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"MODIFICATION TO AREA NAVIGATION EQUIPMENT FOR INSTRUMENT TWO-SEGMENT APPROACHES"

Title

~~FINAL REPORT~~

~~FOR~~

OPER~~ATIONAL AVIONICS RETROFIT KIT~~

(~~AREA NAVIGATION SYSTEM~~)

PROGRAM

Modifications to Area Navigation Equipment for Instrumented Two-Segment Approaches

31 JULY 1975

Prepared under Contract NAS 2-7420

By

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Cedar Rapids, Iowa

For

Ames Research Center
National Aeronautics and Space Administration

TABLE OF CONTENTS

TABLE OF CONTENTS - CONT'D

APPENDICES

LIST OF ILLUSTRATIONS

LIST OF TABLES

LIST OF ABBREVIATIONS

A/C - aircraft
ADF - automatic direction finder
AGL - above ground level
ALCU - arithmetic, logic, and control units
ALT - altitude
AP - autopilot
ARINC - Aeronautical Radio, Inc.
ASC - aircraft systems coupler
ATC - air traffic control
ATR - Austin Trumbull Radio
CADC - central air data computer
CDU - control display unit
CRT - cathode ray tube
CTD - crosstrack distance
DEV - deviation
DIG - digital
DME - distance measuring equipment
ETA - estimated time of arrival
FAA - Federal Aviation Administration
FD - flight director
FDSU - flight data storage unit
FMEA - failure mode and effect analysis
F.O. - first officer
GMT - Greenwich Mean Time
GS - glide slope
HDG - heading
HSI - horizontal situation indicator
Hg - mercury
IAS - indicated air speed
ILS - instrument landing system
I/O - input/output
LOC - localizer
MTBF - mean time between failures
MTU - magnetic tape unit
NASA - National Aeronautics and Space Administration
NCU - navigation computer unit
RMI - radio magnetic indicator
RTCA - Radio Technical Commission for Aeronautics
RNAV - Area ~~random~~ navigation
SID - standard instrument departure
STAR - standard terminal approach route
STC - supplemental type certificate
TAS - true air speed
UA - United Airlines
VOR - very high frequency omni-range

1.0 INTRODUCTION

This report is the final technical report covering the work performed by the Collins Radio Group of Rockwell International under NASA contract NAS 2-7420. The work was performed during the period from November 1972 through March 1975.

1.1 Background

As part of continuing research by the Ames Research Center of the National Aeronautics and Space Administration in the area of airport noise reduction, programs were initiated to demonstrate the feasibility of the two-segment approach concept under near-operational conditions.

The first of these was the evaluation of a glide slope computer system which relied upon an ILS localizer beam for lateral guidance, and depended upon a DME co-located with the glide slope antenna on the ground for distance to airport data. That system was test flown in a Boeing B727-200 aircraft.

The second system, which is the subject of this report, utilized an RNAV system to execute the two-segment approach and thus eliminated the requirement for a co-located DME. It also, down to appropriate minimums, permitted non-precision approaches to be made to runways not equipped with ILS systems. A DC-8-61 was selected for the program because it represented an aircraft type with a high noise level and an extended commercial service life, and because it was representative of aircraft which might carry a sophisticated RNAV system.

Separate contracts were awarded to United Airlines (UA) and to Collins Radio. UA was responsible for the installation and flight evaluation of the system. Collins was responsible for the design and fabrication of the RNAV retrofit kit to be used on the aircraft. NASA, UA, and Collins were jointly involved in the system definition.

1.2 Objectives

The program objectives stated in the NASA Request For Proposal were:

1. Develop a near-operational avionic retrofit kit for the DC-8-61 airplane that will aid the pilot in making a two-segment approach and that is representative of systems that might be used in air carrier service.
2. Develop a two-segment approach profile and piloting procedure for the DC-8-61 airplane that will provide adequate safety margin under adverse weather, in the presence of system failures, and with the occurrence of an abused approach.
3. Demonstrate the two-segment approach procedure and equipment to line pilots under conditions which are representative of those encountered in air carrier service.

The RFP included the requirement that the system be capable of making pure RNAV two-segment approaches to non-instrumented runways as well as to ILS-equipped runways.

The system was to provide vertical and lateral guidance during two-segment noise abatement approaches having the vertical profile shown below.

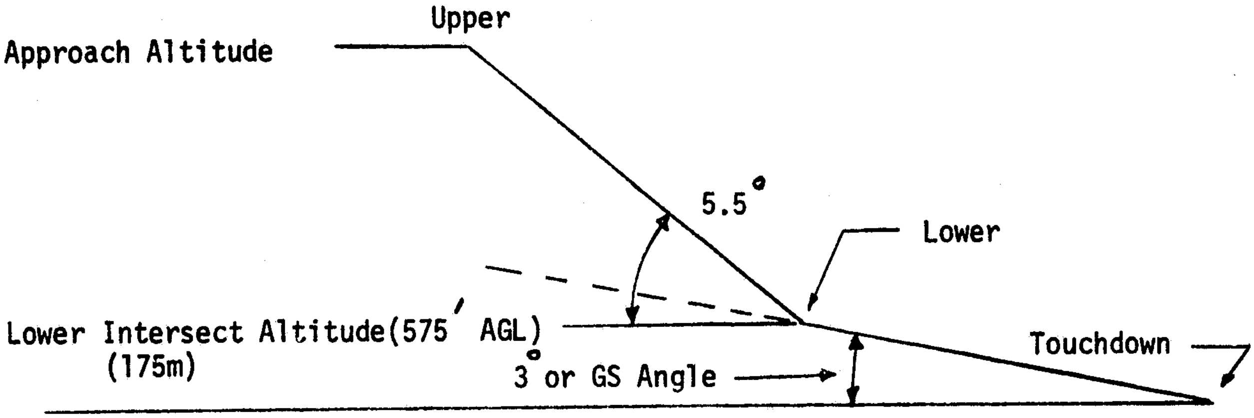


Figure 1.2-1

The noise abatement is achieved by increasing the distance between the aircraft and the ground during a large portion of the approach, and by the reduced thrust required during the descent along the upper segment of the approach.

The approach and intercept altitudes and the upper segment slope were determined by terminal area and aircraft operational considerations, UA flight simulation, and finally by UA flight tests.

1.3 Program Description

The program tasks fell into a chronological sequence of program phases. The first was a specification phase, in which the system interfaces with the aircraft were defined and cost effective compromises arrived at with regard to modification of RNAV equipment and existing aircraft systems. In the same manner, the operational desires of the airline were specified and the impact on the basic RNAV system examined. This was followed by an engineering simulation phase in which the system concepts were modeled, first in analog form and subsequently with the first operational software.

In the case of the control laws, the flight director and autopilot models were based on data supplied by UA. The model of the DC-8-61 was based on data from the aircraft manufacturer.

Actual flight operations started with the installation of the equipment and engineering flights to evaluate the performance of the system and modify it as required.

At the end of the engineering flights there were Supplemental Type Certification (STC) flights and a guest pilot evaluation phase where a group of pilots from several air carriers, government, and other concerned agencies had an opportunity to fly two-segment approaches.

The aircraft then went into revenue service for evaluation of the system by UA line pilots.

Activity on the above tasks started in late November of 1972 with advance NASA funding and the contract was signed on 22 February, 1973.

System definition and hardware development continued through July 1973, at which time it became apparent that the software development for the program could not be completed in time to meet the September schedule for the engineering evaluation flights.

The basic cause of the slippage was due to a Collins decision to base the noise abatement software upon that being developed for the ANS-70A which was predicted to have ample core space and a simplified architecture. However, the system was not operational at the time of the decision and unexpected difficulties were encountered which resulted in both late delivery and memory capacity problems.

A decision was made at that point to proceed with a two-phase program, with both phases proceeding in parallel.

The Phase I program was planned to make maximum use of the results of the previous glide slope computer two-segment approach program. The intent was to emulate with software, in the general purpose computer of the RNAV system, the hardware computational functions of the computer that Collins developed for that program under NASA contract NAS 2-7269.

Like the system it was emulating, the Phase I system relied upon the standard flight director and autopilot localizer tracking for lateral guidance, and required a DME transponder co-located with the glide slope antenna on the ground.

The capabilities of the RNAV computer and its control and display unit were used for easy variation of system parameters, but the system had no RNAV capability.

The system was developed and flown in November of 1973 to take advantage of the UA aircraft availability, establish the acceptable vertical profile for the DC-8-61 and to measure the noise levels for that aircraft.

The Phase II system was developed to meet the objectives of the original program, incorporation of two-segment approach capability into an operational RNAV system.

The subject of this report is the Phase II system. A description of the Phase I system is provided in Appendix 2.

The Phase II system was installed late in January of 1974 and engineering flight evaluation started. This effort was continued with on-site support through the STC and guest pilot evaluation flights in March and April. The aircraft was then returned to revenue service. During May some software modifications were incorporated to improve the system's operation and the in-service evaluation flights began with flight managers in June. The line pilot evaluation started 30 July and was completed 28 February 1975.

Throughout this period, the software was updated to incorporate current airport data and program problems were corrected as they were discovered. Field service and factory support was supplied as required.

Because the RNAV system used in this program was not a standard item in the UA fleet, failed units were sent to the Collins Cedar Rapids facility where the necessary test equipment was available. Spare equipment was kept on board the aircraft and at a UA maintenance base to replace the failed units. Collins prepared line maintenance and checkout procedures to assist UA personnel in identifying faults and in system checkout. While this method of support was the only practical approach under the circumstances, it involved many problems which would not have been encountered in normal airline service. In general, the routing of the aircraft resulted in its being available at the UA maintenance base only every other day and the service personnel had no special test equipment and limited exposure to the system.

In addition to direct support of the operational system, Collins made available to UA at Denver a simulator which included controls, cooling, racks and interconnections for the Navigation Computer Unit (NCU), Control Display Unit (CDU), and Flight Data Storage Unit (FDSU) of the RNAV system plus a Horizontal Situation Indicator (HSI) and progress annunciators. This was used to train pilots and RNAV technicians.

Collins also made their hybrid simulation facility at Cedar Rapids available to help train UA RNAV technicians at the beginning of the line evaluation phase.

1.4 Guidelines

Certain general guidelines for the design of the system were established by the RFP and by discussions with NASA and UA. These included the following:

1. Although the system was to have full en route RNAV capability, certification was to be obtained only for approach operations because of cost considerations.
2. The system was to be installed on only the pilot's side of the aircraft and there would be no modification of the first officer's equipment or operational modes.
3. The existing modes of the pilot's flight director and autopilot were to be retained so the pilot could revert to them if he so desired.

The system was to be designed for easy retrofit.

2.0 SYSTEM DESCRIPTION

2.1 Concept Overview

The system uses the inherent three-dimensional navigation capability of the RNAV system to provide guidance on the two-segment profile shown in Figure 1.2-1. In the absence of an ILS system, lateral guidance is based on VOR/DME data. If an ILS system is available, the VOR/DME data is used to intercept the localizer, which is then used for lateral guidance. The vertical axis guidance is based on VOR/DME data and altitude until a glide slope signal is available.

As described in the following section, the system also incorporated special safety and mode switching logic functions unique to the two-segment approach and special handling of two-segment flight plans. Full capability to revert to the standard aircraft systems was provided.

The basic RNAV system which was modified to add noise abatement approach capability was one version of the Collins ANS-70A.

The ANS-70A is fundamentally an ARINC Mark II system providing the following capabilities:

1. Automatic navigation over a complete route. Includes computing vertical and lateral deviation and steering commands, automatic course selection, and automatic nav radio selection.
2. Display of flight performance data. Includes wind velocity, track angle, drift angle, ground speed, present position, radio stations in use, navigation mode, required vertical speed and angle to make good the next waypoint, cross-track distance, course/distance/time to the next waypoint, and GMT.

