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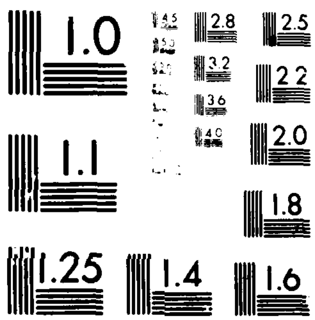
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Report No. FAA-RD-80-35

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DETERMINATION OF THE IMPACT OF DIGITAL DATA BROADCAST ON FLIGHT TECHNICAL ERROR

Donald W. Richardson, Ph.D

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FEBRUARY 1980
FINAL REPORT

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16. Abstract

This report documents the data reduction and analysis of existing flight test data regarding the digital data broadcast system (DDBS) concept of automating cockpit data input procedures in an area navigation environment. Particular attention is paid to the statistical quantification of the impact of the DDBS concept on pilot steering performance, mainly flight technical error (FTE).

Results of this analysis indicate that DDBS significantly reduces both pilot blunder rate and FTE, for both the enroute and approach phases of flight.

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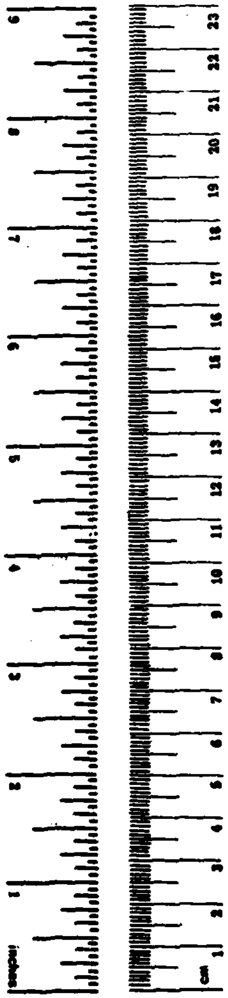
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

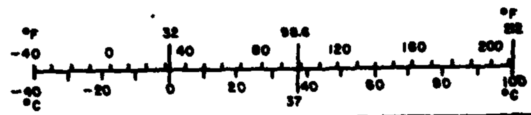
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	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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1.0 INTRODUCTION

1.1 GENERAL

This document is intended to serve as a basic data report, primarily as an aid in establishing a data base regarding pilot performance in an area navigation (RNAV) operational environment. The two principal pilot performance measures treated in this report are blunders and steering or flight technical error (FTE). The quantitative data contained herein is directly correlated to, and supplements, the more qualitative data contained in Reference 1, Report No. FAA-RD-76-60, "Evaluation of Digital Data Broadcast for Area Navigation". In order to effectively evaluate the results and conclusions contained in this present document, some basic material has been extracted from Reference 1 and included in this report for clarity. The data presented in this report has been processed and analyzed specifically for this contract, and has not been previously documented.

1.2 BACKGROUND

At the present time, the dramatic expansion of avionics technology is giving increased emphasis to the concept of area coverage navigation systems as a companion to, if not a replacement for, the existing VOR-based airway system. Independent of the specifics of the navigation sensor used (VOR/DME, Loran-C, Omega/VLF, GPS/NAVSTAR), there are serious implications regarding cockpit workload and pilot steering performance (sometimes highly correlated with a measure called flight technical error, or FTE) that must be considered and, if possible, quantified as regards eventual certification of such systems for use in the National Airspace System. The Federal Aviation Administration (FAA) is continuously involved in an ongoing program of analytical, simulation and flight test efforts aimed at acquiring a substantive quantitative data base relating to the overall subject of the interrelationship between pilot performance factors, avionics system functional design criteria, and overall navigation system use performance, particularly as regards avionics certification standards, ATC operational procedures and airspace planning guidelines.

Previous FAA activity (Contract No. DOT-FA75WA-3634) had sponsored a hardware development program and flight test evaluation of a concept known as the Digital Data Broadcast System (DDBS). The basis of this concept involved the use of the existing Distance Measuring Equipment (DME) channel as a data link medium for transmitting the location of RNAV waypoints comprising complete Standard Instrument Departure (SID) and Standard Terminal Arrival Route (STAR) routes. These waypoints were automatically received in the aircraft and used by a low cost single waypoint airborne RNAV computer as a possible means of minimizing pilot workload and blunders in setting the series of waypoints that comprise the SID or STAR route into this type of computer, thus potentially improving the pilot steering performance. During the performance of the referenced contract, the data acquired during the flight tests were reduced as regards a quantitative comparison of blunder performance and a subjective evaluation of pilot workload reduction. Data relating to the quantitative evaluation of FTE was originally recorded during these tests but was not processed or analyzed as part of the original contract.

1.3 OBJECTIVE

It is the purpose of this effort to document the additional data reduction and analysis of the existing DDBS test data for the purpose of statistically quantifying the impact of the DDBS cockpit data input automation concept on pilot steering performance, namely FTE. The results contained herein will add one more necessary element in the overall matrix of data regarding FTE and pilot performance for area coverage navigation systems. As a general case, the blunder/workload data should be able to be extrapolated to other area navigation sensor systems offering the potential for cockpit data automation, and not constrained to the specifics of VORTAC navigation. However, the absolute impact of DDBS on FTE performance must be carefully considered in the light of VORTAC signal characteristics and their possible correlation with FTE as observed in other flight test experiments (Reference 2).

In particular it must be noted that the FTE data contained in this present report should be considered primarily in the context of a direct comparison with previously measured FTE data taken on a "baseline" RNAV flight test experiment as reported in Reference 3. As presented in this report, the impact of DDBS is evaluated in terms of <u>relative</u> improvement in steering performance rather than as an <u>absolute</u> value of FTE per se. Further discussions in Section 3 of this report will amplify this point.

2.0 EXPERIMENTAL APPROACH

2.1 INTRODUCTION

As mentioned previously in Section 1, this report will supplement and amplify the qualitative data that was originally presented in Reference 1. However, in order to properly interpret the quantitative results developed in this present report, it was felt necessary to include sufficent information to describe the basic test environment, conditions, procedures and equipment. This is particularly true when the comparison is ultimately drawn in Section 3 between the DDBS test results and the FTE values obtained from the non-DDBS "baseline" flight experiment. For this reason the following subsections are included. Some, but not all, of the experiment description has been extracted or reconstructed from material originally presented in Reference 1.

2.2 DDBS CONCEPT

Preliminary analysis [4] indicated that a digital data broadcast system (DDBS) concept could be used and applied as a potential means of reducing cockpit workload and pilot blunders. The initial requirements of a DDBS were derived from an operational analysis that preceded the design of DDB engineering model hardware, and which defined an operational concept and functional requirements for that system. The next logical step, following the fabrication and laboratory testing of the engineering model DDBS, was the evaluation, under actual operational flight conditions, of quantifiable pilot performance parameters as affected by the DDBS units.

As described in Reference 4, Digital Data Broadcast is a technique in which the DME or Tactical Air Navigation (TACAN) ground-to-air radio link is used to carry RNAV-referenced data into the aircraft. In the engineering model of the system that was fabricated, the data transmitted consisted of the identification code, latitude, longitude, magnetic variation and elevation of the transmitting station, and the RNAV distances, RNAV bearings, sequence numbers and group (route) identifiers of the waypoints referred to that station. These latter two items of information are used in a concept of transmitting the entire sequence of RNAV waypoints, which define a STAR, such that the pilot may select only a STAR designator in order to acquire the entire STAR route. The digital information, except for the ground station identifiers, then is decoded, stored, and displayed to the pilot by the DDBS airborne decoder. The applicable navigation data decoded by the DDBS airborne equipment then are fed into the RNAV computer as required for computations of pertinent RNAV parameters. This automatic acquisition of RNAV waypoint data accomplishes two major goals. First, no pilot workload is involved in setting these data into the computer, since it is done automatically. Second, no human error can be introduced by missetting coordinates or track information.

The particular DDBS hardware fabricated for this program was specifically designed to be interfaced with an existing single waypoint analog course line computer, which comprises the majority of those systems currently being used in single-pilot applications. This interface was extremely simple and necessitated only a minor modification to the existing RNAV computer hardware.

2.3 BASELINE COMPARISON CONCEPT

The history of the flight testing of area navigation devices spans more than 25 years. For a variety of reasons these previous flight tests, while providing interesting background information, were not particularly pertinent to the problem at hand. Specifically those tests that were run prior to 1972 did not necessarily reflect the concepts and procedures currently postulated for our future RNAV environment. Another important issue in the gathering of pertinent data on a particular subject involving experimentation is the establishment of a coordinated concept of data collection, in which the types of data and the experiments themselves are structured on a common basis, such that data from one experiment to another can be cross-correlated.

It has been a matter of some historical interest that data previously obtained has been widely scattered in the type and quality thereof, making comparisons between systems and different types of procedures extremely difficult. It is also true that in many instances in the past, the types of data that have been collected have been qualitative or subjective in nature. Primarily, it is interpretive as far as attitudes by both controllers and pilots is concerned. A more quantitative, systematic type of data collection and data analysis needs to be established in order to get meaningful results from experiments which are costly and often few and far between.

Using lessons of the past as a guideline and the Task Force report [5] as a forcing function, a concept of coordinated data collection was initiated and has been successfully applied to all of the controlled RNAV flight tests performed since 1974. The particular approach that was implemented was a data collection and flight evaluation program which coordinates cockpit simulations, experimental flight tests, operational flight tests, and real time terminal area simulations to gather and evaluate those data considered necessary in order to reach an intelligent set of decisions concerning RNAV.

The critical issue that has been kept in mind during the planning phase has been to maintain a strict discipline concerning commonality in order to allow extrapolation and cross-correlation. Commonality in this case does not always mean commonality of equipment, since different equipments must of necessity be evaluated in order to establish differences between performance, both accuracy and functional. The commonality which must be maintained refers to the more ATC environment related issues, such as commonality of routes (both enroute and terminal area), commonality of procedures (both pilot and controller), commonality of the data acquisition concept (parameters, sampling rate, accuracy levels, etc.) and finally, the commonality as far as the techniques of data analysis are concerned, so that the same assumptions, ground rules, compromises, etc., are applied whereever possible to each of the data sources that are used to establish the overall data base.

In order to realistically evaluate such interrelated and involved elements as ATC procedures, controller phraseology, pilot/controller/avionics functions, etc., it was decided to start from a common baseline of routes which were practical from an airspace design point of view - ones that were in concert with the basic guidelines set down by the Task Force. For that reason one basic route structure was selected to be the common element in several of the later simulation and flight experiments performed in the overall effort of which the DDBS experimental development effort was one important element. The total route structure, which is shown in Figure 2.1, was basically the New York design resulting from the analytical effort of Reference 6, with principal emphasis on the early phases of RNAV implementation when the transition from a VOR/radar

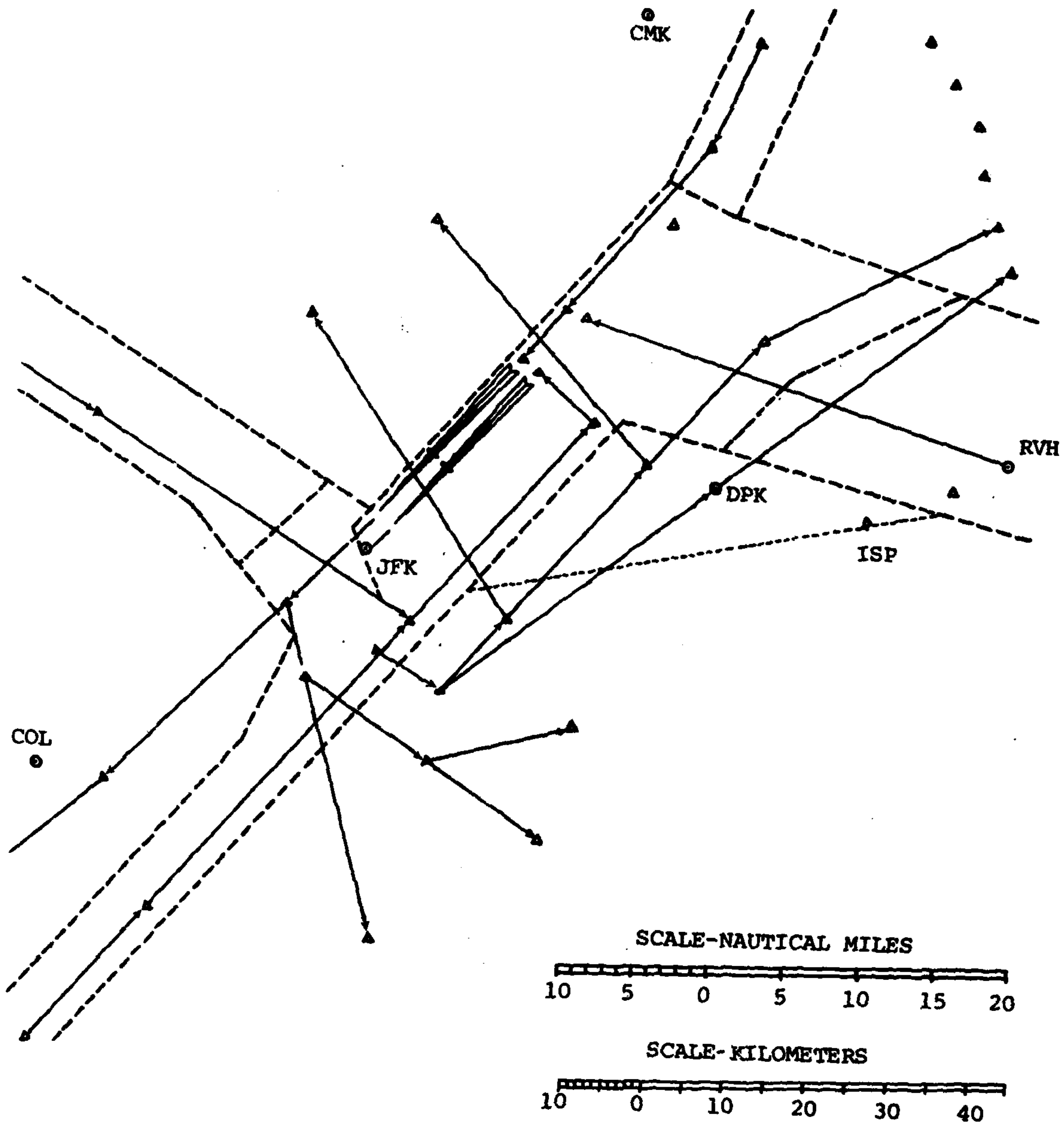

Figure 2.1 Controller-Modified Route Structure

vector environment to an RNAV environment is of critical importance. This route structure, with minor variations to suit the individual circumstances, was used in the real time simulations of References 7 and 8, the cockpit simulations of Reference 2, and the baseline flight test of Reference 3.

In the flight tests of Reference 3, referred to as the "baseline" flight tests, the same basic flight paths which were included in the referenced simulations were used to form a series of RNAV SIDs and STARs which were overlaid over the NAFEC airport. A light twin engine aircraft (Aero Commander 500) using a simple single waypoint general aviation type analog RNAV system was flown under simulated instrument flight conditions, over a route that approximated the same paths that would be flown in the New York terminal area in an RNAV environment. These routes are shown in Figure 2.2.

For the DDBS flight experiments which formed the basis of this research study, a continuing and concerted attempt was made to maintain maximum commonality with the baseline experiments of Reference 3. In this way direct comparisons of pilot performance could be made. In the DDBS experiment, the following items were either similar or identical to the "baseline" RNAV flight tests:

Test Aircraft -	Identical between each test (Aero Commander 500)
Test Location -	Identical (NAFEC terminal area)
Test Routes -	Identical between each test
Test Pilots -	The three DDBS subject pilots were selected from the pool of the original six subject pilots of the "baseline" tests
RNAV Equipment-	DDBS engineering model, modified an RNAV computer identical to the "baseline" test set
Equipment Location -	The DDBS unit was located in the same place in the cockpit as was the RNAV unit in the "baseline" test
Test Instrumentation -	Identical between each test
Data Processing and Analysis -	Identical between each test

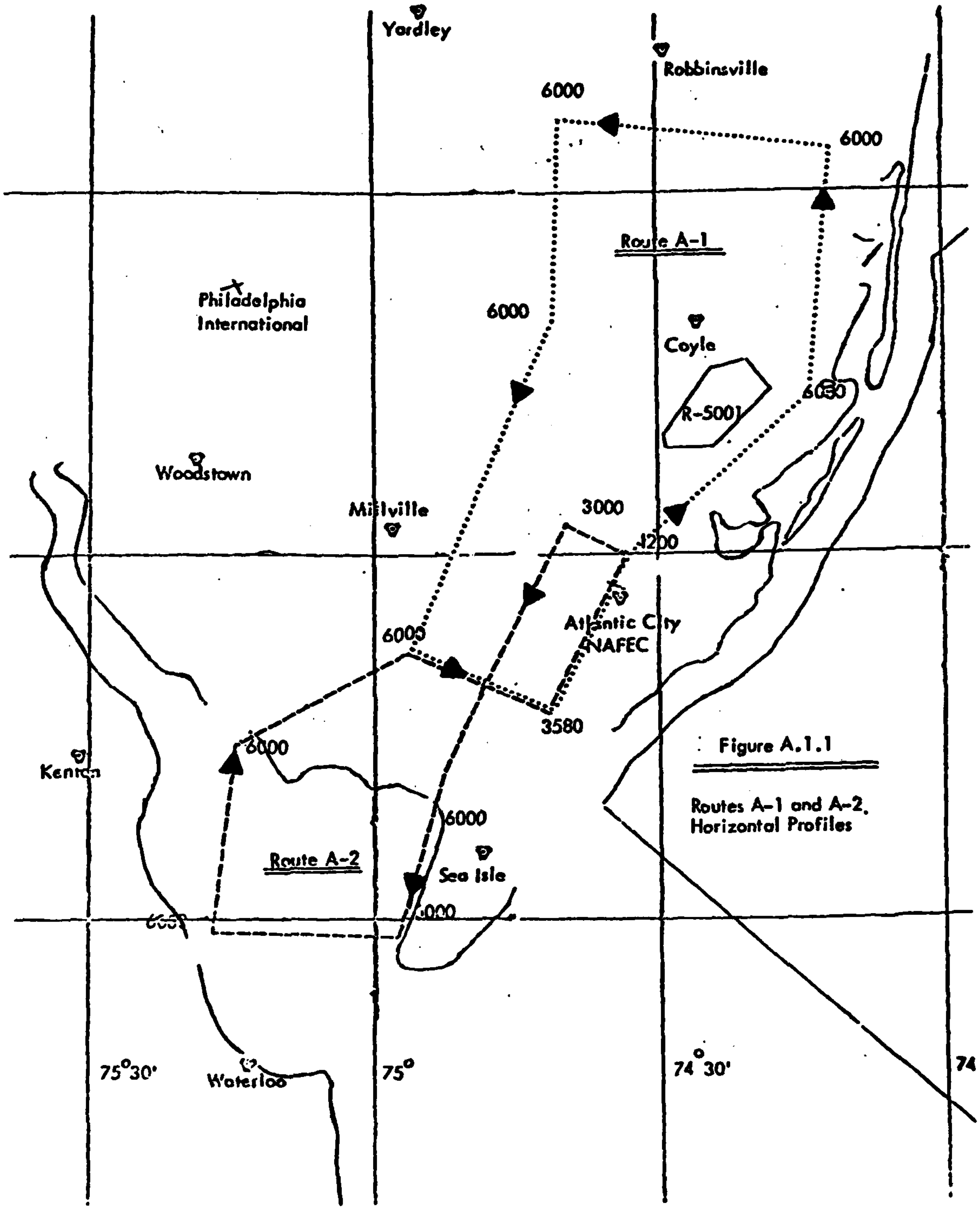

Figure 2.2 Routes A-1 and A-2 Horizontal Profiles

In this manner, a direct comparison of the two major variables of interest to this study, namely the numerical values of blunders per flight and the statistical measures of pilot steering performance (FTE) can be made between the "baseline" tests of Reference 3 and the subsequent DDBS experiment.

2.4 EXPERIMENT DESIGN

While the basic premise of this original DDBS experiment was to evaluate the particular features of the DDBS concept as embodied by the Engineering Model hardware, every attempt was made to maintain a maximum of commonality with the baseline comparison experiment of Reference 3. Three subject pilots were used in the DDBS flight test program from an original pool of six pilots who participated in the baseline experiment. All of the subject pilots were, therefore, familiar with RNAV operations and the flight characteristics of the test aircraft, and were responsible for all of the required navigation and communication tasks. All flights were flown simulating IFR conditions by using an inflight training hood. The safety pilot was the designated pilot in command, and would intervene only for traffic avoidance when, and if, such situations arose. Each subject pilot was briefed in the operational use of the tested DDBS engineering airborne model including a one hour orientation flight prior to the collection of flight test data. Pilots did not know when an impromptu traffic flow clearance would be given. A summary of the subject pilots' experience level is presented in Table 2.1.

Table 2.1 Flight Experience of Subject Pilots in Hours

Subject Pilot	Total	Instrument	Multi-Engine	Light Twin	RNAV
A	400	70	175	175	75
B	10,500	700	3,500	300	30
C	15,900	700	11,500	300	45

A basic DDBS flight test program was designed consisting of six dedicated flight tests for which specific objects were defined as follows:

1. Waypoint Nomenclature - RNC vs DWN -- Evaluate the relative merits of two distinct waypoint identification techniques. From the standpoint of operational utility, should the

preferred waypoint designation technique be the route numbering concept (RNC) in which the pilot enters a single five character data entry into the airborne decoder which designates the entire selected RNAV arrival or departure route, or the discrete waypoint numbering concept (DWN) in which the pilot enters the individual code number of each waypoint he wishes to use?

2. Traffic Flow Transition -- Evaluate and isolate problem areas (operational and procedural) in the terminal area by using the DDBS concept during traffic flow (runway in use) changes and impromptu sequences within a broadcast flow.
3. Waypoint Sequences - Auto vs Manual -- Determine from a design requirement viewpoint whether automatic waypoint sequencing is a desirable system feature.
4. Broadcast Flow Cycle Time -- Determine the operational acceptable value of broadcast cycle time from a minimum of 10 seconds to a maximum of 30 seconds.
5. Waypoint Storage -- Determine the optimum or acceptable number of waypoint storage registers.
6. VNAV Impact -- Determine the impact of VNAV procedures on the DDBS user, concerning such variables as workload, blunder reduction, and changes in aircraft steering performance.

Overlaid above all of the preceding detailed objectives, which were selected to optimize the design features of an ultimate DDBS system, was the basic criteria of overall blunder performance, pilot steering performance and outer loop airspace utilization.

The primary DDBS flight test program consisted of flying terminal area SIDs and STARs. A total of three test patterns of waypoints were transmitted over the experimental VORTAC (VOR colocated with TACAN). Each of the test patterns contained several RNAV departures and arrivals, but all were referenced to a specific runway in use. The three test patterns were the following:

1. Northeast (runway 04) Departure/Arrival (Figures 2.3 thru 2.5)
2. Southeast (runway 13) Departure/Arrival (Figures 2.6 thru 2.8)
3. Northwest (runway 31) Departure/Arrival (Figures 2.9 thru 2.11)

Four different routes were flown on the three combined test patterns. As in a normal operational situation, all arrival and departure route patterns for one specific traffic flow (i.e., Northeast) were broadcast at any given time. This corresponds to the fact that while one runway is active (in use for arrivals and departures), the actual arrivals and departures to and from any given airport can operate in any direction. In the situation when the active runway is changed (i.e., from Northeast flow, runway 04 to Northwest flow, runway 31), the entire broadcast pattern would be changed (from Figures 2.3 thru 2.5 to Figures 2.9 thru 2.11). The shaded route segments on each test pattern denote the particular route flown on that specific test pattern.

1. Northeast Pattern -- (Figures 2.3 through 2.5) -- The aircraft would be flown utilizing the Tango Departure (D24NE) to a "direct-to" transition at the Tango waypoint for the Victor arrival (A27NE) to a landing on runway 04. Note the RNC type route designator, where D indicates departure route, 24 indicates the center of the departure octant through which the departure will be made, and NE indicates the Northeast runway (04) is the current runway flow in use.
2. Southeast Pattern -- (Figures 2.6 through 2.8) -- The aircraft would be flown utilizing the Tango Departure (D24SE) to a "direct-to" transition at the Tango waypoint for the Victor arrival (A27SE) to a landing on runway 13.
2. Northeast Pattern -- (Figures 2.9 through 2.11) -- This pattern was utilized whenever an impromptu traffic flow change was required. The aircraft was flown as in the Northeast pattern (1) until halfway between Victor and Gulf waypoints. At that point, the aircraft was cleared (impromptu) for the Victor arrival (A27NW), coinciding with a traffic flow change by the broadcasting VORTAC station from the Northeast to the Northwest test pattern. At 2.0 nautical miles "To" Gulf, one of two new clearances were given; proceed direct to Somer or Port waypoints. If the aircraft went by way of the Somer waypoint, a new clearance was given just 2.0 nm short of it for a direct-to-Day waypoint. No new clearances (impromptu) were given if the aircraft went by way of Port waypoint. Landings on this pattern were made to runway 31.

