Digital Data Broadcast: An Aid to Area Navigation

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Preliminary analysis has indicated that a digital data broadcast system (DDBS) concept could be applied as a potential solution to the problems of cockpit workload, pilot blunders, and airborne data storage when considered in terms of the utilization of area navigation (RNAV) within our National Airspace System (NAS). The basic philosophy of the program described in this paper was to evaluate concurrently both the operational impact of the DDBS concept under a set of flight evaluations and the technical feasibility of a DDBS engineering model. The principal conclusion of this program substantiates and amplifies the original goals of the DDBS development effort, namely, a reduction of cockpit workload, pilot blunders, and steering errors.

Statement of the Problem

ONE of the identifiable elements of the Upgraded Third Generation (UG3RD) Air Traffic Control (ATC) system currently under development by the Federal Aviation Administration is the concept of area navigation (RNAV). Previous reports[1-3] have shown that the implementation of RNAV into the National Airspace System (NAS) would result in a major operational and economic improvement in both the air carrier and general aviation sectors, as well as to the ATC system itself. Airspace capacity and controller productivity would be demonstrably increased, and significant fuel and time savings would be afforded the airspace users. A necessary corollary to these statements, however, is the consideration of user costs required to achieve these benefits. RNAV equipment costs must match, to some degree, the pocketbooks of the aircraft owners, be they airlines or individuals. Thus there have been developed a wide variety of RNAV computers, ranging in price from $2,000 for a single-waypoint manually operated system, designed specifically for the lower end of the general aviation spectrum, to sophisticated highly automated multifunction systems designed for use in high-performance airline aircraft, which can cost up to $150,000.

It is a continuing anachronism in today's world of advanced technology that avionics systems are designed and built such that the most highly automated aids to navigation and flight control, systems which require almost no pilot operation and intervention, only can be afforded by owners of expensive aircraft, flown by highly skilled, trained, and experienced professional pilots, who, among our overall pilot population, probably need these aids least of all. It is the other end of the spectrum, the infrequent general aviation pilot who must operate in the same airspace, through the same weather, and under the same ATC rules, who needs the maximum of assistance such that his performance, particularly under stress, does not deteriorate to the point where the safety and efficient operation of the overall ATC system is not compromised. It is in this vein that the development and test program discussed in this paper was conceived.

One of the major concerns regarding the operational utilization of RNAV as an integral part of the NAS is the necessary consideration of such interrelated factors as cockpit workload, pilot blunders, and data/waypoint storage requirements for airborne systems. The basic concept of RNAV involves the use of multiple waypoints (or fixes), which define a desired route of flight not constrained by radials emanating from fixed ground navigational facilities, which is the basis of today's VOR (VHF Omnidirectional Range) airways structure. Although the potential of pilot blunders due to cockpit workload may exist during all phases of flight, it is particularly critical during terminal area operations at high-density airports where the cockpit workload, including communications, is traditionally high. In the case of the general aviation RNAV system, the cockpit workload under single-pilot IFR (Instrument Flight Rules) conditions is particularly high, because of the limited waypoint storage and the requirement to insert the waypoint coordinates manually in the terminal area, where the waypoint spacing can be as close together as five miles. Consideration of techniques to minimize potential pilot blunders is a subject worthy of investigation.

Preliminary analysis indicated that a digital data broadcast system (DDBS) concept could be used and applied as a potential means of reducing cockpit workload and pilot blunders. The initial requirements of a DDBS were derived from an operational analysis[4] that preceded the design of

