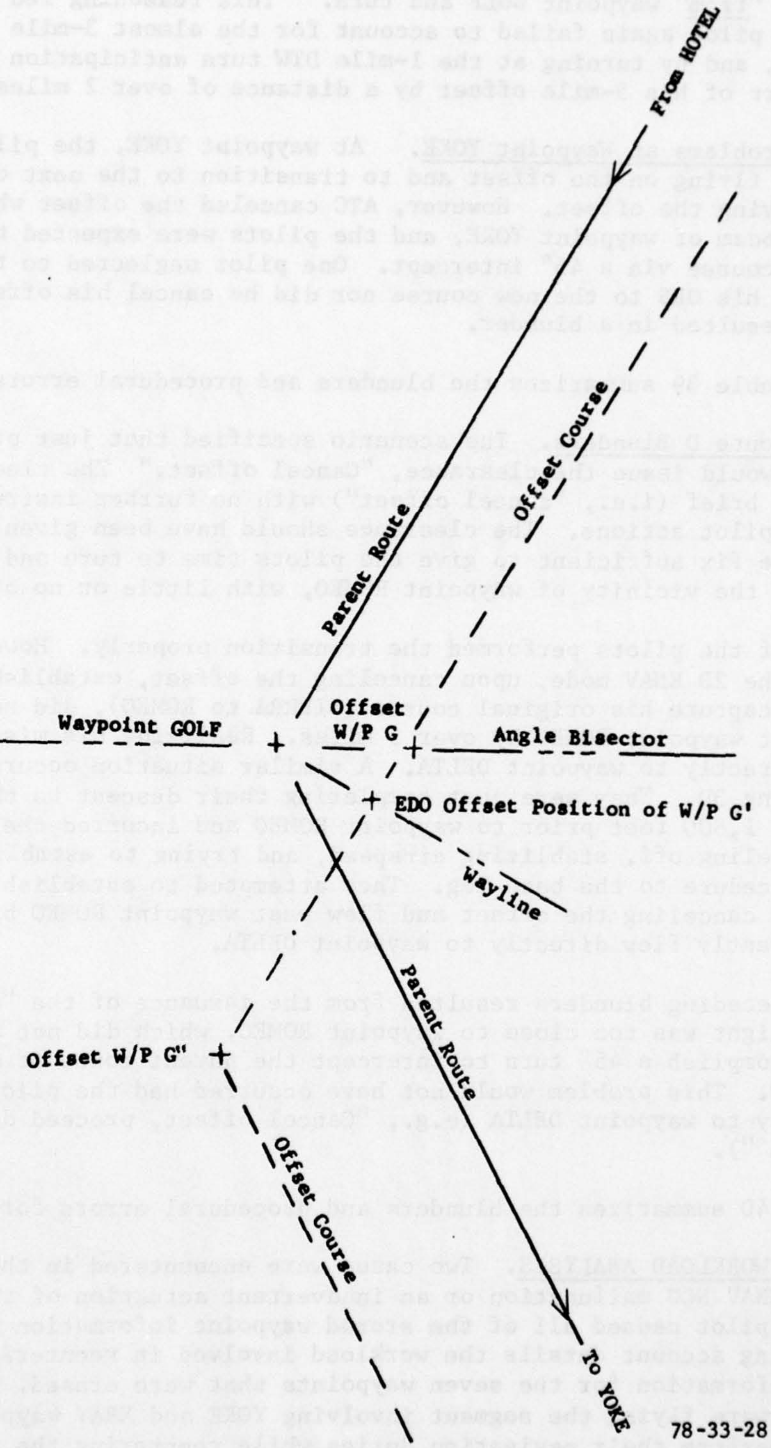

FIGURE 28. ROUTE C TRANSITIONS AT WAYPOINT GOLF

4-miles DTW "from" waypoint GOLF and turn." This reasoning led to a blunder because the pilot again failed to account for the almost 3-mile distance still to be flown, and by turning at the 1-mile DTW turn anticipation point, found himself short of his 5-mile offset by a distance of over 2 miles.

Problems at Waypoint YOKE. At waypoint YOKE, the pilots expected to continue flying on the offset and to transition to the next course and continue flying the offset. However, ATC canceled the offset when the aircraft was abeam of waypoint YOKE, and the pilots were expected to return to the parent course via a 45° intercept. One pilot neglected to turn here. He never reset his OBS to the new course nor did he cancel his offset. Eventually the error resulted in a blunder.

Table 39 summarizes the blunders and procedural errors for Route C.

Data Route D Blunders. The scenario specified that just prior to waypoint ROMEO, ATC would issue the clearance, "Cancel offset." The clearance was purposely made brief (i.e., "cancel offset") with no further instructions in order to observe pilot actions. The clearance should have been given at a distance prior to the fix sufficient to give the pilots time to turn and intercept the base leg in the vicinity of waypoint ROMEO, with little or no overshoot.

Four of the pilots performed the transition properly. However, one pilot flying in the 2D RNAV mode, upon canceling the offset, established 45° intercept angle to recapture his original course (SIERRA to ROMEO), did not reset the OBS, and overshot waypoint ROMEO by over 5 miles. Realizing his mistake, he turned and flew directly to waypoint DELTA. A similar situation occurred with two pilots flying 3D. They were just completing their descent to the desired altitude of 1,800 feet prior to waypoint ROMEO and incurred the additional workload of leveling off, stablizing airspeed, and trying to establish the "cancel offset" procedure to the base leg. They attempted to establish a 45° intercept angle after canceling the offset and flew past waypoint ROMEO by 2.5 miles and subsequently flew directly to waypoint DELTA.

The preceding blunders resulted from the issuance of the "cancel offset" when the flight was too close to waypoint ROMEO, which did not allow sufficient time to accomplish a 45° turn to intercept the parent route at or prior to waypoint ROMEO. This problem would not have occurred had the pilot been told to fly directly to waypoint DELTA (e.g., "Cancel offset, proceed direct to waypoint DELTA ").

Table 40 summarizes the blunders and procedural errors for Route D.

DATA ENTRY WORKLOAD ANALYSIS. Two cases were encountered in the data in which either an RNAV NCU malfunction or an inadvertent actuation of the "ERASE" button by the pilot caused all of the stored waypoint information to be erased. The following account details the workload involved in reentering the required waypoint information for the seven waypoints that were erased. In both cases, the pilots were flying the segment involving YOKE and XRAY waypoints and continued to perform their navigation duties while reentering the required waypoints.

TABLE 39. DATA ROUTE C--ANALYSIS OF BLUNDERS AND PROCEDURAL ERRORS

REGION	No. OF ERRORS	No. OF BLUNDERS	COMMENT, DESCRIPTION, AND POSSIBLE CAUSE
HOTEL-GOLF	2	0	Bias Errors. NSE plus FTE led to bias of 6,100 and 7,600 feet.
GOLF	3	4	Blunders turned short, often at wayline. Two 3D pilots who had large H-G biases (0.5 and 1.25 miles) turned short, but because of their North bias were able to hold inside error limits. The third pilot who had an error started his turn at 1-mile DTW past GOLF, discovered his error, and made a 45° cut to offset GOLF-YOKE course. His maximum error was 7,900 feet.
YOKE	0	1	Failed to make turn at waypoint YOKE when flying 5-mile right offset. Never turned or set OBS until he received the "cancel offset" clearance.

TABLE 40. DATA ROUTE D--ANALYSIS OF BLUNDERS AND PROCEDURAL ERRORS

REGION	No. OF ERRORS	No. OF BLUNDERS	COMMENTS, PROBABLE CAUSE, AND DISCUSSION
HOTEL-GOLF	1	0	Additive bias: FTE and NSE lead to errors of up to 6,700 feet.
GOLF	3	0	Two pilots started their turns late, 1.7 and 2.9 miles DTW past waypoint and overshot 6,200 feet and 8,800 feet. One pilot carried approximately 0.7 FTE which, coupled with 4,000 feet NAV system error resulted in an error of 7,800 feet at GOLF.
YOKE	2	0	1. Pilot did not start offset turn at YOKE, flew straight on 242° course until almost 1-1/4 miles off offset course, then made S-turn cancellation of offset.
			2. Pilot lost all waypoints, busy reentering way-points, overshot return to parent course by 6,600 feet.
ROMEO	1	3	1. Error: late clearance, 1/4 mile past waypoint ROMEO, pilot turned but flew 1.8 miles beyond ROMEO-DELTA course line.
			2. Clearance blunder. Two pilots canceled offset by making S-transition to extension of downwind leg.
			3. Pilot error. "Pilot forgot to cancel offset at base leg" per observer's notes. Made a 60° cut past downwind leg.

In the first case, the pilot was using the 3D RNAV mode and was flying on course. During this segment, the pilot was not required to fly offsets; however, he was assigned an altitude and did climb from 7,000 feet to 12,000 feet using VNAV. The sequence of events was as follows (times represent seconds elapsed from the start of the problem):

1. At time 1465 (prior to entering the segment) the pilot canceled the offset mode by switching the mode selector on switch on the RNAV CDU from offset to enroute mode. Coincident with this action, all of the waypoint information was erased from memory, including the previously entered desired altitude.

2. At time 1478 the pilot reentered the desired altitude (12,000 feet).

3. At time 1547 the pilot put the RNAV system into the entry mode and prepared to reenter the required seven waypoints. The chronology in table 41 presents the time and actions required to reenter the seven waypoints. The total elapsed time used to reenter the seven waypoints was 606 seconds.

For the second case, the pilot was also using the 3D RNAV mode and was flying a 3-mile right offset, having been cleared as follows: "Offset right 3-mile climb to reach 12,000 feet 10 miles past waypoint XRAY," the malfunction occurred at time 1530 without any warning and was not related to any pilot/CDU keyboard actions. At time 1580 the pilot put the RNAV system into the entry mode and prepared to reenter the required seven waypoints. The chronology in table 42 presents the time and actions used to reenter the seven waypoints. The total elapsed time used to reenter the seven waypoints was 655 seconds.

If the preceding time factors used to reenter all lost waypoint information can be considered normal, the reentry of these data constitutes a major time-consuming pilot workload that can have a serious effect on the performance of other necessary pilot functions. The problem would be most acute for a pilot conducting the flight without a copilot to provide assistance. If the loss of RNAV data occurred in actual flight under conditions of time-critical high pilot workload, the prudent pilot would report his dilemma to ATC and abandon his guidance to be radar vectored by ATC.

<u>TERMINOLOGY, PHRASEOLOGY, AND GROUND RULES USED WHEN ISSUING OR RECEIVING AN RNAV CLEARANCE IN THESE TESTS</u>. The following is a list of terminologies used in the RNAV simulation experiments which are unique to RNAV systems:

1. Extend: Proceed on present course/track/offset to a specified point/distance beyond the point where a pilot would normally initiate a preplanned action.

2. Shorten: Proceed on present course/track/offset to a specified point/distance short of the point would normally initiate a preplanned action.

TABLE 41. TIME AND ACTIONS REQUIRED TO ENTER SEVEN WAYPOINTS--FIRST CASE

Start Time	Destination Fix	Action	End Time
1582	XRAY	Entered waypoint XRAY	1621
1659	XRAY	Entered waypoint WHISKEY	1682
1695	XRAY	Started entering waypoint SIERRA (frequency/elevation)	1707
1752	XRAY	Entered waypoint SIERRA	1774
1806	XRAY	Started entering ROMEO--made error. Entered 0.9°. Stopped, probably to reevaluate inputs (frequency, elevation, bearing)	----
1888	XRAY	Finished entering waypoint ROMEO	1912
1920	XRAY	Started entering DELTA (frequency/ elevation)	1922
1944	XRAY	Entered waypoint DELTA	1963
1984	XRAY	Started entering BRAVO	1986
2036	XRAY	Entered waypoint BRAVO	2061
2070	XRAY	H-ALRT light start	----
2086	XRAY	Started OBS reset	2100
2107	XRAY	Started turn	2155
2163	WHISKEY	Entered waypoint ALPHA	2188

TABLE 42. TIME AND ACTIONS REQUIRED TO ENTER SEVEN WAYPOINTS--SECOND CASE

Start Time	Destination Fix	Action	End Time
1589	XRAY	Entered waypoint XRAY	1634
1681	XRAY	Entered waypoint WHISKEY	1722
1737	XRAY	Entered waypoint SIERRA	1751
1774	XRAY	Entered waypoint ROMEO	1783
1850	XRAY	Entered waypoint DELTA	1863
1918	XRAY	H-ALRT light start	----
2044	XRAY	Started OBS reset	2066
2050	XRAY	Started turn	2149
2211	WHISKEY	Entered waypoint BRAVO	2222
2228	WHISKEY	Entered waypoint ALPHA	2244

3. Offset: A desired parallel track left or right of the parent or designated route specified in nautical miles. Note: The term "offset" was also used when the aircraft was flying on an offset; i.e., "maintain present offset to . . .", or it can be combined with "track:" i.e., "extend present offset track to intercept . . ."

4. Distance to waypoint (DTW): The distance in nautical miles measured over the ground from a point directly beneath the aircraft to or from a selected waypoint.

In addition to the RNAV terminologies used in this study, a set of operational RNAV ground rules was established:

1. When given a parallel offset, pilots were expected to continue to maintain the offset along the prescribed course(s) until it was canceled or further instructions were issued by ATC.

2. When instructed to "cancel offset," pilots were expected to return immediately to their parent course using a 45° intercept or vector heading(s) if issued by ATC.

3. All parallel offsets flown with respect to the base leg were to be terminated upon interception of the final approach course.

4. Parallel offsets were to be issued in the following sequence:

   a. Direction (left or right)
   b. Distance (nautical miles)

5. When an ATK point/distance clearance was issued, the new pseudo waypoint location was assigned the same altitude restriction as the parent waypoint.

OBSERVATIONS BASED ON THE DATA OBTAINED FROM THIS EXPERIMENT.

1. The magnitude of the contribution of the OBS setting error to the overall RNAV total system crosstrack error suggests that analog OBS entry is a major limitation to improvement of horizontal tracking precision that can be expected of area navigation systems. This error is not unique to area navigation systems, but is also present in VOR radial navigation systems. It is possible that if OBS settings were accomplished via a digital input directly into the RNAV unit, the angular error due to analog OBS settings could be eliminated, and a more accurate presentation of horizontal position on the CDI needle would result.

2. The RNAV system evaluated in this study was not protected from consequences of power fluctuations and/or extraneous erase signals. Reentry of waypoint data is time consuming and causes the pilot to be distracted from his ongoing tasks. This potential problem area could be resolved by application of state-of-the-art technology.

Addition of RNAV CDU design features such as clear numerics display, prominent decimal point, and a protective guard on the erase switch would relieve pilot workload.

3. Implementation of RNAV into the ATC system will require comprehensive training programs which will take into account interaction between the pilot, the air traffic controller, and the RNAV avionics system.

4. It has been observed during the series of ATC dynamic simulations and cockpit simulations that proficiency on the part of the controller in handling RNAV-equipped aircraft will require appropriate training.

ANALYSIS OF PILOT COMMENTS. At the completion of the four data flights, each of the pilots was given a questionnaire which covered three major areas; RNAV control display unit, pilot procedures, and pilot workload. This analysis of pilot comments will be somewhat broad, with emphasis placed only on significant responses. A summation of the pilots' responses to the questionnaire can be found in appendix D.

RNAV Control Display Unit. The pilots experienced only minor difficulties in entering waypoint information, except as noted previously in the data entry workload section. The most common error was forgetting to activate the proper function switch first.

The "HALRT" light proved of considerable value in alerting the pilot in sufficient time to prepare for waypoint arrival and/or other required pilot actions which center in the waypoint vicinity such as turns, new course settings, and updating.

Numerous adverse comments regarding the CDU layout of the RNAV system tested ranged from its having a very faint decimal point to the relocation of certain switch positions. Two items of major concern were: (1) the "erase" position of the data mode switch is not guarded and it is easy to accidentally erase all entries in the computer; and (2) the waypoint display selector switch and waypoint NAV selector switch sometimes canceled a double waypoint advance (instead of a single advance) when activated once.

Further, the RNAV system used in these tests was discovered to have another potentially dangerous characteristic. Upon entry of a right offset (if the "insert" button was pushed once) the CDI needle would displace in the proper direction (right). However, when the insert button was pushed a second time, occasionally the CDI needle became displaced to the left by an amount equal to the original offset displacement.

Initial left offsets were not influenced by the results of double inserts. It is apparent that the circuitry software logic requires modification to correct this problem.

Pilot Procedures. This section presents an analysis of the pilot responses to questions related to pilot charts, 2D RNAV and 3D VNAV operations, turns, and offsets.

The pilots were almost unanimous in their approval of numbering the waypoints on their charts to coincide with their numbered waypoint entries.

There was some obvious difference between 2D and 3D flights, which centered mainly around climbing and descending to the prescribed altitudes. Most pilots (13 out of 16) preferred to reach altitudes as soon as possible, rather than at the waypoint, since it reduced pilot workload at the waypoint.

Since the pilots preferred to reach altitudes as soon as possible, as was expected, they also preferred to climb/descend at a rate commensurate with aircraft performance rather than fly a computed VNAV flightpath angle (which rarely exceeded 2.5°) that required a low climb/descent rate and therefore consumed more time.

The pilots were told to use turn anticipation and were briefed on one method. However, the pilots were divided in their application of turn anticipation techniques.

The use of inappropriate techniques resulted in several undershoot/over shoot problems for certain offset turns and interceptions.

Additional problems were encountered by those pilots flying 3D offset climb/descent profiles utilizing an along-track point on the next course. At the turn point, a precise RNAV entry procedure had to be followed, or a loss of vertical guidance (FPA) to the along-track point occurred. When this happened, the remainder of the climb/descent segment had to be flown without VNAV and along-track assistance.

Furthermore, some overshoot problems were encountered during offset turns with no along-track guidance. This was basically a pilot procedural problem in estimating the DTW point to turn and was most noticable on turns of more than 90° where the turn was on the same side of the course as the offset.

Finally, due to the short (6-mile) base leg, and the inclusion of left and right offsets flown on the base leg, some pilots experienced difficulties tracking on base leg offsets and the subsequent interception of the final approach course. These difficulties resulted from insufficient planning and culminated in high pilot workload.

Pilot Workload. In response to the questions regarding workload, there was a diversity of opinions expressed by the pilots. Most pilots had no trouble understanding the ATC phraseology. The ATC communication workload was considered normal, while overall cockpit workload was regarded as moderate. When asked if a single pilot under IFR conditions could utilize an RNAV system, similar to the system tested in this study, 50 percent of the pilots indicated that a single pilot could utilize such a system without additional avionics equipment; the other 50 percent indicated that it should not be used without a flight director and autopilot. Seven of these eight pilots stated that the cockpit workload was moderate to heavy with the existing avionics configuration.

SUMMARY OF RESULTS

Examination of the data has produced the following results.

PHASE I: WITH FLIGHT DIRECTOR.

1. During both the planned and impromptu segments of the flights, 2 σ TSCT and 2 RMS TSCT steady state tracking data for centerline and offset tracking were within a $\pm$1.5 nautical mile error range.

2. Lag times were found to be a function of situation (defined as a combination of the geometry of the parent and offset courses), turns required, actual flight configuration of the simulated aircraft, the pilot, and the specific clearances.

3. Lag times for pilot response to ATC RNAV clearances were not distributed as a gaussian (or normal) random variable, and no general statistical fit was apparent between the experimental data and any tested particular probability density function model.

4. It was possible to predict three graduated intervals of lag time by analyzing an ATC instruction and the conditions which existed at the time the instruction was issued. These intervals may be classified generally as follows: short (6 to 10 seconds), intermediate (16 to 25 seconds), and long (30 to 50 seconds).