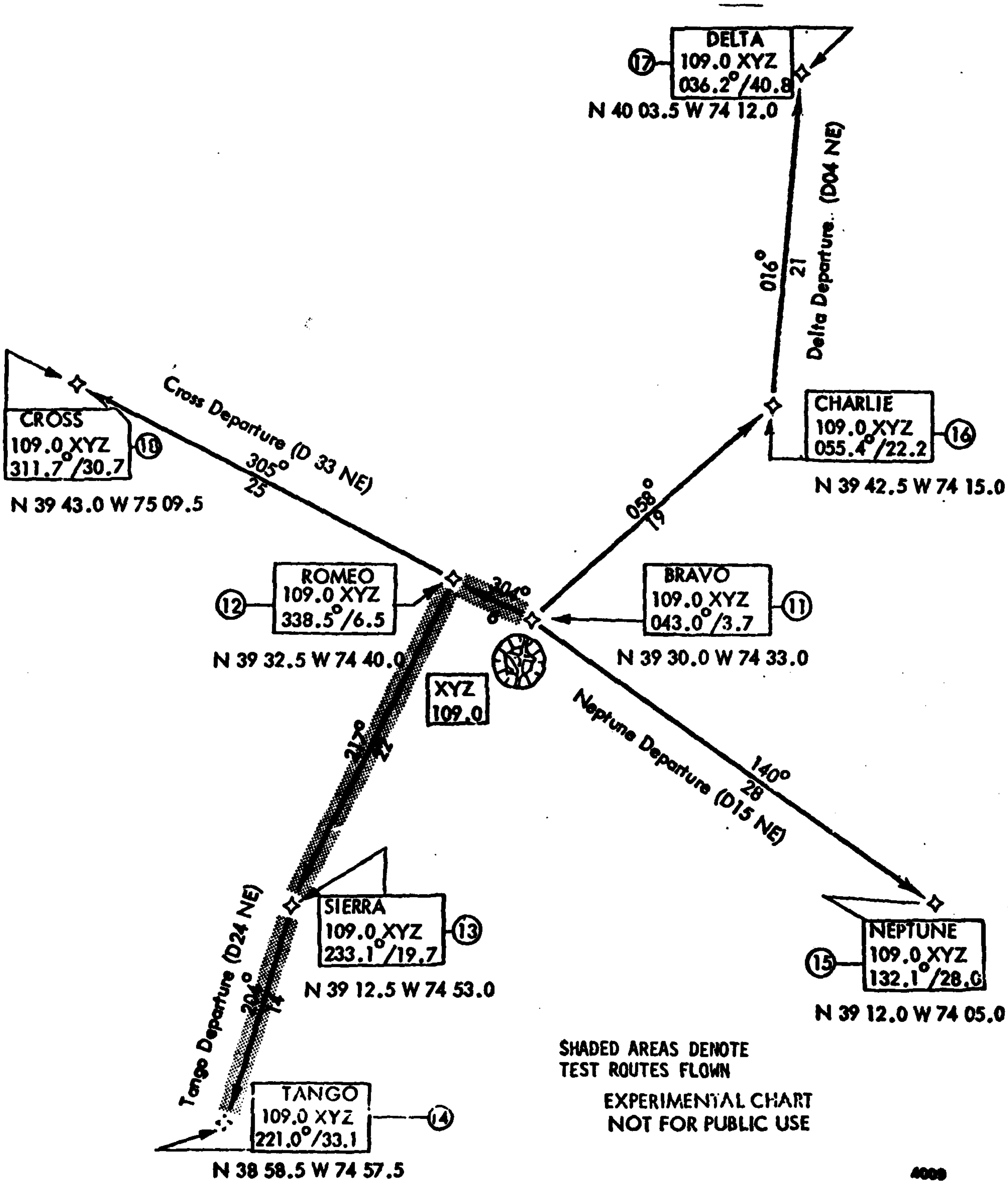

Figure 2.3 Northeast RNAV Departures

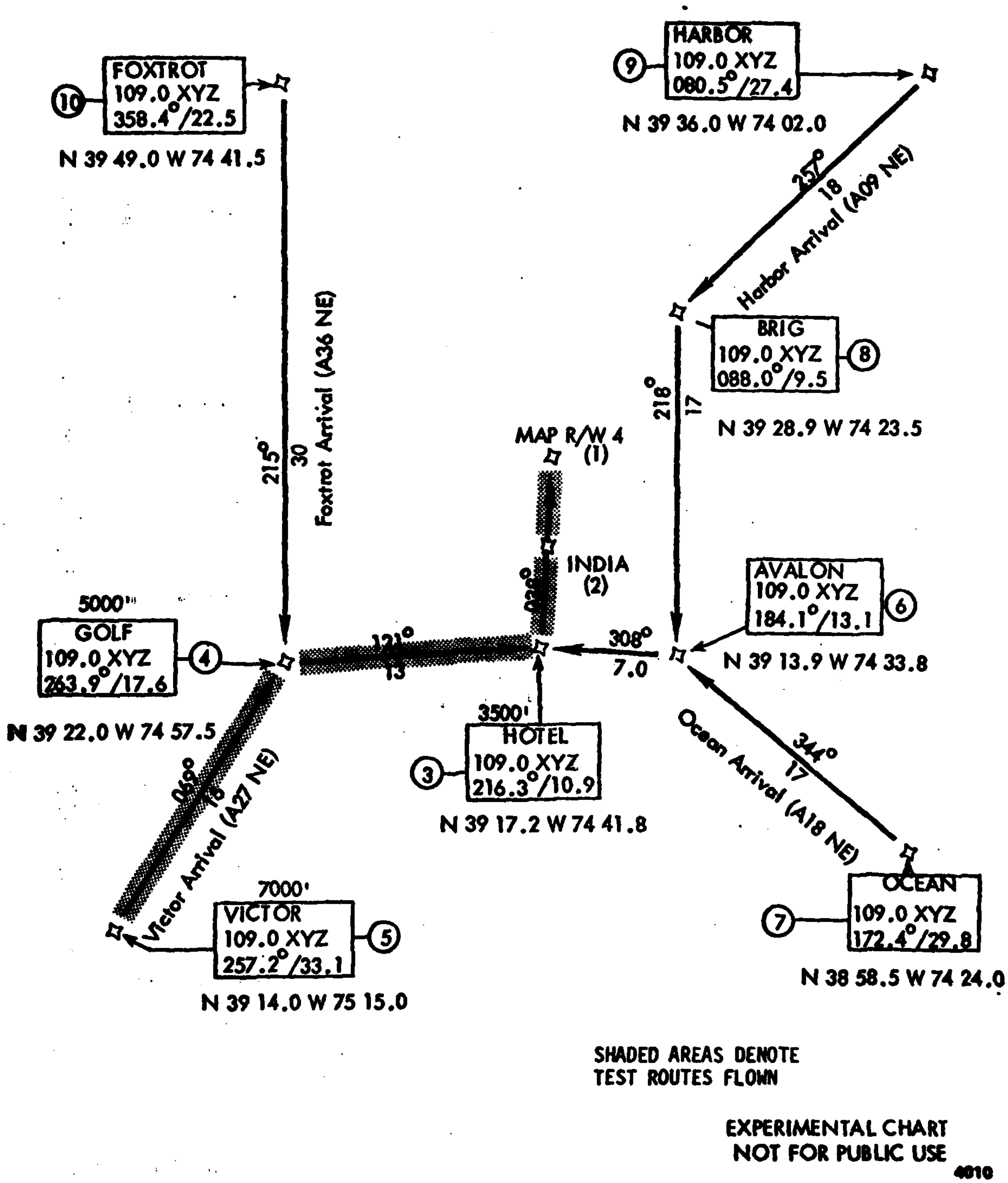

Figure 2.4 Northeast RNAV Arrivals/Hotel Transition

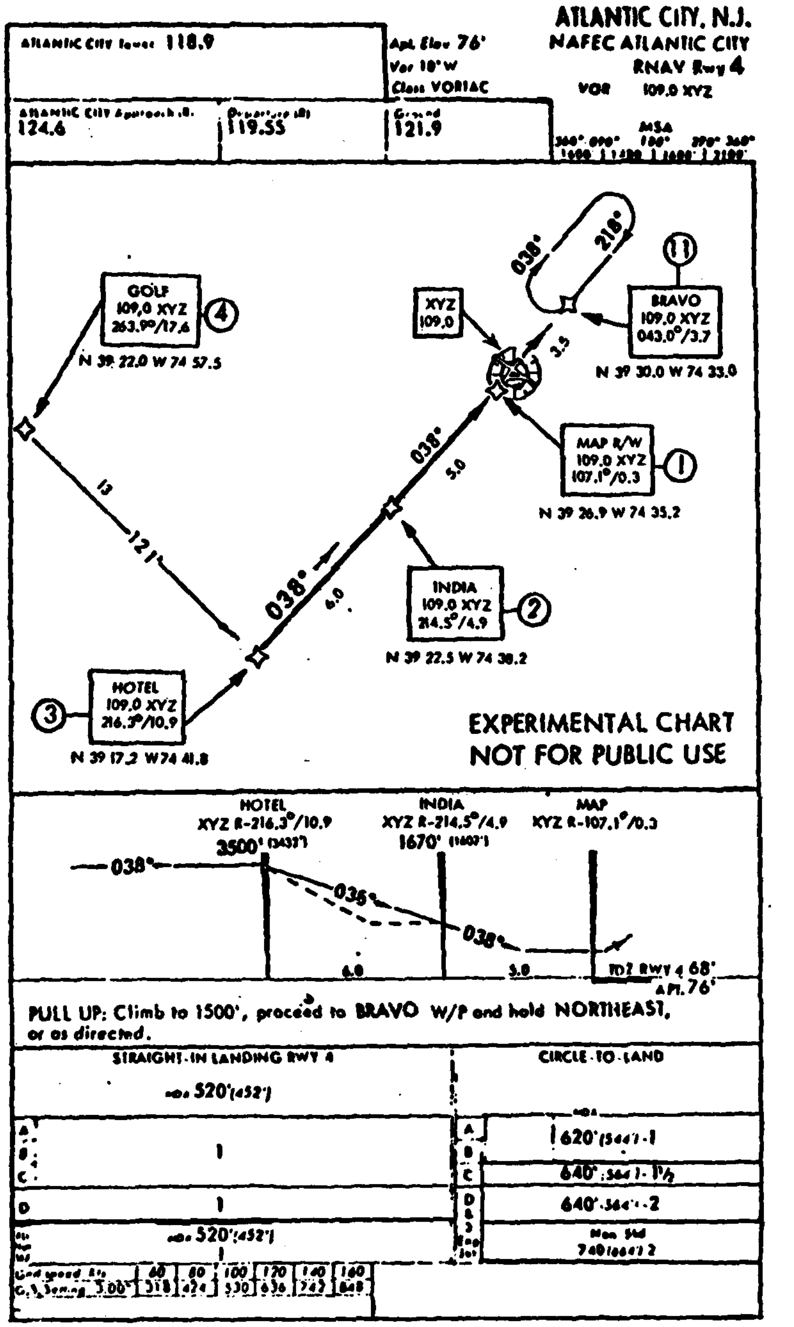

Figure 2.5 Northeast RNAV Approach Plate

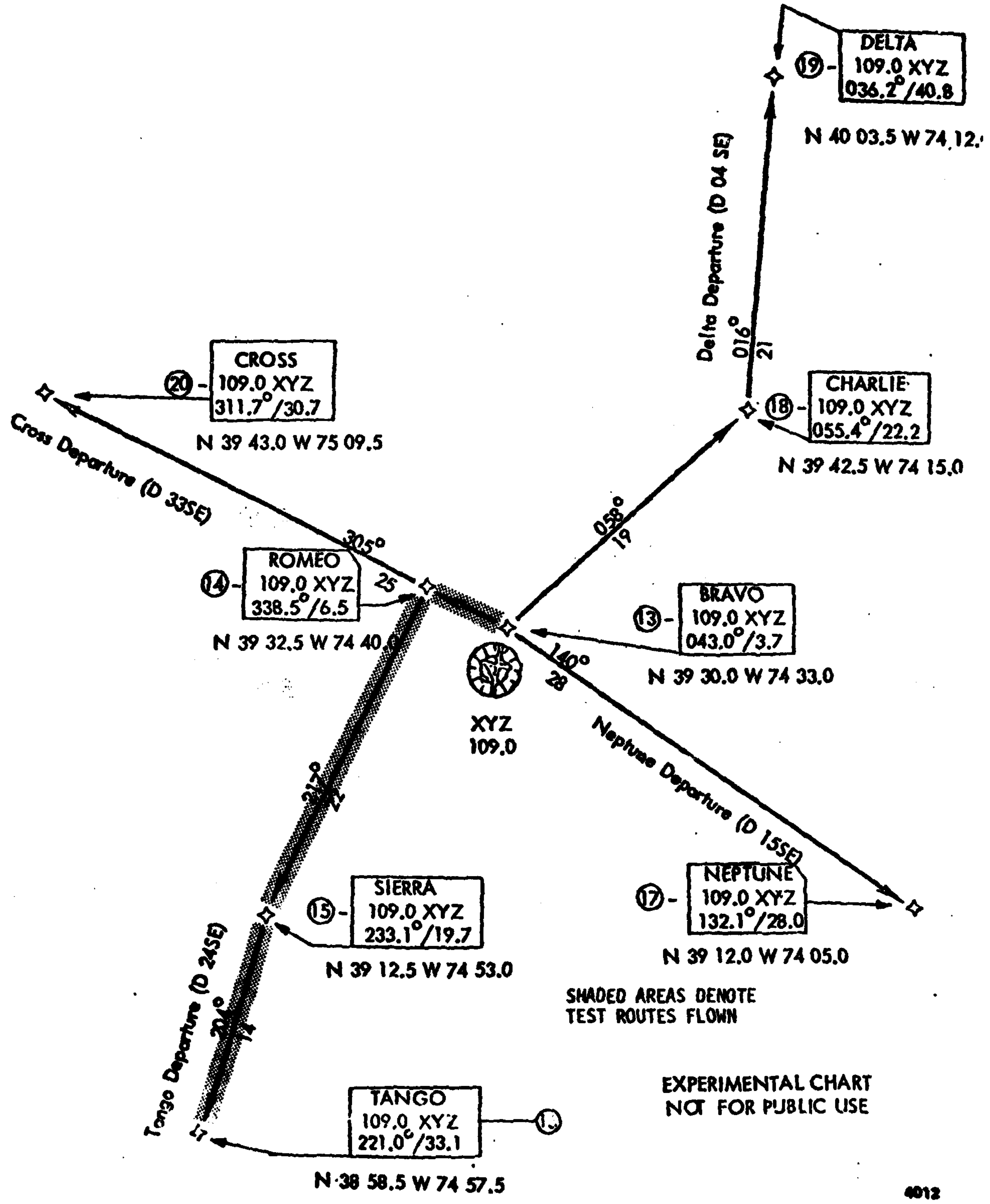

Figure 2.6 Southeast RNAV Departures

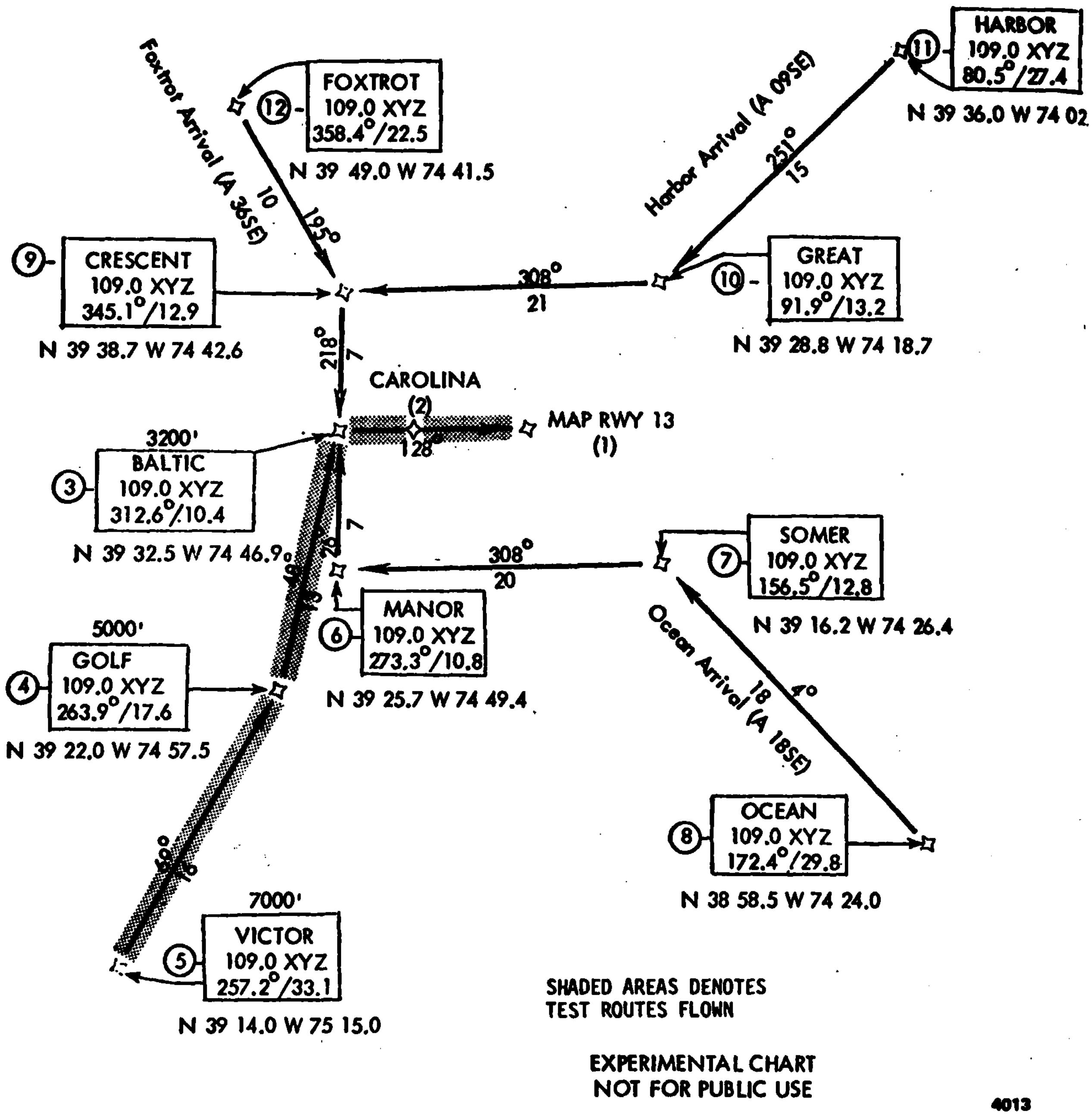

Figure 2.7 Southeast RNAV Arrivals/Baltic Transition

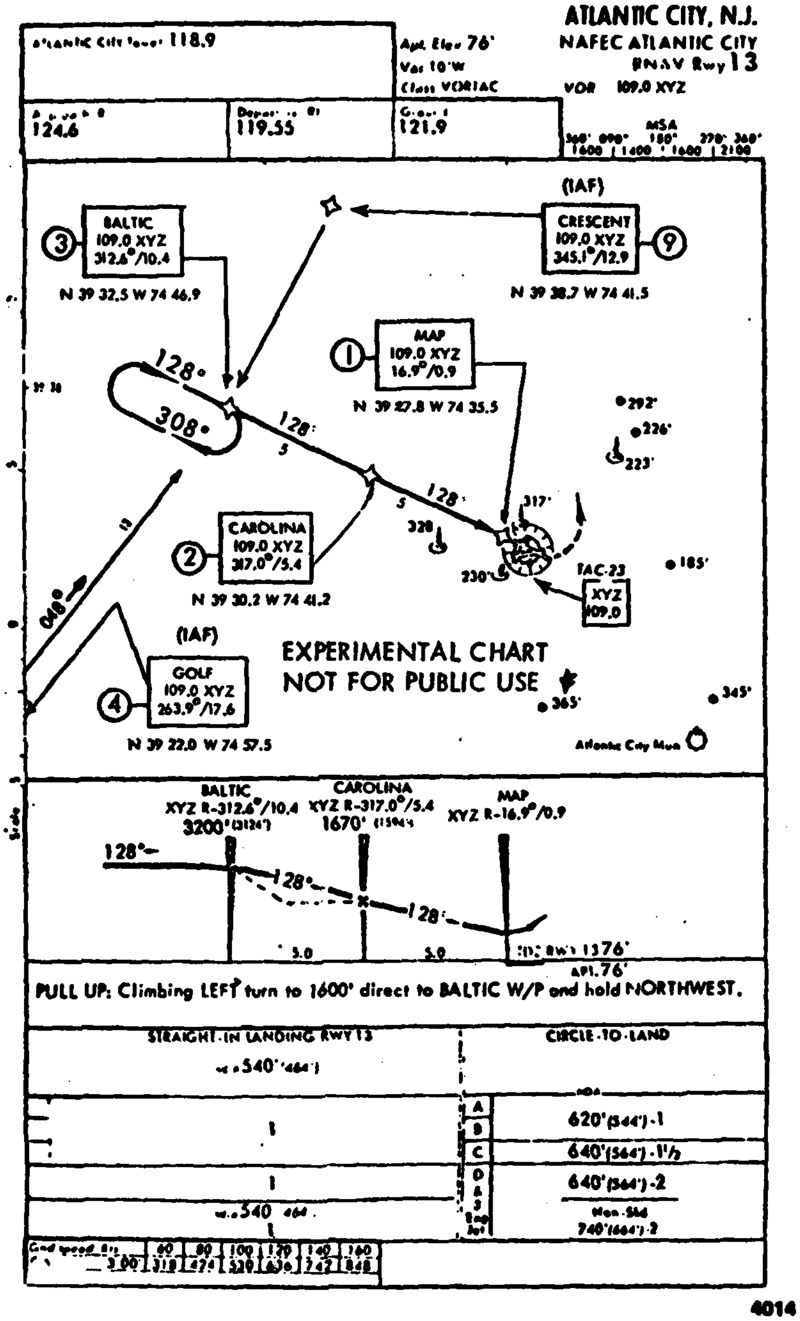

Figure 2.8 Southeast RNAV Approach Plate

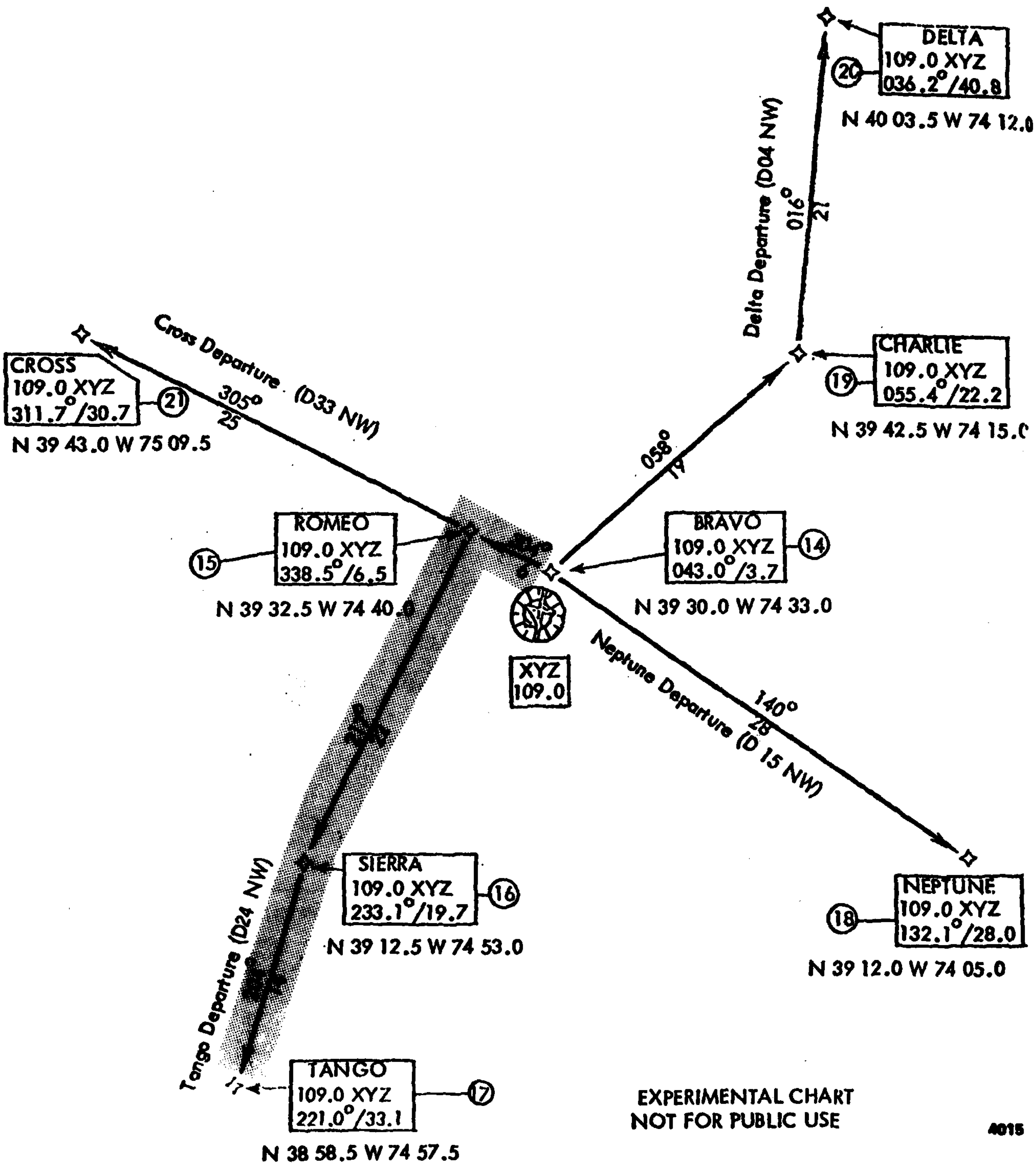

Figure 2.9 Northwest RNAV Departures

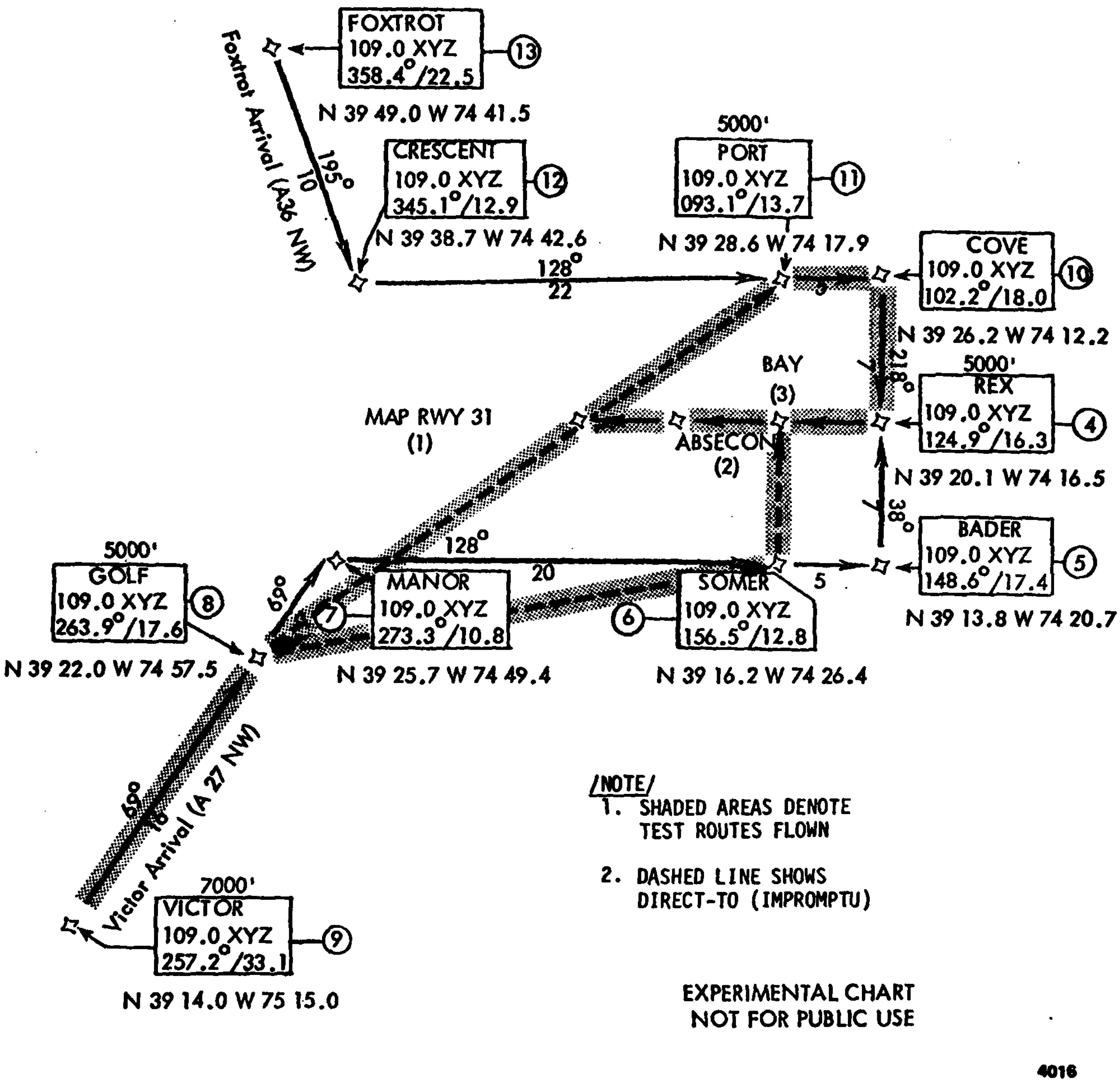

Figure 2.10 Northwest RNAV Arrivals/Bay Transition

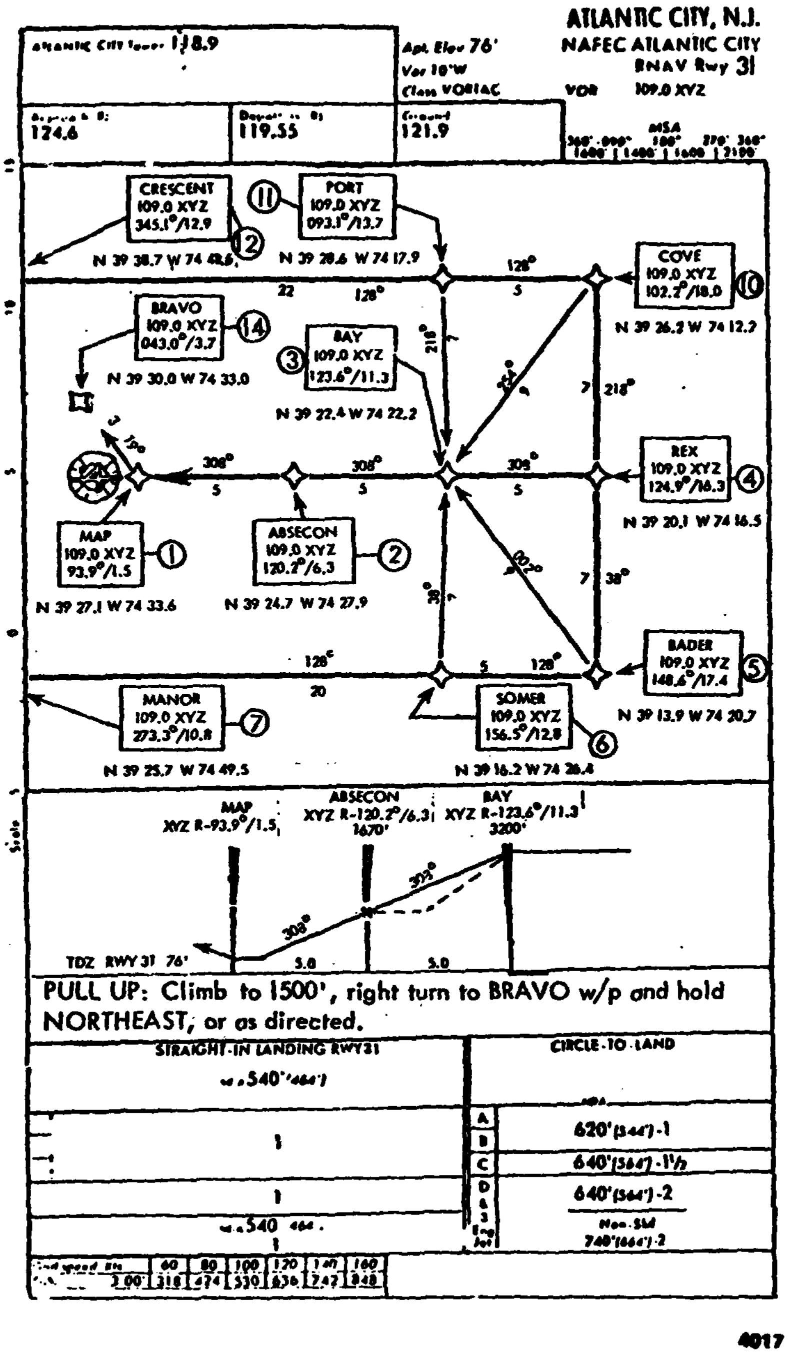

Figure 2.11 Northwest RNAV Approach Plate

2.5 DATA REDUCTION AND ANALYSIS TECHNIQUES

As discussed previously, the two major issues concerning this experimental program were the comparison of pilot blunders and pilot steering performance between the baseline RNAV experiments (non-DDBS) and the DDBS experiments. Each of these issues utilized widely differing data acquisition and analysis techniques in order to reach particular conclusions, and therefore they are each briefly explained in the following paragraphs.

During the flight tests, a trained cockpit observer monitored and maintained an accurate log of routine and special events that occurred during a given flight. The flight logs recorded by the cockpit observer proved to be the major source of data acquisition from which blunder results could be evaluated. In addition, the correlation between the observer logs and EAIR radar plots was also used to identify the relative seriousness of any blunders as regards airspace utilization. Figure 2.12 indicates typical EAIR radar plot results from the baseline flight tests of Reference 3, with indications of the protected airspace limits and annotations from the observer's logs. The major issue at stake as regards this current effort is the development, either through flight hardware or cockpit procedures, of a means of improving pilot blunder performance in a dynamic flight environment. Automation aids, such as the DDBS, may very well alter the character of the pilot's role in the navigation and control mission he has traditionally undertaken. Since the very nature of the pilot's task is interpretive and adaptive, measurement of his performance as regards decision making and attentiveness must also be somehwat qualitative or subjective.

As regards the statistical quantification of pilot steering performance or flight technical error, a process identical to that carried out for the baseline tests was utilized. An airborne digital recorder (Incre-Data Mark II) recorded the following parameters on magnetic tape. Each of these parameters was recorded once per second.

- Time (coordinated with EAIR radar time for correlation purposes)
- Crosstrack Deviation
- Distance to Waypoint
- Altitude

NAFEC ONE RNAV STAR
North Arrival Echo Waypoint
95° Left Hand Turn
CDI Sensitivity = 1/4 nm/dot

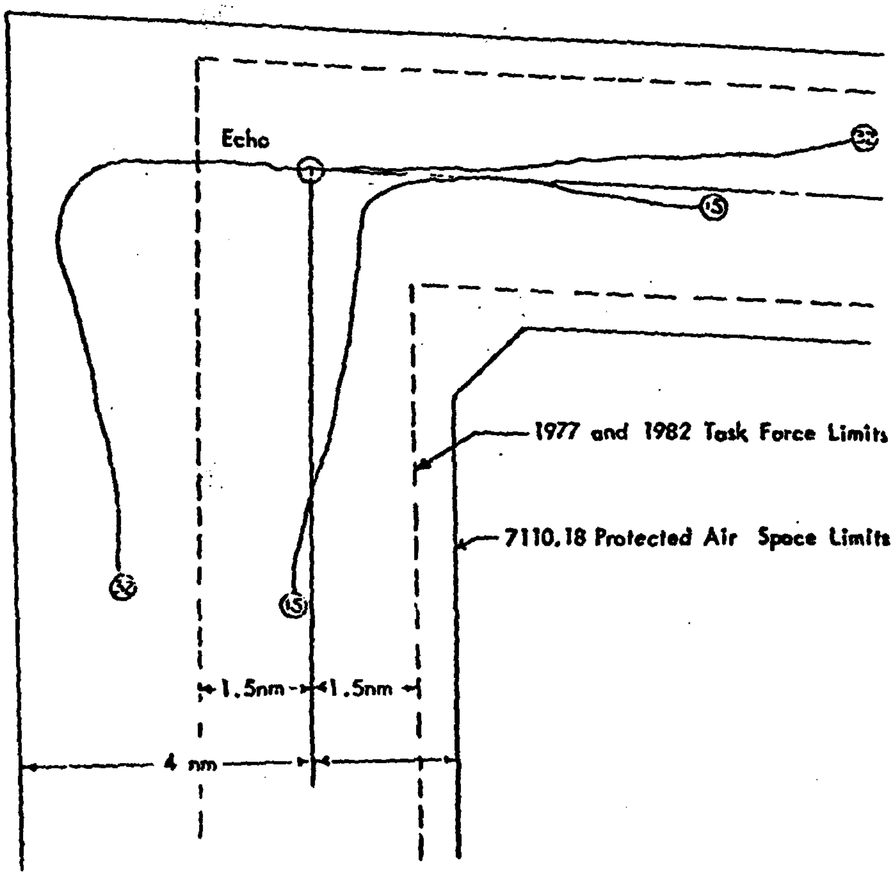

Figure 2.12 NAFEC ONE RNAV STAR

- Heading
- Vertical Deviation
- DME Distance to Station
- VOR Bearing to Station
- Selected Track Angle
- Event Marker

Subsequent to each flight the magnetic tape was removed from the aircraft and run through a software program which converted the recordings to engineering units (degrees, feet, miles, etc.) and provided a "quick look" printout of the results of that flight. By visual inspection of this printout, a sample of which is shown in Figure 2.13, an initial determination of the validity and/or reasonableness of the data can be made. In this way, if for some reason the data was not valid or acceptable, the test could be rescheduled or the deficiency corrected before the test program was continued.

During the flight the EAIR precision tracking radar recorded the actual position of the aircraft on magnetic tape. The following parameters were recorded ten times per second on tape and printed out as hard copy immediately subsequent to each flight. Figure 2.14 illustrates a typical EAIR tracking printout.

- Azimuth (accurate to 0.011°)
- Elevation (accurate to 0.011°)
- Range (accurate to 20 yards)
- Latitude
- Longitude
- Height
- Real Time

In addition to the recorded position of the aircraft, a visual trace was made in real time. The traces for all of the valid data flights run during this test program are contained in Appendix A. These plots also indicate the intended aircraft track per the flight test plan for that specific flight. This trace allows a visual inspection of the flight for correlation with the observer's logs. Using these plots, certain portions of the EAIR tracking data and/or the airborne Incre-Data data <u>may</u> be edited out as being invalid or not pertinent to

HH	MM	SS		M	S		CTD	VTD	DWP	DME	ALT	DALT	HEADING		VOR		OBS	SET
10	30	46	0	E	3	R	0.2	300	8.4	12.6	19.60	5171	14.6	5.2	1	9.0	16	6.6
10	30	51	0	E	3	R	0.2	300	8.3	12.7	19.65	5236	15.2	5.9	1	8.7	17	6.6
10	30	56	0	E	3	R	0.1	300	8.1	12.8	19.70	5207	15.7	6.5	1	8.0	16	6.6
10	31	1	0	E	3	R	0.1	300	7.9	12.9	19.70	5340	16.9	7.6	1	7.7	16	6.6
10	31	6	0	E	3	R	0.1	300	7.8	13.0	19.73	5400	16.7	7.4	1	7.2	16	6.6
10	31	11	0	E	3	R	0.1	300	7.7	13.2	19.66	5493	15.2	5.9	1	6.9	16	6.6
10	31	16	0	E	3	R	0.0	300	7.5	13.3	19.68	5581	14.0	4.5	1	6.6	16	6.6
10	31	21	0	E	3	R	-0.0	300	7.3	13.4	19.60	5630	12.6	3.0	1	6.2	16	6.6
10	31	26	0	E	3	R	-0.1	300	7.1	13.6	19.77	5723	11.9	2.4	1	6.0	16	6.6
10	31	31	0	E	3	R	-0.0	300	7.1	13.7	19.74	5723	12.0	2.5	1	5.4	16	6.6
10	31	36	0	E	3	R	-0.1	300	6.8	13.8	19.79	5828	10.8	1.7	1	5.1	17	6.6
10	31	46	0	E	3	R	-0.1	300	6.6	14.0	19.63	5860	10.3	1.1	1	4.6	16	6.6
10	31	51	0	E	3	R	-0.2	300	6.5	14.2	19.66	5972	10.8	1.8	1	3.8	16	6.6
10	31	56	0	E	3	R	-0.2	300	6.4	14.4	19.68	5989	11.0	1.7	1	3.9	17	6.6
10	32	1	0	E	3	R	-0.2	300	6.2	14.5	19.74	6047	11.0	1.2	1	3.3	16	6.6
10	32	6	0	E	3	R	-0.2	300	6.1	14.6	19.89	6140	11.7	2.3	1	2.3	16	6.6
10	32	11	0	E	3	R	-0.1	300	5.9	14.8	19.71	6134	14.0	4.0	1	2.0	16	6.6
10	32	16	0	E	3	R	-0.2	300	5.8	15.0	19.66	6206	12.6	3.2	1	1.9	16	6.6
10	32	21	0	E	3	R	-0.2	300	5.5	15.0	19.53	6222	9.1	9.6	1	1.6	16	6.6
10	32	26	0	E	3	R	-0.2	300	5.4	15.1	19.74	6321	7.8	8.8	1	1.6	16	6.6
