NASA CR 137680

IMPLICATIONS OF

EQUIPPING A DC-8-61 FLEET

WITH RNAV/TWO-SEGMENT APPROACH AVIONICS

("Fleet Retrofit Report")

February, 1975

Prepared under Contract NAS 2-7475

by

UNITED AIRLINES

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Ames Research Center
Moffett Field, California

Prepared by:

Erik B. Anderson
Assistant to the Program Director

Approvals:

Gordon W. Brown
Manager, Flight Operations

George K. Schwind
Program Director

Kent R. Bourquin
NASA Technical Monitor

(NASA-CR-137680) IMPLICATIONS OF EQUIPPING A DC-8-61 FLEET WITH RNAV/TWO-SEGMENT APPROACH AVIONICS (United Air Lines, Inc.) 14 p HC $3.25 CSCL 17G G3/04

N75-23544

Unclas

19201

TABLE OF CONTENTS

INTRODUCTION

This report was completed as a part of United Airlines work under contract to NASA to develop, flight test, and evaluate an area navigation (RNAV) system modified to provide flight guidance for making two-segment noise abatement approaches.

The scope of this report is to discuss the implication of equipping United's fleet of 30 DC-8-61 aircraft with RNAV two-segment approach avionics. The basis for making this assessment is the experience obtained in the evaluation program under contract with NASA. This evaluation included development and evaluation of the procedures in a flight simulator, installation of a Mark II area navigation system in one DC-8-61 aircraft, development and evaluation of RNAV/two-segment capabilities out-of-service by the project team, out-of-service evaluation of the procedures by representatives of the industry, and an evaluation by line pilots in regular air carrier service. Although the basis of this estimate is a Mark II system, and United is not considering installation of this type of equipment, the estimates herein should be valid for other RNAV systems presently being considered for future installation by airlines.

In this report it is assumed that RNAV systems are installed and operating prior to the addition of a two-segment approach capability, and that the costs of the RNAV have therefore been justified without regard to its potential in providing two-segment guidance. This is an important provisio which must be kept in mind throughout the reading of this report. An attempt has been made to answer some of the most important questions raised by this assumption without allowing the report to become overwhelmed by the complex issues involved in the RNAV implementation question. It is also assumed that a two-segment requirement would affect all narrow-bodied aircraft rather than just DC-8-61s.

The submittal of this report should not be construed as indicating that United Airlines has determined that two-segment approaches or area navigation operations should become standard air carrier procedures, nor that United Airlines intends to implement any of the procedures or policies referred to or implied in this report.

SUMMARY

Due to the costs of implementing two-segment approaches with special purpose computers, and the fact that such systems rely on special ground equipment not generally in use today, it is useful to consider the possibility of adding a two-segment approach capability to area navigation (RNAV) systems. Although RNAV is not widely used in the present ATC environment, it is foreseen as an important factor in the ATC system of the future.

The addition of the capability to provide two-segment approach navigation in an RNAV system which already interfaces with the standard Instrument Landing System (ILS) is estimated to cost $1430 per aircraft. This includes the cost to add an approach progress display, to make necessary modifications to RNAV software, and to develop special approach plates. The necessary aircraft modifications could be incorporated within 1 1/2 years without requiring special aircraft out-of-service time. It is assumed that line pilot and maintenance personnel training could be incorporated in existing recurrent training programs, and that incremental costs associated with such training would therefore be negligable.

The cost estimate is extremely sensitive to the assumptions made, particularly with regard to the "base" RNAV system to which the two-segment approach is added and the extent of growth provisions made at the time RNAV is installed.

INSTALLATION

Philosophy of Incorporation

Two-Segment Mechanization: RNAV versus Special Purpose Computer

The implications of installing dual special purpose analog computers to provide a two-segment approach capability are presented in NASA CR 137586. (Ref. 1) The conclusion of that report was that such a system could be installed at a cost of $37,000 per aircraft assuming the system could be installed concurrent with airframe overhaul. The advance notice of proposed rule making (Ref 2) issued by FAA on the subject of "Two-Segment ILS Noise Abatement Approaches" assumed this type of system would be used. However, a number of factors make it worthwhile to consider the possibility of modifying area navigation (RNAV) equipment to provide the same capabilities.

