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A COMPARISON OF TWO COMMERCIAL AND THE TERMINAL CONFIGURED VEHICLE AREA NAVIGATION SYSTEMS

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Boeing Commercial Airplane Company

June 17, 1976

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16. Abstract

A comparison was made of some of the more important features of two commercially available area navigation systems and the Terminal Configured Vehicle (TCV) area navigation system. Topics discussed included system design criteria, system elements, calculation of the navigation solution, and presentation of guidance information.

Modifications to either of the commercial systems hardware or software are constrained by revenue airline operations and economics. The TCV area navigation system was designed as a research tool requiring a high degree of flexibility. This flexibility was achieved by orienting the system implementation towards software and expanded interface capability.

Each of the commercial systems was designed to satisfy a different ARINC characteristic. Neither system was designed for operation with any specific flight instrumentation or autopilot installation. The TCV system, however, was designed as an element of an integrated airplane flight system which includes flight controls, auto-throttle, and display elements.

Both of the commercial systems currently use electro-mechanical instrumentation as their primary displays for presenting guidance information. The TCV system utilizes CRT displays which allow a greater flexibility for presenting guidance and situation information.

The commercial systems present two- and three-dimensional navigation and guidance profiles. The TCV system presents complete two-, three-, and four-dimensional navigation and guidance profiles with the time guidance based on earth referenced ground speeds.

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SUMMARY

The Terminal Configured Vehicle (TCV) area navigation (RNAV) system and two commercially available RNAV systems are compared. The important aspects of the three RNAV systems may be summarized as follows:

1. Both system A and system B RNAV systems are designed to be commercial products constrained by revenue airline economics. The TCV RNAV system is a research system designed to be as flexible as possible so that a wide range of test programs can be conducted in a timely and economical manner.

2. All three systems were designed to different criteria-- System A to ARINC Characteristic 582; system B to ARINC Characteristics 583; and the TCV RNAV system as an element of an integrated research system.

3. Both system A and system B RNAV systems are two- and three-dimensional systems. The TCV RNAV system has two-, three-, and four-dimensional navigation and guidance capabilities.

4. Neither system A or system B RNAV systems were designed for a specific autopilot or flight display. The TCV RNAV system is an element of a total airplane system including display and flight control subsystems.

5. The TCV RNAV system uses CRT's for both ADI and HSI displays which allow both situation and predictive information to be furnished to the pilots.

INTRODUCTION

The purpose of this report is to discuss some of the more important similarities and differences between two commercially available area navigation systems (system A and B) and the Terminal Configured Vehicle RNAV system. Topics to be discussed include system design criteria, system elements, calculation of the navigation solution, and presentation of guidance information. No attempt will be made to compare data documenting system accuracies or to compare pilot opinions as to the appropriateness of available features or ease of operation.

DESIGN CRITERIA

The design constraints and objectives for each of the RNAV systems are different. System A and B were developed for the commercial market for air operations in today's environment. Their designs were constrained by the requirements of revenue airline operations including dispatch reliability, maintainability, cost of ownership, interface and functional standardization, and FAA certification. The TCV RNAV system was designed as an element of an integrated flight controls, display, and navigation system. It was intended to be used as a research tool which required flexibility for a wide range of experiments. This flexibility was achieved by orienting the RNAV system towards software and expanded interface capability.

Each of these RNAV systems was designed to different specifications. System A was designed to satisfy ARINC Characteristic 582 which requires a high level of program sophistication and automation. System B was designed to satisfy the upper spectrum of ARINC Characteristic 583 which includes requirements from simple station oriented systems to sophisticated inertially integrated RNAV systems. The TCV RNAV system is operationally similar to the ARINC Characteristic 582, but was designed as an element of an integrated navigation, flight controls, and display system originally intended for the Boeing SST airplane. The integration concept of the TCV system contrasts with both the A and B RNAV systems which are not tailored to any specific display or flight control system.

SYSTEM ELEMENTS

Figure 1 shows the basic elements of an RNAV system with its inputs (navigation sensors) and its outputs (flight controls and instrumentation). All three of the RNAV systems incorporate a Navigation Computer Unit (NCU), and a Control Display Unit (CDU), as their basic components. Additionally, a means to store basic flight data (nav-aid locations, routes, airways, etc.) must be provided.

The NCU for all three RNAV systems is a digital computer. System A uses 16K words of magnetic core for processing and limited data storage. An optional, separate, auxiliary memory unit, which consists of 16K words of magnetic core, may be used for data storage and will provide additional capacity for navigation software.

The NCU on system B utilizes 5K words of ROM (read only memory) and 4K words of RAM (random access memory). The RAM extracts instructional routines and flight data, as required, from a magnetic storage disc.

Approximately 73K sixteen bit words of the magnetic disc are used for processing.

The NCU on the TCV system uses 32K words of magnetic core for navigation and guidance calculations and flight data storage. In addition, another 8K word processor is used for the guidance display calculations required for each of the CRT flight displays.

Computer capacity and software organization determines to a great extent the available options and the time it takes the CDU to access the NCU for a transfer of information. NCU access time for System A can be as much as two seconds since immediate interruption of some NCU software routines by CDU/NCU transactions is prevented. Response times for System B and the TCV systems are imperceptible to the pilot.