10	32	31	0	E	3	R	-0.2	300	5.2	15.4	19.82	6403	8.0	9.2	1	1.4	16	6.6
10	32	36	0	E	3	R	-0.2	300	5.2	15.4	19.61	6381	7.8	8.5	1	0.5	16	6.6
10	32	41	0	E	3	R	-0.2	300	4.9	15.6	19.78	6463	8.0	9.0	1	0.2	17	6.6
10	32	46	0	E	3	R	-0.2	300	4.7	15.7	19.65	6507	8.4	9.8	1	9.9	16	6.6
10	32	51	0	E	3	R	-0.2	300	4.5	15.9	19.82	6628	9.6	0.7	1	9.6	16	6.6
10	32	56	0	E	3	R	-0.2	300	4.5	16.0	19.74	6800	12.0	2.6	1	9.5	16	6.6
10	33	1	0	E	3	R	-0.2	300	4.2	16.1	19.67	6633	12.6	2.8	1	9.1	16	6.6
10	33	6	0	E	3	R	-0.2	300	4.0	16.3	19.67	6705	8.9	9.7	1	9.1	17	6.6
10	33	11	0	E	3	R	-0.2	300	3.9	16.4	19.20	6600	7.8	9.1	1	8.7	16	6.6
10	33	16	0	E	3	R	-0.3	300	3.7	16.5	19.34	6710	8.0	8.9	1	8.4	16	6.6
10	33	21	0	E	3	R	-0.3	300	3.6	16.6	19.21	6699	8.0	9.3	1	8.5	16	6.6
10	33	26	0	E	3	R	-0.4	300	3.4	16.8	19.30	6787	8.9	9.3	1	8.2	16	6.6
10	33	31	0	E	3	R	-0.4	300	3.2	17.0	19.45	6896	8.0	8.9	1	7.9	16	6.6
10	33	36	0	E	3	R	-0.4	300	3.0	17.0	19.24	6907	6.6	7.6	1	7.5	16	6.6
10	33	41	0	E	3	R	-0.4	300	3.8	17.2	19.26	6946	6.1	6.8	1	7.0	16	6.6
10	33	46	0	E	3	R	-0.4	300	2.6	17.3	19.23	7028	6.3	6.7	1	7.0	16	6.6
10	33	51	0	E	3	R	-0.4	300	2.4	17.5	19.34	7066	5.9	7.0	1	6.7	16	6.6
10	33	56	0	E	3	R	-0.4	300	2.3	17.7	19.28	7072	6.8	7.5	1	6.5	16	6.6
10	34	1	0	E	3	R	-0.5	300	2.1	17.7	19.29	7154	7.2	8.5	1	6.6	16	6.6
10	34	6	0	E	3	R	-0.1	300	1.9	17.9	19.30	7220	6.3	6.5	1	6.4	9	9.2
10	34	11	0	E	3	R	0.5	300	1.8	18.1	19.37	7307	0.9	1.6	1	6.3	337	5.4

Figure 2.13 Sample "Quick Look" Airborne Data Printout

			LAT-LON-ALT	CG 1375 CONAN	R 300	BOLZ	ROCKVILLE,MD.
	EAIR PROGRAM (OCT. 1973)			RUN NO. 1 OF R 300		TASK	0 DATE 7/11/78
KO= 0.	K1= 0.	K2=	1.0000 K3=	0.			
			LATITUDE, LONGITUDE, AND ALTITUDE				
	TIME	AZIMUTH	ELEVATION	RANGE	LATITUDE	LONGITUDE	HEIGHT
33598.9	9/19/58.9	204.296	0.615	200838.000	38.56.54.736	74.53.23.802	3224.7500
33599.0	9/19/59.0	204.296	0.615	200838.000	38.56.54.736	74.53.23.802	3224.7500
33600.0	9/20/ 0.	204.291	0.604	200850.000	38.56.54.540	74.53.23.648	3186.7500
33601.0	9/20/ 1.0	204.274	0.604	200850.000	38.56.54.307	74.53.22.978	3186.7500
33602.0	9/20/ 2.0	204.247	0.593	200862.000	38.56.53.806	74.53.21.931	3148.2500
33603.0	9/20/ 3.0	204.217	0.571	200862.000	38.56.53.365	74.53.20.716	3071.0000
33604.0	9/20/ 4.0	204.203	0.549	200874.000	38.56.53.049	74.53.20.228	2994.5000
33605.0	9/20/ 5.0	204.181	0.536	200874.000	38.56.52.731	74.53.19.342	2946.0000
33606.0	9/20/ 6.0	204.126	0.536	200886.000	38.56.51.851	74.53.17.176	2946.2500
33607.0	9/20/ 7.0	204.060	0.547	200880.000	38.56.50.984	74.53.14.467	2985.0000
33608.0	9/20/ 8.0	204.005	0.558	200880.000	38.56.50.221	74.53.12.236	3023.5000
33609.0	9/20/ 9.0	203.961	0.560	200874.000	38.56.49.665	74.53.10.419	3032.7500
33610.0	9/20/10.0	203.925	0.560	200862.000	38.56.49.274	74.53. 8.912	3032.7500
33611.0	9/20/11.0	203.884	0.569	200850.000	38.56.48.812	74.53. 7.172	3061.5000
33612.0	9/20/12.0	203.843	0.571	200850.000	38.56.48.242	74.53. 5.500	3071.0000
33613.0	9/20/13.0	203.799	0.580	200838.000	38.56.47.743	74.53. 3.649	3099.7500
33614.0	9/20/14.0	203.763	0.593	200826.000	38.56.47.368	74.53. 2.132	3147.5000
33615.0	9/20/15.0	203.739	0.612	200814.000	38.56.47.144	74.53. 1.057	3215.0000
33616.0	9/20/16.0	203.728	0.645	200790.000	38.56.47.233	74.53. 0.480	3329.7500
33617.0	9/20/17.0	203.695	0.659	200778.000	38.56.46.895	74.52.59.073	3377.5000
33618.0	9/20/18.0	203.651	0.659	200754.000	38.56.46.507	74.52.57.167	3377.2500
33619.0	9/20/19.0	203.618	0.656	200742.000	38.56.46.158	74.52.55.766	3367.2500
33620.0	9/20/20.0	203.588	0.634	200718.000	38.56.45.947	74.52.54.424	3289.5000
33621.0	9/20/21.0	203.544	0.615	200694.000	38.56.45.547	74.52.52.522	3222.0000
33622.0	9/20/22.0	203.486	0.604	200670.000	38.56.44.965	74.52.50.057	3183.0000
33623.0	9/20/23.0	203.434	0.602	200658.000	38.56.44.361	74.52.47.877	3173.0000
33624.0	9/20/24.0	203.412	0.593	200640.000	38.56.44.217	74.52.46.895	3144.0000
33625.0	9/20/25.0	203.401	0.591	200622.000	38.56.44.229	74.52.46.356	3134.0000
33626.0	9/20/26.0	203.379	0.593	204834.000	38.56. 5.681	74.53. 6.454	3227.7500
33627.0	9/20/27.0	203.335	0.593	200586.000	38.56.43.661	74.52.43.493	3142.7500
33628.0	9/20/28.0	203.288	0.593	200574.000	38.56.43.134	74.52.41.532	3142.5000
33629.0	9/20/29.0	203.236	0.602	200562.000	38.56.42.543	74.52.39.345	3171.0000
33630.0	9/20/30.0	203.181	0.604	200550.000	38.56.41.910	74.52.37.045	3180.5000
33631.0	9/20/31.0	203.134	0.591	200532.000	38.56.41.432	74.52.35.057	3132.0000
33632.0	9/20/32.0	203.091	0.569	200520.000	38.56.40.935	74.52.33.210	3055.0000
33633.0	9/20/33.0	203.052	0.549	200502.000	38.56.40.571	74.52.31.562	2987.2500
33634.0	9/20/34.0	203.027	0.549	200490.000	38.56.40.346	74.52.30.491	2987.2500
33635.0	9/20/35.0	203.005	0.549	200478.000	38.56.40.162	74.52.29.540	2986.7500

Figure 2.14 Typical EAIR Tracking Radar Printout

the particular situation. In particular, since the RNAV system does not provide command guidance around turns, only steady state (non-turning) data was used in the quantification of FTE. After data editing, time correlating with the observer's data logs and establishing start/stop of valid data, the EAIR data tape was time merged with the Incredata tape, producing the Airborne/Radar Data Merge File shown in Figure 2.15.

For the purposes of this particular analysis, the mean and standard deviation of the crosstrack deviation (equivalent to FTE) was calculated from every ten second interval of data considered to be valid from the Data Merge File, as shown in Figure 2.15. These statistical measures were calculated for the following combinations of test paramters:

- For each individual route segment (track between any two waypoints)
- For each flight (aggregation of all segments comprising one complete flight)
- For each pilot (aggregation of all flights flown by each subject pilot)
- For entire test (aggregation of all flights flown by all pilots)

These data were then compared to the results for the baseline tests, reported in Reference 3 in an identical manner, for the final resolution of the quantitative impact of the DDBS concept of cockpit data input automation on pilot steering performance. Chapter 3 discusses the results of the analysis of both the blunder data and the FTE data resulting from this experiment.

