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EVALUATION OF DIGITAL DATA BROADCAST FOR AREA NAVIGATION

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R. Elliott

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April 1976

INTERIM REPORT

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16. Abstract

The objectives of this program were to evaluate the Digital Data Broadcast (DDB) system in the following areas: (1) Substantiate a predicted reduction in cockpit workload and pilot blunder provided by the addition of broadcast data into the RNAV environment. (2) Assess the technical performance characteristics and overall feasibility of a DDB Engineering Model hardware unit. (3) Determine the operational utilization of the DDB concept for RNAV in the terminal area. The results of this program were: (1) The results of the DDB Flight Test program indicate a positive reduction in cockpit workload and pilot blunder through the utilization of the DDB concept in the RNAV environment system. (2) The DDB concept was satisfactorily proved by the utilization of the DDB Engineering Model hardware. Specific areas of recommended improvement are modifications to X-mode DDB pulse spacing and to waypoint designators. (3) The operational utilization of the DDB concept permits its user to devote more time to cockpit management duties, since it reduces the required RNAV navigation input times and, thereby, reduces cockpit workload.

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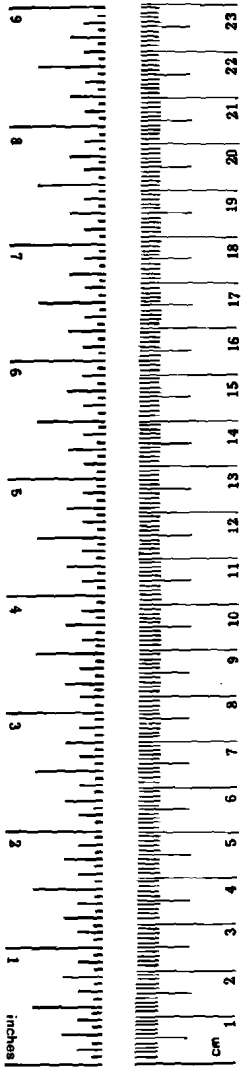
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

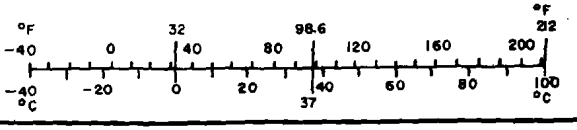
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2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



PREFACE

This document consists of an interim report describing the engineering effort and results obtained from the test and evaluation of the Government-furnished Engineering Model DDB equipment. The testing of the DDB equipment was conducted at the National Aviation Facilities Experimental Center (NAFEC), New Jersey during the period 19 August to 13 November 1975. This report is submitted in fulfillment of the requirements of Section 2.9 of the Digital Data Broadcast System Task Plan (TR-1282) by Sierra Research Corporation under Contract No. DOT-FA75WA-3634. A major portion of the activity conducted under this task was performed by Champlain Technology Industries, Division of Systems Control, Incorporated under Sierra letter Subcontract No. S30989-9.

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1.0 EXECUTIVE SUMMARY

1.1 OBJECTIVES

The primary objectives of this program are to evaluate the operational impact of the Digital Data Broadcast (DDB) concept under a set of operationally oriented flight evaluations, and the basic technical feasibility of a selected DDB Engineering Model hardware unit. These objectives can be summarized as follows:

- Substantiate a predicted reduction in cockpit workload and pilot blunder provided by the addition of broadcast data into the RNAV environment.

- Assess the technical performance characteristics and overall feasibility of a DDB Engineering Model hardware unit, including recommendations for improvements.

- Determine the operational utilization of the DDB concept in the terminal area, including the compatibility of broadcast navigation information with controller-initiated maneuvers.

1.2 APPROACH

The basic method of approach was to install, check out, and modify, as necessary, Government-furnished DDBS equipment to perform a flight test program (Reference 1) consisting of six dedicated flight tests for which specific objectives have been defined as follows:

a. Waypoint Nomenclature: RNC vs. DWN

To evaluate the relative merits of two distinct waypoint identification techniques. From the standpoint of operational utility, determine whether the preferred waypoint designation technique should be the Route Numbering Concept (RNC) or the Discrete Waypoint Numbering Concept (DWN).

b. Traffic Flow Transition

To evaluate the DDB concept and validate the existence of operational and procedural problem areas in the terminal environment during traffic flow (runway in use) changes and impromptu sequences within a broadcast flow.

c. Waypoint Sequences: Automatic vs. Manual

To determine from a design requirement whether the automatic waypoint sequencing feature is a desirable DDB system characteristic.

d. Broadcast Flow Cycle Time

To determine an operationally acceptable value of the broadcast data cycle time ranging from a minimum of 10 seconds to a maximum of 30 seconds.

e. Waypoint Storage

To determine the optimum or acceptable number of user DDB waypoint storage registers for an operational environment.

f. VNAV Impact

To determine the impact of VNAV procedures concerning such variables as workload and blunder reductions and improvements in aircraft steering performance on the DDB user.

Each of the previous dedicated tests included flights by pilots representative of both ends of the proficiency spectrum. Each flight was analyzed not only to evaluate the specific test objectives but also to obtain supplementary knowledge pertinent to the introduction and acceptance of DDB into the terminal area environment. Pilot blunders and cockpit workload were recorded, as well as deficiencies observed with the tested DDB Engineering Model equipment configuration. Operational utilization benefits of the DDB-equipped aircraft were analyzed, discussed and extrapolated from the available flight test data. The recommendation for an advanced DDB Engineering Model was concluded and would require specific DDB system changes. Specification requirements concerning these technical and operational changes for both the airborne and ground DDB equipment evolved.

1.3 RESULTS

The following summarized results are pertinent to the major DDB test objectives. For a complete detailed analysis, refer to Sections 4.0 and 5.0.

- The results of the DDB Flight Test program indicate a positive reduction in cockpit workload and pilot blunder through the utilization of the DDB concept in the RNAV environment system. Of 26 data flights flown by 3 subject pilots, only 4 blunders were recorded. This is approximately 13% of the total blunders

recorded (32) in the baseline General Aviation RNAV Flight Test (Reference 2), which did not use DDB.

- The DDB concept was satisfactorily proved by the utilization of the DDB Engineering Model hardware, whose purpose was primarily to isolate areas requiring further development, as well as equipment design limitations. An overall analysis of these deficiencies indicates that a majority of the deficiencies are directly related to DDB hardware and/or software functional problems in the DDB Engineering Model.
- The operational utilization of the DDB concept permits its user to devote more time to cockpit management duties, since it reduces the required RNAV navigation input times and, thereby, reduces overall cockpit workload. Blunder potential is greatly reduced by making most of the navigation task a planning one and by reducing the number of required inputs as the result of the automatic acquisition of entire SIDs or STARs. For a complete discussion of the operational utilization benefits of the DDB concept, refer to Section 5.0.

1.4 RECOMMENDATIONS

Recommendations for a candidate design of an advanced DDB system based on observations of the performance of the flight-tested DDB Engineering Model are discussed in Section 6.0. Basically, the recommendations include corrections to the recorded deficiencies of the tested DDB Model, as well as specification changes (Reference 3) for a future design concerning the technical and operational requirements aspects. The major recommended changes are the modification of X-mode pulse spacing to assure reliable data reception and a change in the designation of DDB waypoints to a 5-Alpha character from the tested 3-numerical-character format. This format would conform to the current RNAV charting requirements and future implementation needs.

1.5 CONCLUSIONS

The major conclusions from the results of the DDB Flight Test Program can be summarized as follows:

- DDB reduces cockpit workload.
- DDB reduces pilot blunders.
- The preferred waypoint designation technique is the Route Number Concept (RNC).

- DDB offers significant operational advantages, particularly during traffic flow changeovers.

- The maximum broadcast data flow cycle time is 30 seconds.

- Manual waypoint sequencing is preferred over automatic waypoint sequencing.

- A minimum of six waypoint storage registers should be provided by the DDB airborne equipment.

- VNAV does not impose too high a workload on the RNAV/DDB user.

The results of the DDB Flight Test Program indicate that the DDB concept could be utilized and applied as a potential reducer of cockpit workload and pilot blunders. This would have a direct impact on the reduction of Flight Technical Error (FTE) and airspace utilization by the DDB-equipped user aircraft.

2.0 INTRODUCTION

One of the major concerns regarding the operational utilization of Area Navigation (RNAV) as an integral part of the National Airspace System is the consideration of such interrelated factors as cockpit workload, pilot blunders, and data/waypoint storage requirments for airborne systems. Although the potential of pilot blunders resulting from cockpit workload may exist to some degree during all phases of flight, it is particularly critical during terminal area high-workload operations at high-density airports. Preliminary analysis indicates that a Digital Data Broadcast System (DDBS) concept could be utilized and applied as a potential reducer of cockpit workload and pilot blunders. The initial requirements for the feasibility of a DDB system were derived from an operational analysis (Reference 4), which preceded the fabrication of DDB Engineering Model hardware and which defined the system design concept and functional requirements for that system. This report covers the flight test and results of the tested DDB Engineering Model hardware and the verification of operational significance of the DDB concept through the flight test demonstration.

2.1 THE DIGITAL DATA BROADCAST CONCEPT

Digital Data Broadcast is a technique wherein the DME (or TACAN) ground-to-air radio link is used to carry RNAV-referenced data into the aircraft. In this feasibility test configuration of the data broadcast system, the data transmitted consisted of the identification code, latitude, longitude, magnetic variation and elevation of the radiating station, and the RNAV distances (Rho's), RNAV bearings (Theta's), sequence numbers and group (route) identifiers of the waypoints referenced to that station. This digital information, except for the ground station latitude, longitude, magnetic variation and elevation, is decoded, stored and displayed to the pilot by the DDB airborne decoder. The applicable broadcasted RNAV data decoded by the DDB airborne equipment is then appropriately interfaced with the RNAV computer as required for computations of pertinent RNAV navigation parameters.

2.2 THE DIGITAL DATA BROADCAST FLIGHT TEST PROGRAM

The DDB Flight Test Program consisted of subject areas critical to the design, development and implementation of DDB in the anticipated terminal area navigation environment. The flight test program consisted of six dedicated flight tests for which specific objectives were defined. Although dedicated flight plans were outlined for each of the subject areas, the primary objectives of the DDB Flight Test Program were (1) to substantiate the predicted reduction in cockpit workload and pilot blunders provided by the addition of broadcast data in the RNAV environment, (2) to assess the feasibility of the DDB Engineering Model design and (3) to evaluate the operational utilization of the DDB Concept.

The flight test program consisted of 26 data flight during the testing period of 15 September 1975 to 13 November 1975. The tests were conducted at the National Aviation Facilities Experimental Center (NAFEC) at Atlantic City, New Jersey and were performed using the DDB Engineering Model hardware and the Intercontinental Dynamics VNAV Computer (Figure C-2) installed in a CTI-owned twin-engine Aero Commander 500 (Figure C-3). Airborne data were recorded on an Incre-Data Corporation Mark IIA digital data acquisition system (Figure C-4), as well as a hand written flight test log by a trained cockpit observer. The E-AIR tracking radar at NAFEC was utilized as the indicator of actual aircraft position. Three different RNAV traffic patterns were designed, and flown by three subject pilots. The routes flown included ATC-initiated traffic flow changes (runway changes), as well as impromptu sequences (direct-to) within the route flown. Test results were to be summarized in tabular (statistical) form for comparison with RNAV data (Flight Technical Error and Airspace Utilization) from previous RNAV tests (Reference 2) and subsequent programs. Owing to time and technical considerations, however, the quantification of the DDB/RNAV statistical data is not included in this report. Rather, the DDB test results were qualitatively analyzed through the use of cockpit observer flight logs, subjective interpretation and experience.

3.0 DISCUSSION OF TESTS

This section discusses the DDB Flight Test Program requirements, equipment description, data acquisition/reduction and general test description, including test profiles, subject pilots, test matrix and test procedures. For a complete description of the DDB Flight Test requirements, refer to Reference 1, "DDB Technical and Operational Test Plan and Test Procedures". A brief discussion of the DDB Flight Test requirements and a summary of the tests follow.

3.1 EQUIPMENT SUMMARY

Complementary to the DDBS TACAN ground equipment modifications already incorporated into the parent RTN-2 test facility, the following is a detailed list of the Airborne DDB Engineering Model hardware installed in the test airplane:

a. EDMAC Model 9040 Airborne Decoder S/N 1

b. King Model KDM - 705 DME Interrogator (Modified)

c. King Model KNC - 610 RNAV Computer (Modified)

d. King Model KNI - 520 Course Deviation Indicator

e. King Model KFS - 560 Frequency Selector

f. King Model KNR - 601 Navigation Receiver

The DDB airborne system components were installed in the test aircraft by the subcontractor (CTI) and maintained, along with the ground station equipment, by engineering personnel of the Sierra Research Corporation. Basic installation and interface with required avionics components were accomplished in accordance with the installation requirements defined in Reference 5. The operational features of the tested DDB Engineering Model 9040 Airborne Decoder are presented in Appendix B and Reference 6. They are included in this report, so that the reader will have a data base for interpretation of flight test results, including documented operational deficiencies and recommended operational and technical requirements applicable to the DDB test equipment configuration. Appendix C figures (photographs) show the arrangement of DDB equipment (Figure C-1) as installed on the instrument panel of the test aircraft; a closeup view of the EDMAC Model 9040 Airborne Decoder and control/display unit as installed (Figure C-2) and the Aero Commander test aircraft (N3832C) at the NAFEC ramp (Figure C-3).

3.2 DATA ACQUISITION/REDUCTION

3.2.1 Data Acquisition

This section discusses the data acquisition methods in the DDB Flight Test Program.

a. Airborne Instrumentation

The test aircraft included the following airborne instrumentation for real-time recording on an Incre-data data recorder, which was mounted on an onboard instrumentation rack. (Appendix C, Figure C-4).

(1) Crosstrack Deviation Indicator (CDI)

(2) Distance-to-Waypoint (DTW)

(3) DME

(4) Vertical Track Deviation (VNAV)

(5) Real Time

(6) Event Marker

Calibrations of the applicable flight instruments were performed prior and subsequent to the overall flight test program to assure the accuracy of the RNAV-associated airborne equipment.

b. Ground-Referenced Data

The E-AIR tracking radar at NAFEC was utilized as the indicator of actual aircraft position, by detecting and recording (real time) the azimuth, elevation and altitude of the test aircraft. In addition, E-AIR radar tracking plots of each route profile flown were utilized for qualitative evaluation of total crosstrack system error.

c. Cockpit Observer Flight Logs

During 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 flight test results could be evaluated (see Section 3.2.2). Following is a summary of flight test

data recorded by the cockpit observer and pertinent to the relative evaluation of test objectives.

(1) Verification of waypoint information (P , O) being received. (Waypoint in use and the selected position are in the Display Select Control).

(2) Verification of waypoint identification number on waypoint storage registers.

(3) The execution of the Auto-Manual-Step sequence switch.

(4) The execution of the Waypoint Select switch during DWN operations.

(5) The execution of the Route Select switch during traffic flow changes.

(6) Verification of the In-Use lamp and Station Select display.

(7) Procedural/blunder error, defining most probable cause.

(8) Cockpit workload, especially during impromptu maneuvers and final approach phase of flight.

(9) Cockpit management related to the administration of route charts, (i.e., pilot's verification of waypoint received) and deviation from flight plan, if any, and reason.

(10) ATC clearances/traffic conflicts.

(11) Cross-check of the following instruments and/or indicators:

CDI	Heading
DTW	Altitude
To/From Flag	Airspeed
Loss of DME Signal	

(12) Verification of OBS course selected.

(13) Enroute/Approach (CDI sensitivity changeover).

(14) VNAV procedures.

d. Flight Reports

A brief summary of flight test results is written at the conclusion of each test by the cockpit observer and safety pilot. Subject pilot's comments were incorporated, so as to document any particular event or reason for decision making during the course of flight testing.

3.2.2 Data Reduction

Originally, the planned data reduction process was to include the processing of flight test data in a format comparable to previous General Aviation Baseline Flight Tests (Reference 2). These were to include quantification of statistical data concerned primarily with Flight Technical Error (FTE) and Total System Crosstrack Error (TSCT). The data required to process the above data was properly acquired, but the data processing to complete this effort was not completed on schedule and could not be used in this analysis without delaying the overall evaluation and incurring additional costs. Therefore, a desirable quantification of the flight test data, including FTE and TSCT statistical data for comparison to previous tests (Reference 2) and subsequent programs, is not included in this report. The data reduction effort has thus evolved into a qualitative evaluation of flight test data through subjective analysis and interpretation of manually recorded airborne data as discussed previously. This includes visual examination of E-AIR radar tracking plots for substantiation of pertinent data parameters and editing of data judged invalid as the result of ground based or airborne equipment problems.

3.3 SUBJECT PILOTS

From the original pool of six pilots who took part in the non-DDB General Aviation Flight Test (Reference 2), three were utilized in the DDB Flight Test Program. The subject pilots were familiar with RNAV operations and the flight characteristics of the test aircraft, and were responsible for the required navigation and communication tasks. All flights were flown simulating IFR conditions by utilizing an in-flight training hood. The safety pilot was the designated pilot in command and would only intervene for traffic avoidance, when and if such situations arose. Each subject pilot was briefed in the operational use of the tested DDB Engineering Airborne Model, including a one-hour orientation flight prior to collection of flight test data. Pilots were not informed when an impromptu traffic flow change clearance would be given. A summary of the subject pilot's experience level is in Table 3-1.

TABLE 3-1. 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	500	20
C	15,900	700	11,500	500	45

3.4 TEST PROFILES

The basic DDB Flight Test Program consisted of flying terminal area SIDs and STARs. Three test patterns were transmitted over the experimental VORTAC. Each test pattern contains several RNAV departures and arrivals, but all are referenced to a specific runway in use. The three test patterns flown were the following:

Northeast RNAV Departure/Arrival (Figures 3-1 through 3-3)

Southeast RNAV Departure/Arrival (Figures 3-4 through 3-6)

Northwest RNAV Departure/Arrival (Figures 3-7 through 3-9)

The shaded route segments on each test pattern denote the particular route flown on that specific test pattern. Four different routes were flown in the combined three test patterns.

a. Northeast Pattern (Figures 3-1 through 3-3):

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.

b. Southeast Pattern (Figures 3-4 through 3-6):

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.

c. Northwest Pattern (Figures 3-7 through 3-9):

This pattern was utilized whenever an impromptu traffic flow change was required. The aircraft was flown as in the Northeast pattern (a) until halfway between Victor and Golf waypoints. At that point, the aircraft was cleared (impromptu)