The CDU is an input-output device that the pilot uses to access the NCU. It consists of a keyboard and an electronic display. System A's CDU has a CRT display and a 54-button keyboard (6 buttons being used for data entries). System B's CDU has a LED display and a 30-button keyboard (5 buttons being used for data entries). The TCV CDU (referred to as a Navigation and Control Display Unit or NCDU) has a CRT display and a 49-button keyboard (1 button being used for data entry). Initial reaction to all the CDU's is that they are too complex. However, with an appropriate amount of training, pilots seem to have little trouble operating the CDU's.

The manner in which basic flight data is stored for use by each RNAV system varies in both types of storage units and capacity. System A incorporates a separate Flight Data Storage Unit (FDSU) which is a magnetic tape, cartridge-loaded device. The plug-in cartridge allows the stored flight data to be up-dated when required. Each magnetic tape cartridge has a capacity in excess of 12 million bits. Since tape speed is limited (about 2,000 thirty-two bit words per second), there can be a significant delay in accessing certain information. To alleviate this access delay time, 2,000 words of NCU core memory have been allocated for active flight data storage. Once the pilot has defined his desired route, the NCU scans the FDSU and retrieves the known required information (up to 2,000 words) necessary to navigate along the desired route. The pilot must reinitiate this scan if the airplane is flown outside the area covered by the flight data stored in the NCU.

System B stores all of its flight data internally to the NCU on a magentic disc. Stored flight data can be accessed almost instantaneously. Approximately 1.3 million bits of the 2.5 million bit disc capacity has currently been allocated for the flight data. The stored data may be up-dated on the ground through an external tape loader.

Because the TCV system is not intended for commercial operations, there is no requirement for extensive navigation flight data storage. Consequently, the TCV system does not need a large capacity data storage capability. Current implementation for data storage is 8K twenty-four bit words of the NCU magnetic core. An additional 32K words could be added to the NCU if required to expand either software or data storage capability. Stored flight data may be accessed almost instantaneously. Changes to the NCU software and stored flight data may be accomplished before each flight by loading the contents of a different data tape into the NCU memory.

CALCULATION OF THE NAVIGATION SOLUTION

The basic task of the NCU in any RNAV system is to calculate an estimate of the airplane's present position and velocity from available navigation sensor information. The navigation solution, calculated on a real time basis, is compared with the desired position and velocity to obtain error signals from which guidance information is generated.

The equations for deriving airplane position in a set of earth referenced coordinates from a given set of navigation sensor inputs are fairly standard for all RNAV systems. Hence, the accuracy of the navigation solution obtained is principally dependent upon the type of navigation sensor inputs being used. It has been shown in other reports (reference 1) that with proper airplane geometry, a dual DME position estimate is more accurate than a position estimate based on dual VOR or VOR/DME signals.

A summary of the prime and reversionary nav-aid signal inputs for the subject systems is shown in Table 1.

System A automatically selects and tunes a pair of VOR/DME stations (when available) based on existing airplane-station geometry. A weighting matrix is computed which makes the NCU use the most favorable combination of available signals to determine the navigation position estimate. The weighting has the effect, when suitable station geometry exists, of making the first sensor priority appear to be DME/DME.

System B uses a single VOR/DME station to provide the position estimate. The station with the best geometric relationship, considering the airplane's current position and the programmed path direction, is automatically selected and tuned.

With suitable station geometry the TCV system utilizes DME/DME signal inputs to determine the best position estimate. If station geometry is poor, or no station is available, the TCV system will revert to VOR/DME inputs. Selection and tuning of DME stations is automatic.

All three of the RNAV systems use inertial (INS) information or Air Data Computer (ADC) information, as available, for improving the quality of the short term navigation solution by smoothing. When radio navigation signals are invalid, INS or ADC information is used as the sole input upon which the navigation solution is based.

All three RNAV systems have the ability to supply two- and three-dimensional navigation and guidance information. The TCV RNAV system can, in addition, calculate a time profile (four-dimensional mode) based on a programmed ground speed profile and a specified time to be at any one of the waypoints used to define the programmed path.

Some of the pertinent characteristics of each of the RNAV systems are summarized in Table 2. Unless a feature is currently available and implemented, it is listed as not provided.

GUIDANCE AND DISPLAYS

The type of display which an RNAV system uses to present its guidance information to the pilot has a significant influence on the type of information process in the NCU. Dynamic response information is particularly difficult to present with conventional electro-mechanical indicators. CRT displays, however, are very flexible and have the potential to present information and employ formats that would be difficult or impossible with electro-mechanical instrumentation.

Both system A and system B use conventional electro-mechanical Attitude Director Indicator (ADI) and Horizontal Situation Indicator (HSI) instrumentation currently found in the cockpit. System A does have an optional CRT map display (at the present time the only operator flying with the CRT map is a KC-135 airplane used in the USAF's Speckled Trout Program). However, system A's CRT map is intended to supplement, not replace, the pilot's HSI. System B does not have a CRT map available at this time but there are plans to offer a CRT map at a later date.