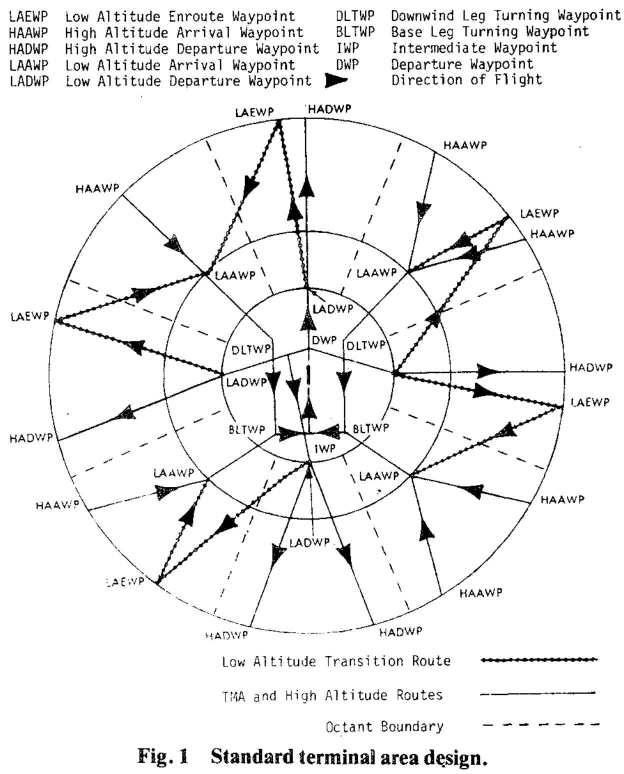

Fig. 1 Standard terminal area design.

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DDB engineering model hardware, and which defined an operational concept and functional requirements for that system. This paper will discuss the flight test of that hardware, and will present the results of those tests in the context of verification of the significance of the DDB through the flight test demonstration.

Digital Data Broadcast Concept

Figure 1 illustrates the standard terminal area design concept, originally postulated by the FAA/Industry RNAV Task Force[5] as a candidate for the application of RNAV to arrival and departure route design. Figure 2 depicts an actual application of this philosophy to the Miami area. Notice the existence of multiple RNAV waypoints, which in sequence define such an RNAV standard terminal arrival route (STAR). Although not all charted waypoints are explicitly required in order to perform this maneuver, all waypoints that define route turn points (HARRIS, BAKER, FROG, KROME) are required, plus additional waypoints, such as PORTLAND. For the simple general aviation RNAV system, the pilot must insert the range and bearing coordinates of each waypoint manually, plus the desired track angle, sequentially after passing the previous one.

Digital data broadcast is a technique in which the DME (Distance Measuring Equipment) [or TACAN (Tactical Air Navigation)] ground-to-air radio link is used to carry RNAV-referenced data into the aircraft. In the engineering model configuration of the system that was tested, 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. These latter two items of information are used in a concept of transmitting the entire sequence of RNAV waypoints, which define a STAR such that the pilot may select only a STAR designator in order to acquire the entire STAR route. This digital information, except for the ground station identifiers, then is decoded, stored, and displayed to the pilot by the DDB airborne decoder. The applicable navigation data decoded by the DDB airborne equipment then are fed into the RNAV computer as required for computations of pertinent RNAV parameters. This automatic acquisition of RNAV waypoint data accomplishes two major goals. First, no pilot workload is involved in inserting these data into the computer, since it is done automatically. Second, no human error can be introduced by missetting coordinates or track information.

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

Table 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

Flight Test Program

The DDB flight test program consisted of a number of subject areas critical to the design, development, and implementation of DDB in the anticipated area navigation environment. The flight test program consisted of six dedicated flight tests for which specific objectives have been defined. Although dedicated flight plans were outlined for each of the problem areas, the primary objectives of the DDB flight test program were: 1) to substantiate the predicted reduction in cockpit workload and pilot blunder 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 flights during the testing period of Sept. 1975 to Nov. 1975. The tests were