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TIME	DIS.TO WAYPOINT (NM)	EAIR LATITUDE DEG/MIN/SEC	EAIR LONGITUDE DEG/MIN/SEC	EAIR ALT. (FT)	EVENT MARKER	CROSSTRACK DEVIATION (NM)	VERTICAL TRACK DEVIATION (FT)	DME (NM)	CAL. STATUS	PARITY ERROR	REDUN. ERROR	BIT COUNT ERROR
15/ 9/21.000	4.96	39/30/57.1	74/35/ 0.1	1910.2	EM	0.1049	251.3	4.149	0.	0.15	0.	0.
15/ 9/22.000	4.82	39/30/58.6	74/35/ 2.4	1918.5	EM	-0.0058	251.3	4.100	0.	0.05	0.	0.05
15/ 9/23.000	5.00	39/31/ 0.2	74/35/ 4.6	1928.7	EM	-0.0117	251.3	4.003	0.	0.10	0.	0.10
15/ 9/24.000	4.78	39/31/ 1.8	74/35/ 6.8	1938.2	EM	0.0117	251.3	4.221	0.	0.15	0.05	0.05
15/ 9/25.000	4.32	39/31/ 3.4	74/35/ 9.0	1948.5	EM	-0.0466	251.3	4.221	0.	0.10	0.	0.
15/ 9/26.000	4.69	39/31/ 5.0	74/35/11.3	1959.7	EM	-0.0932	251.3	4.149	0.	0.15	0.	0.05
15/ 9/27.000	4.59	39/31/ 6.5	74/35/13.5	1970.7	EM	-0.0583	251.3	4.197	0.	0.10	0.	0.05
15/ 9/28.000	4.14	39/31/ 8.1	74/35/15.8	1984.5	EM	-0.0932	251.3	4.294	0.	0.	0.	0.05
15/ 9/29.000	5.50	39/31/ 9.6	74/35/18.0	1997.2	EM	-0.0932	251.3	3.906	0.	0.	0.	0.
15/ 9/30.000	4.69	39/31/11.1	74/35/20.2	2010.7	EM	-0.1165	251.3	4.367	0.	0.15	0.	0.05
15/ 9/31.000	4.50	39/31/12.6	74/35/22.6	2023.7	EM	-0.0990	251.3	4.367	0.	0.10	0.	0.
15/ 9/32.000	3.74	39/31/14.1	74/35/24.8	2035.7	EM	-0.1049	251.3	3.930	0.	0.10	0.05	0.10
15/ 9/33.000	4.46	39/31/15.7	74/35/27.1	2051.7	EM	-0.1049	251.3	4.967	0.	0.10	0.05	0.05
15/ 9/34.000	4.41	39/31/17.4	74/35/29.3	2064.0	EM	-0.1223	251.3	4.464	0.	0.	0.	0.05
15/ 9/35.000	3.74	39/31/18.9	74/35/31.6	2076.0	EM	-0.2039	251.3	4.918	0.	0.15	0.05	0.10
15/ 9/36.000	5.32	39/31/20.3	74/35/34.0	2093.5	EM	-0.1922	251.3	4.391	0.	0.15	0.05	0.05
15/ 9/37.000	4.19	39/31/21.9	74/35/36.3	2111.2	EM	-0.1922	251.3	4.513	0.	0.10	0.	0.
15/ 9/38.000	4.14	39/31/23.4	74/35/38.7	2126.0	EM	-0.2389	251.3	4.561	0.	0.10	0.	0.05
15/ 9/39.000	4.41	39/31/24.9	74/35/41.0	2138.0	EM	-0.2680	251.3	4.464	0.	0.10	0.05	0.10
15/ 9/40.000	4.78	39/31/26.3	74/35/43.3	2148.5	EM	-0.2389	251.3	4.513	0.	0.15	0.	0.15
15/ 9/41.000	4.19	39/31/27.8	74/35/45.5	2158.5	EM	-0.2505	251.3	4.682	0.	0.15	0.05	0.10
15/ 9/42.000	4.14	39/31/29.3	74/35/47.8	2171.2	EM	-0.2971	251.3	4.755	0.	0.10	0.	0.10
15/ 9/43.000	4.96	39/31/30.7	74/35/50.1	2183.5	EM	-0.3379	251.3	4.658	0.	0.10	0.05	0.05
15/ 9/44.000	3.69	39/31/32.2	74/35/52.5	2194.7	EM	-0.2855	251.3	4.658	0.	0.10	0.	0.05
15/ 9/45.000	4.05	39/31/33.5	74/35/54.9	2202.2	EM	-0.3088	251.3	4.707	0.	0.10	0.	0.
15/ 9/46.000	5.32	39/31/34.9	74/35/57.3	2209.5	EM	-0.3787	251.3	4.731	0.0	0.10	0.	0.05
15/ 9/47.000	3.96	39/31/36.3	74/35/59.7	2213.5	EM	-0.3637	251.3	4.682	0.	0.15	0.	0.
15/ 9/48.000	4.69	39/31/37.4	74/36/ 2.1	2212.2	EM	-0.3495	251.3	4.901	0.	0.10	0.	0.05
15/ 9/49.000	3.51	39/31/38.8	74/36/ 4.6	2212.7	EM	-0.3554	251.3	4.852	0.	0.10	0.05	0.05
15/ 9/50.000	3.92	39/31/40.2	74/36/ 7.1	2216.7	EM	-0.4078	251.3	4.804	0.	0.10	0.	0.10
15/ 9/51.000	3.92	39/31/41.5	74/36/ 9.5	2220.5	EM	-0.4253	251.3	4.779	0.	0.15	0.	0.10
15/ 9/52.000	3.47	39/31/42.8	74/36/12.1	2226.5	EM	-0.4311	251.3	4.901	0.	0.10	0.05	0.05
15/ 9/53.000	3.51	39/31/43.9	74/36/14.6	2236.5	EM	-0.4253	251.3	4.876	0.	0.10	0.	0.
15/ 9/54.000	4.14	39/31/45.1	74/36/17.1	2246.2	EM	-0.3637	251.3	4.682	0.	0.10	0.10	0.

EVENT MARKER- ENROUTE MODE - EM, EVENT 1 - EM 1, EVENT 2 - EM 2, EVENTS 1+2 - EM 1/2
APPROACH MODE - AM, EVENT 1 - AM 1, EVENT 2 - AM 2, EVENTS 1+2 - AM 1/2

Figure 2.15 Airborne/Radar Data Merge File

3.0 FINDINGS AND RESULTS

3.1 GENERAL

As discussed previously in Reference 1, the flight research phase of the DDBS test program consisted of thirty six (36) flights flown at the FAA NAFEC facility at Atlantic City, New Jersey during the test period of September 15, 1975 to November 13, 1975. Of these flights, twenty six (26) were for data collection purposes, with the rest devoted primarily to equipment shakedown or pilot orientation purposes.

Tables 3.1 through 3.3 show the actual DDBS flight test runs flown by each of the three subject pilots, whose experience level has been shown in Table 2.1. Table 3.1 illustrates that portion of the test matrix flown by subject pilot A. Notice that the matrix is balanced among the sixteen (16) flights as regards the primary test variables discussed in Section 2.4 with the exception of the waypoint storage issue. The original test matrix established in Reference 4 had defined a 40%-60% split between the 2- and 6- waypoint test. When the original two pilot matrix had to be perturbed, for scheduling reasons, to accomodate an additional subject pilot (subject pilot C), this planned distribution was not directly achievable. Tables 3.2 and 3.3 present that portion of the test matrix which was flown by subject pilot B and C. Table 3.4 shows an overall summary of test variables per subject pilot per number of flights. Reference to Table 3.4 will indicate the relative balance of the final DDBS flight test matrix as actually flown.

In each of the previously referenced Tables 3.1 through 3.3, the arrival/departure designator code in the tables (i.e., A27SE) refers to the DDBS nomenclature code of an arrival or departure route previously defined as part of a broadcast traffic flow pattern, in this case the Southeast traffic flow for runway 13 arriving through the 270° arrival octant. Likewise a D24NE refers to a departure route from runway 04 departing through the 240° departure octant in a selected and broadcast traffic flow. The remaining major headings of the tables merely refer to the configuration of specific test variables in a given flight test.

3.2 BLUNDER ANALYSIS

As discussed in Section 2, a major factor in the design of this DDBS experiment in particular, and the continuing series of area navigation pilot performance studies in general, was the establishment of a maximum of commonality among experimental variables. In order to

Table 3.1 DDBS Flight Test Matrix Flown by Subject Pilot "A"

Figur

Flight Number	Flight Test Date	Departure Route	Arrival Route	Arrival Traffic Flow Change & Impromptu	Waypoint Storage	Manual or Auto	RNC or DWN	Traffic Flow Cycle Time (seconds)	Approaches 2D RNAV or 3D RNAV
1	10/21/75	D24NE	A27NE	None	6	M	RNC	10	3D
2	10/21/75	D24NE	A27NE	None	6	M	DWN	10	3D
3	10/22/75	D24SE	A27SE	None	6	M	RNC	30	2D
4	10/22/75	D24SE	A27SE	None	2	M	DWN	30	2D
5	10/22/75	D24NE	A27NE	A27NW (GOLF to SOMER to BAY)	2	M	DWN	10	3D
6	10/22/75	D24NE	A27NE	A27NW/A36NW (GOLF to PORT)	6	M	DWN	30	2D
7	10/23/75	D24NE	A27NE	A27NW/A36NW (GOLF to PORT)	6	A	RNC	30	2D
8	10/23/75	D24NE	A27NE	A27NW/A36NW (GOLF to PORT)	6	M	RNC	30	2D
9	10/23/75	D24NE	A27NE	A27NW (GOLF to SOMER to BAY)	6	M	RNC	10	3D
10	10/23/75	D24SE	A27SE	None	6	A	RNC	10	3D
11	10/23/75	D24NE	A27NE	None	6	A	RNC	30	2D
12	10/23/75	D24NE	A27NE	None	2	A	DWN	30	2D
13	10/24/75	D24NE	A27NE	A27NW (GOLF to SOMER to BAY)	6	A	RNC	10	3D
14	10/24/75	D24SE	A27SE	None	6	A	DWN	10	3D
15	10/24/75	D24NE	A27NE	A27NW (GOLF to SOMER to BAY)	6	A	DWN	30	2D
16	10/24/75	D24NE	A27NE	A27NW/A36NW (GOLF to PORT)	2	A	DWN	10	3D

Table 3.2 DDBS Flight Test Matrix Flown by Subject Pilot "B"

Flight Number	Flight Test Date	Departure Route	Arrival Route	Arrival Traffic Flow Change & Impromptu	Waypoint Storage	Manual or Auto	RNC or DWN	Traffic Flow Cycle Time (seconds)	Approaches 2D RNAV or 3D VNAV
1	10/28/75	D24NE	A27NE	None	6	M	RNC	10	2D
2	10/28/75	D24SE	A27SE	None	2	M	DWN	10	2D
3	10/28/75	D24NE	A27NE	A27NW/A36NW (GOLF to PORT)	6	A	DWN	10	2D
4	10/28/75	D24NE	A27NE	A27NW (GOLF to SOMER to BAY)	6	A	RNC	30	3D
5	10/28/75	D24SE	A27SE	None	6	A	RNC	10	2D
6	10/29/75	D24NE	A27NE	A27NW/A36NW (GOLF to PORT)	6	M	RNC	30	3D

Table 3.3 DDBS Flight Test Matrix Flown by Subject Pilot "C"

Flight Number	Flight Test Date	Departure Route	Arrival Route	Arrival Traffic Flow Change & Impromptu	Waypoint Storage	Manual or Auto	RNC or DWN	Traffic Flow Cycle Time (seconds)	Approaches 2D RNAV or 3D VNAV
1	11/12/75	D24NE	A27NE	None	2	A	DWN	10	2D
2	11/12/75	D24NE	A27NE	A27NW/A36NW (GOLF to PORT)	2	A	DWN	30	3D
3	11/12/75	D24NE	A27NE	None	6	M	RNC	30	3D
4	11/12/75	D24NE	A27NE	A27NW	6	M	RNC	10	2D

Table 3.4 DDBS Flight Test Matrix Summary of Variables/ Subject Pilot/Number of Flights

Flight Test Matrix Variables	Number of Flights			Total
	Subject Pilot A	Subject Pilot B	Subject Pilot C	(all pilots)
NUMBER OF FLIGHTS	16	6	4	26
<u>Waypoint Sequencing</u>				
a) Auto Mode	8	3	2	13
b) Manual Mode	8	3	2	13
<u>Waypoint Selection</u>				
a) RNC	8	4	2	14
b) DWN	8	2	2	12
<u>Approach-Descend</u>				
a) 2D RNAV	8	4	2	14
b) 3D RNAV/VNAV	8	2	2	12
<u>Waypoint Storage</u>				
a) 2 W/P	4	1	2	7
b) 6 W/P	12	5	2	19
<u>Traffic Flow Cycle Time</u>				
a) 10 Seconds	8	4	2	14
b) 30 Seconds	8	2	2	12
<u>Traffic Flow Change</u>				
a) Arrivals	8	3	2	13
<u>Impromptu</u>				
a) Golf-Somer-Bay (2)	4	1	1	6
b) Golf-Port	4	2	1	7

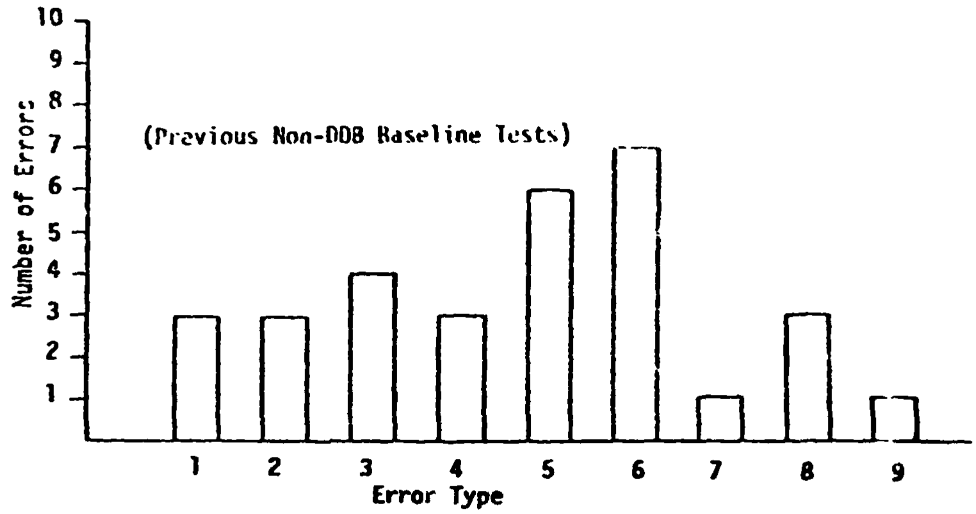
assess the DDBS potential for effecting a reduction in pilot-induced blunders, this data analysis included a direct comparison of blunder error data between the DDBS flight test program and the "baseline" general aviation RNAV flight test previously reported in Reference 3. This comparison is particularly valid since the DDBS test aircraft, cockpit configuration and basic RNAV system, and test routes were identical or similar to a major degree to the baseline experiment. In addition the total number of test flights were nearly equal (30 for baseline vs 26 for DDBS), and most importantly the three DDBS subject pilots were part of the original baseline subject pilot population. Particularly in the case of blunders, where data was recorded on an individual pilot basis, a direct comparison can be made concerning the impact of DDBS on blunder performance for each specific pilot.

Figure 3.1, appearing in Reference 1, shows the pilot's RNAV control errors, by type, which were observed during the previous baseline tests. An examination of this figure indicated that thirty-one (31) subject pilot errors were documented. This computes to an average value of 1.03 errors per flight. In the twenty-six (26) DDBS data flights flown by the three subject pilots, only four pilot-induced blunders were recorded. This results in an average value of 0.15 errors per flight, or a reduction of 86% in pilot blunders which could be attributed to the utilization of DDBS in the RNAV environment of the terminal area.

A summary of the pilot blunder data recorded during these tests is presented in Table 3.5. An analysis of this data indicates that only two of the four blunders actually resulted in a violation of protected airspace. Analysis of these data also shows that pilot A had a blunder rate of only 0.06 errors per flight as opposed to 0.17 and 0.50 for pilots B and C, respectively. This seeming disparity could very well be attributed to the fact that pilot A had been involved in the preliminary analysis and design of the DDBS hardware and therefore was much more familiar with its theory of operation than the other two subject pilots. That fact notwithstanding, even the poorest pilot from a blunder standpoint had an error rate of only 0.50 errors per flight as compared to the average value of 1.03 from the baseline test.

Table 3.5 DDB Flight Test Pilot Blunder Analysis

Subject Pilot	Type of Error	Description	Probable Cause	Airspace Violation
A	Selected Wrong RNAV Arrival (RNC Method)	Selected A24SE Arrival instead of A27SE	Incomplete update and/or not sufficient DDB training. Transition was from D24SE departure (Pilot changed D to A only)	NO
B	Selected Wrong Waypoint (DWN Method)	Selected waypoint Cove (WP No. 10) instead of Port (WP No. 11). Pilot noticed error in less than 2 minutes.	High workload due to impromptu traffic flow change followed by a direct-to clearance.	NO
C	Lost RNAV Guidance (DWN Method)	Pilot did not make provisions for acquisition of next waypoint after the active waypoint would sequence out. (Auto mode was selected).	Pilot was limited (test) to a maximum use of 2 waypoints storage	YES
C	OBS	Selected an OBS of 038° instead of 120°. Pilot misread the RNAV charts (OBS of 038° is for final approach segment)	Pilot was distracted while listening to extraneous radio communications	YES



1. VORTAC Frequency
2. CDI Sensitivity Change
3. Waypoint Radial
4. Waypoint Distance
5. OBS Course
6. Waypoint Altitude Set (VNAV)
7. Steering Horizontal
8. Steering Vertical
9. Wrong Waypoint

Figure 3.1 General Aviation RNAV Control Errors by Type (Baseline Experiment)

Another interesting evaluation of blunder data is to compare the value of blunders per flight between the identical pilots from the baseline tests of Reference 3 and the current DDBS tests. Table 3.6 illustrates the fact that for DDBS subject pilots A and B, their rate of blunders per flight was reduced markedly to values approximately 15% and 10% respectively of the baseline values. Subject pilot C had an increase in blunder rate per flight to 125% of his original baseline error rate. In the overall sense, pilot C's increase does not appear to have the statistical significance of pilots A and B's drastic error rate reduction. The average error rate for the identical three pilots decreased to 17% of their baseline value, again a significant reduction.

Table 3.6 Procedural Error Rate Per Flight

DDBS Subject Pilot	Procedural Error Rate Per Flight	
	Baseline	DDBS
A	0.4	0.06
B	1.8	0.17
C	0.4	0.50
Average	0.87	0.15

3.3 FTE ANALYSIS

The second quantifiable measure of the impact of the DDBS concept on pilot performance is the comparative evaluation of flight technical error. As discussed in Section 2, since this DDBS flight test experiment was designed to be identical to the experiment described in Reference 3 as regards flight routes, equipment, instrumentation and data reduction, a direct comparison of the results of the two experiments can be made. In the blunder analysis described earlier in this chapter, a pilot-by-pilot comparison of blunders per flight was made. In the case of FTE, however, Reference 3 did not document FTE on a per-pilot basis. For that reason, FTE statistics contained herein will be compared on an overall test data basis. It will be shown that the data sample used for this comparison is of a magnitude that the comparisons made are statistically definitely significant.

As outlined in Section 2, the deflection of the course deviation indicator (CDI) was used as the measure of pilot steering performance. The pilot's primary control function was to maneuver the aircraft to keep the CDI needle centered at all times. The deflection (if any) of that needle was a direct measure of how far from the centerline of the desired ground track (the line proceeding into the "To" or active waypoint at the selected OBS bearing) the RNAV system thinks it is. The output of crosstrack deviation from the RNAV computer drives the CDI in a linear manner. That is to say, the deflection of the CDI needle is directly proportional to the linear distance off track. For the DDBS tests, a deflection of one "dot" (approximately .125 inches) on the face of the CDI instrument normally indicated a crosstrack deviation of 1.0 nm. During the final approach portion of the flight, normal pilot operating procedure was to switch the scale sensitivity of the output of the RNAV computer to 0.25 nm per dot.

The airborne instrumentation recorded, as one of its parameters, the electrical signal of crosstrack deviation sent from the RNAV computer to the CDI instrument. This value, seen as the CDI column on Figures 2.13 and 2.15, was used to compute the FTE statistics presented in this section. As discussed previously, the CDI value at every 10 seconds of merged data was originally aggregated into data sets for each DDBS flight segment (between two waypoints), and then further combined into groups of flight segments categorized as "terminal" and "approach" phases of flight for comparison with the baseline data of Reference 3. Appendix B contains the original data sets used for these aggregations. Note in Appendix B that the number of data samples (column N) is shown for each segment. As stated in Section 2, some data from each flight was selectively edited out prior to statistical evaluation for a variety of reasons. Thus the data samples are not identical for each flight over the same course. This same data editing technique was applied to the baseline data of Reference 3 however, so any comparisons between the two data sets can be made on the same basis. For the same basic reason, two flights flown by subject pilot B were not included in the FTE data set. The performance of the instrumentation was such on these two flights that the data was not considered to be valid. Table 3.7 contains the results of the initial aggregation of the data of Appendix B combined into FTE values of mean ($\bar{x}$) and two sigma presented on a per flight per pilot basis, indicating also the number (N) of 10 second data samples for each flight.

Table 3.7 CDI Aggregation

Total Per Flight Per Pilot				
Flight No.	Pilot	N	$\bar{X}$	2σ
1	A	209	.135	1.442
2	A	200	.097	1.572
3	A	192	-.015	.758
4	A	196	-.066	.708
5	A	238	-.141	1.275
6	A	262	-.138	1.068
7	A	277	.150	.815
8	A	256	.203	.712
9	A	246	.210	.800
10	A	192	.259	.897
11	A	137	.150	.746
12	A	127	.075	.694
13	A	161	.033	.487
14	A	188	-.033	.876
15	A	216	.052	.711
16	A	211	-.094	.792
1	B	146	-.120	.635
4	B	198	-.201	.612
5	B	184	.028	.578
6	B	204	-.007	.617
1	C	205	-.023	.942
2	C	257	.045	.955
3	C	199	-.086	.825
4	C	232	.022	.741

Further statistical aggregation of these data results in Table 3.8, when the FTE performance of all flights flown by each pilot is presented on a per pilot basis and then as a total FTE statistic for the entire DDBS flight test program. Two incidental comments on Table 3.8 are in order. It is interesting to note that while the blunder analysis presented previously indicated that subject pilot A had the lowest blunder rate per flight, this same subject pilot had the poorest FTE performance. This could have resulted from the fact that subject pilot A was by far the least experienced of the three subjects as far as total flying hours was concerned, although he has the most familiarity with the DDBS equipment per se. The other note regarding Table 3.8 is the fact that there is very little difference in the two sigma FTE values between the three pilots. On an overall basis their performance was quite consistent. This can also be seen from an examination of Table 3.7.

Table 3.8 DDBS - CDI Aggregation

Total All Flights Per Pilot (combined terminal and approach data)			
Pilot	N	$\overline{X}$	2σ
A	3308	.054	.986
B	732	-.073	.636
C	893	-.006	.876
Total All Flights	4933	.024	.927

For purposes of the objective comparison of FTE between the DDBS tests and the baseline tests of Reference 3, the test data has been aggregated into the terminal and approach phases of flight. Table 3.9 presents the directly relatable results of these tests. As can be seen, the sample sizes between the two tests are quite comparable for each phase. While the mean values are somewhat different, which does have an impact when total airspace utilization is considered, the principal measure of comparison, the two sigma values of FTE, are markedly improved through the use of DDBS in both phases of flight.

Table 3.9 FTE Summary
(Baseline vs DDBS)

Flight Test	Phase	N	FTE (nm) $\overline{X}$	FTE (nm) 2σ
Baseline (Ref. 3)	Terminal Approach	5602* 519**	-.247 -.340	1.540 1.661
DDBS	Terminal Approach	4439† 494††	.027 -.005	.950 .684

*SID and STAR to Hotel or Baltic Waypoint
**Entire Final Approach Segment Hotel-India-Map and Baltic-Carolina-Map

†SID and STAR to Hotel, Baltic or Bay Waypoint
††Entire Final Approach Segment Hotel-India-Map, Baltic-Carolina-Map and Bay-Map

(See Figures 2.3 through 2.11)

In the strict statistical sense, the mere observation that two values are "markedly different" has no quantifiable meaning. For this reason, the variance between the standard deviations of the baseline test and the DDBS test was determined using the variance ratio test. The variance ratio test is defined as:

$$F = \frac{\text{greater estimate of the variance of the population}}{\text{lesser estimate of the variance of the population}}$$

The Null Hypothesis was used, applying Bessel's correction to the variance to arrival at the best estimates. F distribution tables were used[9] to determine the probability level of significance of variation. All results of these calculations showed probability levels of high significance, meaning that there was only a very small chance that the results could have arisen by chance. Table 3.10 summarizes these findings. It defines the flight test data sets by flight phase (approach or terminal). The probability level describes the level of significance or chance that the result could have arisen by chance, i.e., p = .05, 1 chance in 20; p = .01, $\frac{1}{100}$; p = .005, $\frac{1}{200}$; p = .001, $\frac{1}{1000}$. Table 3.11 shows the set of variables which were used for the variance ratio test calculations.

Table 3.10 FTE Significance Values

Flight Test	Phase	FTE Sample Points	FTE Probability Level
Baseline DDBS	Terminal	5602 4439	p = .001
Baseline DDBS	Approach	519 494	p = .001

The equation $\hat{\sigma}_1^2 = (\frac{n_1}{n_1 - 1})\sigma_1^2$ was applied to the baseline and DDBS flight test data for each phase in Table 3.11. Taking the terminal phase as an example, the baseline is defined as n_1 = 5602, σ_1 = .770; and DDBS is defined as n_2 = 4439, σ_2 = .475. Therefore:

$$\hat{\sigma}_1^2 = (\frac{5602}{5601}).770^2 = .593 \text{ with } 5601 \text{ df.}$$

In a like manner:

$$\hat{\sigma}_2^2 = (\frac{4439}{4438}).475^2 = .226 \text{ with } 4438 \text{ df.}$$

Then, by definition, the variance ratio F is:

$$F = \frac{.593}{.226} = 2.62$$

Table 3.11 FTE Variance Test Variables

Flight Test	Phase	N	σ	Degrees of Freedom df (n-1)
Baseline DDB	Terminal	5602 4439	.770 .475	5601 4438
Baseline DDB	Approach	519 494	.831 .342	518 493

The number of degrees of freedom is 5601 for the greater variance estimate and 4438 for the lesser variance estimate. Entering the F distribution tables[9] for the variance ratio with these degrees of freedom (in this case considered to be infinite because of the very large values), the value of F = 2.62 is seen to be greater than the F values for either the .005 level and the .001 level. Therefore, the significance of variance between the standard deviations is much less than the .001 level and is regarded as having a probability level of $p = .001$, one chance in 1,000 of the observed result arising by chance. The significance test was similarly applied to the approach phase data set, also yielding a probability level of $p = .001$, as summarized in Table 3.10.