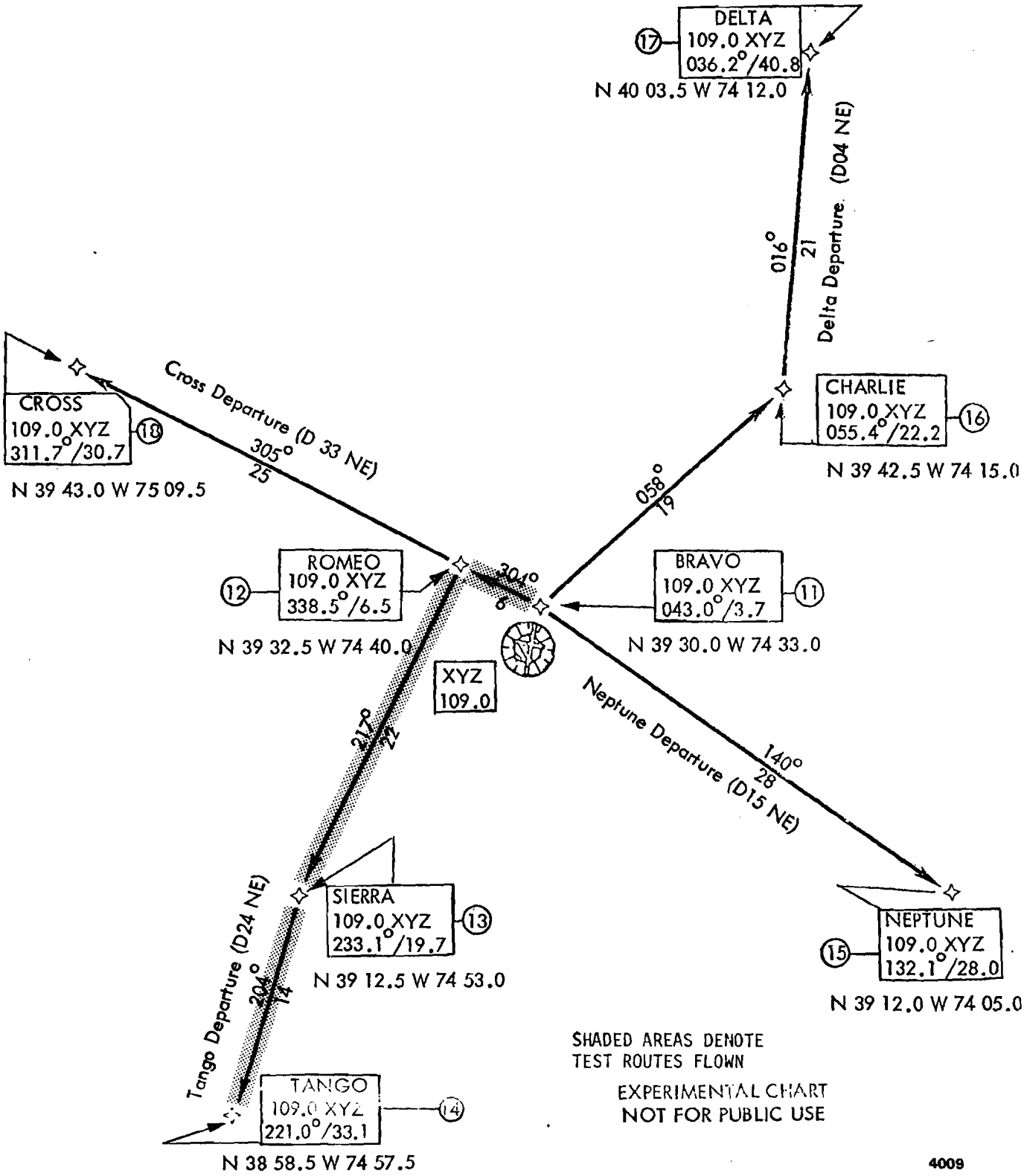


FIGURE 3-1. NORTHEAST RNAV DEPARTURES

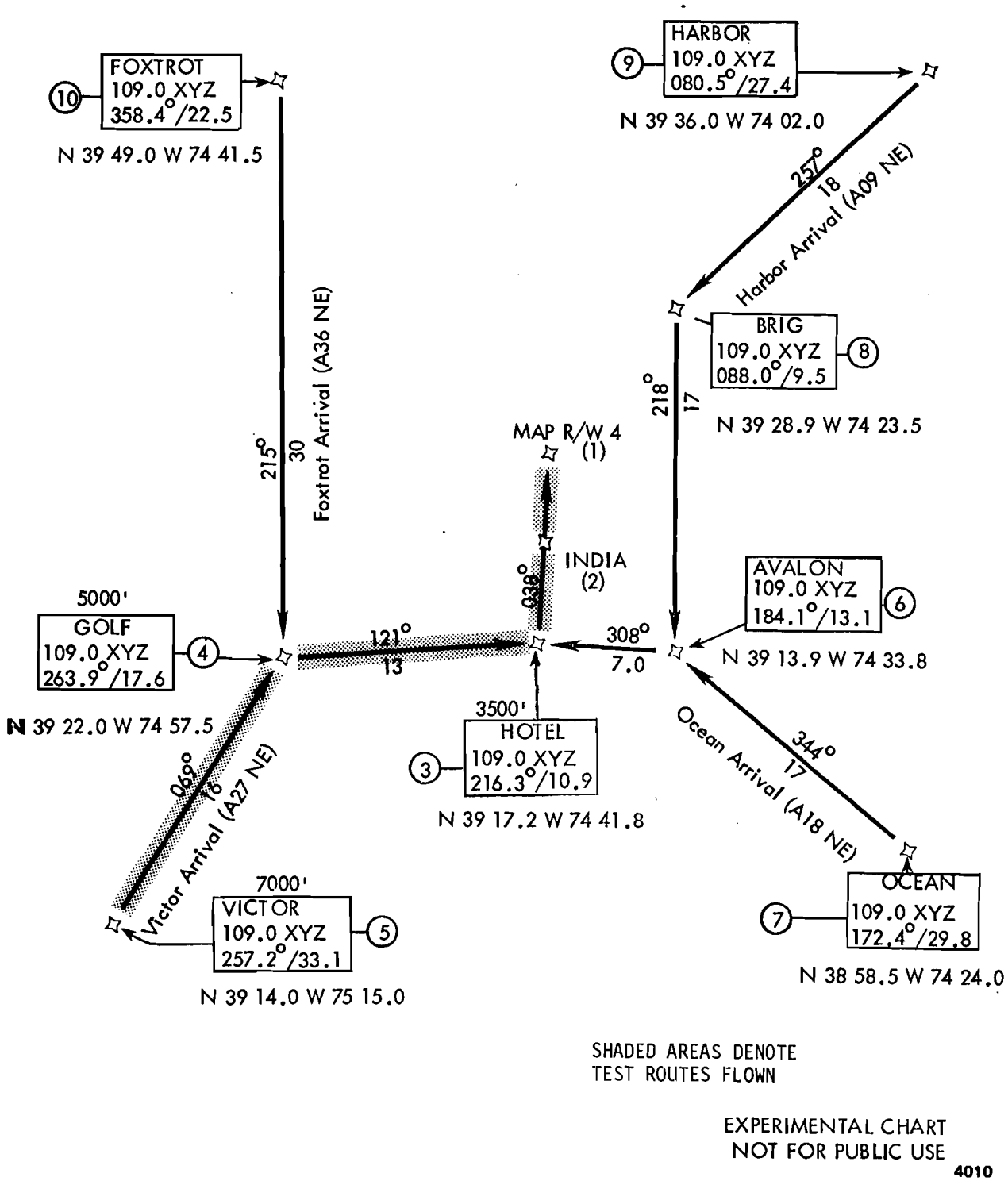


FIGURE 3-2. NORTHEAST RNAV ARRIVALS/HOTEL TRANSITION

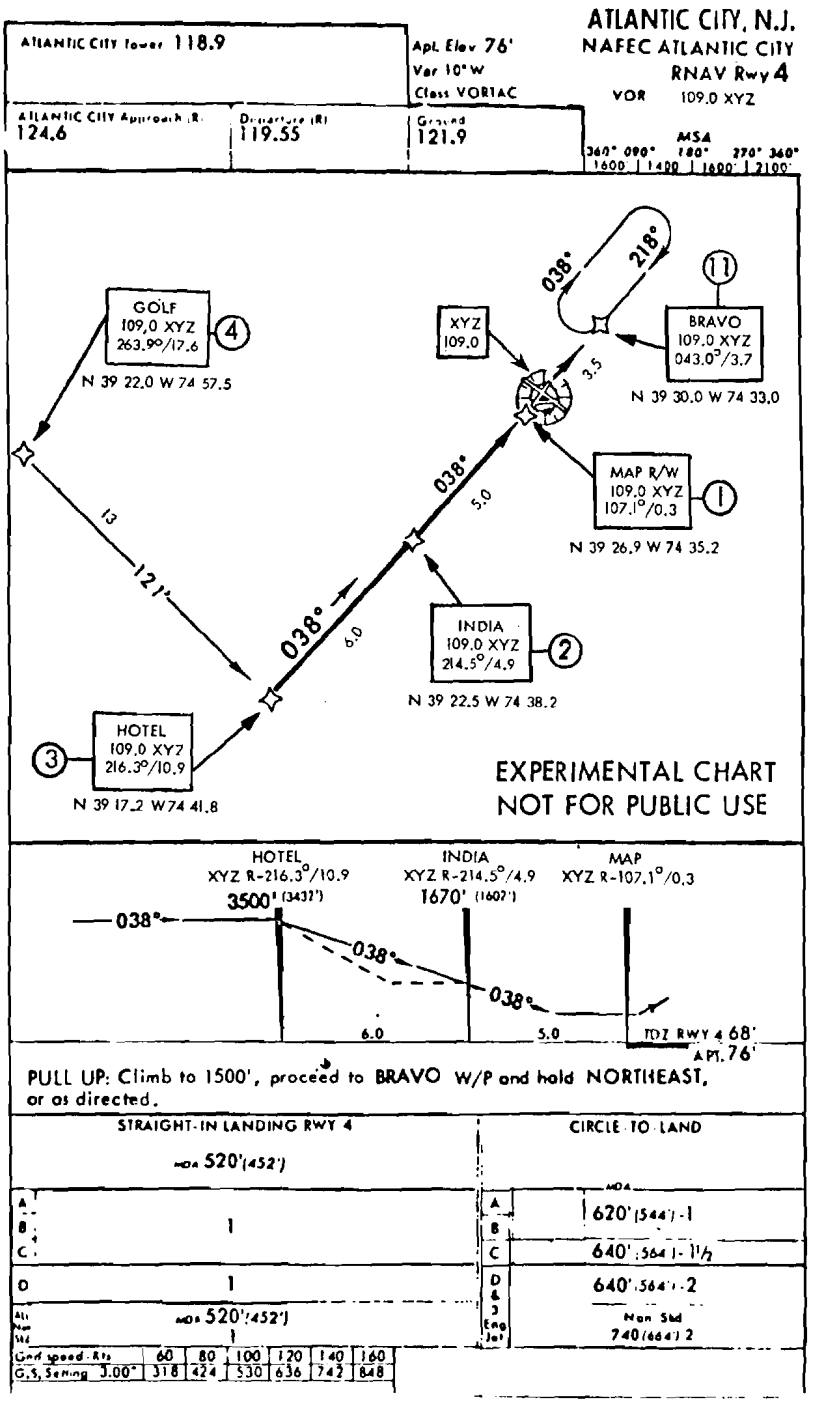


FIGURE 3-3. NORTHEAST RNAV APPROACH PLATE

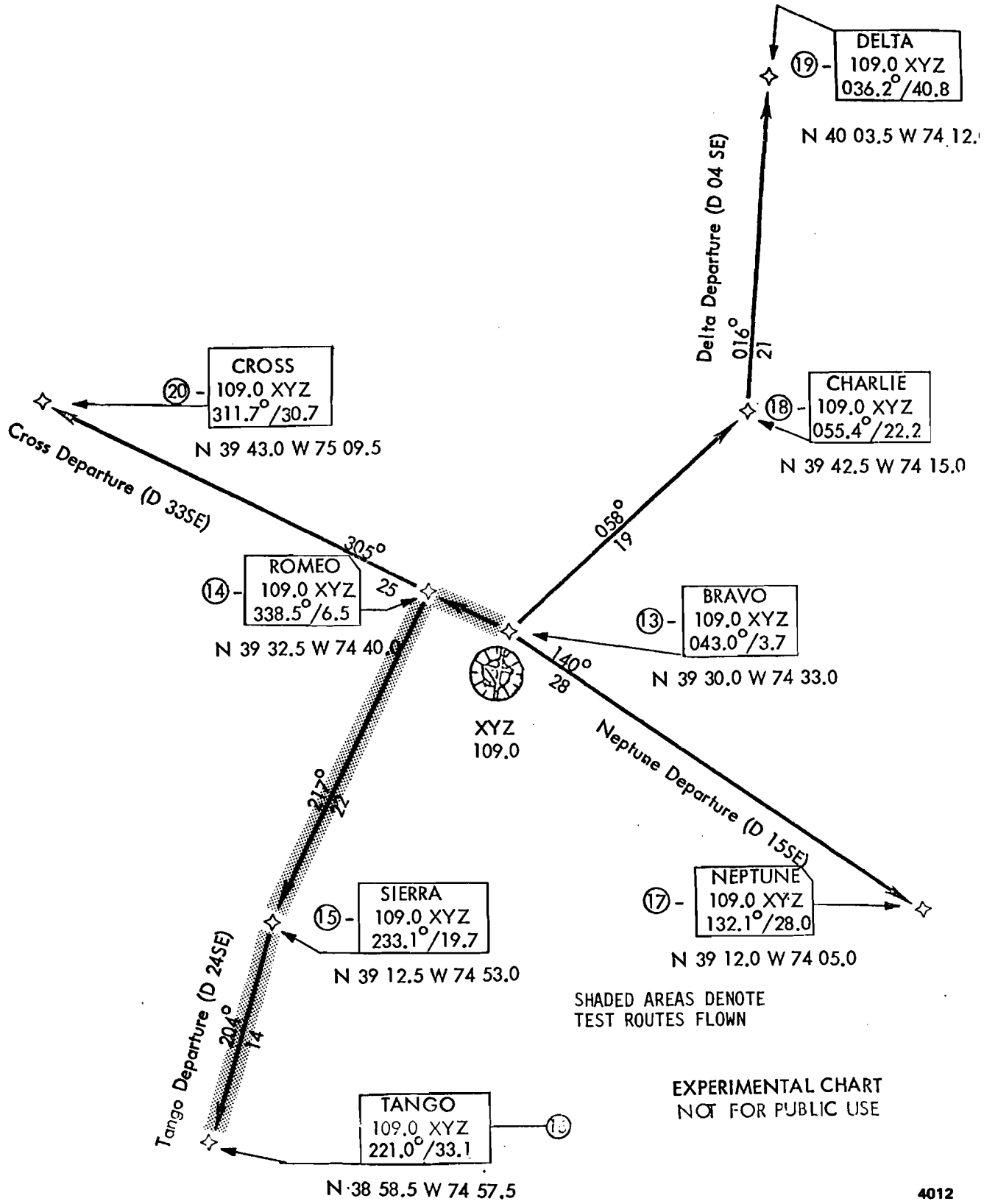


FIGURE 3-4. SOUTHEAST RNAV DEPARTURES

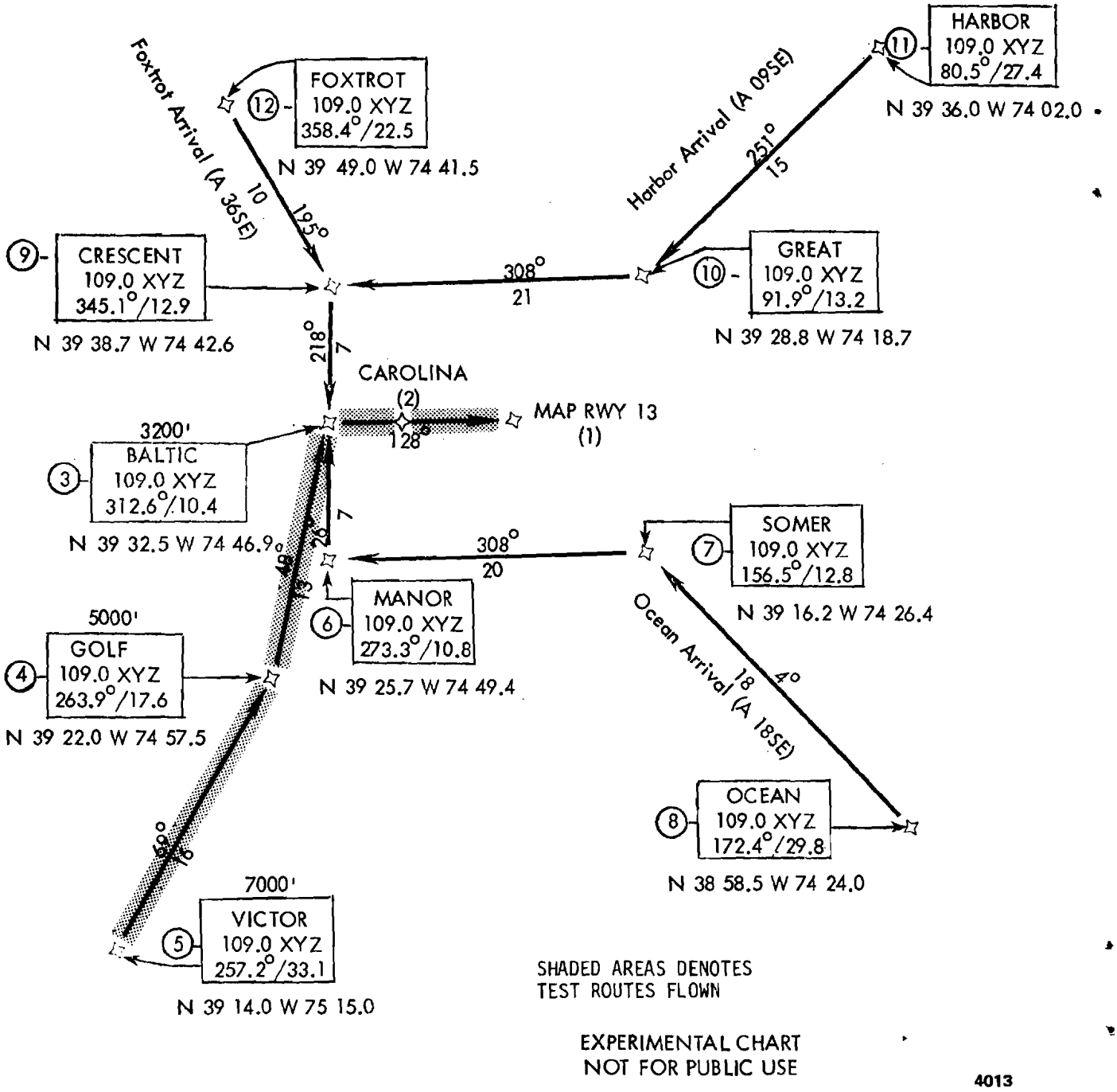


FIGURE 3-5. SOUTHEAST RNAV ARRIVALS/BALTIC TRANSITION

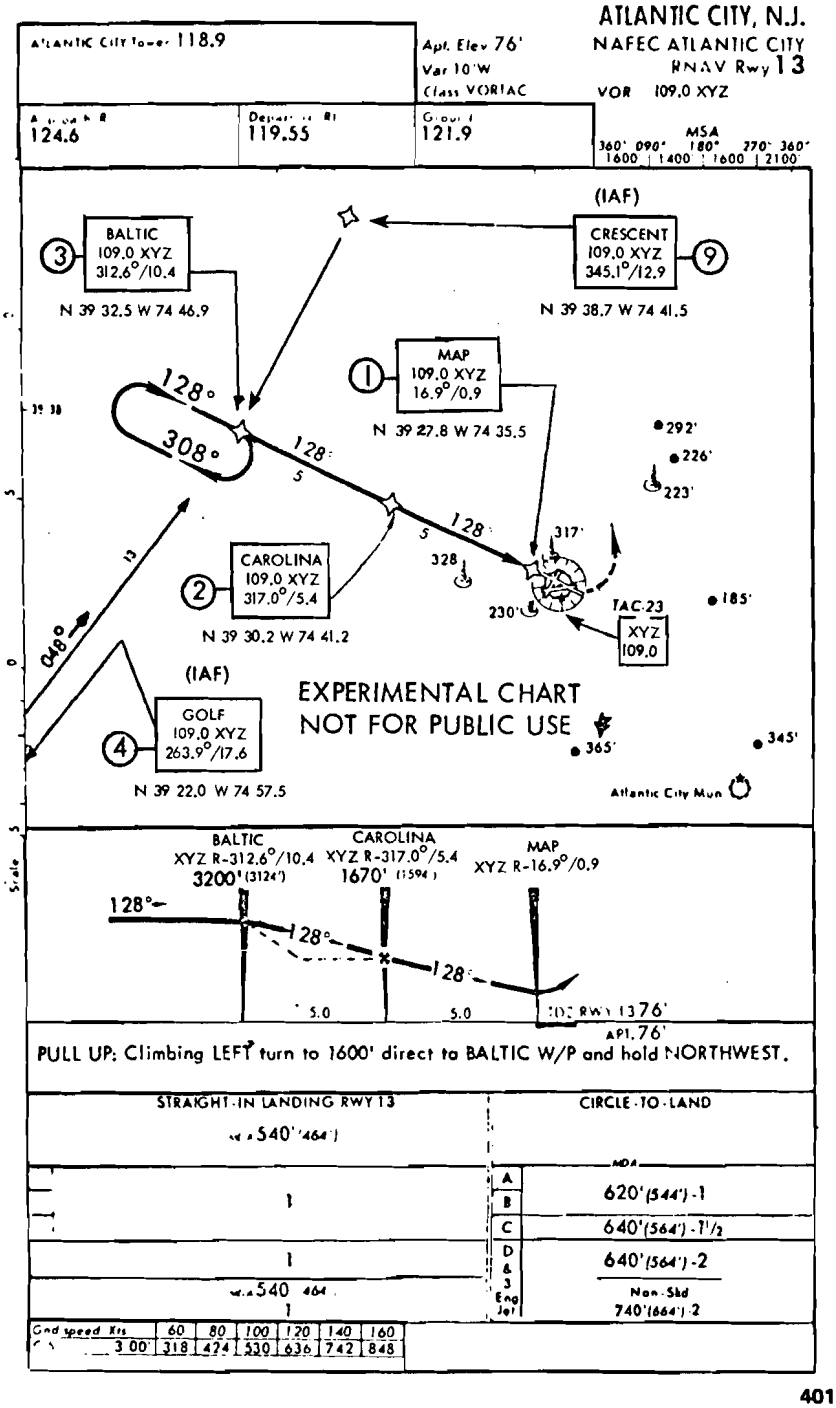


FIGURE 3-6. SOUTHEAST RNAV APPROACH PLATE

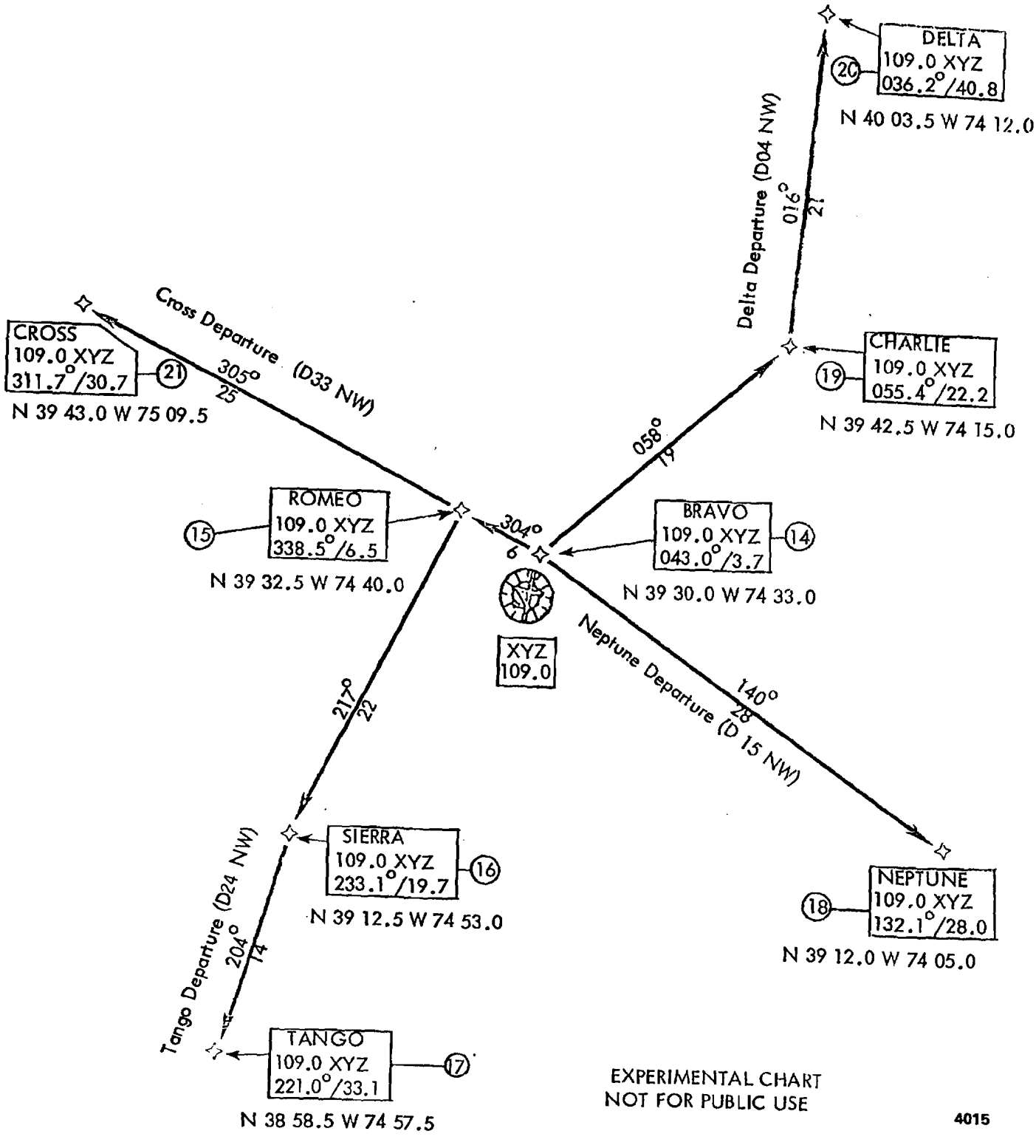


FIGURE 3-7. NORTHWEST RNAV DEPARTURES

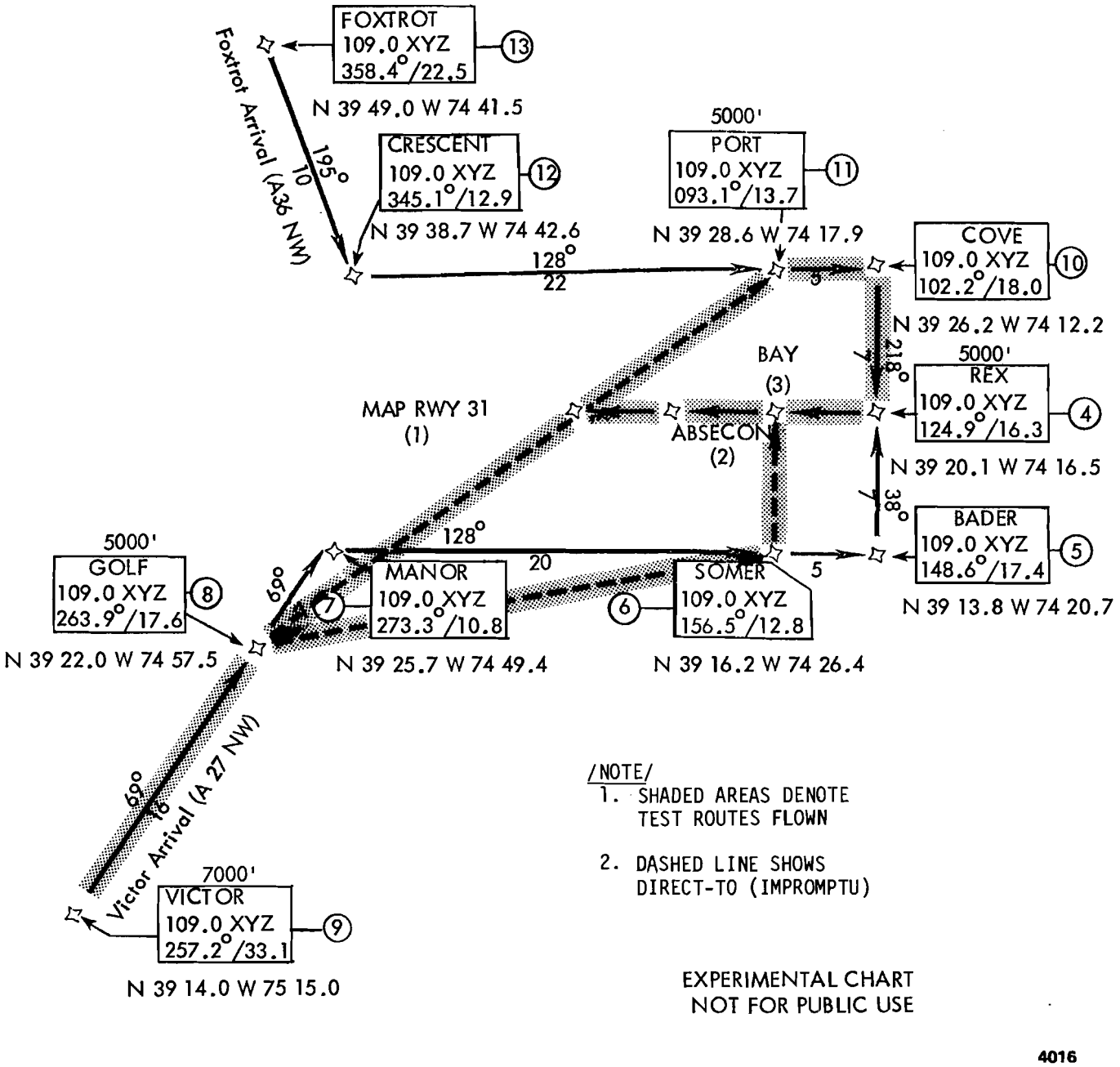


FIGURE 3-8. NORTHWEST RNAV ARRIVALS/BAY TRANSITION

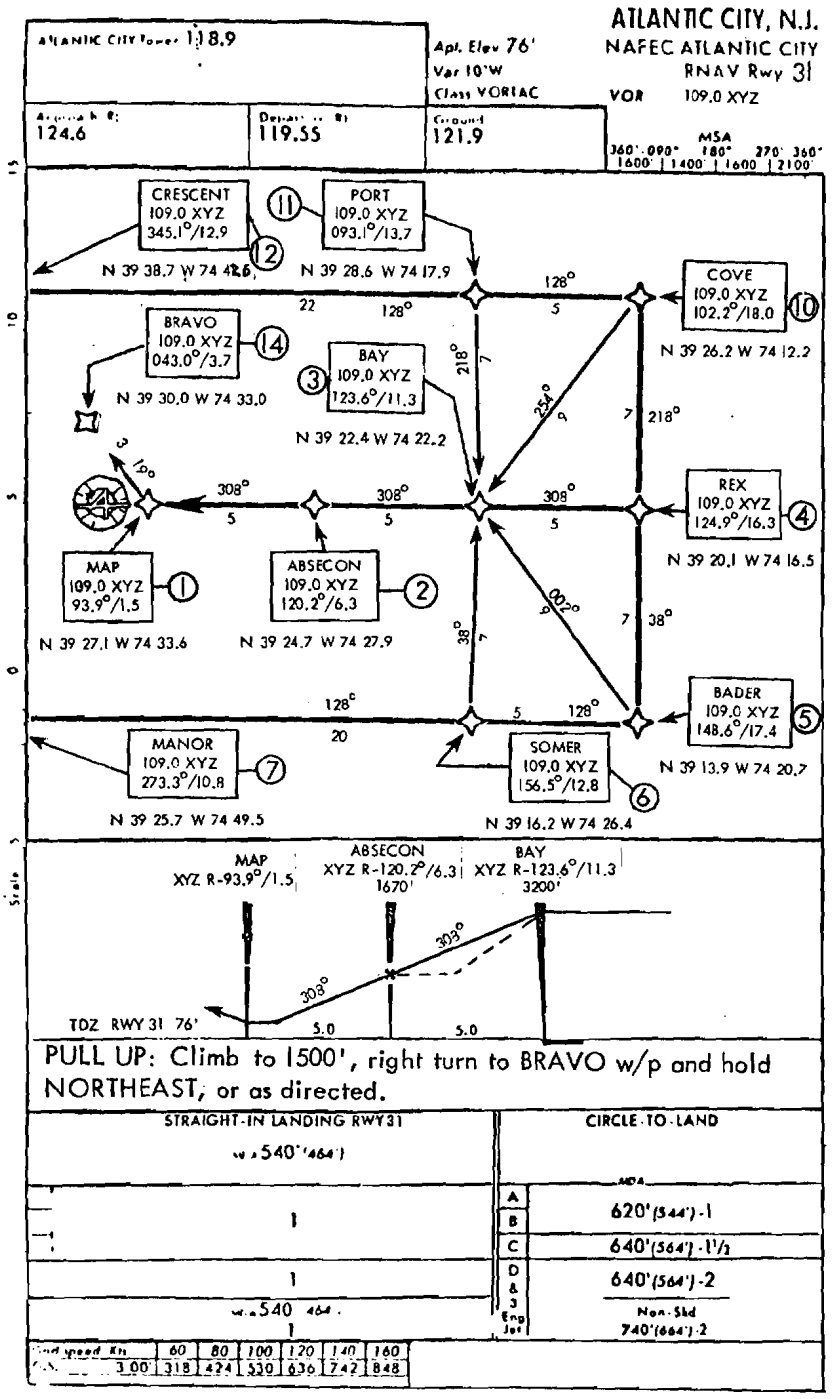


FIGURE 3-9. NORTHWEST RNAV APPROACH PLATE

for the Victor arrival (A27NW), coinciding with a traffic flow change by the broadcasting station from the Northeast to the Northwest test pattern. At 2.0 nautical miles "To" Golf, one of two new clearances would be 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 nautical miles short of it for a direct-to Bay waypoint. No new clearances (impromptu) were given, if the aircraft went by way of Port waypoint. Landings on this pattern were to runway 31.

3.5 FLIGHT TEST DESCRIPTION

Thirty-six flights were flown in the DDB Flight Test Program at NAFEC during the test period. Of these, nine were for shakedown/pilot orientation purposes, one resulted in an abort as the result of ground station problems and 26 were for data collection purposes. Tables 3-2 through 3-4 show the DDB flight test matrix (distribution, test description and the routes flown) by each of the subject pilots. The departure/arrival route designator code in the tables (i.e., D24NE), refers to the DDB nomenclature code of a departure route previously defined as part of a broadcast traffic flow pattern, in this case, the Northeast traffic flow. Likewise, an A27NE DDB route code refers to an arrival route in a selected and broadcast Northeast traffic flow. The remaining major headings of the tables simply refer to the configuration of specific test variables in a given flight test. As the result of schedule conflicts, subject pilot B was able to fly only six tests instead of the desired 16 flights as per subject pilot A. The remaining portion of the intended flight test matrix for subject pilot B was to be flown by subject pilot C. However, time limitations and scheduling problems permitted only four additional flights by subject pilot C. Table 3-5 shows a flight test summary of test variables per subject pilot per number of flights. It is presented to denote the balanced characteristics of the DDB flight test matrix. The 40% - 60% split between the 2- and 6-waypoint storage test was preestablished during test planning.

TABLE 3-2. DDB FLIGHT TEST MATRIX FLOWN BY SUBJECT PILOT "A"

Flight Test 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	10/21/75	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 3-3. DDB FLIGHT TEST MATRIX FLOWN BY SUBJECT PILOT "B"

Flight Test 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
17	10/28/75	D24NE	A27NE	None	6	M	RNC	10	2D
18	10/28/75	D24SE	A27SE	None	2	M	DWN	10	2D
19	10/28/75	D24NE	A27NE	A27NW/A36NW (GOLF to PORT)	6	A	DWN	10	2D
20	10/28/75	D24NE	A27NE	A27NW (GOLF to SOMER to BAY)	6	A	RNC	30	3D
21	10/28/75	D24SE	A27SE	None	6	A	RNC	10	2D
22	10/29/75	D24NE	A27NE	A27NW/A36NW (GOLF to PORT)	6	M	RNC	30	3D

TABLE 3-4. DDB FLIGHT TEST MATRIX FLOWN BY SUBJECT PILOT "C"

Flight Test 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
23	11/12/75	D24NE	A27NE	None	2	A	DWN	10	2D
24	11/12/75	D24NE	A27NE	A27NW/A36NW (GOLF to PORT)	2	A	DWN	30	3D
25	11/12/75	D24NE	A27NE	None	6	M	RNC	30	3D
26	11/12/75	D24NE	A27NE	A27NW	6	M	RNC	10	2D

TABLE 3-5. DDB FLIGHT TEST MATRIX SUMMARY OF TEST VARIABLES/SUBJECT PILOT/NUMBER OF FLIGHTS

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

4.0 DISCUSSION OF RESULTS

4.1 BLUNDER ANALYSIS

The purpose of this section is to present the data obtained during the DDB Flight Test Program regarding the number, frequency and types of pilot blunders recorded. In the 26 data flights flown by the three subject pilots, only four pilot-induced blunders were recorded. These results indicate a positive reduction in pilot blunder afforded by the utilization of the DDB in the RNAV environment of the terminal area. A summary of the recorded pilot blunder data during the tests is presented in Table 4-1. An analysis of this data indicates that only two of the four blunders resulted in a violation of protected airspace.

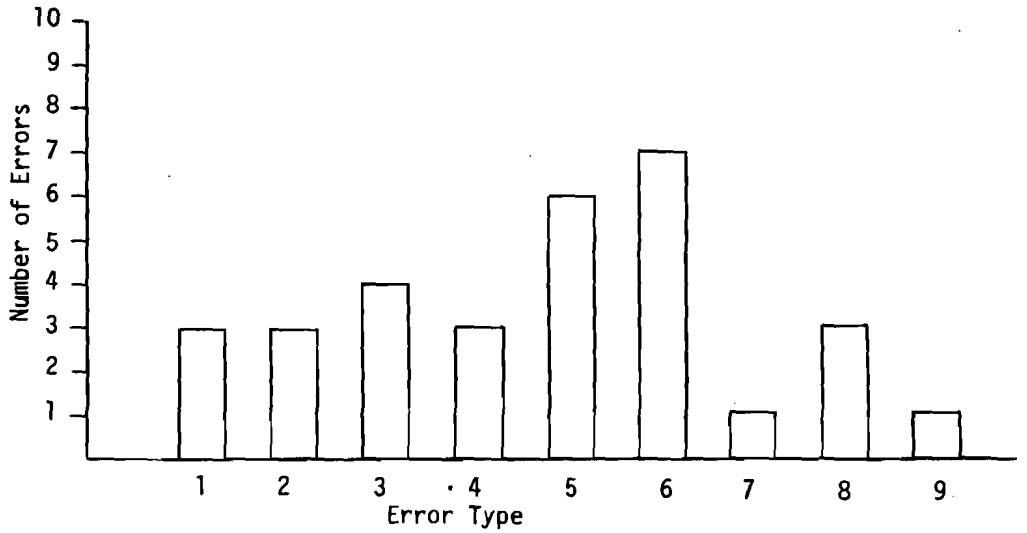
To assess the DDB potential for a reduction in pilot-induced blunders, a comparison of blunder error data was made between the DDB Flight Test Program and the General Aviation RNAV Flight Tests (Reference 2). The General Aviation Flight Tests were chosen because they consisted of an almost equal number of flights (30) and because they utilized, basically, the same type of routes flown in the DDB Flight Test Program and the same kind of RNAV system (single waypoint storage). Moreover, the DDB flight test aircraft and the three subject pilots were utilized during the General Aviation Flight Tests. Figure 4-1 shows the pilot's RNAV control errors, by type, during the previous non-DDB General Aviation Baseline RNAV Tests. An examination of this figure indicates that 31 subject pilot errors were documented. When this total is compared to the four pilot errors recorded in the DDB Flight Test, there is approximately an 87% reduction in the pilot blunders that can logically be attributable to the use of the DDB concept. Further inspection of Figure 4-1, reveals that the most prevailing error (7) was the setting of VNAV desired altitude (30 VNAV operations required). During the DDB tests, no VNAV (waypoint altitude set) errors were recorded (24 operations required). Six errors were recorded in the 248 OBS operations in Reference 2, while only one was recorded in the 228 OBS operations in the DDB tests. Additional inspection of Figure 4-1 (non-DDB) indicates that seven errors were documented concerning waypoint radial or distance input errors against none, as the result of inherent hardware/software capabilities, for the DDB. This brief comparison of blunder data with a comparable number of data samples indicates the significant reduction of pilot blunders afforded by the use of the DDB concept against an almost equal RNAV guidance system. A brief discussion of the four blunders recorded during the DDB test is presented in the following discussion.