The TCV RNAV system presents its guidance on the airplane's Advanced Electronic Display System (ADEDS) which utilizes separate CRT displays for the ADI and the HSI. As the result of using CRT displays, the TCV RNAV system incorporates numerous navigation and guidance features and selectable options that cannot be presented on conventional electro-mechanical instruments.

The TCV's Electronic Attitude Director Indicator (EADI) has a continuous display of inertially referenced flight path angle and potential flight path angle which can be used together for energy management. Vertical Navigation (VNAV) symbology in either situation or flight director mode is selectable by the pilot for display on the EADI. An electronically generated perspective runway symbol, based on the navigation solution, is available to aid in either manual or automatic approaches.

The Electronic Horizontal Situation Indicator (EHSI) offers the pilot a pictorial view of current position with respect to navigation aids, airports, airways, intersections, obstacles, horizontal programmed flight path, etc., in a track-up or north-up mode. Various map scales and display options are individually selectable on either pilot's EHSI. Predictive information is also displayed on the EHSI. A trend vector predicts the airplane's position 30, 60, and 90 seconds ahead based on the airplane's present rate of turn and ground speed. A predictive arc showing the airplane's range-to-go to make good a specified altitude, based on the present inertial flight path angle, also may be displayed. Additionally, both situation and predictive four-dimensional time guidance are provided on the EHSI.

Detailed comparisons of the navigation and guidance features of each system are shown in the appendix. ARINC Characteristic 582 and 583 requirements for each of the compared features are specified. Geometric details of RNAV guidance calculations are also shown.

TABLE 1.- NAVIGATION SENSOR HIERARCHY

PRIORITY	*SYSTEM A	SYSTEM B	TCV
First	DME-DME	VOR-DME	DME-DME
Second	VOR-DME/VOR-DME (weighted average of two stations).	DEAD RECKONING (no radio data available)	VOR-DME
Third	VOR-DME	-	DME ONLY (navigation estimate updated from one station only).
Fourth	VOR-VOR	-	DEAD RECKONING (no radio data available).
Fifth	DEAD RECKONING (no radio data available).	-	-

SMOOTHING

PRIORITY	ALL:
First	Inertial
Second	Air Data (TAS and Heading)
Third	None (No complementation data available

*System A always uses VOR/DME-VOR/DME nav-aid signal inputs when available. However, a weighting matrix is computed which makes the navigation position estimate appear to be calculated with only the nav-aid signal inputs listed above.

TABLE 2.- COMPARATIVE CHARACTERISTICS

FEATURE	SYSTEM A	SYSTEM B	TCV
Design Specification	ARINC 582	ARINC 583	Research
Computer and Data Storage Capacity	16K words magnetic core and 375K words magnetic tape; (optional 16K words magnetic core).	5K ROM, 4K RAM, and 156K word magnetic disc.	32K magnetic core and 8K magnetic core for displays.
Word Length	32 bit	16 bit	24 bit
Data Access Time	can be lengthy if accessed from magnetic tape	immediate	immediate
CDU Display	CRT, 6 line pairs & 1 scratch pad line (16 characters per line)	LED, 2 1/2 lines (11 characters per line)	CRT, 7 lines + 1 scratch pad line (24 characters per line)
Vertical and Horizonal Data	both	either	both
CRT Map	option	no	yes
Time Navigation	no (3D system)	no (3D system)	yes (4D system)
Time Prediction	no	no	yes
Path Prediction	no	no	yes
Altitude Prediction	no	no	yes
Flight Path Angle (Display)	no	no	yes
Flight Path Angle (CDU)	yes	yes	yes
Keyboard Philosophy	dedicated alphanumeric, optional numeric only	shared (telephone type) alphanumeric	dual function dedicated alphanumeric

(continued next page)

TABLE 2.- COMPARATIVE CHARACTERISTICS (CONCLUDED)

FEATURE	SYSTEM A	SYSTEM B	TCV
Keyboard Format	54 keys (48 buttons plus 6 data entry)	30 keys (25 button plus 5 data entry)	49 keys (48 buttons plus 1 data entry)
Prime Position Sensor	DME-DME	VOR-DME	DME-DME