5. Based on the results of the linear model evaluations, the information presented by the flight director command bars (BSB and PSB) during steady state tracking did not significantly contribute to increased TSCT error.

6. The linear regression model, based on the obtained regression coefficients and the mean and sigma TSCT data, shows that the FTE and OBS SET variables are the major components of TSCT error.

7. The calculated RSS statistic proved to be an over-conservative estimator of TSCT errors.

PHASE II: WITHOUT FLIGHT DIRECTOR.

1. There were no statistically significant differences in either TSCT or FTE measures for the 2D and 3D flights.

2. During both the planned and impromptu segments of the flights, the 2 σ TSCT and 2 RMS TSCT steady state tracking data for centerline and offset tracking were within a ±1.5 nautical mile error range.

3. Summary tracking data, in terms of TSCT variability, were more precise for centerline tracking than for offset tracking.

4. Both the 2σ TSCT and 2 RMS TSCT summary data for centerline turns never exceeded a ±2.0 nautical mile error range.

5. The use of along-track offset procedures in conjunction with altitude clearances increased the 2σ and 2 RMS TSCT tracking variability.

6. The use of along-track offset procedures, to arrive at a specified altitude over a waypoint or a specified along-track distance, increased pilot workload.

7. Turns made while maintaining a parallel offset resulted in TSCT errors which exceeded ±2.0 nautical miles when an along-track offset altitude procedure was implemented.

8. The 2σ and 2 RMS RNAV TSCT final approach data resulted in errors that were less than the ±0.9 nautical mile criterion specified in table E-4, appendix E of AC 90-45A. Two blunders which occurred on the base leg were the exceptions.

9. RNAV approaches were conducted on final approach within the limits specified by AC90-45A.

10. Based upon the regression coefficients obtained from the derived linear models, and the mean and σ TSCT summary data, the FTE and OBS SET variables were again found to be the major components of TSCT.

11. A considerable number of the blunders and procedural errors which occurred can be attributed to the wayline logic of the tracking algorithm used by the RNAV system tested. This logic made it difficult to anticipate turns for larger (greater than 90°) turn angles under some offset configurations.

12. The "HALRT" light was found to be of value to the pilot in anticipating turns while flying on centerline. It was found to be of little value when flying in the offset mode.

13. In the event of inadvertent erasure of the stored waypoint data, excessive pilot workload was required to reenter the data.

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SIMULATION STUDY OF THE OPERATIONAL CHARACTERISTICS OF A TWO/TH--ETC(U)
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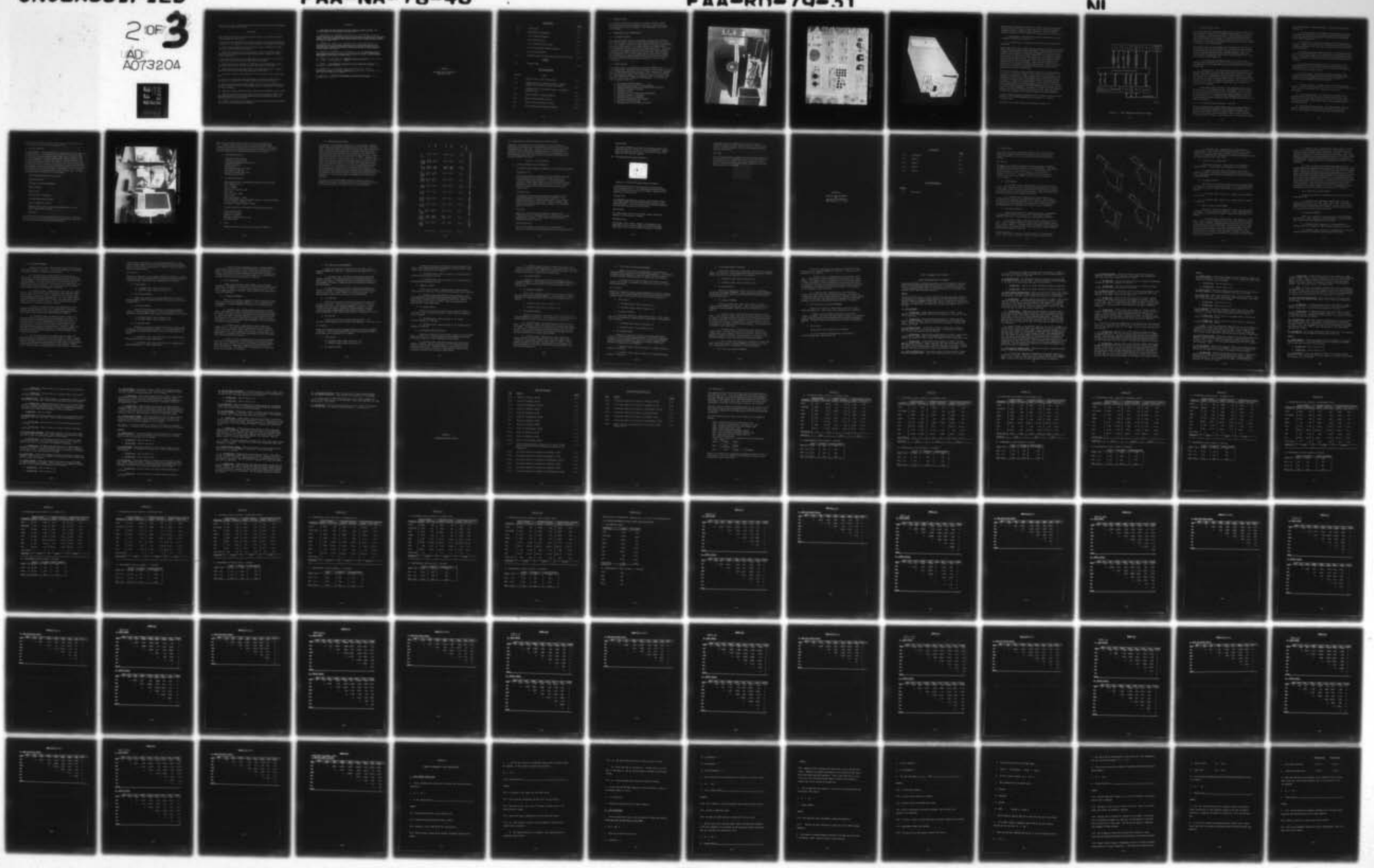


14. As in the case of VOR navigation, RNAV OBS setting errors were influenced by the use of analog input devices.

CONCLUSIONS

The following conclusions are based upon the results of the GAT-2 simulator tests described in this report.

1. The pilot response time to an ATC RNAV clearance will be influenced by the complexity of the command and the functions required to implement that command.

2. Total system crosstrack error will be most greatly influenced by flight technical errors and OBS setting errors.

3. Functional integration of a flight director system and an RNAV system is critical and may require extensive engineering efforts in order to insure system compatability.

4. RSS statistics computed for an RNAV system can be expected to be an over-conservative estimator of that system's TSCT error budget.

5. During steady state tracking, an ARINC Mark 13 level RNAV system can be operated within the TSCT and FTE tolerances specified by AC 90-45A.

6. During centerline turns, ARINC Mark 13 level RNAV system can be operated within the TSCT and FTE tolerances specified by AC 90-45A.

7. Centerline tracking can be expected to be less variable than offset tracking.

8. The use of along-track offset procedures in conjunction with altitude clearances will increase TSCT tracking variability and pilot workload.

9. RNAV tracking algorithms should provide the pilot with the capability to properly anticipate turns of various angles under all conditions of centerline or offset tracking.

10. RNAV data storage systems require protection from inadvertent loss of data.

11. RNAV ATC clearances should be simple (requiring a minimum of pilot data entry/manipulation) to avoid misinterpretations and undesireable delays in compliance with the instruction(s).

12. ATC RNAV instructions which specify along-track offsets containing altitude restrictions will increase pilot workload.

REFERENCES

1. Application of Area Navigation in the National Airspace System, FAA/ Industry RNAV Task Force Report, February 1973.

2. DeBaryshe, B. D., Eldredge, D., Crook, W. G., and Crimbring, W. R., A Simulation Study of Horizontal Offsets, Offset Procedures, and Vertical Profiles Using a 2D/3D Multi-Waypoint RNAV System Coupled with a Flight Director System, Data Report, April 1978.

3. Eldredge, D., Crook, W. G., Debaryshe, B. D., and Crimbring, W. R., A Stimulation Study of Horizontal Offsets, Offset Procedures, and Vertical Profiles Using a 2D/3D Multiwaypoint RNAV System Without a Flight Director, Iterim Report, July 1978.

4. Goldberg, B., Eldredge, D., and Crimbing, W. R., An Evaluation of Turn Anticipation Techniques and Offset Flying Procedures Using a Single-Waypoint RNAV System, Final Report, January 1979.

5. Draper, N. R. and Smith, H., Applied Regression Analysis, 1st ed., Wiley, N. Y., 1966. Particularly pp. 171-172.

6. Siegal, S., Nonparametric Statistics for the Behavioral Sciences, N. Y., McGraw-Hill, 1956. pp 68-75.

7. Efroymson, M. A., "Multiple Regression Analysis," pp. 191-203, Mathematical Methods for Digital Computers, V 1, Ralston, A. and Wilf, H. S., eds., 1st ed., Wiley, N.Y., 1960.

8. Davies, R. G., Computer Programming in Quantitative Biology, N. Y., Academic Press, 1971.

APPENDIX A

EQUIPMENT USED IN THE RNAV
SIMULATION STUDY

CONTENTS

TABLE

ILLUSTRATIONS

A. 1 INTRODUCTION

The simulation equipment consisted of a cockpit simulator, RNAV system flight director system, flight instruments, computerized data collection system, and a X-Y plotter. This equipment is described in detail below.

A. 2 DESCRIPTION OF EQUIPMENT

A. 2. 1 Cockpit Simulator

All testing was done using the Singer-Link General Aviation Trainer GAT-2B twin-engine, general aviation trainer facility shown in Figure A-1. The cockpit is mounted on a two-degree-of-freedom, hydraulically operated, motion system. The aileron and elevator flight controls are hydraulically activated to provide realistic control feel. The trainer is equipped for complete instrument flight rule (IFR) flight capability, including dual navigation communication (NAV/COM) instrumentation and a transponder. It is also equipped with a Collins Radio Company FD-109(V) integrated flight director system and an EDO Commercial Corporation TCE-71A area navigation system, as shown in Figures A-2 and A-3.

A. 2. 2 RNAV System

The RNAV system is an Aeronautical Radio Inc. (ARINC) Mark 13 level configuration, designed to provide guidance in the enroute, terminal area, and final approach phases of flight. It has capability for Standard Instrument Departure (SID), Standard Terminal Arrival Route (STAR), and cruise flight programming. In addition, it allows navigation with respect to a selected or computed vertical profile. The operational features of this system are:

a. 20-waypoint storage capacity
b. Automatic horizontal and vertical guidance
c. Manual flightpath angle and computed flight path angle
d. Automatic frequency selection
e. Manual data entry
f. Automatic time to waypoint and groundspeed
g. Automatic distance to waypoint
h. Parallel offset track capability
i. Conventional flight director guidance
j. Self-check data monitoring
k. Incorporation of slant range correction