Two pilot blunders recorded in the DDB Flight Tests resulted in a violation of protected airspace. One of these was the result of the pilot's being distracted, while listening to extraneous radio communications during a time period requiring an OBS update. The pilot misread the RNAV charts and input an OBS for the final approach segment. Just prior to that,however, the

TABLE 4-1. 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 Way-point (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

(Previous Non-DDB Baseline Tests)



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

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FIGURE 4-1. GENERAL AVIATION RNAV FLIGHT TEST PILOT RNAV CONTROL ERRORS BY TYPE

pilot had updated his RNAV guidance to the desired waypoint by sequencing the DDB waypoint in use. The pilot discovered the error after experiencing unusually large CDI deflections, indicating three to four nautical miles right of the desired course. The pilot commented during postflight debriefing that the low workload inposed upon him by the DDB allowed him to relax his proper and accurate efforts of data management and entry. The other blunder, which resulted in an airspace violation, was primarily due to the lack of proper data management by the subject pilot, who neglected to enter the proper "next" waypoint data into storage register number 2, which was available. This entry was required as the result of the limited (two) waypoint storage capability being tested. The DDB method used in this flight to select waypoint data was the DWN. Proper data entry sequence is required in this case for acquisition of the next waypoint, after the active waypoint in use (storage register number 1) would sequence out. This is a worst case situation during the DDB tests, since the pilot was limited, by a test requirement, to two-waypoint storage throughout the flight, including VNAV procedures. This particular blunder occurred while the aircraft was being turned to the final approach segment. This type of error is very likely to reoccur, if future DDB airborne systems are designed without considering a realistic and operationally meaningful waypoint storage capacity for maximum utilization of the DDB concept.

A third pilot blunder recorded was the selection (RNC method) of a wrong RNAV arrival during the transitioning from an RNAV departure to the desired arrival. The pilot was required to change from the D24SE departure to the A27SE RNAV arrival by selection of the route select thumbwheel switch. However, he changed only the D of the previous departure to an A of a desired arrival, thus selecting the arrival A24SE, which did not exist and causing the appearance of the DME flag. This error lasted for approximately 1.5 minutes and while the aircraft was in a turn to a known heading intercept for the transition to the first waypoint of the desired RNAV arrival. Apparent efforts to troubleshoot appearance of the DME flag by the pilot were futile. The safety pilot was required to correct the error. The subject pilot commented during postflight debriefing that he suspected (as the result of previous experiences) that the appearance of the DME flag was not because of any error on his part, but rather an anomaly of the system. Although the pilot's comments are justified, it is felt that this error resulted from insufficient DDB training in the validation and cross-reference check between the RNAV charts and the DDB route select display.

The fourth pilot blunder recorded was the DWN selecting of a wrong waypoint (Cove) instead of the desired (Port). The pilot had just been cleared (impromptu) for a "direct-to-Port waypoint" (see Figure 3-8). An indirect cause of this blunder was the DWN operating mode of the DDB Engineering Model, which required an unusual workload (see Appendix B.1.6.2 for details of DWN mode). The direct-to traffic clearance was preceded by an impromptu traffic flow change, which necessitated the re-input (DWN method) andvalidation

of all waypoints defining the revised route. During the pilot's validation checks, which was the period when the direct-to clearance was given, he inadvertently selected the wrong waypoint as the active waypoint. (Cove waypoint is next in sequence after Port waypoint.) The pilot caught the error in less than 2.0 nautical miles by requesting confirmation of the last traffic clearance. Proper reacquisition of the desired track was achieved without interference with other traffic and very minimal deviation from course.

4.2 PERFORMANCE CHARACTERISTICS

This section consists of an evaluation of the performance, operational characteristics and the technical design feasibility of the tested DDB Engineering Model airborne equipment. Tables 3-2 through 3-5 illustrate the overall flight test matrix, where specific test variables related to the technical design of the tested DDB airborne model were evaluated during the flight tests. In all cases, the flights were designed to permit multiple evaluation of test variables related to the functional capability of the tested DDB airborne model, as a direct comparison of test parameters (e.g., the evaluation of RNC versus DWN, cycle time (10 seconds versus 30 seconds), auto versus manual waypoint sequence, etc.). This section is concerned primarily with the assessment of these flight test issues.

The results described in this section are based on qualitative and subjective operational analysis through interpretation of manually recorded cockpit observers' flight logs and pilots' comments. A desirable quantification of flight test data, including FTE and TSCT statistical data for comparison to previous tests (Reference 2) and subsequent tests, is not included in this analysis as the result of nonavailability of data processing. It is believed that the overall data analysis and results of the DDB Flight Test were limited because of the lack of FTE and TSCT data, which would have allowed a quantification of the DDB benefits.

Operational and technical deficiencies of the tested DDB Engineering Model were documented in a separate report (Reference 8). Briefly, the DDB operational deficiencies report consists of a description of potentially serious deficiencies, the majority being directly related (1) to the fact that the DDB equipment was Engineering Model hardware and/or (2) to the supporting software functional problems.

Sections 4.2.1 through 4.2.6 present the results of the analysis of the performance characteristics and operational features of the DDB Engineering Model, including the effects on VNAV use during traffic flow changeovers. These results will aid in determining the minimum operational and functional characteristics for future design and development of a DDB airborne system. System 4.2.7 is presented to document noted signal anomalies, which had a marked effect on the utilization of the protected airspace by the test aircraft.

4.2.1 Waypoint Nomenclature: RNC vs. DWN

From the operational viewpoint, the preferred RNAV waypoint designation technique was the Route Numbering Concept (RNC) and not the Discrete Waypoint Numbering (DWN). The RNC method enabled the pilot to select entire RNAV SID or STAR routes by a single data entry, considerably decreasing the pilot's workload, since the requirement for individual waypoint data entry is eliminated. The utilization of the RNC method provided the pilot more time to monitor the navigation flight instruments, thereby eliminating the need to periodically enter required RNAV waypoint data. The RNC method was considered more resistant to possible pilot-induced errors during data input entry than the DWN technique. This was evidenced during the previously discussed blunder analysis (Section 4.1), where a subject pilot selected a wrong waypoint during data validation check of an RNAV arrival input by the DWN method. Although the selection of RNAV waypoint data by either of the DDB acquisition methods (RNC and DWN) is considerably more efficient and resistant to pilot blunders (data entry) than the selection by conventional RNAV methods, it still requires, to a certain extent, the pilot to be the mediator between the RNAV charts and its desired DDB input. The pilot's task of interpreting the RNAV charts for RNAV waypoint data selection is greatly reduced, when utilizing the RNC method, by the simple recognition from the desired RNAV chart of the nomenclature or DDB code of the intended RNAV route (SID or STAR). DDB data entry (RNC method) is then easily accomplished by the single data entry (5-character) into the DDB airborne decoder of the selected RNAV route. However, when utilizing the DWN method, the pilot must identify the individual RNAV waypoint code number of the intended RNAV route by visual inspection of the RNAV chart, and then enter each one of those individually. (See Section B.1.6.2 for details of DWN Mode.) Although the probabilities of incorrectly selecting RNAV bearings (Theta) and RNAV distances (Rho) are eliminated because of the DDB concept itself, the chances of selecting a wrong waypoint (DWN method) is not completely eliminated, because of its uniqueness and the requirement for the pilot to select the proper waypoint numerical code and its proper follow-on sequence in the DDB waypoint storage registers per RNAV waypoint proper sequence and as defined in the RNAV charts. A subjective evaluation of the available flight test data indicates that although the DWN method was found to be less desirable, there were no apparent major differences in the relative merits of selecting RNAV waypoint data by the use of either the RNC or DWN techniques. This resulted primarily from the fact that the DDB concept permits, throughout the terminal area flight envelope, the immediate acquisition of RNAV waypoints in periods of decreased or no workload, complemented by the relative simplicities of waypoint identification and the advantages offered by a comfortable number of waypoint display/storage registers.

4.2.2 Sequencing of Waypoints: Automatic vs. Manual

The tested DDB Engineering Model (airborne) included design features permitting either automatic sequencing of waypoints as activated by the KNC 610 RNAV computer, when the DTW (nm) drops below a predetermined value, or manual sequencing of waypoints as selected by the pilot. The automatic sequencing of waypoints was adjusted in the DDB flight tests to occur at its minimum setting, which was 0.8 nautical mile (DTW) of the active (in use) waypoint. In the 26 data flights flown in the DDB tests, 13 flights were in mode.

Flight test results indicate that the manual sequencing of waypoints is preferred to that of automatic waypoint sequencing. Independent of various documented operational deficiencies (Reference 7) in the use of the automatic sequencing of waypoints, the manual sequencing of waypoints was considered superior, from the standpoint of operational utilization, because of its flexibility of use in the RNAV terminal area environment. The manual sequencing of waypoints permitted the pilot to execute the required waypoint sequencing in the terminal area, including the execution of extended trombone maneuvers, which require the RNAV system to provide DTW in the "From Flag" condition.. The automatic sequencing of waypoints, on the other hand, was limited to operations up to 0.8 nautical mile (DTW) of the active waypoint in the "To Flag" condition only. This presented the following problems:

a. If the CDI needle deflection at waypoint passage was greater than 0.8 nautical mile (DTW), the automatic sequencing of waypoints would not take place and,

b. It caused the elimination of the Missed Approach Waypoint (MAP), when the DTW is less than 0.8 nautical mile, leaving the pilot without RNAV navigation to complete his final approach.

If the automatic sequencing of waypoints is to be retained as a desired feature, a possible solution may be the use of the "To/From" signal to indicate waypoint passage. However, careful examination indicates that false triggering of waypoints sequences can occur in certain circumstances, most notable in base-leg turns, where the subsequent waypoint is abeam the aircraft, when the "To/From" flag signals "FROM". In such cases, the flag will remain in the "From" condition after waypoint sequencing, causing erroneous sequencing to the subsequent waypoint. A combination to "To/From" signal and DTW may be successfully employed to resolve this problem. That is, the automatic sequencing of active (in use) waypoints should occur at the "To/From" flag changeover, but that sequencing shall not be allowed to occur, unless the aircraft is within a specific and lesser

distance (i.e., 2 nautical miles (DTW) of the active (in use) waypoint). However, this solution requires that technical considerations be given to additional variables (e.g., parallel offsets (magnitudes) abeam the active (in use) waypoints). Another suggested solution, which will guard against the false triggering of waypoints sequences, is a combination of "To/From" signal and DTW time. That is, the automatic sequencing of waypoints should occur at the "To/From" flag changeover, but that sequencing shall not be allowed to occur, unless the aircraft is within a specified time span (i.e., 60 seconds) of the active (in use) waypoint. However, implementation of this technique would necessitate the incorporation of a timer for DTW in the DDB airborne decoder.

4.2.3 Waypoint Storage: Two Waypoints versus Six Waypoints

The DDB Flight Test program was configured to include a limited evaluation of an acceptable (or desired) number of waypoints storage. To accomplish a comprehensive evaluation of waypoint storage in the flight test program, it would have been necessary to devote a significant number of flight tests to this objective alone. Because of this factor, and the impact that it would have in diminishing the analysis of other important variables in the limited DDB test program, the waypoint storage experiment was limited to a comparison and analysis of two- (DWN) and six- (DWN and RNC) waypoint storage capabilities. Of the 26 data flights flown in the DDB flight test program, seven were flown utilizing a maximum of two waypoints. The remaining 19 utilized the maximum available six-waypoint storage of the tested DDB Engineering Model. Operational deficiencies concerning the DDB data storage displays in the tested DDB Engineering Model have been documented in a previous report (Reference 7).

The operational evaluation of the waypoint storage experiment indicates that the preferred waypoint storage capacity is the six-waypoint data storage register. The two-waypoint storage tests indicated a considerable increase in the pilots' workload, when compared to the six-waypoint storage experiment. This resulted primarily from the pilots' requirements to set the second waypoint in advance, so that when the active (in use) waypoint sequences out, the RNAV guidance would already be available. This requirement resulted in a gradual increase in the pilots' workload as the aircraft progressed toward the airport. That is, the length of the segments to be flown as the aircraft closes on the airport is reduced in distance, mainly because of the smaller airspace available in normal traffic patterns. These distances are usually shortened to 5.0 and 7.0 nautical miles, depending on the terminal area design of such factors as downwind, base and final approach segment. This can be visualized in Figures 3-8 and 3-9. These shorter segments (5 to 7 nautical miles) normally require a larger pilot workload as the result of the increase in pilot/controller communications, change of VOR frequency, discent and turning of the aircraft in preparation for landing. If the pilot is required to

provide for manual data entry at these times, an additional task is placed upon the pilot, when the cockpit workload is already at its highest level. The chances for pilot blunders are increased. This was the case during the DDB flight test program, when on a similar short segment (base: 7.0 nautical miles) and utilizing a maximum of two-waypoint storage, the pilot lost RNAV guidance as the result of inadvertently failing to see the next-to-be-used waypoint. (For additional information, refer to Blunder Analysis, Section 4.1). On the other hand, the use of six-waypoint storage enabled the pilot to concentrate more effectively on monitoring the required navigational flight instruments. This was evidenced through better cockpit management by the pilot in situations requiring high workload, as indicated by the safety pilot and cockpit observer flight logs. Pilots' comments confirmed the desire for a DDB six-waypoint storage system rather than a limited two-waypoint storage system. A six-waypoint storage DDB system would be most advantageous to its user, since, in the terminal area, most arrivals are comprised of a near equal number of waypoints. The pilot, upon entering the terminal area, would have a definite advantage of having most, if not all the desired route to be flown preselected and validated on the DDB display.

4.2.4 Broadcast Data Cycle Time: 10 Seconds versus 30 Seconds

Broadcast data cycle time is the time required to broadcast a complete set of waypoints, including ground station identifier, which may be defined as a route or routes (RNAV SIDs and/or STARs) for a specific traffic flow broadcast. One of the main test objectives in the DDB flight test program was to determine and recommend an optimum braodcast data cycle time. To this end, two different broadcast data cycles times were considered: 10 seconds and 30 seconds. Before proceeding with the results of this particular test, the following paragraph defines the required hardware/software process for each of the tested data cycle times.

The DDB Engineering Model (ground equipment) had, in the tested configuration, a variable "duty cycle" counter selector covering an interval of 0.10 to 0.99 second. The "duty cycle" is the dead time between transmitted words. By setting this duty cycle to a preselected value, the cycle time of route flows being broadcast can be achieved as a function of words transmitted. Since the test patterns to be flown were planned for broadcast at various cycle sensitivity times (10, 30 and 60 seconds), it was required that the duty cycle be selected as a function of total words transmitted for a complete arrival/departure sector (traffic flow). It was determined during the test planning that the fastest desired cycle time for a broadcast of 10 seconds yielded 78 words at a duty cycle of 0.10 second, which is the minimum achievable. The test patterns flown (Figures 3-1 through 3-9) were designed according to the desired cycle time transmission of 10, 30 and 60 seconds. Tables 4-2 through 4-4 show the DDB flow structure summary for each of the test patterns flown (Southeast, Northeast and Northwest traffic flows). From the previously

TABLE 4-2. SOUTHEAST PATTERN DDB FLOW STRUCTURE SUMMARY

4 SIDs = 12 Waypoints = 40 Words (24 Bits)
4 STARs = 13 Waypoints = 43 Words (24 Bits)
VORTAC ID = 4 Words (32 Bits)
Total Words = 87

Desired Flow Transmission Time	Required Duty Cycle
60.0 Seconds	0.668 Seconds
30.0 Seconds	0.323 Seconds
10.0 Seconds*	0.094 Seconds
10.560 Seconds**	0.10 Seconds

TABLE 4-3. NORTHEAST PATTERN DDB FLOW STRUCTURE SUMMARY

4 SIDs = 12 Waypoints = 40 Words (24 Bits)
4 STARs = 12 Waypoints = 40 Words (24 Bits)
VORTAC ID = 4 Words (32 Bits)
Total Words = 84

Desired Flow Transmission Time	Required Duty Cycle
60.0 Seconds	0.693 Seconds
30.0 Seconds	0.336 Seconds
10.0 Seconds*	0.098 Seconds
10.197 Seconds **	0.10 Seconds

TABLE 4-4. NORTHWEST PATTERN DDB FLOW STRUCTURE SUMMARY

4 SIDs = 12 Waypoints = 40 Words (24 Bits)
2 STARs = 14 Waypoints = 44 Words (24 Bits)
VORTAC ID = 4 Words (32 Bits)
Total Words = 88

Desired Flow Transmission Time	Required Duty Cycle
60.0 Seconds	0.660 Seconds
30.0 Seconds	0.320 Seconds
10.0 Seconds*	0.092 Seconds
10.68 Seconds**	0.10 Seconds

* Minimum achievable duty cycle of 0.10 seconds precluded evaluation of this condition.

** Minimum achievable flow transmission time tested based on 0.10 second duty cycle

mentioned tables, the "duty cycle" at the ground station was selected for the required test pattern flown. In determining the total number of waypoints on a given traffic flow, the following common waypoint (IF, FAF and MAP) were counted only as one each. Two PROM (ground station programmable read only memories) were utilized to program the test patterns. On one PROM, both the Northeast and Northwest traffic flows were program loaded. The other PROM consisted only of the Southeast traffic flow. Traffic flow selection for a desired traffic flow broadcast was accomplished by its proper switch selection (ground station).

The 26 data flights of the DDB flight test program included 14 flights at a preplanned data cycle time of 10 seconds, and 12 at the 30-second cycle time. Flight test results indicate that a 10-second broadcast data cycle time is the more efficient in terms of total reception time (for storage and display of selected DDB data). However, the 30-second cycle time was considered acceptable for the intended use of DDB in the RNAV terminal environment. This is evidenced by a comparison of Tables 4-5 and 4-6. Each shows, respectively, the reception time/waypoints handled in a given flight by the airborne DDB decoder, depending on the cycle time used (10-second or 30 second cycle) and also as a function of the method used (DWN or RNC) to select the desired broadcast data. The comparison of cycle times (10-second and 30-second) to the DWN or RNC methods to select the desired DDB broadcast data was made, since each of these methods, by definition, depends on either a single route entry (RNC), which allows all of the waypoints on that route to be stored and displayed, or a single waypoint entry (DWN), which allows the individual storage and display of the selected waypoint. The "number of waypoints handled", as indicated in Tables 4-5 and 4-6, refer to the total number of waypoints made available to the pilot, on a given flight, by the DDB airborne decoder, including departure, arrival and impromptu/traffic flow change (if any). For detailed information concerning the specific test configuration on a given flight, refer to Table 3-2 through 3-4. An analysis of Tables 4-5 and 4-6 indicates that the 10-second cycle time was considerably more efficient than the 30-second cycle time, since it provided the means for a more rapid availability of selected DDB data for storage and display usage. This is evidenced by an examination of Tables 4-5 and 4-6 as follows: Table 4-5 (10-second cycle time) shows a total average reception time/waypoint of 2.38 seconds (RNC) and 5.66 seconds (DWN); while Table 4-6 (30-second cycle time) indicates a total average reception time/waypoint of 4.06 seconds (RNC) and 6.17 seconds (DWN). Notice that the respective RNC or DWN methods for the 10-second cycle time resulted in less required reception time per waypoint than that of the 30-second cycle time. However, the 30-second cycle time resulted in an operationally acceptable and adequate time cycle during its evaluation on the DDB flight tests. Its total average reception time per waypoint was understandably larger than the 10-second cycle time, but still conservatively low in magnitude. The 30-second cycle time did not cause unusual delays in the execution of RNAV procedures in the terminal area. It did not present any

TABLE 4-5. 10-SECOND CYCLE TIME: AVERAGE BROADCAST DATA RECEPTION TIME/WAYPOINT (DWN AND RNC)

Flight Number	DWN		RNC	
	Waypoints Handled	Average Reception Time (sec)/Waypoint	Waypoints Handled	Average Reception Time (sec)/Waypoint
1			9	3.22
2	8	2.75		
5	12	7.5		
9			18	1.72
10			9	3.33
13			18	2.11
14	8	6.37		
16	12	7.41		
17			9	3.11
18	8	4.75		
19	20	4.55		
21			9	2.11
23	8	6.13		
26			18	2.22
Average (Total)	76	5.66	90	2.38

TABLE 4-6. 30-SECOND CYCLE TIME: AVERAGE BROADCAST DATA RECEPTION TIME/WAYPOINT (DWN AND RNC)

Flight Number	DWN		RNC	
	Waypoints Handled	Average Reception Time (sec)/Waypoint	Waypoints Handled	Average Reception Time (sec)/Waypoint
3			9	7.00
4	8	11.63		
6	20	3.15		
7			23	2.65
8			23	4.26
11			9	5.88
12	8	11.12		
15	17	2.23		
20			18	3.05
22			23	3.17
24	12	9.83		
25			9	6.66
Average (Total)	65	6.17	114	4.06

observed problems for the inflight acquisition of impromptu waypoints or reassignment of RNAV route (traffic flow change).

Further analysis of broadcast data cycle time includes the quantification of maximum and minimum broadcast data reception time of DWN and RNC methods as a function of 10- and 30-second cycle times (Table 4-7). The data presented on Table 4-7 should be interpreted cautiously, since it merely represents the minimum and maximum values of broadcast data reception time experienced throughout the 26 data flights flown. (No averages were computed.) In addition, the recorded values of each data acquisition method (DWN and RNC) are applicable to their own specific functions. That is, the values presented for DWN apply only to a single waypoint reception time, while the reception time values for the RNC method include, in all cases, a total of six waypoints already properly sequenced. An analysis of the data presented in Table 4-7 indicates that the maximum and minimum reception time values, except for the maximum values (DWN and RNC) at a cycle time of 30 seconds, fell within acceptable boundaries for the acquisition and operational use of RNAV broadcast data. The maximum reception time values of the RNC and DWN methods at a cycle time of 30 seconds are much larger in magnitude (50 seconds for RNC and 33 seconds for DWN), when compared to their corresponding values at the 10-second cycle time (24 seconds for RNC and 12 seconds for DWN). The major reason for this is the threefold cycle time in the 30 second cycle. However, the implications of these maximum reception times (33 seconds for DWN and 50 seconds for RNC) at the 30-second cycle time are considered minimal from the operational utilization viewpoint. Considering the maximum reception time of 50 seconds required for the RNC method, these 50 seconds include a total of six waypoints (limited by the number of available waypoint storages) of a selected RNAV route already properly sequenced, resulting in an average of approximately eight seconds per waypoint received, stored and displayed to the pilot by the airborne DDB decoder. These eight seconds (average reception time) per waypoint are far less than the time required (19 seconds, Reference 2) to manually input a single waypoint in a similar tested but non-DDB RNAV system. An analysis of possible operational implications regarding the maximum reception time of 33 seconds (DWN), recorded while in the 30-second cycle time, reveals the following: the circumstances of this occurrence would be most critical, if a "direct-to" impromptu traffic clearance were given to the pilot by the ATC controller, thus requiring the immediate acquisition of the desired waypoint, provided it is not already previously stored in any of the available waypoint storage registers (6). Certainly, this would be a worst case condition requiring the expeditious availability of a desired waypoint by the effective combination of the DDB airborne decoder and the broadcast data cycle time. However, by considering the overall results of Table 4-6, which indicates a total average reception time per waypoint of 6.17 seconds (65 waypoints data sample) for the DWN method, it is felt that the 30-second cycle time would be an acceptable (maximum allowable) cycle time for the intended use of DDB in the RNAV terminal environment.

TABLE 4-7. MAXIMUM AND MINIMUM BROADCAST DATA RECEPTION TIME OF DWN AND RNC METHODS AS A FUNCTION OF 10- AND 30-SECOND CYCLE TIME

Data Acquisition	10-Second (Cycle) Reception Time		30-Second (Cycle) Reception Time	
	Minimum (seconds)	Maximum (seconds)	Minimum (seconds)	Maximum (seconds)
DWN*	2	12	2	33
RNC**	9	24	16	50

* Applies only to a single waypoint reception time
** Reception time in all cases, a total of 6 waypoints

4.2.5 Traffic Flow Transition Effects

One of the test objectives in the DDB flight test program was to evaluate and isolate problem areas (functional and operational, if any) of the DDB Engineering Model as regards its use during the execution of broadcast traffic flow (runway in use) change and impromptu waypoint sequences (direct-to) within a traffic flow. The traffic flow change experiment resulted in the documentation of several operational deficiencies caused primarily by the hardware design of the tested DDB Engineering Model. (For a detailed description of these deficiencies, refer to Reference 7 of this report.) The most significant of these deficiencies is the inability of the DDB airborne decoder to retain previously acquired (stored and displayed) waypoint data after a change of a traffic flow broadcast by the ground station. This particular deficiency resulted in the loss of proper RNAV guidance to the pilot during the period of traffic flow change by the ground station and the time interval required to select/acquire the new route/waypoint to be flown. A most critical operational impact of this deficiency would occur (not tested) when the ATC controller requests the DDB-equipped aircraft to complete the previous pattern (not available because it has been changed), while assigning the new routing (updated traffic flow broadcast) to succeeding aircraft. Since, in the tested configuration, waypoint retention was not possible after a traffic flow change by the ground station, the pilot of the DDB-equipped aircraft would be required to request radar vectors or try to manually input the remaining waypoints by the conventional RNAV method. If the latter option were selected, it would most probably result in a considerable increase in the pilot's workload, not to mention probable violation of the protected airspace, depending on how soon efficient RNAV guidance is restored. The traffic flow change experiment at times resulted in some minor confusion to the subject pilots, owing to the different logic by the DDB airborne decoder, which displayed unselected

waypoints and/or routes, depending on which method was used (DWN or RNC) after a traffic flow changeover by the ground station. The pilot in each case entered the desired RNAV route or discrete waypoint, thus erasing the false waypoint data displayed and stored by the DDB airborne decoder. During the traffic flow change tests, the RNC method proved to be a most valuable and better DDB selector method than that of the DWN technique. The RNC method enabled the pilot to select the desired arrival route by a single data entry, thus making the difficult task of an impromptu traffic flow change an easy one, and consequently allowing him more time to concentrate on other duties. On the other hand, the DWN method, although it enabled the pilot to have immediate RNAV guidance after entering the desired waypoint in the first storage register (waypoint-in-use), it required the individual entry of the remaining waypoints (up to a maximum of 6). In fact, the only pilot blunder recorded during the execution of the impromptu waypoint sequence (direct-to) test was indirectly caused by the DWN operating mode during validation checks of a required reinput RNAV arrival after a traffic flow changeover by the ground station (see Blunder Analysis, Section 4.1). Of critical importance during the traffic flow change tests was the quantification of a technically and operationally acceptable value of broadcast data rate. Test results from the previous section (4.2.4) indicate that a data broadcast rate of 30-second cycle time was adequate for the execution of inflight traffic flow change, as well as for the various required "direct-to" impromptu waypoint sequences.

Although some major operational deficiencies were encountered in the design of the DDB Engineering Mode, the overall concept of the DDB was proven to be very advantageous in the terminal area. It enabled its user a significant reduction in cockpit workload, especially in the oft-encountered situation of a change in active runway.

4.2.6 VNAV Effects

The ability to fly vertical profiles on a 3D RNAV terminal SID/STAR is termed VNAV (Vertical Navigation). Flying VNAV requires inputs for waypoint altitudes, in addition to the normal waypoint information required (bearing and distance). The DDB flight test program was configured to include VNAV as an integral part of the test objectives to permit an assessment of its effect on predicted DDB benefits such as reductions in workload and blunders and improvements in steering performance.

Of the 26 data flights flown in the DDB flight test program, 14 were 2D RNAV and 12 were 3D RNAV. A total of 24 requiring VNAV operations (descents) were executed by the subject pilots. This included 2 VNAV descents per flight. In all cases, the initial VNAV descent was made to the Intermediate Fix (IF), while the other one was between the IF and the Missed Approach Point (MAP). Normally, the aircraft would begin its descent from the enroute assigned altitude (5000') to a desired crossing altitude at the IF of

3200 feet terminating at the MAP (500' altitude). The subject pilots were responsible for the identification and input of the required waypoint crossing altitude by referring to the specified altitudes annotated in the experimental RNAV charts (Figures 3-1 through 3-9).

The VNAV test results indicate a positive reduction in pilot blunder by the utilization of the DDB system in the RNAV terminal environment. No VNAV errors (waypoint altitude set) were recorded during the 24 VNAV operations required in the DDB flight test program. The subject pilots were observed, in the majority of the cases, to readily adapt to the increase in workload level imposed by the VNAV function. A previous comparison of VNAV blunder data (Section 4.1) from the DDB flight test program and the General Aviation RNAV Flight Tests (Reference 2) indicates the magnitude of improvement attributable to the use of the DDB concept. In both these RNAV flight tests, the same VNAV system was used by the same pilots and on almost identical flight profiles. During the tests of Reference 2, a total of seven VNAV errors (waypoint altitude set) were recorded in 30 different VNAV operations (descents).

Observing the pilots' procedures regarding the utilization of the Final Approach Fix (FAF) broadcast waypoint proved of little significance. (The FAF is always 5.0 nautical miles between the IF and the MAP.) Of 12 VNAV final approaches, only once was the FAF waypoint utilized by the subject pilots. If waypoint data were selected by the RNC method, the pilot would sequence out the FAF waypoint as soon as it became active. In a similar manner, whenever using the DWN waypoint selection method, the pilots would omit the data entry for the FAF waypoint. The main reason for this, according to the pilots' comments, is that elimination of the FAF waypoint during 3D (VNAV) descents eliminates the requirement to select its required waypoint altitude (VNAV).

The desirable quantification and analysis of FTE, TSCT and Vertical Track Deviation (VTD) from both 2D and 3D procedures are not included in this report, owing to the unavailability of the required data processing, as previously discussed.