3.4 SUMMARY

The results of the DDBS tests indicated a substantial improvement in pilot blunder performance as influnced by DDBS. An analysis of the blunder performance of three identical subject pilots showed a reduction in blunders per flight in an identical RNAV route structure/test aircraft environment from 0.87 blunders per flight under standard RNAV conditions to 0.15 blunders per flight under DDBS conditions. On an overall pilot population basis the baseline/DDBS comparison was 1.03 to 0.15 blunders per flight, respectively.

Pilot steering performance (FTE) was similarly markedly improved through the introduction of DDBS. Baseline test results indicated mean and two sigma FTE results of $-.247 \pm 1.540$ nm for the terminal phase as compared to 0.27 ± 0.950 nm for the DDBS tests. Similarly, during the final approach phase the baseline results were $-.340 \pm 1.661$ nm as compared to $-.005 \pm .684$ nm for DDBS. Both of these comparisons were found to be significant at the $p = .001$ probability level, indicating an extremely reliable quantitative reduction in steering error due to the decreased cockpit workload afforded by the DDBS concept.

4.0 CONCLUSIONS AND RECOMMENDATIONS

4.1 GENERAL

Ranging from the general to the specific, this report has deliberately attempted to consider only those issues which bear directly on a specific problem solution which is, of course, only a small contributor to the overall solution of the ATC/air traffic growth problem. Area navigation is a concept of air navigation and air traffic control which has given indications through study and simulation of being able to aid in the alleviation of the problems of traffic congestion, traffic delays, and increased ATC system personnel staffing requirements. One major aspect of the implementation of the area navigation concept is the potential problem of increased cockpit workload on pilot performance as regards blunders and steering. The possibility of automating the area navigation cockpit data entry function as a means of reducing cockpit workload and thus improving pilot performance has been advanced as a potential solution to this problem.

4.2 CONCLUSIONS

The studies, simulations and experiments previously reported have established several hypotheses or trends which resulted in three major related areas of pilot/ATC system performance which needed substantiation either subjectively or quantitatively. The results of this DDBS research then, should be considered in light of the following questions:

1. Does the addition of broadcast data into the RNAV environment substantiate the predicted reduction in cockpit workload and pilot blunder performance?
2. Does the addition of digital broadcast data significantly improve the previously unsatisfactory level of pilot steering performance (FTE) for a single waypoint general aviation RNAV system?
3. Is the DDBS concept operationally acceptable in an RNAV terminal area, including the compatibility of broadcast navigation information with controller-initiated maneuvers?

As regards the pilot blunders issue, a considerable amount of research has led to the primary conclusion that <u>any</u> approach which reduces the overall cockpit workload should have a positive impact on reducing blunder rates, considered either on a blunder per flight basis or on a blunder per operation basis. Again, considering the constraining factor of RNAV systems and RNAV routes/procedures, several references have verified a reduction in blunder rate as a function of increasing waypoint storage capacity. Reference 10 observed a direct inverse correlation of blunder rate with systems of waypoint storage of 1, 2 and 8 waypoints. Reference 11 again documented a consistent decrease in blunders per flight with waypoint storage capacities of 1, 2, 4 and 8. In addition, Reference 11 showed, via a side task loading experiment, that the pilot's information processing rate, or his ability to concentrate his attention on supplemental tasks, was worse with a two waypoint system and best with an eight waypoint system. References 12 and 13 both concluded that blunder rate (blunders per operation) as well as blunders per flight could be substantially reduced if the cockpit workload situation were eased, i.e., by reducing the number of operations per flight required.

All of these experiments indicated that some level of pilot blunders could be reduced if the workload on the pilot was reduced. Conversely, it was also shown[12] that the RNAV environment as it was originally conceived requires a level of increased cockpit workload that could adversely affect pilot blunder performance. It was for this reason that the digital data broadcast concept was evolved[4,14] in an attempt to automate the pilot's data entry function, reduce his data input errors and reduce his overall workload, thus potentially reducing his overall blunder rate.

The results of the experiments reported in this document and in Reference 3 verify that the DDBS concept resulted in a dramatic reduction in pilot blunders. In a direct comparison of three identical subject pilots flying the same routes in the same aircraft in the same operational flight environment, the use of DDBS resulted in a reduction of pilot blunders from a value of 0.87 blunders per flight for a conventional single waypoint RNAV system to a value of 0.15 blunders per flight for a DDBS RNAV system. When considering the total data set including all of the subject pilot population the comparison was even more striking, i.e., 1.03 blunders per flight for conventional RNAV as opposed to 0.15 for DDBS. Since these blunder values were obtained in a comparison between two flight experiments that were deliberately designed to have a maximum of commonality between controlled variables such that the conventional RNAV vs DDBS comparison was the only difference, it is considered that the observed blunder rate reduction can be directly ascribed to the influence of the DDBS concept and system implementation.

The second issue, that of pilot steering performance, is of similar importance to the overall acceptance and implementation of area navigation into the National Airspace System. Reference 3 has stated that the levels of flight technical error (FTE) resulting from the baseline testing of a single waypoint area navigation system were unacceptable for certification purposes. The data contained in Reference 3 verifies the fact that the terminal and approach phase values of FTE obtained from the "baseline" RNAV flights tests are far above the values set as the standard for FAA certification[15]. As in the case of pilot blunders, the automation of the data input function through the use of DDBS, and its resultant decrease in pilot workload, was expected to improve the pilot steering performance of the low cost RNAV user to acceptable levels[4].

Again referring to the direct comparison between the results of the baseline experiment of Reference 3 and the current DDBS flight experiment, Table 3.9 has directly documented and verified the initial assumption that DDBS can substantially reduce FTE in an RNAV flight environment. In the case of the basic terminal phase of flight, the conventional RNAV FTE two sigma value of ±1.540 nm was reduced to ±0.950 nm in the case of the DDBS system. This latter value is within the nominal value of 1.0 nm set for terminal phase FTE by AC 90-45A[15] and the RNAV Task Force[5]. Similarly in the final approach phase the conventional RNAV value of ±1.661 nm was reduced to ±0.684 for DDBS. While the DDBS value for approach is still above the nominal value of 0.5 nm[5,15], it is considerably improved.

In considering the verification of the reduction in FTE due to DDBS, the statistical significance of the observed quantitative values must be considered. As has been shown in Chapter 3, the FTE improvements in both terminal and approach phases of flight have been shown to be significant at the $p = .001$ probability level, thus assuring that these experimental results and differences can be considered to be valid.

As regards the operational acceptability of the DDBS concept as an element of any future ATC system, this issue is extremely subjective, and must be approached in the context of providing initial guidelines and observations at this time rather than reaching absolute conclusions. However, the experience gained in the DDBS operational flight test evaluation did allow several pertinent conclusions to be drawn concerning several pertinent issues. A primary benefit of the DDBS concept resulted from the decrease in pilot workload involved in RNAV waypoint definition. This critical navigation input, particularly in the final phases of the terminal area transition, is very time-critical in conventional general aviation RNAV systems:

4.3 RECOMMENDATIONS

Thus far, several critical issues regarding the DDBS concept of cockpit input data automation have been resolved. The technical feasibility of the basic concept and the tested Engineering Model hardware has been proven. The predicted improvement in pilot blunder and steering performance has been verified. The operational suitability of the DDBS concept as an element of the ATC system has been demonstrated. The applicability of the results of this research has been identified.

However, there are still two major areas of uncertainty that remain to be clarified before a final decision can be made regarding the ultimate incorporation of the DDBS concept into the ATC system of the future.

First, the DDBS flight test program was conducted with a single DDBS equipped aircraft flying in a semi-controlled flight environment. It still needs to be demonstrated that a dense terminal area traffic environment can be operated efficiently with some mix of DDBS and non-DDBS aircraft. It is important to define whether or not <u>all</u> aircraft entering a DDBS terminal area <u>must</u> be DDBS equipped as a "price of admission" or whether this equippage is a user option. As in the simulations of References 7 and 8, the logical source of this data would be a real time DDBS terminal area simulation run on the Digital Simulation Facility at the FAA NAFEC facility. As in the previous simulations, the percentage of DDBS equipped aircraft could be varied from 0% to 100%, and such parameters as controller talk time, controller messages, and aircraft delay time could be recorded. In this manner, data pertinent to controller staffing studies could be accumulated along with a further evaluation and refinement of air traffic control procedures in a DDBS/RNAV environment could be acquired.

Second, and directly correlated to the first issue, the degree of implementation of the DDBS concept, and indeed the decision to embark on the program at all, is directly dependent on the economic viability of the concept. From the FAA point of view, capital expenditures will be required in order to convert the current DME ground stations to be able to transmit DDBS messages. The decision as to which, or how many, of the 950 existing ground VOR stations should be modified has not been made. These costs must be balanced off against the potential controller staff savings afforded by DDBS. Similarly, but more difficult to quantify as far as benefits are concerned, the costs and benefits to the airspace user must be quantified. Only after this interrelated benefit/cost ratio analysis has been performed can two major questions be answered:

1. What percentage of airspace users can be expected to equip with DDBS/RNAV?
2. What are the benefit/cost ratios for both the FAA and the airspace users for DDBS implementation?

Both of these efforts must be performed in conjunction with one another before a final evaluation and recommendation regarding the overall DDBS implementation can be made.

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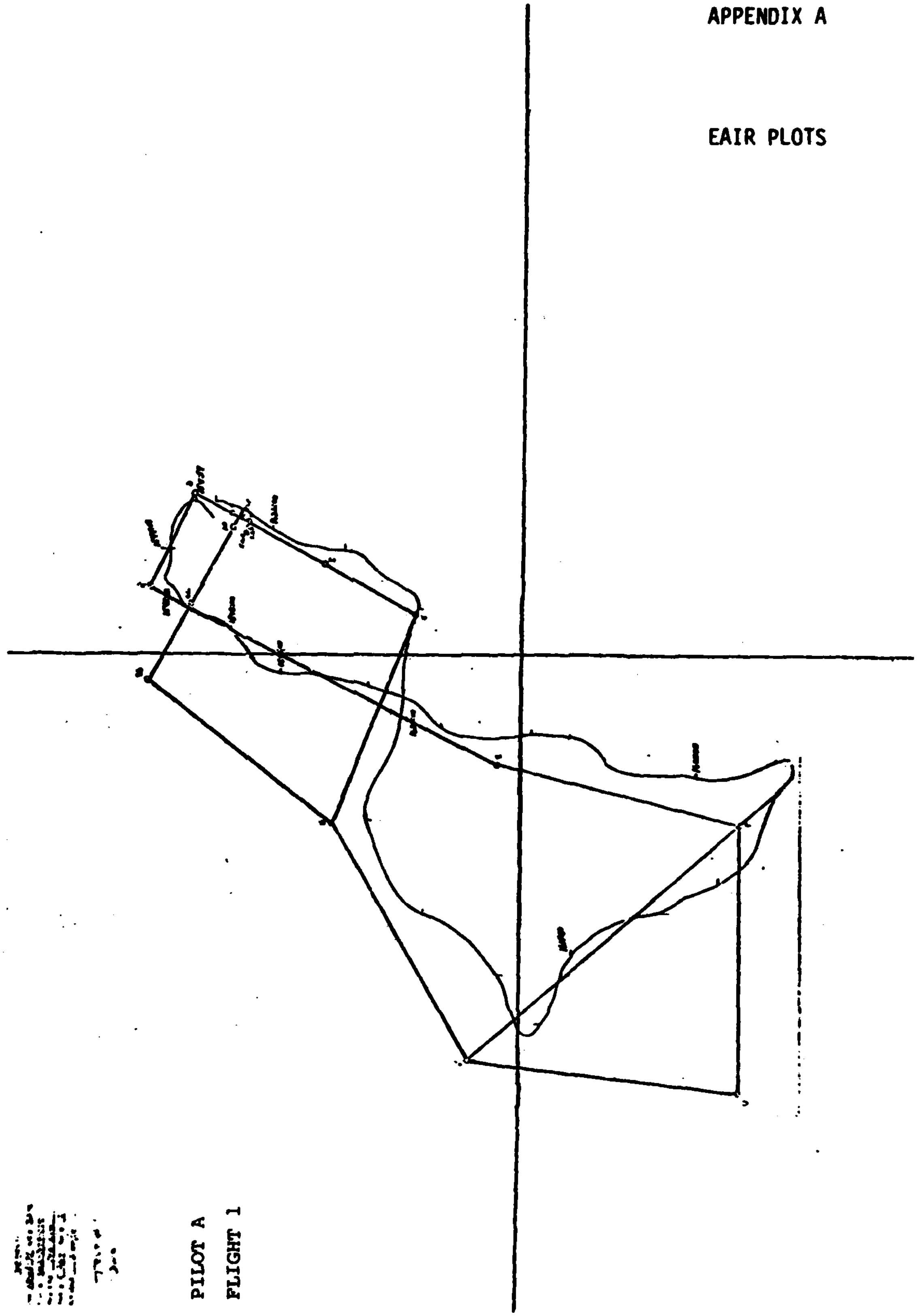
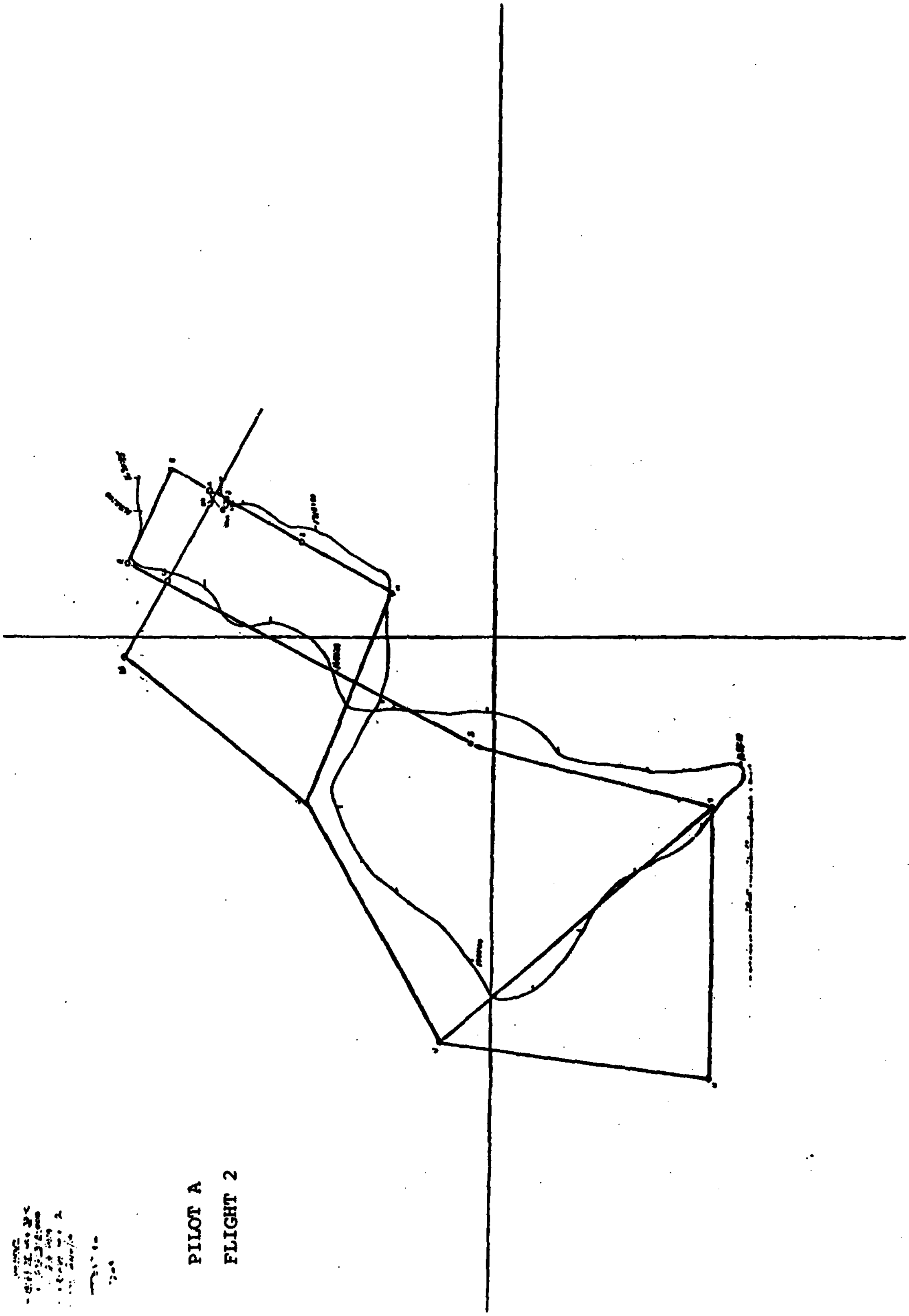
14. I. Ross and J.B. Kennedy, VORTAC Broadcast Data: System Analysis of TACAN and DME for Addition of Broadcast Digital Data. Nutley, New Jersey. ITT Avionics Division, December 1972

15. Department of Transportation, Federal Aviation Administration, Approval of Area Navigation Systems for Use in the U.S. National Airspace System. FAA Advisory Circular 90-45A. Washington, D.C. Government Printing Office, February 1975