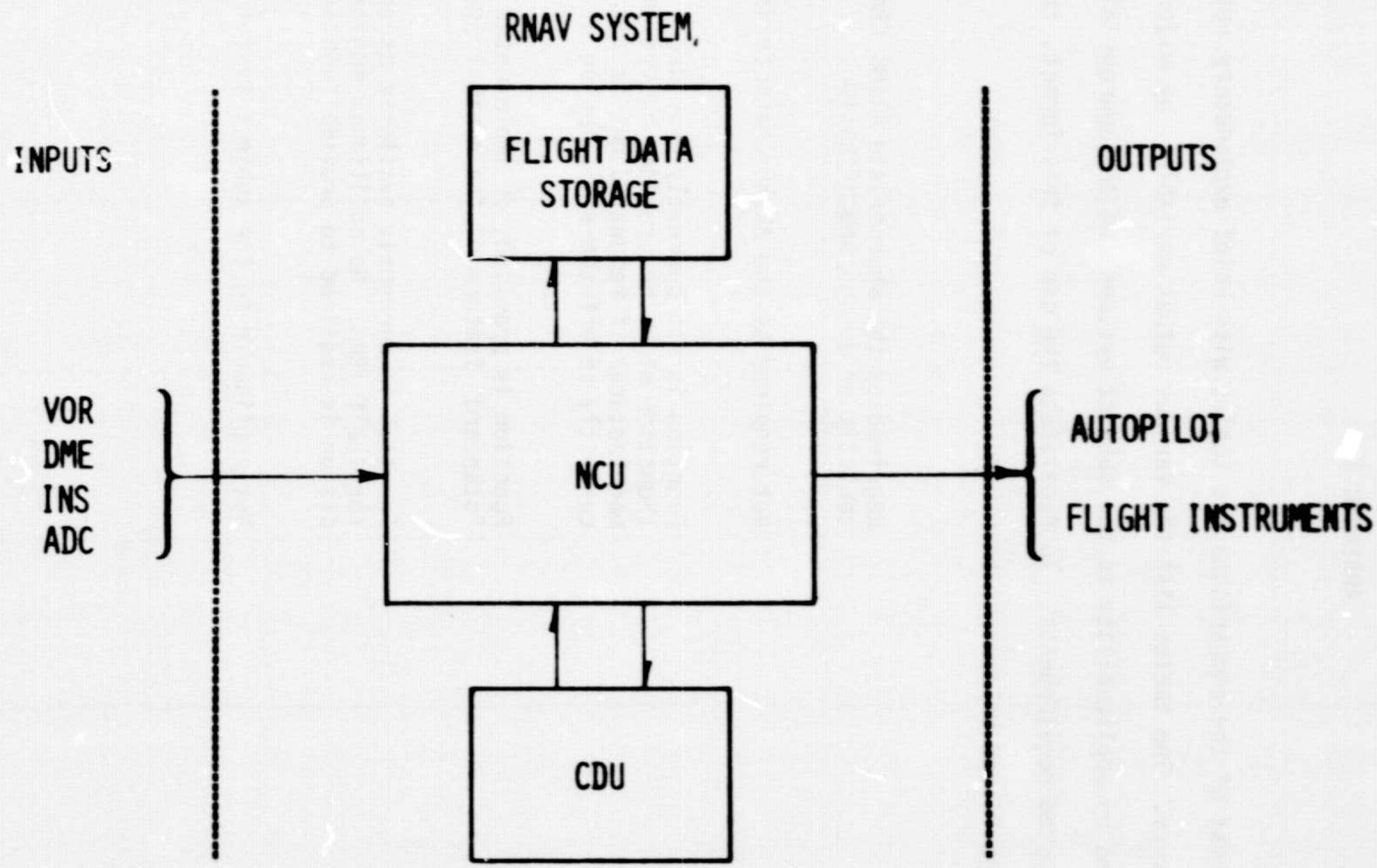

FIGURE 1.- RNAV SYSTEM ELEMENTS, INPUTS, AND OUTPUTS.

APPENDIX 1

The format f the comparisons are tables with brief explanatory notes where necessary. The tables list the various output variables, by major category, and by applicability to the subject systems and the appropriate source of system requirements. To facilitate the use of this format, the abbreviations listed below have been used.

REQ	Required by the appropriate ARINC Characteristic or design specification.
NR	Not required by the ARINC Characteristic.
NP	Function is not currently provided. (Function might be provided by system manufacturer if requested but is not currently an off-the-shelf option.)
PROV	Function is provided, or implemented as a "standard" feature of the nominal system.
OPT	Function is currently available as an off-the-shelf item. No additional engineering design is required to provide function.
NA	Not applicable to the subject system.

TABLE 1 NAVIGATION FUNCTION	SPECIFICATIONS		AVAILABLE SYSTEMS		
	582	583	SYSTEM A	SYSTEM B	TCV
POSITION					
<u>LAT/LONG ON CDU</u>	REQ	REQ	PROV	PROV	PROV
<u>RANGE/BEARING TO WPT</u>					
CDU	OPT	OPT	PROV	PROV	PROV
HSI	OPT	REQ	PROV	PROV	NA
CRT MAP	OPT	OPT	OPT	NP	PROV
<u>RANGE/BEARING TO ACTIVE NAVAID</u>					
CDU	OPT	OPT	PROV	PROV	NP
CRT MAP	OPT	OPT	OPT	NP	PROV
<u>ALTITUDE - MSL</u>					
CDU	NR	NR	NP	PROV	PROV
VELOCITY					
<u>GROUND SPEED</u>					
CDU	REQ	REQ	PROV	PROV	PROV
HSI	REQ	REQ	PROV	PROV	NA
CRT MAP	OPT	OPT	OPT	NP	PROV
<u>TRACK ANGLE</u>					
CDU	REQ	REQ	PROV	PROV	PROV
HSI	REQ	REQ	PROV	PROV	NA
CRT MAP	OPT	OPT	OPT	NP	PROV
<u>FLIGHT PATH ANGLE</u>					
CDU	NR	NR	NP	NP	PROV
EADI/ADI	OPT	OPT	NP	NP	PROV