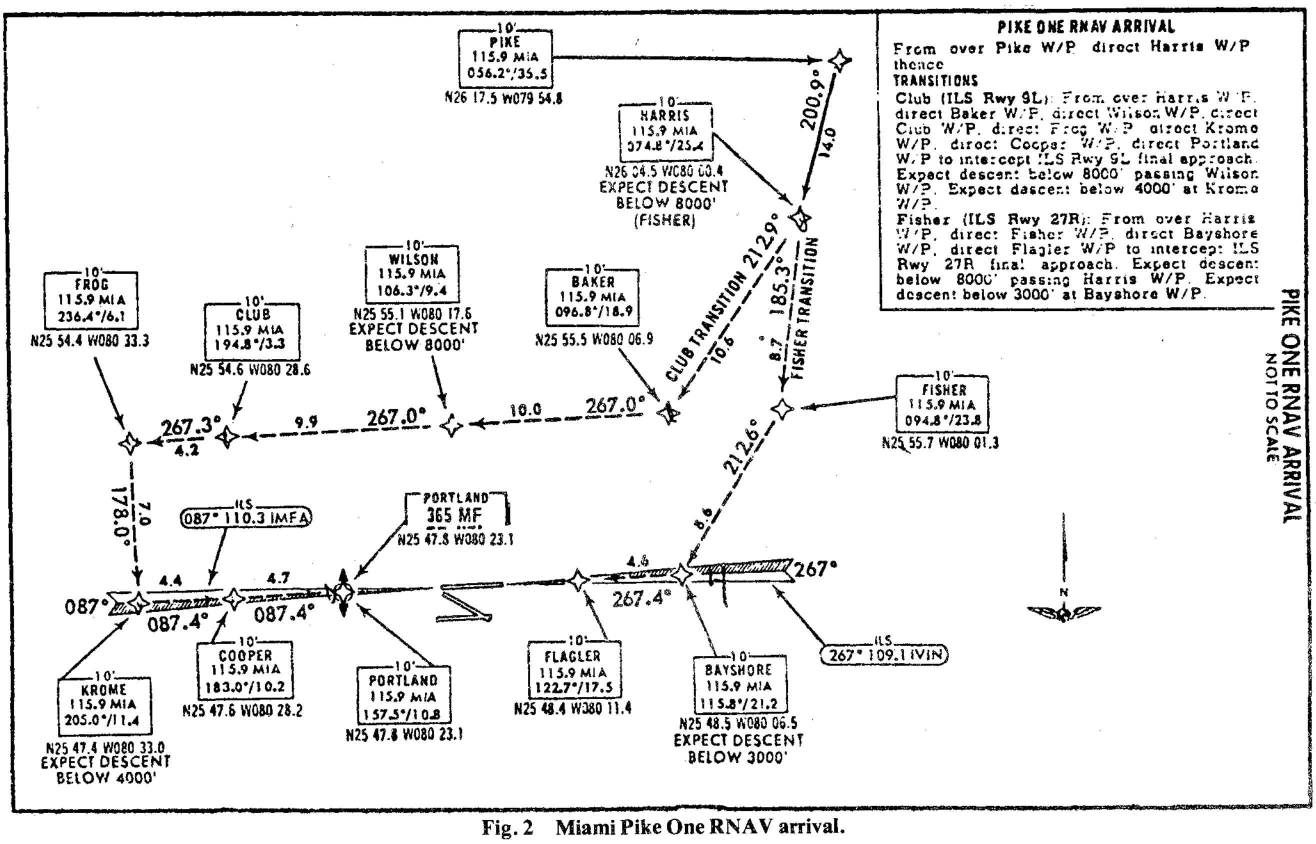

Fig. 2 Miami Pike One RNAV arrival.

conducted at the National Aviation Facilities Experimental Center (NAFEC) at Atlantic City. The tests were performed using the DDB engineering model hardware installed in a contractor-owned twin-engine Aero Commander 500. Airborne data were recorded on a digital data acquisition system, as well as a handwritten flight test log, kept by a trained cockpit observer. The EAIR (Extended Area Instrumentation Radar) tracking radar at NAFEC was used 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 specified waypoints) within the route flown. Specific comparisons were made between blunder data taken during this DDBS test and during a preceding baseline test, using the identical aircraft, test crews, routes, and procedures, while flying in a non-DDBS environment, where all waypoint changes were inserted manually by the pilot.