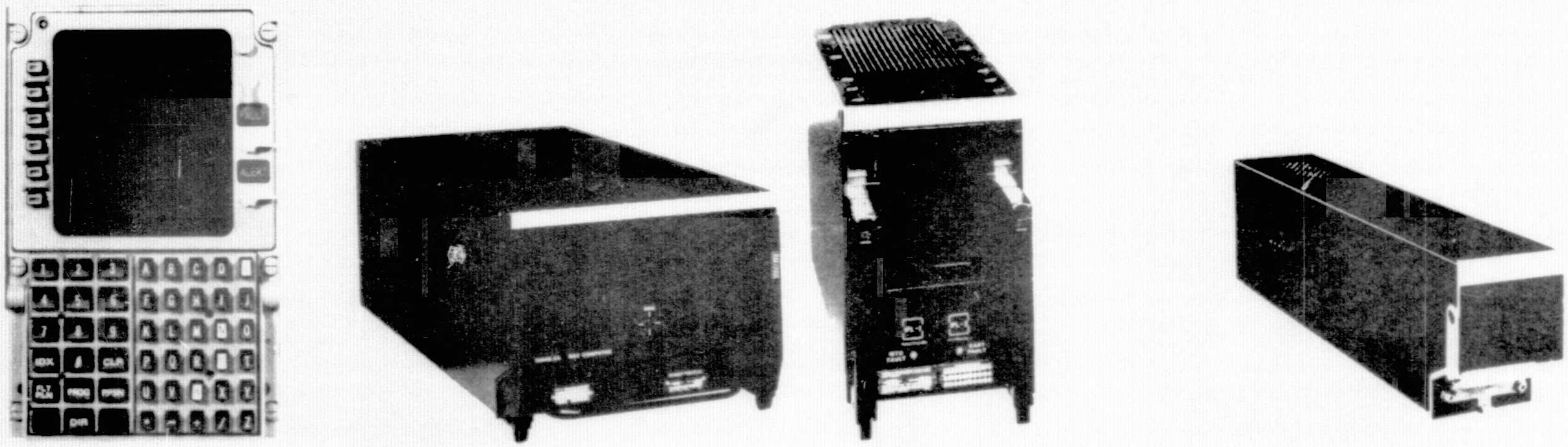
3. Automatic maintenance diagnostic test capability, with annunciation of failed line replaceable units.
4. Storage of airways/waypoint data for non-company route flights.
5. Storage of radio navigation station(VOR/DME) data; identifier, frequency, elevation, magnetic variation, and location.
6. Capability to change or correct an assembled flight plan by inserting airways and waypoint identifiers, holding patterns, SIDs, STARs, headings, vertical speeds and angles, lateral and longitudinal offsets, and waypoints identified by latitude/longitude or by bearing and distance from a waypoint.
7. Capability to load new flight plans in flight for alternate destinations.
8. Verification of navigational sensor data and pilot-entered data for reasonableness, and continuous self-test of computer operations.

As modified for this program, the system permitted noise abatement approaches to be made with or without ILS, to appropriate minimums.

2.2 Equipment Description

The heart of the system hardware complement consisted of the three basic units of the ANS-70A system; the NCU, the CDU, and the FDSU (See Figure 2.2-1). To these were added two units designed for this program, the RNAV switching unit which provided for the transfer of functions between standard avionic systems and the RNAV system, and the tuning line adapter which provided the switching of the navigation receiver tuning between the pilot's manual controller and the NCU. While not part of Collins

DC-8 TWO-SEGMENT SYSTEM HARDWARE



ANS-70A AREA NAVIGATION SYSTEM

INTERFACE UNIT

FIGURE 2.2-1

task in this program, it was necessary to modify some of the aircraft's standard avionics.

1. 8564B-(2X) Navigation Computer Unit (NCU)

   The NCU includes the general purpose digital computer which executes the navigation programs, and the aircraft systems coupler (ASC) which provides the I/O conversions between the digital computer and the multiple analog and digital aircraft sensors and displays.

The NCU has the following features:

a. Data words of 32 bits, plus parity bit.
b. 16,384 word core memory.
c. Half-word (16 bit) instruction format.
d. Instruction set of 78 instructions with direct, literal, indexed, and indirect addressing.
e. Sixteen accumulator/index registers implemented as 60 ns access time scratch pad memory.
f. Program control of I/O operations, providing efficient memory utilization, realistic reversionary modes, and subsystem isolation
g. Buffered aircraft systems interfaces, with monitoring of sensor validity signals and of output conversions.
h. Real-time system executive control, providing efficient allocation of processing time.

The NCU utilizes 690 watts of 400 Hz, single-phase power, and is housed in a 1 ATR long package. It has a maximum weight of 55 lbs(24.9kg) and requires 250 lbs/hr(113 kg/hr) of forced air cooling.

2. 813H-1C Control Display Unit (CDU)

The CDU provides the CRT display and control interface between the pilot and the NCU. Via this unit, the pilot assembles his flight plan and is informed as to system status, flight progress and performance.

The CDU provides a CRT display of six label lines, six data lines, and a scratch pad line, with 16 characters per line. Data displayed on the label and data lines originates in the NCU. The scratch pad line displays data entered by the pilot via the keyboard. This data may then be modified or transferred to the computer and/or data lines (via the computer) by using the various line select or special function keys.

The keyboard provides full alphanumeric data capability, plus dedicated function keys to select the most used data pages. Operational use of the CDU is covered in the following sections. The CRT display is updated by the NCU three times a second, while a local refresh memory updates the display 88 times a second to eliminate flicker. Both manual and automatic brightness control is provided, and the display is legible in a ambient light level of 10,000 foot candles($1.08x10^5$Lux).

The unit has a front panel which is 5.75 inches (14.6 cm) wide and 9 inches (22.9 cm) high.

The maximum weight is 18 pounds (8.2 kg), and the unit uses 125 watts of 400 Hz single phase power. An internal blower provides cooling in free-flow cockpit air.

3. 8848D-2 Flight Data Storage Unit (FDSU) and 7520A-1 Magnetic Tape Unit (MTU).

The FDSU and its replaceable tape cartridge provide the bulk data storage and transfer mechanism for the system. All airways, navigational facility data, and the computer diagnostic and operational programs are stored on the cartridge.

The FDSU provides a two-motor, reel drive, constant reel speed tape drive system under control of the NCU. Data is transferred to the NCU at 23.7 kHz. Write as well as playback capability is provided by the FDSU, however only playback capability was used in this program.

The MTU is a pocket-sized sealed cartridge containing 160 feet (48.8 m) of 1 mil ($2.54x10^{-3}$ cm) computer-grade tape on which can be stored 12 million bits of data. The cartridge also contains the tape heads and the center and end of tape sensors. The tape is always rewound to center after data is accessed in order to minimize data access time. The MTU can be quickly installed and removed from the FDSU without the use of tools.

The FDSU is a 1/2 ATR short unit weighing 14.6 pounds (6.62 kg) and is convection cooled. It requires 19.5 watts of 400 Hz single phase power.

4. 161E-12 RNAV Switching Unit

   The RNAV switching unit is basically an assembly of relays which transfers signal and control circuits between the normal aircraft sensors, displays, flight director and autopilot computers, and the elements of the RNAV system.

   Temperature-altitude and vibration tests were performed in accordance with the applicable RTCA DO-138 tests.

   The unit is housed in a 1/4 ATR short low case, weighs 4 pounds (1.8kg), has a maximum power dissipation of 25 watts, and is convection cooled. It utilizes 28 VDC power.

5. Tuning Line Adapter

   The tuning line adapter is a small unit housing relays to isolate the manual frequency control during RNAV operation, and also incorporates circuitry to provide suitable true airspeed and baro-correction signals for the NCU. It utilizes 28 VDC power.

   The unit was subjected to the temperature-altitude and vibration tests of RTCA DO-138.

With the exception of the Tuning Line Adapter, the system is shown in Figure 2.2-1. Installation drawings are provided in Appendix 6.

2.3 Aircraft Interfaces

A block diagram of the system is shown in Figure 2.3-1, and detailed system interconnect data is provided in Appendix 1.

The RNAV Switching Unit and the Tuning Line Adapter provided the interface switching to allow the pilot to operate in the basic flight director and autopilot modes or in the RNAV mode.

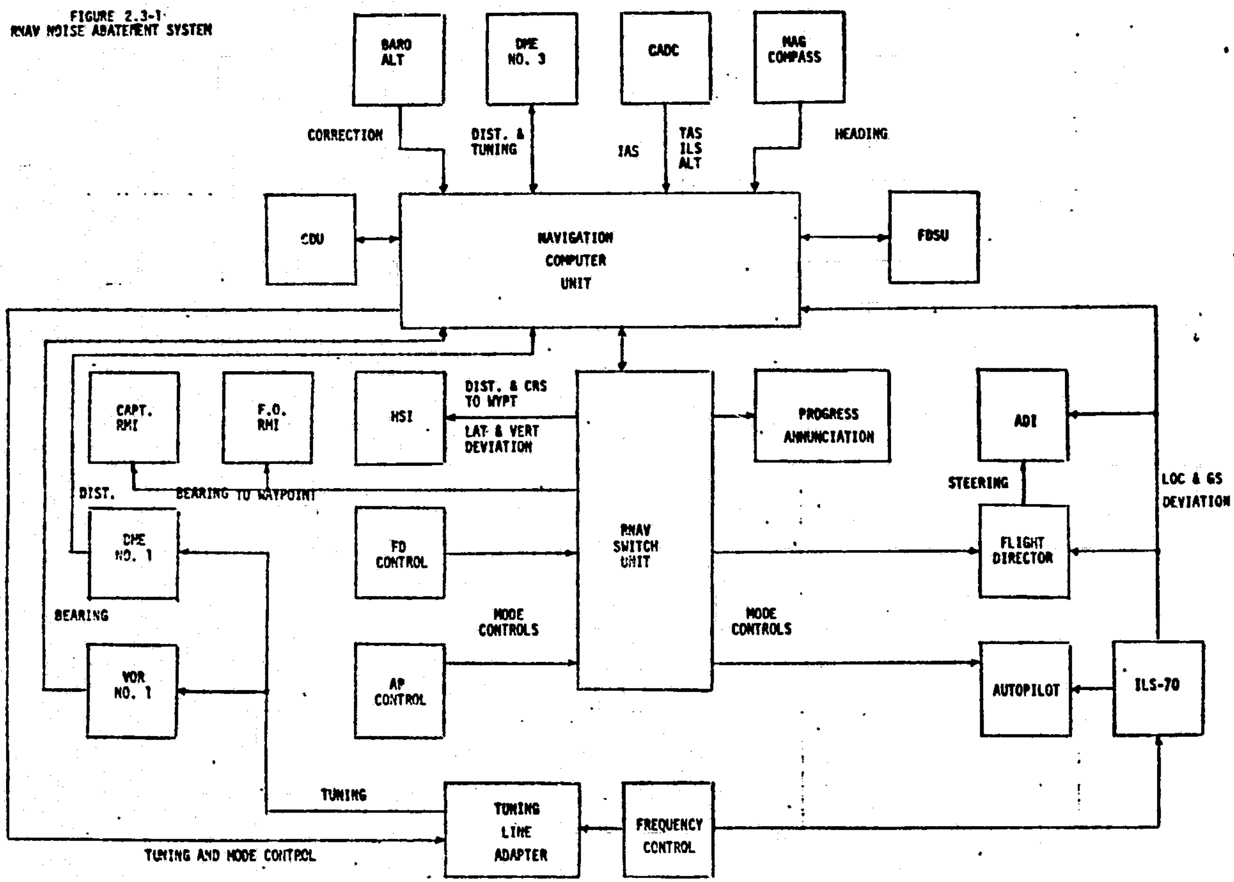
The most convenient interface through which to achieve lateral steering on both the flight director and autopilot was the heading error port normally driven by the heading error output from the pilot's HSI. Transfer of the heading error input between the HSI and the RNAV computer was accomplished with a relay in the RNAV switching unit.

In the case of the vertical axis, the most convenient interface with the flight director and autopilot was through the altitude error port normally fed by an air data computer in the altitude hold mode. The altitude hold mode capability existed on the aircraft's flight director, but is not normally implemented on the DC-8-61 by UA. Because the autopilot transfer function included a vertical rate input term not found on the flight director, it was necessary to provide separate flight director and and autopilot vertical steering outputs from the RNAV computer, the computer autopilot steering signal including a signal to cancel the direct vertical rate input.

The NCU used the standard DME pulse-pair distance signals from an ARINC 568 DME that replaced the pilot's standard DME, and a second DME added for this program.

The pilot's VOR was modified to provide a sine/cosine bearing output for the RNAV system.

FIGURE 2.3-1
RNAV NOISE ABATEMENT SYSTEM



When the RNAV system was engaged, tuning for the pilot's VOR and DME, and the extra DME, was provided through standard ARINC 2X5 tuning outputs from the NCU. Control was switched between the NCU and the pilot's manual control head by relays in the tuning line adapter.

The altitude input to the RNAV system was provided by coarse and fine synchros in the aircraft's CADC. Since only pressure altitude was available, however, it was necessary to add circuitry to the RNAV system to obtain a baro-correction signal from a potentiometer on the pilot's altimeter.

The RNAV system required a true airspeed input, which was available from the CADC only as a low level dc signal and the RNAV computer was modified to accept that signal. Because of the 150 knot lower limit of the true airspeed system, it was also necessary to bring indicated airspeed into the RNAV computer for use when operating at lower airspeeds during approach.