4.3 PROBABLE VOR RADIAL PROBLEMS

This section consists of documentation of two distinctive signal reception difficulties experienced during the entire DDB flight test evaluation, which were considered significant, owing to their frequency of occurrence and their influence in causing the violation of protected airspace limits.

One of these anomalies was characterized by an unusual "bend" on aircraft crosstrack position (Figure 4-2) whenever in the RNAV arrival segment (Victor to Golf). This "bend" was initiated by a steadily increasing CDI

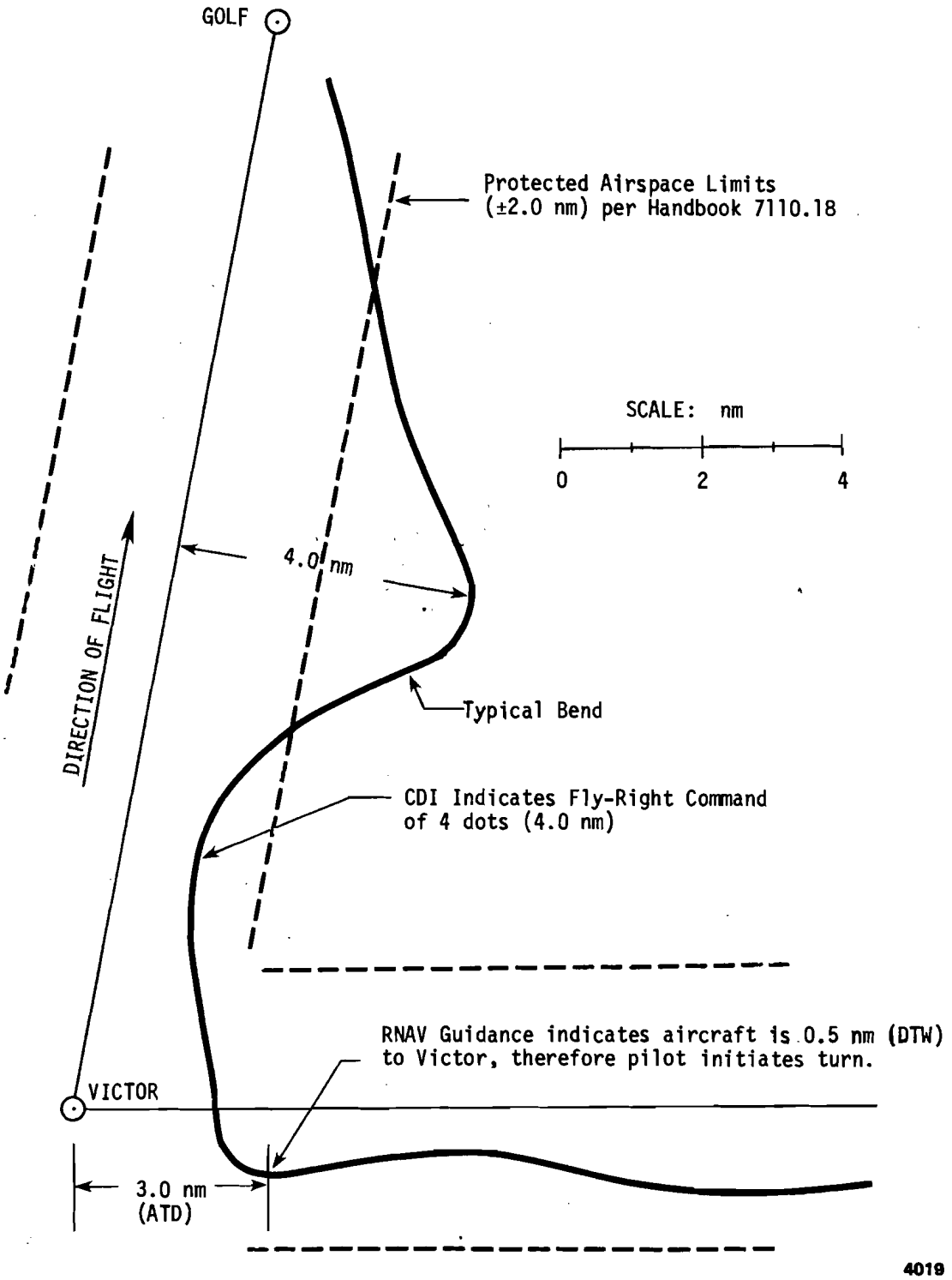


FIGURE 4-2. DDB FLIGHT TEST TYPICAL BEND IN VICTOR TO GOLF SEGMENT AS SHOWN BY AIRCRAFT CROSSTRACK POSITION (RADAR)

fly-right command from 0 to 4 dots (4 nautical miles), which the pilots followed, in all cases, by correcting the aircraft heading accordingly. This caused, as indicated by Figure 4-2, a violation of the current protected airspace (±2 nautical miles) per Handbook 7110.18 (Reference 8), which was extended for approximately 6.0 nautical miles along the desired track.

The other VOR bearing anomaly recorded during the DDB flight test evaluation concerned a gradual divergence (Figure 4-3) of aircraft crosstrack whenever on the RNAV departure segment (Sierra to Tango). As soon as the aircraft passed Sierra waypoint, the CDI would begin to indicate a gradual fly-left command of up to 2 dots (2.0 nautical miles), which the pilots followed by correcting the aircraft heading by approximately the same rate of CDI needle (fly-left) indication. At approximately 1 to 2 nautical miles (DTW) to Tango waypoint, the CDI would always indicate that the aircraft was on the desired track. However, a comparison of the E-AIR radar tracking plots and cockpit observers' notes indicates that the actual aircraft position (crosstrack) was, in the majority of the cases, approximately 3.0 nautical miles left and abeam the Tango waypoint. Examination of tracking radar plots revealed that if each entire flight test profile flown is rotated 5° to 6° clockwise over the ground station origin, the resultant actual aircraft position would fall within ±1.0 nautical mile of each of the waypoints defining the respective flight test profile flown. This is evidenced by comparing Figures 4-2 and 4-3. Notice the 3.0 nautical miles (ATD) when the aircraft initiates a turn at Victor waypoint (Figure 4-2), although the RNAV guidance at that time indicated 0.5 nautical mile (DTW) to Victor. Examination of the tolerance listed in the United States Standard Flight Inspection Manual 3rd Edition (Reference 9) and the manufacturer's handbook for the VOR receiver shows a possible displacement of course for a VOR of 3.5° and an accuracy of 1.5° for the airborne receiver used. This possible tolerance buildup would indicate these were not DDB unique problems. An additional test substantiated the assumption of the 5° to 6° error in the VOR bearing. This test consisted of flying the same test profile using the same experimental VORTAC but utilizing the backup single RNAV waypoint system available in the test aircraft. The results of this special test indicated no differences in actual crosstrack position (radar) plots, including the previously discussed "bend" anomaly.

Since these problem areas were not detected until a significant portion of the flights had been flown and the major objective of the program was to evaluate DDB, it was decided to continue with the DDB flight test and to annotate these major anomalies, so as not to alter the already established ground station signal effects on the test pattern.

A complete flight inspection of the VOR would be required to determine conclusively the cause of these anomalies and would be recommended before any future DDB tests to assure that the technical performance of the DDB concept could be more effectively evaluated.

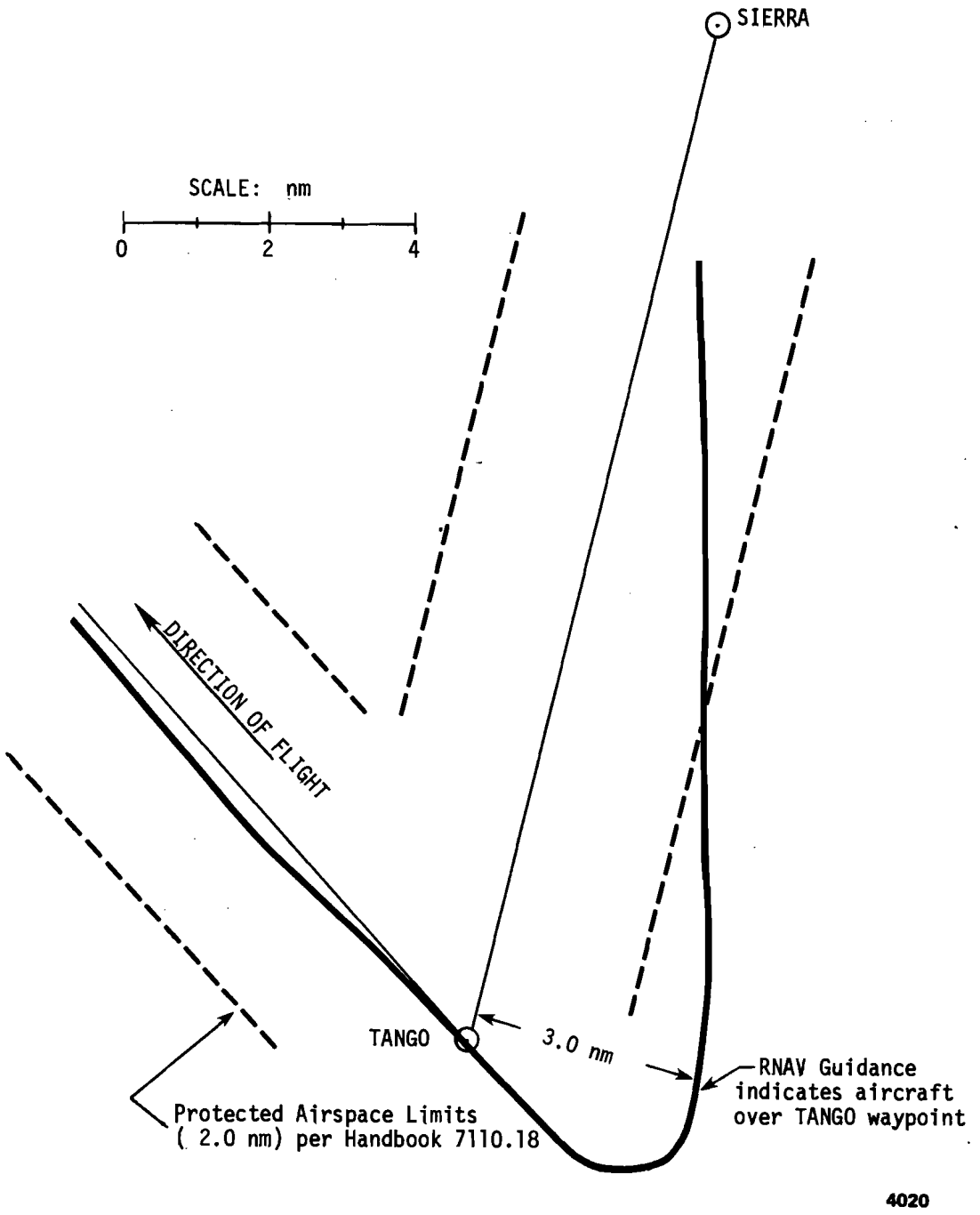


FIGURE 4-3. DDB FLIGHT TEST TYPICAL DIVERGING OF AIRCRAFT CROSSTRACK POSITION (RADAR) IN SIERRA-TO-TANGO SEGMENT

5.0 OPERATIONAL EVALUATION OF THE DDB CONCEPT

This section documents the operational evaluation and utilization of the DDB Engineering Model and the performance characteristics of the DDB concept during the flight evaluation conducted at NAFEC. Though several hardware and software malfunctions were experienced, because the DDB was a feasibility unit, the operational evaluation of the DDB concept produced extremely positive results as regards the benefits afforded by the integration of such a concept into the real-world ATC environment.

5.1 IMPACT OF A DECREASE IN NAVIGATION INPUT TIME

A primary benefit of the DDB concept results from the decrease in pilot workload involved in RNAV waypoint insertion and route definition. This critical navigation input, particularly in the final phases of the terminal area transition, is very time critical in conventional (non-DDB) general aviation RNAV systems. The DDB system alleviates this workload during the terminal transition phase of flight, resulting in the following observed and extrapolated benefits to both the pilot and the ATC system.

5.1.1 Impact of DDB on RNAV Navigation Input Errors and Reduction of Blunders and Procedural Errors

The single most significant advantage of the DDB concept is perhaps the elimination of RNAV waypoint definition input errors. Documentation from previous General Aviation flight tests (Reference 2) of blunder data (presented in Section 4.1) of a conventional RNAV system verify the impact on airspace utilization of procedural errors that occur during the data input task. The utilization of DDB indicates the real potential for a reduction in catastrophic errors, which result in the pilots' flying the aircraft off the desired flight profile, either vertically or horizontally, because of an undetected error in entering the Rho/Theta. For example, during the General Aviation flight test (Reference 2), one of the experienced subject pilots, in entering the Rho/Theta value of the MAP to runway 4 at NAFEC, utilized the correct bearing but entered the distance value of the final approach fix (4.9 nautical miles). The aircraft was then passing the initial fix, inbound on a VNAV approach. The pilot did not have time to verify the Rho/Theta input and did not notice the erroneous DTW value. The aircraft was flown to minimums (400 feet) at a point approximately five miles short of the runway threshold. The subject pilot did not detect the error until the safety pilot removed the instrument flying hood. In this one example, the CDI was essentially centered and there was very little crosstrack deviation from the desired course. If there had been terrain or obstacles at a point five miles sourthwest of the airport, as is the case at many airports, this error would have resulted in a serious accident. The interpretation of the General Aviation flight test documents other instances of this nature (Reference 2).

In the final portion of the RNAV STAR, the task of Rho/Theta input greatly increases the workload and stress on the pilot, due primarily to the close spacing of the waypoints and the added cockpit workload characteristic of terminal area maneuvers, as discussed previously. Under these high workload situations, previous flight tests (Reference 2) have shown that the pilot can make several types of RNAV Rho/Theta input errors, which can be grouped into the following general categories:

- Transposition of the Rho/Theta values
  Example: distance 25 nautical miles, bearing 047°
  becomes: distance 47 nautical miles, bearing 025°

- Utilizing the Rho of one waypoint and the Theta of another waypoint from the RNAV chart

- Misplacing the decimal in entering distance information
  Example: 2.5 nautical miles
  becomes: 25 nautical miles

- Transposing numbers from the chart in data entry
  Example: 331°
  becomes: 313°

Such errors are very difficult for the pilot to detect in a high workload situation. In several instances in the General Aviation flight tests (Reference 2) with conventional RNAV equipment, the pilots, having ignoredgross CDI deflections and unrealistic DME indications which resulted from a Rho/Theta input error, flew a potentially catastrophic profile. On the DDB flight, there was only one brief instance in which the DDB briefly accepted the wrong waypoint definition. This was corrected by the DDB hardware and presented no operational problems on the flight. This particular discrepancy is not expected to reoccur with the recommended redesign of the DDB data acquisition technique (Section 6). This single benefit of DDB has significant impact on the efficiency of flight operations in the terminal area, and directly improves the efficiency of the ATC system in reducing pilot/controller workload by eliminating the source of possible profile deviations.

The DDB system, through the utilization of a significantly simplified route/waypoint input format, eliminates the need for manual data insertion during the critical phases of the terminal transition, especially the final approach. This reduction in both workload and navigation input time dramatically reduced the number of procedural and blunder errors during this evaluation. A comparison with previous flight tests, as shown in Section 4.1, quantifies the frequency and type of errors that were documented in those tests. The problem of providing the operational flexibility of area navigation, without incurring

the associated high cockpit workload and probability of procedural and blunder errors, appears to be significantly alleviated through the utilization of the DDB concept.

5.1.2 Effect of DDB on Aircraft Control Task

The terminal area transition is the period of most intense cockpit activity. Part of this workload is created by the navigation data input function discussed in the previous section, but a significant and critical portion results from aircraft control functions. By decreasing the amount of workload and time involved in navigation input, the pilot has more time to devote to aircraft control and monitoring activities not directly related to navigation tasks (e.g., monitoring and correcting aircraft deviation from a desired altitude, monitoring aircraft performance limitations and effecting changes in configuration to keep the aircraft within the safe flight envelope, monitoring the status of aircraft systems, and correcting for any undesired deviation from that condition considered to be normal or safe). Some of the major items that must be considered in controlling the typical aircraft are:

a. Attitude Control - This involves monitoring the basic flight instruments, which include the airspeed indicator, attitude indicator, altimeter, turn and slip indicator, directional gyros (or HSI) and vertical velocity indicator. These instruments, supplemented with the power instruments, enable the pilot to maintain control of the aircraft under instrument conditions and become extremely important in the terminal area. In the terminal area maneuvering, the aircraft is transitioning through different configurations, as well as airspeeds and altitudes, before stabilizing in a steady flight condition

b. Aircraft Systems - The pilot must constantly monitor all aircraft systems, but in the terminal area, a failure or change in status of one of the major systems is both more likely and more critical to the safe completion of the flight. These systems include aircraft power plant monitors (e.g., RPM manifold pressure, fuel flow, cylinder head temperatures, exhaust gas temperature, and oil temperature). The pilot must also monitor the aircraft electrical system, including circuit breakers, overvoltage relays, battery and alternator monitors and voltameter, aircraft hydraulic system, landing gear and flags, lighting, pressurization, oxygen and environmental control systems

Under normal conditions, controlling the aircraft and monitoring the aircraft's systems require a great deal of concentration and attention.

During the General Aviation flight tests (Reference 2), the navigation workload was shown to detract from the time the pilot had to control the aircraft. This insufficiency of time to devote to the aircraft control task resulted in the aircraft deviating from the desired profile. Review of the observer data logs from the above referenced flight tests indicates many instances in which adequate airspeed and altitude control were not exercised, resulting in a potentially unsafe condition on the final approach. At this point, the aircraft is at minimum altitude and positive control is most essential. An equipment or system failure imposes additional workload and stress on the pilot and demands additional time and attention from the pilot. Although there were no documented aircraft system failures during the flight tests previously discussed, this contingency situation must be considered. Additional provisions must be made to reduce the workload during critical terminal area maneuvers and thereby enable the single pilot to have time available to deal effectively with such situations.

DDB has shown potential for reducing the necessary navigation workload to an extent that will enable the pilot to have the time to deal with critical aircraft control tasks. These factors are becoming more important with high density terminal area procedures and noise abatement approaches.

5.1.3 Effects of DDB on Navigation and Communications Tasks

In the current complex high density terminal area, an increasing portion of the pilot's time is involved in responding to ATC-initiated traffic spacing commands. This requires the pilot to devote more attention to the communication workload and thereby to plan well ahead of the aircraft to effect the proper transition or modification of the terminal route resulting from weather or traffic demands. Communication frequency congestion further complicates the problem of timely communications and requires longer periods of pilot attention to radio transmissions. With the DDB concept, the communication workload is reduced over conventional RNAV procedures, as well as current vectoring procedures, in that flow changes and transitions are defined through ATC selection of the desired flow rather than pilot selection. This benefit results in not only reduced and more effective communication, but also in increased time available to the pilot to concentrate on navigating the aircraft on the modified or newly changed route, rather than becoming involved with the mechanics of reprogramming the RNAV computer or responding to ATC vectors.

Observer and safety pilot logs from the DDB flight test indicate several areas of potential benefit resulting from the decreased workload and increased time available through the utilization of the DDB concept. One of the most important considerations in terminal area operations relates to efficient airspace utilization through reduced FTE. Although there are many factors to consider in evaluating FTE (e.g., ground navigation signal characteristics and navigational display characteristics), an improvement in the

performance of an individual pilot is enhanced through a reduction in workload in setting up the cockpit navigation task. Given more time, it was observed in the DDB test that the pilot concentrated more on the precision flying of the RNAV profile and was able to devote his attention to the higher priority task of controlling the aircraft and responding to navigation guidance rather than the mechanics of navigation input at critical points in the profile.

5.2 POSITIVE IDENTIFICATION OF WAYPOINTS

Perhaps the major disadvantage of the current RNAV concept is that there are no means of identifying RNAV waypoints in a positive, blunderproof manner. Conventional Navaids are identified by frequency selection, and further verified by an Audio Morse Code identifier, which verifies the frequency selected and substantiates the operational status of the navigation facilities. Utilizing RNAV involves selecting the appropriate VORTAC, then defining the Rho/Theta of the waypoint. As Section 5.1 shows, this technique is prone to many errors. Identifying and verifying that the aircraft is being flown to the proper waypoint is of the utmost importance. The DDB waypoint identification concept, in the process of defining either the individual waypoint or the waypoints within a route, utilizes a system that gives positive identification of the waypoint. In the Prototype Engineering Model, this consisted of both a discrete waypoint identification number, as well as a waypoint sequence number and virtually eliminated the problem often encountered in conventional RNAV of requiring the pilot to verify the aircraft position by the time-consuming method of checking Rho/Theta coordinates against the RNAV chart. The DDB technique of waypoint identification has the potential of being further enhanced by a direct readout of the waypoint name, rather than a waypoint identification number. This accommodation is discussed in Section 6.3. The positive identification of waypoint coordinates as implemented in the DDB concept has the potential of providing more effective orientation to the pilot, thus further reducing the workload involved in flying the transition routes in the terminal area.

5.3 AUTOMATIC ASSEMBLY OF WAYPOINTS COMPRISING RNAV SID AND STAR ROUTES

In conjunction with other features previously defined utilizing DDB, the ability to designate and verify a terminal route automatically is a significant benefit of DDB. The elimination of the workload in defining each waypoint comprising a SID/STAR route allows the pilot time to react with greater precision to route modifications that may be anticipated, as well as to eliminate errors that may occur in defining the waypoints in the wrong sequence with CDU-type RNAV systems. The process of route modification is simplified by a combination of the elimination of waypoints and direct-to input to the DDB system. This flexibility of the DDB system is provided by the waypoint storage, which will acquire additional waypoint information. The DDB Engineering Model has the ability to store six waypoints in the proper sequence.

When a waypoint is passed and the storage advances to the proceeding way point, the last register becomes free to acquire additional waypoints that might make up the individual SID/STAC route. The waypoints comprising the RNAV routes are assembled and transmitted in the sequence in which it is anticipated they will be flown. Most anticipated ATC route changes occur within the six-waypoint storage provisions, enabling the pilot to react to the ATC-initiated (or pilot-initiated) route modification. These flow changes are common and are initiated by ATC or the pilot for a number of valid reasons, including wind change, change of weather minimums requiring precision approach and, noise abatement, etc.

The benefits of the automatic assembly of the terminal navigation route and the storage expansion capability were documented in the flight logs on the DDB flight evaluation. The most dramatic benefits were shown with the six-waypoint storage during the traffic flow change experiment. In this experiment, the terminal flow was changed and the subject was required to enter and verify a new route comprised of eight waypoints. In each case, the pilots were able to properly execute this normally complex transition with a minimum workload effort by the utilization of the RNC six-waypoint method.

5.4 IMPACT OF DDB ON RNAV IMPROMPTU ROUTE DEFINITION

The ability of the DDB system to simplify the adaptation to impromptu traffic flow changes is also a significant operational benefit of the DDB concept. In addition to the previously listed advantages, which simplified the pilot workload and the data input and verification tasks, the DDB provides a significant advantage over multiwaypoint RNAV systems with CDU and FDSU capabilities as it relates to the task of reprogramming the RNAV unit to react to a traffic flow change. With a conventional multiwaypoint RNAV system, the pilot is presented the complex and time-consuming task of reprogramming a relatively sophisticated computer for the required series of new waypoints that now define the new RNAV transition. The considerations involved in defining the route, as discussed in the previous sections, are now amplified. The pilot is extremely time limited and the time to perform the navigation input task is condensed. The probability of reprogramming the conventional RNAV system without a major blunder error is considerably reduced. The DDB system makes this task extremely simple and virtually blunderproof, in that the only workload involved is in the selection of the designator for the new route, then proceeding to navigate the aircraft directly to the transition waypoint, after the route data has automatically been acquired by the DDB system. The potential benefits of increased efficiency and reduced airspace utilization are apparent in consideration of the various and different tasks that are to be performed in the limited time frame by the pilot.

5.5 SUMMARY

The DDB concept offers a potential solution to the main deficiencies that affect the successful implementation of RNAV in the National Airspace System. These deficiencies include the unacceptably high cockpit workload associated with non-DDB RNAV and the high probability of blunder and procedural errors that lead to airspace excursions and potentially unsafe flight conditions. The DDB concept provides significant benefits in two closely related areas: (1) DDB has the potential of reducing cockpit workload and providing the pilot the time necessary to concentrate on the task of aircraft control, navigation and ATC interface, and (2) the elimination of RNAV waypoint insertion and route definition errors having the potential of providing unsafe navigation guidance.

6.0 RECOMMENDATIONS FOR AN ADVANCED DIGITAL DATA BROADCAST SYSTEM DESIGN

This section outlines the methods of correcting discrepancies noted during the flight test of the DDB Engineering Model and provides recommendations for changes in any advanced hardware design. A conceptual model of a possible means of implementing these changes is presented and recommendations for additional flight test are outlined.

6.1 GENERAL REQUIREMENTS

6.1.1 The DDB system should be designed with safeguards to operate without being subject to interference from the aircraft navigation or communication systems or other electrical systems. The DDB system should not interfere with other aircraft radios or systems.

6.1.2 The DDB system should be designed with additional safeguards to prevent the display and/or utilization of invalid or incomplete waypoint or route information as documented in the DDB Operational Deficiencies Report (Reference 7).

6.1.3 (a) The DDB should be designed to retain the selected DDB waypoints once they have been acquired and validated. Once validated, they should not be subject to change from ground station inputs (as occurred in the Airborne Engineering Model hardware).

(b) If the traffic flow changes, the pilot should be able to retain the previous route until he selects the new flow, since ATC may require one user aircraft to complete the previous approach route pattern, while assigning the new flow and associative routing to the other succeeding aircraft.

(c) When a new flow and associative route are selected, the waypoint in the active register (from the previous route) should remain in use to provide a reference fix from which to base the transition to the new route.

6.1.4 The minimum waypoint storage capability should be six waypoints. Provisions should be made for the automatic acquisition of waypoint information, when the last register becomes free as the result of the sequencing of the active waypoint out of the display.

6.1.5 The route/waypoints of a broadcasted traffic flow should be acquired, validated and displayed for use within 30 seconds after the selected route/waypoint input. As a register becomes available as the result of sequencing the waypoint in use, the free register should redisplay any additional waypoint (validated) within 30 seconds.

6.1.6 Transmit the pull-up-fix as the last waypoint in the STAR to enable the pilot to proceed with the missed approach without the workload of entering and verifying an additional route or waypoint. The pull-up-fix is the missed approach waypoint and should not be confused with the missed approach point (see Figure 3-3).

6.2 SPECIFIC RECOMMENDATIONS

6.2.1 Provision should be made for an automatic or manual waypoint advance. If the automatic sequencing function is selected, the waypoint should sequence at the TO/FROM flag change.

6.2.2 The waypoint manual step sequence switch should be a separate switch from the auto/manual sequence mode select to avoid inadvertently leaving the selector in an undesired mode of operation through utilizing the step sequence function.

6.2.3 The VORTAC station identification display is considered optional, as the VOR frequency select and data acquisition provide the means to select and validate the station identification, respectively.

6.2.4 The size and lighting characteristics of the Engineering Model were not adequate for easy verification of waypoint information. It is recommended that a larger alphanumeric display that can be interpreted in high ambient lighting conditions be utilized in an advanced DDB Model. The lighting control should be variable from dim to bright, with a stop at both extremes to prevent the pilot from inadvertently passing through the brightest display to a dim condition, as existed on the Engineering Model.

6.2.5 Place the DDB/conventional RNAV select switch on the DDB CDU instead of modifying the KNC 610 RNAV control, as was done in the Engineering Model. The switch will either engage or disengage the DDB input to the RNAV system, and will allow the pilot to insert a conventionally defined waypoint into the route without interfering with the basic DDB information or DDB data acquisition.

6.2.6 Place an OFF/ON DDB data receiver switch on the DDB Control Data Unit (CDU). The OFF/ON switch will activate the DDB unit, and when the IU is receiving valid DDB data, a light at the base of the OFF/ON switch will be activated, showing that the DDB is in use.

6.2.7 Transpose the windows displaying the distance and bearing of the waypoint to show bearing and distance. This will aid in waypoint verification of the information as displayed on the CDU and in the same format as current RNAV charting convention of waypoint information.

6.3 FUTURE RNAV ROUTE DESIGNS AND WAYPOINT CODING PLANS

This section includes a reevaluation of the projected operational environment within which a production system may operate and based on ongoing terminal area design analyses conducted by CTI and recent changes in the FAA concept of waypoint coding. The evolution of these concepts has major impact on the performance characteristics of future DDB systems.

6.3.1 Future Terminal Area Route Designs

Based on a yet unpublished report by CTI entitled "Terminal Area Design - Analysis and Validation of RNAV Task Force Concepts," future RNAV terminal area designs will be of the traffic-oriented route design, typically composed of six basic waypoints that define a standard terminal area arrival route (STAR). An example of this is Figure 6-1, which shows a standard terminal area design. This basic model will be modified, as required, to conform with individual terminal area normal operating procedures and requirements dictated by airport design-terrain and surrounding airports. An example of the implementation of the RNAV STAR is shown in Figure 6-2, the Miami Pike arrival from the northeast quadrant. This STAR incorporates two transitions to land on either the runway oriented to the east (runway 9) or the west (runway 27). The Club transition defines the waypoint that makes up the east flow and the Fisher transition defines the waypoints that make up the west flow. Path-stretching capabilities, which are built into the Club transition, would allow the controller to stretch or shorten the aircraft's path on this RNAV STAR. (Example, a command to proceed from Club waypoint direct to Portland would be an implementation of the trombone maneuver, shortening the aircraft's arrival route for traffic spacing purposes.) In addition to the trombone, ATC can utilize other spacing maneuvers (e.g., direct-to commands, offsets and delay fans) to provide operational flexibility. The off-track maneuvers (delay fan and offset) are cared for procedurally, based on the parent route. Note that the route is identified by the low-altitude arrival (or departure) waypoint. The waypoints that follow comprise the RNAV STAR. The transitions are normally defined by the base-leg turn point. In this example, Club waypoint is the most commonly used base-leg turn point for the transition to runway 9. Frog waypoint is utilized for path stretching. In a similar manner, Fisher waypoint defines the west transition.