Objectives and Approach

The primary objectives of the DDBS flight test program were to evaluate both the operational impact of the digital data broadcast concept under a set of operational oriented flight evaluations, and the basic technical feasibility of a selected DDB engineering model hardware unit. Basically, these objectives can be summarized as follows:

1) Substantiate a predicted reduction in cockpit 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, including recommendations for improvements.

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

The basic method of approach was the development of a flight test program consisting of six dedicated flight tests for which specific objectives have been defined as follows:

1) Waypoint Nomenclature – RNC vs DWN: Evaluate the relative merits of two distinct waypoint identification techniques. From the standpoint of operational utility, should the preferred waypoint designation technique be the route numbering concept (RNC) or the discrete waypoint numbering concept (DWN)?

2) Traffic Flow Transition: Evaluate and isolate problem areas (operational and procedural) in the terminal area by using the DDB concept during traffic flow (runway in use) changes and impromptu sequences within a broadcast flow.

3) Waypoint Sequences – Auto vs Manual: Determine from a design requirement whether automatic waypoint sequencing is a desirable system feature.

4) Broadcast Flow Cycle Time: Determine the operational acceptable value of broadcast data cycle time from a minimum of 10 sec to a maximum of 30 sec.

5) Waypoint Storage: Determine the optimum or acceptable number of waypoint storage registers.

6) VNAV Impact: Determine the impact of VNAV procedures on the DDB user, concerning such variables as workload and blunder reduction and improvements in aircraft steering performance.

Subject Pilots

Three subject pilots were used in the DDB flight test program from an original pool of six pilots who took part in a non-DDB general aviation flight test, which was used as a comparison baseline. All of the subject pilots were familiar with RNAV operations and the flight characteristics of the test aircraft, and were responsible for all of the required navigation and communication tasks. All flights were flown simulating IFR conditions by using an in-flight training hood. The safety pilot was the designated pilot in command, and

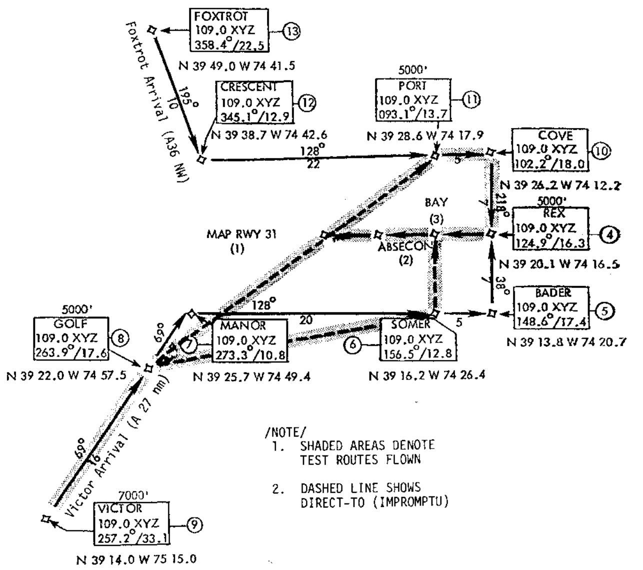

Fig. 3 Northwest RNAV arrivals/Bay transition.

would intervene only 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 1-hr orientation flight prior to collection of flight test data. Pilots did not know when an impromptu traffic flow change clearance would be given. A summary of the subject pilot's experience level is presented in Table 1.

Test Profiles and Flight Test Description

The basic DDB flight test program consisted of flying terminal area SID's (Standard Instrument Departures) and STAR's. A total of three test patterns was transmitted over the experimental VORTAC (VOR colocated with TACAN). Each of the test patterns contains several RNAV departures and arrivals, but all are referenced to a specific runway in use. Figure 3 illustrates one typical pattern.