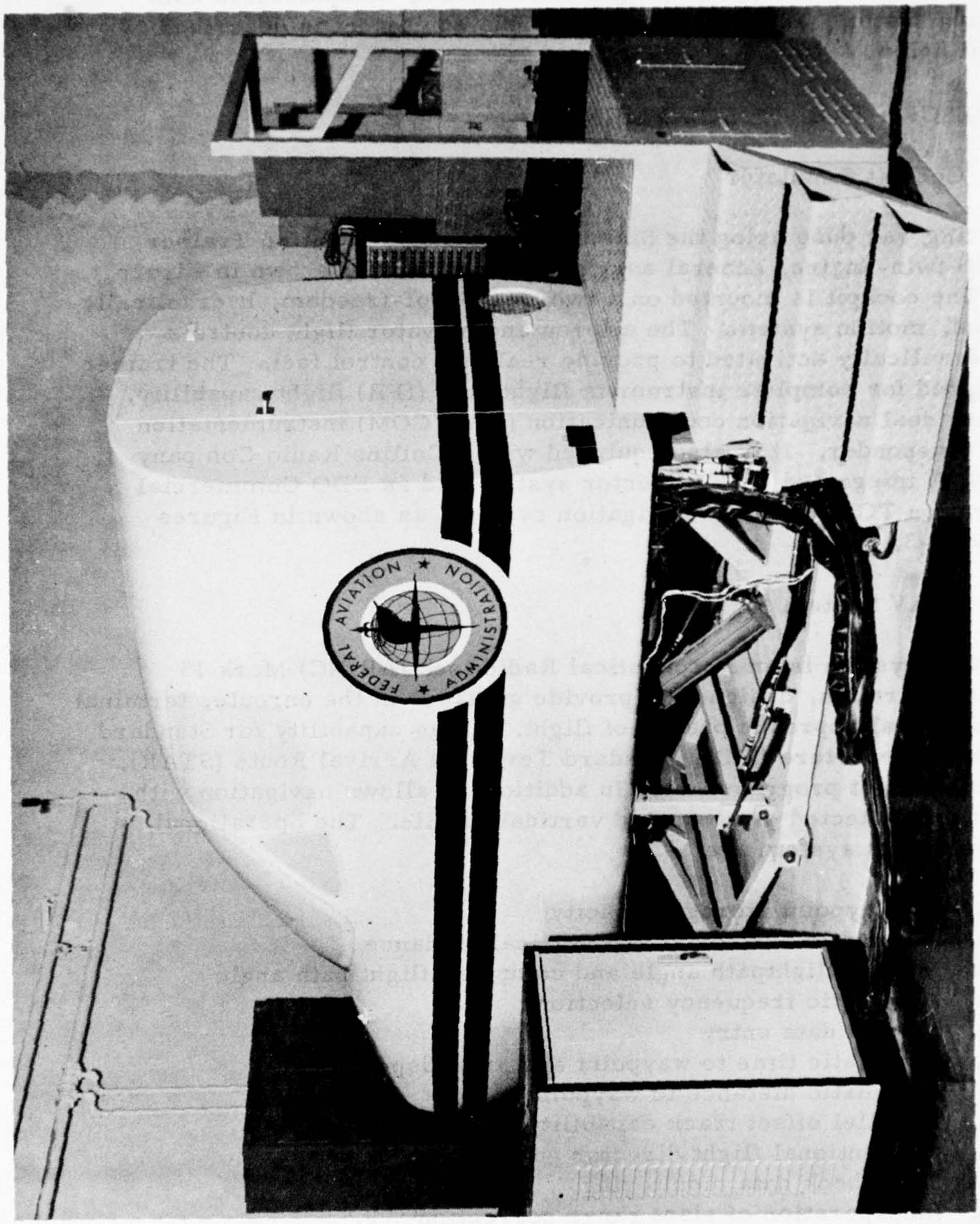


FIGURE A-1. EXTERIOR VIEW--GAT-2B SIMULATION

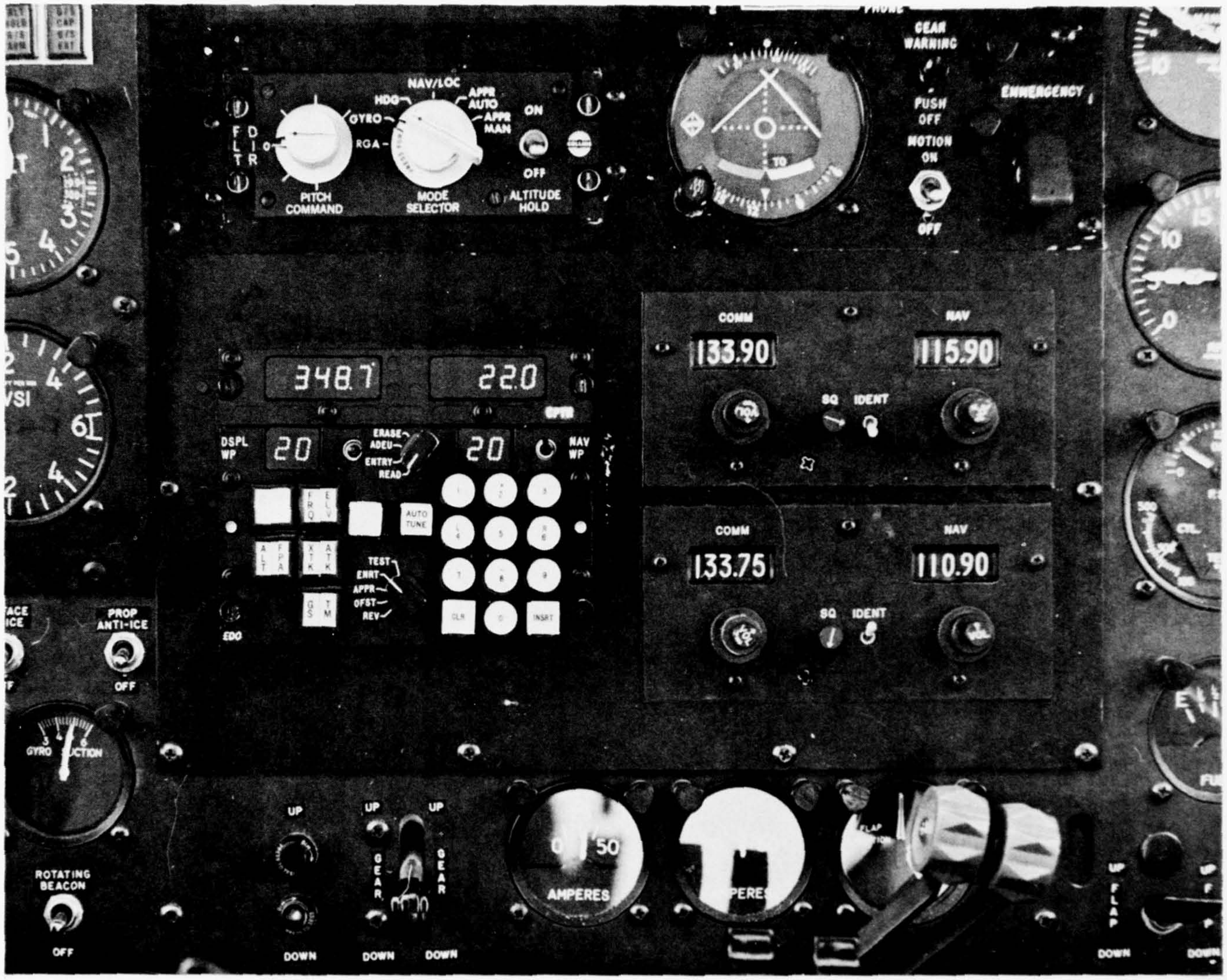


FIGURE A-2. ARINC MARK 13 LEVEL RNAV SYSTEM--CONTROL DISPLAY UNIT MONITORED IN GAT-2B COCKPIT

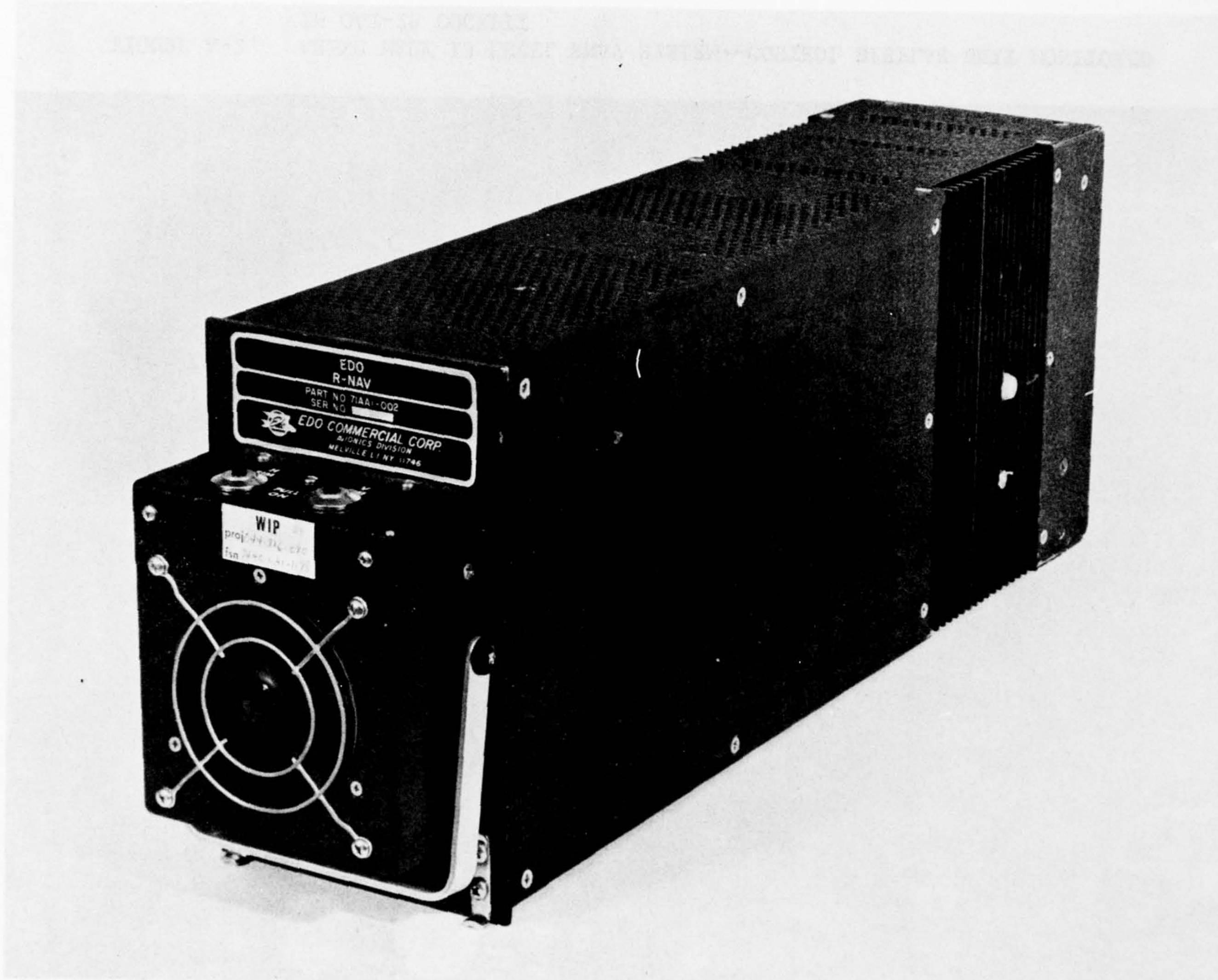


FIGURE A-3. ARINC MARK 13 LEVEL RNAV SYSTEM--NAVIGATION COMPUTER UNIT

The navigation computer unit (NCU) of the RNAV system accepts inputs from the very high frequency omnirange (VOR), distance measuring equipment (DME), compass heading, altimeter, and true airspeed signals; and processes these signals to provide guidance with respect to:

1. A preplanned, prestored three-dimensional RNAV route leg or approach/departure procedure, or

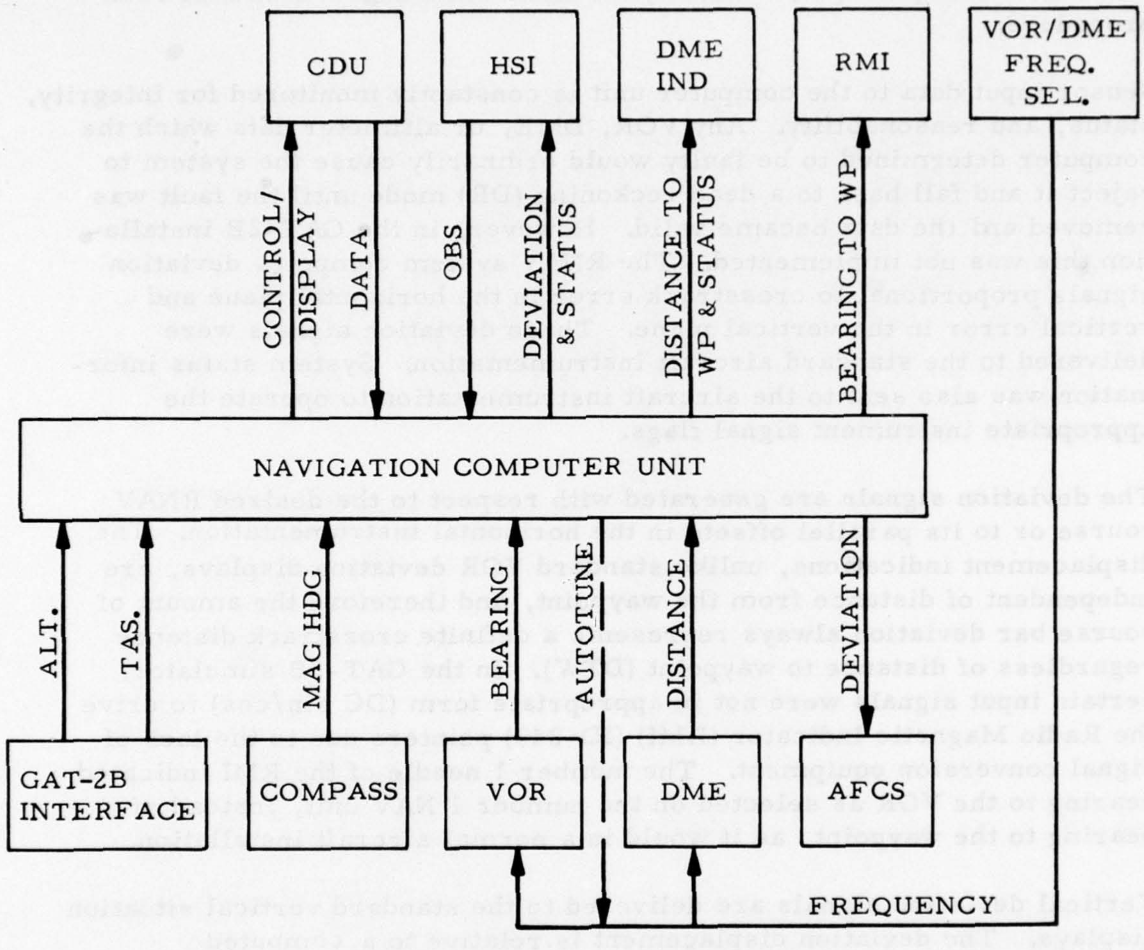
2. An impromptu, manually inserted route leg or terminal area procedure.

Sensor input data to the computer unit is constantly monitored for integrity, status, and reasonability. Any VOR, DME, or altimeter data which the computer determined to be faulty would ordinarily cause the system to reject it and fall back to a dead reckoning (DR) mode until the fault was removed and the data became valid. However, in the GAT-2B installation this was not implemented. The RNAV system computes deviation signals proportional to crosstrack error in the horizontal plane and vertical error in the vertical plane. These deviation signals were delivered to the standard aircraft instrumentation. System status information was also sent to the aircraft instrumentation to operate the appropriate instrument signal flags.

The deviation signals are generated with respect to the desired RNAV course or to its parallel offsets in the horizontal instrumentation. The displacement indications, unlike standard VOR deviation displays, are independent of distance from the waypoint, and therefore the amount of course bar deviation always represents a definite crosstrack distance regardless of distance to waypoint (DTW). In the GAT-2B simulator, certain input signals were not in appropriate form (DC sin/cos) to drive the Radio Magnetic Indicator (RMI) (ID-249) pointers due to the lack of signal conversion equipment. The number 1 needle of the RMI indicated bearing to the VOR as selected on the number 1 NAV unit, instead of bearing to the waypoint, as it would in a normal aircraft installation.

Vertical deviation signals are delivered to the standard vertical situation displays. The deviation displacement is relative to a computed vertical profile.

The RNAV system block design is presented in Figure A-4.



78-33-4

FIGURE A-4. RNAV INTERFACE--SYSTEM BLOCK DIAGRAM

A. 2. 3. Flight Director System

The Collins FD-109(V) integrated flight director system consists of an attitude director indicator, a horizontal situation indicator, and instrument amplifier, a roll steering computer, a pitch steering computer, and a flight director control panel. The attitude direction indicator (ADI) and horizontal situation indicator (HSI) are mounted on the instrument panel. The system is controlled by the selector switches mounted on the system mode control panel.

The ADI features a 3D color display of aircraft attitude with steering commands to rotate for takeoff and climb; maintain a desired attitude, capture and hold a desired altitude, heading, localizer, VOR, or tactical air navigation (TACAN) course; and automatically capture and descend along the glideslope beam to the runway touchdown zone. The main features of this display are:

1. Aircraft symbol and attitude display. The fixed, delta-shaped symbol represents the aircraft. Aircraft pitch and roll attitudes are displayed by the relationship of the aircraft symbol to the movable attitude tape.

2. Command bars. The command bars display computed bank and pitch commands; these bars move up or down to command the pitch attitude required to maintain the desired vertical situation. The bars roll right or left to command the right or left turn required to capture and maintain a selected heading or radio course, such as capturing and tracking a VOR radial. To satisfy the commands, the aircraft is maneuvered so that the aircraft symbol is "flown into" the command bars until the two are aligned.

3. Glideslope pointer and scale. The glideslope pointer represents the center of the glideslope beam and displays vertical displacement of the aircraft from beam center. This pointer is in view only if the navigation receiver is tuned to an instrument landing system (ILS) localizer frequency, or if flying an RNAV flightpath angle. This is a raw glideslope deviation information only, the unprocessed output of the glideslope receiver.

A. 2. 3. 1 Horizontal Situation Indicator - 331A-8H

The Horizontal Situation Indicator (HSI) displays aircraft position and heading with respect to magnetic north and selected heading, slant range in nautical miles (nmi) to a selected DME or TACAN station, digital course readout, lateral deviation, relative bearing, direction to a selected VOR, TACAN, or localizer course, and vertical deviation from the glideslope or flight path angle. The main features of this display are:

1. Aircraft symbol. When related to the movable parts of the horizontal situation indicator, the fixed, miniature aircraft symbol shows aircraft position in relation to the azimuth card and ground-based radio navigation aids.

2. Azimuth card. Heading information from a gyrostabilized magnetic compass is displayed by the rotating azimuth card. Aircraft heading is indicated on the card under the lubber line at the top center of the instrument.

3. Heading marker and heading-set knob. The heading marker is set to the desired heading on the azimuth card by rotating the "HDG" knob. In the heading mode, the command bars in the attitude direction indicator display bank commands to turn to and maintain the selected heading.

4. Course arrow and course-set knob. The course arrow is the yellow arrow that is rotated against the azimuth ring by the "COURSE" knob to a magnetic course that coincides with the desired VOR or TACAN or localizer course.

5. Course readout. The course counter in the upper right corner of the instrument improves the accuracy and speed of course selection by giving a digital readout on the VOR or TACAN or localizer course indicated by the course arrow.

6. Distance readout. A digital readout of TACAN slant range distance in nautical miles (DME), and slant range corrected distance to way-line is given by the readout in the upper left corner of the instrument.

7. Course deviation bar. The HSI course deviation bar has two dots (at 5/16 inch and 5/8 inch) on either side of center. This distance of $\pm$ 5/8 inch represents $\pm$ 4 nmi in the crosstrack dimension for the enroute mode, and $\pm$ 1 nmi in the crosstrack dimension for the approach mode.

8. Glideslope deviation pointer. The HSI glideslope deviation pointer has two dots (at 5/16 inch and 5/8 inch) above and below center. This distance of $\pm$ 5/8 inch represents $\pm$ 600 feet in the

vertical track dimension for the enroute mode, and ± 300 feet in the vertical track dimension for the approach mode.

A. 2. 4 Data Collection

The Xerox XDS-530 computer (Figure A-5) interfaces with the GAT-2B cockpit simulator. The software used directs the computer to read into memory analog and digital signals using analog-to-digital (A/D) conversion equipment and direct input/output (DIO) equipment. The data are collected on magnetic tape, with a 1-second clock interrupt used to control system timing. The format on the data collection tape consists 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 are 180 words in length. The header record is created from card input at the beginning of each GAT-2B data run. The information input via the header record is as follows:

Label which identifies the type of test

Date (Mo:Day:Yr)

Problem start time (Hr:Mn:Sc)

Subject number

Subject name

Flight number (sequential)

Aircraft identification (ACID)

Subject replication number

Experimentation design matrix interexperimental variable number and number of levels

Comments

These cards have a specific format which is easy to use, reasonably flexible, and serves to identify the data at data reduction time, since these data are recorded directly on the data tapes.

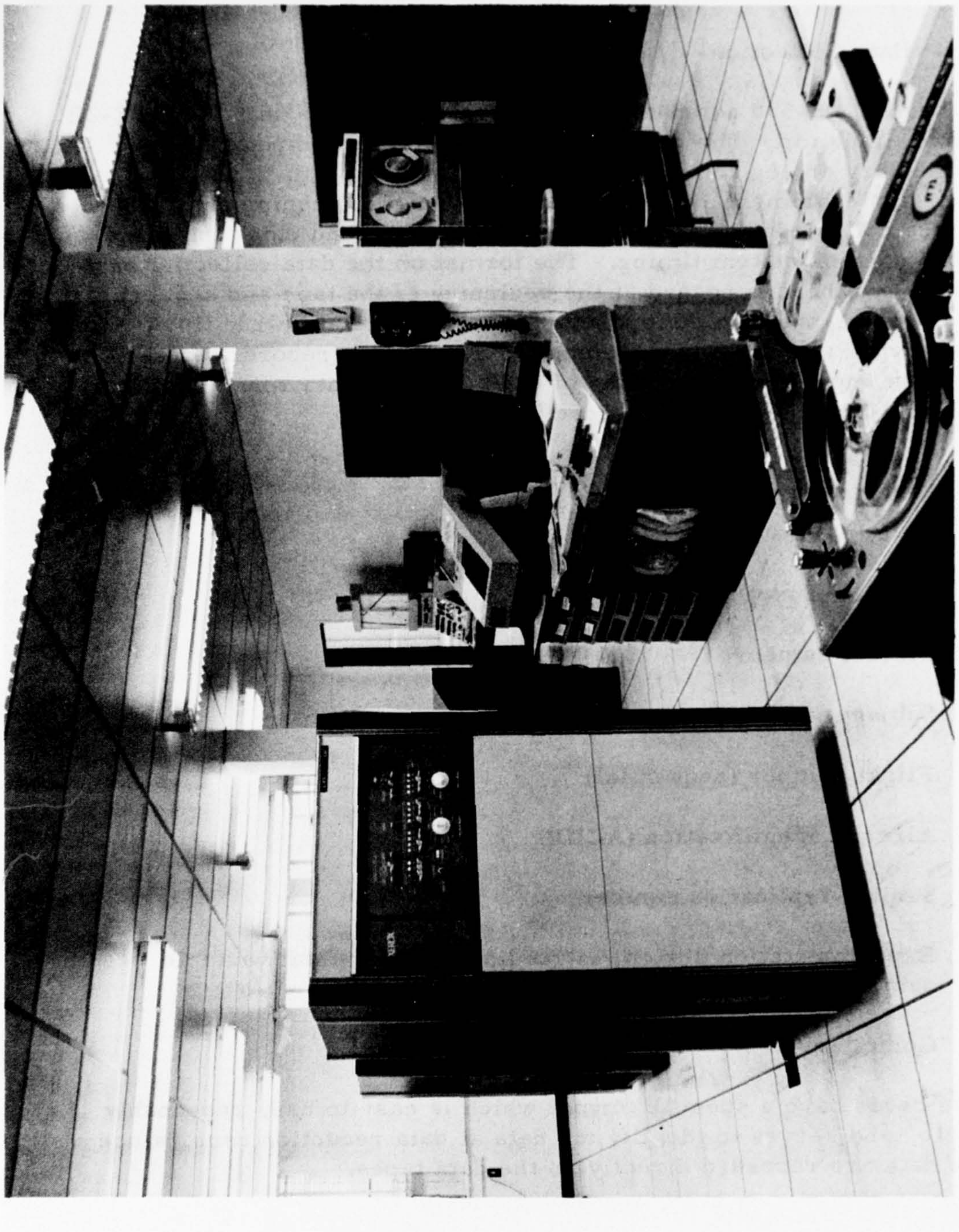


FIGURE A-5. XDS-530 MINICOMPUTER SYSTEM

Each data item within a data record is a 16-bit, fixed-point word (i. e., a digital representation of the raw-from analog and digital voltages) as measured from the GAT-2B interface devices. Provisions have been made for up to 180 data items to be recorded every second. For this experiment, the following data items were recorded:

1. Aircraft parameters:

   X position of the GAT-2B
   Y position of the GAT-2B
   Z position (altitude) of the GAT-2B
   Indicated airspeed
   Wind velocity
   Heading (earth axis yaw angle)
   Aircraft axis roll rate
   Aircraft axis pitch rate, and
   Indicated rate of climb

2. Navigation parameters:

   NAV frequency No. 1 (connected to autotune on RNAV unit)
   NAV frequency No. 2
   Rho - (RNAV)
   Theta - (RNAV)
   Course-set knob OBS - HSI
   CDI - HSI
   To/from arrow - (HSI)
   DTW - (HSI)
   Glideslope Pointer - (HSI)
   Desired flightpath angle (manually entered or computed)-(RNAV)
   Desired altitude - (RNAV), and
   Navigation waypoint number - (RNAV)

3. Computed parameters (Computer Generated Parameters):

   Crosstrack deviation
   Along track deviation
   Distance to wayline
   Distance to angle bisector, and
   Segment number

4. Time:

   Elapsed time from 1-second clock interrupt - XDS-530

5. RNAV parameter table:

In addition to all of the data collected on a 1-second basis, different types of data are collected directly from the RNAV, NCU, and CDU units. These data relate to the input and output operations that result from the pilot seeking information or entering information via the CDU, and from the automatic status monitoring of the RNAV NCU. The data in this table are in the form of time tags which are created every time an item is either turned "ON" or "OFF." Initially, all values in the table are set to a minus one (-1). This value is replaced with a time tag that represents the initial time of occurrence of an item. A second time tag in a succeeding block represents the time at which the item is terminated. The time tag is based on elapsed time from the 1-second clock interrupt in the XDS-530B and is consistent with the regular data record time base; therefore, it can be correlated with ongoing aircraft navigation and computed parameters. An example of this RNAV parameter summary table is presented in Figure A-6. This summary table is computed at the end of every segment.

In addition to the GAT-2B/XDS-530B data collection system, an Electronic Associates Incorporated (EAI-1131) X-Y plotter was used to track the progress of the flight over the prescribed route.