Interfaces were also present to permit the RNAV system to control some of the flight director and autopilot modes, to provide a bearing output for the RMI's and to operate the approach progress displays.

2.3.1 Aircraft System Modifications

To permit full utilization of the RNAV system, it was necessary to modify some of the standard avionic units on the UA aircraft, which was not basically configured for an RNAV installation. The modifications were:

1. VOR Receiver

The pilot's VOR receiver (a Collins 51RV-2) was modified to provide sine and cosine station bearing outputs for use by the RNAV computer in accordance with service bulletin No. 22. Existing functions were not affected.

2. DME

The pilot's ARINC 521 DME was replaced with an ARINC 568 DME to permit the RNAV computer to tune it with ARINC 2X5 control lines, and to provide a distance readout compatible with the RNAV computer input. In addition, to enable the RNAV system to obtain DME-DME position fixes, an additional DME was added to the aircraft.

3. HSI

The pilot's standard HSI was replaced with a new unit, (a modified Collins 331A-8D) having the following additional capability:

a. ARINC six-wire digital data input to accept DME or RNAV distance data.

b. A course arrow drive system which permitted either local or remote control of its position. The local/remote switch on the HSI's course set knob was also used as the switch to engage the RNAV system.

c. A heading bug drive system which permitted either local or remote control of its position. This feature was intended to be used when the system design called for the NCU to drive the heading bug and use the heading error output to provide flight director and autopilot steering.

4. Air Data System

The air data system was modified to provide the RNAV computer with true airspeed, indicated airspeed, and barometric altitude referenced to 29.92 in. of Hg.

5. Baro Altitude

A potentiometer pickoff was provided on the pilot's altimeter to indicate the baro setting to the RNAV computer.

6. ILS Receiver

Since the navigation receiver had to operate in the VOR mode during the approach, an independent ILS receiver (a Collins ILS-70) was added to provide the localizer and glide slope signals. This unit also operated as the glide slope receiver in the normal or non-RNAV modes.

7. Flight Director Controller

An RNAV mode position was added to the pliot's flight director controller.

8. Autopilot Controller

The AUX NAV position on the autopilot controller, not presently used, was used as the RNAV mode for the autopilot.

9. ADI

The standard unit was modified to provide raw glide slope and localizer signal displays.

2.3.2 RNAV System Modification

In addition to the modifications listed above, it was also necessary to make some modifications to the basic RNAV equipments and of course to the software. The modifications are as follows:

A. NCU

The changes to the NCU were in the aircraft systems coupler section (I/O) in order to handle some of the interfaces with the aircraft. They were:

a. Dc-to-digital input card added to provide four inputs to accept baro-correction and true airspeed signals.

b. Assembler/buffer card removed, as no serial digital inputs were used.

c. Ac-to-digital card modified to add second converter for auto-throttle input. (requirement for auto throttle later dropped)

d. Dc-to-digital converters added to handle glide slope and localizer signals.

e. Digital-to-synchro converter added to provide separate AP and FD vertical steering outputs.

f. Rate-to-digital card added. (part of the above converter addition).

g. Modified monitor card. (to provide monitoring of the added converters).

h. Digital-to-dc output card modified to add an 8 volt output (not used in Phase II).

B. CDU

The shape of the standard CDU was not compatible with the space available in the pedestal of the DC-8-61. While space was available outboard of the pilot's left leg, this was operationally unacceptable and NASA amended the contract to have the units suitably modified. This was done without modifying the basic electronics; however altitude and vibration tests were performed on the mechanically modified units to verify the absence of any problems.

C. Software

The basic software was one version of that used in the ANS-70A, and the development of the two-segment software was influenced by the desire to retain as much of that as possible. The modifications included changes in the data base, I/O, steering, logic, and navigation functions. These changes required about 1700 additional words of memory.

Navigation

The standard ANS-70A filter characteristics were used to process the VOR and DME data, except for a change (for ILS approaches) which increased the velocity term in the co-variance matrix for the state response due to noise by a factor of 8. This change shortened the time required for the filter to update the wind estimate and improved the performance in the face of high wind shears.

Data Base

In the standard ANS-70A system, the FDSU would typically have stored on tape the navigation aids and airways for the continental U. S., plus route data peculiar to the user. The data required for navigation in a particular area would be moved from tape to the computer's memory by a search based on the aircraft's position. The limited memory space available after the two-segment capability was added to the system made it initially impossible to include this capability, and a "tabled" data base was constructed for this program in which all of the navigation data was stored in the computer memory. Because of the limited memory space, this data base was limited to the specific airports at which two-segment approaches were to be made, plus the minimal en route data required. A flight data loader capable of using the tape data base was developed near the start of the line service phase of the program, but it was decided to stay with the tabled data base. The tabled data base does have the advantage of not requiring tape searches as the flight progresses since all data is in core memory. As the UA route structure changed during the line service evaluation, the data base was revised to cover the required airports.

Input/Output Functions

The basic ANS-70A was structured to accept and output data with ARINC formats and on specific hardware ports. Several modifications were thus required to meet the unique interfaces required by the aircraft and this program. These included the following:

a. The standard ANS-70A accepts dual VOR/DME inputs. The secondary VOR was not used on this program.

b. The ARINC data bus inputs were not used, because the aircraft had no sources in those formats.

c. The normal TAS input is an ARINC synchro. Because no such signal was available from the aircraft CADC, the software was modified to utilize the available dc TAS and TAS reference signals.

d. The normal input to the system is baro-corrected altitude. On this aircraft only pressure altitude was available and the software was modified to accept dc baro-correction and reference signals and generate the corrected altitude signal.

e. The aircraft's standard flight director was not used in the altitude hold mode, and the transfer characteristics of that port (used for vertical steering) were not compatible with those of the autopilot. The software was modified to provide separate flight director and autopilot vertical steering output signals with different characteristics. The autopilot itself did not have an interface matching the standard ARINC RNAV output.

f. Since this system was to be used in a regime below the 150 knot limit of the TAS system, software was added to accept the IAS input and to provide for a smooth transition between the two signals.

g. The software accepted and processed the input and output discretes such as flight director and autopilot mode switches unique to this system.

h. Inputs for the ILS signals were added.

i. Outputs to drive the progress annunciators were added.

j. The software provided a bearing to waypoint output rather than the standard track angle error output.

k. A desired course output for the HSI was provided in place of a drift angle plus track angle error output.

l. The standard CDU system status display page was modified to include new sensors such as the glide slope and localizer receivers. During the line evaluation phase, this page was further modified to add a code word signifying the reason for any aborts incurred and the state of the program as it progressed through the STAR.

Vertical Steering

The basic ANS-70 vertical steering law was used with few modifications for RNAV/RNAV approaches. One modification was the incorporation of a high gain latch to improve the vertical profile tracking after each leg was captured. As implemented, the latch could be defeated if the pilot flew the aircraft above the extended profile of the next leg (assuming that the next leg was a descent) before the switching distance for that leg was reached. If he did so, the deviation would be diverging and latching would not occur until the overshoot was corrected and the aircraft converged on the desired profile. (See Recommendations).

Another modification of the basic ANS-70 steering laws was required to achieve capture of the glide slope beam. Assigning a standard deviation sensitivity to the glide slope signal enables a vertical deviation from the glide slope beam to be calculated based on the estimated distance from the glide slope transmitter, and the calculated value can be used directly in the steering equations. Normally, however, the ANS-70A bases its switch to capture a new leg on a computed distance from the transition point between legs, and the difference between the VOR/DME/altimeter-referenced upper segment and the local referenced lower segment (glide slope) could result in a switch above or below the desired glide slope deviation required for a smooth (and safe) capture. The capture of the glide slope, therefore, is based on the actual sensed closure on the beam rather than being referenced to the flight plan. To avoid capturing a secondary lobe of the glide slope beam, the capture was not armed until the aircraft was five miles from touchdown. (See Recommendations). The system normally provides only one vertical steering output. Two were required for this program because of the different transfer characteristics of the flight director and autopilot.

Lateral Steering

The lateral steering signal is normally computed by comparing the position estimate with the desired flight plan. This was not adequate for localizer tracking and the lateral steering was accomplished first by using the linearized localizer signal instead of flight plan cross-track in the steering equations. At a later date, the program was modified to transfer the localizer steering to the flight director and autopilot at five miles from touchdown, and still later in the program to transfer as soon as convergence on the localizer was verified.

A phenomena which became apparent as the recordings of the line service flights were examined was that lateral drifts of more than two dots deviation (equivalent localizer) were occurring on some RNAV/RNAV approaches. Computer simulations showed that cross wind shear could cause this to occur and methods of combatting it were examined. (See Recommendations).

Flight Plan

The addition of the two-segment capability to the basic RNAV system required numerous modifications in the methods of handling the waypoints in the flight plan.

The standard RNAV system allowed the generation of a flight plan constructed of stored waypoints or navigation aids, or pilot generated waypoints defined in terms of latitude and longitude or bearing and distance from a known point. Normally, it is permissible to modify the course into the "TO" waypoint, and to edit altitudes. Because the two-segment approach is defined by transition altitudes and slopes that are fixed however, the three dimensional points defining the profile were handled by special rules.

1. Altitudes could not be edited.
2. Courses between waypoints could not be edited.
3. The STAR waypoints could be entered or deleted from the flight plan only as a group.
4. Waypoints could not be entered in the flight plan between STAR waypoints.

By pressing the line select key for STARS on the CDU index page, access was gained to the pages which grouped by airport the two-segment STAR's for each runway. The waypoints for a selected STAR could then be placed in the flight plan as a group.

The two-segment STAR's were denoted by NB or NI suffixes which indicated RNAV/RNAV or RNAV/ILS approaches respectively. The STARlists also included strings of waypoints for transitions in the terminal area leading to the STAR.

The STAR itself always consisted of four three-dimensional waypoints lined up on the runway centerline; the transition between the approach altitude and the upper segment (UPPER), the transition between the upper segment and the lower segment or glide slope (LOWER), a touchdown point (TD), and a go-around point 1000 feet above the far end of the runway.

The data base for a given STAR also included primary and secondary navigation aids. The primary station was always a VOR/DME, the one used by the FAA to define the waypoints on the RNAV approach plates. The secondary aid was a DME chosen where possible to give good DME-DME geometry.

Program Protection Logic

In addition to the safety protection discussed in Section 2.7, the software included logic to protect against faults generated internally. Some of these protectors were associated with the computer itself and some with the specific two-segment software. In the first category were such things as a self-test program run every 128 milliseconds to check basic operations of the arithmetic logic and control unit (ALCU) and memory, time-outs associated with the aircraft systems coupler (ASC) to flag the system invalid if the ASC is not serviced by the main program, and hardware/software monitors which verify that certain converters have operated correctly and that output flags have been set as requested.

The two-segment program included checks that certain program events and distances occurred in the proper sequence, and subprograms included checks that would cause the system to abort if data required by that program was not available at the time requested.

2.4 Pilot Procedures and Interfaces

The RNAV system was engaged through a switch located on the pilot's HSI. When pulled out, the standard functions of the pilot's flight director and autopilot were available to him, and the course knob operated manually to set the desired course for ILS of VOR functions. When the knob was pushed in, the normal deviation signal on the HSI was replaced with the cross-track deviation signal from the RNAV computer. The indicator on the HSI normally used to show glide slope deviation was also switched at this time to show the vertical deviation signal computed by the RNAV system.

With the RNAV system engaged, the RNAV computer commenced to autotune the navigation receivers. A lamp added to the pilot's manual frequency control head was illuminated at this time to indicate that the control head now controlled only the added ILS receiver. To aid pilot recognition of the fact that the RNAV system was engaged, an indicator on the HSI was switched from "RAD" to "RNV". As a further aid, the digital DME distance readout on the upper right corner of the HSI was extinguished and the upper left corner readout labeled DIST TO WYPT was energized to display the computed distance to the "TO" waypoint in the RNAV flight plan.

With the navigation radios devoted to the RNAV computer, the normal radio-dependent flight director and autopilot functions were not available, and the RNAV system incorporated interlocks to flag the steering invalid if the pilot selected such a mode.

When the course knob was pushed in, the manual set capability was disabled and the RNAV computer commenced to drive the HSI course needle to the course to the "TO" waypoint in the flight plan.

The number one needle on the pilot's RMI was switched from its normal VOR/ADF function and was driven by the RNAV computer to indicate the bearing to the "TO" waypoint.

At this point, the RNAV system was providing bearing, course, distance and deviation displays, but was not coupled to the steering systems. The flight director and autopilot could still be operated in their normal heading modes.