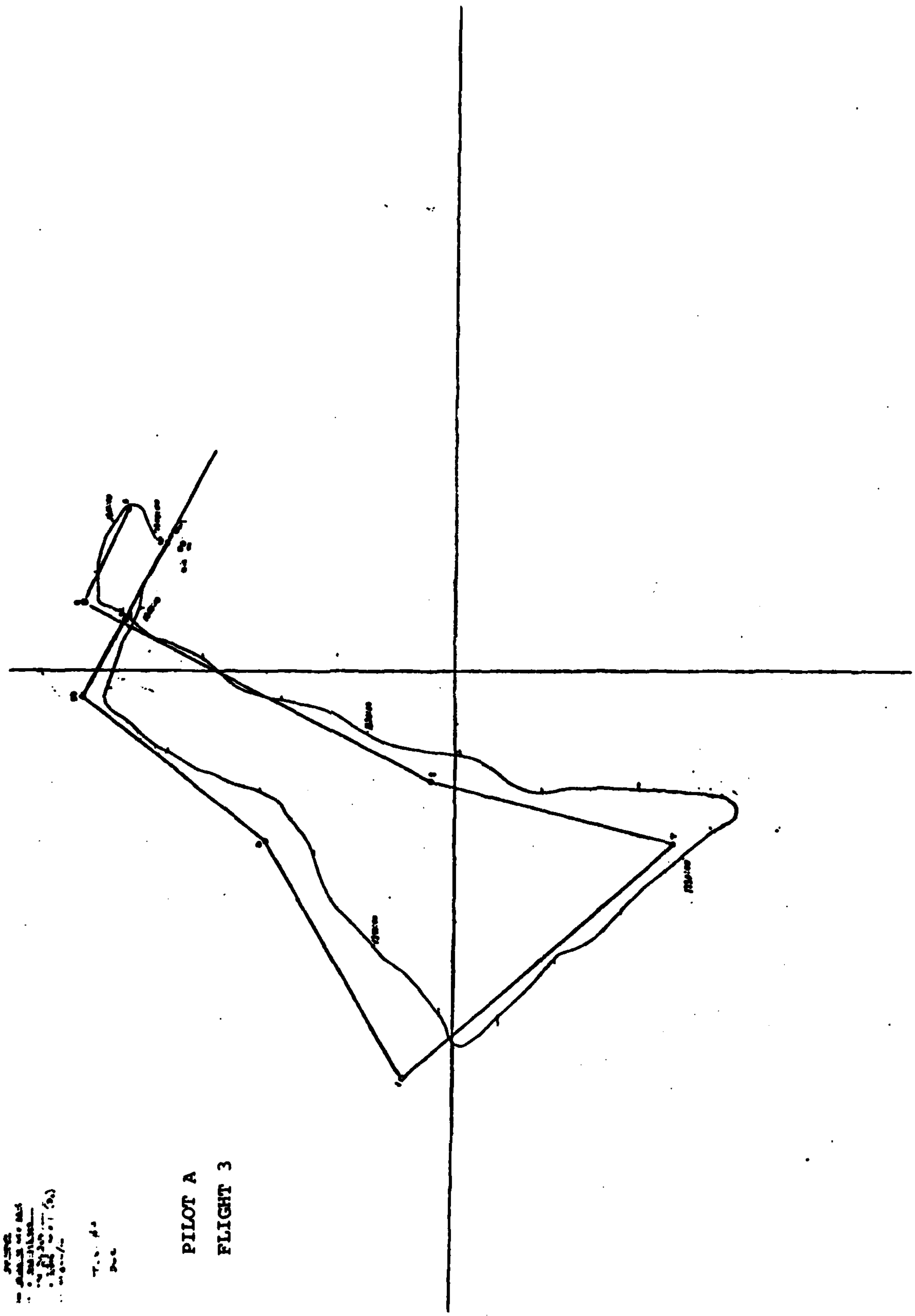
APPENDIX A

EAIR PLOTS





PILOT A
FLIGHT 2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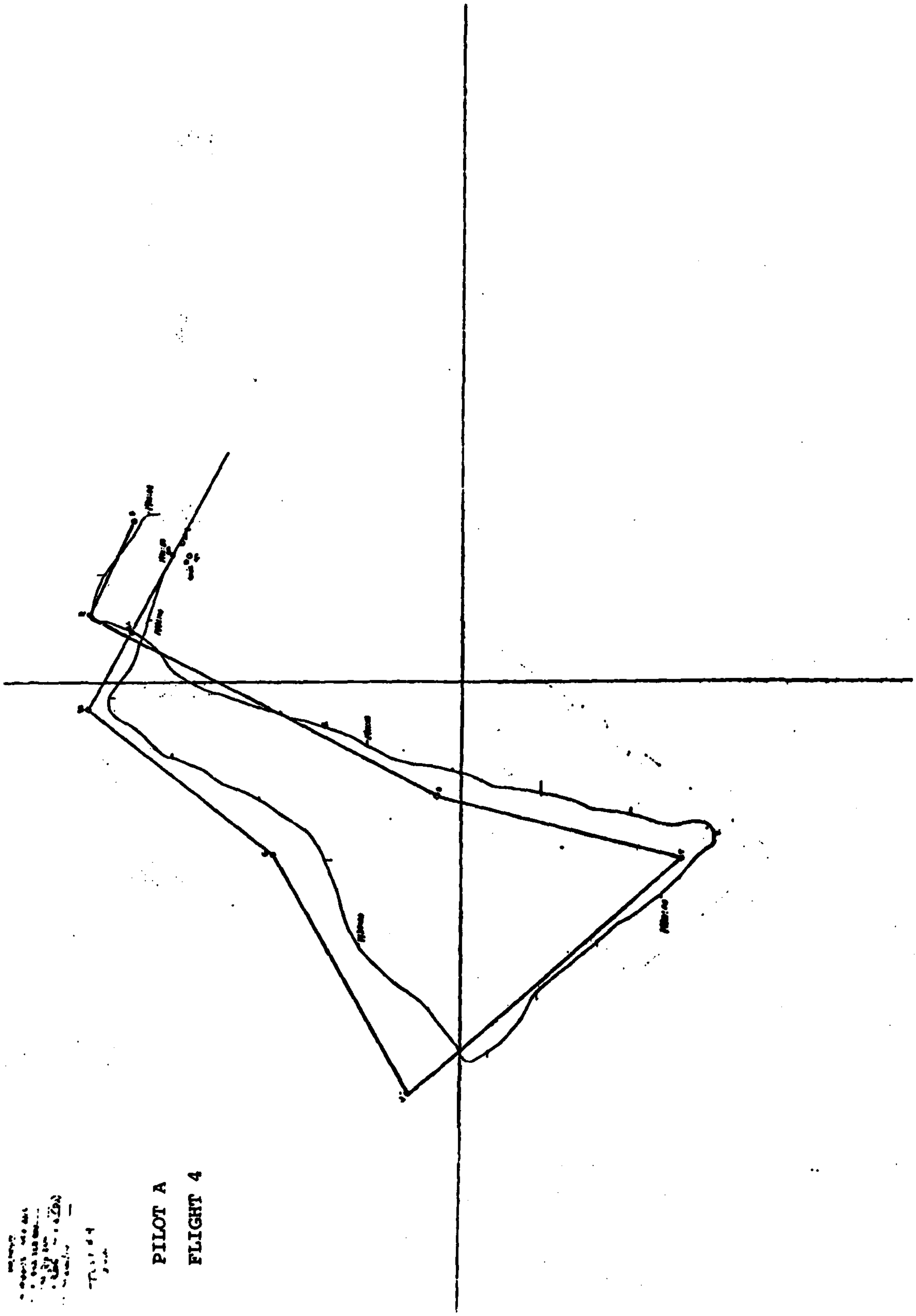
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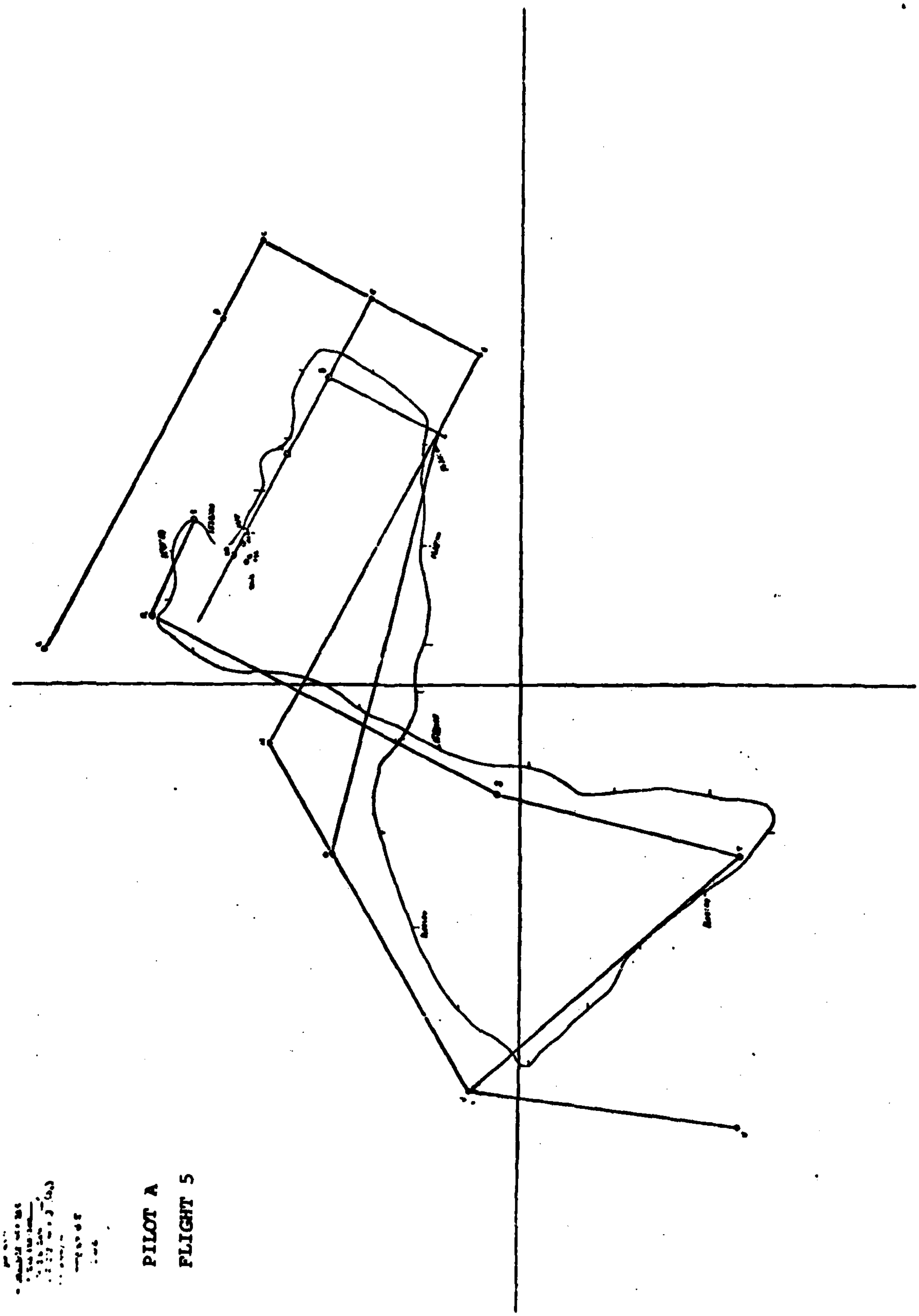
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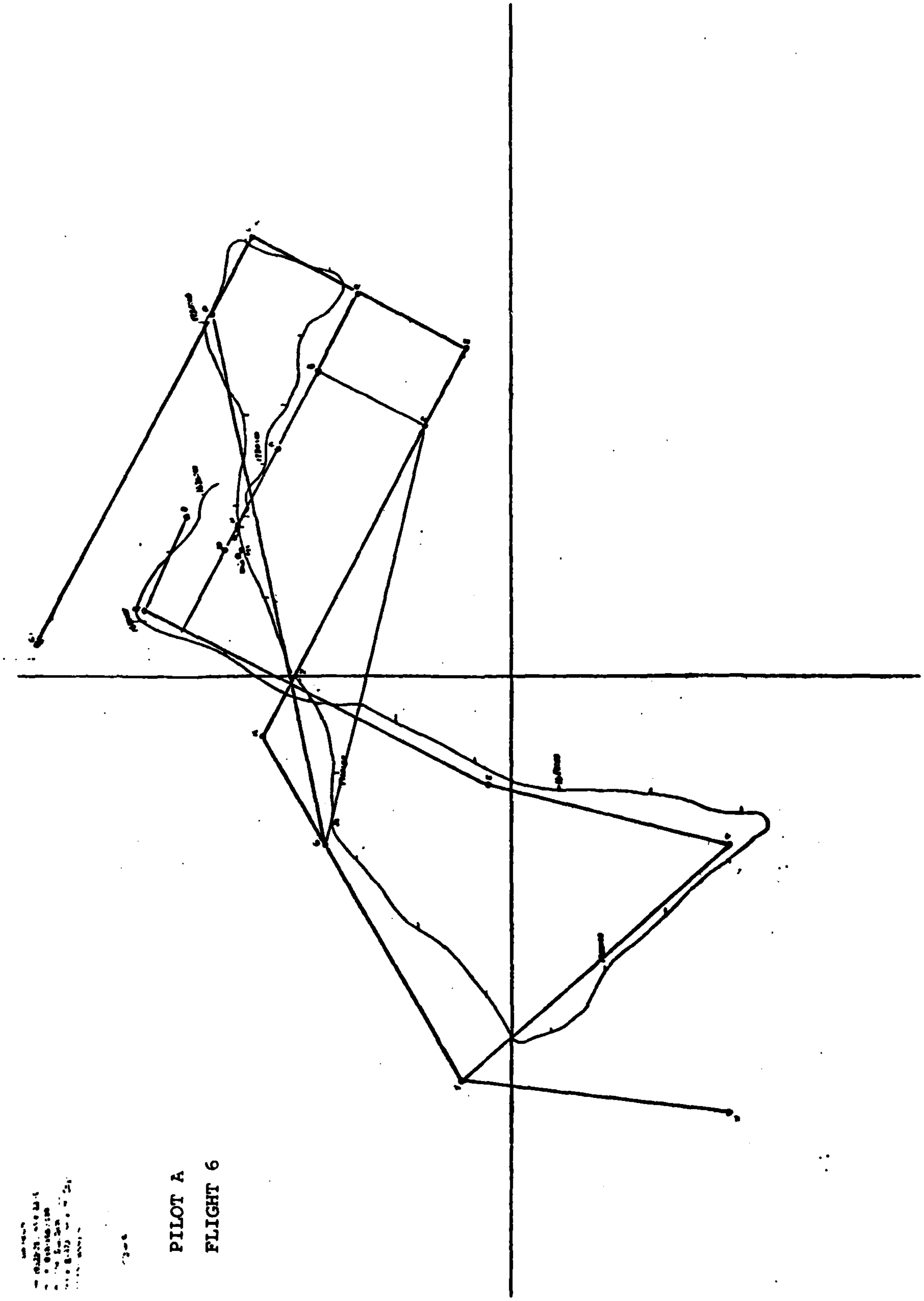

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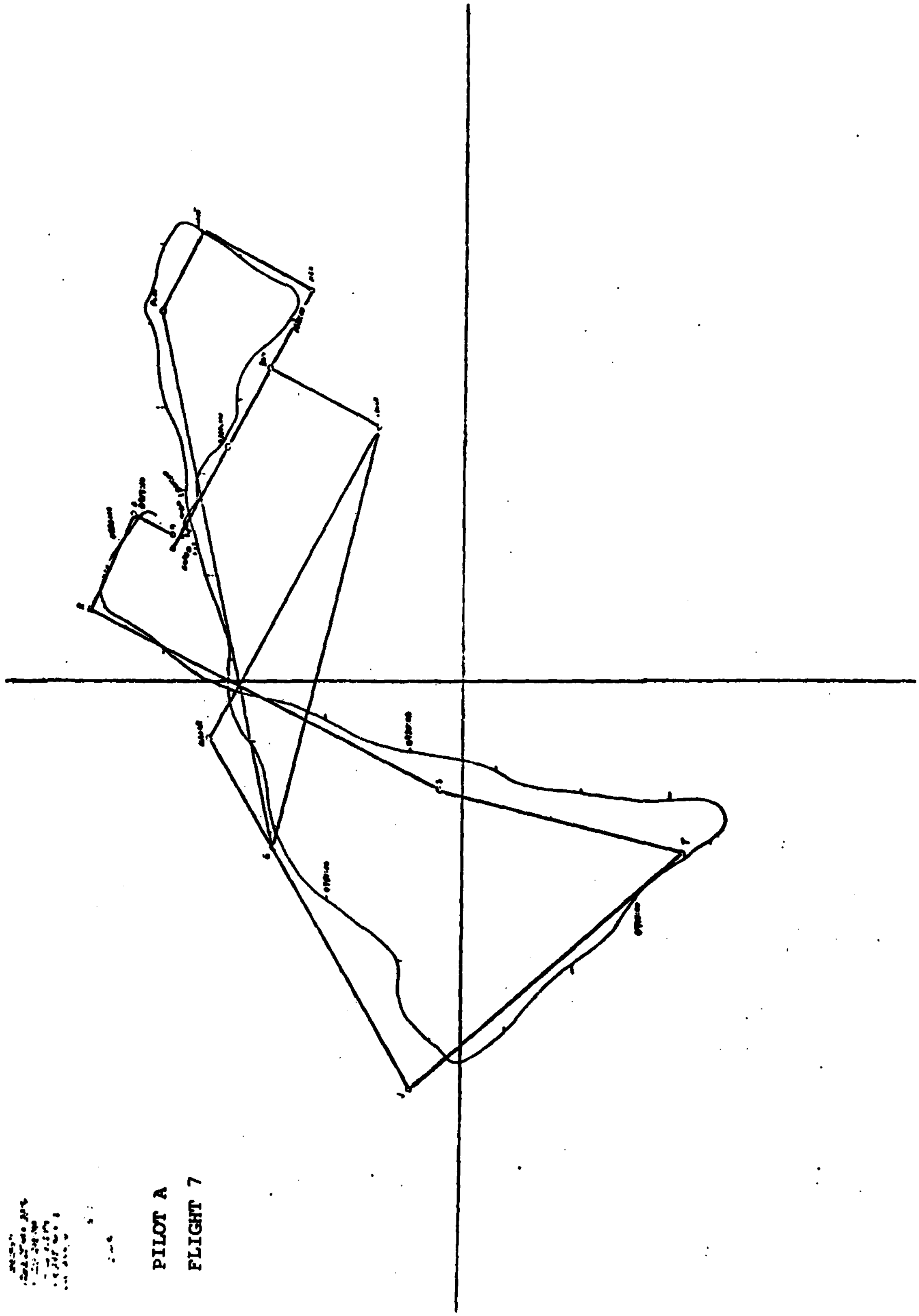
FLIGHT 6



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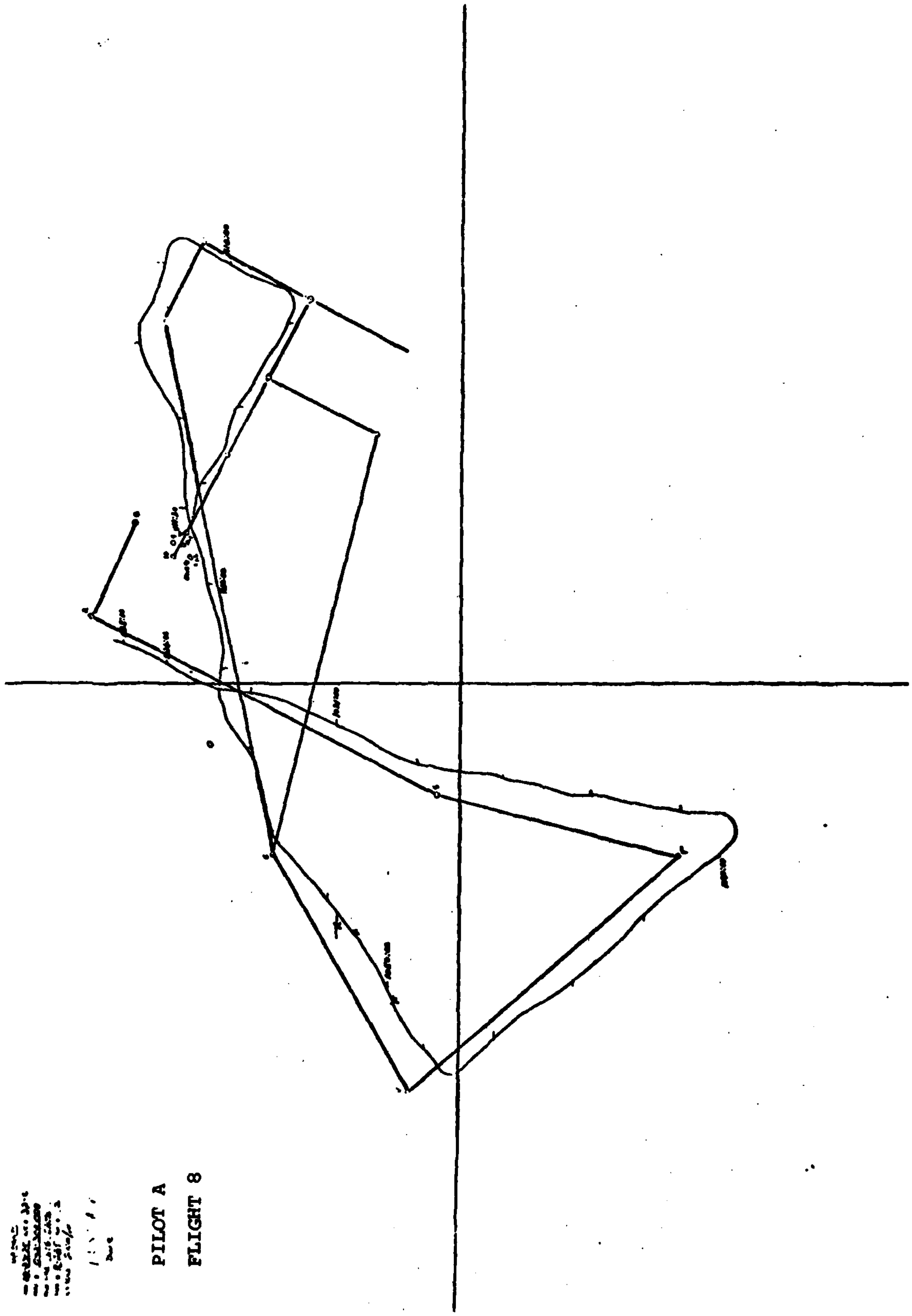

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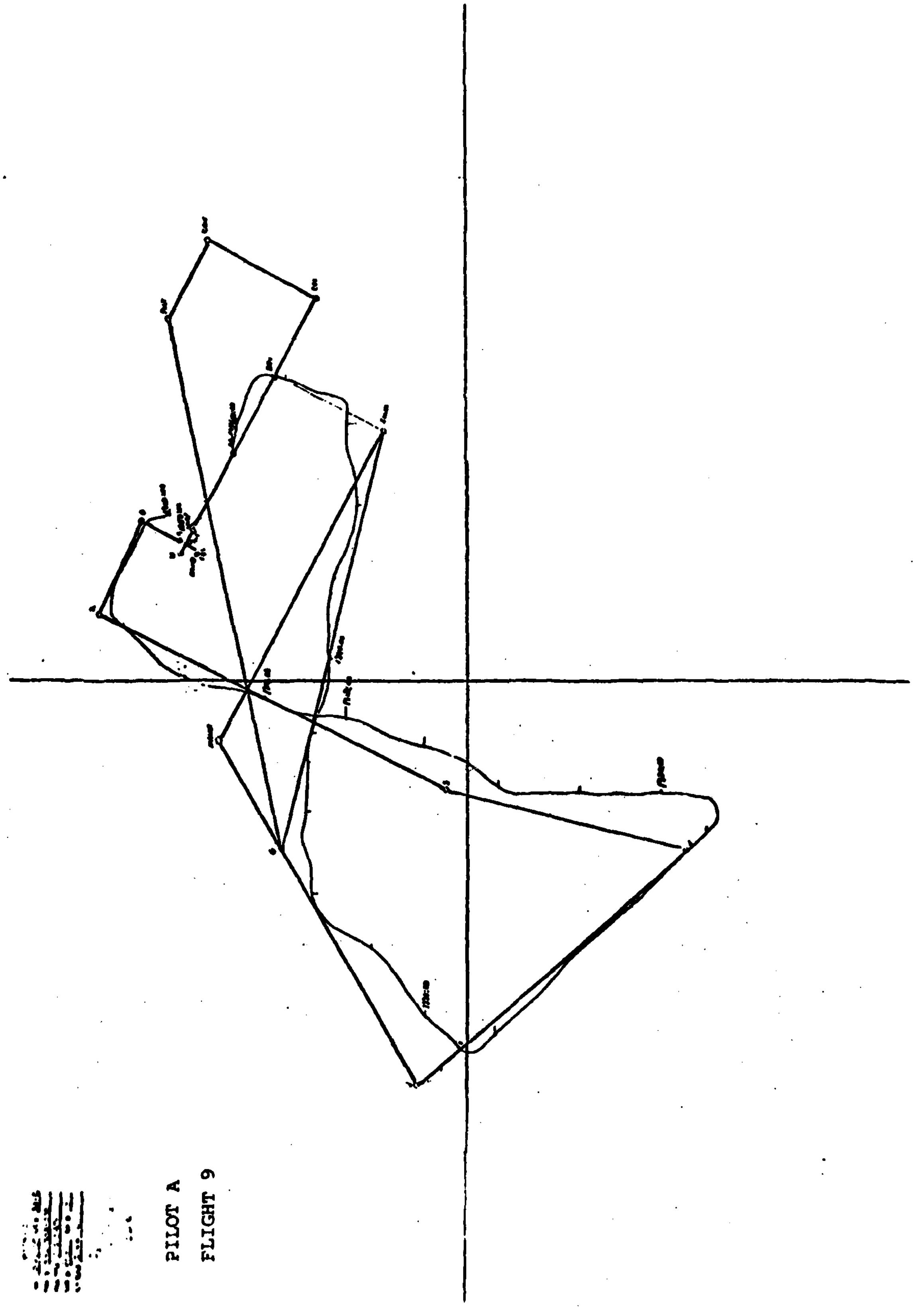
FLIGHT 8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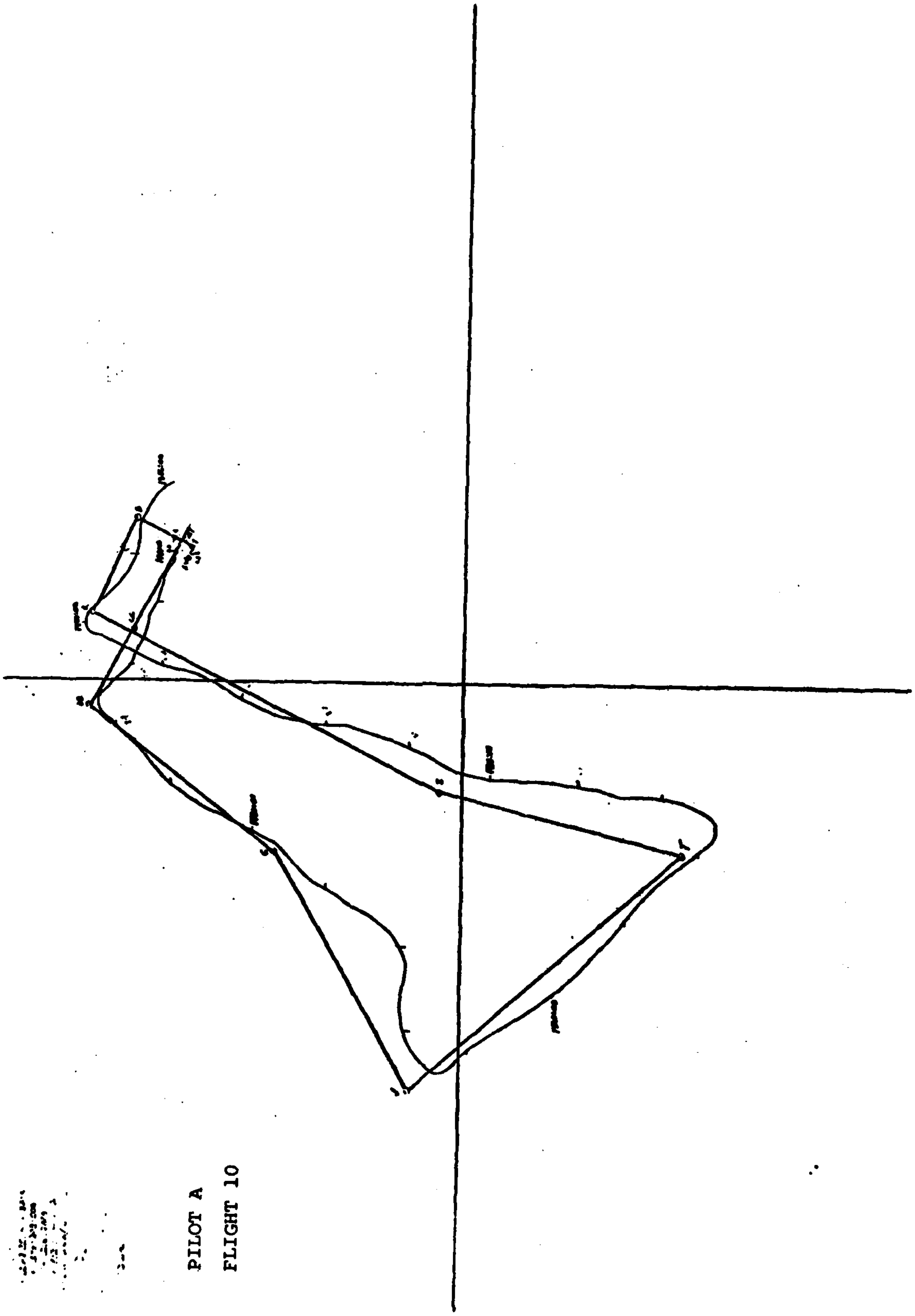