1	TEST ØFSET APPR	ERASE ENTRY READ	HALRT DR RMS	VØR DME HDG	WPNAV WPDIS WPU/D	XTK XTKL XTKR	ATK ATK+ ATK-	CLEAR FREQ ELEV	INSERT BRG DIST	VNAV ALT FPA	AUTØ GS/TM TEST	SEG	
Q	-1	-1	575	-1	-1	-1	-1	604	605	345	345	3	
	-1	345	-1	-1	-1	-1	-1	-1	-1	405	-1	3	ØN
Q	-1	404	-1	-1	345	-1	-1	-1	-1	345	345	3	
Q	-1	-1	634	-1	-1	-1	-1	605	606	-1	-1	3	
	-1	404	-1	-1	-1	-1	-1	-1	-1	603	-1	3	ØFF
Q	-1	603	-1	-1	-1	-1	-1	-1	-1	404	-1	3	
Q	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	3	
	-1	603	-1	-1	-1	-1	-1	-1	-1	604	-1	3	ØN
Q	-1	-1	-1	-1	-1	-1	-1	-1	-1	405	-1	3	
Q	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	3	
	-1	-1	-1	-1	-1	-1	-1	-1	-1	605	-1	3	ØFF
Q	-1	-1	-1	-1	-1	-1	-1	-1	-1	603	-1	3	
Q	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	3	
	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	3	ØN
Q	-1	-1	-1	-1	-1	-1	-1	-1	-1	605	-1	3	

77-10-6

Figure A-6 RNAV PARAMETER SUMMARY TABLE - FROM DATA REDUCTION AND ANALYSIS PRINTOUT

A. 3 Flight Director Warning Flags and Corrective Action

Although a few flight director system failures occured during the experiment, these flights were immediately terminated and rerun with full flight director capability. However, during normal operation with a flight director should certain malfunctions occur, limited system operation can be accomplished with certain of the warning flags in view. The following listing calls out the flag in view and the information that remains reliable in each case.

Table A-1 - Warning Flags

A. 329 B-8G attitude director indicator

The 329B-8G flag-display is explained in the following paragraphs.

Glideslope Flag

The GS flag indicates a malfunction of the glideslope receiver or the reception of an unreliable glideslope signal at the selected localizer (ILS) frequency. Vertical commands received in APPR modes cannot be used, but lateral command information in the HDG or NAV/LOC modes is still correct. Attitude, heading, and VOR/LOC position information can still be used.

Computer Flag

The CMPTR flag monitors the data inputs applicable to the selected flight director system mode of operation. If the CMPTR flag appears, command information is lost, and the ADI command bars go out of view. Attitude, heading, radio position, and glideslope information continues to be displayed and is still correct.

Gyro Flag

Appearance of the GYRO flag indicates a failure in the vertical reference or attitude circuits. Attitude and command information is unusable. Radio and heading information is still displayed and is correct.

Rate-of-turn Flag

The R/T flag appears when rate-of-turn information is incorrect. All command and attitude information is still correct.

Runway Flag

The runway (RWY) flag circuits are functioning whenever the navigation receiver is tuned to a localizer frequency. Appearance of the flag does not drive the command bar out of view unless the NAV flag also appears.

B. 331-SH Horizontal Situation Indicator

Figure A-7 331A-SH Horizontal Situation Indicator

Limited flight director system operation is still possible with some flags in view. The following discussion describes various failures which cause flags to appear, indicates which flight data is still reliable.

Heading Flag

The HEADING flag indicates a failure in the compass system. All heading display and command information must be considered unreliable. For terminal operation, VOR/LOC deviation and glideslope information is still correct.

Miles Shutter

The miles shutter conceals the MILES counter when tacan distance is not available or reliable.

Glideslope Flag

The GS flag, when visible, indicates a malfunction of the glideslope receiver or the reception of an unreliable glideslope signal at the selected localizer frequency. Vertical commands received in APPR modes cannot be used, but command information in the HDG or NAV/LOC modes is still correct. Attitude, heading, and NAV/LOC position information can still be used.

NAV Flag

The NAV flag indicates unreliable lateral deviation information. This could indicate a malfunction in the tacan or the VOR, or it could mean an unreliable radio signal. Appearance of the flag is a warning that all lateral deviation displays and the ADI roll commands are unreliable.

APPENDIX B

DETAILED ROUTE CLEARANCES
AND
EXPECTED PILOT RESPONSES:
DATA ROUTES A, B, C, AND D

CONTENTS

ILLUSTRATIONS

B. 1 Introduction

This section provides a detailed description of the ATC clearances which were issued and the particular actions that the pilots were expected to perform, based on the ATC clearance using the RNAV system.

B. 2 Route A

The pilots were allowed to eliminate entering waypoints JULIETTE and INDIA for their takeoff/climbout to waypoint HOTEL. This option was exercised for all four routes; A, B, C, and D (Figure B-1). Prior to takeoff, the pilots were cleared to "cross waypoint HOTEL at 3,500 feet." After setting OBS (219°) and setting the RNAV system to waypoint HOTEL, pilot actions were expected to be as follows:

1. After takeoff:

a. 2D RNAV mode: Flight director mode selector in "NAV-LOC." Climb manually at their own desired climb rate at an airspeed of 140 knots. Adjust the pitch command control to position the command bars on the ADI to a desired climbing attitude. Follow command bars for horizontal tracking to maintain course 219°.

b. 3D RNAV mode: Flight director mode selector in "APPR-AUTO," and VNAV selector button activated. Enter altitude (3,500 feet) and flightpath angle (FPA).[1] Fly climb profile at 140 knots by reference to command bars for horizontal and vertical guidance. Glideslope pointers on HSI/ADI can be used for cross reference.

2. At waypoint HOTEL

After setting OBS (300°), completing the turn, and updating to waypoint GOLF, pilots were cleared to "offset right 3 miles--maintain 3,500 feet." Pilot actions were expected to be as follows.

a. 2D RNAV mode: Flight director mode selector in "NAV-LOC." Enter crosstrack (XTK) of 3 miles right, and set RNAV system mode switch to "OFST." Fly flight director command of 45° to intercept heading, center CDI needle and fly 3-mile right offset. Engage altitude hold switch to maintain 3,500 feet.

[1]Pilot causes RNAV computer to calculate FPA by pressing "FPA" button. This action is indicated herein by the term "enter FPA."

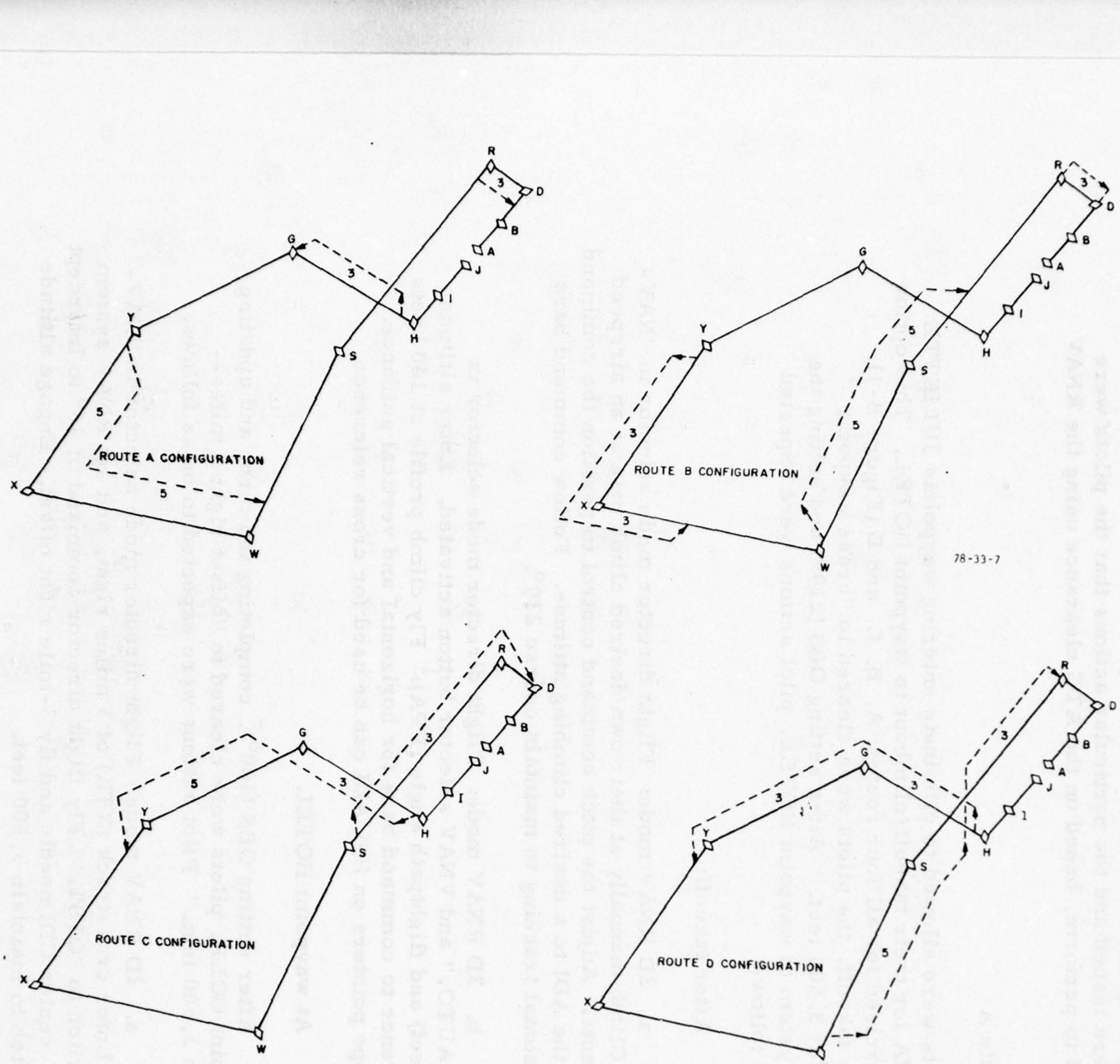


FIGURE B-1. THE FOUR OFFSET ROUTE STRUCTURES EVALUATED IN THIS EXPERIMENT

b. 3D RNAV mode: Flight director mode selector in "APPR-AUTO," and VNAV selector button activated. Enter cross-track (XTK) of 3 miles right and set RNAV system mode switch to "OFST." Fly flight director command of 45° intercept heading to center CDI needle and fly 3-mile right offset.

3. 3nmi DTW to waypoint GOLF

Pilots were cleared to "cancel offset, cleared direct to waypoint GOLF." Pilot actions were expected to be as follows:

a. Pilots would turn RNAV system mode switch from "OFST" to "ENRT," and center the CDI needle by means of the OBS knob. Pilots then would follow the command bars to turn and fly direct to waypoint GOLF.

4. At waypoint GOLF

The Pilots were cleared to "climb to cross waypoint YOKE at 7,000 feet--report over waypoint YOKE." After setting OBS (242o) and updating to waypoint YOKE, pilot actions were expected to be as follows:

a. 2D RNAV mode: Same as 1a, except reference altitude is 7,000 feet.

b. 3D RNAV mode: Same as 1b, except reference altitude is 7,000 feet.

5. After passing waypoint YOKE

Pilots were cleared to "offset left 5 miles, climb to reach 12,000 feet, 10 miles past waypoint XRAY." After setting OBS (212°) and updating to waypoint XRAY, pilots' actions were expected to be as follows:

a. 2D RNAV mode: Flight director mode selector in "NAV-LOC." Enter crosstrack (XTK) of 5 miles left, and set RNAV system mode switch of "OFST." Fly flight director command bars to 45° left intercept heading to center CDI needle. Climb manually at a desired climb rate at an airspeed of 140 knots and adjust the pitch command control to position command bars to desired climb attitude. Fly command bars to maintain 5-mile left offset. Maintain 5-mile left offset around corner at waypoint XRAY to 10 miles past waypoint XRAY, and level at 12,000 feet.

b. 3D RNAV mode: Flight director mode switch in "APPR-AUTO," and VNAV selector button activated. Enter crosstrack of 5 miles left, and set RNAV system mode switch to "OFST." Fly flight director command of 45° intercept heading to center CDI needle. Enter altitude (12,000 feet), and alongtrack (ATK) of plus (+) 10. Enter flight-path angle (FPA), and fly flight profile at 140 knots by reference to command bars. Glideslope pointers on HSI/ADI can be used for cross reference.

c. Note: In order to successfully negotiate the turn at waypoint XRAY and simultaneously maintain the 5-mile left offset, pilots had to set their new OBS course (101°) at least 8 miles DTW to waypoint XRAY. This was necessary because at the initial entry of (+) 10 miles along track (ATK), the RNAV assumed this pseudo-waypoint to be on the same course (212°) but beyond waypoint XRAY. Upon changing OBS to 101°, the pseudo-waypoint now changes by an amount which varies with the amount of offset and turn angle, resulting in an increase in flightpath angle (FPA) when on an inside offset, and a decrease in FPA when on an outside offset. Pilots flying 2D were expected to continue their manual climb around the corner to 12,000 feet. Pilots flying 3D were expected to re-enter FPA and fly the new profile to 12,000 feet.

6. At 10 ATK (from) waypoint XRAY

Pilots were cleared to "maintain present course to intercept flight plan route."

a. All pilots were expected to maintain the 5-mile left offset and accelerate to 170 knots. When about 1 mile from waypoint WHISKEY (turn anticipation), set OBS to 024° for new course and set RNAV mode switch from "OFST" to "ENRT." Pilots would then follow the command bars to intercept the new course.

7. At waypoint WHISKEY

Pilots were cleared to "descend to cross waypoint SIERRA at 7,000 feet." After updating to waypoint SIERRA, and setting OBS to 024°, pilot actions were expected to be as follows:

a. 2D RNAV mode: Sames as 1a, except profile is a descent, reference altitude is 7,000 feet, and airspeed is 160 knots.

b. 3D RNAV mode: Same as 1b, except profile is a descent, regerence altitude is 7,000 feet, and airspeed is 150 knots.

8. At waypoint SIERRA

Pilots were cleared to "descend and maintain 1,800 feet and offset right 3 miles on base leg." After setting OBS (037°) and updating to waypoint ROMEO, the pilots were expected to:

a. 2D RNAV mode: Flight director mode selector in "NAV-LOC." Descend manually at desired descent rate at 160 knots, and adjust pitch command control to position command bars to desired descent attitude. Level off at 1800 feet. At about 4 miles DTW to waypoint ROMEO, set OBS to 125°, and enter 3-mile right offset. Set RNAV system switch of "OFST." Fly command bars to turn and fly base leg offset, and reduce airspeed to 130 knots.

b. 3D RNAV mode: Flight director mode switch in "APPR-AUTO," and VNAV selector button activated. Enter altitude of 1800 feet and ATK of minus (-) 3 miles. Enter FPA. Fly descent profile at 160 knots by reference to command bars. At about 4 miles DTW to waypoint ROMEO, set OBS to 125°, enter 3-mile right offset, and set RNAV system mode switch to "OFST." Fly command bars to turn and fly base leg. Reduce airspeed to 130 knots.

c. Note: A specific procedure was established for intercepting the final approach course: at 1.5 miles DTW to waypoint DELTA the pilots were to turn to intercept the final approach course at 30° angle. Pilot actions were expected to be as follows:

(1) 2D RNAV mode: Set heading marker on HSI to 30° intercept heading, and flight director mode selector to "HDG." Fly command bars to 30° intercept heading. Set RNAV mode switch to "REV" for ILS localizer heading (ILS), or final approach course heading (RNAV). Set flight director mode switch to "NAV-LOC" and intercept final approach course/localizer. Maintain 1,800 feet to OM (ILS) or to waypoint BRAVO (RNAV). Pilots flying an RNAV approach would set the RNAV system mode switch to "APPR" and complete the approach.

(2) 3D RNAV mode: Set heading marker on HSI to 30° intercept heading, and flight director mode selector to "HDG." Engage altitude hold switch (1800 feet), and fly command bars to 30° intercept heading. Set RNAV system mode switch to "REV" (ILS) or final approach course heading (RNAV). Set flight director mode switch to "APPR-AUTO" and fly to intercept final approach course/localizer, maintaining

1,800 feet to the OM (ILS) or to waypoint BRAVO (RNAV). Pilots flying an RNAV approach will enter minimum descent altitude (MDA), FPA, set RNAV system mode switch to "APPR," and fly the approach using the command bars.

B.3 Route B

Pilots were cleared to "cross waypoint HOTEL at 3,500 feet--maintain 3,500 feet." After setting OBS (219°) and setting the RNAV system to waypoint HOTEL, pilot actions were expected to be as follows:

1. After takeoff

   a. 2D RNAV mode: same as Route A, 1a.
   b. 3D RNAV mode: same as Route A, 1b.

2. At waypoint HOTEL

Pilots were expected to set OBS (300°) for new course to waypoint GOLF, update to waypoint GOLF, and maintain 3,500 feet to waypoint GOLF.

3. At waypoint GOLF

Pilots were cleared to "climb to cross waypoint YOKE at 7,000 feet--report waypoint YOKE." After setting OBS (242°) and updating to waypoint YOKE, pilot actions were expected to be as follows:

   a. 2D RNAV mode: same as Route A, 4a.
   b. 3D RNAV mode: same as Route A, 4b.

4. At waypoint YOKE

Pilots were cleared to "offset right 3 miles, climb to rach 12,000 feet 10 miles past waypoint XRAY." After setting OBS (212°) and updating to waypoint XRAY, pilot actions were expected to be as follows:

a. 2D RNAV mode: same as Route A, 5a, except offset is entered and flown as a 3-mile right offset.

b. 3D RNAV mode: same as Route A, 5b, except offset is entered and flown as a 3-mile right offset.

c. Note: In order to negotiate the turn at waypoint XRAY to succeed in maintaining the 3-mile right offset, all pilots had to set their new OBS course (101°) at about 2 miles DTW past waypoint XRAY. Pilots flying 2D were expected to continue their manual climb around the corner to 12,000 feet. Pilots flying 3D were expected to re-enter FPA and fly the new profile to 12,000 feet.

5. At 10 ATK XRAY

Pilots were cleared to "cancel offset--report waypoint WHISKEY." All pilots were expected to set RNAV system mode switch from "OFST" to "ENRT," turn 45° left to intercept the parent route (101°), and accelerate to 170 knots. Pilots would fly the command bars for the 45° intercept.

6. At waypoint WHISKEY

Pilots were cleared to "offset left 5 miles, descent to reach 7,000 feet 10 miles past waypoint SIERRA." After setting OBS (024°) and updating to waypoint SIERRA, pilot actions were expected to be as follows:

a. 2D RNAV mode: Flight director mode switch in "NAV-LOC." Enter XTK of 5 miles left, and set RNAV system mode switch to "OFST." Fly flight director command bars to 45° intercept heading to center CDI needle. Descend manually at a desired descent rate at an airspeed of 160 knots and adjust pitch command control to position command bars to maintain desired descent attitude. Fly command bars to maintain 5-mile left offset.

b. 3D RNAV mode: Flight director mode selector in "APPR-AUTO," and VNAV selector button activated. Enter XTK of 5 miles left and set RNAV system mode switch to "OFST." Enter an ATK of plus (+) 10. Enter altitude of 7,000 feet, and enter FPA. Fly flight director command of 45° intercept heading to center CDI needle and fly descent profile at 160 knots.

c. Note: In order to negotiate the turn at waypoint SIERRA to succeed in maintaining the 5-mile left offset, all pilots had to set their new course OBS (037°) at about 1 mile DTW to waypoint SIERRA. Pilots flying 2D were expected to continue their descent around the corner to 7,000 feet. Pilots flying 3D were expected to re-enter FPA and fly the new profile to 7,000 feet.

7. At 7,000 feet (10 ATK SIERRA)

Pilots were cleared to "cancel offset, descend to cross waypoint ROMEO at 1,800 feet." Pilot actions were expected to be as follows:

a. 2D RNAV mode: Set RNAV system mode switch from "OFST" to ENRT." Fly command bars to 45° intercept heading to parent course (037°). Manually descend at a desired descent rate and an airspeed of 160 knots. Adjust the pitch command bars to desired descent attitude.

b. 3D RNAV mode: Set RNAV system mode switch from "OFST" to "ENTR." Fly flight director command of 45° to intercept parent course (037°). Enter altitude of 1,800 feet, and FPA. Fly descent profile at 160 knots by reference to command bars.