Installation of special two-segment computer systems concurrent with airframe overhaul extends the implementation period to nearly a decade. On the other hand, installation of such systems over shorter periods of time increase the costs significantly due to aircraft out-of-service time required for such installations. When reasonable implementation periods are considered, it is noted that area navigation systems may be becoming a significant factor in the airline environment in the same time frame. This, together with the fact that RNAV systems include most of the aircraft systems interface necessary for a two-segment capability and thus significantly reduce implementation costs, make RNAV an attractive alternative to special purpose computers for providing two-segment approach guidance. At the same time, consideration of RNAV's capability to provide for two-segment approaches raises serious questions about the justification of special purpose computer installations which could become obsolete as soon as RNAV was installed.

The special purpose computer technology which has proven operationally acceptable for two-segment (ref. 3) relies on a Distance Measuring Equipment (DME) transmitter collocated at the Instrument Landing System (ILS) glideslope transmitter to provide the special guidance system with the distance-to-touchdown information necessary to accurately and consistantly position the noise abatement upper segment with respect to the runway. The primary disadvantage of this system is this requirement for special ground equipment. Although ILS systems are installed at approximately 500 runways in the U.S., collocated DME's are installed at less than 20 of these. The FAA estimates the cost of DMEs to be $50,000 each or $5 million for the 100 runways proposed in the 1974 ANPRM (Ref 2). In constrast, RNAV systems provide a means to implement precision two-segment approaches at most runways now equipped with an ILS system without requiring additional ground facilities, and in addition provide non-precision two-segment approaches at most runways not equipped with instrument landing aids.

A Prognosis for RNAV

The key question with respect to RNAV is "when?" If the Government determines that two-segment approaches are in the public interest, it must then determine a realistic RNAV implementation schedule to assess whether or not limited and more costly systems for two-segment approaches can be justified in the interim. Without considering the timing aspects, RNAV has a clear cost-benefit advantage over special purpose systems for two-segment approaches if the RNAV system are installed for other purposes. Modifications to add two-segment to RNAV are less expensive and at the same time provide the capability at many more runways than the special purpose computer.

In a January, 1975 magazine article David R. Israel, FAA Deputy Associate Administrator for Engineering and Development, made the following statements regarding RNAV:

> "Intergration and utilization of RNAV in "two-, three, and four dimensional" versions is a goal of the upgraded third generation [National Airspace] System.... The problems with RNAV are related less to equipment development than to proper intergration of the capability into the existing ground-based system. An active study of possible features and cost-benefits of area navigation capabilities is now underway... It is possible that by 1980 the en-route airways structure at high altitudes and in those dense terminal areas where positive control is exercised will be almost entirely based on area navigation capabilities." (Ref 4)

In 1973 the FAA/Industry RNAV Task Force issued a detailed report discussing the application of RNAV to the airspace system (Ref 5). This report describes the various steps required to implement RNAV in terms of concepts labeled "1972," "1977," and "1982." It appears, however, that actual implementation is about 5 years behind this conceptual model. When and if UA decides to install RNAV, it is estimated that fleet-wide installation will require at least 5 years.

The airlines (through the Air Transport Association -ATA) have recognized the potential improvements in air traffic management that are available through the application of area navigation. However, ATA Operations policy on RNAV is that the continued airline endorsement of an area navigation oriented ATC system is contingent upon the FAA demonstrating specific quantitative substantiation of the cost benefits to be derived to the airlines and ATC (Ref 6). The FAA has undertaken simulations of RNAV oriented enroute and terminal area ATC environments to assess the specific economic justification. If RNAV is justified, then a realistic schedule for RNAV implementation must be set forth. After such a schedule is determined, the Government can make a valid cost-benefit assessment of special purpose and RNAV implemented two-segment installations which includes consideration of timing aspects which may significantly affect both costs and benefits.

RNAV System Two-Segment Capabilities

Collins ANS-70A

The Collins Radio Co. ANS-70A Automatic Navigation System used in the evaluation of RNAV/Two-Segment approaches is an ARINC 582 Mark II* area navigation system. This system was previously certified on the Gulfstream aircraft. Reference 7 is a complete operational description of the basic system. The system provides navigation capability using a general purpose digital computer to statistically filter and combine navigational data from radio, magnetic, and air data systems. The system provides the capability to automatically navigate over a complete vertical and lateral flight plan and select navigation radio frequencies. It can display a complete array of flight performance data in addition to the crew selected and fully editable flight plan. The only capability described in Ref. 7 which was not included in the evaluation installation was the arm-to-capture the flight plan vertical profile. However, only certain terminal area operations for two-segment approaches were certified for use in revenue service in this evaluation.

The software modifications required for the addition of the two-segment approach capability to the ANS-70A were in four categories: data base, input/output functions, navigation functions, and logic functions. The extent of these revisions are detailed in Section 5 of the Reference 9.