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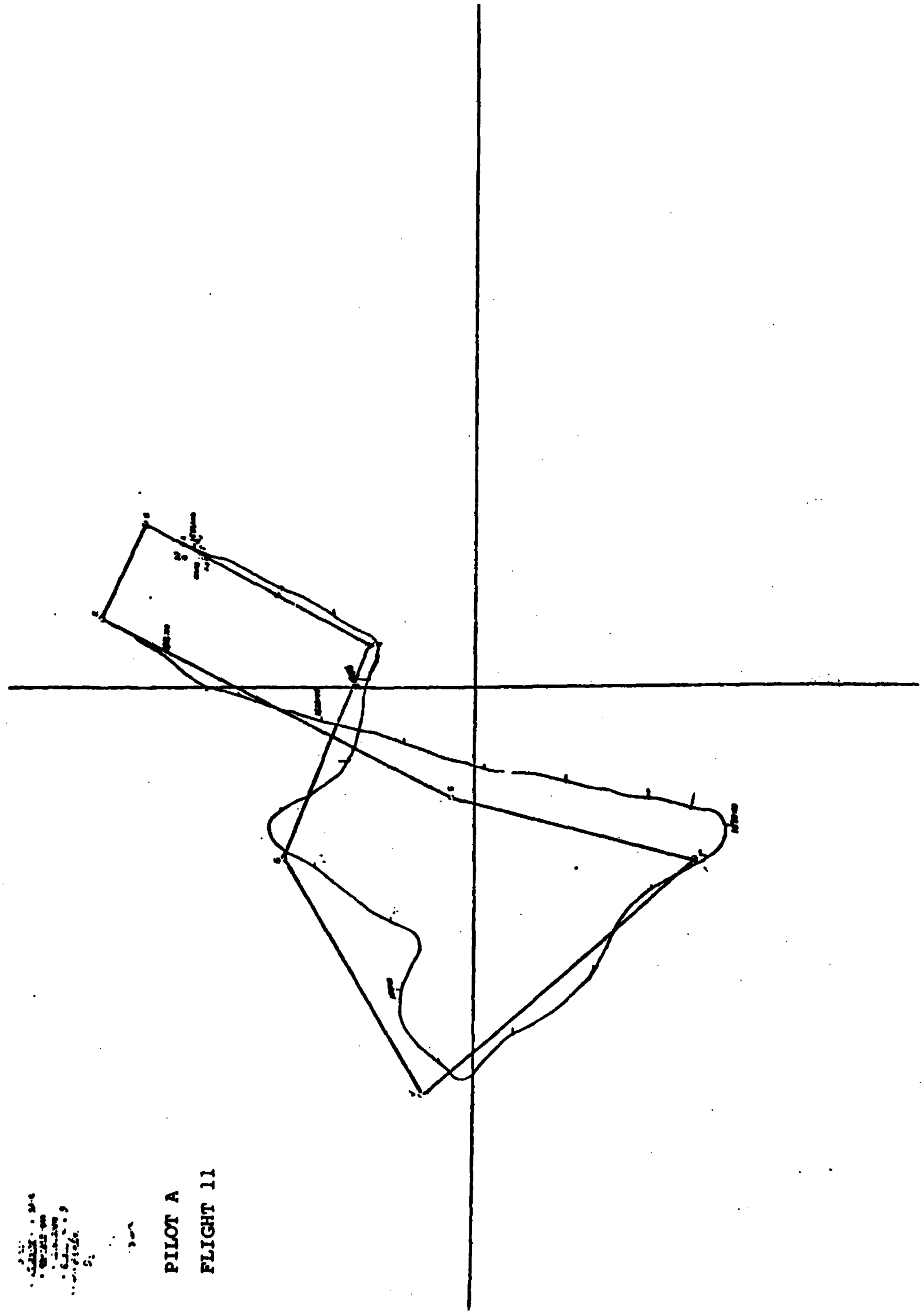
FLIGHT 10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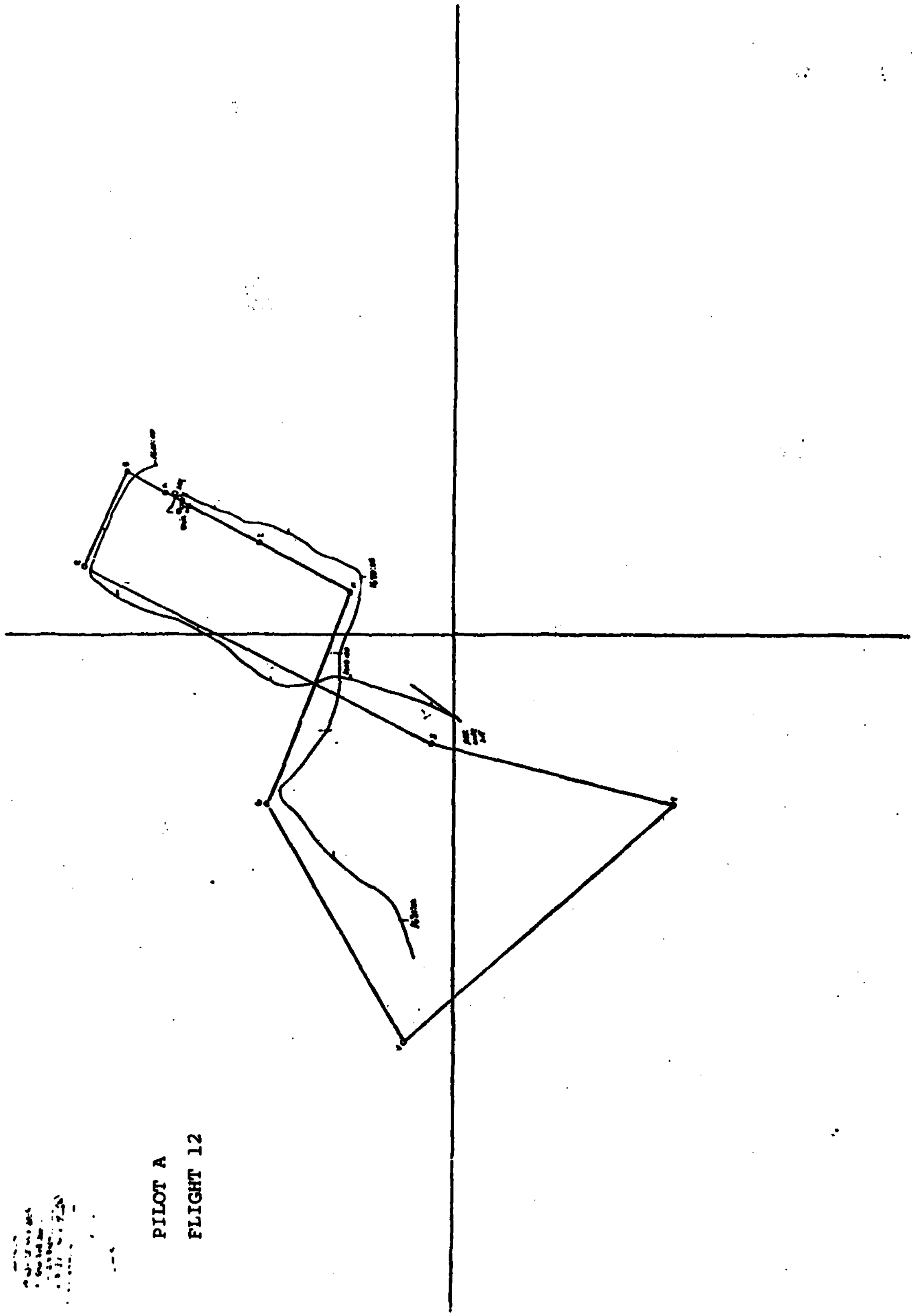
FLIGHT 11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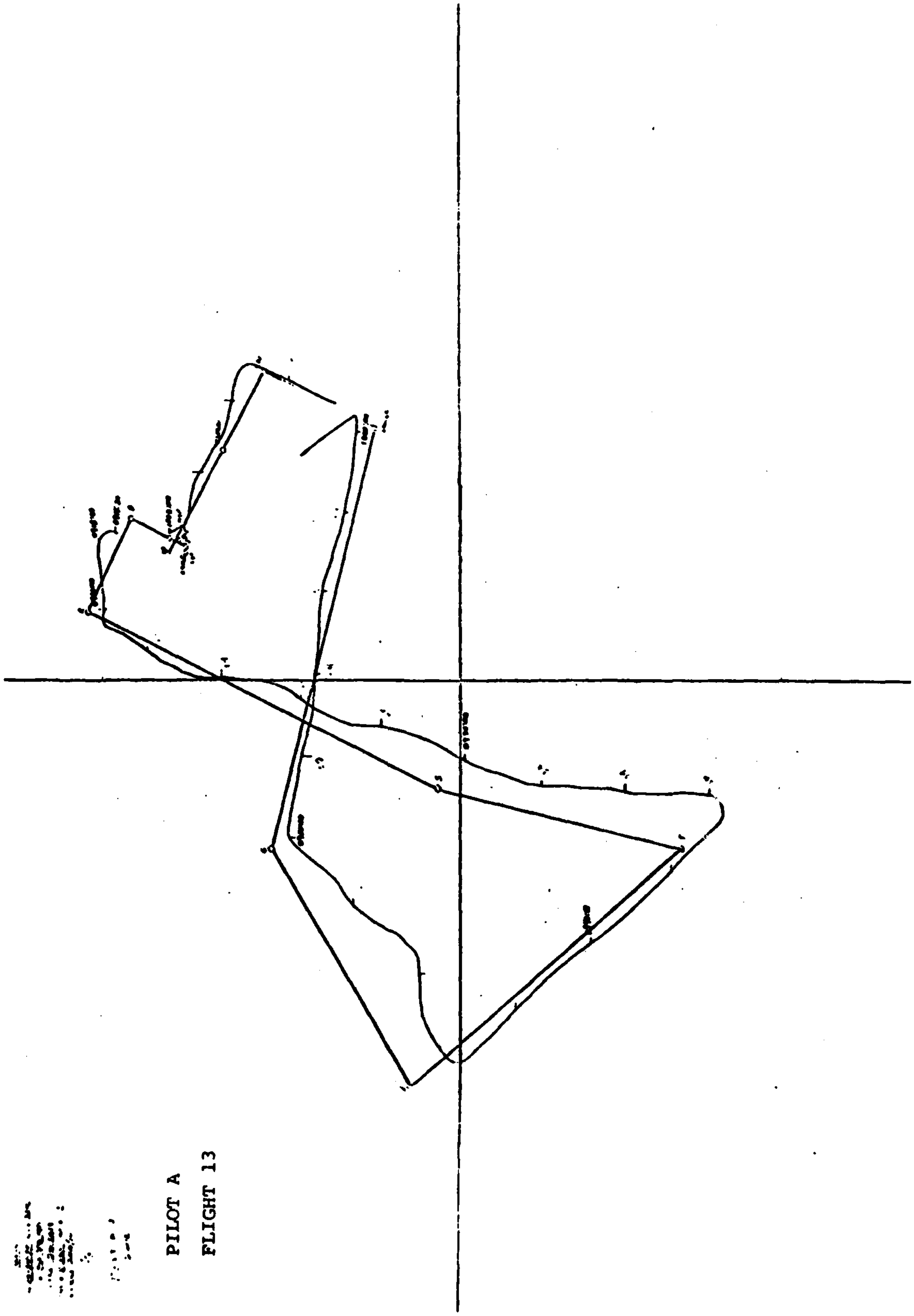
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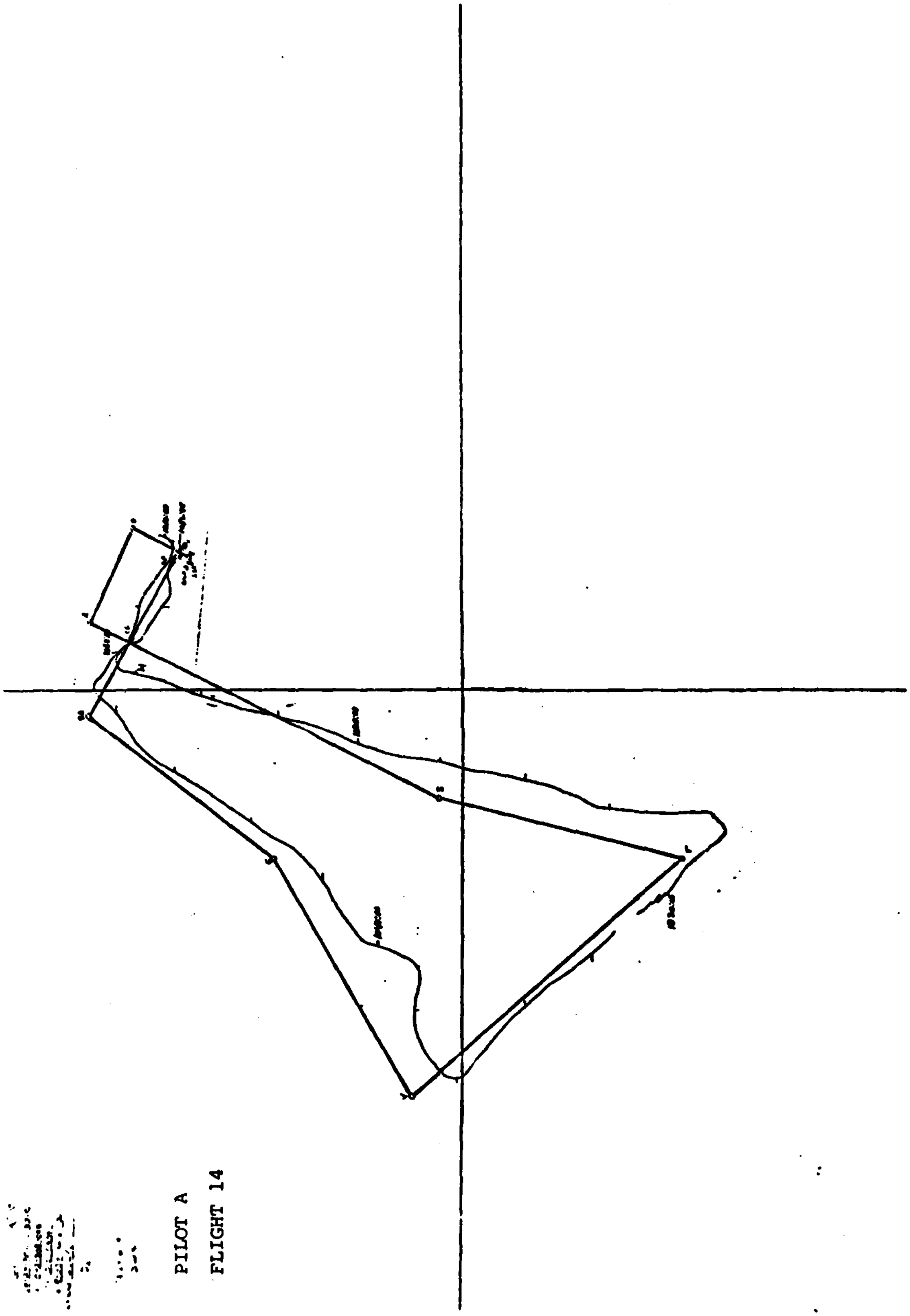

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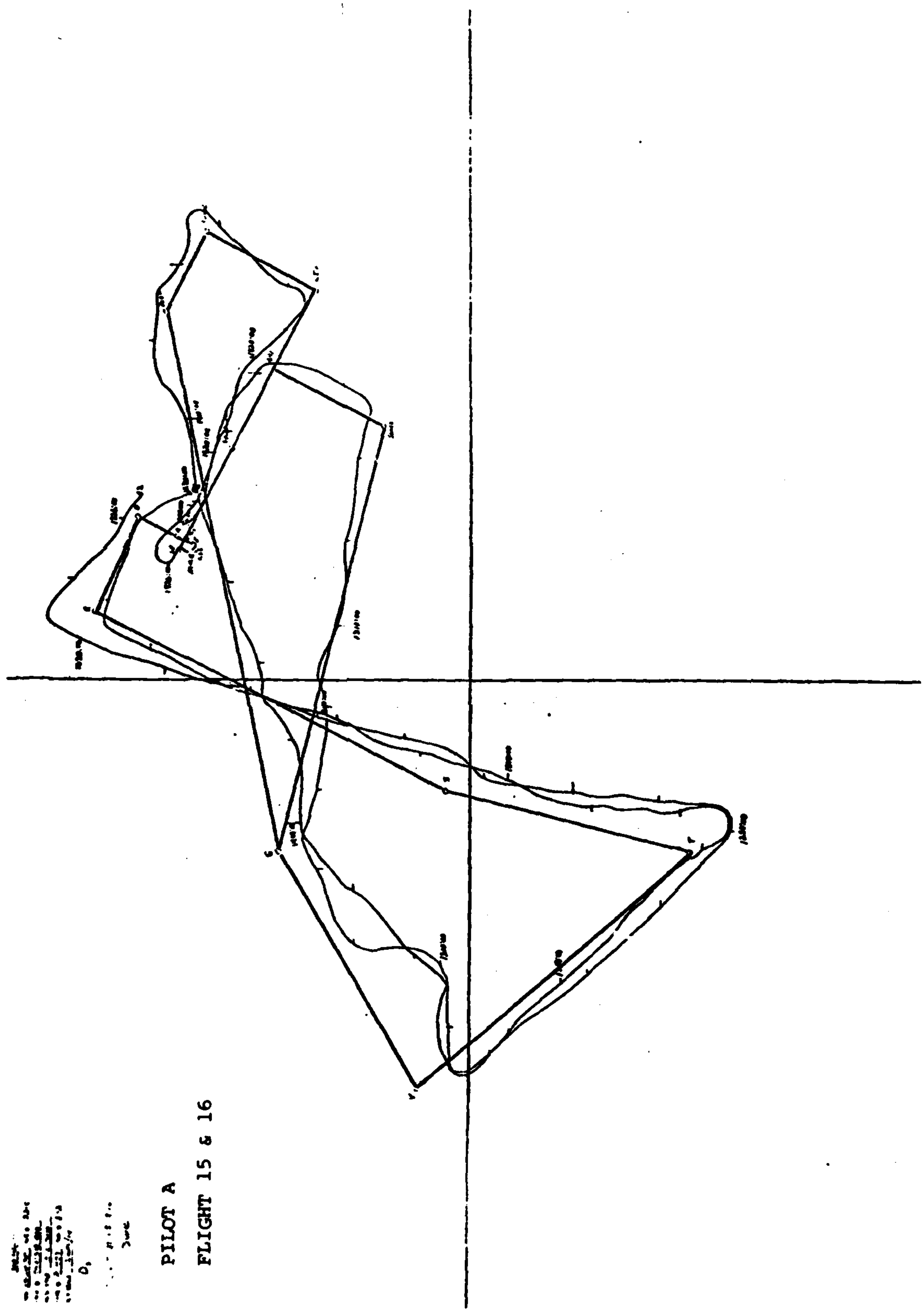
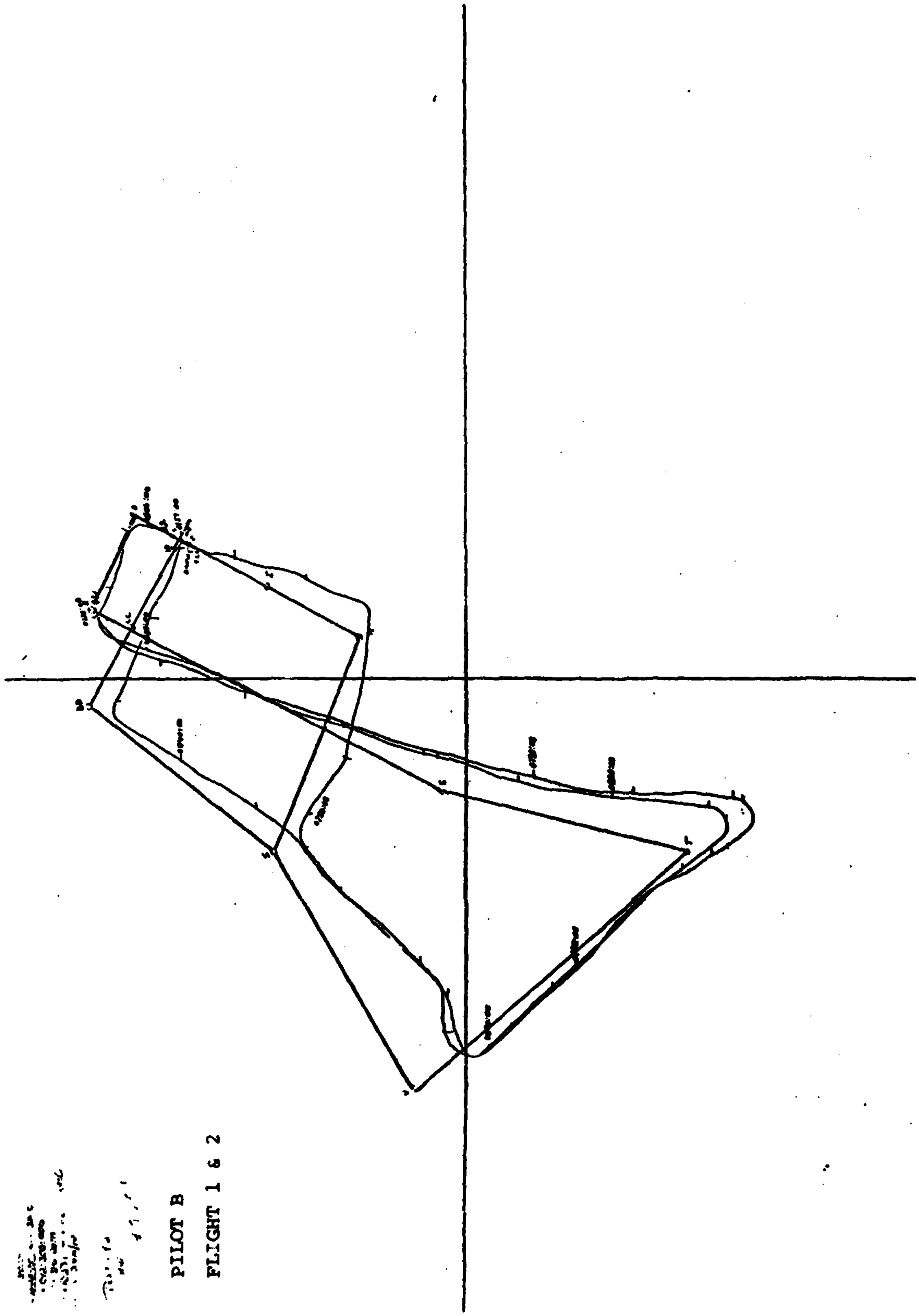
FLIGHT 14