Owing to the expected implementation of this concept, as well as for operational considerations previously discussed, it is recommended that any advanced DDB System Model utilize, as its primary means of identifying and designating an RNAV terminal route, the route-oriented (RNC) system of SID/STAR identification.

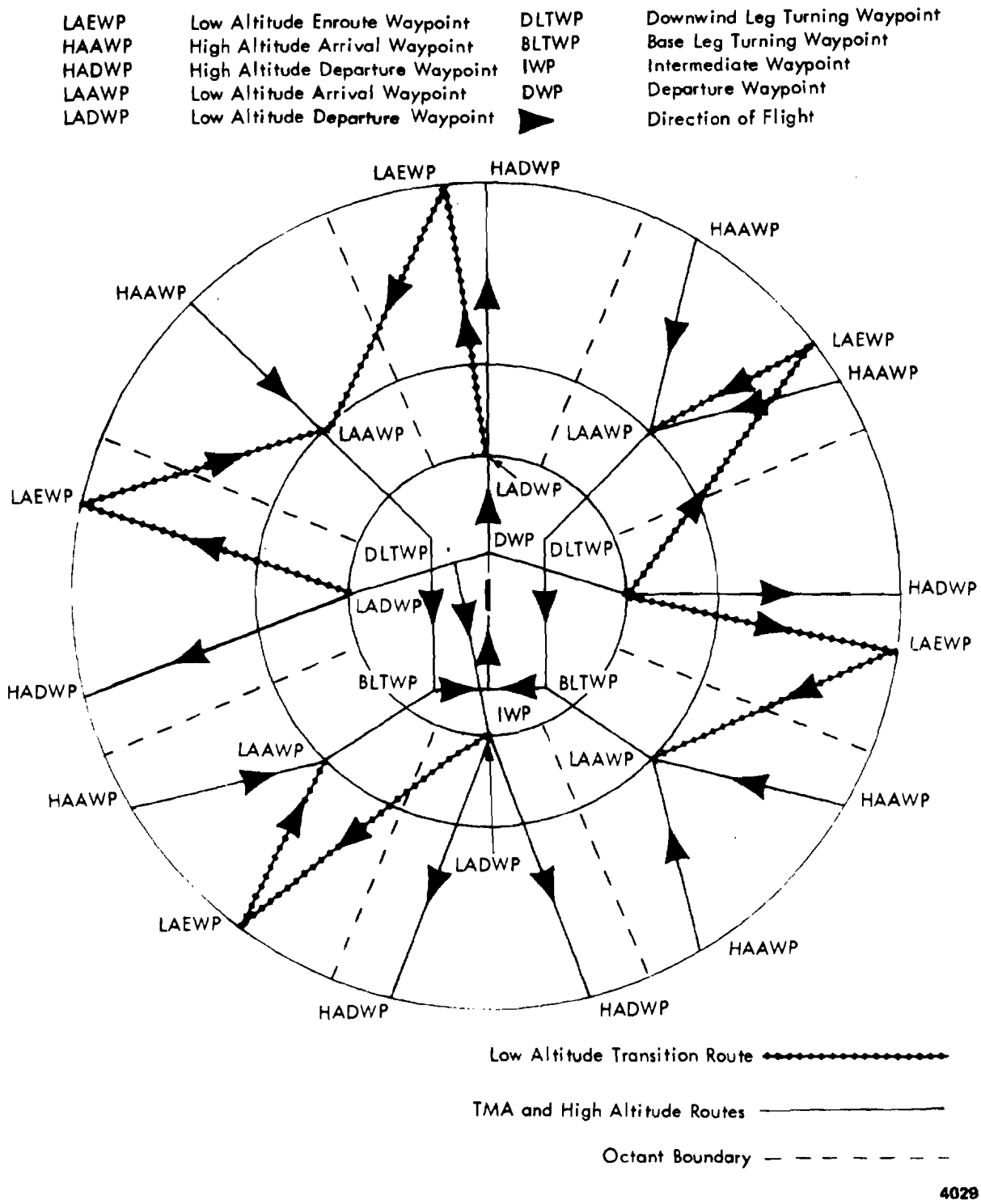


FIGURE 6-1. STANDARD TERMINAL AREA DESIGN

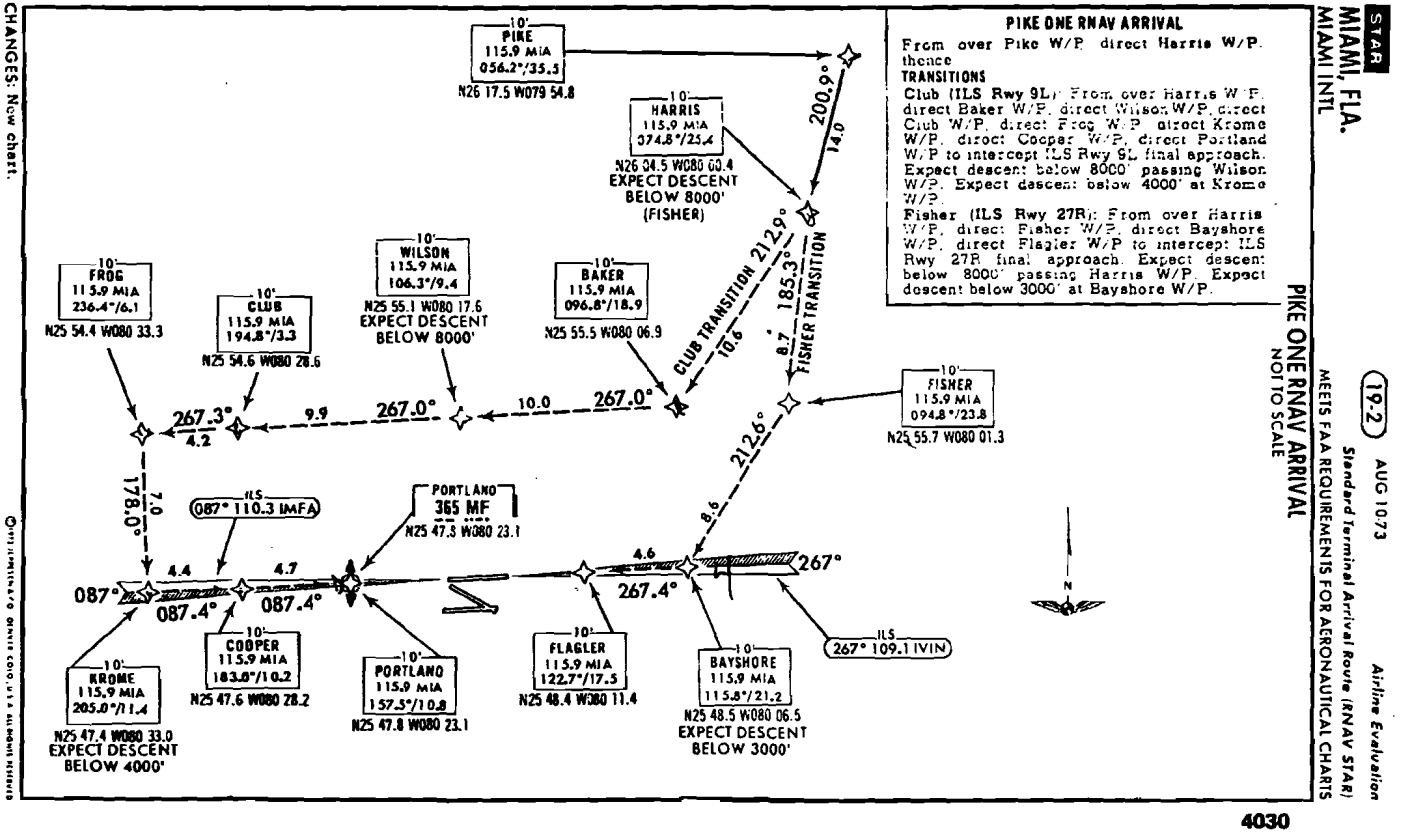


FIGURE 6-2. MIAMI PIKE ONE RNAV ARRIVAL

6.3.2 Future FAA Route Coding System

The FAA is in the process of implementing an Air Traffic Operational Coding System, which replaces the requirement for multiple code systems for various location names with a five-alpha code. This provides one code for use with ground and airborne computers and for voice communications. This system is presently incorporated into the current RNAV high-altitude charts designed for enroute use and is being implemented on RNAV Instrument Approach Plate (IAP). An example appears in Figure 6-3. The procedure is documented in FAA Order 7350.2B. All existing two-alpha, two-number and one-alpha codes (example: M024C) will be replaced with a five-letter pronounceable name. This code serves as the computer code, the assigned identifier and the waypoint name. This five-letter code of all intersections, DME fixes, waypoints, route turning points, boundary crossing points, and ATC coordination fixes will be updated gradually to coincide with normal revision procedures and publication revision dates.

The primary impact of the implementation of this concept of waypoint naming is the tremendous savings in air/ground computer systems by significantly reducing the number of information elements that must be stored. Additionally, there is the considerable cost savings in charting and revision requirements, as it will not be necessary to produce redundant charts overlayed with a waypoint identification code compatible with a specialized navigation system.

6.4 RECOMMENDATIONS

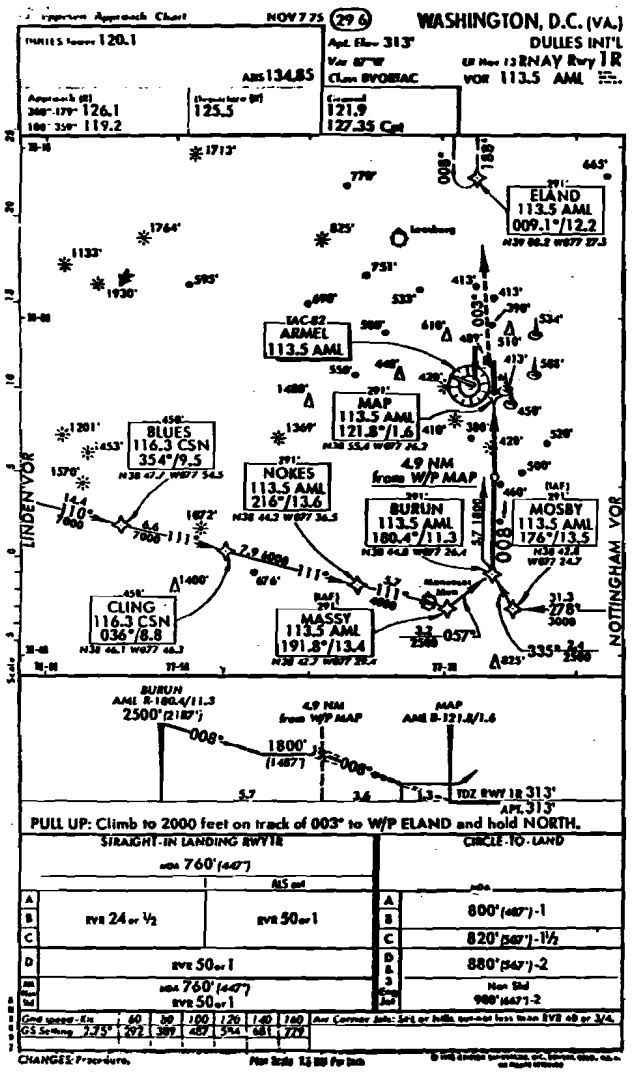
It is recommended that the DDB waypoint designation technique be changed from a numeric waypoint designation with a waypoint sequence number (3 numerics) to a 5-alpha waypoint designator. As the coding requirement for the route/waypoint data will be reorganized in a future model, this additional capability is worthy of consideration for the following reasons:

a. RNAV Equipment Data Entry Compatibility

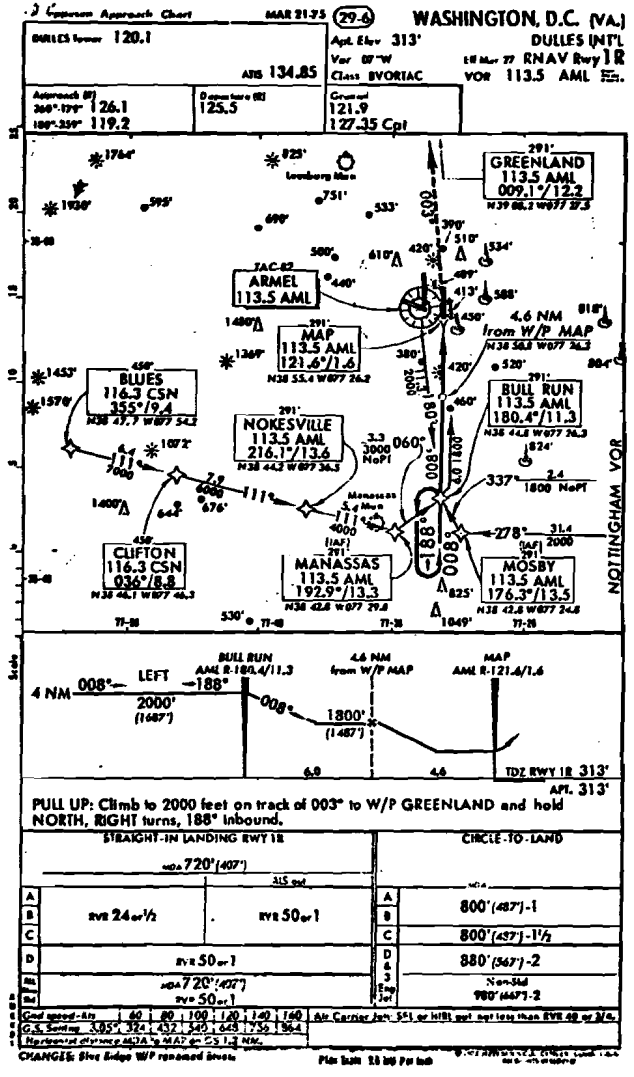
The 5-alpha code fits the ARINC CDUs, since 5 alpha is the scheme upon which the CDUs were designed. Future DDB units may be interfaced with ARINC equipment specifications, which would reduce equipment compatibility problems. The VORTAC would function essentially as a ground-based FDSU.

b. Data Verification

With the concept of pronounceable 5 alpha, the verification of spoken clearance with a chart should be operationally compatible and significantly less blunder prone than current designation techniques.



Present 5 Alpha Concept Under Implementation



Previous Conventional Waypoint Designation

4031

FIGURE 6-3. ROUTE CODING

c. Chart Simplicity and Correlation

The 5 alpha would provide for CDU, chart, and voice compatibility and would present no problems concerning chart clutter or legibility.

d. Voice Communication and Phonetic Discrimination

The 5 alpha may present some problems in the area of voice communications, particularly to someone unfamiliar with a given terminal area. The 5 alpha could create names which are meaningless in a geographic or procedural sense. The advantages of 5 alpha, which far outweigh the disadvantages, are carefully designed to bypass this potential problem area.

e. Minimum Characters of Data Entry

Utilizing the RNC method of route designation, the 5-alpha system requires no additional alphanumeric keyboard.

f. Compatible with Clearance Amendments

Implemented in an operationally meaningful manner on a DDB CDU, the system would be compatible with foreseeable clearance amendments.

Due to the ongoing implementation of the 5-alpha concept, and the waypoint designation by the FAA, and the potential benefits outlined above, it is recommended that serious consideration be given to changing the DDB waypoint identification techniques from a 3-numeric to a 5-alpha identifier.

In addition to the previously recommended change, it is recommended that the route select technique be redesigned to a simpler, less blunder-prone identifier consisting of an arrival/departure single-alpha select (A-D); a route select identifier, which would key on the low-altitude arrival or departure (RNAV SID/STAR) sector number clockwise, beginning at the northern-most sector; and the transition route for final approach select, which would be a single-numeric select. This display would provide the information required by the computer to identify, code and display a selected RNAV SID or STAR. An example follows and is based on the STAR developed for flight test at NAFEC:

Victor arrival, Hotel transition = A27NE

A = arrival 27 = from the west NE = landing Rwy 4

The new technique would not have the potential advantage of geographic orientation inherent in the previous identifier; however, it would be shorter and less blunder prone. On data entry, the pilot would identify the route code adjacent to the appropriate SID/STAR designation in the RNAV chart.

Victor arrival, Hotel transition = A32

A = arrival 3 = third STAR clockwise from the north 2 = second instrumented runway clockwise from north (could also be used to designate parallel runway or transitions to satellite airports).

6.5 CANDIDATE DESIGN

This section presents a conceptual model (Figure 6-4) of a possible advanced DDB interface unit design, which incorporates the recommendations from Sections 6.1 and 6.3. The functions and route select and data display techniques can be rearranged as necessary and more efficient lighting and switching systems may be utilized.

Item 1: OFF/ON and DDB IN USE DISPLAY - pushbutton-type switch with a light at the base that illuminates on receiving valid DDB signal.

Item 2: MANUAL/AUTO SEQUENCING FUNCTION - pushbutton or toggle switch, which selects automatic or manual sequencing of waypoint.

Item 3: DDB/RNAV Select - toggle switch or pushbutton that activates or deactivates DDB function from RNAV system.

Item 4: WAYPOINT IN USE Display - displays waypoint name and Rho/Theta.

Item 5: WAYPOINT SEQUENCE Select - allows the operator to transfer waypoint information from memory to the active waypoint register by pushing the sequence select button. Waypoint information from register 3 moves into register 2 in memory and the free register (register 6) will acquire any additional broadcast waypoints in sequential order.

Item 6: WAYPOINT STORAGE Display - indicates the 5-alpha identifier of the five waypoints in storage memory.

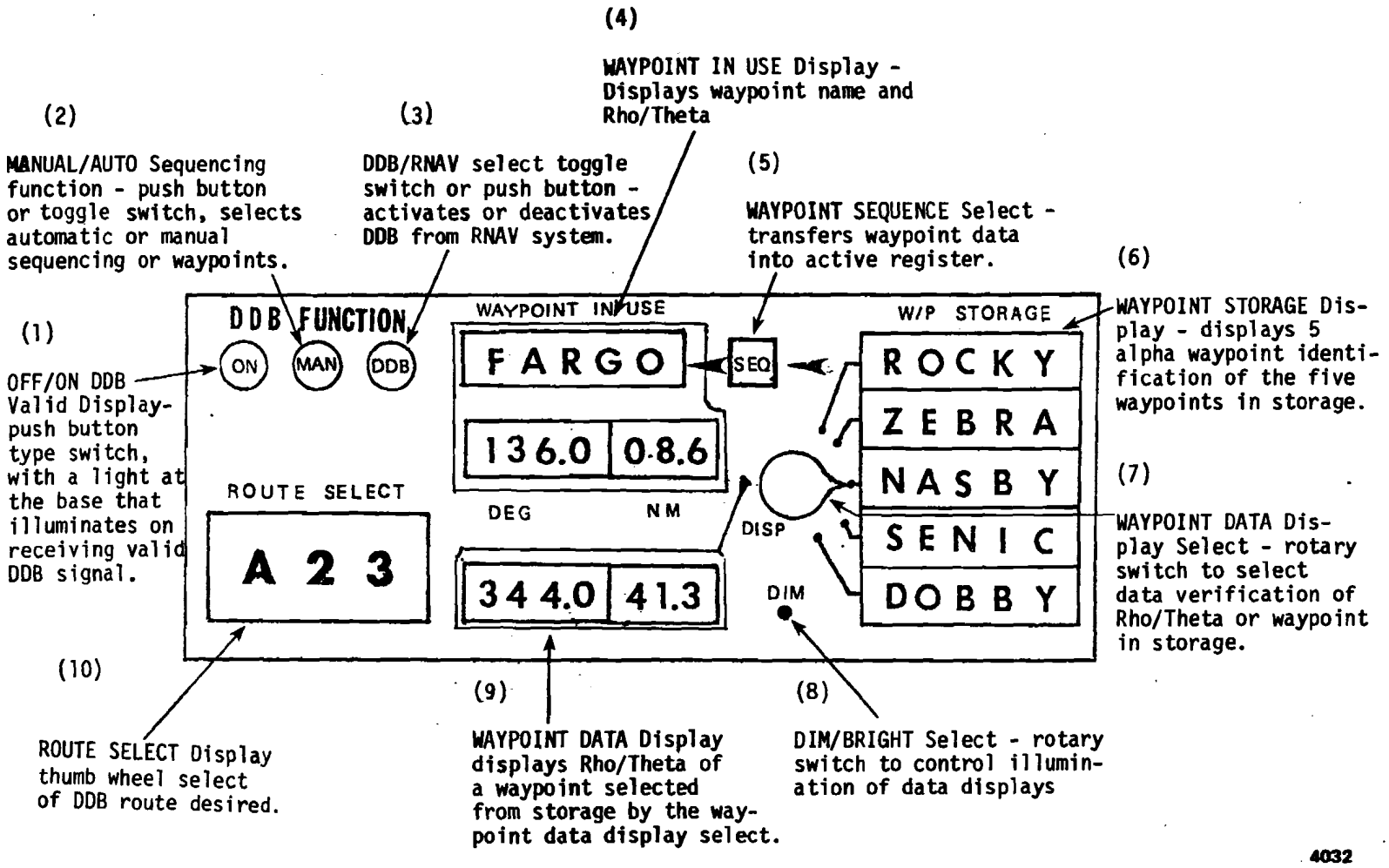


FIGURE 6-4. CONCEPTUAL MODEL OF A POSSIBLE SECOND GENERATION DDB INTERFACE UNIT DESIGN

Item 7: WAYPOINT DATA Display Select - rotary switch to select data verification of Rho/Theta of waypoints in storage (Item 6).

Item 8: DIM/BRIGHT Select - rotary switch to control illumination of data displays.

Item 9: WAYPOINT DATA Display - indicates the Rho/Theta of a waypoint selected from storage by the waypoint data display select (Item 7).

Item 10: ROUTE SELECT/Display - thumbwheel select of DDB route designator.

6.6 ADDITIONAL FLIGHT TESTS

The DDB Engineering Model accomplished its primary goals, which were to demonstrate the feasibility of the DDB concept, and to isolate areas requiring further development, as well as equipment design limitations. Recommendations for a candidate design of an advanced airborne DDB System Model based on the performance of the flight-tested DDB Engineering Model have been previously discussed (Section 6.5). The next logical step in the current DDB development effort is the implementation of the required modifications, followed by additional flight tests of the new redesigned DDB interface unit. Although the evolution of a detailed feasibility flight-test plan applicable to the advanced DDB unit is not part of this task, it is deemed that an approach to this effort would be the consideration of the flight-test topics and their rationale as contained in Sections 6.7, 6.8 and 6.9.

6.7 TEST OBJECTIVES

a. Perform a DDB flight-test program (40 hours) under actual operational conditions and in a high-density terminal area location such as Miami, Denver, Chicago, etc. This would permit a realistic evaluation of the DDB concept under a set of operationally oriented flight-test conditions. The previous DDB tests performed at NAFEC included simulation of traffic congestion, but this could not be compared to the actual operational traffic environment of a high-density terminal area.

b. Quantify the impact of DDB and its potential reduction of such elements of airspace design as FTE and TSCT in a realistic operational environment and compare these results to non-DDB (conventional RNAV) flight tests to be performed in the same terminal area, by the same pilots and using the same VORTAC.

c. Evaluate the functional and technical performance of the advanced DDB unit, including previously required modifications to the original DDB Engineering Model and incorporation of new features (e.g., the 5-alpha waypoint designation).

d. Confirm the reduction of pilot blunders and cockpit workload by the utilization of the DDB concept under actual operational conditions in a high-density terminal area.

6.8 TECHNICAL CONSIDERATIONS

The requirements for the previously specified modifications of X-mode pulse spacing, 5-alpha waypoint designators, and correction of interference problems should be examined in greater detail. The pulse spacing should be verified by testing to assure compliance with the constraints of the DME/TACAN requirements. The size of the word, as proposed in the specification for incorporation of 5-alpha waypoint designators, should be verified to assure the probability of detection conforms to the required data reception cycle time. The compatibility of all components of the DDB system should be verified by means of bench and flight testings. The proposed DDB flight tests in a high-density terminal area might present problems in the maintenance and operation of the ground station during installation of DDB equipment and conduct of flight test. A means to minimize this impact would be to install an additional DME transmitter to transmit the DDB data on a test frequency and thereby not interfere with the electrical or physical operation of the ground station. The required hardware and technology to implement this configuration are readily available.

6.9 DATA ACQUISITION/REDUCTION

The test aircraft would be instrumented, similar to the configuration utilized in the previous DDB tests, to record the required data parameters. In lieu of the E-AIR tracking radar, which was used to determine the actual aircraft position in the previous DDB tests, the ARTS III tracking radar could be utilized in the proposed flight-tests to accomplish the same objective. The use of the ARTS III tracking radar, under flight-test conditions, has been satisfactorily demonstrated by CTI in previous FAA flight-test programs at such locations as Miami and Denver. The required software (computer programs) to retrieve the desired data from the ARTS III tracking radar and the subsequent merger with time-correlated airborne data (FTE, TSCT), including calculation of statistical data, is available (CTI). One advantage of the ARTS III radar is its continuous availability, as opposed to the limited-time availability of the E-AIR tracking radar at NAFEC.

7.0 CONCLUSIONS

These conclusions are based on a comprehensive qualitative analysis of the performance and operational characteristics and the basic technical design feasibility of a flight-tested DDB Engineering Model equipment. They include an operational evaluation, based on the available data, of the DDB concept in the terminal area. The following summaries represent the major conclusions from the results of the DDB flight-test program:

- DDB Reduces Pilot Blunder

  The results of the DDB Flight-Test program indicate a positive reduction in pilot blunders by the utilization of the DDB in the RNAV environment. In the 26 data flights flown by the three subject pilots, only four blunders were recorded. This is approximately 13% of the 32 blunders recorded in the General Aviation RNAV Flight Test (Reference 2), which did not use DDB.

- DDB Reduces Cockpit Workload

  The operational utilization of the DDB concept permits its user to devote more time to cockpit management duties, since it reduces the required RNAV navigation input times and thereby the cockpit workload. Consequently, blunder potential is greatly reduced by making planning tasks of the navigation tasks by reducing the number of required inputs by the automatic acquisition of entire RNAV SIDs and STARs.

- The Preferred Waypoint Designation Technique Is The Route Number Concept (RNC)

  The RNC method enabled the pilot to select entire RNAV SID or STAR routes by a single data entry. This method decreased considerably the pilot's workload, since the requirement for individual waypoint data entry is eliminated.

- DDB Offers Significant Operational Advantages, Particularly During Traffic Flow Changeovers

  The DDB system enables its user to simplify the adaptation to impromptu (ATC) traffic route changes, particularly in the often encountered situation of a change in active runway. The DDB system makes this task extremely simple and virtually blunderproof, as the only workload required is

the selection of the designator for the new route, then proceeding to navigate the aircraft directly to the transition waypoint, after the route data has automatically been acquired by the DDB system.

- The Maximum (Allowable) Digital Broadcast Data Flow Cycle Time Is 30 Seconds

  The 30-second digital broadcast data flow cycle time was determined to be an acceptable (maximum allowable) value for the intended use of DDB in the RNAV terminal environment.

- Manual Waypoint Sequencing Is Preferred to that of Automatic Waypoint Sequencing

  Based on its flexibility of use in the RNAV terminal area environment, the manual sequencing of waypoints was considered superior from the standpoint of operational utilization. The automatic sequencing of waypoints was limited to RNAV operations up to 0.8 nautical mile (DTW) of the active (in use) waypoint. This presented some operational problems (i.e., the elimination of the Missed Approach Point (MAP)), when the DTW is less than 0.8 nautical mile.

- The Minimum DDB Waypoint Storage Capacity Should Be Six Waypoints

  The six-waypoint storage DDB system would be most advantageous to its user, since, in the terminal area, most arrivals are comprised of a near equal number of waypoints. The pilot, upon entering the terminal area, would have a definite advantage of having most, if not all the desired route to be flown already selected and validated on the DDB display.

- VNAV Does Not Impose too High a Workload on the RNAV/DDB User

  The subject pilots were observed, in the majority of the cases, to handle rather easily the increase in workload level imposed by the addition of the VNAV function. This is substantiated by the fact that no VNAV errors were documented during the DDB tests.

- Operational Evaluation of the DDB Concept

The DDB concept offers a potential solution to the main deficiencies that affect the successful implementation of RNAV in the national navigation system. These deficiencies include the unacceptably high cockpit workload associated with non-DDB RNAV and the high probability of blunder and procedural errors that lead to airspace excursions and potentially unsafe flight conditions. The DDB concept provides significant benefits in two closely related areas: (1) DDB has the potential of reducing cockpit workload and of providing the pilot the time necessary to concentrate on the task of aircraft control, navigation and ATC interface task; and (2) elimination of RNAV waypoint definition errors that have the potential of providing unsafe navigation guidance.

- Deficiencies and Recommendations

The DDB concept was satisfactorily proved by the utilization of the DDB Engineering Model Hardware. The DDB Engineering Model served its purpose, which was to identify areas requiring further development, as well as equipment design limitations, which are covered in detail in the text of this report and the deficiencies report. The overall analysis of the deficiencies indicates a majority of the problems are directly related to the fact that the DDB hardware and software were engineering models. The major problems were X-mode DDB pulse spacing, waypoint identification, and susceptibility to aircraft interference. These are areas that should be considered for improvement in the development of any future DDB equipment.