8. At 5,000 feet

Pilots were cleared to "extend present course to offset left 3 miles on base leg." Pilot actions were expected to be as follows: All pilots descend to cross waypoint ROMEO at 1,800 feet, continue on 037° course for about 2 miles past waypoint ROMEO, and enter 3-mile left offset--setting RNAV mode selector switch to "OFST." After setting OBS to 124°, pilots would follow the command bars to 124°.

9. On base leg

Pilots were cleared "for RNAV/ILS approach." For execution of final approach turn and RNAV/ILS approach, see Route A, 8c.

B.4 Route C

Pilots were cleared to "cross waypoint HOTEL at 3,500 feet--maintain 3,500 feet." After setting OBS (219°) and selecting waypoint HOTEL, pilot actions were expected to be as follows:

1. After takeoff

a. 2D RNAV mode: Same as Route A, 1a.
b. 3D RNAV mode: Same as Route A, 1b.

2. At waypoint HOTEL

Pilots were cleared to "offset left 3 miles--maintain 3,500 feet." After setting OBS (300°) and updating to waypoint GOLF, pilot actions were expected to be as follows:

a. 2D RNAV mode: Same as Route A, 1a, excpet offset is left and 45° intercept turn is left.

b. 3D RNAV mode: Same as Route A, 1b, except offset is left and 45° intercept turn is left.

3. Midway to GOLF

Pilots were cleared to "extend present course to offset right 5 miles on next leg." Pilot actions were expected to be as follows:

a. 2D RNAV mode and 3D RNAV mode: Maintain 3-mile left offset until 3 to 4 miles DTW past waypoint GOLF. Update to waypoint YOKE, set OBS (242°), enter XTK of 5 miles right, and set RNAV system mode switch to "OFST." Follow command bars to intercept the 5-mile right offset.

4. At waypoint GOLF

Pilots were cleared to "climb to cross waypoint YOKE at 7,000 feet--report reaching 7,000 feet." Pilot actions were expected to be as follows:

a. 2D RNAV mode: Same as Route A, 1a, except reference altitude is 7,000 feet.

b. 3D RNAV mode: Same as Route A, 1b, except reference altitude is 7,000 feet.

5. At waypoint YOKE (7,000 feet)

Pilots were cleared to "cancel offset, climb to cross waypoint XRAY at 12,000 feet." After updating to waypoint XRAY and setting OBS (212°), pilot actions were expected to be as follows:

a. 2D RNAV mode: Set RNAV system mode switch from "OFST" to "ENRT," and fly command bars to 45° intercept heading to parent course (212°). Manually climb at a desired climb rate to 12,000 feet at airspeed of 140 knots. Adjust pitch command control to position command bars to desired climb attitude.

b. 3D RNAV mode: Set RNAV system mode switch from "OFST" to "ENRT," and fly flight director command of 45° to intercept parent course (212°). Enter altitude of 12,000 feet and FPA. Fly climb profile at 140 knots by reference to command bars.

6. At waypoint XRAY

Pilots were cleared to "maintain 12,000 feet--report at waypoint WHISKEY." After updating to waypoint WHISKEY and setting OBS (101°), pilots would maintain 12,000 feet manually or engage altitude hold.

7. At waypoint WHISKEY

Pilots were cleared to "descend to cross waypoint SIERRA at 7,000 feet--report waypoint SIERRA." After updating to waypoint SIERRA and setting OBS (024°), pilot actions were expected to be as follows:

a. 2D RNAV mode: Same as Route A, 7a.

b. 3D RNAV mode: Same as Route A, 1b.

8. At waypoint SIERRA

Pilots were cleared to "offset left 3 miles, descend to cross waypoint ROMEO at 1,800 feet." After updating to waypoint ROMEO and setting OBS (037°), pilot actions were expected to be as follows:

a. 2D RNAV mode: Flight director mode switch in "NAV-LOC." Enter XTK of 3 miles left, and set RNAV system mode switch to "OFST." Fly flight director command bars to 45° intercept heading to center CDI. Descend manually at a desired descent rate to 1,800 feet at an airspeed of 160 knots, and adjust pitch command control to position command bars to desired pitch attitude.

b. 3D RNAV mode: Flight director mode selector in "APPR-AUTO" and VNAV selector button activated. Enter XTK of 3 miles left, and set RNAV system mode switch to "OFST." Enter altitude of 1,800 feet and FPA. Fly flight director command to 45° intercept heading to center CDI needle and fly descent profile at 160 knots with command bars.

9. Three miles past waypoint ROMEO

Pilots were cleared to "cancel offset, cleared direct to waypoint DELTA--cleared for your RNAV/ILS approach." At this point, the pilots are maintaining a 3-mile left offset around the corner at waypoint ROMEO, and pilot actions are expected to be as follows:

See Route A, 3, for pilot actions, and substitue waypoint DELTA for clearance destination. In addition, see Route A, 8c note, for final procedure.

B. 5 Route D

Pilots were cleared to "cross waypoint HOTEL at 3, 500 feet--maintain 3, 500 feet." After setting OBS (219°) and setting the RNAV system to waypoint HOTEL, pilot actions were expected to be as follows:

1. After takeoff

a. 2D RNAV mode: Same as Route A, 1a.

b. 3D RNAV mode: Same as Route A, 1b.

2. At waypoint HOTEL

Pilots were cleared to "offset right 3 miles." After setting OBS (300°) and updating to waypoint GOLF, pilot actions were expected to be as follows:

a. 2D RNAV mode: Same as Route A, 2a.

b. 3D RNAV mode: Same as Route A, 2b.

3. At waypoint GOLF

Pilots were cleared to "climb to cross waypoint YOKE at 7, 000 feet, report reaching waypoint YOKE." Pilots were expected to maintain the 3-mile right offset around the corner at waypoint GOLF and after setting OBS (242°) and updating to waypoint YOKE, pilot actions were expected to be as follows:

a. 2D RNAV mode: Same as Route A, 1a, except reference altitude is 7, 000 feet.

b. 3D RNAV mode: Same as Route A, 1b, except reference altitude is 7, 000 feet.

4. At waypoint YOKE (7,000 feet)

Pilots were cleared to "cancel offset, climb to cross waypoint XRAY at 12,000 feet." After setting OBS (212°) and updating to waypoint XRAY, pilot actions were expected to be as follows:

a. 2D RNAV mode: Same as Route C, 5a.

b. 3D RNAV mode: Same as Route C, 5b.

5. At waypoint XRAY

Pilots were expected to continue on course, maintaining 12,000 feet to waypoint WHISKEY. After updating to waypoint WHISKEY and setting OBS (101°), pilots would maintain 12,000 feet manually or engage altitude hold.

6. At waypoint WHISKEY

Pilots were cleared to "offset right 5 miles, descend to cross waypoint SIERRA at 7,000 feet." After setting OBS (024°) and updating to waypoint SIERRA, pilot actions were expected to be as follows:

a. 2D RNAV mode: Flight director mode switch in "NAV-LOC." Enter XTK of 5 miles right, and set RNAV system mode switch to "OFST." Fly flight director command bars to 45° intercept heading to center CDI needle. Descend manually at a desired descent rate at an airspeed of 160 knots, and adjust pitch command control to position command bars to maintain desired descent attitude. Fly command bars to maintain 5-mile right offset.

b. 3D RNAV mode: Flight director mode selector in "APPR-AUTO" and VNAV selector button activated. Enter XTK of 5 miles right, and set RNAV system mode switch to "OFST." Enter altitude of 7,000 feet and FPA. Fly flight director command of 45° intercept heading to center CDI needle and fly descent profile.

c. Note: Pilots were expected to maintain the 5-mile right offset around the corner at waypoint SIERRA, leveling off at 7,000 feet, setting OBS (037°), and updating to waypoint ROMEO.

7. Five miles past waypoint SIERRA

Pilots were cleared to "cross course to offset left 3 miles descend to cross waypoint ROMEO at 1,800 feet." Pilot actions were expected to be as follows:

a. 2D RNAV mode: Flight director mode switch in "NAV-LOC." Enter XTK of 3 miles left (RNAV system mode switch still in "OFST)." Fly flight director command bars to 45° intercept heading to center CDI needle. Descend manually at a desired descent rate at an airspeed of 160 knots, and adjust pitch command control to position command bars to maintain desired descent attitude. Fly command bars to maintain 3-mile left offset.

b. 3D RNAV mode: Flight director mode selector in "APPR-AUTO" and VNAV selector button activated. Enter XTK of 3 miles left (RNAV system mode switch still in "OFST)." Enter altitude of 1,800 feet and FPA. Fly flight director command of 45° intercept heading to center CDI needle and fly descent profile at 160 knots.

8. Two miles prior to waypoint ROMEO

Pilots were cleared to "cancel offset--cleared for your RNAV/ILS approach." Pilot actions were expected to be as follows:

a. Pilots would set RNAV system mode switch from "OFST" to "ENRT," and center the CDI needle by means of the *OBS* knob. Pilots would then follow the command bars to turn and fly to waypoint ROMEO. All pilots would reduce airspeed to 130 knots for flying base leg.

9. On base leg

Pilot actions were expected to be as follows:

a. For execution of final approach, turn right for RNAV/ILS approach. See Route A, 8c.

PHASE II <u>WITHOUT</u> FLIGHT DIRECTOR

ROUTE DESCRIPTION AND ATC CLEARANCE

This section provides a detailed description of the ATC clearances that were issued and the particular actions that the pilots were expected to perform based on the ATC clearance using the RNAV system. It takes into account (1) pilot procedures (preferred), (2) routing procedures, (3) expected pilot actions, and (4) expected route procedures.

ROUTE A.

For all four routes (A, B, C, and D) (figure B-1), the pilots were allowed to, and preferred to, eliminate entering waypoints JULIETTE AND INDIA for their takeoff/climb-out to waypoint (w/p) HOTEL. Prior to takeoff, the pilots were cleared to "cross w/p HOTEL at 3,500 feet, maintain 3,500 feet." After setting OBS (219°) and updating to w/p HOTEL, pilot actions were expected to be as follows:

1. AFTER TAKEOFF.

a. 2D RNAV Mode: Flight director mode selector in "GYRO." Climb manually at their own desired climb rate at an airspeed of 140 knots and level off at 3,500 feet.

b. 3D RNAV mode: Flight director mode selector in "GYRO," and VNAV selector button activated. Enter altitude (3,500 feet) and flightpath angle (FPA). Manually fly climb profile at 140 knots by reference to glide slope pointers on HSI/ADI.

2. AT WAYPOINT HOTEL. Pilots were cleared to "offset right 3 miles--maintain 3,500 feet." After setting OBS (300°) and updating to w/p GOLF, pilot actions were expected to be as follows:

a. 2D RNAV mode: Flight director mode selector in "GYRO." Enter cross-track (XTK) of 3 miles right and set RNAV system mode switch to "OFST." Manually turn right 45°, fly to center CDI needle, and fly 3-mile right offset.

b. 3D RNAV mode: Flight director mode selector in "GYRO," and VNAV selector button activated. Enter crosstrack (XTK) of 3 miles right and set RNAV system mode switch to "OFST." Manually turn right 45° and fly to center CDI needle. Enter altitude (3,500 feet) and flightpath angle (FPA). Manually maintain 3,500 feet by reference to glide slope pointers on HSI/ADI.

3. DTW TO WAYPOINT GOLF. Pilots were cleared to "cancel offset, cleared directed to Waypoint GOLF." Pilot actions were expected to be as follows:

a. Pilots would set RNAV system mode switch from "OFST" to "ENRT" and center the CDI needle by means of the OBS knob. Then they would manually turn left and fly direct to w/p GOLF.

4. AT WAYPOINT GOLF. The pilots were cleared to "climb to cross w/p YOKE at 7,000 feet--report over w/p YOKE." After setting OBS (242°) and updating to w/p YOKE, pilot actions were expected to be as follows:

a. 2D RNAV mode: Same as 1a, except reference altitude is 7,000 feet.

b. 3D RNAV mode: Same as 1b, except reference altitude is 7,000 feet.

5. AFTER PASSING WAYPOINT YOKE. Pilots were cleared to "offset left 5 miles, climb to reach 12,000 feet 10 miles past w/p XRAY." After setting OBS (212°) and updating to w/p XRAY, pilot's actions were expected to be as follows:

a. 2D RNAV mode: Flight director mode selector in "GYRO." Enter crosstrack of 5 miles left and set RNAV system mode switch in "OFST." Manually turn left 45° and fly to center CDI needle. Climb manually at a desired climb rate at an airspeed of 140 knots. When CDI needle is centered, fly 5-mile left offset. Maintain 5-mile left offset around corner at w/p XRAY to 10 mile past w/p XRAY, and level at 12,000 feet.

b. 3D RNAV mode: Flight director mode selector crosstrack (XTK) of 5 mile left and set RNAV system mode switch to "OFST." Manually turn left 45° and fly to center CDI needle. Enter altitude (12,000 feet) and along track (ATK) of plus (+) 10. Enter flightpath angle (FPA). Manually fly climb profile at 140 knots by reference to glide slope pointer on HSI/ADI. When CDI needle centers, manually fly 5-mile left offset. Maintain 5-mile left offset around corner at w/p XRAY to 10 miles past w/p XRAY and level at 12,000 feet.

c. Note: In order to successfully negotiate the turn at w/p XRAY so as to maintain the 5-mile left offset, the pilots had to set their new OBS course (101°) at least 8 miles DTW to w/p XRAY. This is necessary because, at the initial entry of plus (+) 10 miles ATK, the RNAV positions this ATK point on the same course (212°) but 10 miles beyond w/p XRAY. Upon changing OBS to 101°, the 10-mile ATK point changes its reference location via the new wayline, and hence, the ATK distance to go now becomes less due primarily to the offset distance (5 miles), and results in an increase in FPA for the final portion of the climb profile. Pilots flying 3D were expected to reenter flightpath angle (FPA) at the turn point and fly the newly computed FPA to 12,000 feet. Pilots flying 2D were expected to continue their manual climb around the corner to 12,000 feet.

6. AT 10-MILE ATK WAYPOINT XRAY. Pilots were cleared to "maintain present course to intercept flight plan route."

a. All pilots were expected to maintain the 5-mile left offset and accelerate to 170 knots. When about 1-mile from w/p WHISKEY (turn anticipation), set OBS to 024° for new course and set RNAV mode switch from "OFST" to "ENRT." Pilots flying both 2D and 3D RNAV mode would turn manually.

7. AT WAYPOINT WHISKEY. Pilots were cleared to "descend to cross w/p SIERRA at 7,000 feet." After updating to w/p SIERRA, and setting OBS to 024°, pilot actions were expected to be as follows:

a. 2D RNAV mode: Same as 1a, except profile is a descent, and reference altitude is 7,000 feet, airspeed is 160 knots.

b. 3D RNAV mode: Same as 1b, except profile is a descent, reference altitude is 7,000 feet, and airspeed is 160 knots.

8. AT WAYPOINT SIERRA. Pilots were cleared to "descend and maintain 1,800 feet and offset right 3 miles on base leg." After setting OBS (037°) and updating to w/p ROMEO, the pilots were expected to:

a. 2D RNAV mode: Flight director mode selector in "GYRO." Descent manually at their own descent rate at the airspeed of 160 knots, level off at 1,800 feet. At about 4 miles DTW to w/p ROMEO, set OBS to 125° and enter 3- mile right offset. Set RNAV system mode switch in "OFST." Manually turn right to fly a centered needle on base leg offset and reduce airspeed to 130 knots.

b. 3D RNAV mode: Flight director mode selector in "GYRO," and VNAV selector button activated. Enter altitude of 1,800 feet and ATK of minus (-) 3 miles. Enter FPA and fly descent profile manually at 160 knots, by referemce to glide slope pointers on HSI/ADI. At about 4 miles DTW to w/p ROMEO, set OBS to 125° and enter a 3-mile right offset. Set RNAV system mode switch of "OFST." Manually fly base leg offset and reduce airspeed to 130 knots.

9. A specific procedure was established for intercepting the final approach course: At 1.5 miles DTW to w/p DELTA, the pilots were to turn so as to intercept the final approach course at a 30° angle. Pilot actions were expected to be as follows:

a. 2D RNAV mode: Manually turn to 30° intercept heading, put RNAV system mode switch in "REV" for ILS localizer capture or leave it in "ENRT" for RNAV course capture. Set OBS to inbound final approach course/localizer heading. Intercept final approach course/localizer and maintain 1,800 feet to OM (ILS) or w/p BRAVO (RNAV). Pilots flying an RNAV approach would set the RNAV system mode switch to "APPR" at w/p BRAVO and complete the approach.

b. 3D RNAV mode: Manually turn to 30° intercept heading, and put RNAV system mode switch to "REV" for ILS localizer capture or leave it in "ENRT" for RNAV course capture. Set OBS to inbound final approach course/localizer heading, and set flight director mode selector to "APPR-AUTO" and intercept final approach course/localizer, maintaining 1,800 feet to the OM (ILS) or w/p BRAVO (RNAV). Pilots flying an RNAV approach will enter minimum descent altitude (MDA) and FPA, set RNAV system mode switch to "APPR," and fly the approach using the glide slope pointers on the HSI/ADI for altitude reference.

ROUTE B.

1. AFTER TAKEOFF. Pilots were cleared to "cross w/p HOTEL at 3,500 feet--maintain 3,500 feet." After setting OBS (219°) and updating w/p HOTEL, pilot actions were expected to be as follows:

a. 2D RNAV mode: Same as route A, 1a.

b. 3D RNAV mode: Same as route A, 1b.

2. AT W/P HOTEL. Pilots were expected to set OBS (300°) for new course to w/p GOLF, update to w/p GOLF, and maintain 3,500 feet to w/p GOLF.

3. AT W/P GOLF. Pilots were cleared to "climb to cross w/p YOKE at 7,000 feet--report w/p YOKE." After setting OBS (242°) and updating to w/p YOKE, pilot actions were expected to be as follows:

a. 2D RNAV mode: Same as route A, 4a.

b. 3D RNAV mode: Same as route A, 4b.

4. AT W/P YOKE. Pilots were cleared to "offset right 3 miles, climb to reach 12,000 feet, 10 miles past w/p XRAY" after setting OBS (212°) and updating to w/p XRAY, pilot actions were expected to be as follows:

a. 2D RNAV mode: Same as route A, 5a, except offset is entered and flown as a 3-mile right offset.

b. 3D RNAV mode: Same as route A, 5b, except offset is entered and flown as a 3-mile right offset.

c. Note: In order to successfully negotiate the turn at w/p XRAY so as to maintain the 3-mile right offset, all pilots had to set their new OBS course (101°) at about 2 miles DTW past w/p XRAY. Pilots flying 2D were expected to continue their manual climb around the corner to 12,000 feet. Pilots flying 3D were expected to FPA and fly the new profile to 12,000 feet.

5. AT 10 MILES ATK XRAY. Pilots were cleared to "cancel offset--report w/p WHISKEY." All pilots were expected to set RNAV system mode switch from "OFST" to "ENRT," turn 45° left to intercept the parent route (101°), and accelerate to 170 knots. All pilots would manually turn 45° left to intercept the parent course.

6. AT W/P WHISKEY. Pilots were cleared to "offset left 5 miles, descend to reach 7,000 feet, 10 miles past w/p SIERRA." After setting OBS (024°) and updating to w/p SIERRA, pilot actions were expected to be as follows:

a. 2D RNAV mode: Flight director mode switch in "GYRO." Enter cross-track (XTK) of 5 miles left, and set RNAV system mode switch to "OFST." Manually turn left 45° and fly to center CDI needle. Descend manually at a desired descent rate at an airspeed of 160 knots. When CDI needle is centered, fly 3-mile left offset.

b. 3D RNAV mode: Flight director mode selector in "GYRO," and VNAV selector button activated. Enter crosstrack of 5 miles left and set RNAV mode switch to "OFST." Enter altitude of 7,000 feet and an ATK of plus (+) 10 miles. Enter FPA. Manually turn left 45° and fly to center CDI needle. Manually fly descent profile at 160 knots by reference to glide slope on HSI/ADI. When CDI needle centers, fly 5-mile offset.

c. Note: In order to successfully negotiate the turn at w/p SIERRA so as to maintain the 5-mile left offset, all pilots had to set their new course OBS (037°) at about 1-mile DTW to w/p SIERRA. Pilots flying 2D were expected to continue their descent around the corner to 7,000 feet. Pilots flying 3D were expected to reenter FPA and fly the new profile to 7,000 feet.