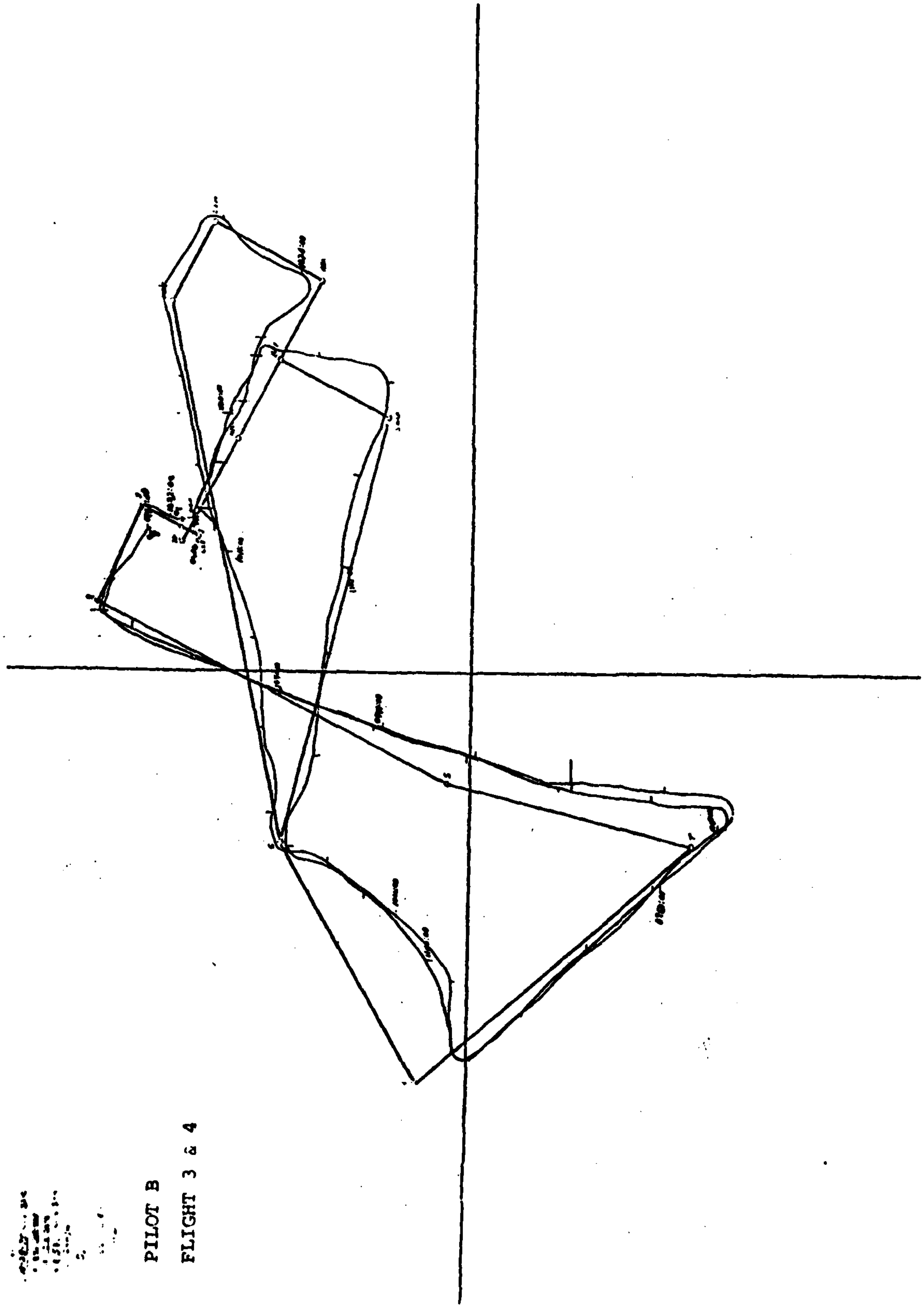


PILOT A
FLIGHT 15 & 16



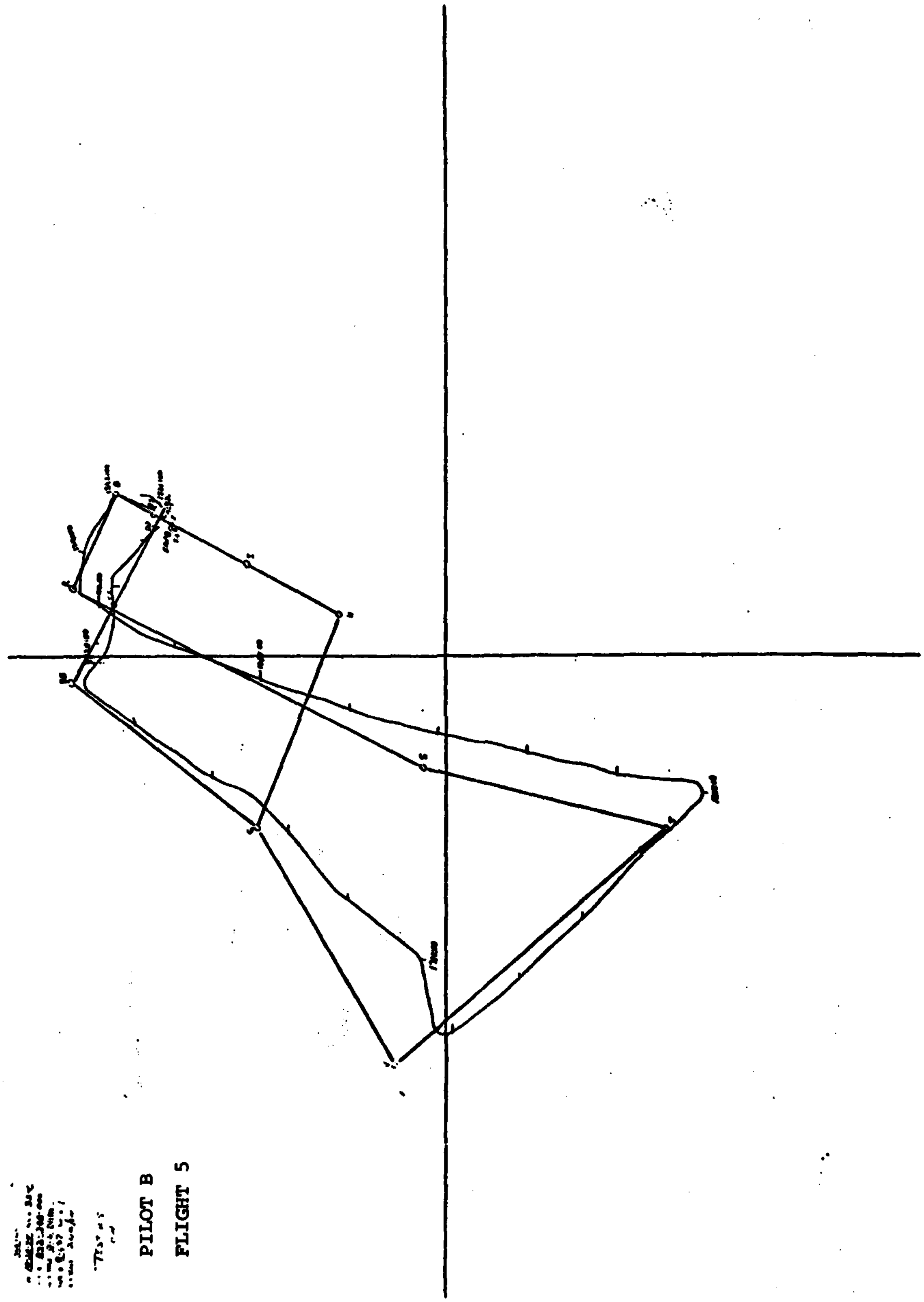
PILOT B

FLIGHT 1 & 2



PILOT B

FLIGHT 3 & 4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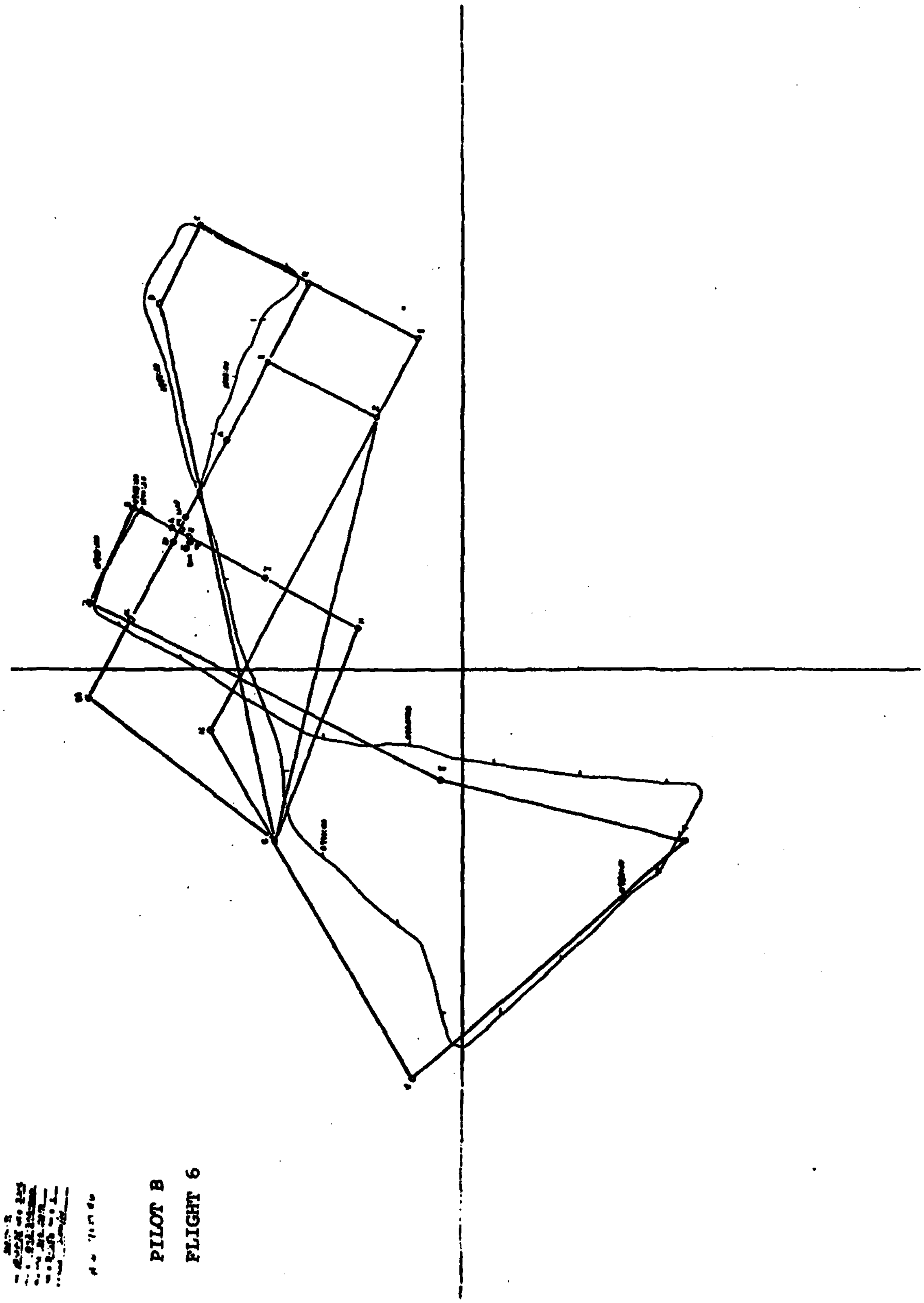
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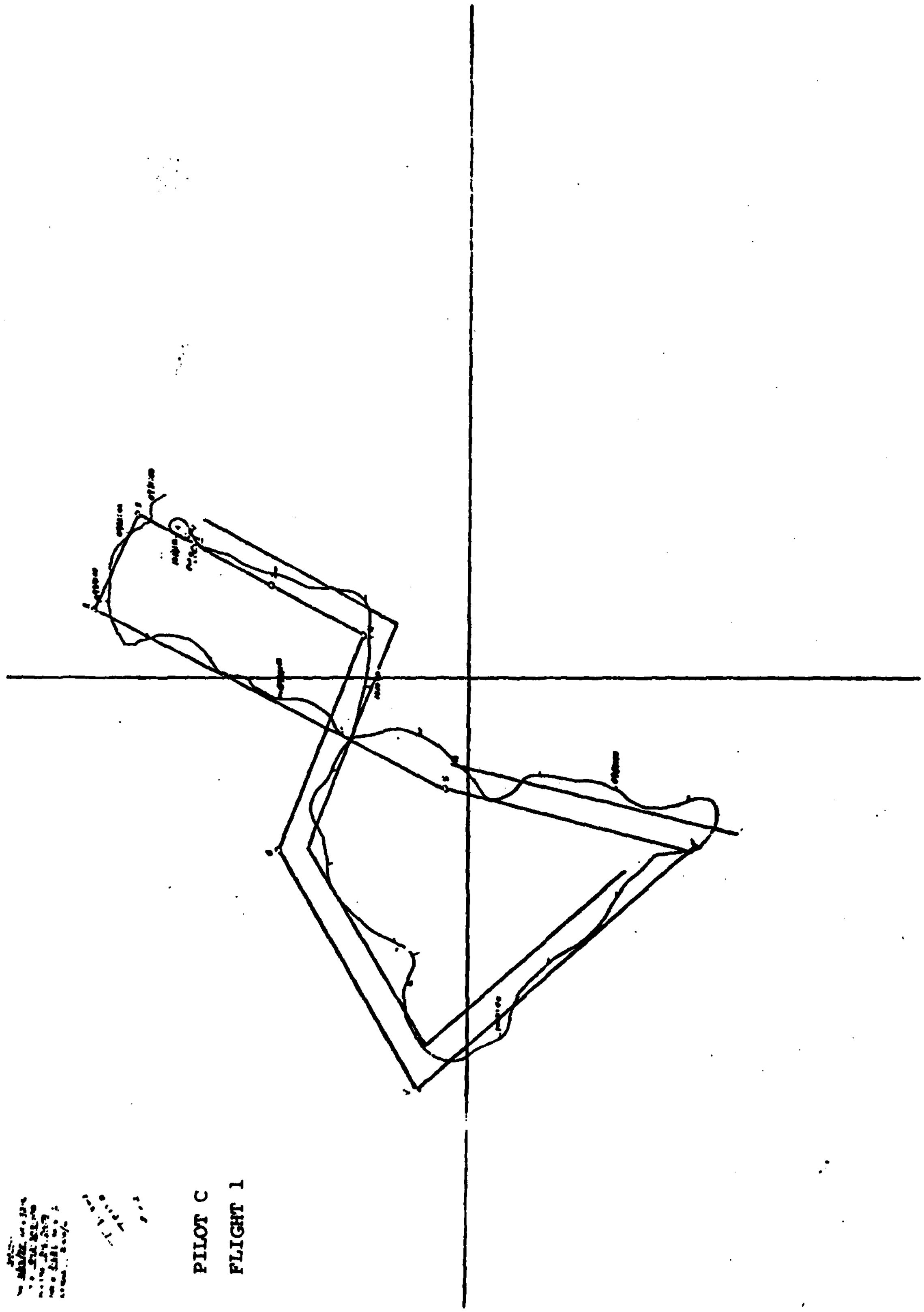
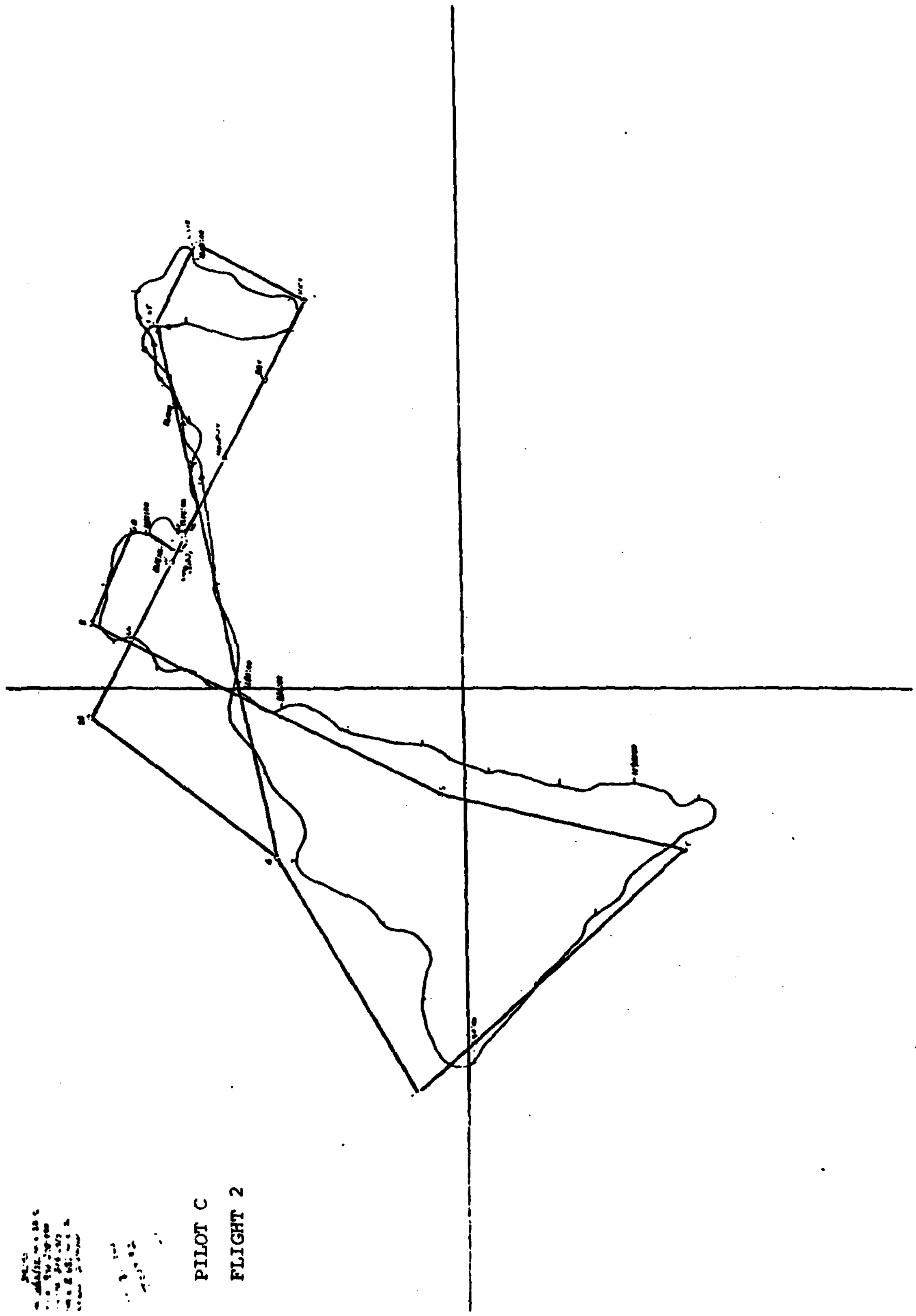
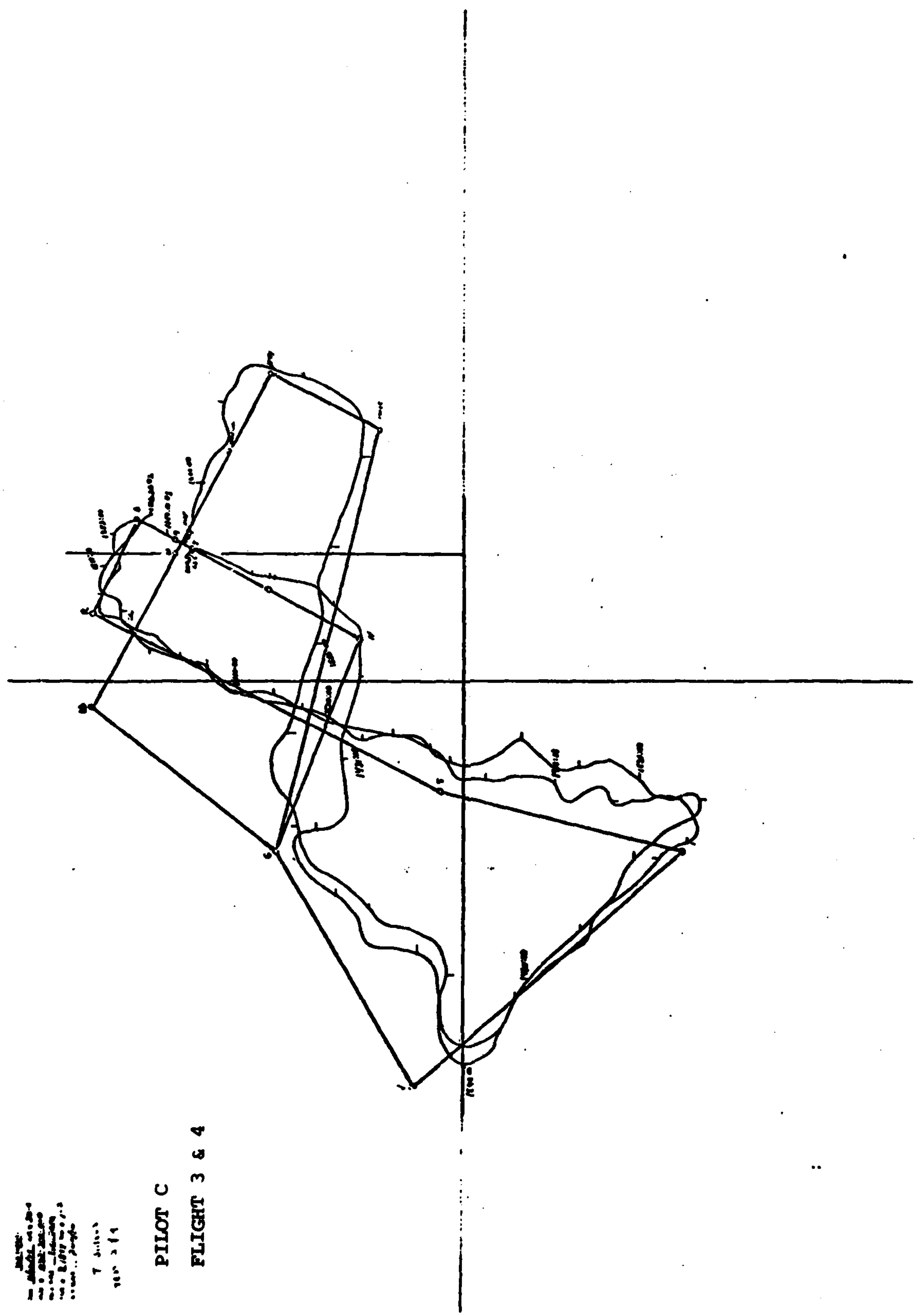

PILOT C
FLIGHT 1



PILOT C
FLIGHT 2


PILOT C
FLIGHT 3 & 4

FTE DATA

DDBS Test Data

No. of Samples	Flight No.	Pilot	Segment	CDI Sensitivity Mode	CDI Aggregate $\bar{X}$	CDI Aggregate σ
17	1	A	B-R	E	.195	.247
60	1	A	R-S	e	.397	.876
17	1	A	S-T	E	-.399	.339
58	1	A	T-V	E	.054	.872
16	1	A	V-G	E	.235	.386
22	1	A	G-H	E	.138	.327
19	1	A	H-M	A	-.112	.288
12	2	A	B-R	E	.129	.621
58	2	A	R-S	E	.199	1.192
20	2	A	S-T	E	.350	.922
46	2	A	T-V	E	-.024	.423
24	2	A	V-G	E	-.040	.482
17	2	A	G-H	E	-.070	.473
23	2	A	H-M	A	.112	.218
16	3	A	B-R	E	-.197	.214
38	3	A	R-S	E	.058	.420
22	3	A	S-T	E	-.074	.439
48	3	A	T-V	E	.052	.339
26	3	A	V-G	E	-.268	.412
17	3	A	G-Baltic	E	.075	.424
25	3	A	B-M	A	.119	.125

DDBS Test Data

No. of Samples	Flight No.	Pilot	Segment	CDI Sensitivity Mode	CDI Aggregate	
					X	σ
14	4	A	B-R	E	.162	.378
43	4	A	R-S	E	-.014	.234
23	4	A	S-T	E	.018	.425
50	4	A	T-V	E	-.029	.283
31	4	A	V-G	E	-.244	.461
15	4	A	G-Baltic	E	-.376	.295
20	4	A	B-M	A	-.022	.257
21	5	A	B-R	E	.146	.358
40	5	A	R-S	E	-.015	.383
20	5	A	S-T	E	.410	.345
46	5	A	T-V	E	.264	.267
21	5	A	V-G	E	-.062	.460
40	5	A	G-Somer	E	-.984	.686
16	5	A	S-Bay	E	-.739	.631
34	5	A	Bay-M	A	-.111	.334
10	6	A	B-R	E	-.170	.461
42	6	A	R-S	E	.019	.319
24	6	A	S-T	E	-.199	.307
42	6	A	T-V	E	-.129	.507
17	6	A	V-G	E	.022	.447
66	6	A	G-Port	E	-.400	.729
8	6	A	Port-Cove	E	-.283	.166
14	6	A	Cove-Rex	E	.255	.350
11	6	A	Rex-Bay	E	-.453	.480
28	6	A	Bay-Map	A	.167	.253

DDBS Test Data

No. of Samples	Flight No.	Pilot	Segment	CDI Sensitivity Mode	CDI Aggregate X	CDI Aggregate σ
11	7	A	B-R	E	.271	.261
44	7	A	R-S	E	-.051	.264
26	7	A	S-T	E	-.033	.346
50	7	A	T-V	E	.141	.299
13	7	A	V-G	E	-.202	.516
72	7	A	G-Port	E	.178	.316
12	7	A	Port-Cove	E	.567	.224
17	7	A	Cove-Rex	E	.367	.432
10	7	A	Rex-Bay	E	1.127	.439
22	7	A	Bay-Map	A	.011	.297
44	8	A	R-S	E	.071	.369
25	8	A	S-T	E	.173	.445
44	8	A	T-V	E	.066	.297
17	8	A	V-G	E	.355	.309
65	8	A	G-Port	E	.208	.335
10	8	A	Port-Cove	E	.514	.135
16	8	A	Cove-Rex	E	.286	.265
12	8	A	Rex-Bay	E	.710	.260
23	8	A	Bay-Map	A	.168	.215

DDBS Test Data

No. of Samples	Flight No.	Pilot	Segment	CDI Sensitivity Mode	CDI Aggregate	
					X	σ
12	9	A	B-R	E	.373	.268
50	9	A	R-S	E	.071	.392
31	9	A	S-T	E	.206	.463
39	9	A	T-V	E	.090	.123
20	9	A	V-G	E	.404	.299
64	9	A	G-Somer	E	.267	.527
11	9	A	Somer-Bay	E	.143	.084
19	9	A	Bay-Map	A	.374	.259
14	10	A	B-R	E	.757	.455
52	10	A	R-S	E	.067	.317
31	10	A	S-T	E	.339	.335
38	10	A	T-V	E	.116	.372
9	10	A	V-G	E	.179	.468
25	10	A	G-Baltic	E	.856	.249
23	10	A	Baltic-Map	A	-.099	.165
47	11	A	R-S	E	.162	.301
15	11	A	S-T	E	.372	.257
26	11	A	T-V	E	-.021	.441
8	11	A	V-G	E	-.217	.421
20	11	A	G-H	E	.105	.226
21	11	A	H-Map	A	.356	.401

DDBS Test Data

No. of Samples	Flight No.	Pilot	Segment	CDI Sensitivity Mode	CDI Aggregate X	CDI Aggregate σ
9	12	A	B-R	E	.423	.089
49	12	A	R-S	E	.174	.399
	12	A	S-T	E		
	12	A	S-V	E		
20	12	A	V-G	E	.017	.318
28	12	A	G-H	E	-.009	.260
21	12	A	H-Map	A	-.140	.213
15	13	A	S-T	E	.026	.406
37	13	A	T-V	E	.008	.182
13	13	A	V-G	E	-.054	.286
61	13	A	G-Somer	E	-.017	.172
13	13	A	Somer-Bay	E	.354	.223
22	13	A	Bay-Map	A	.078	.215
	14	A	B-R	E		
55	14	A	R-S	E	-.224	.281
27	14	A	S-T	E	-.133	.598
40	14	A	T-V	E	-.010	.205
14	14	A	V-G	E	.326	.385
32	14	A	G-Baltic	E	.028	.370
20	14	A	Baltic-Map	A	.237	.682

DDBS Test Data

No. of Samples	Flight No.	Pilot	Segment	CDI Sensitivity Mode	CDI Aggregate	
					X	σ
14	15	A	B-R	E	.421	.097
52	15	A	R-S	E	.146	.258
32	15	A	S-T	E	-.178	.338
40	15	A	T-V	E	.252	.336
3	15	A	V-G	E	.398	.098
38	15	A	G-Somer	E	-.140	.336
15	15	A	Somer-Bay	E	-.191	.347
22	15	A	Bay-Map	A	.013	.263
	16	A	B-R	E		
39	16	A	R-S	E	-.143	.258
7	16	A	S-T	E	.356	.117
41	16	A	T-V	E	-.123	.321
18	16	A	V-G	E	-.611	.257
76	16	A	Golf-Port	E	.050	.426
10	16	A	Port-Cove	E	-.189	.349
8	16	A	Cove-Rex	E	.110	.399
	16	A	Rex-Bay	E		
12	16	A	Bay-Map	A	-.293	.204
15	1	B	R-S	E	-.170	.186
23	1	B	S-T	E	-.170	.407
41	1	B	T-V	E	.062	.249
19	1	B	V-G	E	-.360	.338
21	1	B	G-H	E	.002	.258
27	1	B	H-Map	A	-.251	.225

DDBS Test Data

No. of Samples	Flight No.	Pilot	Segment	CDI Sensitivity Mode	CDI Aggregate	
					X	σ
4	4	B	B-R	E	.042	.036
45	4	B	R-S	E	-.068	.194
19	4	B	S-T	E	-.315	.450
39	4	B	T-V	E	-.179	.224
5	4	B	V-G	E	-.164	.492
52	4	B	G-Somer	E	-.299	.340
9	4	B	Somer-Bay	E	-.432	.324
25	4	B	Bay-Map	A	-.148	.220
19	5	B	B-R	E	-.010	.227
48	5	B	R-S	E	.065	.223
22	5	B	S-T	E	.278	.423
40	5	B	T-V	E	-.041	.224
17	5	B	V-G	E	-.231	.223
28	5	B	G-Baltic	E	.019	.207
10	5	B	Baltic-Carolina	A	.114	.402
15	6	B	B-R	E	.162	.217
4	6	B	R-S	E	.293	.202
25	6	B	S-T	E	-.091	.237
41	6	B	T-V	E	-.219	.171
11	6	B	V-G	E	-.266	.267
57	6	B	G-Port	E	-.012	.244
9	6	B	Port-Cove	E	.408	.262
16	6	B	Cove-Rex	E	.455	.147
10	6	B	Rex-Bay	E	-.173	.462
16	6	B	Bay-Map	A	.044	.149

DDBS Test Data

No. of Samples	Flight No.	Pilot	Segment	CDI Sensitivity Mode	CDI Aggregate	
					X	σ
15	1	C	B-R	E	-.277	.385
65	1	C	R-S	E	.168	.454
28	1	C	S-T	E	.258	.561
40	1	C	T-V	E	-.229	.377
11	1	C	V-G	E	.113	.231
22	1	C	G-H	E	-.237	.388
24	1	C	H-Map	A	-.233	.344
16	2	C	B-R	E	-.075	.162
69	2	C	R-S	E	.226	.349
41	2	C	S-T	E	.134	.490
43	2	C	T-V	E	-.123	.272
5	2	C	V-G	E	.460	.664
53	2	C	G-Pat	E	-.233	.422
11	2	C	Port-Cove	E	1.003	.582
19	2	C	Cove-Rex	E	-.210	.357
	2	C	Rex			
14	3	C	B-R	E	-.263	.269
54	3	C	R-S	E	-.031	.327
31	3	C	S-T	E	.057	.421
39	3	C	T-V	E	-.107	.218
11	3	C	V-G	E	.246	.440
30	3	C	G-H	E	-.282	.662
20	3	C	H-Map	A	-.180	.281

DDBS Test Data

No. of Samples	Flight No.	Pilot	Segment	CDI Sensitivity Mode	CDI Aggregate	
					X	σ
13	4	C	B-R	E	-.266	.336
68	4	C	R-S	E	.146	.278
29	4	C	S-T	E	.113	.529
43	4	C	T-V	E	-.026	.280
10	4	C	V-G	E	-.192	.532
40	4	C	G-Somer	E	.121	.263
11	4	C	Somer-Bay	E	-.119	.360
18	4	C	Bay-Map	A	-.287	.361