A total of 36 flights were flown in the DDB flight test program at NAFEC during the testing period of Sept. 1975 through Nov. 1975. Of these 36 flights, 9 flights were for shakedown/pilot orientation purposes, 1 flight resulted in an

Table 2 DDB flight test matrix summary of test variables/subject pilot/number of flights

	Number of flights			
Flight test matrix variables	Subject pilot A	Subject pilot B	Subject pilot C	Total (all pilots)
Number of flights	16	6	4	26
Waypoint sequencing				
Auto mode	8	3	2	13
Manual mode	8	3	2	13
Waypoint selection				
RNC	8	4	2	14
DWN	8	2	2	12
Approach-descend				
2D RNAV	8	4	2	14
3D RNAV/VNAV	8	2	2	12
Waypoint storage				
2W/P	4	1	2	7
6 W/P	12	5	2	19
Traffic flow cycle time				
10 sec	8	4	2	14
30 sec	8	2	2	12
Traffic flow change arrivals	8	3	2	13
Impromptu				
GOLF-SOMER-BAY (2)	4	1	1	6
GOLF-PORT	4	2	1	7

abort due to ground station problems, and 26 flights were for data collection purposes. Table 2 shows a summary of all test variables per subject pilot per number of flights. It is presented mainly to denote the balanced characteristics of the DDB flight test matrix. The variables contained in this table correspond to the issues previously identified as test objectives. The 40-60% split between 2 and 6 waypoint storage tests was pre-established during test planning.

Data Acquisition/Reduction

Airborne Instrumentation

The test aircraft included the following airborne instrumentation for real time recording on a Incredata data recorder, mounted on an onboard instrumentation rack: 1) cross-track deviation indicator (CDI), 2) distance-to-waypoint (DTW), 3) DME, 4) vertical track deviation (VNAV), 5) real time, and 6) event marker. Calibrations of the preceding applicable flight instruments were performed prior to and subsequent to the overall flight test program to assure the accuracy of the RNAV associated airborne equipment.

Ground Referenced Data

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

Cockpit Observer Flight Logs

During all flight tests, a trained cockpit observer monitored and kept 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. Following is a summary of the flight test data recorded by the cockpit observer pertinent to the relative evaluation of test objectives:

1) Verification of waypoint information (ρ,θ) being received (waypoint in use plus whichever selected position is in the display select control).

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

3) Procedural/blunder error, defining most probable cause.

4) Cockpit workload, particularly during impromptu maneuvers and final approach phase of flight.

5) 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.

6) ATC clearances/traffic conflicts.

7) Cross check of the following instruments and/or indicators: CDI, to/from flag, heading, airspeed, DTW, loss of DME signal, and altitude.

8) Verification of OBS (Omni-bearing selector) course selected.

9) Enroute/approach (CDI sensitivity changeover).

10) VNAV procedures.

Flight Reports

A brief summary of flight test results was 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 the flight testing.

Blunder Analysis

The data obtained during the DDB flight test program regarding the number, frequency, and types of pilot blunder data recorded were presented herein. Of 26 data flights flown by 3 subject pilots, only 4 pilot-induced blunders were recorded. These results indicate a positive reduction in pilot blunder afforded by the use 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 3. An analysis of these data indicates that only 2 of the 4 blunders resulted in a violation of protected airspace as defined by projected RNAV route design criteria.

In order to assess the DDB potential for a reduction of pilot-induced blunders, a comparison of blunder error data was made between the DDB flight test program and the preceding non-DDBS general aviation RNAV flight tests. These tests were chosen because they consisted of an almost equal number of flights (30) and because they used, 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 all three of the subject pilots were used during the general aviation flight tests. Figure 4 is presented to show the pilots' RNAV control errors, by type, during the previous non-DDB general aviation RNAV flight tests. An examination of this figure indicates that a total of 31 subject pilot errors recorded in the DDB flight test, there is an approximate 87% reduction in the pilots' blunders which logically is attributable to the use of the DDB concept. Further inspection of Fig. 4 reveals that the most common (6) error was the setting of VNAV desired altitude (30 VNAV operations were required). During the DDB tests, no VNAV (waypoint altitude set) errors were recorded (24 operations were required). There were 248 OBS operations in Ref. 6 with 6 errors recorded, vs 228 OBS operations in the DDB tests with just 1 error recorded. Additional inspection of Fig. 4 (non-DDB) indicates that a total of 7 errors were documented concerning waypoint radial or distance input errors, against none for DDB due to the inherent hardware/software capabilities. 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.