7. AT 7,000 FEET (10 MILES ATK). Pilots were cleared to "cancel offset, descend to cross w/p ROMEO at 1,800 feet." Pilot actions were expected to be as follows:

a. 2D RNAV mode: Set RNAV system mode switch from "OFST" to "ENRT." Manually turn right 45° to intercept parent course (037°) and descend at a desired descent rate to 1,800 feet at an airspeed of 160 knots.

b. 3D RNAV mode: Set RNAV system mode switch from "OFST" to "ENRT." Manually turn right 45° to intercept parent course (037°). Enter altitude of 1,800 feet and FPA. Manually fly descent profile at 160 knots by reference to glide slope pointers on HSI/ADI.

8. AT 5,000 FEET. Pilots were cleared to "extend present course to offset left 3 miles on base leg." Pilot actions were expected to be as follows: All pilots descend to cross w/p ROMEO at 1,800 feet, continue on 037° course for about 2 miles past w/p ROMEO, and enter 3-mile left offset--setting RNAV mode selector switch to "OFST." After setting OBS to 124°, pilots would manually turn to 124°.

9. ON BASE LEG. Pilots were cleared "for RNAV/ILS approach." For execution of final approach turn and RNAV/ILS approach, see route A, 8e.

ROUTE C.

1. AFTER TAKEOFF. Pilots were cleared to "cross w/p HOTEL at 3,500 feet--maintain 3,500 feet." After setting OBS (219°) and updating to w/p HOTEL, pilot actions were expected to be as follows:

a. 2D RNAV mode: Same as route A, 1a.

b. 3D RNAV mode: Same as route A, 1b.

2. AT W/P HOTEL. Pilots were cleared to "offset left 3 miles--maintain 3,500 feet," After setting OBS (300°) and updating to w/p GOLF, pilot actions were expected to be as follows:

a. 2D RNAV mode: Same as route A, 1a, except offset is left and 45° intercept turn is left.

b. 3D RNAV mode: Same as route A, 1b, except offset is left and 45° intercept turn is left.

3. MIDWAY TO GOLF. Pilots were cleared to "extend present course to offset right 5 miles on next leg." Pilot actions were expected to be as follows:

a. 2D RNAV mode: Maintain 3-mile left offset until 3-4 miles DTW past w/p GOLF. Update to w/p YOKE, set OBS (242°), enter crosstrack of 5 miles right, and set RNAV system mode switch to "OFST." Manually hold heading to intercept 5-mile right offset (allowing for turn anticipation).

3D RNAV mode: Same as 3a above.

4. AT W/P GOLF. Pilots were cleared to "climb to cross w/p YOKE at 7,000 feet--report reaching 7,000 feet," Pilot actions were expected to be as follows:

a. 2D RNAV mode: Same as route A, 1a, except reference altitude is 7,000 feet.

b. 3D RNAV mode: Same as route A, 1b, except reference altitude is 7,000 feet.

5. AT W/P YOKE 7,000 FEET. Pilots were cleared to "cancel offset, climb to cross w/p XRAY at 12,000 feet." After updating to w/p XRAY and setting OBS (212°), pilot actions were expected to be as follows:

a. 2D RNAV mode: Set RNAV system mode switch from "OFST" to "ENRT" and manually turn left 45° to intercept parent course (212°). Climb at a desired climb rate to 12,000 feet at an airspeed of 140 knots.

b. 3D RNAV mode: Set RNAV system mode switch from "OFST" "ENRT" and manually turn left 45° to intercept parent route (212°). Enter altitude of 12,000 feet and FPA. Manually fly climb profile to 12,000 feet at 140 knots by reference to glide slope pointers on HSI/ADI.

6. AT W/P XRAY. Pilots were cleared to "maintain 12,000 feet-- report w/p WHISKEY." After updating to w/p WHISKEY and setting OBS (101°), pilots would maintain 12,000 feet manually.

7. AT W/P WHISKEY. Pilots were cleared to "descend to cross w/p SIERRA at 7,000 feet--report w/p SIERRA." After updating to w/p SIERRA and setting OBS (024°), pilot actions were expected to be as follows:

a. 2D RNAV mode: Same as route A, 7a.

b. 3D RNAV mode: Same as route A, 1b.

8. AT W/P SIERRA. Pilots were cleared to "offset left 3 miles, descend to cross w/p ROMEO at 1,800 feet." After updating to w/p ROMEO and setting OBS (037°), pilot actions were expected to be as follows:

a. 2D RNAV mode: Flight director mode switch in "GYRO." Enter cross-track (XTK) of 3 miles left, and set RNAV system mode switch to "OFST." Manually turn left 45° and fly to center CDI needle. Descent manually at a desired descent rate at an airspeed of 160 knots. When CDI is centered, fly 3-mile left offset.

b. 3D RNAV mode: Flight director mode selector in "GYRO" and VNAV button activated. Enter XTK to 3 miles left, and set RNAV system mode switch to "OFST." Manually turn left 45° and fly to center CDI. Enter altitude of 1,800 feet FPA. Fly descent profile at 160 knots by reference to glide slope pointers on HSI/ADI. When CDI needle centers, fly 3-mile left offset.

9. 3 MILES PAST W/P ROMEO. Pilots were cleared to "cancel offset, cleared direct to w/p DELTA--cleared for your RNAV/ILS approach." At this point, the pilots are maintaining a 3-mile left offset around the corner at w/p ROMEO, and pilot actions are expected to be as follows:

See route A, 3, for pilot actions, and substitute w/p DELTA for clearance destination. In addition, see route A, 8e note, for final approach procedure.

ROUTE D.

1. AFTER TAKEOFF. Pilots were cleared to "cross w/p HOTEL at 3,500 feet--maintain 3,400 feet." After setting OBS (219°) and updating to w/p HOTEL, pilot actions were expected to be as follows:

a. 2D RNAV mode: Same as route A, 1a.

b. 3D RNAV mode: Same as route A, 1b.

2. AT W/P HOTEL. Pilots were cleared to "offset right 3 miles." After setting OBS (300°) and updating to w/p GOLF, pilot actions were expected to be as follows:

a. 2D RNAV mode: Same as route A, 2a.

b. 3D RNAV mode: Same as route A, 2b.

3. AT W/P GOLF. Pilots were cleared to "climb to cross w/p YOKE at 7,000 feet, report reaching w/p YOKE." Pilots were expected to maintain the 3-mile right offset around the corner at w/p GOLF and after setting OBS (242°) and updating to w/p YOKE, pilot actions were expected to be as follows:

a. 2D RNAV mode: Same as route A, 1a, except reference altitude is 7,000 feet.

b. 3D RNAV mode: Same as route A, 1b, except reference altitude is 7,000 feet.

4. AT W/P YOKE (7,000 FEET). Pilots were cleared to "cancel offset, climb to cross w/p XRAY at 12,000 feet." After setting OBS (212°) and updating to w/p XRAY, pilot actions were expected to be as follows:

a. 2D RNAV mode: Same as route C, 5a.

b. 3D RNAV mode: Same as route C, 5b.

5. AT W/P XRAY. Pilots were expected to continue on course, maintaining 12,000 feet to w/p WHISKEY. After updating to w/p WHISKEY and setting OBS (101°), pilots would maintain 12,000 feet manually.

6. AT W/P WHISKEY. Pilots were cleared to "offset right 5 miles, descend to cross w/p SIERRA at 7,000 feet." After setting OBS (024°) and updating to w/p SIERRA, pilot actions were expected to be as follows:

a. 2D RNAV mode: Flight director mode switch in "GYRO." Enter XTK of 5 miles right, and set RNAV system mode switch to "OFST." Manually turn right 45° and fly to center CDI needle. Descend manually at a desired descent rate at an airspeed of 160 knots. When CDI needle is centered, fly 5-mile right offset.

b. 3D RNAV mode: Flight director mode selector in "GYRO," and VNAV selector button activated. Enter XTK of 5 miles right, and set RNAV system mode switch in "OFST." Manually turn right 45° and fly to center CDI needle. Enter altitude of 7,000 feet and FPA. Manually fly descent profile at 160 knots by reference to the glide slope pointers on the HSI/ADI. When CDI needle centers, fly 5-mile right offset.

c. Note: Pilots were expected to maintain the 5-mile right offset around the corner at w/p SIERRA, leveling off at 7,000 feet, setting OBS (037°) and updating to w/p ROMEO.

7. 5 MILES PAST W/P SIERRA. Pilots were cleared to "cross course to offset left 3 miles to cross w/p ROMEO at 1,800 feet." Pilot actions were expected to be as follows:

a. 2D RNAV mode: Flight director mode switch in "GYRO." Enter XTK of 3 miles left (RNAV system mode switch still in "OFST"). Manually turn left 45° and fly to center CDI needle. Descend manually at a desired descent rate at an airspeed of 160 knots. When CDI needle is centered, fly 3-mile left offset. Level off at 1,800 feet.

b. 3D RNAV mode: Flight director mode switch in "GYRO" and VNAV selector button activated. Enter XTK of 3 miles left (RNAV system mode switch still in "OFST"). Manually turn left 45° and fly to center CDI needle. Enter altitude of 1,800 feet and FPA. Manually fly descent profile at 160 knots by reference to glide slope pointers on the HSI/ADI. When ADI needle centers, fly 3-mile left offset.

8. 2 NMI PRIOR W/P ROMEO. Pilots were cleared to "cancel offset--cleared for your RNAV/ILS approach." Pilot actions were expected to be as follows:

a. Pilots would set RNAV system mode switch from "OFST" to "ENRT" and center the CDI needle by means of the OBS knob. Pilots would manually turn right and fly direct to w/p ROMEO.

9. ON BASE LEG. Pilot actions were expected to be as follows: For execution of final approach, turn right and RNAV/ILS approach. See route A, 8e.

APPENDIX C

REGRESSION ANALYSIS DETAILS

LIST OF TABLES

LIST OF TABLES -(Cont'd)

C. 1 Introduction

This appendix consist of 26 tables which contain the statistical data from the regressions. They are divided into regressions of data for the four routes (A, B, C, and D) separated in terms of 3D guidance data only, 2D data guidance only and combined data from both 3D and 2D guidance. In addition, there was a grand total regression of all data points, 3D and 2D, base and offset, routes A, B, C, and D.

The first 13 tables contain the statistical data, the "A" portion of each table lists the regression coefficients for the regression runs. The "B" portion compares the one-sigma values of TSCT and various RSS calculations.

The abbreviations used in Tables C-1 through C-26 are defined as follows:

TSCT - Total System Cross Track Error, nmi
FTE - Flight Technical Error, nmi (taken as - CDI)
NSE - Navigation System Error, nmi (TSCT-FTE)
OBSE - OBS Setting Error, nmi
BSB - Bank Steering Bar Reading, degrees
VDI - Vertical Deviation Indicator reading, feet
PSB - Pitch Steering Bar reading, degrees
IAS - Indicated Airspeed
2D/3D Flag - binary (0 or 1) indicator of 2D or 3D guidance, 2D=1, 3D=0

$$\text{RSS-1} = \sqrt{(\sigma \text{CDI}^2 + \sigma \text{NSE})^2}$$

$$\text{RSS-2} = \sqrt{\sigma \text{CDI}^2 + \sigma \text{OBSE}^2}$$

$$\text{RSS-3} = \sqrt{\sigma \text{CDI}^2 + \sigma \text{OBSE}^2 + (\sigma \text{VDI}/6080)^2}$$

Tables C-14 through C-26 contain the correlation matrices for the 37 regressions. Since these matrices are diagonally symmetric, only the top half of each is presented.

TABLE C-1

A. STATISTICAL DATA, ROUTE A - 3-D MODE, W/FD

	BASE COURSE		OFFSET COURSE		BASE+OFFSET COURSES	
VARIABLE	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.
TSCT	.125	.419	.120	.460	.124	.429
FTE(CDI)	-.0489	.270	-.149	.427	-.0726	.317
NSE	.0766	.317	-.0297	.174	.0515	.293
OBSE	-.0164	.381	.157	.344	.0246	.380
BSB	4.629	7.036	5.256	4.311	4.723	5.394
VDI	3.119	110.12	16.17	117.01	6.188	111.97
PSB	.0292	1.863	.134	.768	.0483	1.626
IAS	152.95	11.24	156.46	14.98	153.71	12.33
2D/3D Flag	0	0	0	0	0	0
SAMPLES		6182		1923		8105

B. COMPARISON OF TSCT and RSS, 1 σ VALUES

	BASE	OFFSET	BASE + OFFSET
TSCT nm	.419	.460	.429
RSS - 1 nm	.416	.461	.431
RSS - 2 nm	.467	.548	.495
RSS - 3 nm	.467	.549	.495

TABLE C-2

A. STATISTICAL DATA, ROUTE A - 2-D MODE, W/FD

	BASE COURSE		OFFSET COURSE		BASE+OFFSET COURSES	
VARIABLE	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.
TSCT	.128	.490	.0680	.555	.115	.506
FTE (CDI)	-.0628	.233	-.162	.502	-.0846	.315
NSE	.0652	.442	-.0943	.228	.0302	.410
OBSE	-.0337	.434	.141	.407	.00456	.434
BSB	5.033	4.985	4.786	5.068	4.979	5.020
VDI	-979.56	120.56	-997.	0	-983.39	105.40
PSB	.511	2.198	1.013	1.351	.621	2.053
IAS	159.58	11.026	163.31	7.899	160.33	10.553
2D/3D Flag	1.0	0	1.0	0	1.0	0
SAMPLES	6068		1706		7774	

B. COMPARISON of TSCT and RSS, 1 σ VALUES

	BASE	OFFSET	BASE+OFFSET
TSCT nm	.490	.555	.506
RSS - 1 nm	.500	.552	.517
RSS - 2 nm	.492	.647	.536
RSS - 3 nm	.493	.647	.537

TABLE C-3

A. STATISTICAL DATA ROUTE A - 3D/2D MODE, W/FD

	BASE COURSE		OFFSET COURSE		BASE+OFFSET COURSE	
VARIABLE	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.
TSCT	.127	.456	.0953	.507	.120	.468
FTE (CDI)	-.0557	.252	-.155	.464	-.0785	.317
NSE	.0710	.384	-.0601	.204	.0410	.356
OBSE	-.0250	.408	.149	.375	.0148	.407
BSB	4.793	5.347	5.035	4.687	4.844	5.209
VDI	-483.66	503.82	-460.12	512.98	-478.29	505.72
PSB	.264	2.03	.547	1.167	.328	1.893
IAS	156.05	11.63	159.68	12.64	156.78	11.98
2D/3D Flag	.495	.500	.470	.499	.490	.500
SAMPLES	12250		3629		15879	

B. COMPARISON of TSCT and RSS, 1 σ VALUES

	BASE	OFFSET	BASE+OFFSET
TSCT nm	.456	.507	.468
RSS - 1 nm	.460	.507	.476
RSS - 2 nm	.480	.597	.516
RSS - 3 nm	.487	.603	.523

TABLE C-4

A. STATISTICAL DATA, ROUTE B - 3-D MODE, W/FD

	BASE COURSE		OFFSET COURSE		BASE+OFFSET COURSES	
VARIABLE	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.
TSCT	-.0211	.221	.159	.430	.0549	.338
FTE (CDI)	-.0506	.177	-.0377	.378	-.0452	.280
NSE	-.0717	.190	.121	.196	.00973	.215
OBSE	.169	.240	-.0928	.336	.0587	.312
BSB	4.133	4.418	4.246	4.509	4.180	4.456
VDI	-1.263	114.81	1.288	67.41	-.195	97.80
PSB	.0234	1.575	.0308	1.216	.0265	1.461
IAS	142.05	18.82	148.33	12.15	144.59	16.65
2D/3D Flag	0	0	0	0	0	0
SAMPLES	5,560		4,052		9,612	

B. COMPARISON of TSCT and RSS, 1 σ VALUES

	BASE	OFFSET	BASE+OFFSET
TSCT nm	.221	.430	.338
RSS - 1 nm	.260	.426	.353
RSS - 2 nm	.298	.506	.419
RSS - 3 nm	.299	.506	.420

TABLE C-5

A. STATISTICAL DATA, ROUTE B - 2-D MODE, W/F D

VARIABLE	BASE COURSE MEAN	BASE COURSE STD. DEV.	OFFSET COURSE MEAN	OFFSET COURSE STD. DEV.	BASE+OFFSET COURSES MEAN	BASE+OFFSET COURSES STD. DEV.
TSCT	-.113	.385	.0502	.379	-.0435	.391
FTE (CDI)	.00661	.287	-.0137	.271	-.00204	.281
NSE	-.107	.269	.0365	.286	-.0456	.285
OBSE	.163	.274	-.00255	.495	.0926	.393
BSB	5.152	4.248	5.612	5.263	5.348	4.712
VDI	-863.8	405.7	-982.49	119.34	-914.38	322.83
PSB	.949	2.130	1.365	2.060	1.126	2.108
IAS	152.4	21.30	162.22	12.05	156.52	18.60
2D/3D Flag	1.0	0	1.0	0	1.0	0
SAMPLES	4991		3706		8,697	

B. COMPARISON of TSCT and RSS, 1 σ VALUES

	BASE	OFFSET	BASE + OFFSET
TSCT nm	.385	.379	.391
RSS - 1 nm	.394	.395	.401
RSS - 2 nm	.397	.565	.482
RSS - 3 nm	.402	.566	.486

TABLE C-6

A. STATISTICAL DATA, ROUTE B - 3D/2D MODE, W/FD

	BASE COURSE		OFFSET COURSE		BASE+OFFSET COURSES	
VARIABLE	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.
TSCT	-.0646	.313	.107	.410	.0847	.367
FTE (CDI)	-.0235	.238	-.0262	.332	-.0247	.281
NSE	-.0881	.232	.0808	.247	-.0162	.253
OBSE	.166	.256	-.0496	.442	.0747	.353
BSB	4.615	4.367	4.898	4.930	4.729	4.614
VDI	-409.28	519.83	-468.66	500.70	-434.0	512.6
PSB	.461	1.951	.668	1.801	.548	1.926
IAS	146.85	20.708	154.91	13.95	150.13	18.57
2D/3D Flag	.473	.499	.478	.500	.474	.499
SAMPLES	10,551		7,758		18,329	

B. COMPARISON of TSCT and RSS, 1σ VALUES

	BASE	OFFSET	BASE + OFFSET
TSCT nm	.313	.410	.367
RSS-1 nm	.332	.414	.379
RSS-2 nm	.349	.537	.451
RSS-3 nm	.360	.543	.459

TABLE C-7

A. STATISTICAL DATA, ROUTE C, 3 - D MODE, W/FD

	BASE COURSE		OFFSET COURSE		BASE+OFFSET COURSES	
VARIABLE	MEAN	STD. DEV.	MEAN	STD.DEV.	MEAN	STD.DEV.
TSCT	0.218	0.369	.130	.395	.183	.381
FTE (CDI)	-.130	0.262	-.0463	.316	-.0971	.288
NSE	0.088	0.258	.0834	.232	.0862	.248
OBSE	-.039	0.414	.0124	.299	-.0190	.374
BSB	4.802	4.925	3.982	5.536	4.479	5.189
VDI	-.306	66.49	22.008	132.30	8.475	98.47
PSB	-.013	1.147	.113	1.157	.0366	1.150
IAS	153.69	13.53	154.50	12.42	153.87	13.13
2D/3D Flag	0	0	0	0	0	0
SAMPLES	6,227		4,048		10,275	