8.0 REFERENCES

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2. R.J. Adams, "Preliminary RNAV Avionics Standards (2D and 3D Area Navigation Systems)," Interim Report No. FAA-RD-75-178, Champlain Technology Industries, July 1974 (Published November 1975)

3. "Federal Aviation Administration Specification Changes for the Digital Data Broadcast System," February 1976

4. "TACAN/DME Digital Data Broadcast Design Plan," Report No. FAA-RD-74-161, Volumes 1, 2, 3, 4 and 5, EDMAC Associates Inc., East Rochester, New York, September 1974

5. "DDB Installation Checkout Test Plan and Test Procedures," Sierra Research Corp., July 1975

6. "Instruction Manual for Digital Data Broadcast Airborne Decoder/ Interface Equipment," EDMAC Associates Inc., East Rochester, New York, November 1974

7. "Digital Data Broadcast System Deficiencies," Report No. TR-1350, Sierra Research Corp., March 1976

8. "Air Traffic Control Service for Area Navigation Equipped Aircraft Operating in the United States National Airspace System," FAA Handbook 7110.18, 27 February 1970

9. "VOR/VORTAC Siting Criteria Handbook," FAA Handbook 6700.11, December 1968

10. "Air Traffic Operational Coding System," FAA Order No. 7350.2B

APPENDIX A

DDBS TEST CONSIDERATIONS

A.1 GENERAL

A.1.1 Ground Installation

The installation at NAFEC of the DDBS TACAN ground equipment modification kits to realize the DDB capability was performed by FAA personnel. However, the GFP software to program the ground equipment Programmable Read Only Memories (PROMs) with the particular NAFEC test routes required modification by SRC to eliminate inherent program errors. With the program corrected, the PROMs were then discovered to have faulty memory locations. Consequently, the vendor for the PROMs was contacted and SRC was informed that these PROMs were no longer in production. A method was then developed, in consultation with the technical officer, to bypass the faulty memory location. After the data broadcast waypoint information had been loaded into memory, the DDB-modified TACAN ground station was calibrated in accordance with the FAA-approved Installation Checkout Test Plan and Test Procedures (Reference 5).

A.1.2 Aircraft Installation

In a parallel effort with the ground equipment installation, the airborne equipment was installed in the test aircraft and preliminary flights were flown at West Palm Beach, Florida and Buffalo, New York to assure proper operation of the basic RNAV system without DDB. The test aircraft was then flown to NAFEC to commence the checkout of the combined DDB ground-to-air broadcast link.

A.1.3 Test System Operation

Initial testing of the ground/airborne DDB equipment at NAFEC and subsequent evaluation of the airborne decoder unit at Buffalo, New York, revealed that the DDBS Engineering Model, as configured, was unable to operate on the X-mode DDB pulse spacings with sufficient reliability to perform any flight testing. Consultations with the Technical Officer and NAFEC Program Area Manager resulted in the development and utilization of a modified mode of DDBS operation during the Flight Test. This special mode permitted collection of operational data without delaying the program,while the basic DDB X-mode anomaly was resolved. The method that was devised involved operating the equipment with X-mode frequency assignments, while using the pulse coding of the Y mode (for the digital portion,including interrogation/decoding the DDBS coding/decoding). The airborne equipment

required reconfiguration and the ground equipment required adjustment. This method enabled the airborne DDB to acquire the data being transmitted by the ground station.

A.1.4 Functional Deficiencies

The airborne DDB was reinstalled in the aircraft and shakedown flight tests showed intermittent operation of the DDB in regard to its ability to hold waypoints, once they were acquired, and the ability of the airborne DDB to drive the RNAV computer. These were hardware deficiencies that do not reflect on the utility of the DDBS concept. The problems were traced to two basic causes. The first one was that the interface lines were susceptible to noise introduced in the aircraft environment and the second involved integrated circuits and/or interconnections in the experimental model airborne DDB, which were intermittent. Corrective action was taken to achieve a temporary solution to enable the pursuit of the primary task goals. The decision to concentrate on the primary task objectives of the flight tests was the only feasible approach, in view of budgetary and time constraints.

A.2 DETAIL PREPARATION FOR FLIGHT TEST

To permit the achievement of the flight-test objectives, certain corrective actions were taken to make the DDB system operational.

A.2.1 DDB Fortran Program Errors

The DDB system utilizes a Fortran Program to convert the Flight Test Station and waypoint parameters to formatted data bits required for programming into the Ground Equipment memory storage devices.

A.2.1.1 Description of Software Problems

The Fortran Program that was furnished as GFE under task IA contained two types of errors. The first type of error would not let the program execute properly and the second type was such that a properly executed program would not present a set of data as expected by the DDBS hardware.

Type 1 error - Loading Program

	PROGRAM CARD ID NO.	CHANGE
a.	EDMCO 335	Index I should be BI for desired operation to run
b.	EDMCO 338	Incorrect card placed here in original deck
c.	EDMCO 388	Missing comma in Read statement

Type 2 error - Operating

The first problem of this type was of the following nature. In the lower section of the ROM, a memory pointer is stored, containing the starting and ending addresses of each flow stored. The format of this output data, as produced by the loading program, disagreed with the format expected by the ground equipment Data Encoder as described by its schematics. The second problem involved the address used for the special IAF, FAF, and MAP data points. With the other data in the ROM, a different address was used for Waypoint and Route Sequence Numbers, Range and Bearing. However, in the initial program, the same address was used for all three types of data for these special points. The third problem was that the flow selection switch on the front panel of the ground station equipment selected the wrong flow, because the memory pointers were not stored in the proper locations in the ROM.

A.2.1.2 Solution of Software Problems

The problems were corrected by incorporation of the following changes:

a. Memory pointer format error

CARD ID NO.	CHANGE
EDMCO 442	Replace "13" with "I + 7"
EDMCO 443	Replace "OUTPT (I)" with "OUTPT (I + 19)"

b. Address of IAF, FAF, MAP data words

CARD ID NO.	CHANGE
EDMCO 334	Replace upper limit of Do loop with "32"
After EDMCO 335	Add following:

```
      L = 1
      DO 308 I = 28, 31
      OUTPT (I) = P STFX (7, L)
  308 L = L + 1
```

CARD ID NO.	CHANGE
EDMCO 348	Replace upper limit of Do loop with "32"
After EDMCO 349	Add following:
	L = 1
	DO 310 I = 28, 31
	OUTPT (I) = P STFX (8, L)
310	L = L + 1

c. Memory pointer (flow)

CARD ID NO.	CHANGE
EDMCO 435	Replace "O" with "1"

Following the incorporation of these corrections, the modified Fortran Program was used to generate the formatted digital data bit patterns for the traffic flows specified in the DDBS Technical and Operational Test Plan and Test Procedures (Reference 1).

A.2.2 GFE ROM Faulty Memory Locations

The DDBS ground equipment utilizes one ROM PC card to store the waypoint flows to be transmitted to the airborne unit. Three ROM cards were supplied as GFE (labelled A, B, and C) but the equipment is designed to use only one ROM card at a time. The flight test uses three flows (Northeast, Northwest and Southeast) but only two flows will fit in a single card. As a result, the Northeast and Northwest were stored in one memory card and the Southeast and Northwest were stored in a second card.

The difficulty occurred because none of the three ROM cards were fully operational. All have at least one memory address where one data word (32 bits) cannot be stored or read (see figure A-1). The Northwest and Northeast flows were programmed into the "C" card. Address 207 was avoided by entering an undecodable word code in that memory location and shifting the remaining data up one address in memory.

The memory card "B" has the upper quarter of memory unusable and without reprogramming the entire card to take advantage of every available corner of memory, both the Southeast and the Northwest flows would not fit. It should be noted for any future use that reprogramming is possible but

	Memory Card A	Memory Card B	Memory Card C
Programmed Start/Stop Flow Address	South east 21 - 147 North west 2ØØ - 327	South east 21 - 150 North west 2ØØ - 327	North west 21 - 150 North east 2ØØ - 324
Unusable addresses due to ROM malfunction 1) verified 2) believed bad	 1Ø, 21-37, 54 11-2Ø	 132, 3ØØ - 327 327 - 377	 2Ø7 none
Effect of Faulty Addresses	$1Ø_8$ = pointer word for north west flow therefore this flow can not be selected from this ROM. As a result the north west flow has not been checked out. (21 - 37, 54) These addresses are in the middle of the south east flow and as a result the data in these addresses must be moved up in memory, entering an unused decode in the word code (sec. fig. 3).	(132) all zero's have been programmed into this address word code, thus it becomes an unused decode to the air-borne equipment. The data from this location and above in memory have been moved up one address (300 - 327) As a result the northwest flow as defined for this test becomes unusable	(207) same as address 132 from B card
Test Operational Flows	None	South east	North west and North east
Future Status	Unusable NW Flow	Usable any flow (faulty addresses bypassed)	Usable Any Flow (faulty address bypassed)

NOTE: Memory Addresses identified in octal code.

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FIGURE A-1. MEMORY STATUS CARD

offers no guarantee of success, since the new locations to be used have not been checked and some could have faulty addresses.

The Northwest pointer word in memory card "A" is unusable and, as a result, this flow cannot be selected from this card. In addition, numerous bad addresses were found in the Southeast flow. Because of the large number of problems with this card and the knowledge that the "B" and "C" cards would supply all the data needed, attempts to make this card operational were dropped.

In the final test configuration, the "C" card supplied the cluster data for the Northeast and Northwest flows, while substituting the "B" card provides the Southeast flow. Figure A-2 shows the word format used in memory, while figure A-3 describes the bit codes used to represent the alpha character and the word codes. The memory layout is shown in figure A-4.

A.2.3 Installation/Checkout of Airborne Equipment

The airborne equipment was installed in the test aircraft at West Palm Beach, Florida. The equipment was checked out at West Palm Beach and a problem with the DME was detected. The airborne decoder equipment was brought to Buffalo for repair and modification.

A.2.3.1 Sequencing Adjustment

The GFE Model 9040 Airborne Decoder was designed, in the automatic mode, to sequence waypoints, when the distance to waypoint output of the RNAV computer dropped below 2.5 nmi (nautical miles indicated). Coordination meetings to plan the flight tests revealed that this fixed 2.5 nmi setting was not the preferred setting for the flight tests. A simple change, which consisted of adding a variable resistor in parallel with a fixed resistor such that the sequencing level of the unit could be adjusted from 2.5 nmi to 0.5 nmi, was incorporated into the airborne decoder. It was determined at NAFEC that 0.8 nmi was the optimum level to conduct the tests. At the same time the problem in the DME was corrected, the DME was calibrated and performance-tested according to specification requirements of the manufacturer's manual.

A.2.4 Checkout and Calibration of DDB-Modified TACAN

The GFP DDBS ground modification to the number 2 equipment located at NAFEC experimental VORTAC test site in building 196 was installed prior to the initiation of the subject contract. The parent VORTAC was operating on channel 27X, using a LO-BAND X-channel antenna.

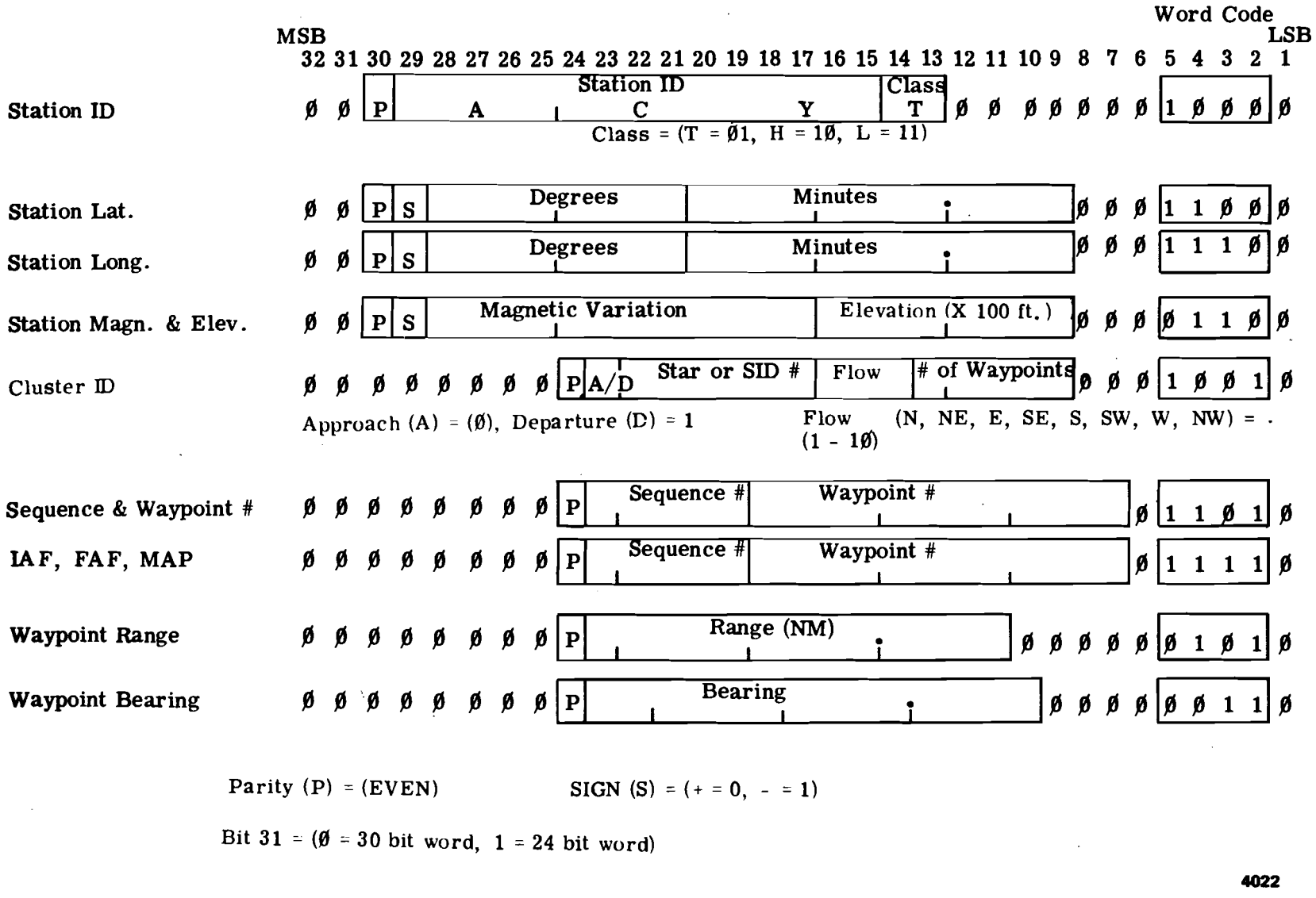


FIGURE A-2. TEST WORD FORMAT FOR DDB ROM MEMORY

	GROUND			AIRBORNE		
Type Word	Hex	ROM Word Code	Converted Word Code	Hex	Status
	Ø	Ø Ø Ø Ø	1 Ø Ø Ø	8	unused decode
	1	Ø Ø Ø 1	Ø Ø Ø Ø	Ø	unused decode
	2	Ø Ø 1 Ø	1 1 Ø Ø	1 2	unused decode
Waypoint Bearing	3	Ø Ø 1 1	Ø 1 Ø Ø	4	Waypoint Bearing
	4	Ø 1 Ø Ø	1 Ø 1 Ø	1 0	Unused decode
Waypoint Range	5	Ø 1 Ø 1	Ø Ø 1 Ø	2	Waypoint Range
Station Magn. & Elev	6	Ø 1 1 Ø	1 1 1 Ø	1 4	Station Magn. & Elev.
	7	Ø 1 1 1	Ø 1 1 Ø	6	Unused Decode
Station ID	8	1 Ø Ø Ø	1 Ø Ø 1	9	Station ID
Cluster ID	9	1 Ø Ø 1	Ø Ø Ø 1	1	Cluster ID
	10	1 0 1 0	1 1 Ø 1	1 3	Unused decode
	11	1 0 1 1	Ø 1 Ø 1	5	Unused decode
Station Lat.	12	1 1 0 0	1 0 1 1	1 1	Station Lat.
Sig. & Waypoint #	13	1 1 0 1	Ø Ø 1 1	3	Seq. & Waypoint #
Station Long.	14	1 1 1 0	1 1 1 1	1 5	Station Long.
IAF, FAF, MAP	15	1 1 1 1	0 1 1 1	7	IAF, FAF, MAP

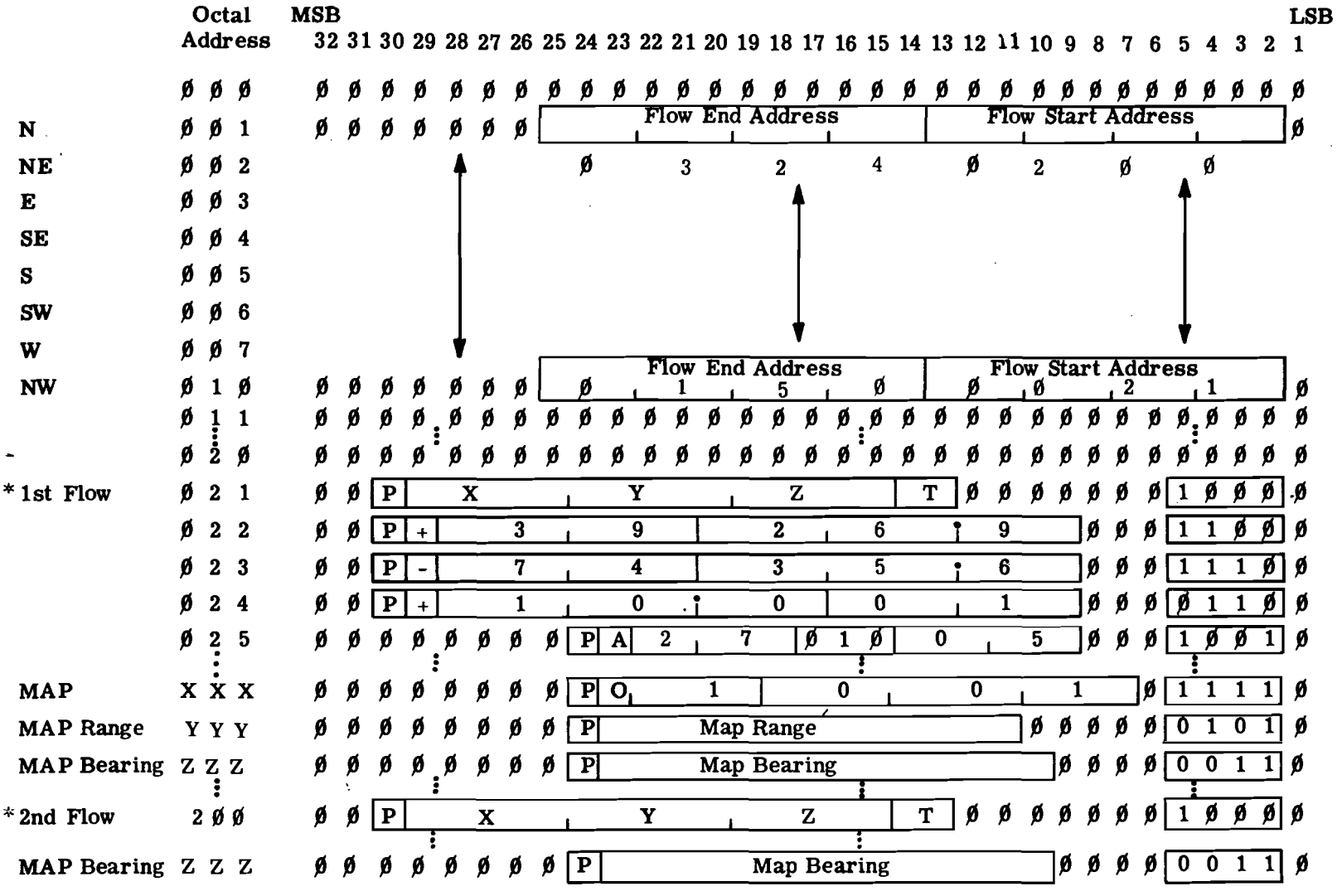
ALPHA CONVERSION

		Hex				
A	(1)	01	Ø Ø Ø Ø 1	N	16	Ø 1 1 1 Ø
B	(2)	02	Ø Ø Ø 1 Ø	O	17	0 1 1 1 1
C	(3)	03	Ø Ø Ø 1 1	P	20	1 Ø Ø Ø Ø
D	(4)	04	Ø Ø 1 Ø Ø	Q	21	1 Ø Ø Ø 1
E	(5)	05	Ø Ø 1 Ø 1	R	22	1 Ø Ø 1 Ø
F	(6)	06	Ø Ø 1 1 Ø	S	23	1 Ø Ø 1 1
G	(7)	07	Ø Ø 1 1 1	T	24	1 Ø 1 Ø Ø
H	(8)	10	Ø 1 Ø Ø Ø	U	25	1 Ø 1 Ø 1
I	(9)	11	Ø 1 Ø Ø 1	V	26	1 Ø 1 1 Ø
J		12	Ø 1 Ø 1 Ø	W	27	1 Ø 1 1 1
K		13	Ø 1 Ø 1 1	X	30	1 1 Ø Ø Ø
L		14	Ø 1 1 Ø Ø	Y	31	1 1 Ø Ø 1
M		15	Ø 1 1 Ø 1	Z	32	1 1 Ø 1 Ø

NOTE: All numerics in BCD code

4021

FIGURE A-3. DDBS WORD + ALPHA/NUMERIC CODE FORMATS



NOTE: Exemplary flow start/stop addresses relate to memory test card C.
* 1st flow is NW; 2nd flow is NE

4026

FIGURE A-4. LOWER SECTION OF DDB GROUND STATION MEMORY

A.2.4.1 Calibration of Modified TACAN

Prior to the initiation of the DDB technical and operational test and evaluation, the checkout and calibration of the DDBS-modified TACAN was performed. The RTC-2/RTB-2 equipment certification performance checks in FAA Handbook S.M.P. 6780.3 and the GFP instruction manuals were performed in accordance with the DDBS Installation Checkout Test Plan and Test Procedures. The equipment was calibrated to meet the performance requirements of these documents. The required GFE maintenance and repair required during this phase and which were not part of the DDBS modification were reported on maintenance logs as required by the contract. The ground system performance data was recorded on FAA Form 418-3S and is presented in this document as figures A-5 and A-6.

A.2.5 Interference Investigation

The orientation flights revealed several modes of erratic operation of the DDB system. The most severe anomalies were traced to a condition when the aircraft was at short distances to the waypoint and there was a high volume of traffic on the communications transmitter. The investigation revealed the following types of problems.

A.2.5.1 Uninitiated Flow Clearing

A flow would be acquired and displayed by the airborne decoder and then the flow would be cleared, without any action being taken to initiate the clearing. The problem was traced to the channel change line, which runs between the King 705 DME and the 9040 airborne decoder. This line was susceptible to any fast rise time pulses or extraneous pickup when the microphone of the communications was keyed. A temporary solution was implemented by disconnecting the line and grounding it at the airborne decoder, since only one ground frequency was used for the flight test.

A.2.5.2 Waypoint Sequencing

The waypoints, as displayed on the airborne decoder, were sequenced in a random manner, when in the auto mode of operation. This problem was traced to the Model 9040 Airborne Decoder, using the Distance to Waypoint output of the RNAV computer to determine when the waypoint in use should be sequenced to the next waypoint. This line, as used by the decoder, has a scale factor of approximately 30 millivolts per mile. The impedance of the input circuit is relatively high and as a result, any fast rise

TECHNICAL PERFORMANCE RECORD — TACAN

STATION: NAFEC | CHANNEL NO.: 27 | YEAR: 1975 | SUPERVISOR'S SIGNATURE: [illegible]

BEACON TYPE: RTB-2 #2 (GFM) | BEACON S/N: 5-2 | TMC TYPE: RTC-2 | TMC S/N: 3

LINE	DATE	TIME	MONITOR NO. (1 OR 2)	PEAK POWER OUTPUT	N BURST DURATION (1-21μ PULSE)	AUX BURST DURATION (1-9μ PULSE)	IDENT TONE (GROUPS BETWEEN BURSTS)	BCN RECVR SENSITIVITY dbm	BCN RECVR SELECTIVITY (SENSITIVITY ± 160 KC) -dbm	(SENSITIVITY ± 160 KC) -dbm	(PPS AT + 900KC)	(PPS AT - 900KC)	BCN RECVR DECORDER TOLERANCE (MIN)	(MAX)	MON RECVR SENS ALARM -dbm	BCN REPLY DELAY	MON REPLY DELAY ALARM (MIN)	(MAX)	BCN PULSE SPACING	MON PULSE SPACING ALARM (MIN)	(MAX)	BCN PULSE WIDTH	MON PULSE WIDTH ALARM (MIN)	(MAX)	BCN SQUITTER COUNT
				(1)	(2)	(3)	(4)	(5)	(6)				(7)		(8)	(9)	(10)		(11)	(12)		(13)	(14)		(15)
	NOMINAL		2	10KW	3.0μS	9.6μS	9	94	93	93	17	15	12	13.8	94	50.0	-0.6	+0.6	12.0	11.6	12.4	3.5	3.0	4.0	7200
1	2/5/75		2	13.5KW	3.4μS	9.5.6	9	94	93	93	27	22	10.5	13.5	92	50.04	-0.6	+0.6	12.1	11.5	12.7	3.4	3.03	4.10	7130
2	2/5/75			15.5KW									(C)				(D)								7604
3				(A)																					(B)
4																									
5																									
6																									
7																									
8																									
	TOL	INITIAL		9-11KW	±5μS	±1μS		92	±0	±0	<25	<25	≤11	≥13	≤90	±.1	-.6	+.6	±.1μS	±.1μS	±.1μS	±.3	±.1μS	±.1μS	±60
	TOL	OPER		6-11KW	±10μS	±2μS		90	±3.5	±3.5	<25	<25	≤11	≥13	≤90	±.1	-.6	+.6	±.2μS	±.2μS	±.2μS	±.5	±.2μS	±.2μS	±120
11															±0										
12																									
13																									
14																									
15																									
16				Note 8																					
17																									
18				(A) Coupler Ser No 5/8 Power Diode 14												Yes	112		990	MHZ					
19				(B) Normal with DDBS																					
20																									
21				(C) Using Monitor Spacing Adjust																					
22				(D) Monitor Setting																					
23																									
24																									
25																									
26																									
27																									
28																									
29																									
30																									

FAA Form 418-35 (10-68) SUPERSEDES FAA FORMS 418D1 PT 1 418D1 PT 2 418D1 ANT 418D2 4005

FIGURE A-5. DDB MAINTENANCE PERFORMANCE DATA SHEET

TECHNICAL PERFORMANCE RECORD — TACAN CONTINUED

LINE	DATE	TIME	MONITOR NO. (1 OR 2)	MON SQUITTER RATE ALARM (MIN) (16)	MON SQUITTER RATE ALARM (MAX) (16)	BCN SPECTRUM LOWER SIDEBAND (17)	BCN SPECTRUM UPPER SIDEBAND (17)	MON PEAK POWER ALARM (18)	MON AVG POWER ALARM (Re-Peak) (19)	ANTENNA SPEED (PERIOD) (20)	ROTATION RATE GATE (21)	BCN AZIMUTH ERROR (15 CPS) (22)	BCN AZIMUTH ERROR (135 CPS) (22)	MON AZIMUTH ERROR ALARM (+15 CPS) (23)	MON AZIMUTH ERROR ALARM (-15 CPS) (23)	MON AZIMUTH ERROR ALARM (+135 CPS) (23)	MON AZIMUTH ERROR ALARM (-135 CPS) (23)	MONITOR IDENTITY ALARM (OFF) (24)	MONITOR IDENTITY ALARM (CONST) (24)	DIALING, ALARM AND TRANSFER (CHECK) (25)	WAVEFORM AT TP3760 (26)	EQUIPMENT TO NORMAL (27)	REMARKS	INITIALS
NOMINAL				2550	2850	63	60	5KW	5KW	66,667	200	0.0	0.0	4.5	4.5	1.0	1.0	75	5	✓	40	✓		
1				2525	2866	58	69	5KW	5KW	66,682	300													
2																								
3																								
4																								
5																								
6																								
7																								
8																								
	TOL	INIT		±20	±20	±57	±57	±5%	±5%	±25	±10US			±4°	±4°	±1°	±1°	±5	±1					
	TOL	AFTER		±40	±40	±57	±57	±10%	±10%	±138	±200US			±4°	±4°	±1°	±1°	±10	±2					
11														(or Radial during FT)										
12																								
13																								
14																								
15																								
16																								
17																								
18																								
19																								
20																								
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25																								
26																								
27																								
28																								
29																								
30																								

4006

FIGURE A-6. DDB MAINTENANCE PERFORMANCE DATA SHEET

time signals or extraneous noises are induced on this line. A temporary solution was effected by performing the following steps.

a. Removing the error measurement lines so that the fast rise time signals would not cause an acquired flow to be sequenced out.

b. By adjusting the level at which the waypoint sequencing logic operated to 0.8 nmi instead of the 0.5 nmi, which had been requested for the flight tests.

c. By requesting the pilots to keep the volume of traffic on the communications transmitter at a minimum, when flying in the automatic mode and at short distances to waypoints.

These steps were by no means an adequate solution but they reduced the problems to a level that flights could be flown without redesigning the circuitry.