Operational Evaluation of the DDB Concept

This section will document the operational evaluation and use of the DDB engineering model and the performance characteristics of the DDB concept as tested during the flight evaluation conducted at NAFEC. Although several hardware and software malfunctions were experienced using the DDB engineering model unit, the operational evaluation of the DDB concept produced extremely positive results with regard to the benefits afforded by the integration of such a concept into the real-world ATC environment.

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 definition. This critical navigation input, particularly in the final phases of the terminal area transition, is very time-critical in conventional general aviation RNAV systems. The DDB 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.

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

Perhaps the single most significant advantage of the DDB concept is the elimination of RNAV waypoint definition input errors. Documentation from previous general aviation flight tests of blunder data of a conventional RNAV system verifies 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 possibly catastrophic errors, resulting in the pilot flying the aircraft off the desired flight profile either vertically or horizontally because of an undetected error in entering the Rho/Theta.

Table 3 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 insufficient DDB training. Transition was from D24SE departure (pilot changed D to A only).	No
B	Selected wrong waypoint (DWN method)	Selected waypoint COVE (WP No. 10) instead of PORT (WP No. 11). Pilot noticed error in less than 2 minutes.	High workload due to impromptu traffic flow change followed by a direct-to clearance.	No
C	Lost RNAV guidance (DWN method)	Pilot did not make provisions for acquisition of next waypoint after the active waypoint would sequence out. (Auto mode was selected).	Pilot was limited (test) to a maximum use of 2 waypoints storage.	Yes
C	OBS	Selected an OBS of 038° instead of 120°. Pilot misread the RNAV charts (OBS of 038° is for final approach segment).	Pilot was distracted while listening to extraneous radio communications.	Yes

In the final portion of the RNAV STAR, the task of Rho/Theta input adds a great deal of workload and stress to the pilot, primarily because of the close spacing of the waypoints and additional cockpit workload characteristic of terminal area maneuvers, as discussed previously. Under these high workload situations, previous flight tests[6] have shown that the pilot can make several types of RNAV Rho/Theta input errors. These errors can be grouped into general categories:

1) Transposition of the Rho/Theta values (example: distance 25 n.mi., bearing 047°, becomes distance 47 n.mi., bearing 025°).

2) Using the Rho of one waypoint and the Theta of another waypoint from the RNAV chart.

3) Misplacing the decimal in entering distance information (example: 2.5 n.mi. becomes 25 n.mi.).

4) Transposing numbers from the chart in data entry (example: 331° becomes 313°).

The DDBS, through the use 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 errors and blunder errors during this evaluation. A comparison with previous flight tests, as shown in the preceding, quantified 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 alleviated significantly by use of the DDB concept.

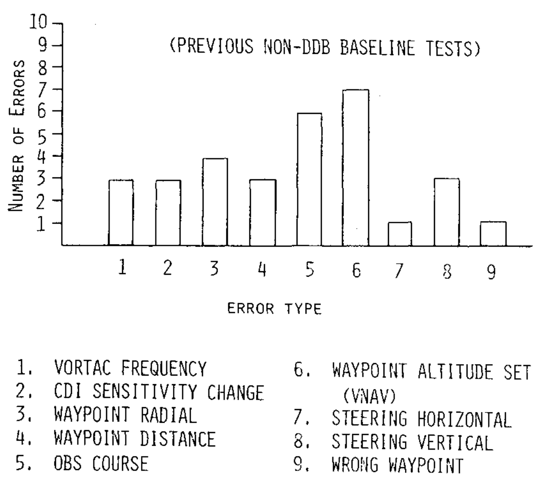

Fig. 4 General aviation RNAV flight test pilot RNAV control errors by type.