The pilot's control interface with the RNAV system itself was via the CRT display and keyboard of the CDU. Through this unit the pilot could assemble a flight plan for automatic execution or manually control heading, vertical speed, and navigation radio tuning. The data available for display on the unit consisted of:

a. Status of all sensors feeding the system.

b. Aircraft altitude.

c. Radio stations being tuned and whether or not their data was valid. (Identifying letters of the radio stations were displayed and a "V" or "D" symbol was displayed for each valid VOR or DME signal).

d. Bearing and distance to any waypoint or navigation aid from present position.

e. Course between waypoints in the flight plan.

f. Latitude and longitude of any waypoint or navigation aid.

g. Aircraft's ground track, drift angle, and ground speed.

h. Wind velocity vector.

i. Lateral and vertical deviation from the flight plan.

j. Greenwich Mean Time (GMT) and Estimated Time of Arrival (ETA) at the next waypoint.

k. Time to reach any point at present ground speed.

l. Lists of all Standard Terminal Approach Routes (STARs).

m. Present position.

The pilot first initialized the system by entering his present position and placing an origin/destination airport pair in the flight plan. From that point on, the system would (if engaged) automatically tune the radios available to it, and use their information and the air data system inputs to calculate the aircraft's position.

An en route flight plan could be constructed by selecting from the stored waypoints and navigation aids, by entering the latitude and longitude of a desired waypoint, or by defining waypoints in terms of bearing and distance from any previously defined waypoint.

RNAV steering commenced with the selection of RNAV on the flight director controller or AUX NAV on the autopilot controller.

Once the RNAV mode was selected on either the autopilot of flight director, neither of these systems could be operated in the heading modes and the steering would be flagged invalid on the system selecting that mode.

The autopilot could, however, be operated in the TURN KNOB mode.

Two-segment approach operations started when the pilot selected a noise abatement approach STAR from the list provided for each airport and inserted it in the flight plan. For this program, the STAR's were identified as follows:

25 LNB (typical)

where:

25 indicated the magnetic heading of the runway to the nearest 10 degrees.

L (left) was omitted in the case of a single runway on the specified heading, and was either L (left) or R (right) in the case of parallel runways.

NB indicated that the STAR was for a noise abatement approach without ILS. NI indicated a noise abatement approach with ILS.

The selection of a noise abatement STAR would result in a flight plan display similar to that shown in Figure 2.4-1.

When the RNAV system computed that the distance to the runway threshold along the selected flight path was less than 30 nautical miles (55.6 km), (See Figure 2.4-2), the RNAV annunciator on the Approach Progress Display (See Figure 2.4-3) would be illuminated amber if the following conditions were met:

1. RNAV system engaged (course selector on the HSI pushed in and "RNV" annunciated).
2. RNAV selected on the flight director controller or AUX NAV selected on the autopilot controller.

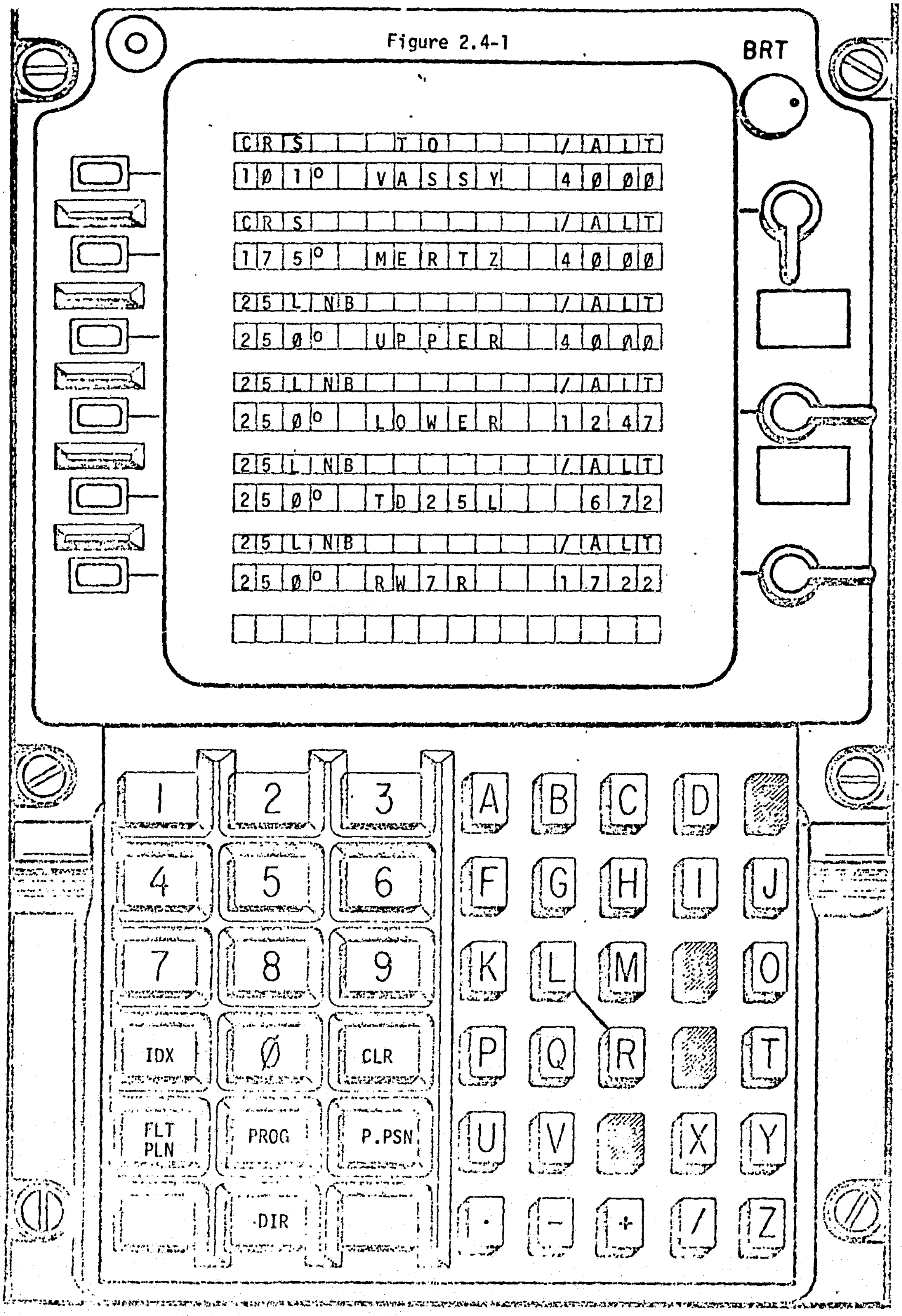

BRT
CRS TO /ALT
101° VASSY 4000
CRS /ALT
175° MERTZ 4000
25LNB /ALT
250° UPPER 4000
25LNB /ALT
250° LOWER 1247
25LNB /ALT
250° TD25L 672
25LNB /ALT
250° RW7R 1722
1 2 3 A B C D
4 5 6 F G H I J
7 8 9 K L M O
IDX Ø CLR P Q R T
FLT PLN PROG P.PSN U V X Y
DIR · – + / Z

Figure 2.4-1

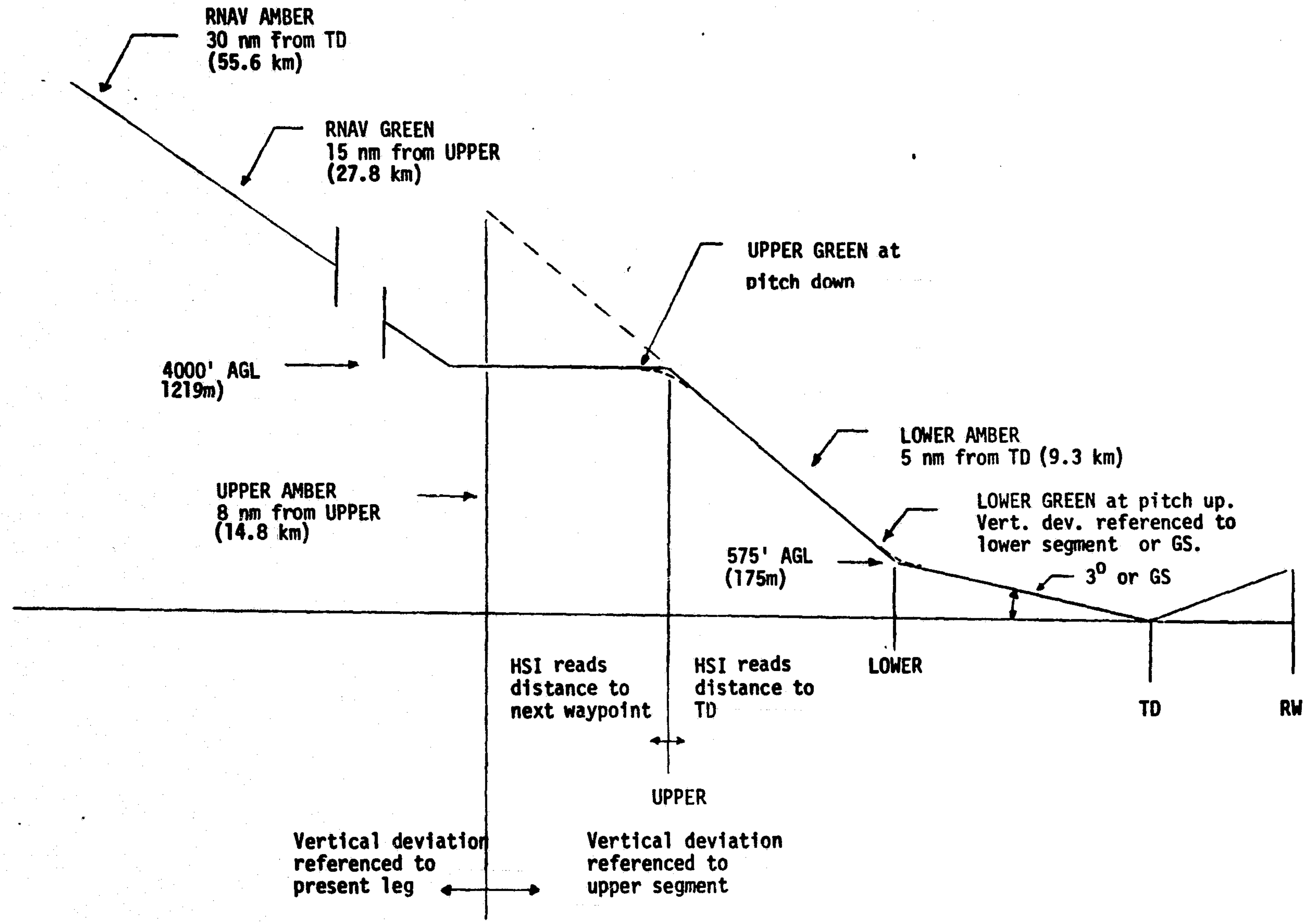
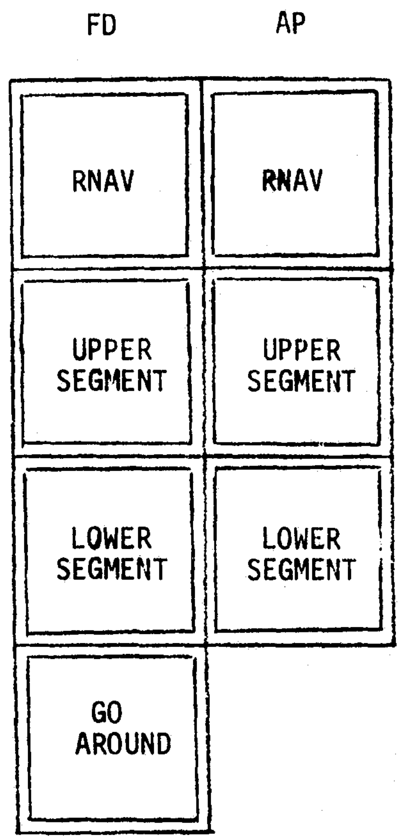


Figure 2.4-2
RNAV Two-Segment Approach



AMBER (ARM) AND GREEN (CAPTURE)

GO AROUND GREEN ONLY

FIGURE 2.4-3
APPROACH PROGRESS DISPLAY

When the distance to the UPPER waypoint (point defining the upper end of the steep approach segment) was less than 15 nautical miles (27.8 km) the RNAV light was switched from amber to green. The HSI alert light was inhibited from indicating waypoint approach after RNAV amber.

At eight miles (14.8 km) from the UPPER waypoint, the UPPER progress annunciator was switched to amber and the HSI vertical deviation started to show deviation from the extended upper segment rather than the leg being flown.