The data base handling was changed from the normal ANS-70A load-from-tape-as-needed basis to a "tabled" data base in which all navigation data necessary for this program was stored in the computer memory. This was done because of the limited memory in the hardware/software system used, but should not affect implementation in future systems.

Most of the input-output changes required related to interfacing the ANS-70A with the existing aircraft equipment complement or to meet UA operational requirements. The only additions to input-output functions related directly to two-segment were approach progress display outputs and CDU outputs of maintenance related information (abort codes and approach state numbers). ILS inputs had to be added, but the ARINC Mark II specification reserves pins for ILS augmentation regardless of the two-segment capability.

The use of ILS inputs was the primary source of changes to the navigation functions of the basic system. An RNAV system installed without regard to two-segment approach requirements may interface with the ILS, in which case most of the navigation changes and many of the logic changes necessary for RNAV/ILS two-segment approaches would have already been part of the system.

---

* ARINC numbers are designations of "characteristics" developed by Aeronautical Radio, Incorporated which are used as a means of providing various standards for airborne equipment.

Numerous modifications were made to the basic RNAV program logic including special rules for handling waypoints defining the approaches, special radio tuning logic, progress annunciation logic, and safety protection logic. Except for the radio tuning logic, most of these changes are directly attributable to the addition of two-segment, but some of them would be necessary (albeit in a less complex manner) in any RNAV system interfacing with the ILS.

A single system interfacing with the Captain's displays and sensors was evaluated although UA would install dual RNAV systems in any fleet-wide installation. Dual systems may result in cross-cockpit discrepencies in guidance information. Among those airlines desiring dual installations questions regarding the extent and means of reducing these discrepencies within the individual airlines' philosophies of dual system independence should be resolved through consideration of non-two-segment RNAV terminal area and approach guidance, and should not be affected by a decision to add a two-segment capability.

Other RNAV Systems

Any RNAV system which includes a vertical navigation (VNAV) capability is fundamentally capable of providing guidance to intercept the ILS glideslope at some predefined point. It is important to realize, however, that the two-segment approach developed for operational acceptability includes certain features which are deemed necessary but which are not included in the basic RNAV concept.

In order to assure a smooth transition with full guidance between RNAV and the ILS, it appears that ILS processing within the RNAV system is necessary. This is due to the fact that the RNAV may place the aircraft in such a position that existing autopilot and flight director glideslope capture and track control laws are not useable. Both the ARINC Mark II and Mark 13 specifications currently reserve pins to bring ILS information into the RNAV, and examples of both types of systems have successfully demonstrated hybrid RNAV-ILS operation. In addition, the experience gained from the present evaluation indicates that the vertical and lateral navigation functions should be decoupled as much as possible. This would allow, for instance, the initiation of a two-segment vertical profile without regard to lateral flight plan as well as the capability to track localizer while on RNAV vertical guidance.

Even the capabilities to provide VNAV and process ILS signals do not assure an RNAV system's adaptability to two-segment. Special logic capabilities must be provided, particularly safety protection logic to prevent unsafe guidance caused by errors or malfunctions in input systems or within the RNAV. The RNAV must therefore be able to discriminate between normal and two-segment operations in order to properly cue these various safety protectors when applicable. This discrimination requires either a pilot input to the system or the ability to identify specialized data base within the system. Similarly, approach progress annunciation must be provided to meet an operators requirements, and the RNAV hardware and software must therefore be capable of providing such specialized outputs. In short, from the RNAV system's point-of-view, a two-segment approach is more than just another set of vertical and lateral waypoints. This is true for non-precision RNAV/RNAV approaches as well as those which interface with the ILS.

Interfacing Aircraft Systems

Installation of an RNAV system is a major undertaking. By its nature it interfaces with many of the navigation and guidance sub-systems in the aircraft. However, most of the interfaces required for RNAV/Two-Segment Approaches would be included in an RNAV system installed without regard to two-segment capabilities.

In this report it is assumed that if an RNAV system were installed which was designed for terminal area as well as enroute operations, interface with the ILS system would be completed to allow continuous operation from RNAV into standard ILS approaches. Such an interface requires separate VOR and ILS radios rather than combined receivers such as are typical today. Policy decisions regarding such issues as auto/manual-tuning configuration and the extent of reversionary (non-RNAV) capabilities can be made independent of two-segment approach considerations. However, the capability to revert from RNAV/ILS two-segment operations to standard ILS operations in case of an abort due to the two-segment protection features must be maintained. In the evaluation installation a switching unit provided reversionary capability which restored the aircraft interface to the non-RNAV state. In an installation without a hardware implemented reversionary mode, a means should be provided to quickly rever the RNAV system to pure ILS operation.