B. COMPARISON of TSCT and RSS, 1σ VALUES

	BASE	OFFSET	BASE + OFFSET
TSCT nm	0.369	.395	.381
RSS-1 nm	0.368	.392	.380
RSS-2 nm	0.490	.435	.472
RSS-3 nm	0.490	.436	.472

TABLE C-8

A. STATISTICAL DATA, ROUTE C, 2-D MODE, W/FD

	BASE COURSE		OFFSET COURSE		BASE+OFFSET COURSES	
VARIABLE	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.
TSCT	0.192	0.450	.0647	.426	.143	.445
FTE (CDI)	-0.125	0.289	-.0354	.330	-.0909	.309
NSE	0.0664	0.327	.0294	.314	.0522	.322
OBSE	-0.0257	0.443	-.0220	.309	-.00748	.398
BSB	5.39	4.72	5.067	5.201	5.266	4.907
VDI	-945.8	284.6	-854.8	337.7	-911.05	313.11
PSB	0.988	1.65	.711	1.596	0.882	1.632
IAS	163.7	8.90	163.58	10.15	163.51	9.424
2D/3D Flag	1.0	0.	1.0	0	1.0	0.
SAMPLES	5827		3602		9429	

B. COMPARISON of TSCT and RSS, 1 σ VALUES

	BASE	OFFSET	BASE+OFFSET
TSCT nm	0.450	.426	0.445
RSS-1 nm	0.436	.455	0.446
RSS-2 nm	0.529	.451	0.504
RSS-3 nm	0.531	.455	0.506

TABLE C-9

A. STATISTICAL DATA, ROUTE C - 3D/2D MODE, W/FD

	BASE COURSE		OFFSET COURSE		BASE+OFFSET COURSES	
VARIABLE	MEAN	STD. DEV	MEAN	STD. DEV.	MEAN	STD. DEV.
TSCT	.205	.410	.0990	.411	.164	.414
FTE (CDI)	-.128	.276	-.0411	.323	-.0941	.298
NSE	.0776	.294	.0579	.275	.0699	.287
OBSE	-.0328	.429	.0170	.304	-.0135	.386
BSB	5.086	4.833	4.493	5.406	4.849	5.071
VDI	-457.4	513.9	-390.8	504.6	-431.5	511.0
PSB	.471	1.495	.394	1.410	.441	1.505
IAS	158.3	12.6	158.7	12.3	158.3	12.4
2D/3D Flag	.483	.500	.471	.499	.479	.500
SAMPLES	12,054		7650		19,704	

B. COMPARISON of TSCT and RSS, 1 σ VALUES

	BASE	OFFSET	BASE+OFFSET
TSCT nm	.410	.411	.414
RSS - 1 nm	.403	.424	.414
RSS - 2 nm	.510	.443	.488
RSS - 3 nm	.516	.451	.495

TABLE C-10

A. STATISTICAL DATA, ROUTE D - 3-D MODE, W/FD

	BASE COURSE		OFFSET COURSE		BASE+OFFSET COURSES	
VARIABLE	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.
TSCT	.0143	.314	-.0315	.371	-.00433	.339
FTE (CDI)	-.0730	.285	-.0311	.246	-.0559	.270
NSE	-.0587	.158	-.0626	.350	-.0603	.254
OBSE	.0704	.421	.170	.462	.111	.441
BSB	3.991	4.645	4.203	4.823	4.077	4.720
VDI	-.868	118.81	9.872	67.81	3.506	101.71
PSB	.124	2.174	.151	.984	.135	1.846
IAS	143.16	19.42	153.53	13.22	147.25	17.93
2D/3D Flag	0	0	0	0	0	0
SAMPLES	6,063		4,174		10,237	

B. COMPARISON of TSCT and RSS, 1 σ VALUES

	BASE	OFFSET	BASE+OFFSET
TSCT nm	.314	.371	.339
RSS - 1 nm	.326	.428	.371
RSS - 2 nm	.508	.524	.517
RSS - 3 nm	.509	.524	.518

TABLE C-11

A. STATISTICAL DATA, ROUTE D - 2-D MODE, W/FD

VARIABLE	BASE COURSE MEAN	BASE COURSE STD. DEV.	OFFSET COURSE MEAN	OFFSET COURSE STD. DEV.	BASE+OFFSET COURSES MEAN	BASE+OFFSET COURSES STD. DEV.
TSCT	-.00538	.374	.0817	.425	.0308	.398
FTE (CDI)	-.0790	.347	-.0866	.207	-.0821	.297
NSE	-.0844	.175	-.00495	.390	-.0514	.288
OBSE	.0775	.374	.102	.416	.0879	.392
BSB	4.807	5.112	4.272	5.032	4.584	5.085
VDI	-778.88	494.03	-921.80	251.5	-838.24	420.24
PSB	.769	1.814	.934	1.619	.837	1.737
IAS	152.16	20.76	165.07	10.92	157.38	18.51
2D/3D Flag	1.0	0	1.0	0	1.0	0
SAMPLES	5,803		4,125		9,928	

B. COMPARISON of TSCT and RSS, 1 σ VALUES

	BASE	OFFSET	BASE+OFFSET
TSCT nm	.374	.425	.398
RSS - 1 nm	.389	.442	.413
RSS - 2 nm	.510	.464	.492
RSS - 3 nm	.517	.466	.496

TABLE C-12

A. STATISTICAL DATA, ROUTE D - 3D/2-D MODE, W/FD

VARIABLE	BASE COURSE		OFFSET COURSE		BASE+OFFSET COURSES	
	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.
TSCT	.00466	.345	.0248	.403	.0130	.370
FTE (CDI)	-.0759	.317	-.0587	.229	-.0688	.284
NSE	-.0713	.167	-.0339	.372	-.0559	.271
OBSE	.0739	.399	.136	.441	.0995	.418
BSB	4.390	4.896	4.237	4.927	4.321	4.922
VDI	-381.35	525.96	-453.21	500.89	-410.92	516.30
PSB	.439	2.082	.540	1.393	.480	1.862
IAS	147.39	20.57	159.18	13.43	152.10	18.83
2D/3D Flag	.489	.500	.497	.500	.492	.500
SAMPLES	11,866		8,299		20,165	

B. COMPARISON of TSCT and RSS, 1 σ VALUES

	BASE	OFFSET	BASE+OFFSET
TSCT nm	.345	.403	.370
RSS - 1 nm	.358	.436	.393
RSS - 2 nm	.509	.497	.505
RSS - 3 nm	.516	.504	.512

TABLE C-13

GRAND TOTAL REGRESSION - ROUTES A, B, C, and D, 3D/2D MODES W/FD

ALL COURSE SEGMENTS except TURNS AND TRANSITIONS

A. STATISTICAL DATA

VARIABLE	MEAN	STD. DEV.
TSCT	.0741	.409
FTE (CDI)	-.0665	.295
NSE	.00801	.295
OBSE	.0451	.394
BSB	4.661	4.947
VDI	-434.2	516.2
PSB	.453	1.734
IAS	154.15	16.48
2D/3D Flag	.484	.500
SAMPLES	74,057	

B. COMPARISON of TSCT and RSS, 1 σ VALUES

TSCT	.409
RSS_1	.417
RSS_2	.492
RSS_3	.499

TABLE C-14

ROUTE A, 3D

A. BASE COURSE

	TSCT	CDI	NSE	OBSE	BSB	VDI	PSB	IAS	2D/3D
TSCT	1.	-.656	.766	-.672	.0514	-.282	-.115	.303	0
CDI		1.	-.0178	-.0339	.00245	.211	.0591	.145	0
NSE			1.	-.920	.0670	-.194	-.101	.524	0
OBSE				1.	-.106	.186	.110	-.430	0
BSB					1.	.0302	.179	.0160	0
VDI						1.	.599	-.160	0
PSB							1.	-.168	0
IAS								1.	0
2D/3D									0

B. OFFSET COURSE

	TSCT	CDI	NSE	OBSE	BSB	VDI	PSB	IAS	2D/3D
TSCT	1.	-.926	.371	-.131	-.0497	.444	-.0552	-.480	0
CDI		1.	.00804	-.0856	.0673	-.423	.0350	.468	0
NSE			1.	-.556	.0338	.136	-.0598	.121	0
OBSE				1.	.0635	-.0171	.0668	.146	0
BSB					1.	.0218	.0391	.0413	0
VDI						1.	.0271	-.287	0
PSB							1.	.134	0
IAS								1.	0
2D/3D									0

TABLE C-14 Cont'd

C. BASE PLUS OFFSET COURSES

	TSCT	CDI	NSE	OBSE	BSB	VDI	PSB	IAS	2D/3D
TSCT	1.	-.731	.675	-.534	.0419	-.0894	-.104	.0568	0
CDI		1.	.00929	-.0726	.0237	-.0134	.0499	.250	0
NSE			1.	-.862	.0871	-.146	-.0983	.354	0
OBSE				1.	-.0927	.146	.107	-.238	0
BSB					1.	.00992	.0600	.0380	0
VDI						1.	.508	-.191	0
PSB							1.	-.0984	0
IAS								1.	0
2D/3D									0

TABLE C-15

ROUTE A, 2D

A. BASE COURSE

	TSCT	CDI	NSE	OBSE	BSB	VDI	PSB	IAS	2D/3D
TSCT	1.	-.434	.880	-.839	-.0982	-.0669	-.127	.0131	0
CDI		1.	-.0466	.00723	.150	-.0470	.129	.109	0
NSE			1.	-.927	-.0296	-.0987	-.0730	-.0720	0
OBSE				1.	-.00254	.0760	.0627	-.192	0
BSB					1.	.0886	.0707	.0421	0
VDI						1.	-.147	-.354	0
PSB							1.	-.0582	0
IAS								1.	0
2D/3D									0

B. OFFSET COURSE

	TSCT	CDI	NSE	OBSE	BSB	VDI	PSB	IAS	2D/3D
TSCT	1.	-.912	.425	.0503	.00407	0	.0625	.229	0
CDI		1.	-.0149	-.245	-.00573	0	-.0874	-.204	0
NSE			1.	-.417	-.00273	0	-.0404	.108	0
OBSE				1.	-.00824	0	-.180	.487	0
BSB					1.	0	.0395	.0700	0
VDI						1.	0	0	0
PSB							1.	-.157	0
IAS								1.	0
2D/3D									0

TABLE C-15(Cont'd)

C. BASE PLUS OFFSET COURSES

	TSCT	CDI	NSE	OBSE	BSB	VDI	PSB	IAS	2D/3D
TSCT	1.	-.586	.782	-.631	-.0721	-.0549	-.0981	.0446	0
CDI		1.	.0471	-.0979	.0873	-.0213	.0464	-.00696	0
NSE			1.	-.853	-.0218	-.0839	-.0852	.0496	0
OBSE				1.	-.0719	.0561	.0448	-.0572	0
BSB					1.	.0918	.0608	.0372	0
VDI						1.	-.150	-.347	0
PSB							1.	.0498	0
IAS								1.	0
2D/3D									0.

TABLE C-16

ROUTE A, 3D/2D

A. BASE COURSE

	TSCT	CDI	NSE	OBSE	BSB	VDI	PSB	IAS	2D/3D
TSCT	1.	-.539	.832	-.767	-.0152	-.0397	-.121	.143	.00265
CDI		1.	.0188	-.0129	.0760	.0470	.0952	.114	-.0275
NSE			1.	-.919	.0334	-.0177	-.0777	.247	-.0139
OBSE				1.	-.0741	.0491	.0792	-.296	-.0212
BSB					1.	-.0368	.0761	.0528	.0456
VDI						1.	-.0772	-.336	-.975
PSB							1.	-.00439	.122
IAS								1.	.286
2D/3D									1.

B. OFFSET COURSE

	TSCT	CDI	NSE	OBSE	BSB	VDI	PSB	IAS	2D/3D
TSCT	1.	-.916	.404	-.0286	-.0172	.0984	.00069	-.213	-.0507
CDI		1.	-.00283	-.173	.0278	-.0327	-.0455	.201	-.0140
NSE			1.	-.466	.0205	.171	-.102	-.0724	-.158
OBSE				1.	.0249	.0186	-.0931	.234	-.0210
BSB					1.	.0518	.0169	.0326	-.0500
VDI						1.	-.368	-.307	-.986
PSB							1.	.103	.376
IAS								1.	.270
2D/3D									1.

TABLE C- 16 - Cont'd

C. BASE PLUS OFFSET COURSES

	TSCT	CDI	NSE	OBSE	BSB	VDI	PSB	IAS	2D/3D
TSCT	1.	-.650	.737	-.588	-.0158	-.00555	-.0987	.0456	-.00993
CDI		1.	.0349	-.0857	.0565	.0131	.0524	.125	-.0175
NSE			1.	-.851	.0306	.00342	-.0807	.173	-.0280
OBSE				1.	-.0511	.0453	.0635	-.149	-.0246
BSB					1.	-.0195	.0757	.0521	.0266
VDI						1.	-.119	-.322	-.978
PSB							1.	-.0249	.155
IAS								1.	.277
2D/3D									1.

TABLE C-17

ROUTE B, 3D

A. BASE COURSE

	TSCT	CDI	NSE	OBSE	BSB	VDI	PSB	IAS	2D/3D
TSCT	1.	-.563	.637	-.474	.0795	-.102	.0184	.301	0
CDI		1.	.278	-.242	.0748	.118	-.0470	.0808	0
NSE			1.	-.776	.162	-.00849	-.0228	.426	0
OBSE				1.	-.124	.0662	.0488	-.130	0
BSB					1.	.134	.212	.0832	0
VDI						1.	.617	.108	0
PSB							1.	.109	0
IAS								1.	0
2D/3D									0

B. OFFSET COURSE

	TSCT	CDI	NSE	OBSE	BSB	VDI	PSB	IAS	2D/3D
TSCT	1.	-.889	.477	.0464	.0279	-.0654	.0937	.122	0
CDI		1.	-.0228	-.142	.0128	.0947	-.0838	-.0612	0
NSE			1.	-.172	.0854	.0389	.0438	.150	0
OBSE				1.	.0995	-.0986	.0638	.0225	0
BSB					1.	-.0725	.0347	.0750	0
VDI						1.	.480	-.0697	0
PSB							1.	.0533	0
IAS								1.	0
2D/3D									0

TABLE C-17-Cont'd)

C. BASE PLUS OFFSET COURSES

	TSCT	CDI	NSE	OBSE	BSB	VDI	PSB	IAS	2D/3D
TSCT	1.	-.773	.564	-.220	.0482	.0666	.0509	.226	0
CDI		1.	.0883	-.164	.0348	.0887	-.0592	.0120	0
NSE			1.	-.559	.121	.0110	.00290	.371	0
OBSE				1.	-.0139	-.00122	.0449	-.135	0
BSB					1.	.0687	.143	.0796	0
VDI						1.	.554	.0684	0
PSB							1.	.0936	0
IAS								1.	0
2D/3D									0

TABLE C-18

ROUTE B, 2D

A. BASE COURSE

	TSCT	CDI	NSE	OBSE	BSB	VDI	PSB	IAS	2D/3D
TSCT	1.	-.716	.667	-.592	-.0410	.0246	-.0278	.0928	0
CDI		1.	.0434	.0177	.0419	.0921	.0143	-.153	0
NSE			1.	-.828	-.0138	.133	-.0244	-.0304	0
OBSE				1.	-.0319	-.197	.0275	.00625	0
BSB					1.	.0754	.104	.0614	0
VDI						1.	.224	-.501	0
PSB							1.	-.149	0
IAS								1.	0
2D/3D									0

B. OFFSET COURSE

	TSCT	CDI	NSE	OBSE	BSB	VDI	PSB	IAS	2D/3D
TSCT	1.	-.659	.700	-.145	-.125	-.00087	.0249	.240	0
CDI		1.	.0768	-.121	.136	.0620	.110	-.164	0
NSE			1.	-.308	-.0360	.0577	.137	.161	0
OBSE				1.	-.103	-.0330	-.0423	.171	0
BSB					1.	-.0415	.112	.0117	0
VDI						1.	-.0974	-.296	0
PSB							1.	.0824	0
IAS								1.	0
2D/3D									0

TABLE C-18-(Cont'd)

C. BASE PLUS OFFSET COURSES

	TSCT	CDI	NSE	OBSE	BSB	VDI	PSB	IAS	2D/3D
TSCT	1.	-.685	.696	-.352	-.0686	-.0201	.0143	.178	0
CDI		1.	.0470	-.0481	-.0829	.0835	.0490	-.155	0
NSE			1.	-.530	-.0119	.0537	.0686	.0907	0
OBSE				1.	.0405	-.0670	-.0318	.00734	0
BSB					1.	.0331	.111	.0531	0
VDI						1.	.128	-.494	0
PSB							1.	-.0500	0
IAS								1.	0
2D/3D									0.

TABLE C-19

ROUTE B, 2D/3D

A. BASE COURSE

	TSCT	CDI	NSE	OBSE	BSB	VDI	PSB	IAS	2D/3D
TSCT	1.	-.678	.656	-.531	-.0103	.124	-.0478	.120	-.147
CDI		1.	.110	-.0793	.0668	-.0474	.0219	-.0316	.120
NSE			1.	-.799	.0547	.120	-.0422	.131	-.0754
OBSE				1.	-.0785	-.0619	.0334	-.0573	-.0111
BSB					1.	-.0533	.172	.0983	.116
VDI						1.	-.0527	-.388	-.828
PSB							1.	-0264	.241
IAS								1.	.251
2D/3D									1.

B. OFFSET COURSE

	TSCT	CDI	NSE	OBSE	BSB	VDI	PSB	IAS	2D/3D
TSCT	1.	-.798	.588	-.0693	-.0634	.126	-.00198	.0832	-.133
CDI		1.	.0179	-.119	.0690	-.0225	.0290	-.0689	.0363
NSE			1.	-.275	-.0126	.178	.0356	.0457	-.172
OBSE				1.	.114	-.115	.0304	.144	.107
BSB					1.	-.146	.128	.105	.138
VDI						1.	-.353	-.522	-.981
PSB							1.	.240	.370
IAS								1.	.498
2D/3D									1.

TABLE C-19 (Cont'd)

C. BASE PLUS OFFSET COURSES

	TSCT	CDI	NSE	OBSE	BSB	VDI	PSB	IAS	2D/3D
TSCT	1.	-.727	.645	-.298	-.0298	.107	-.0113	.146	-.135
CDI		1.	.0559	-.0976	.0673	-.0338	.0225	-.0446	.0765
NSE			1.	-.542	.0316	.118	.00777	.163	-.111
OBSE				1.	.0216	-.0655	.0107	-.0373	.0482
BSB					1.	-.0956	.151	.102	.126
VDI						1.	-.180	-.425	-.890
PSB							1.	.110	.292
IAS								1.	.319
2D/3D									1.