Prior to the upper amber condition, the lateral and vertical deviations were displayed as linear deviation from the flight plan profile. After upper amber, the deviations were switched to angular.

In the case of vertical deviation, the angular reference point was the runway touchdown point and the deviation sensitivity corresponded to that of a standard glide slope signal. The amount of deviation corresponded to the displacement from the leg being flown (after upper green). If an ILS approach was being flown, the deviation on the HSI would be switched to the actual glide slope deviation rather than the RNAV computed value, at lower green.

The angular reference point for RNAV lateral deviation computations was an assumed localizer location two miles from the runway touchdown point, and the deviation sensitivity corresponded to that of a nominal localizer signal. The amount of deviation corresponded to the deviation from the flight plan leg being flown. If an ILS approach was being flown, the HSI deviation would be switched to the actual localizer deviation as soon as the lateral steering was switched to that beam.

When UPPER became the "TO" waypoint on an ILS approach and the aircraft approached the localizer beam under the conditions discussed in Section 2.5.1, the lateral steering would be transferred to the flight director and autopilot computers. There was no direct indication of this transfer to the pilot (see Recommendations).

When the upper capture point was reached, the UPPER annunciator was switched to green. At UPPER waypoint passage, the DIST TO WYPT indicator on the HSI would show the distance to the touchdown point.

The LOWER annunciator would be switched to amber when the distance to the touchdown point was less than five nautical miles (9.3 km).

When the pitch-up point for the lower segment flight path was reached, the LOWER annunciator was switched from amber to green, and the HSI vertical deviation was referenced to the extended lower segment (or glide slope). At the same time, the go-around mode was armed and remained armed until the touchdown point was reached.

Pressing the go-around switch, or in the case of an RNAV/RNAV approach passage of LOWER, would result in the disengagement of the autopilot, the flight director vertical steering being biased from view, illumination of the GO-AROUND light, and cancellation of all other progress annunciations. The go-around annunciation was cancelled when the go-around waypoint was no longer the "TO" waypoint. Normal waypoint capture was inhibited when the touchdown point was the "TO" waypoint.

If the touchdown point was passed without go-around being selected, the GO-AROUND light was illuminated and the system operated as if go-around had been manually selected.

2.5 Guidance and Contol Laws

Since basic vertical and lateral control laws of the form shown in this section were already implemented in the ANS-70A, effort was directed to modification of those laws as required to achieve the desired performance with the DC-8-61 and its flight director and autopilot.

2.5.1 Lateral Steering

The lateral steering output from the RNAV system was a roll command derived basically from a deviation term (cross-track difference between the aircraft's position and the desired flight path) and a deviation rate term (derived from the difference between the track angles of the aircraft and the flight plan. Unmodified, this steering law produces undesi able exponential course captures, and a bank limiting law was used to produce a more constant bank condition while capturing. Cross-track deviation was also limited to provide the desired course-cut angles for initial and lateral offset captures.

The linear portion of the steering law may be expressed as follows:

$$\Phi_C = K1\ (CTDS + K3*TAER)$$

where:

Φ_C = Linear law bank command in degrees

$K1$ = Gain factor = $\dfrac{1.35 \times 10^5}{V_g \sqrt{V_g}}$

$K2$ = Gain factor = $0.155 + 0.00475\ V_g$

CTDS = Limited value of cross-track distance in nautical miles

TAER = Track angle error (difference between aircraft ground track and the desired flight plan course

K3 = K2/K1

V_g = Aircraft ground speed in knots

The ground speed vector is determined by using the airspeed vector (gyro-stabilized magnetic compass and air speed) and the wind speed vector from the navigation filter. The magnetic compass heading was corrected to true heading by using the magnetic variation of the nearest navigation aid stored in the data base. See Figure 2.5-1.

The value of CTDS is determined from the following:

a) If |CTD|>10 nm, CTDS = K3*COCU*CTD/ CTD

b) If |CTD|<10 nm, CTDS = CTD or K3*COCU*CTD/ CTD , whichever is smaller.

where:

CTD = crosstrack distance in nautical miles, (CTD/|CTD|) = sign of cross-track term.

COCU = desired course-cut angle (angle at which the flight plan course is to be intercepted, in degrees.

c) If an ILS approach is being made and the localizer has been captured, CTDS = LOC DEV * DIST

where:

LOC DEV = localizer deviation in radians (dots * scalar)

DIST = computed distance between the localizer and the aircraft in nautical miles.

Localizer capture through the RNAV computer occurs when the distance to the localizer is between 1 and 25 nautical miles (1.85 and 46.3 km), the "TO" waypoint is UPPER or LOWER, and the course change at the "TO"

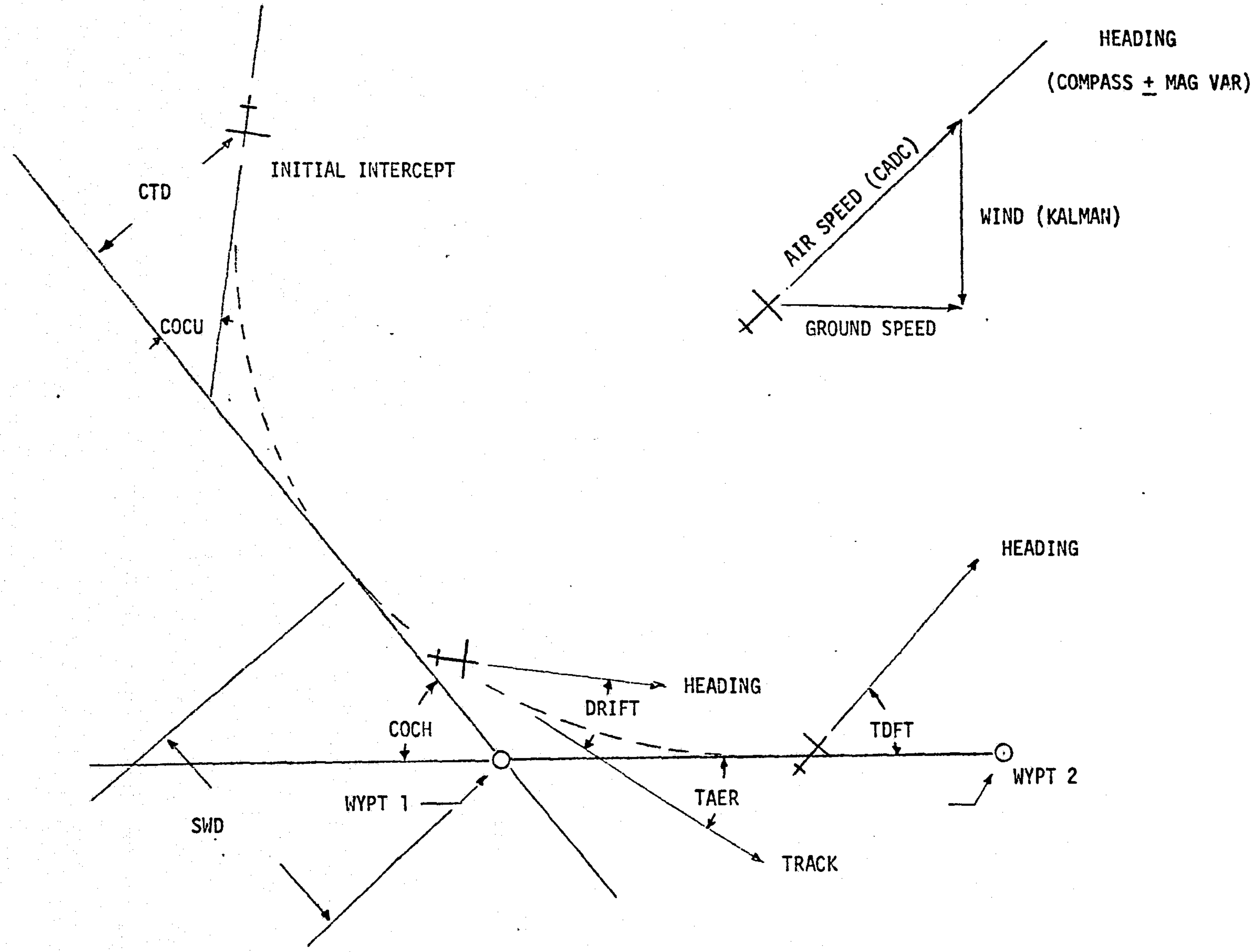


FIGURE 2.5-1

LATERAL STEERING

waypoint is less than 5 degrees. If these conditions are met, the track angle error is less than 15 degrees, and the localizer deviation is less than 1.5 dots, then lateral steering is transferred to the normal localizer modes of the flight director and autopilot, and they make their own steering computations.

The value of the desired course-cut angle in the above equation (COCU) is a function of the type of intercept being made. If returning to the flight plan from a lateral offset, COCU is 45 degrees. If intercepting a course after starting a teardrop turn, COCU is 90 degrees upon initiation and 45 degrees after the track to the desired course becomes less than 45 degrees. For leg-to-leg captures, COCU is 90 degrees if the course change is greater than 45 degrees, and 45 degrees if the change is less than 45 degrees. If the cross-track distance is less than 10 nautical miles (18.5 km), the track angle error is less than 10 degrees, and the aircraft is not executing a teardrop turn, COCU is 90 degrees.

The above steering command is used until the command reaches a limiting value given by the following equation:

$$\Phi_L = \tan^{-1}\left[2\frac{V_a^{\,2}}{g \times CTD} \left(\sin\left(\frac{\alpha}{2}\right) \sin\left(\frac{\alpha}{2} + TDFT\right) - \frac{\alpha}{2} \sin\left(TDFT\right)\right)\right] * 57.29578$$

where:

Φ_L= Bank limit in degrees

V_a= Aircraft air speed in knots

g= Acceleration due to gravity in nm/ hr^2

CTD = Cross-track distance in nm.

α = amount of heading change required in radians, and is equal to TAER-TDFT-DRIFT.

TAER = Track angle error of aircraft to course in radians (note change from previous equations)

DRIFT = Present drift angle in radians (difference between present track and heading)

TDFT = Tracking drift in radians

$$= \text{ARCSIN} \frac{V_w * \text{Sin}\ (DT - W)\ )}{V_a}$$

V_W = Velocity of wind in knots

V_a = Aircraft air speed in Knots

DT = Desired ground track direction in radians

The roll command output was limited to a maximum of 5 degrees per second, and then acceleration limited by passing it through a 1 second lowpass filter.

The point at which the cross-track deviation and track angle error ceased to reference the present flight plan leg and commence to reference the leg to be captured is defined as the lateral switching distance (SWD) and was computed as follows:

$$SWD = \min \frac{(.155 + 0.00475\ V_g)*\ V_g^{3/2}\ (COCH)}{(1.35 \times 10^5\ (\ 1+ 0.002\ (\ V_g - 150))\ \sin\ (COCH)}, 10\ nm$$

where:

SWD = Distance in nautical miles to the "TO" waypoint

V_g = Aircraft ground speed in knots

COCH = Course change in degrees

2.5.2 Vertical Steering

The vertical steering output from the RNAV computer is a pitch command derived from the difference between commanded and actual altitude rate, modified by ground speed, and has the form:

$$\theta_C = (-HE/LA+\dot{H}C-\dot{H}A-HELP)\ (-41.3)/V_g \text{ in degrees}$$

where:

θ_C = pitch command

HE = altitude error from the desired path in feet

LA = the larger of 2.63 or $|HE|/\sqrt{2an\ |HE|}$ in seconds

an = 0.0243 g

g = 32.2 fps^2 (9.8 mps^2)

$\dot{H}C$ = desired rate of descent (tangent of flight plan vertical path angle times ground speed) in fps.

$\dot{H}A$ = actual rate of descent (computed from change in altitude)

V_g = ground speed

HELP = the quantity labeled HELP is necessary because of the low bandwidth vertical steering interface used in this aircraft. It essentially provides an impulse of controlled duration to start the aircraft pitching in the desired direction to speed captures. The value of HELP is:

$$HELP = \dot{H}C_n * \frac{T_1 s}{T_1 s+1} * \frac{1}{T_2 s+1} * \frac{A}{\tau s+1}$$

where:

$\dot{H}C_n$ = desired altitude rate of the leg to be captured.

A = 0.985 + ($\Delta\dot{H}C)^2$/ 19109, limited to the range from 1.0 to 1.5

$\tau = 0.12^*|\Delta\dot{H}C|$

$\Delta\dot{H}C$ = difference in desired altitude rate on the leg presently being flown and the desired rate on the leg being switched to.

T_1 = 33 seconds for autopilot, 12 seconds for flight director.

T_2 = 5 seconds for autopilot, τ seconds for flight director.