Effect of DDB on Aircraft Control Task

The terminal area transition, as stated previously, 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 that are not directly related to navigation tasks. These tasks include such items as 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. 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.

Effects of DDB on Navigation and Communication 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 that the pilot devote more attention to the communication workload in order to plan well ahead of the aircraft, to effect the proper transition or modification of the terminal route because of 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; thus flow changes and transitions are defined through ATC selection of the desired flow rather than pilot selection. This benefit is not only in 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 because of the decreased workload and increased time available through the use of the DDB concept. One of the most important considerations in terminal area operations relates to efficient airspace utilization through reduced flight technical error (FTE). Although there are many factors to consider in evaluating FTE, such as ground navigation signal 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.

Positive Identification of Waypoints

Perhaps the major disadvantage of the current RNAV concept is that there is currently no means to identify 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. The use of RNAV involves selecting the appropriate VORTAC, then defining the Rho/Theta of the waypoint. 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, uses a system that gives positive identification of the waypoint. In the DDB engineering model this consisted of both a discrete waypoint identification number, as well as a waypoint sequence number. This 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. 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.

Automatic Assembly of Waypoints Comprising RNAV SID and STAR Routes

In conjunction with other features previously defined using DDB, the ability to designate and verify a terminal route automatically is a significant benefit. The elimination of the workload in defining each waypoint that comprises a SID/STAR route allows the pilot the 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 (Control/Display Unit)-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 succeeding waypoint, the last register becomes free to acquire additional waypoints that might make up the individual SID/STAR route. The waypoints comprising the RNAV routes are assembled and transmitted in the order 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 aids, noise abatement, etc.

The benefits of the automatic assembly of the terminal navigation route and the storage expansion capacity 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 execute this normally complex transition properly with a minimum workload effort by use of the RNC six-waypoint method.

Impact of DDB on RNAV Impromptu Route Definition

The ability of the DDBS to simplify the adaptation to impromptu traffic flow changes is also a significant operational benefit of the DDB concept. In addition to the advantages listed previously, which simplified the pilot workload and the data input and verification task, the DDB provides a significant advantage over multiwaypoint RNAV systems with CDU and FDSU (Flight Data Storage Unit) 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 with 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. All of the considerations involved in defining the route as discussed in the previous sections now are 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 reduced considerably. The DDS system makes this task extremely simple, and virtually blunder proof; the only workload involved is in the selection of the designator for the new route. Then the pilot navigates the aircraft directly to the transition waypoint after the route data have been acquired automatically by the DDBS. The potential benefits of increased efficiency and reduced airspace utilization are apparent in consideration of the differing tasks that are to be performed in the limited time frame by the pilot.

Conclusions

These conclusions are based on a comprehensive qualitative analysis of the performance and operational characteristics in addition to the basic technical design feasibility of flight tested DDB engineering model airborne equipment. These conclusions include an operational evaluation of the DDB concept in the terminal area based on the available data. The following major conclusions from the results of the DDB flight test program can be summarized as follows:

1) DDB reduces pilot blunder.

2) DDB reduces cockpit workload.

3) The preferred waypoint designation technique is the RNC.

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

5) The maximum (allowable) digital broadcast data flow cycle time is 30 sec.

6) Manual waypoint sequencing is preferred to that of automatic waypoint sequencing.

7) The minimum DDB waypoint storage capacity should be six waypoints.

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

The DDB concept offers an effective solution to some potential problems that could affect the successful implementation of RNAV in the NAS. These problems include the high cockpit workload associated with non-DDB RNAV, and the 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) the potential of reducing cockpit workload and providing the pilot with the time that is necessary to concentrate on the task of aircraft control, navigation, and ATC interface task; and 2) the elimination of RNAV waypoint definition errors that have the potential of creating unsafe navigation guidance.

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