A.2.6 X-Mode DDB Pulse Spacing

The spacing of the DDB "A" pulse in relationship to the second pulse of the normal TACAN pulse pair (as shown in figure A-7) results in the inability of the Model 9040 Airborne Video Detector to detect a pulse with sufficient reliability to enable a consistent message reception. The Model 9040 was operated, after adjustment, in the X-Mode in both the laboratory and aircraft at NAFEC and it was able to acquire and display a flow from a 10-sec data cycle in approximately 4 minutes, when it received video from the King 705 DME. It was determined that an acquisition time of this duration was not adequate to perform flight tests. The waveform of the video is shown in figure A-8. The nominal 3.5-microsecond pulse transmitted by the TACAN ground station is stretched by the IF in the airborne receiver. This stretching of the pulse was also observed in TACAN ground station monitor equipment and the Sierra TACAN test set. To understand the problem, the following summary of the operation of the airborne video detector is presented. The three input signals to the comparator in question are: 1/2 amplitude video, delayed video, and peak detector. The leading edge of the detected video pulse is generated when the amplitude of the delayed video signal exceeds the amplitude of the 1/2 amplitude video. The detected video pulse is truncated, when either (1) the amplitude of the delayed video is less than the amplitude of the 1/2 amplitude video or (2) when the amplitude of the 1/2 amplitude video is less than the amplitude of the peak detector. The second mechanism (2) is normally intended to eliminate unwanted low-amplitude spurious video signals from being decoded. The leading edge of the detected video triggers a monostable multivibrator, which enters a pulse of a fixed width into a shift register for decoding. When the second pulse of the TACAN pair and the "A" pulse of

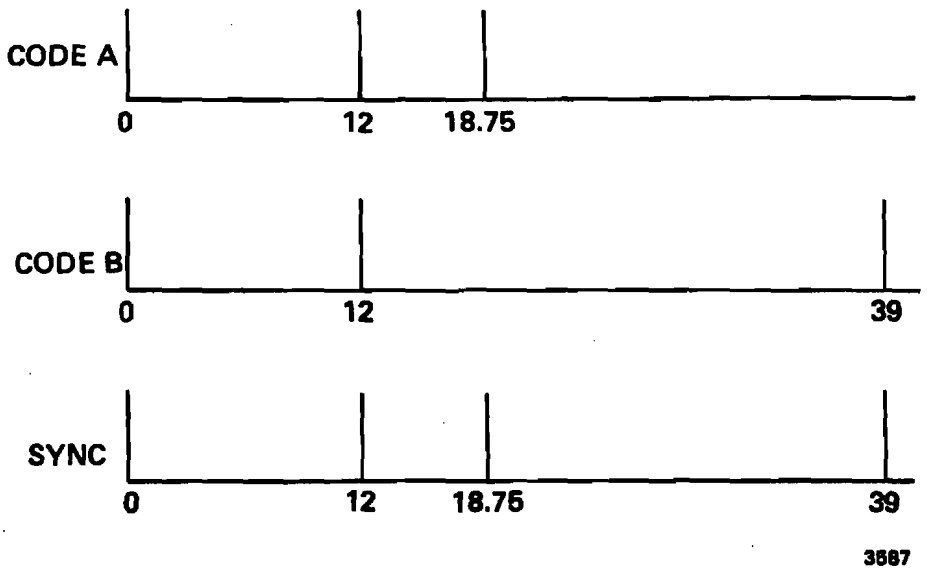
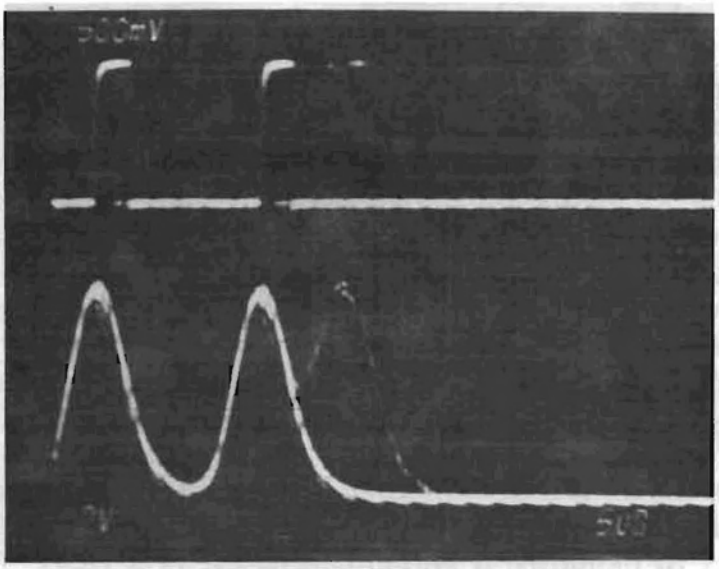


FIGURE A-7. X-CHANNEL DDBS CODES

DETECTED
VIDEO
10 X PROBE

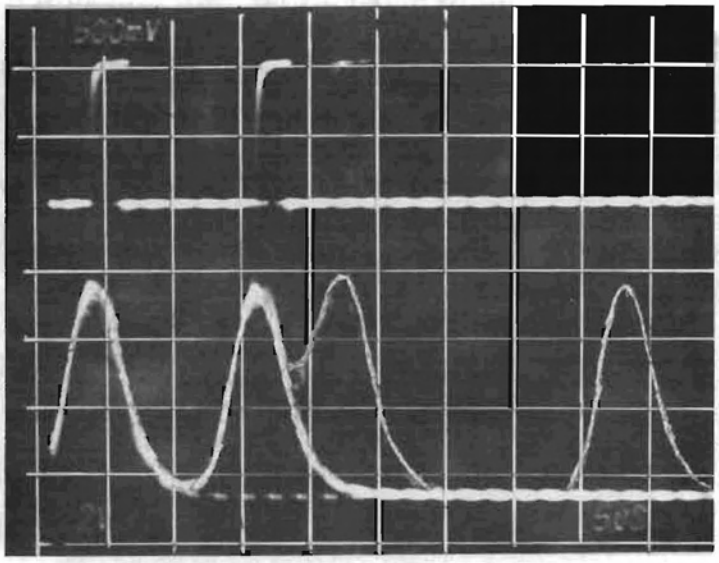
705
VIDEO



ORIGINAL PHOTO

DETECTED
VIDEO
10 X PROBE

705
VIDEO



RETOUCHED PHOTO
TO HIGHLIGHT VIDEO
AND GRATICULES

4001

FIGURE A-8. KING 705 DME VIDEO

DDB code overlap at the 50% point of the video, the output of the detector is at a constant level for the period of the overlap and there is no leading edge to trigger the mono to enter the pulse of fixed width into the shift register decoder. This condition can be partially corrected by changing the setting of the control on (2) the peak detector, but then the 50% point of the video is no longer used for timing of the pulses (the basic reference of TACAN pulses) and the detection of the video becomes very susceptible to normal perturbation of the signal level. Given this set of conditions, if the "A" pulse is detected, the detection point may vary widely with signal strength variations. This effect is accentuated by fast amplitude-modulation of the transmitted "TACAN" signal and slow AGC in the DME receiver. The problem can also be compounded, if a tight decode tolerance is used in the airborne receiver. On the other hand, if a very loose decoding tolerance is used, there is a real possibility of decoding a reference pulse as a DDB "B" pulse. It should be noted that the overlap problem is not present in the Y-mode pulse coding of the DDB system (for reference, see figure A-9).

A.2.6.1 X-Mode Problems and Y-Mode Capabilities

A brief but informative test was conducted at SRC in Buffalo using a modified TACAN simulator to determine the cause of X-mode problems observed at NAFEC and to examine Y-mode capabilities. The modified TACAN simulator, which had the capability of accepting a pulse train from an external source and outputting the pulse train in conjunction with the normal TACAN pulses, was used to test the video decoding capability of the DDB system. The DDB pulse spacings for X- and Y-modes were simulated and were used as an external input to the modified simulator. The modified simulator was set up with the following conditions:

Channel	27 X
Squitter rate	0
MRB	disabled
ARB	disabled
% 15-Hz modulation	0
% 135-Hz modulation	0
Reply Efficiency	0
External pulse input	860 DDB pulses/sec

The results of using the X-mode DDB pulse spacings at various RF power levels are shown in Table A-1.

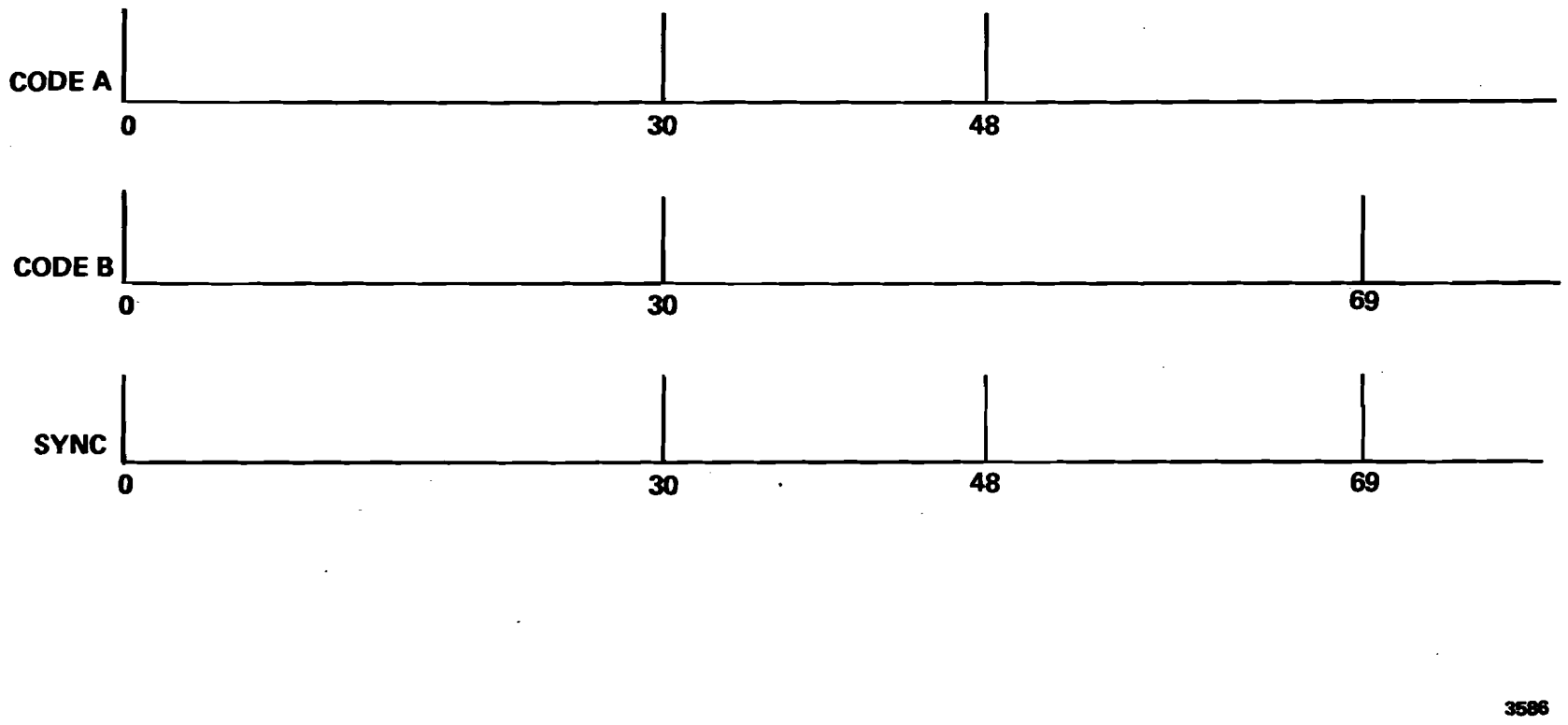


FIGURE A-9. Y-CHANNEL DDBS CODES

TABLE A-1. X-MODE PULSE DETECTION WITHOUT MODULATION

RF Level	DDB Pulses Transmitted	"A" Pulses Detected	Bit Detection Probability
-40	860	855	.994
-50	860	855	.994
-60	860	842	.979
-65	860	738	.858
-70	860	591	.687

The data taken for Table A-1 was repeated using the Y-mode DDB pulse spacings and is presented in Table A-2.

TABLE A-2. Y-MODE PULSE DETECTION WITHOUT MODULATION

RF Level	DDB Pulses Transmitted	"A" Pulses Detected	Bit Detection Probability
-40	860	858	.997
-50	860	858	.997
-60	860	858	.997
-65	860	845	.982
-70	860	830	.965

The modulation percentage was then set to 15 Hz = 22%, and 135 Hz = 22%. The data shown in Table A-3 was taken to compare X- and Y-modes of operation.

TABLE A-3. COMPARISON OF X- AND Y-MODES PULSE DETECTION WITH NORMAL MODULATION

		X-Mode		Y-Mode	
RF Level	DDB pulses Transmitted	"A" Pulses Detected	Bit Detection Probability	"A" Pulses Detected	Bit Detection Probability
-50	860	803	.933	858	.997
-60	860	758	.881	858	.997
-70	860	544	.632	820	.953

The modulation percentage was then set to the value corresponding to that which was measured as the output of the experimental VORTAC at NAFEC: 15 Hz = 22% and 135 Hz = 34%.

TABLE A-4. COMPARISON OF X- AND Y-MODE PULSE DETECTION WITH HIGH MODULATION

		X-Mode		Y-Mode	
RF Level	DDB Pulses Transmitted	"A" Pulses Detected	Bit Detection Probability	"A" Pulses Detected	Bit Detection Probability
-40	860	780	.906	840	.976
-50	860	748	.869	832	.967
-60	860	638	.741	800	.930
-70	860	437	.508	735	.854

A.2.7 Pulse Spacing Constraints for Data Pulse Coding

The basis for selecting the original pulse spacing is given in the GFE TACAN/DME Digital Data Broadcast Design Plan, Volume 2. Portions of the referenced document are reproduced in the following text to assure compliance with the original requirements, as well as the additional findings of the tests conducted in this task.

A.2.7.1 Selections of Data Pulse Positions (Previous Criteria)

Four basic constraints were considered in the selection of the data pulse positions.

a. Avoid generating spurious pulse pairs which can trigger Ground or Airborne Pulse Pair Decoders and/or Airborne TACAN Burst Detectors.

b. Avoid pulse spacings less than 5 microseconds apart to prevent distortion.

c. Avoid large spacings, so that no spurious pairs will be formed by data pulse and the next TACAN/DME pairs following the System Dead Time.

d. Avoid spacings where Reference Burst Pulses can be mistaken for data pulses. (This will occur, if the data spacing is coincident with burst pulse spacings.)

The results of the aforementioned tests revealed that, owing to pulse stretching in the airborne DME IF, the pulse spacing requirement be increased from 5 microseconds to 10 microseconds to prevent pulse distortion and to enable adequate detection probability. This modifies the original requirements as shown in Section A.2.7.2.

A.2.7.2 Selection of Data Pulse Position (Present Criteria)

a. Avoid generating spurious pulse pairs which can trigger Ground or Airborne Pulse Pair Decoders and/or Airborne TACAN Burst Detectors.

b. Avoid pulse spacings less than 10 microseconds apart to prevent pulse distortion.

c. Avoid large spacings, so that no spurious pairs will be formed by data pulse and the next TACAN/DME pairs following the System Dead Time.

d. Avoid spacings where Reference Burst Pulses can be mistaken for data pulses. (This will occur, if the data spacing is coincident with burst pulse spacings.)

A.2.8 Pulse Spacing Rationale

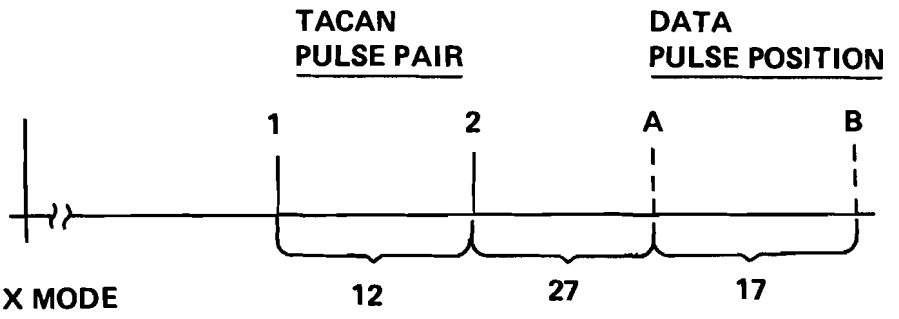
As stated in the original analysis, it is apparent that the idealized conditions cannot be totally achieved. The best approach is to evaluate each of the constraints and determine the pulse spacing which yields the best set of results in regard to its compliance with the basic principles of TACAN/DME operation. The selected pulse spacing and the various combinations of pulse pair spacings generated by both the previous X-mode DDB pulse spacing and the recommended X-mode DDB pulse spacing are shown in figure A-10.

The evaluation of the pulse spacings as they apply to the constraints are listed below:

Constraint No. 1: The on-channel equipment pulse spacings, as shown in figure A-11, are satisfied. The off-channel equipment pulse spacings, as shown in figure A-12, are satisfied, with the exception of the 27- and 34-microsecond spacings. The 27-microsecond spacing existed previously and the 34-microsecond space replaces a 21-microsecond spacing of the previous group. The rationale in this case is the same as before: these spacings would have negligible affect on any Y-mode equipment and it is projected that the requirements of this constraint are satisfied.

Constraint No. 2: The requirements of this constraint are satisfied.

Constraint No. 3: The requirements of constraints No. 1 and No. 2 yield a larger maximum pulse width than that previously required. This maximum of 56 microseconds is substantially



Pulse Combinations	Old X Mode Spacing (μs)	New X Mode Spacing (μs)
1-2	12	12
1-A	18	39
1-B	39	56
2-A	6	27
2-B	27	34
A-B	21	17

NOTE: All Time Values in microseconds

4002

FIGURE A-10. ALL COMBINATIONS OF PULSE PAIR SPACINGS RESULTING FROM SELECTED CODE STRUCTURE

X Mode Transponder

Pair Spacings to Avoid	"On Channel" Equipment Which Could Be Affected
12 ± 5 μs*	Airborne TACAN/DME X Mode Pulse Pair Decoders
12 ± 2 μs 24 ± 2 μs 36 ± 2 μs . . etc.	Airborne TACAN X Mode Auxiliary Burst Decoder
30 ± 2 μs 60 ± 2 μs . . etc.	Airborne TACAN X Mode North Burst Detector

*Many Airborne TACAN/DME Interrogators have decoding tolerances specified up to ± 5 μs.

4003

FIGURE A-11. ORIGINAL REQUIREMENT (X-MODE)

Y Mode Transponder

Pair Spacings to Avoid	"On Channel" Equipment Which Could be Affected
12 ± 5 μs	Airborne TACAN X Mode Air-to-Air Pulse Pair Decoder
15 ± 2 μs 30 ± 2 μs 45 ± 2 μs etc.	Airborne TACAN Y Mode North and Auxiliary Reference Burst Detectors
24 ± 5 μs	Airborne TACAN Y Mode Air-to-Air Pulse Pair Decoder
30 ± 5 μs	Airborne TACAN Y Mode Ground-to-Air Pulse Pair Decoder
36 ± 2 μs	Y Mode Ground Transponder Pulse Pair Decoder

4004

FIGURE A-12. ORIGINAL REQUIREMENT (Y-MODE)

less than the 69 microseconds of the Y-mode pulse spacing that was used in flight test. It is projected that the requirements of the constraint would be satisfied by the recommended pulse spacing.

Constraint No. 4: This constraint is satisfied.

The set of pulse spacings shown in figure A-10 appears to satisfy the original and the new requirements. A consideration of the method of implementation of the transmission of the pulse codes and the advance in the state of the art in ROM technology would suggest that any future DDB be implemented using electronically erasable and reprogrammable PROMS to implement the pulse spacings. This technique would permit the easy evaluation of not only this pulse code but variations to it, as well as different codes in any subsequent units.

A.2.9 Probability of Accepting Waypoint Data

As noted, specific measurements were made, using a simulator, to determine the DDB equipment's ability to receive any individual transmitted data bit. In each case, the number of received pulses of a given type was divided by the number that was transmitted (between DME ident cycles), and the result was interpreted as the probability, p_b, of receiving a given transmitted bit.

For the present DME/DDB design, these bit probabilities are a strong function of received signal strength, code-spacing, percent of 15-Hz and 135-Hz modulation, etc.

Before discussing the measured bit probabilities, it is worthwhile to examine the relationship between these bit probabilities and the probability of receiving a given word (or a set of three words corresponding to identity, range, and bearing of a given waypoint). Most data words in the DDB consist of 24 bits (including sync bits), although there is a 30-bit ID word. Each word is transmitted twice (and when both transmissions are successfully received, the two words must agree).

In general, the probability of a lost bit is higher than the false bit decode probability. The ensuing discussion will be concerned with the problem of successfully receiving a three-word group corresponding to a single waypoint, and will ignore the probability of "false" bit decodes (e.g., decoding an "A" for a "B"). Obviously, the computation would be more complex, and the actual probabilities of detection would be somewhat lower, if the false decode probabilities were included.

In this simple analysis, the probability of correctly receiving a transmitted n-bit word is given by

$$p_{w1} = p_b^{\,n}$$

No distinction will be made between detecting a sync bit and detecting an "A" or "B" (0 or 1) data bit.

If a word consists of 24 (or 30) bits, a very high bit-reception probability is required to ensure a reasonably high word-detection probability. Thus, the single-transmission word-decode probability is generally much smaller than the bit-detection probability, just as the probability of winning 24 of 24 games of chance is significantly lower than the probability of winning any one game.

One other complication must be accounted for. Since each word is transmitted twice (and since bit-reception errors have been ignored in this analysis), the probability of receiving at least one of the twice-repeated transmissions of each word is given by:

$$p_{w2} = 1 - (1 - p_{w1})^2 = 2p_{w1} - p_{w1} - p_{w1}^{\,2}$$

However, the probability of receiving all three relevant sets of data corresponding to a particular waypoint would be given by:

$$p_3 = p_{w2}^{\,3}$$

This probability is highly relevant: unless all three words are detected, the data for that particular waypoint is lost and cannot be recovered until the next update.

A.2.9.1 Repeated Transmissions

The probability of updating the three words associated with a given waypoint is increased by resorting to multiple transmission/reception cycles. Thus, if n "tries" are allowed, then the probability of decoding all three words associated with a given waypoint (after n tries) is given by:

$$p_{nt} = 1 - (1 - p_3)^n$$

This higher probability of updating is automatically achieved by the DDB but at the expense of increasingly longer delays in updating the waypoint data.

A.2.9.2 Multiple Waypoint Data

The flight tests used typical sequences of up to 6 waypoints. Thus, successful operation of the DDB was monitored by examining all six stored waypoint data sets. The probability of successfully receiving the data words associated with all "k" waypoints (after n transmissions) is given by:

$$p_{kwp} = p_{nt}^{k}$$

This can be substantially lower than the probability of recovering the data associated with a specified waypoint.

A.2.10 Specific Calculations

A computer program was written to calculate the various DDB probabilities associated with selected bit detection probabilities ranging from 0.90 to 0.999 (figure A-13). A particular computer printout (figure A-14) indicates that the probability of updating all 6 waypoints (after three tries) is almost 99%, if the bit detection probability is 0.99, but the updating probability falls to a very low level (21%), if the bit detection probability falls to 0.97. (This is shown in graphical form in figure A-15.)

This result indicates that a very high bit detection probability is required to permit successful operation of a DDB with the present system parameters. As noted earlier, the bit detection probability is a strong function of signal-to-noise level and of selected coding. This implies that the DDB should be used with suitably strong transmitters (and reasonably low noise-figure receivers) and also that care be used in selecting the coding.

It should be stressed that the calculated multiple waypoint update probabilities are a function of the requirement for updating all data for a given waypoint on a single transmission. If shorter data words were utilized, and if the individual words could be updated on different transmissions, then a significant improvement in update probability could be achieved. This approach should be investigated, if a decision is made to build an operational DDB.

```
, C            0123456789012345678901234567890123456789012345678901234567890
, 100  FORMAT(1H0,F10,4,5F13,10)
, C    2345678901234567890123456789012345678901234567890
, 150  FORMAT('O BIT PROB   1WORD PROB  2 TRANS PROB  3-WORD PROB
,     1        'N-TRY PROB  K-STRING PROB')
, 200  FORMAT(1H1,'# TRANSMISSION TRIES,  # WAYPOINTS',2I4)
,      DO 95 N=1,10
,      DO 95 N=2,6
,      NN=N
,      KK=K
, 50   WRITE(12,200) NN,KK
,      IF(NN.LT.1)GO TO 96
,      F=1.
,      DP=.001
,      WRITE(12,150)
,      DO 94 I=1,19
,      P=P-DP
,      IF(I.EQ.10) DP=.01
,      PW1=P**24
,      PW2=1.-(1.-PW1)**2
,      P3=PW2**3
,      PNTRY=1.-(1.-P3)**NN
,      PSTRING=PNTRY**KK
,      WRITE(12,100)P,PW1,PW2,P3,PNTRY,PSTRING
, 94   CONTINUE
,      IF(N.NE.10.OR.K.NE.6) GO TO 95
,      WRITE(10,200)
,      READ(11)NN,KK
,      GO TO 50
, 95   CONTINUE
, 95   CONTINUE
,      STOP
,      END
```

4027

FIGURE A-13. PROGRAM TO CALCULATE DDB PROBABILITIES

TRANSMISSION TRIES, # WAYPOINTS 3 6

BIT PROB	1WORD PROB	2 TRANS PROB	3-WORD PROB	N-TRY PROB	K-STRING PROB
0.9989	0.9762728800	0.9994369700	0.9983118100	0.9999999400	0.9999995800
0.9979	0.9530857800	0.9977990300	0.9934116000	0.9999997000	0.9999981500
0.9969	0.9304270100	0.9951595600	0.9855488500	0.9999969600	0.9999817000
0.9959	0.9082850200	0.9915883500	0.9749767100	0.9999843200	0.9999059400
0.9949	0.8866484700	0.9871513800	0.9619472600	0.9999448600	0.9996691900
0.9939	0.8655063500	0.9819114200	0.9467099300	0.9998486600	0.9990922800
0.9929	0.8448478500	0.9759277700	0.9295077300	0.9996497000	0.9979000000
0.9919	0.8246623800	0.9692566900	0.9105764600	0.9992848600	0.9957168100
0.9909	0.8049395600	0.9619513700	0.8901420800	0.9986741500	0.9920712100
0.9899	0.7856692000	0.9540622800	0.8684207200	0.9977219100	0.9864090600
0.9799	0.6157724800	0.8523691800	0.6192744900	0.9448130700	0.7113369100
0.9699	0.4814184400	0.7310648500	0.3907218500	0.7738238500	0.2147101700
0.9599	0.3754073900	0.6098840800	0.2268515800	0.5378439400	0.0242068170
0.9499	0.2919840800	0.4987134300	0.1240375000	0.3278649400	0.0012421381
0.9399	0.2264959800	0.4016914900	0.0648153400	0.1821151900	0.0000364818
0.9299	0.1752193500	0.3197368300	0.0326872220	0.0948912500	0.0000007300
0.9199	0.1351756400	0.2520788300	0.0160180330	0.0472884770	0.0000000111
0.9099	0.1039880500	0.1971625600	0.0076643160	0.0228171940	0.0000000001
0.8999	0.0797644800	0.1531665900	0.0035932892	0.0107412930	0.0000000000

4028

FIGURE A-14. PROBABILITY OF SUCCESSFULLY DECODING WAYPOINTS

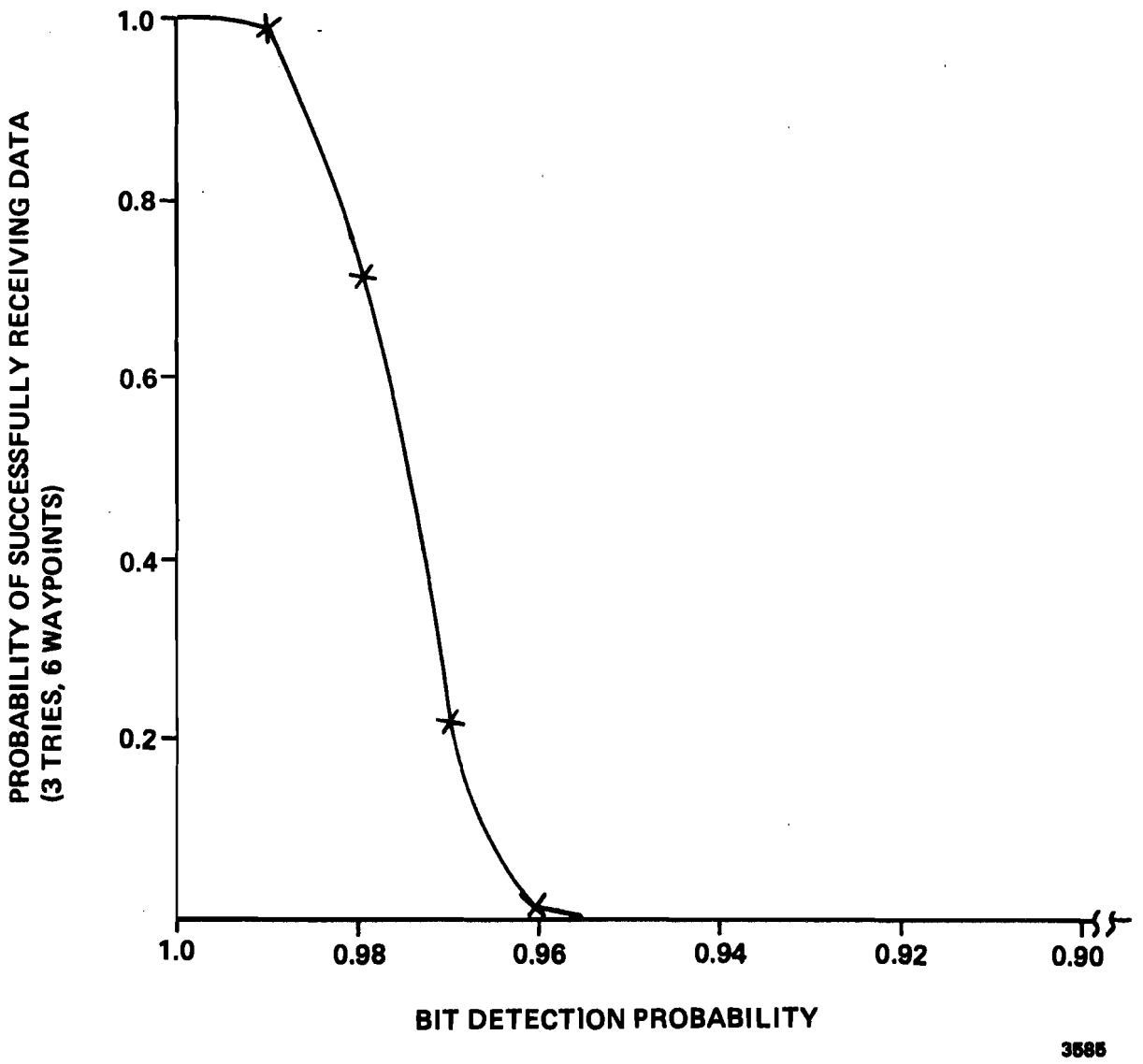


FIGURE A-15. PROBABILITY OF SUCCESSFULLY RECEIVING WAYPOINT DATA VERSUS BIT DETECTION PROBABILITY

APPENDIX B

OPERATIONAL FEATURES OF THE TESTED DDB ENGINEERING MODEL (9040) AIRBORNE DECODER

The purpose of this appendix is to present a description of the operational features of the tested DDB Engineering Model airborne decoder as shown in the Instruction Manual for Digital Data Broadcast (Reference 5). These operational features are presented, so that the reader will have a data base for interpretation of flight-test results, including documented operational deficiencies and recommended operational and functional requirements applicable to the installed DDB equipment in the test aircraft.