The value of $(-HE/LA + \dot{H}C)$ is limited to 15 fps (4.6 mps) greater than $\dot{H}C$.

HELP is applied at the switch point and left in until the next switch point.

In order to improve the vertical path tracking after the vertical path change has been made, the time constant LA was forced to the limit value of 2.63 as soon as the path deviation was small enough to reach a calculated LA value of 2.75 or less. It was then held at that value until the switchimg distance for the next leg was reached.

In the ILS mode, the equations are modified at glide slope capture to use linearized glide slope deviation in place of altitude error. (HE equals glide slope deviation in radians times distance to touchdown).

The point at which the steering ceases to reference the present leg and commences to reference the next leg in the flight plan is the vertical switching distance (SWDV), and is computed as follows:

$$SWDV = |LAA1^*V_g * \cos(COCH) + CTD * \sin(COCH)|$$

where:

SWDV = along-track distance to go at switching point

LAA1 = the larger of 7.5 and $(\dot{H}A - \dot{H}C_n)/2$ an, during en route operations.

LAA1 = the larger of 2.63 and $(\dot{HA}-\dot{HC}_n)/2\ an$, during approach operations.

an = 0.0243 g

g = 32.2 fps (9.8 mps)

CTD = cross-track distance in nautical miles

COCH = lateral course change angle

SWDV is limited to a maximum of 10 nautical miles.

The acceleration limits used in the vertical steering equations were selected on the basis of computer simulations and UA pilot preference.

Except as noted above, the autopilot and flight director vertical steering outputs differed in the inclusion in the autopilot output of a vertical rate term to cancel an equivalent rate signal fed to the autopilot by its air data system when operating in the altitude hold mode.

2.6 RNAV Navigation

2.6.1 Position Determination

The RNAV system navigates by determining the aircraft's position and comparing it with the flight plan to develop deviation and steering signals.

The position determination is made by using a modified Kalman filter to process the following signals:

1. VOR bearing from one station
2. DME distance from two stations
3. Magnetic heading
4. Air speed

The basic ANS-70A can operate with dual VOR,DME, and inertial sensors

(with growth for a third inertial sensor) but only the above signals were used on this program.

If valid radio signals are not available, the system operates in a dead reckoning mode. It also operates in that mode if only a single axis (VOR only or DME only) radio sensor is available.

Within the system, computations are made in latitude and longitude and in true coordinates. The required conversion from the magnetic compass and VOR signals is made by using the magnetic variation stored for each VOR station to correct the individual station signals, and the magnetic variation of the closest navigation aid to correct the compass signal.

The basic ANS-70A filter gains were selected on the basis of extensive simulation and flight experience to give smooth flight characteristics in the face of predicted sensor noise and to meet the accuracy requirements of the FAA's AC 90-45.

The filter outputs are position and velocity (wind) updates. The ground speed vector is computed using the air speed vector (heading and air speed) and the wind vector from the filter.

The difference between the ground speed vector and the flight plan course becomes the track angle error input to the steering equations, while the distance between the aircraft's position and the course (measured along a perpendicular to the course) becomes the cross-track deviation input for steering.

The flight plan course is normally computed as the course between the "FROM" and "TO" waypoints in the flight plan, however the course into the "TO" waypoint (except for two-segment STAR waypoints) could be directly specified by the pilot. Regardless of how entered into the computer, all waypoints are handled internally in lat/long coordinates and courses are computed relative to true north. Conversions to magnetic north are made for CDU and HSI displays.

Lateral deviation is normally computed by calculating the bearing and distance between the present position and the "TO" waypoint, and using the cosine of the angle between that bearing and the course to compute the cross-track distance. En route the lateral deviation was displayed on the HSI with a linear sensitivity of 1 nm per dot. After upper amber, the ratio of the cross-track distance to the along-track distance to touchdown plus 2 nm, times a nominal localizer sensitivity scalar of 1 dot per 0.0147 radians, was used to produce an angular deviation display. In the case of an ILS approach, the actual localizer deviation was displayed after the steering commenced to use that signal.

In the vertical axis, the vertical path angle into the "TO" waypoint was computed by using the vertical and horizontal distances between the "FROM" and "TO" waypoints. This angle and the along-track distance between the "TO" waypoint and the present position were then used to compute the desired altitude, which was compared with the actual altitude to determine the vertical deviation. En route, the vertical deviation was displayed on the HSI with a sensitivity of 100 feet per dot.

After upper amber, the ratio of the vertical deviation to the along track distance to touchdown, times a nominal glide slope deviation sensitivity scalar of 1 dot per 0.00628 radians, was used to produce an angular deviation display. In the case of an ILS approach, the actual glide slope deviation was displayed after glide slope capture.

2.6.2 Radio Selection Techniques

During en route operation, automatic station selection logic in the RNAV computer selects station pairs so that DME/DME navigation is used as much of the time as possible. The NCU then tunes the pilot's VOR and paired DME plus the second DME automatically. The computer ranks the available stations according to their distance from the aircraft. The first and second ranked stations are tested with respect to the aircraft's position for proper DME/DME geometry. If the first and second ranked stations do not result in DME/DME navigation, the first and third ranked stations are tested, etc.. If none of the available stations satisfies DME/DME geometry criteria, the system reverts to VOR/DME operation using the first and second ranked stations. When the system is operating in the VOR/DME mode, it will continuously test available stations for proper DME/DME geometry and revert to that mode when possible.

The automatic station selection logic is initiated whenever any of the following cinditions indicate retuning is necessary.

1. The stored range limit for a station being used is exceeded. The radius of coverage for high altitude stations is generally 130 nm (241 km), and 25 (46.3 km) or 40 nm (74.1km) for low altitude stations.
2. Radio data cannot be used for navigation for 30 seconds for one of the following reasons:

a. Flag validity.

b. Incorrect comparison of commanded and tuned frequencies.

c. Sensor limitations such as:

(1) VOR cone of confusion. Data is not used when the aircraft is within a 45 degree cone around a station.

(2) DME station proximity. Data is not used if the distance to the station is less than $V_g^2/ 28{,}800$ nm, because the acceleration may cause DME sensor errors.

d. Radio data reasonableness. Measured bearings and distances from the receivers are tested for reasonableness before being used for navigation computations. If the data exceeds the 4 sigma expected error, derived by the filter for the aircraft position, it is rejected.

Stations may be tuned manually by the pilot, using the Present Position page on the CDU. If a station is manually tuned from the CDU, it is used until out of range.

The automatic radio station selection technique described above is the method normally used by the RNAV system. For two-segment approach operations, however, the automatic tuning was changed to require that the primary VOR/DME radios be tuned to a specific station. The navigation accuracy required for the two-segment approach is higher than for en route operations, and there is no guarantee that all stations which could be automatically tuned would have the required accuracy.

When a noise abatement STAR was entered in the flight plan, the tuning logic was changed as soon as the RNAV amber region was entered. At that time, the computer attempted to tune the radios stored in the data base for that particular STAR. If it failed to tune the primary VOR and DME successfully by the time that upper amber was reached, the steering validity was dropped, biasing the flight director steering from view and disengaging the autopilot.

If the primary radios became invalid for more than 15 seconds after upper amber, the steering validity was also dropped, except in the case of an RNAV/ILS approach after ILS capture, when valid VOR and DME signals are no longer required.

The radio abort point was originally set at RNAV green, but approaches were being aborted occasionally when the radios were taken away from the computer in the terminal area when the pilot elected to switch back momentarily to the standard aircraft configuration.

The 15 second delay was added during the initial flight test period in order to prevent aborts due to momentary radio loss.

Late in the program, a change was made in the logic that controlled the use of the VOR and DME signals by the navigation filter during en route operations. The change consisted of forcing the system to revert to the dead reckoning mode if only one VOR or one DME was available. The filter performance was found to be degraded if driven by a sensor providing data in only one axis.

2.7 Safety Considerations

The RNAV noise abatement program drew heavily upon the preceding 727 glide slope computer program in the design of the safety protectors. In addition, the basic RNAV computer programs incorporated several protectors. The protectors consisted of the following:

1. Abort if an altitude of less than 550 ft (168 m) above field elevation was reached prior to capturing the lower segment.
2. Abort if the aircraft was more than 750 feet (229 m) past LOWER prior to glide slope beam capture.
3. Glide slope capture not allowed unless the aircraft is less than 5 miles (9.3 km) from touchdown in order to protect against false glide slope beam lobes. (See Recommendations).
4. Abort if the localizer deviation exceeded 2 dots after capture.
5. Abort if below glide slope for more than 10 seconds on the upper segment.
6. Abort if within 5 miles (9.3 km) from touchdown and glide slope deviation is zero without glide slope capture.
7. Computer self-test.
8. Computer monitoring of sensor validity (flags) and navigation radio data reasonableness.
9. Computer checks on manually entered data (format and range).
10. Computer checks on baro-correction circuit continuity.
11. Computer prohibitions on STAR data editing.
12. Computer checks on proper approach event sequence.
13. Relay interlocks on FD, AP, and RNAV switches to prohibit improper system setup.

In the engineering evaluation system, there was an additional protector in the form of a message to remind the pilot to tune the ILS receiver. (See Recommendations).

A protector to cross check the First Officer's baro altitude with the pilot's was considered, but rejected as it violated UA's cross-cockpit isolation philosophy. A requirement to have the pilot acknowledge that he had set the baro-correction was also rejected on the grounds that it was an unnecessary duplication of a standard checklist item.

The effects of various system faults are shown in Table 2.7-1. The table lists the flags that were displayed and any CDU message that would be displayed on the status page..A steering flag would result in the flight director steering bars being driven from view and the autopilot being disengaged.

A relay interlock in the RNAV Switching Unit prevented the flight director or autopilot from being engaged in the RNAV mode if the flight had already progressed to the upper green state.

The following notes apply to Table 2.7-1:

1. If the aircraft reaches a point that would allow the localizer to be used in the steering or transfer to the flight director or autopilot, failure to have a valid localizer flag will cause an abort.
2. These flags must be invalid for 15 consecutive seconds in order to cause an abort. The same abort logic is used if the computer detects invalid VOR/DME tuning or invalid data.
3. While internal checks are made as indicated, the presence of a STAR would normally guarantee the presence of both lateral and vertical events in the flight plan.

ORIGINAL PAGE IS OF POOR QUALITY

TABLE 2.7-1

FAILURE MODES	FLIGHT CONDITIONS																																				CDU MESSAGE
	EN ROUTE			RNAV AMBER			RNAV GREEN			UPPER AMBER						UPPER GREEN						LOWER AMBER						LOWER GREEN						GO AROUND			
										RNAV			ILS			RNAV			ILS			RNAV			ILS			RNAV			ILS						
	L	V	S	L	V	S	L	V	S	L	V	S	L	V	S	L	V	S	L	V	S	L	V	S	L	V	S	L	V	S	L	V	S	L	V	S	
1. NCU FAILURE	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	COMPUTER FAILURE (IF POSSIBLE)
2. VOR NO. 1 FLAG (2)										X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X							FAULT VOR 1
3. DME NO. 1 FLAG (2)										X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X							FAULT DME 1
4. DME NO. 2 FLAG																																					FAULT DME 2
5. GLIDESLOP REC FLAG																			X	X	X				X	X	X				X	X	X				FAULT GS
6. LOC REC FLAG													(1)	(1)	(1)				X	X	X				X	X	X				X	X	X				FAULT LOC
7. FDSU FAILURE	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	FDSU FAILURE
8. CDU FAILURE	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	CDU FAILURE (IF POSSIBLE)
9. COMPASS FAILURE	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	FAULT HDG 1
10. IAS OR TAS FLAG	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	FAULT CADC 1
11. ALT FLAG		X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	FAULT CADC 1
12. BAD BARO MONITOR CHK		X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	
13. NO "TO" LATERAL EVENT(3)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
14. NO "TO" VERTICAL EVENT(3)		X	X		X	X		X	X		X	X		X	X		X	X		X	X		X	X		X	X		X	X		X	X		X	X	
15. BELOW GS >10 SEC																			X	X	X				X	X	X										
16. >2 DOTS LOC DEV.													(5)	(5)	(5)				(5)	(5)	(5)										X	X	X				
17. POWER INTERRUPT							X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
18. >75 FT BELOW LOWER ALT										X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X										
19. >750 FT PAST LOWER																									X	X	X										
20. STATE SEQUENCE ERROR (4)				X	X	X										X	X	X	X	X	X																

L = HSI NAV FLAG
V = HSI GS FLAG
S = STEERING (FD & AP) FLAG

4. State sequence errors may occur as the result of software program checks to verify that the flight plan events and distances are consistent with the sequence of events required for a two-segment approach.
5. Abort if transfer to the flight director or autopilot has taken place.