TABLE C-20

ROUTE C, 3D

A. BASE COURSE

	TSCT	CDI	NSE	OBSE	BSB	VDI	PSB	IAS	2D/3D
TSCT	1.	-.716	.703	-.346	.027	-.115	.059	.067	0
CDI		1.	-.007	-.0001	-.012	.141	.008	.167	0
NSE			1.	-.495	.026	-.020	.093	.265	0
OBSE				1.	.031	.037	-.019	.379	0
BSB					1.	-.005	.003	.025	0
VDI						1.	.108	-.069	0
PSB							1.	.087	0
IAS								1.	0
2D/3D									0

B. OFFSET COURSE

	TSCT	CDI	NSE	OBSE	BSB	VDI	PSB	IAS	2D/3D
TSCT	1.	-.810	.598	-.586	.0532	-.308	.00917	.348	0
CDI		1.	-.0132	.0864	.0306	.229	-.108	-.118	0
NSE			1.	-.880	.132	-.212	-.132	.432	0
OBSE				1.	-.125	.255	.0919	-.358	0
BSB					1.	-.0744	-.117	.0965	0
VDI						1.	.396	-.112	0
PSB							1.	-.0890	0
IAS								1.	0
2D/3D									0

TABLE C-20- (Cont'd)

C. BASE PLUS OFFSET COURSES

	TSCT	CDI	NSE	OBSE	BSB	VDI	PSB	IAS	2D/3D
TSCT	1.	-.761	.656	-.423	.0468	-.226	.0322	.172	0
CDI		1.	-.00989	.0397	-.00362	.202	-.0361	.0505	0
NSE			1.	-.605	.0681	-.115	.0115	.321	0
OBSE				1.	-.0272	.132	.0206	.157	0
BSB					1.	-.0523	-.08823	.0512	0
VDI						1.	.261	-.0810	0
PSB							1.	.0199	0
IAS								1.	0
2D/3D									1.

TABLE C-21

ROUTE C, 2D

A. BASE COURSE

	TSCT	CDI	NSE	OBSE	BSB	VDI	PSB	IAS	2D/3D
TSCT	1.	-.688	.767	-.395	-.0626	-.0517	.0915	.0446	0
CDI		1.	-.0623	.0419	.0829	-.0270	.0008	-.00931	0
NSE			1.	-.507	-.0129	-.0953	.127	.0507	0
OBSE				1.	.0110	.0287	-.0308	.147	0
BSB					1.	.0451	-.0835	-.0059	0
VDI						1.	-.170	-.412	0
PSB							1.	.245	0
IAS								1.	0
2D/3D									0

B. OFFSET COURSE

	TSCT	CDI	NSE	OBSE	BSB	VDI	PSB	IAS	2D/3D
TSCT	1.	-.689	.640	-.512	-.159	.251	.0135	-.138	0
CDI		1.	.126	-.126	.113	-.0269	-.0258	.154	0
NSE			1.	-.827	-.0958	.312	-.00923	-.0253	0
OBSE				1.	.0989	-.199	-.0182	-.112	0
BSB					1.	-.0236	.0375	.159	0
VDI						1.	-.0266	.0239	0
PSB							1.	.151	0
IAS								1.	0
2D/3D									0

TABLE C-21-Cont'd)

C. BASE PLUS OFFSET COURSES

	TSCT	CDI	NSE	OBSE	BSB	VDI	PSB	IAS	2D/3D
TSCT	1.	-.689	.720	-.428	-.0945	.0492	.0740	-.0269	0
CDI		1.	.00539	-.00456	.0910	-.00807	-.0208	.0607	0
NSE			1.	-.595	-.0433	.0599	.0812	.0182	0
OBSE				1.	.0363	-.0368	-.0317	.0588	0
BSB					1.	.00807	-.0329	.0666	0
VDI						1.	-.119	-.209	0
PSB							1.	.207	0
IAS								1.	0
2D/3D									0

TABLE C-22

ROUTE C, 3D/2D

A. BASE COURSE

	TSCT	CDI	NSE	OBSE	BSB	VDI	PSB	IAS	2D/3D
TSCT	1.	-.699	.740	-.372	-.0217	.00760	.0629	.0365	-.0323
CDI		1.	-.0373	.0224	.0350	-.00680	.00492	.0868	.00874
NSE			1.	-.500	.00350	.00305	.0997	.135	-.0354
OBSE				1.	.0225	-.00449	-.0181	.263	.0160
BSB					1.	-.0446	-.0231	.0370	.0608
VDI						1.	-.351	-.450	-.919
PSB							1.	.256	.335
IAS								1.	.398
2D/3D									1.

B. OFFSET COURSE

	TSCT	CDI	NSE	OBSE	BSB	VDI	PSB	IAS	2D/3D
TSCT	1.	-.745	.620	-.548	-.0545	.110	-.00563	.0943	-.0790
CDI		1.	.0616	-.0174	.0705	.00768	-.0559	.00552	.0170
NSE			1.	-.840	.00131	.173	-.0741	.147	-.0984
OBSE				1.	-.0198	-.0429	.0328	-.228	.0159
BSB					1.	-.104	.0347	.149	.100
VDI						1.	-.148	-.330	-.867
PSB							1.	.106	.212
IAS								1.	.369
2D/3D									1.

TABLE C-22-Cont'd)

C. BASE PLUS OFFSET COURSES

	TSCT	CDI	NSE	OBSE	BSB	VDI	PSB	IAS	2D/3D
TSCT	1.	-.720	.694	-.426	-.0281	.0385	.0426	.0558	-.0485
CDI		1.	.00206	.0155	.0426	.00726	-.0132	.0537	.0113
NSE			1.	-.599	.00540	.0608	.0576	.144	-.0560
OBSE				1.	.00410	-.0107	-.0148	.111	.0136
BSB					1.	-.0722	.00479	.0809	.0776
VDI						1.	-.277	-.403	-.899
PSB							1.	.211	.289
IAS								1.	.388
2D/3D									1.

TABLE C-23

ROUTE D, 3D

A. BASE COURSE

	TSCT	CDI	NSE	OBSE	BSB	VDI	PSB	IAS	2D/3D
TSCT	1.	-.865	.431	-.0326	-.0202	-.0843	.0363	-.0312	0
CDI		1.	.0805	-.161	.00353	.149	-.0153	-.0821	0
NSE			1.	-.354	-.0337	.0997	.0437	-.209	0
OBSE				1.	.111	-.0629	-.0611	.464	0
BSB					1.	.105	.0660	.0999	0
VDI						1.	.219	-.0215	0
PSB							1.	-.144	0
IAS								1.	0
2D/3D									0

B. OFFSET COURSE

	TSCT	CDI	NSE	OBSE	BSB	VDI	PSB	IAS	2D/3D
TSCT	1.	-.416	.769	-.691	-.00834	-.304	-.111	.577	0
CDI		1.	.261	-.263	-.0387	.207	-.0748	.0755	0
NSE			1.	-.918	-.0361	-.176	-.170	.667	0
OBSE				1.	.0478	.221	.211	-.506	0
BSB					1.	.0397	.0659	.0360	0
VDI						1.	.539	.116	0
PSB							1.	.0810	0
IAS								1.	0
2D/3D									0

TABLE C- 23-(Cont'd)

C. BASE PLUS OFFSET COURSES

	TSCT	CDI	NSE	OBSE	BSB	VDI	PSB	IAS	2D/3D
TSCT	1.	-.673	.619	-.347	-.0159	-.148	-.00336	.152	0
CDI		1.	.164	-.189	-.0110	.163	-.0258	-.0128	0
NSE			1.	-.664	-.0331	-.0235	-.0313	.190	0
OBSE				1.	.0849	.0279	.00536	.156	0
BSB					1.	.0831	.0513	.0819	0
VDI						1.	.235	.0171	0
PSB							1.	-.0808	0
IAS								1.	0
2D/3D									0

TABLE C-24

ROUTE D, 2D

A. BASE COURSE

	TSCT	CDI	NSE	OBSE	BSB	VDI	PSB	IAS	2D/3D
TSCT	1.	-.885	.384	.130	-.00745	-.0430	.0261	-.0418	0
CDI		1.	.0910	-.176	-.00332	.0886	.0158	-.0844	0
NSE			1.	-.0710	-.0225	.0846	.0874	-.257	0
OBSE				1.	.0184	-.0422	-.0589	.318	0
BSB					1.	-.0193	-.0912	.0980	0
VDI						1.	-.105	-.489	0
PSB							1.	-.0286	0
IAS								1.	0
2D/3D									0

B. OFFSET COURSE

	TSCT	CDI	NSE	OBSE	BSB	VDI	PSB	IAS	2D/3D
TSCT	1.	-.403	.875	-.725	-.0438	.191	-.172	-.197	0
CDI		1.	.0907	-.159	.121	.0253	.0797	-.120	0
NSE			1.	-.873	.0163	.221	-.145	.151	0
OBSE				1.	-.0370	-.159	.118	-.371	0
BSB					1.	.0431	-.0551	.056	0
VDI						1.	.0454	.152	0
PSB							1.	-.0141	0
IAS								1.	0
2D/3D									0

TABLE C-24-(Cont'd)

C. BASE PLUS OFFSET COURSES

	TSCT	CDI	NSE	OBSE	BSB	VDI	PSB	IAS	2D/3D
TSCT	1.	-.693	.669	-.269	-.0290	.00381	-.0505	.0631	0
CDI		1.	.0715	-.164	.0329	.0770	.0323	-.0887	0
NSE			1.	-.542	-.00620	.0858	-.0374	-.00474	0
OBSE				1.	-.00736	-.0744	.0153	.113	0
BSB					1.	.00670	-.0796	.0608	0
VDI						1.	-.0741	-.412	0
PSB							1.	-.00522	0
IAS								1.	0
2D/3D									0

TABLE C-25

ROUTE D, 2D/3D

A. BASE COURSE

	TSCT	CDI	NSE	OBSE	BSB	VDI	PSB	IAS	2D/3D
TSCT	1.	-.876	.405	.0483	-.0155	-.00908	.0260	-.0423	-.0284
CDI		1.	.0867	-.166	-.00112	.0673	-.00192	-.0835	-.00944
NSE			1.	-.215	-.0338	.109	.0489	-.246	-.0767
OBSE				1.	.0660	-.0329	-.0605	.385	.00886
BSB					1.	-.0603	-.00265	.116	.0832
VDI						1.	.138	-.389	-.740
PSB							1.	-.0393	.162
IAS								1.	.219
2D/3D									1.

B. OFFSET COURSE

	TSCT	CDI	NSE	OBSE	BSB	VDI	PSB	IAS	2D/3D
TSCT	1.	-.415	.828	-.705	-.0264	-.0993	-.101	.408	.140
CDI		1.	.167	-.207	.0341	.134	-.0211	-.0553	-.121
NSE			1.	-.891	-.00759	-.0252	-.123	.408	.0775
OBSE				1.	.00651	.0491	.121	-.437	-.0763
BSB					1.	.00694	-.00761	.0443	.00719
VDI						1.	-.222	-.360	-.930
PSB							1.	.142	.281
IAS								1.	.428
2D/3D									1.

TABLE C-25-(Cont'd)

C. BASE PLUS OFFSET COURSES

	TSCT	CDI	NSE	OBSE	BSB	VDI	PSB	IAS	2D/3D
TSCT	1.	-.685	.646	-.306	-.0208	-.0502	-.0166	.113	.0475
CDI		1.	.113	-.174	.0101	.0859	-.00606	-.0637	-.0461
NSE			1.	-.599	-.0179	.0215	-.0287	.0874	.0165
OBSE				1.	.0396	-.00336	.00057	.125	-.0276
BSB					1.	-.0288	-.0208	.0783	.0490
VDI						1.	-.171	-.376	-.815
PSB							1.	.0268	.193
IAS								1.	.269
2D/3D									1.

TABLE C-26

GRAND TOTAL, ALL ROUTES, 3D/2D

BASE PLUS OFFSET COURSES

	TSCT	CDI	NSE	OBSE	BSB	VDI	PSB	IAS	2D/3D
TSCT	1.	-.692	.691	-.418	-.0152	.0145	-.0235	.124	-.0323
CDI		1.	.0390	-.0801	-.0426	.00606	.0162	.00451	.00499
NSE			1.	-.657	.0173	.0328	-.0272	.175	-.0422
OBSE				1.	-.00050	.00166	.0188	-.00148	-.00037
BSB					1.	-.0650	.0548	.103	.0702
VDI						1.	-.205	-.388	-.884
PSB							1.	.116	.235
IAS								1.	.303
2D/3D									1.

APPENDIX D

SUMMARY OF RESPONSES TO PILOT QUESTIONNAIRE

A. RNAV CONTROL DISPLAY UNIT.

1. Did you experience any difficulty or confusion when entering waypoint information?

a. No 4 Yes 4

b. If yes, please explain: ____________________

Comment:

(P-2) Having wrong mode set to enter specific info.

(P-3) Detracts from flying aircraft--need a copilot.

(P-4) Failing to look at mode button for inserting info.

(P-6) Minor--waypoint advance switch skipped occasionally making entires awkward.

2. a. The "H" alert feature of the EDO RNAV flashed when .9 minutes to/from the waypoint. Is this feature of significant importance?

No 0 Yes 8

If yes, please explain: ______________________________

Comment:

(P-1) Is standard in INS, Omega, any other RNAV system.

(P-2) Alerts waypoint approaching and helps with turn anticipation.

(P-3) Does wake one up. Like to see "H" changed to another letter. "H" means altitude or height.

(P-4) Gives pilot time to reassess the turn and check next course.

(P-5) 1a. After offset is canceled, the info remains in call-out until another offset is entered.

2a. The "erase" position is not guarded. This position should be guarded the same as "Rev."

(P-6) 1a. CDU needs insertion indicator (flash the insert button).

2a. Color code plus (+) and minus (-). Decimal point is too dim. Plus (+) and minus (-), and (L) and (R) should be available from separate buttons.

(P-8) 2a. Previous offsets still stored and visible--confusing.

4. Did you find the EDO RNAV capability of only being able to enter one altitude/FPA (VNAV) at a time:

a. too restrictive?

b. satisfactory because it did not cause confusion?

B. PILOT PROCEDURES.

1. Given an aeronautical chart, would you physically number each waypoint on the chart that you had stored in your RNAV?

a. No 0 Yes 8

b. Would this be practical for up to:

(1) 5 waypoints? 0

(2) 10 waypoints? 3

(3) 20 waypoints? 2

(4) over 20 waypoints? 3

2. Did you have any trouble keeping track of yourself on the pilot charts?

a. No 7 Yes 1

b. If no, please explain:____.

Comments:

(P-5) Use of numbers on chart with waypoint names required careful entries.

(P-7) No--due to numbering system.

(P-8) Not when you number waypoint to match what you have stored.

3. Can you think of any practical method (other than physically numbering in the route segments) of correlating the EDO navigation waypoint information with your routing on the aeronautical chart?

a. No 8 Yes 0

b. Please explain:____.

Comments:

(P-6) Waypoints should correlate with simple ident codes on the NAV chart itself. Numbering is probably the easiest way now because most RNAV equipments have number-identified waypoints. Letter codes would work, too, but in any case, each published waypoint needs a discrete ident (numbers or letters) that can be inserted in the RNAV box.

4. Did you experience any confusion or difficulty in entering offsets with "alongtrack" (ATK) points?

a. No 5 Yes 3

b. Please comment:

Comment:

(P-5) This operation takes considerable training and experience.

(P-6) Requires too much calculation to adjust for lack of RNAV equipment capability.

5. With regard to reaching assigned altitudes at the same time you arrived at the waypoint (VNAV), would you prefer to reach altitude:

a. prior to waypoint? 7

b. at the waypoint? 1

c. If a how, far prior? ________ Why? ____________________

Comment:

(P-2) 5 miles--ease workload.

(P-3) 5 miles--reduce workload at waypoint.

(P-4) Climb as quickly as allowed--fuel saving.

(P-5) Climb is predicated on aircraft performance, hence distance from waypoint is not important.

(P-6) 1-2 miles. Mostly to avoid added work of turning, leveling, and updating.

(P-7) Approximate normal climb distance.

(P-8) 5 miles--for turn anticipation, speeds, and offsets.

6. How often did you fly in the "read" mode?

a. Rarely 2 Occasionally 3 Often 2 Always 1

b. Is this a useful feature? No 0 Yes 8

c. What information did you monitor most?

(1) BRG/DIST 4

(2) FREQ/ELEV 2

(3) ALT/FPA 4

(4) OTHER (XTK/ATK 1), (GS/TM 2)

7. While flying an approved RNAV SID or STAR under IFR, would you probably:

a. Let the RNAV compute a flightpath angle (FPA) to your next required altitude and fly that FPA? No 5 Yes 3

b. Enter your own best estimated FPA and fly it to your required altitude?

No 5 Yes 3

c. Not use an FPA and climb/descend to your altitude at a rate commensurate with your aircraft performance? No 3 Yes 5

8. Did you use any particular technique of applying turn anticipation while flying offsets?

a. No 3 Yes 5

b. Please describe it. ______________________________

Comment:

(P-3) One-half speed plus overshoot 1.5 to 1 mile on outside, lead one-half speed--1 mile to waypoint.

(P-5) Determine if turn is long or short of 90° point. Prior to turn point select next radial--fly heading to intercept.

(P-6) Lead the turn by one-half of 1 percent of the airspeed. This turned out to be slightly too small, so I used two- to three-tenths of a mile more after the first two or three turns. The flaw was due mostly to inadequate back commands of flight director.

(P-7) Use an imaginary course line and where they intersect or cross, start turn after adjusting distance from intersection for indicated airspeed.

(P-8) Offsets provide a means of segregating aircraft of varying performance characteristics for arrival sequencing. Is this means more acceptable than:

a. speed control? No 7 Yes 1

b. delay fans? No 7 Yes 1

10. Did you have any difficulty executing climbing/descending turns while in an offset?

a. No 7 Yes 1

b. Please explain.____

Comment:

b. (P-6) Any turn (more than 10°-15°) requires careful and continuous though concentration to avoid overshoot, because of the lack of computer subroutine to accomplish the offset turn efficiently. Pilot workload gets high.

11. If two or more aircraft are assigned parallel offsets along a common course, what would you consider the minimum separation distance between them should be?

	Terminal area	Enroute area
a. With radar monitoring	11-5 min	3-6 min
b. Without radar monitoring	2-10 min	5-10 min

12. When intercepting the final approach course (RNAV-ILS) from an inside offset (base leg), did you have sufficient time to fully prepare and fly your approach?

a. No 7 Yes 9

b. Please explain. ______________________________

Comment:

b. (P-2) Outside offsets were somewhat confusing due to intercept angles, especially when transitioning to ILS or normal approach.

(P-3) However, autopilot or copilot would reduce workload.

(P-4) Only if all parameters (checklist, aircraft configuration, speed, etc.) taken care of early enough.

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SIMULATION STUDY OF THE OPERATIONAL CHARACTERISTICS OF A TWO/TH--ETC(U)
AUG 79 D ELDREDGE, W G CROOK, B D DEBARYSHE

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(P-6) It was always successful but always hectic. Mostly due to very short base leg involved. The RNAV itself worked fine but the patterns and flight director caused excessive single-pilot workload.

(P-8) Base leg was about 6 miles. Hitting your altitude on programed FPA, planning time for turn, and set final approach intercept--things get very busy.

C. PILOT WORKLOAD.

1. Did you have any difficulty understanding the offset instructions/ phraseology in your communications?

2. How would you rate your overall cockpit workload during your RNAV simulation flights?

a. Minimal 1 Moderate 5 Heavy 2

b. Please explain. ______________________________

Comment:

b. (P-3) On final approach only.

(P-4) Minimal enroute. Moderate on approach from 15 miles to runway.

(P-6) Minimal - intermittent. Moderate - average. Heavy - intermittent.

3. Do you think RNAV systems similar to EDO in design and function can be flown by a single pilot under IFR:

	No	Yes
a. With flt. dir./autopilot?	1	7
b. No flt. dir./autopilot?	6	2
c. In an ENAV environment?	4	4
d. In a mixed RNAV/non-RNAV environ.?	6	2

Comment:

e. (P-4) In visual conditions the amount of head down time would make the flight less safe than normal.

(P-5) Single pilot operation in a high density area would result in heavy workload.

(P-6) Pilot needs proficiency!

4. Was the ATC communication workload:

a. Excessive? 1 Normal? 6 Light? 1