If an RNAV system were installed which did not interface with the ILS, a non-precision RNAV/RNAV two-segment capability could be added with about the same impact as is discussed in this report. However, the addition of a two-segment RNAV/ILS mode would be more complex than is assumed here. ILS augmentation would require an additional input card in the RNAV (approximately $500 per computer), and changes in navigation radio receiver requirements to allow simultaneous VOR and ILS tuning.

One hardware requirement for two-segment approaches which may be an addition to the RNAV system is the Approach Progress Display (APD). If the RNAV system includes a sophisticated mode annunciator, display of the approach event progression may be incorporated in such an annunciator, but for purposes of this report it is assumed that an APD would have to be added. For example United's DC-8's do not have a mode annunciator suitable for modification to two-segment use. On the evaluation aircraft, therefore, a modified B-727 type APD was added for use during RNAV/Two-segment approach operations. This unit was not used for standard ILS approaches on the DC-8 (as it is in the B-727), but it could be readily adapted to use for more than just two-segment approaches.

OPERATIONS

Fleet Build-Up

Given that the fleet is already equipped with RNAV, the phasing in of a two-segment capability would not present any major problems. If the aircraft is fully modified for the two-segment capability at the time the RNAV equipment is installed, the two-segment approach could be activated throughout the fleet virtually instantaneously with the issuance of the RNAV software which completes the two-segment capability. If, on the other hand, any system interface or equipment installation (e.g. approach progress display), remained to be completed after the RNAV is installed, it would probably be no more than could be accomplished during any regular aircraft service visit requiring one shift (8 hours) or more of elapsed time. For example, at UA such work could be coordinated with maintenance checks which occur approximately annually on each airframe. In such a situation fleet wide activation could be accomplished in about a year. (Current DC-8-61 Maintenance Check interval is 11 1/2 months, current maximum for any fleet is 14 1/2 months.)

If hardware modifications to the RNAV components were required, these could be coordinated with the aircraft modifications. The typical method for accomplishing this is to modify all spare components prior to the initiation of the aircraft work, and then install a modified unit on the aircraft if one has not been installed through unit replacement prior to the time of aircraft modification. This method requires that the hardware modifications do not interfere with the unit's operation in unmodified aircraft, which should not be difficult to insure for this type of change.

Crew Training

Qualified pilots should be able to satisfactorily execute two-segment approaches in line service without simulator training. However, one practical means of qualifying pilots would be to incorporate the two-segment approach into the present curricula of recurrent pilot training. This could be done with insignificant initial investment and incremental recurrent costs.

Those pilots not previously qualified on the DC-8 could be qualified for two-segment approaches during their initial DC-8 transition training.

System Maintenance

Prior to the addition of a two-segment approach capability, the complex interface of the RNAV system with many other aircraft systems will require sophisticated maintenance procedures to provide adequate troubleshooting and fault isolation. Since the RNAV computer will be the central input/output point of the aircraft navigation system, it is logical that it be called upon to provide a significant amount of maintenance assistance. This can be provided through maintenance annunciators and self-test capabilities. The RNAV control-display unit can be utilized as a means of maintenance interrogation/annunciation.

The addition of two-segment approaches to the RNAV system should include additional maintenance assistance due to the safety protectors which are part of the approach. It is frequently not obvious to the flight crew that an abort is caused by something external to the RNAV, or even external to aircraft. This information must be available either to the crew or to maintenance personnel to avoid unnecessary removal of serviceable equipment. The potential of digital RNAV systems to provide this type of information was demonstrated during the evaluation program by the abort code display.

Maintenance testing of the RNAV system, either functional checks after component replacement or operational checks for overhaul level maintenance should not be significantly affected by the addition of a two-segment approach capability. The addition could be adequately covered in revisions to existing RNAV system maintenance and overhaul reference documentation and to mechanic training curricula.

COSTS

Initial Costs

Costs to retrofit an existing dual RNAV system to incorporate a two-segment approach capability are extremely sensitive to a number of factors. These include the characteristics of the existing RNAV system with respect to growth provisions and the facility of adding to or changing existing system logic, and the extent, if any, of aircraft interface provisions installed at the time the RNAV system is originally installed.