The system modes and annunciator logic are summarized in Tables 2.7-2 and 2.7-3.

2.8 Summary of RNAV Modifications for Two-Segment Approaches.

For this program, two types of hardware modifications were made to the basic RNAV system. The I/O section of the RNAV computer was modified to interface with some of the existing avionics of the aircraft, and the CDU was mechanically modified to fit into the throttle pedestal of the aircraft. Neither of these modifications were specifically related to two-segment approaches.

An area in which there was no hardware impact on this program but in which the addition of two-segment approach capability could cause an impact is in memory size. If the RNAV computer has limited growth capability and all of its existing functions must be retained, additional memory should be required to handle the two-segment approach functions.

The software must, of course, be modified to add the two-segment approach capability. The extent of the change may range from simple logic to handle such things as approach progress display and safety protection, to modification of the I/O handling and the basic steering mechanization. In this program, the computer memory could not accomodate all of the desired RNAV and two-segment

TABLE 2.7-2

FLIGHT CONDITIONS		MODE SELECTORS		STEERING COMMANDS		APPROACH PROGRESS DISPLAY (AP AND/OR FD)	HSI DISPLAYS (1) (2)	
GENERAL	SPECIFIC	AP	FD	AP	FD		VERT	LAT
Enroute	RNAV OFF	All modes normal, AUX NAV not available.	All modes normal, RNAV not available	Normal for available modes, disconnect or out-of-view in other modes.		OFF	Normal	
	RNAV ON	ILS & LOC/VOR not available. HDG SEL available if FD not in RNAV mode.	VOR/LOC & APPR not available. FI available if AP not in AUX NAV mode.			OFF	Deviation from vertical flight path on GS bar. Deviation from lateral flight path on course dev. bar.	
		AUX NAV	RNAV	Steering to flight plan profile.		OFF		
Terminal Area	Less than 30 NM from runway touchdown.	"	"	"		RNAV Amber	"	
	Less than 15 miles from UPPER.	"	"	"		RNAV Green	"	
	Less than 8 miles from UPPER.	"	"	If RNAV/ILS STAR, LOC DEV <1.5 dots TRK angle error <15 deg, UPPER is "TO" waypoint, and course change to next leg< 5 deg, lateral steering switched to FD/AP LOC modes. (3)		UPPER Amber	Deviation from extended upper segment on GS bar. Deviation from lateral flight path on course dev bar. (3)	
	UPPER Capture	(AUX NAV not selectable after this point.)	(RNAV not selectable after this point.)	"		UPPER Green	"	
	Less than 5 NM from runway	"	"	Lateral steering commands switched to FD and AP LOC modes, if RNAV/ILS STAR.		LOWER Amber	"	
	LOWER Capture	"	Go-Around Armed	Vertical steering commands to capture glideslope, if RNAV/ILS STAR.		LOWER Green	Deviation from glideslope on GS bar, if RNAV/ILS STAR.	
	LOWER Passage	AP Disconnect If RNAV/RNAV STAR	"	AP Disconnect	Vertical steering out-of-view, lat steering to FLT Plan if RNAV/RNAV STAR.	Go-around ON, All other displays OFF, if RNAV/RNAV STAR.	Deviation from RNAV flight path, if RNAV/RNAV	
	Go-Around (Manual)	AP Disconnect	RNAV	AP Disconnect	Vertical steering out-of-view. Lateral steering to flight plan.	Go-Around ON, all other displays OFF.	Deviations from RNAV flight path.	
	Runway threshold passage without manual go-around	"	"				"	
	Go-Around way-point transition	Same as enroute						

(1) HSI mode annunciator reads "RAD" if RNAV OFF, "RNV" if RNAV ON.
(2) HSI course arrow displays course to next waypoint if RNAV system is ON.
(3) If RNAV/ILS STAR, LOC dev displayed on HSI and used in RNAV steering when UPPER is "TO" waypoint and course change to next leg < 5 deg.

2-SEGMENT ANNUNCIATOR, MONITOR, AND DISCONNECT LOGIC

FLIGHT CONDITION	ANNUNCIATOR LOGIC (1) FLIGHT DIRECTOR	ANNUNCIATOR LOGIC (1) AUTOPILOT	FLIGHT DIRECTOR STEERING FLAG MONITORS	AUTOPILOT DISCONNECTS IF	FLIGHT DIRECTOR STEERING OUT OF VIEW IF
RNAV Amber	A/C 30 NM from runway threshold.		Normal FD valid (A): NCU master warn, valid RNAV mode, valid TAS, IAS, ALT, HDG, and BARO monitor.	(A) Invalid or normal disconnect	(A) Invalid
RNAV Green	A/C 15 NM from UPPER waypoint. RNAV amber extinguished.		Normal FD and (A) valid. (B): Primary VOR/DME valid.	(A) Invalid or normal disconnect. (B)	(A) Invalid (B)
UPPER Amber	A/C 8 NM from UPPER waypoint.		Normal FD and (A)(B) valid. (C): LOC valid (if in range for ILS approach) (D): Below minimum altitude	(A) Invalid or normal disconnect (B) (C) (D)	(A) Invalid (B) (C) (D)
UPPER Green	A/C at upper capture point. (2) UPPER amber extinguished		Normal FD, (A), (B), (C), (D) valid (E): GS valid (ILS approach) (F): Below GS for 10 sec. (ILS)	(A) Invalid or normal disconnect. (B) (E) (C) (F) (D)	(A) (B) (E) (C) (F) (D)
LOWER Amber	A/C 5 NM from lower waypoint.		Normal FD, (A), (B), (C), (D), (E), (F) (G): GS Dev = 0 (ILS) (H): Minimum distance to runway (ILS)	(A) Invalid or normal disconnect. (B) (E) (H) (C) (F) (D) (G)	(A) Invalid (B) (E) (H) (C) (F) (D) (G)
LOWER Green	A/C at lower capture point (or glideslope capture point in the case of an RNAV/ILS approach). LOWER amber extinguished.		Normal FD, (A), (B) if not an ILS approach, (C), (E)	(A) Invalid or normal disconnect. (B) If not an ILS approach (C) (E)	(A) Invalid. (B) If not an ILS approach (C) (E)
Lower Passage	A/C passing lower. If RNAV/RNAV approach go-around illuminated and all other annunciators extinguished.		Normal FD, (A), B if not an ILS approach (C)(E).	(A) Invalid, RNAV/RNAV approach, or normal disconnect (C) (E)	(A) Invalid (B) If not an ILS approach (C) (E) Vertical out of view if RNAV/RNAV
Go-Around	Go-around switch manually actuated in lower green region. All annunciators except go-around extinguished.		Normal FD, (A)	Forced disconnect (normal)	Vertical forced out (normal). (A) Invalid.
Runway Threshold Passage	Go-Around illuminated, all other annunciators extinguished.		Normal FD, (A)	Forced disconnect (normal)	Vertical forced out (normal). (A) Invalid

(1) RNAV system on, AP and/or FD in RNAV mode, and RNAV STAR in flight plan.
(2) FD and AP cannot be switched to RNAV unless one or the other is already in RNAV prior to reaching this point.

TABLE 2.7-3

approach functions, and rather than impact the physical capabilities of the computer, some of the RNAV functions (of the ANS-70A) were modified as discussed in Section 2.3.2.

3.0 SYSTEM PERFORMANCE

3.1 Simulation Description

Initially, analog computer simulations were performed to help establish the desired control laws. When the laws were implemented in the digital computer software, simulation was performed on the Collins hybrid computer test facility. This effort continued in conjunction with the engineering evaluation flight program in order to finalize the control laws. Figure 3.1-1 shows the hybrid computer test configuration.

The EAI analog computer contained the models of the vertical and lateral axis dynamics of the DC-8-61, plus models of the aircraft's autopilot and flight director. These were driven by the steering commands from the RNAV computer or cockpit controls. The PACER-100 digital computer used the analog signals to determine the relative motion of the modeled aircraft, adding the initial conditions to determine the aircraft's latitude, longitude, altitude, and velocity. This information was then used to generate pseudo sensor data for the RNAV computer inputs. The digital to analog converter (DTA) was used both as a communications channel between the physical locations of the RNAV and PACER computers, and to convert the pseudo sensor signals into formats identical to those that would feed the aircraft systems coupler section of the RNAV computer in the aircraft. ADI, HSI, approach progress annunciators, altimeter, and control wheel were provided in a cockpit mockup for flight director operations.

The PACER computer included provisions for switching sensor validity signals ay will, for inserting controlled levels of noise into the VOR/DME and air data signals, and for inserting fixed or sheared wind levels.

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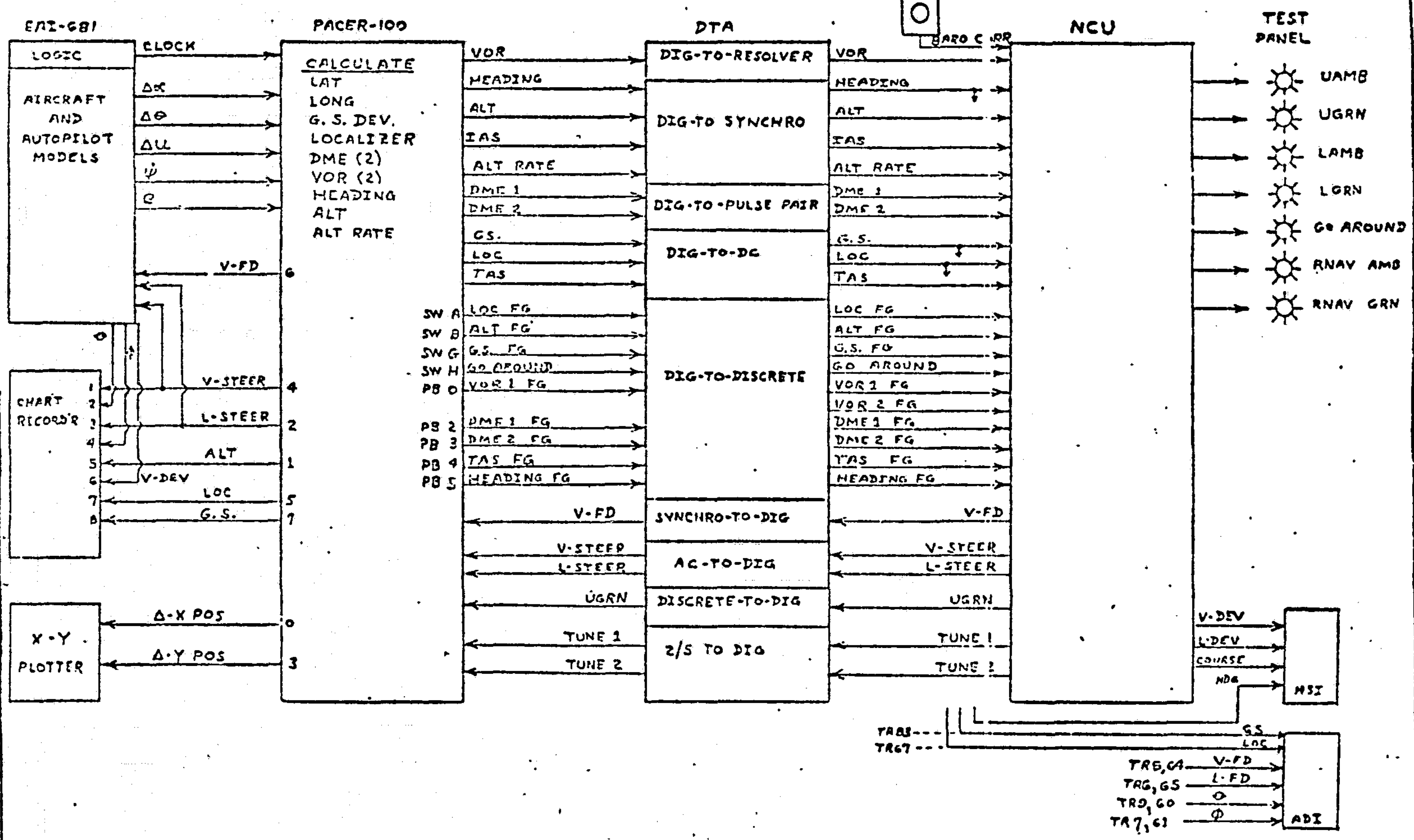


FIGURE 3.1-1. TEST CONFIGURATION

SCALE REV SHEET 4

The PACER would also sense the tuning outputs from the RNAV computer and broadcast radio sensor data corresponding to the selected stations.