TABLE 1 (CONTINUED) NAVIGATION FUNCTIONS	SPECIFICATIONS		AVAILABLE SYSTEMS		
	582	583	SYSTEM A	SYSTEM B	TCV
PREDICTIVE INFO					
LATERAL - CURVED TREND VECTOR					
CRT MAP	NR	NR	OPT	NP	PROV
VERTICAL - ALTITUDE RANGE INTERCEPT					
CRT MAP	NR	NR	NP	NP	PROV
WIND DATA					
DIRECTION					
CDU	REQ	NR	PROV	PROV	PROV
SPEED					
CDU	REQ	NR	PROV	PROV	PROV
DRIFT ANGLE					
CDU	REQ	REQ	PROV	PROV	PROV
OTHER OUTPUT FUNCTIONS					
TRUE HEADING					
CDU	NR	REQ	NP	PROV	PROV
POTENTIAL FLIGHT PATH ANGLE					
EADI/ADI	NR	NR	NP	NP	PROV
TO SPECIFIED LOCATION ...					
...RELATIVE BEARING - CDU	OPT	REQ	PROV	PROV	NP
- CRT MAP	OPT	OPT	OPT	NP	PROV
...RELATIVE FLIGHT PATH ANGLE					
- CDU	NR	NR	NP	PROV	PROV
SUPPORT					
AUTOTUNING	REQ	REQ	PROV	PROV	PROV

TABLE II GUIDANCE PATH DEFINITION	SPECIFICATIONS		AVAILABLE SYSTEMS		
	582	583	SYSTEM A	SYSTEM B	TCV
WAYPOINT SPECIFICATION					
LAT/LON - CDU	REQ	REQ	PROV	PROV	PROV
RANGE/BEARING - CDU	REQ	REQ	PROV	PROV	PROV
IDENTIFIER - CDU	REQ	REQ	PROV	PROV	PROV
CRT MAP CURSOR	OPT	OPT	OPT	NP	NP
PRESTORED PATHS					
CORE MEMORY	NA	NA	PROV	NA	PROV
FDSU (TAPE)	OPT	NA	PROV	NA	NA
DISC STORAGE	NA	OPT	NA	PROV	NA
LATERAL					
COMPLETE 2D PATH					
GREAT CIRCLE WPT-WPT SEGMENTS	REQ	REQ	PROV	PROV	PROV
CIRCULAR ARC LEG-LEG TRANSITIONS	NR	OPT	PROV[3]	PROV	PROV
LONG TURN (DME ARC) SEGMENTS	NR	NR	NP	PROV	PROV
LATERAL OFFSET PATHS	REQ	REQ	PROV	PROV	PROV[2]
HOLDING PATTERNS	NR	NR	PROV	PROV	PROV[2]
INCOMPLETE LATERAL PATHS					
TRACK/HEADING LEGS	NR	NR	PROV	PROV	PROV[1]
RADIALS INBOUND/OUTBOUND	NR	NR	PROV	NP	PROV[2]

NOTES: [1] IMPLEMENTATION USES CRT MAP AND AGCS CONTROL PANEL

[2] IMPLEMENTATION USES CRT MAP

[3] TURNS ARE ACCOMPLISHED BY CAPTURING THE NEXT PATH LEG THROUGH A BANK LIMITING PROCESS

TABLE II (CONTINUED) GUIDANCE PATH DEFINITION	SPECIFICATIONS		AVAILABLE SYSTEMS		
	582	583	SYSTEM A	SYSTEM B	TCV
VERTICAL					
COMPLETE 3D PATH					
STRAIGHT LINE WPT-WPT	OPT	REQ	PROV	PROV	PROV
ALONG-TRACK OFFSET	OPT	OPT	PROV	PROV	NP
INCOMPLETE VERTICAL PATH					
COMMAND FPA LEG	NR	NR	PROV	PROV	PROV
COMMAND IAS LEG	NR	NR	NP	PROV	PROV
COMMAND VERTICAL SPEED LEG	NR	NR	PROV	NP	NP
ALT/RANGE INTERCEPT	NR	NR	NP	NP	PROV[1]
ALT INTERCEPT AT WPT	NR	NR	PROV	PROV	PROV[1]
SPEED/TIME					
COMPLETE 4D TIME PATH					
GROUND SPEED PROFILE + TIME AT ALL WPTs	OPT	OPT	NP	NP	PROV

NOTES:

1. IMPLEMENTATION USES CRT MAP AND AGCS CONTROL PANEL.

TABLE III GUIDANCE FUNCTIONS	SPECIFICATIONS		AVAILABLE SYSTEMS		
	582	583	SYSTEM A	SYSTEM B	TCV
LATERAL					
CROSS-TRACK DISTANCE (XTK) - NM					
CDU	REQ	REQ	PROV	PROV	PROV
HSI	NR	NR	NP	NP	NA
CRT MAP	OPT	OPT	OPT	NP	PROV
CROSS-TRACK DEVIATION (XTK) - DOTS					
HSI	REQ	REQ	PROV	PROV	NA
DESIRED TRACK ANGLE (DTK)					
CDU	REQ	REQ	PROV	PROV	PROV
HSI	REQ	REQ	PROV	PROV	NA
CRT MAP	OPT	OPT	OPT	NP	PROV
TRACK ANGLE ERROR (TKE)					
CDU	REQ	REQ	PROV	PROV	PROV
HSI	REQ	REQ	PROV	PROV	NA
CRT MAP	OPT	OPT	OPT	NP	PROV
EADI/ADI	OPT	OPT	NP	NP	PROV
TRACK ANGLE ERROR PLUS DRIFT ANGLE					
HSI	REQ	REQ	PROV	PROV	NA
CRT MAP	OPT	OPT	OPT	NP	NP