The ARINC Mark II specification reserves pins for ILS inputs to the computer, and Collins Radio has estimated the cost of ILS input cards required to be $500 each ($1000 per dual installation) based on a quantity of 200 cards. However, it is assumed here that the existing RNAV system interfaces with the ILS system for the purpose of making an automatic transition from RNAV to ILS flight modes prior to adding two-segment approaches to the system. As previously discussed, the system must also have certain growth capabilities with respect to discrete inputs and outputs, as would be necessary to drive an approach progress display for example. It is assumed that the wiring provisions for such discretes required for a two-segment approach capability would be completed at the time the RNAV systems are installed. Utilization of such provisions, it is assumed, would at most require the installation of connectors.

Approach progress displays are estimated to cost $350.00 each, and other hardware may cost an additional $50.00 per aircraft. Installation could be accomplished in approximately 10 man-hours (2 hours of sheet metal work and 8 hours of electrical work). At $20 (fully burdened) per hour, labor costs would be $200. Engineering costs on a per aircraft basis would be negligable. The total cost of a dual APD installation is therefore estimated to be $950.00. The cost of similar modifications to flight simulators would add about 3% or $30.00 on a per aircraft basis.

The equipment manufacturer software development costs are estimated to be $100,000. Since two-segment approaches would likely affect at least the entire narrow-bodied fleet of 330 aircraft rather than just DC-8-61s, this cost would be written off at a rate of about $300 per aircraft. As with the aircraft hardware installation costs, the software costs are sensitive to the provisions and capabilities included prior to the addition of two-segment approach logic. " It becomes very expensive very rapidly to add software to a computer that is approaching saturation. " (Ref 9).

The one time costs to modify flight crew training materials and to update maintenance reference information is assumed to be negligable on a per aircraft basis. If the entire industry required 800 new approach plates, the cost to United on a per aircraft basis (again based on all 330 narrow-bodied aircraft) is estimated to be $150. Based on these assumptions, and others in this report as applicable, the initial costs of providing a two-segment approach capability in an existing RNAV system are estimated to be $1430. per aircraft.

Recurring Costs

If the software required to add two-segment approaches to RNAV includes revision to the self-test and/or maintenance assistance routines in the RNAV system, additional recurring maintenance on the system should be minimal in comparison to the entire RNAV system maintenance costs. It should be emphasized, however, that this will be strongly affected by the quality of initial flight crew and maintenance personnel training and of maintenance troubleshooting assistance provided by the RNAV system itself and mechanic reference documents. The two-segment approach includes the addition of safety protection logic which, if not fully understood, could easily lead to the needless removal of serviceable avionics.

The potential impact of two-segment approaches on fuel costs have been a source of speculation throughout the program. This subject was not specifically investigated. In Reference 1 it was estimated that fuel savings due to lower power settings on the upper segment may be of the same order of magnitude as additional maintenance costs for a special purpose computer system. Conversely, during the DC-8/RNAV program it appeared that extended downwind legs might be required to allow a minimum length upper segment within certain logic constraints of the system developed, thereby adding to fuel costs. More recently, however, indications are that the logic constraints can be overcome in such a way that extended downwind legs would not be required. The fuel savings due to lower power on the upper segment is a qualitative observation in need of quantitative investigation.

References

1. United Airlines, Fleet Retrofit Report, NASA CR 137586, July 30, 1973.

2. Department of Transportation - Federal Aviation Administration Two-Segment ILS Noise Abatement Approach: Advance Notice of Proposed Rule Making, Federal Register 3/26/74; Docket No. 13579; Notice No. 74-12.

3. United Airlines, Operational Flight Evaluation of the Two-Segment Approach for Use in Airline Service, NASA CR 2515

4. David R. Israel, "Air Traffic Control: Upgrading the Third Generation" Technology Review, January 1975

5. Department of Transportation - Federal Aviation Administration "Application of Area Navigation in the National Airspace System: A report by FAA/Industry RNAV Task Force" February, 1973.

6. The Air Transport Association Operations Policy on RNAV is provided in an October 17, 1974 letter from Walter Jensen, ATA V-P Operations and Engineering to the FAA.

7. Collins Radio Co. Operator's Guide: ANS-70A Automatic Navigation System, February 1, 1974.

8. Collins Radio Group, Rockwell International Functional Description of the NASA-Ames Noise Abatement Area Navigation System, July 24, 1974 submitted in fulfillment of a requirement of contract NAS2-7420

9. Collins Radio Group, Rockwell International, Final Report for Operational Avionics Retrofit Kit, prepared under contract NAS 2-7420.