B.1 MODIFIED EQUIPMENTS

The EDMAC Associates Model 9040 Digital Data Broadcast airborne decoder provides for the direct transfer of area navigation information from the VORTAC facility to the airborne RNAV computer. The model 9040 is specifically designed to operate with modified King Radio Avionic Equipment. These instructions detail the operation of the model 9040 with a modified KNC610 RNAV computer and a modifiedKDM705 DME Interrogator.

Interfacing with these modified avionic equipments are unmodified equipments consisting of a KFS560 Nav Frequency Selector, a KNI520 Course Deviation Indicator, and a KNR601 Navigation Receiver. The operation of the DME interrogator and the unmodified equipments is exactly as found in the appropriate King Radio manuals.

A small toggle switch has been installed on the KNC610 RNAV computer to allow operation with or without Digital Data Broadcast. With this switch in the down position, the Digital Data Broadcast is not being utilized by the RNAV system. Waypoint information is placed in the computer by the use of the front panel DISTANCE and BEARING controls. In this mode, the operation of the KNC610 is axactly as described in the King Radio manual. Placing this switch in the up position disables the RNAV computer front panel range and bearing inputs and causes the computer to obtain this information from the Digital Data Broadcast decoder. If the RNAV computer is operating in the RNAV mode using information from the decoder, a small IN USE lamp will be illuminated on the decoder front panel. It is this mode of operation that will be described in this manual.

The airborne decoder obtains the area navigation information by decoding pulse position modulated broadcast data contained on the reply signals of the ground-based TACAN or DME transponder. Selected portions of this broadcast data are displayed to the operator and stored, and the range and bearing data of the desired waypoint are furnished to the RNAV computer.

B.2 DATA CHARACTERISTICS

Each of the waypoints supported by a given VORTAC installation is defined by a unique three-digit number. Associated with this unique number are the Rho (range) and Theta (bearing) coordinates of this waypoint position with respect to the position of the VORTAC site. It is thus possible to uniquely define a particular RNAV waypoint by the call letters of the VORTAC facility and a three-digit number.

In addition to the individual waypoints, preplanned RNAV approaches and departures are defined. These are referred to as SIDs (Standard Instrument Departures), and STARs (Standard Terminal Arrival Routes). It is possible to have the decoder acquire the information for a complete SID or STAR by merely inputting the nomenclature of the desired route to the decoder.

To provide for proper assembly of the SID or STAR information by the airborne equipment, a special number, called a route sequence number, has been assigned to each waypoint of the route. These route sequence numbers of the preplanned routes are in increasing order as the radius from the terminal area increases. Departures, therefore, will normally be flown with the route sequence numbers increasing as the aircraft proceeds to successive waypoints. Approaches, on the other hand, will normally be flown with the route sequence numbers decreasing as the aircraft proceeds to successive waypoints.

B.3 DECODER MEMORY

The airborne decoder contains a memory, which provides for the storage of information for up to six waypoints. This memory is divided into six sections, each capable of storing the three-digit waypoint identification number, the two-digit route sequence number, and the four-digit range and bearing coordinates. Information for the waypoint being used is always stored in section 1 of the memory. Information for the next successive waypoint is stored in section 2 of the memory. Successive waypoint information is stored in sections 3 through 6 of the memory and in the order which it is intended to be utilized.

B.4 ROUTE DEFINITION

There are two methods available to the operator for calling out the desired flight path. If the desired path is a SID or STAR, it is only necessary to enter the nomenclature of the route into the airborne decoder. This will allow the decoder to obtain the range and bearing coordinates for each of the waypoints on the entire flight path. If it is desired to follow other than a preplanned flight path, or to incorporate special maneuvers into the preplanned

flight path, the identification number(s) of the desired waypoint(s) can be entered into the decoder. The decoder will then acquire the range and bearing coordinates of the desired waypoints and fed them into the RNAV computer as required. The manual entering of waypoint identification numbers is referred to as "string your own waypoints" operation.

B.5 CONTROL FUNCTIONING

Figure B-1 shows the front panel layout of the model 9040 airborne decoder. The function of the individual panel items are as follows:

Item 1: IN USE Lamp - Indicates that the computer is in the RNAV mode and is utilizing information stored in section 1 of the decoder memory.

Item 2: STATION Display - Indicates the call letters of the VORTAC facility from which the DME Interrogator is receiving data.

Item 3: WAYPOINT IN USE * IDENT - Indicates the three-digit identification number stored in section 1 of the decoder memory.

Item 4: WAYPOINT IN USE * SEQ NO - Indicates the route sequence number stored in section 1 of the decoder memory.

Item 5: WAYPOINT IN USE * NM-DEG - Indicates the range and bearing information stored in section 1 of the decoder memory.

Item 6: DATA STORAGE * NM-DEG Display - Indicates the range and bearing information stored in sections 2 through 6 of the decoder memory (as selected by Item 10).

Item 7: Part of DATA STORAGE Display - Indicates the three-digit identification number and the route sequence number stored in section 2 of the decoder memory.

Item 8: Part of DATA STORAGE Display - Indicates the three-digit identification number and the route sequence number stored in section 3 of the decoder memory.

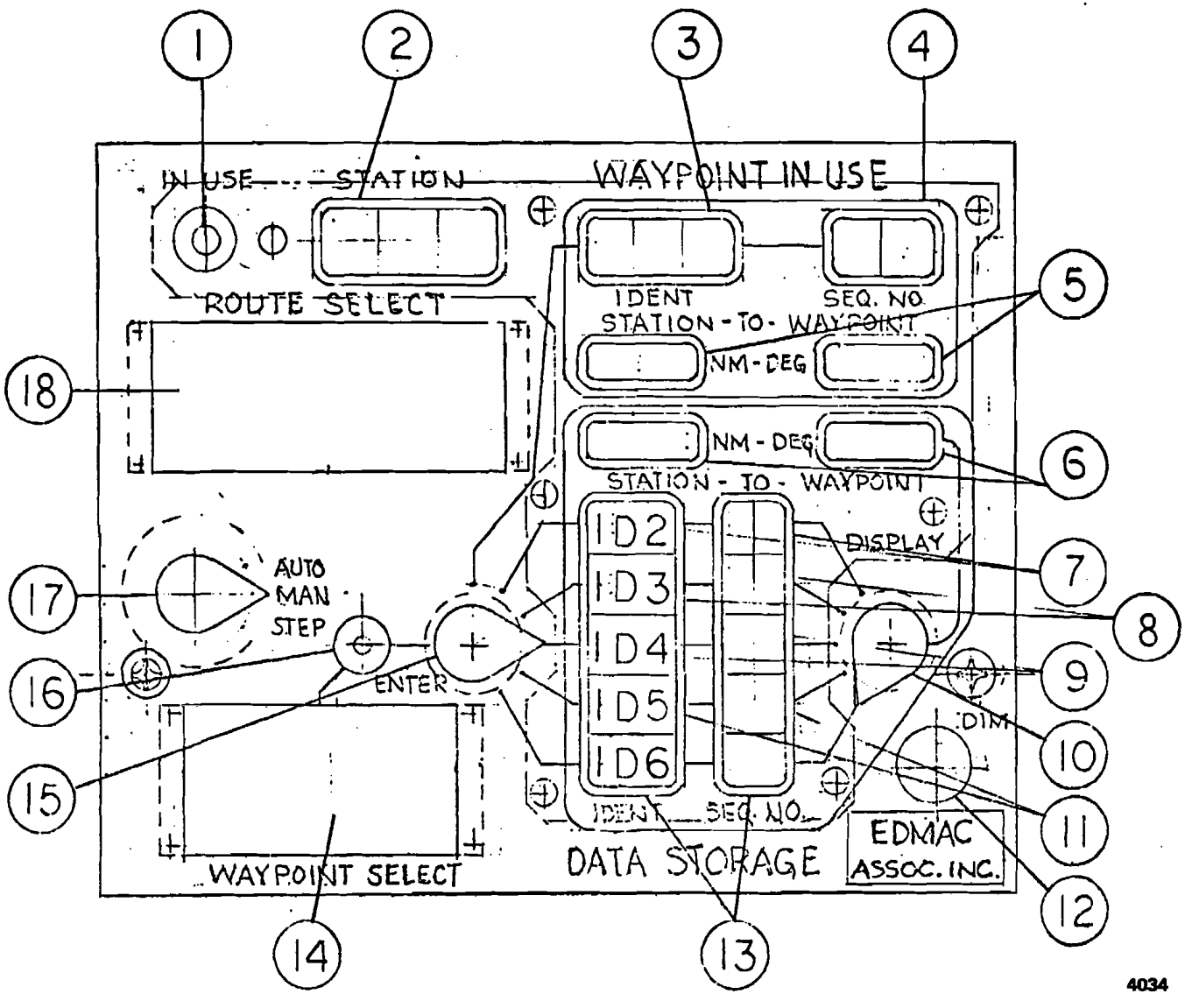


FIGURE B-1. FRONT PANEL LAYOUT OF MODEL 9040 AIRBORNE DECODER

Item 9: Part of DATA STORAGE Display - Indicates the three-digit identification number and the route sequence number stored in section 4 of the decoder memory.

Item 10: DISPLAY Select Control - Selects the section of the decoder memory for which the range and bearing information is shown in the DATA STORAGE * NM-DEG display (Item 6).

Item 11: Part of DATA STORAGE Display - Indicates the three-digit identification number and the route sequence number stored in section 5 of the decoder memory.

Item 12: DIM - Controls the brilliance of the decoder front panel display.

Item 13: Part of DATA STORAGE Display - Indicates the three-digit identification number and the route sequence number stored in section 6 of the decoder memory.

Item 14: WAYPOINT SELECT - Controls from which the operator may enter the three-digit identification number of a desired waypoint into the decoder memory.

Item 15: ENTER Rotary Switch - Selects the section of the memory into which the three-digit identification number set into Item 14 will be entered.

Item 16: ENTER Toggle Switch - A momentary contact switch which, when operated to the right momentarily, will enter the three-digit identification number set into Item 14 into the decoder memory section selected by Item 15.

Item 17: SEQUENCE Switch - Allows the operator to initiate a sequence action, which is accomplished by transferring the information in section 2 of the memory to section 1, the information in section 3 to section 2, section 4 to 3, 5 to 4, and the information in section 6 to section 5. A sequence action is initiated when the operator rotates the switch to the STEP position. The switch will spring return to

the MAN position. If the operator places the switch in the AUTO position, a sequence action will automatically be initiated, when the NAUT. MILES indication (Distance-to-go) on the KNC610 RNAV computer drops below approximately 2.5 miles.

Item 18: ROUTE SELECT SWITCHES - Controls from which the operator may set the nomenclature of a desired SID or STAR into the decoder.

B.6 OPERATING PROCEDURES

To place the decoder in operation, the following procedures are recommended:

a. Channel the NAV receiver and the DME Interrogator to the operating frequencies of a VORTAC facility transmitting DDB. The decoder will begin to acquire the broadcast data as soon as the DME Interrogator obtains range lock. The call letters of the selected station will appear in the STATION display within a few seconds.

b. Enter the designation of the desired SID or STAR on the ROUTE SELECTOR thumbwheel switches (18) (figure B-1). The decoder will then acquire and store the information for the first six waypoints (or all waypoints, if the route contains less than six) in the selected route. The information will be displayed in the following manner:

(1) <u>WAYPOINT IN USE Display</u>

This display will show all the broadcast data for the first waypoint to be utilized. The IDENT window will indicate the unique identification number of the waypoint. The SEQ NO window will indicate the route sequence number of the first waypoint to be used. For a SID, this will always be the number 1. For a STAR, the SEQ NO displayed will always be the highest, and successive waypoints will be in descending order. The STATION-TO-WAYPOINT windows will indicate the range and bearing information for the first waypoint to be utilized.

(2) DATA STORAGE Display

The DATA STORAGE display will indicate the broadcast information for the remaining successive waypoints (up to five). The identification number and route sequence number of the second waypoint to be utilized (stored in section 2 of the memory) will be shown in the windows (7). The waypoint information in section 3 will be shown in window (8). The waypoint information in section 4 will be shown in (9), section 5 in (11), and section 6 in (13). The range and bearing information stored for any of these waypoints may be displayed in window (6) by selecting the desired memory section with switch (10).

c. Place the small toggle switch on the RNAV computer front panel to the up or DDB position. This will cause the IN USE lamp on the decoder to illuminate, and the range and bearing information in the WAYPOINT IN USE display to be entered in the RNAV computer. (The computer mode switch must be in either the RNAV or APPR positions for the lamp to light and the information to be entered.) If the computer is in the VOR DME mode, the IN USE lamp will not illuminate and no information will be entered into the computer. If there is no information in section 1 of the decoder memory, the Distance-to-Go and the LOC flags will come into view.

d. Enter the desired track angle into the OBS and utilize the RNAV computer to fly to the waypoint in the normal manner.

e. Sequencing of the decoder to successive waypoints may be accomplished by two different methods. If the sequencing switch (17) of the decoder is in the AUTO position, sequencing to the next waypoint will occur automatically, when the RNAV Distance-to-Go indication drops below about 2.5 nautical miles. If the sequencing switch is in the MAN position, sequencing will be accomplished by rotating the switch to the STEP position momentarily. Upon release, the switch will return to the MAN position. Sequencing will be evidenced by observing on the display that the information in section 2 of the memory has advanced to section 1 and is now the WAYPOINT IN USE. Section 3 has advanced to section 2, section 4 to 3, etc.

B.6.1 "String Your Own" Operation (DWN Method)

a. Channel the NAV receiver and the DME Interrogator to the operating frequencies of a VORTAC facility transmitting DDB.

The decoder will begin to acquire the broadcast data as soon as the DME Interrogator obtains range lock. The call letters of the selected station will appear in the STATION display (2) within a few seconds.

b. Place the ROUTE SELECT thumbwheel switches (18) to the designation of a route not being utilized in the geographical area. Enter the unique identification number of the first waypoint to be utilized on the WAYPOINT SELECT thumbwheel switches (14). Place the rotary ENTER switch (15) in its most counterclockwise position, such that the point lines up with the panel line going to the WAYPOINT IN USE display. Momentarily push the ENTER toggle switch (16) to the right to enter the identification number on switch (14) into memory section 1. This identification number will immediately appear in window (3). Enter the succeeding waypoint into the other memory sections in the same manner, positioning the rotary switch (15) to the desired section. When the decoder has acquired the range and bearing information, a "c" will appear in the Route Sequence Number display for the corresponding waypoint. The range and bearing information for each stored waypoint may be examined in the same manner as for a SID or STAR (RNC Method).

The desired waypoint identification numbers may be entered in any order into the different sections of the decoder memory. It is important that the DME be tuned to the correct operating channel before entering the waypoints, as the rechanneling of the DME completely erases the entire decoder memory. It is not necessary that the DME acquire range lock before entering waypoint identification numbers into the decoder. The decoder will not, however, be able to acquire range and bearing information for the waypoints, until the DME interrogator has acquired range lock.

c. Sequence the decoder and operate the RNAV computer in the same manner as when using SIDs or STARs. (RNC Method.)

d. If it is desired to modify waypoints, once they have been entered, it is only necessary to enter another waypoint identification number in place of the one to be removed. When the new identification number is entered, the route sequence, range, and bearing information, which might have been present in the given section of the memory, will be erased, and the decoder will promptly attempt to acquire information for the new waypoint.

B.6.2 Modifying a SID or STAR

If it is desired to modify a preplanned route structure by the addition of a holding pattern, a delay fan, a delay trombone, or other similar maneuver, the additional waypoints may be added to the decoder memory. This is accomplished in the following manner:

a. Select the desired route in the same manner as "To Utilize a Preplanned Route Structure (SID or STAR)".

b. Select the memory section, which is to be modified, by selector switch (15).

c. Enter the new waypoint identification number in the same manner as "To String Your Own Waypoints". The decoder will acquire the broadcast data for this waypoint and will place a small "c" in the route sequence number window, when this data is entered in storage. The route information that was previously occupying this memory section will be shifted back one section (i.e., if a new waypoint is entered into section 2 of the memory, the route information in section 2 is transferred to section 3).

d. Waypoints entered by the operator may be modified by the operator in the same manner as "To String Your Own Waypoints". It is not, however, possible to modify waypoints acquired as part of the route structure. If it is desired to delete a waypoint from a SID or STAR, this can be done only by immediately sequencing through the undesired waypoint, when it becomes WAYPOINT IN USE.

Modifications to SIDs or STARs may be made before the decoder has acquired the route information. When the broadcast data for the route is required, the decoder will skip over memory sections which have manual entries. It is important, however, that the DME channeling and ROUTE SELECT switches be correctly set before entering waypoint identifications manually.

The intensity of the LED front panel display may be varied by adjustment of the DIM control (12). Rechanneling of the DME Interrogator at any time will erase the entire memory of the decoder. Manipulation of any one of the ROUTE SELECT switches (18) will erase the entire waypoint storage memory of the decoder, leaving only the STATION display intact. If data is in storage, the memory is erased, and if the data is required, it will be reacquired in its virgin form, with no sequence actions having been performed and no operator modifications having taken place.

APPENDIX C

PHOTOGRAPHS OF TEST EQUIPMENT

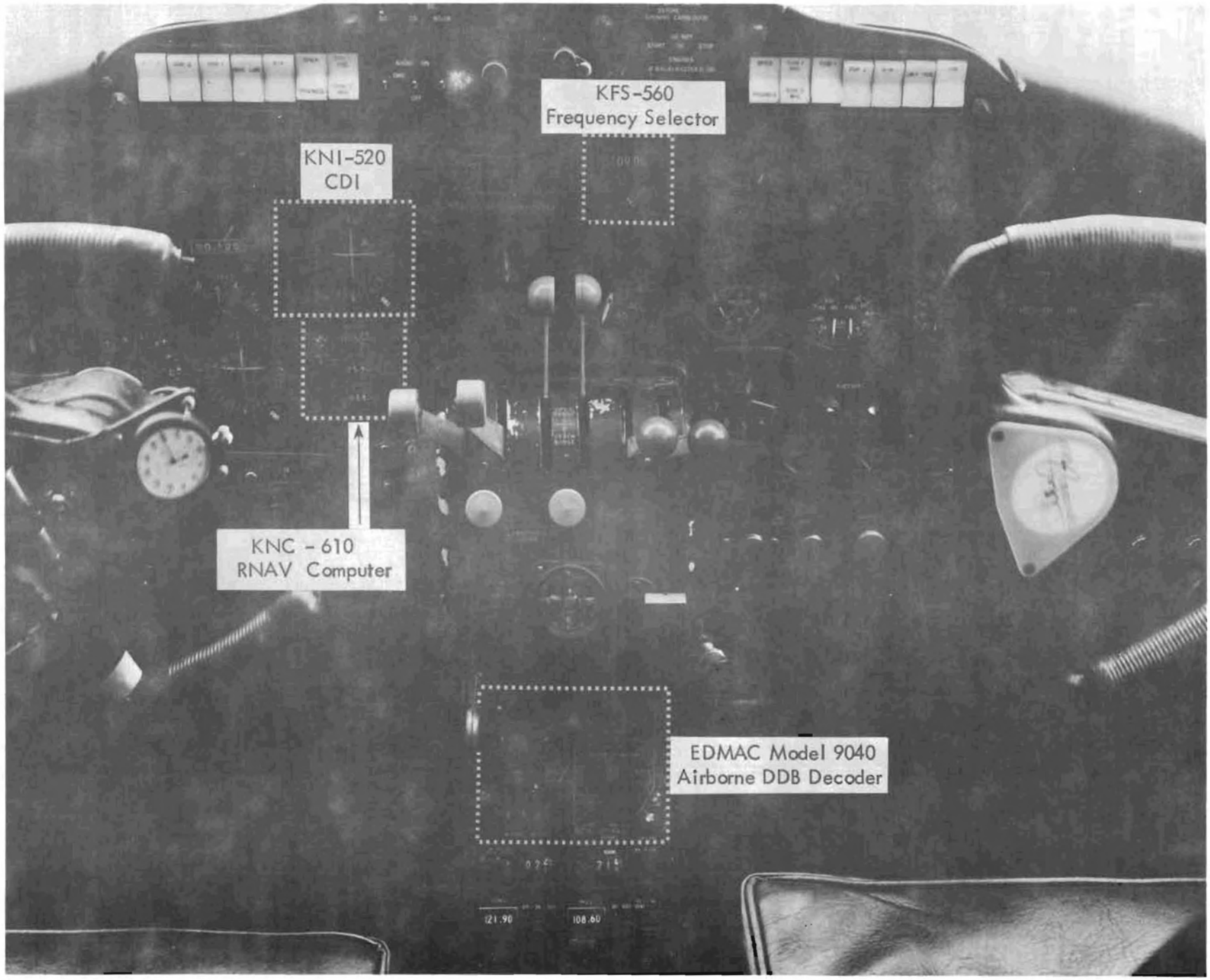


FIGURE C-1. DDB EQUIPMENT ARRANGEMENT IN TEST AIRCRAFT

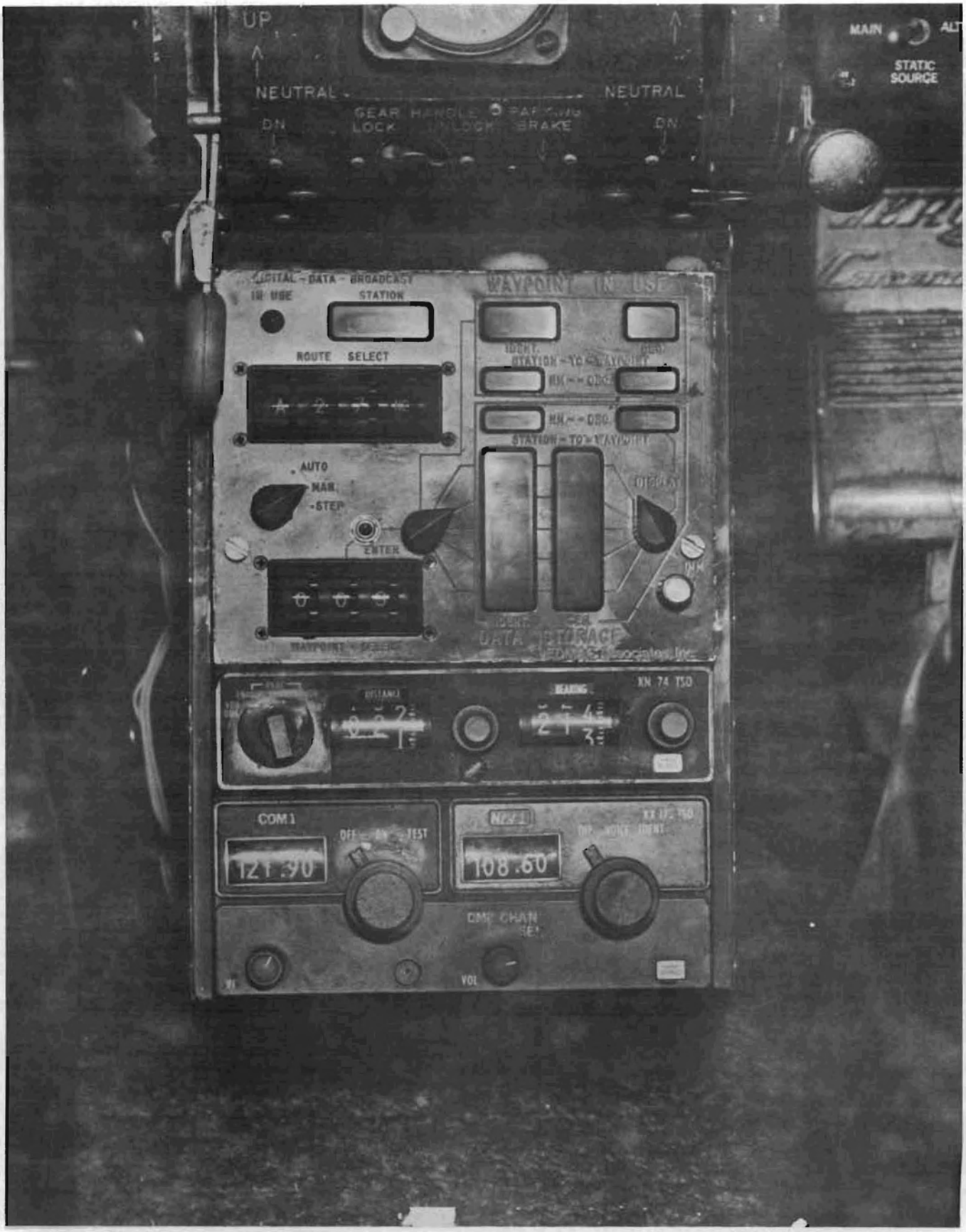


FIGURE C-2. EDMAC MODEL 9040 AIRBORNE DDB DECODER, CLOSEUP VIEW

FIGURE C-3. AERO COMMANDER TEST AIRCRAFT (N3832C) AT NAFEC RAMP

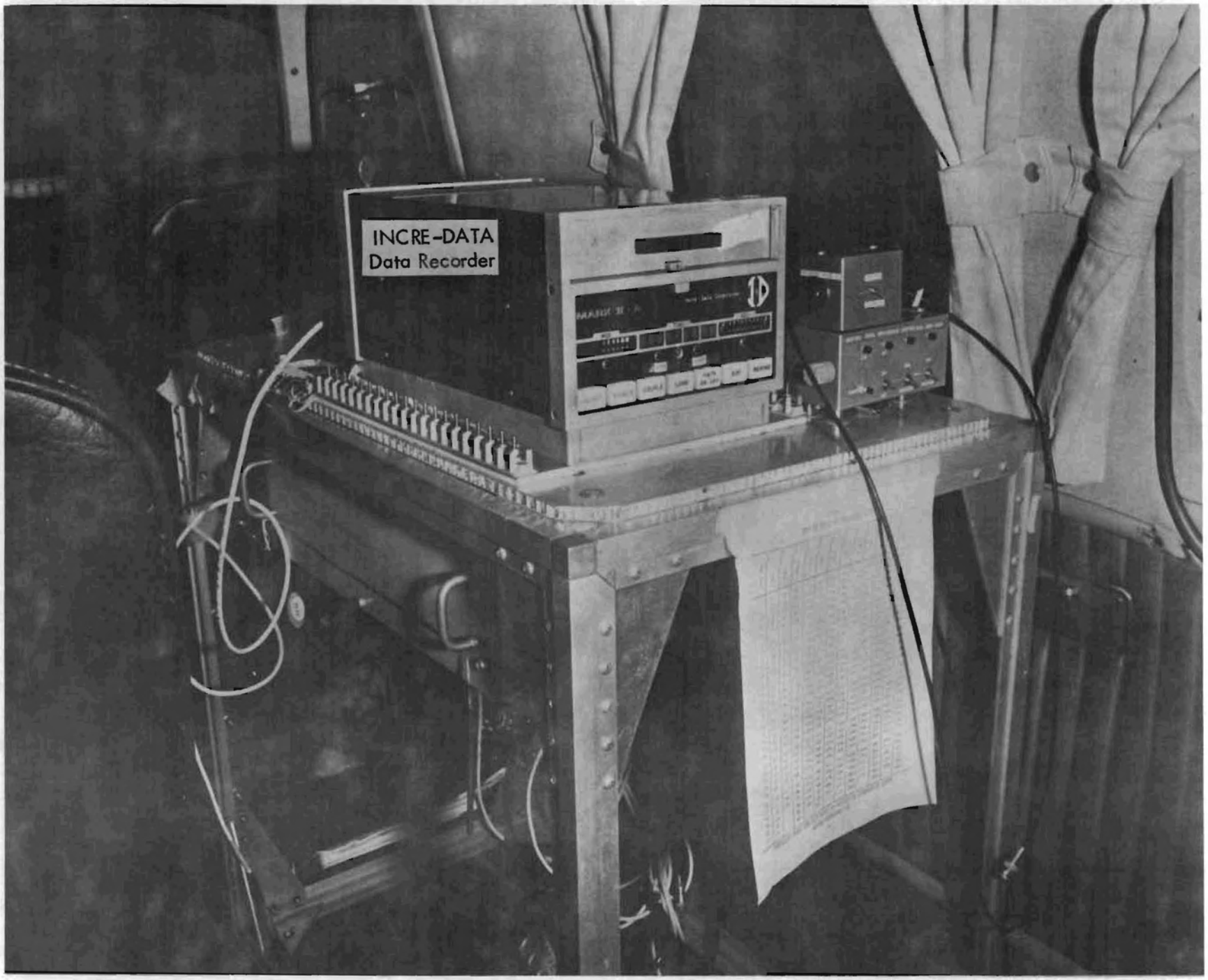


FIGURE C-4. INSTRUMENTATION RACK ABOARD TEST AIRCRAFT