TABLE III (CONTINUED) GUIDANCE FUNCTIONS	SPECIFICATIONS		AVAILABLE SYSTEMS		
	582	583	SYSTEM A	SYSTEM B	TCV
LATERAL (cont.)					
COMMAND HEADING					
CDU	OPT	OPT	PROV	PROV	NP
CRT MAP	OPT	OPT	OPT	NP	PROV
LATERAL STEERING SIGNAL					
AFCS	REQ	REQ	PROV	PROV	PROV
FLIGHT DIRECTOR	OPT	OPT	PROV	PROV	PROV
VERTICAL					
VERTICAL ERROR					
CDU (DISPLACEMENT IN FT)	NR	NR	PROV	PROV	PROV
HSI (DEVIATION IN DOTS)	REQ	REQ	PROV	PROV	NA
ADI/EADI	OPT	OPT	NP	NP	PROV
FLIGHT PATH ANGLE ERROR					
CDU	NR	NR	NP	NP	PROV
EADI/ADI	OPT	OPT	NP	NP	PROV
REQUIRED FLIGHT PATH ANGLE - VERTICAL PATH					
CDU	NR	NR	PROV	PROV	PROV
EADI/ADI	OPT	OPT	NP	NP	PROV
VERTICAL ANGLE PRES POS TO WPT					
CDU	NR	NR	NP	PROV	NP
EADI/ADI	OPT	OPT	NP	NP	PROV

TABLE III (CONTINUED) GUIDANCE FUNCTIONS	SPECIFICATIONS		AVAILABLE SYSTEMS		
	582	583	SYSTEM A	SYSTEM B	TCV
VERTICAL (cont.)					
VERTICAL STEERING SIGNAL					
AFCS	OPT	REQ	PROV	PROV	PROV
FLIGHT DIRECTOR (DISPLAY)	OPT	REQ	PROV	PROV	PROV
SPEED/TIME					
TIME ERROR	OPT	OPT	NP	NP	PROV
TIME ERROR RATE	OPT	OPT	NP	NP	PROV
GROUND SPEED ERROR	OPT	OPT	NP	NP	PROV
THROTTLE COMMAND					
AFCS	OPT	OPT	NP	NP	PROV
DISPLAY	OPT	OPT	NP	NP	PROV
LONGITUDINAL ACCELERATION	NR	NR	NP	NP	PROV

DA	DRIFT ANGLE
DIS	GREAT CIRCLE DISTANCE FROM POS TO NEXT WPT OR DESTINATION
DTK	DESIRED TRACK ANGLE
GS	GROUND SPEED
HDG	TRUE HEADING
POS	PRESENT POSITION
TAS	TRUE AIRSPEED
TK	GROUND TRACK ANGLE
TKE	TRACK ANGLE ERROR
WA	WIND ANGLE
WPT	WAYPOINT
WS	WIND SPEED
XTK	CROSS TRACK DISTANCE

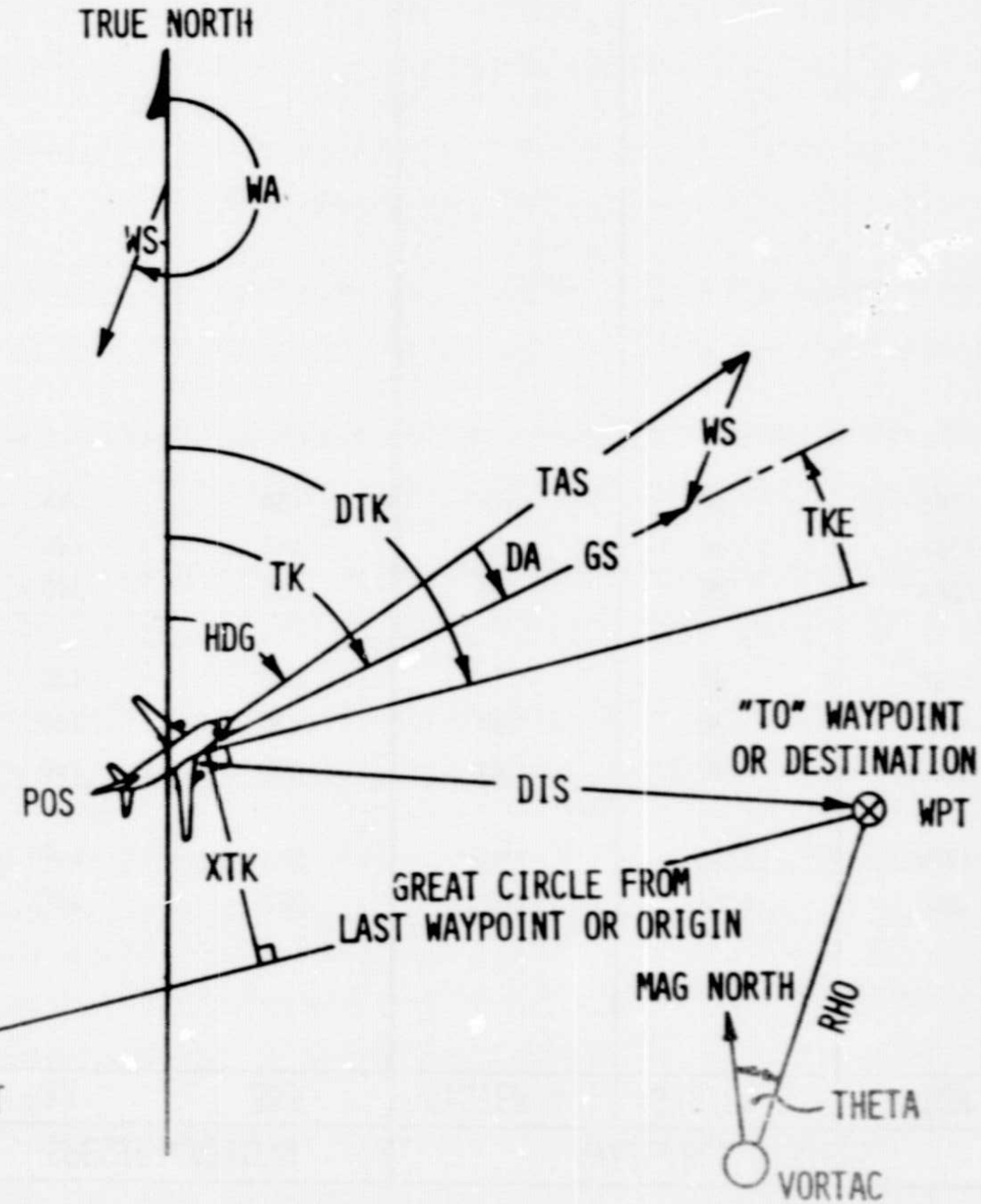

FIG. 1 LATERAL NAVIGATION & GUIDANCE RELATIONSHIPS - BASIC

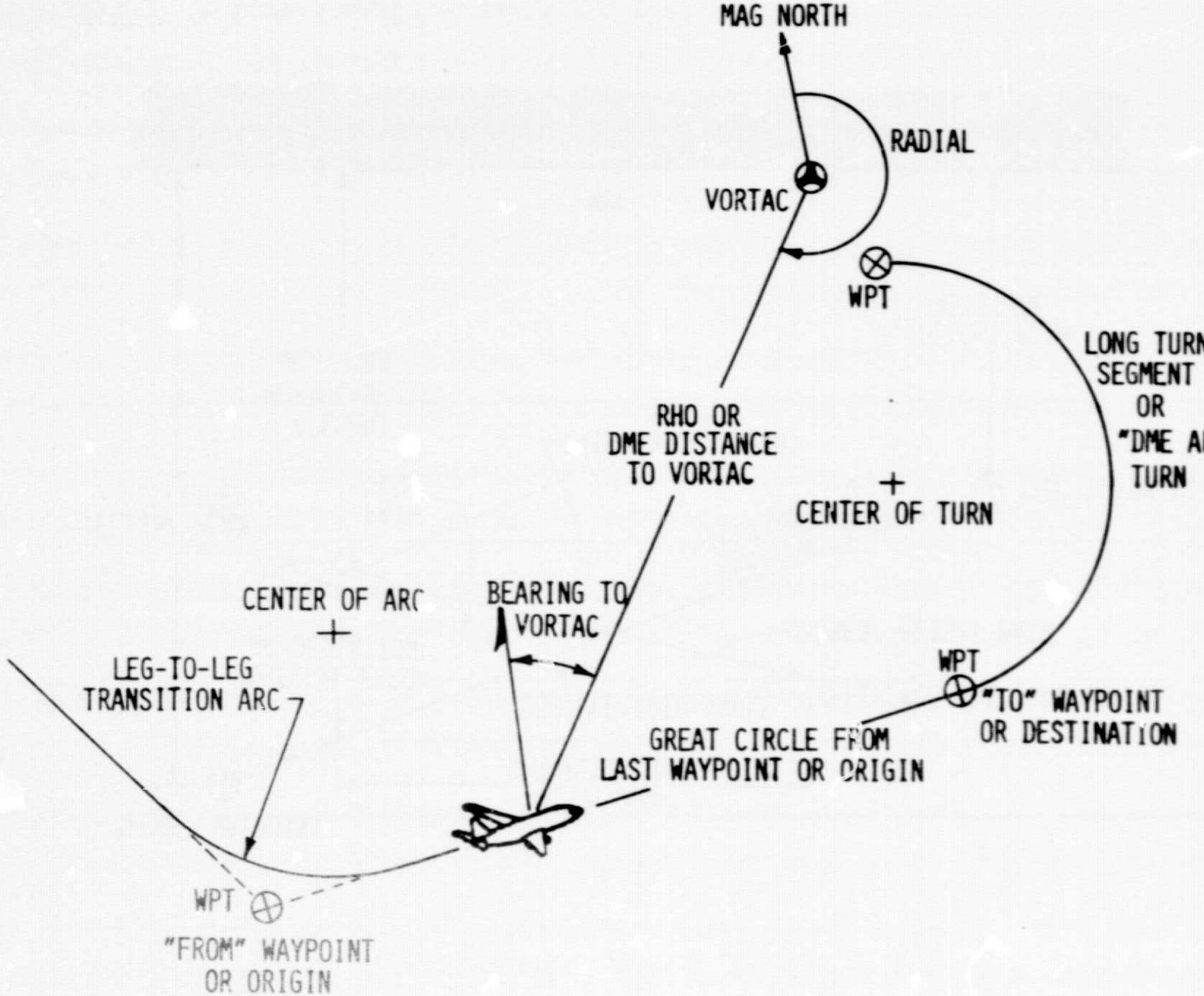

FIG. 2 NAVIGATION & GUIDANCE RELATIONSHIPS - DETAIL & OPTIONS

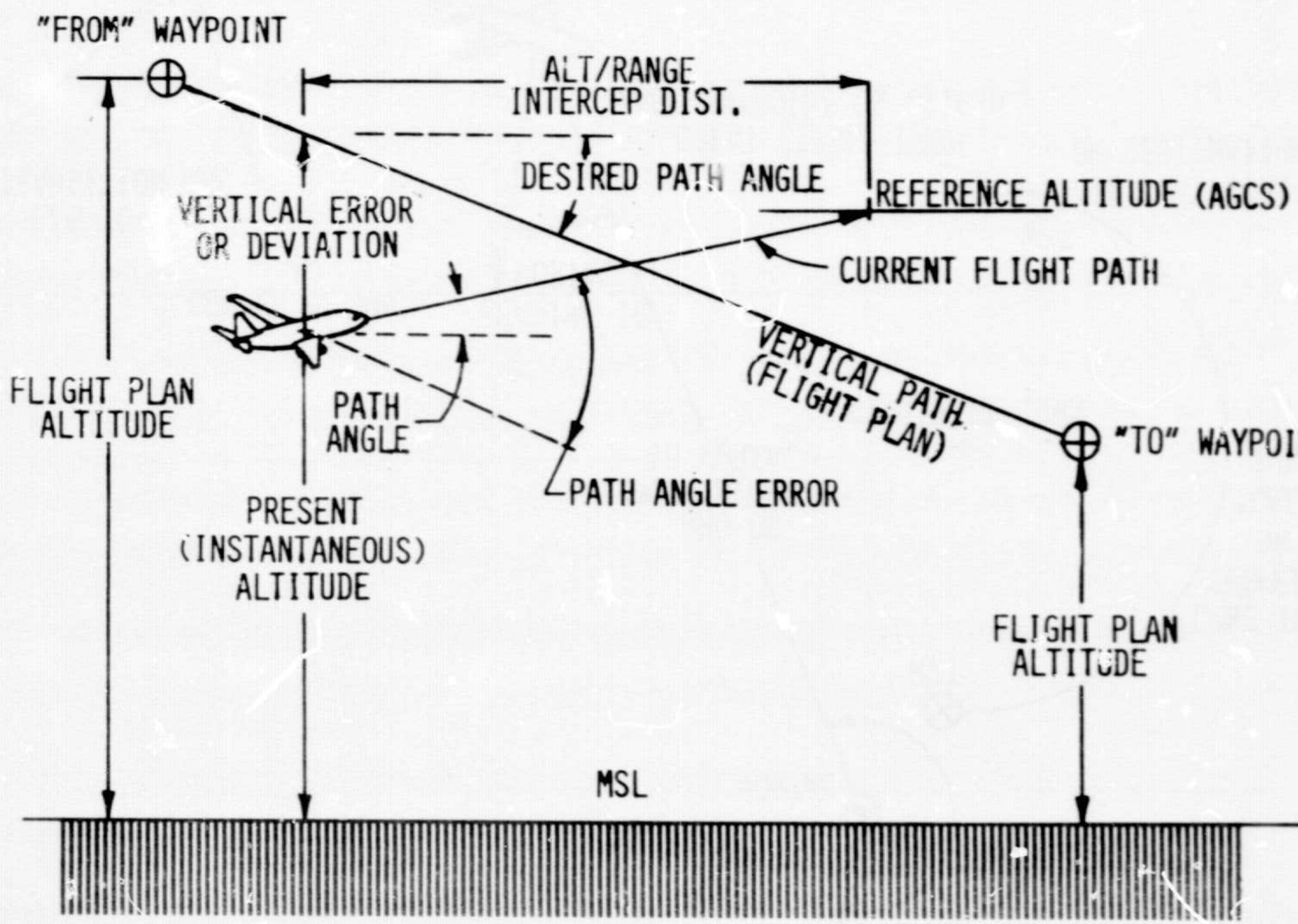

FIG. 3 VERTICAL NAVIGATION & GUIDANCE RELATIONSHIPS

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