3.2 Simulation Results

Figure 3.2-1(a) through 3.2-1(t) show simulations made with the final version of the software used during the line evaluation flights. Figures 3.2-1(a) through 3.2-1(l) show the performance of the system using a single VOR/DME station located on the field, with a variety of wind and noise conditions. Specifically, the approaches are 27RNI and 27 RNB at Chicago's O'Hare airport, using only the ORD radio. In these tests, the wind models are those specified by the NASA RFP:

$W = K/.78(.43 \log_{10} h + 0.35)$ knots,

where K = 25 for headwinds, 10 for tailwinds, and 15 for crosswinds.

h = altitude in feet.

The sensor noise levels were not specified in the RFP, and were asumed to be:

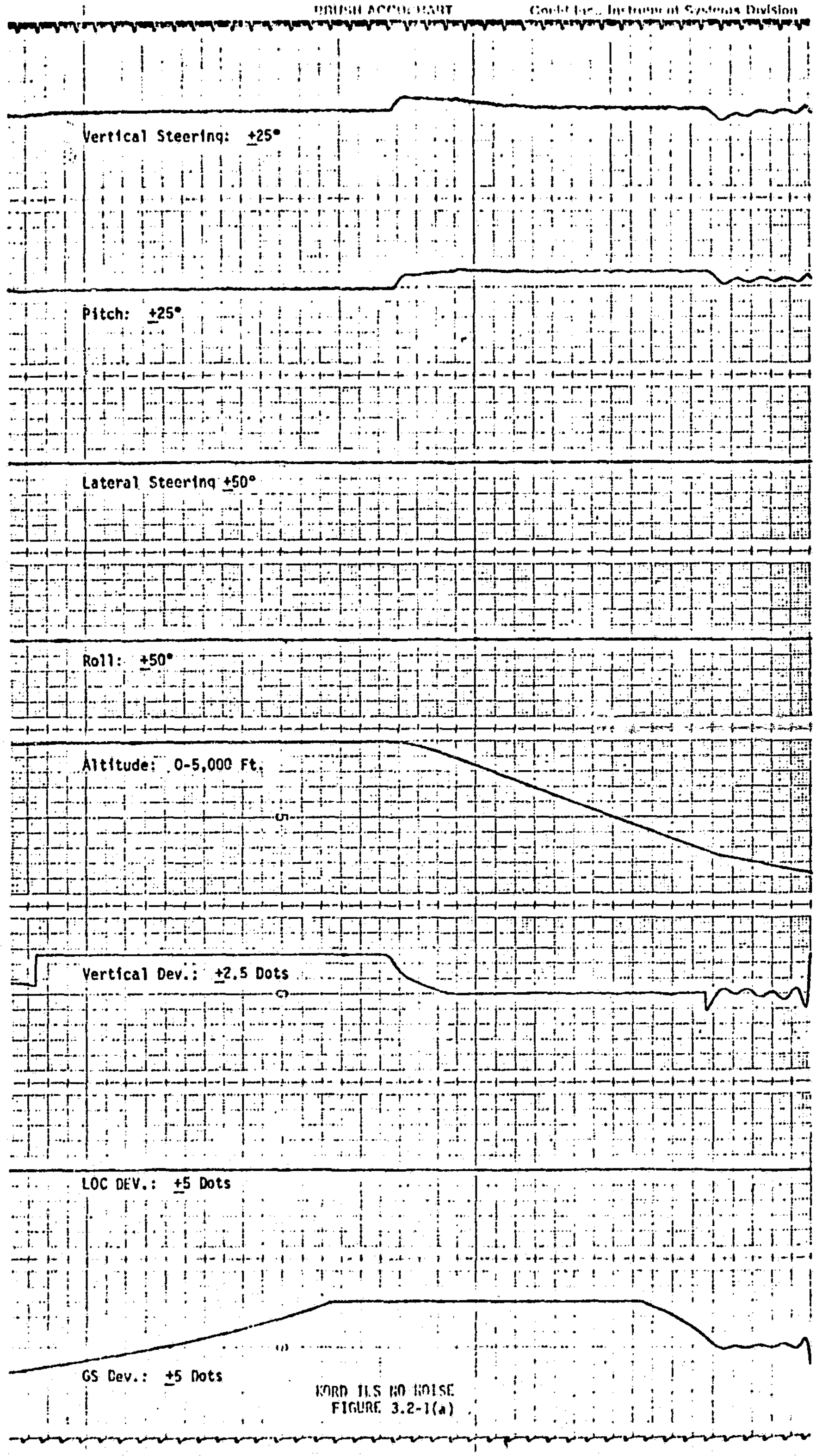
Altitude = 8 ft (2.44m) rms, with a 1.7 second correlation time.

VOR = 1.1 degrees rms, with a 10 second correlation time.

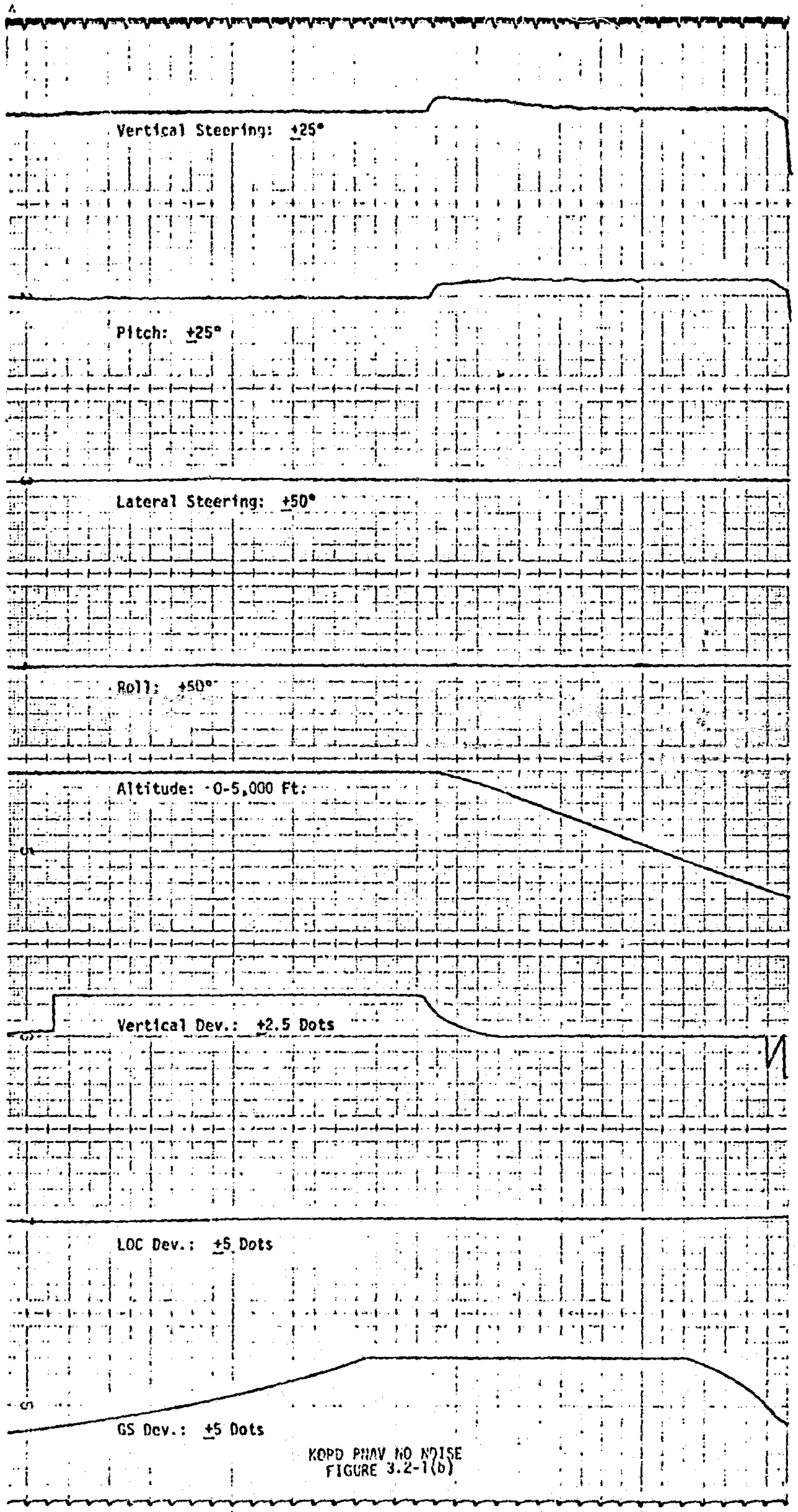
DME = 0.1 nm (185m) bias.

TAS = 3.5 (1.1m) fps rms, with a correlation time of 1.7 seconds.

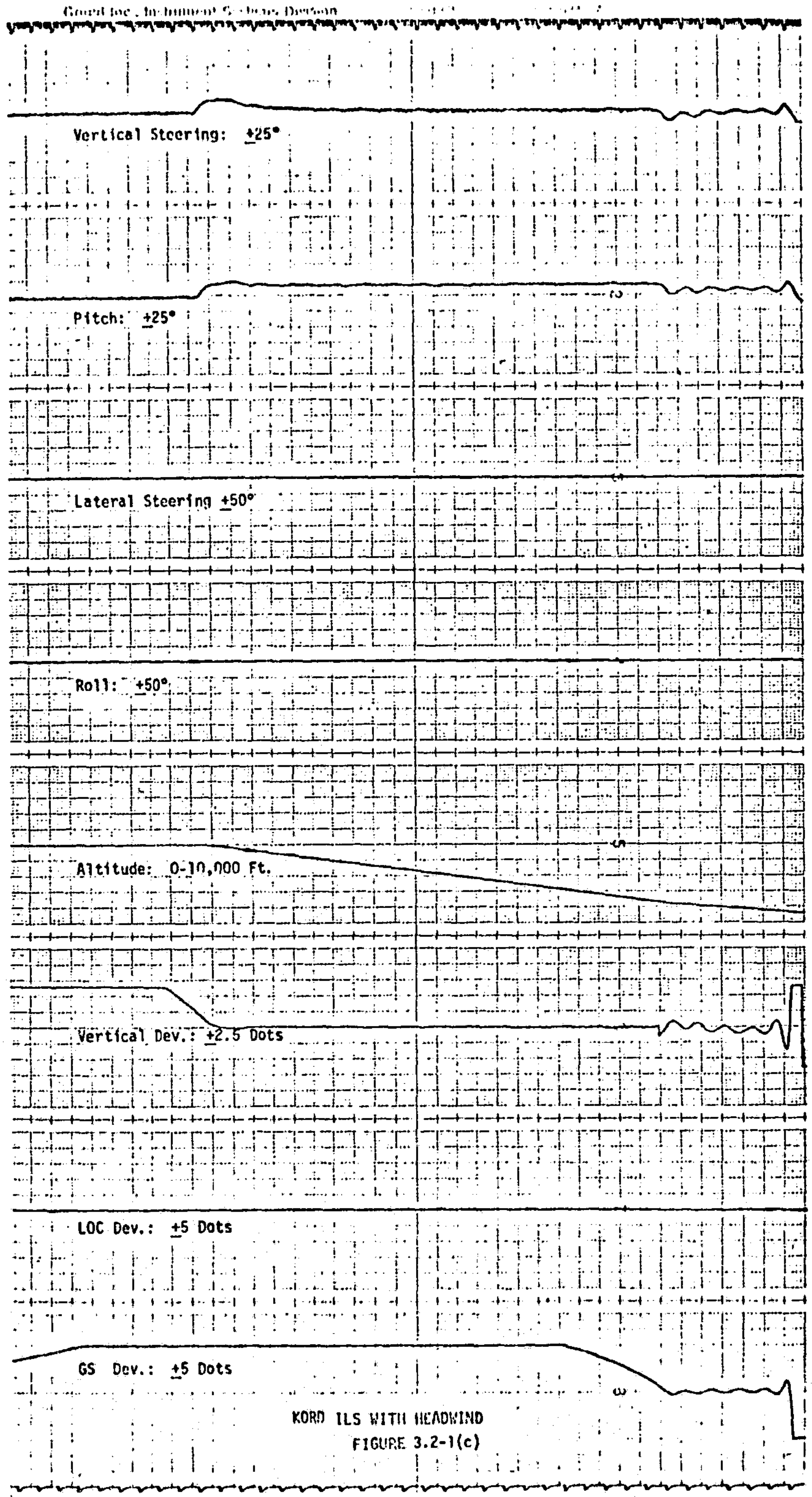
Figures 3.2-1(m) through 3.2-1(p) show the results of adding the secondary DME (OBK) to the system. Figures 3.2-1(q) through 3.2-1(t) show the performance with a single VOR/DME located so that the VOR is the prime sen-



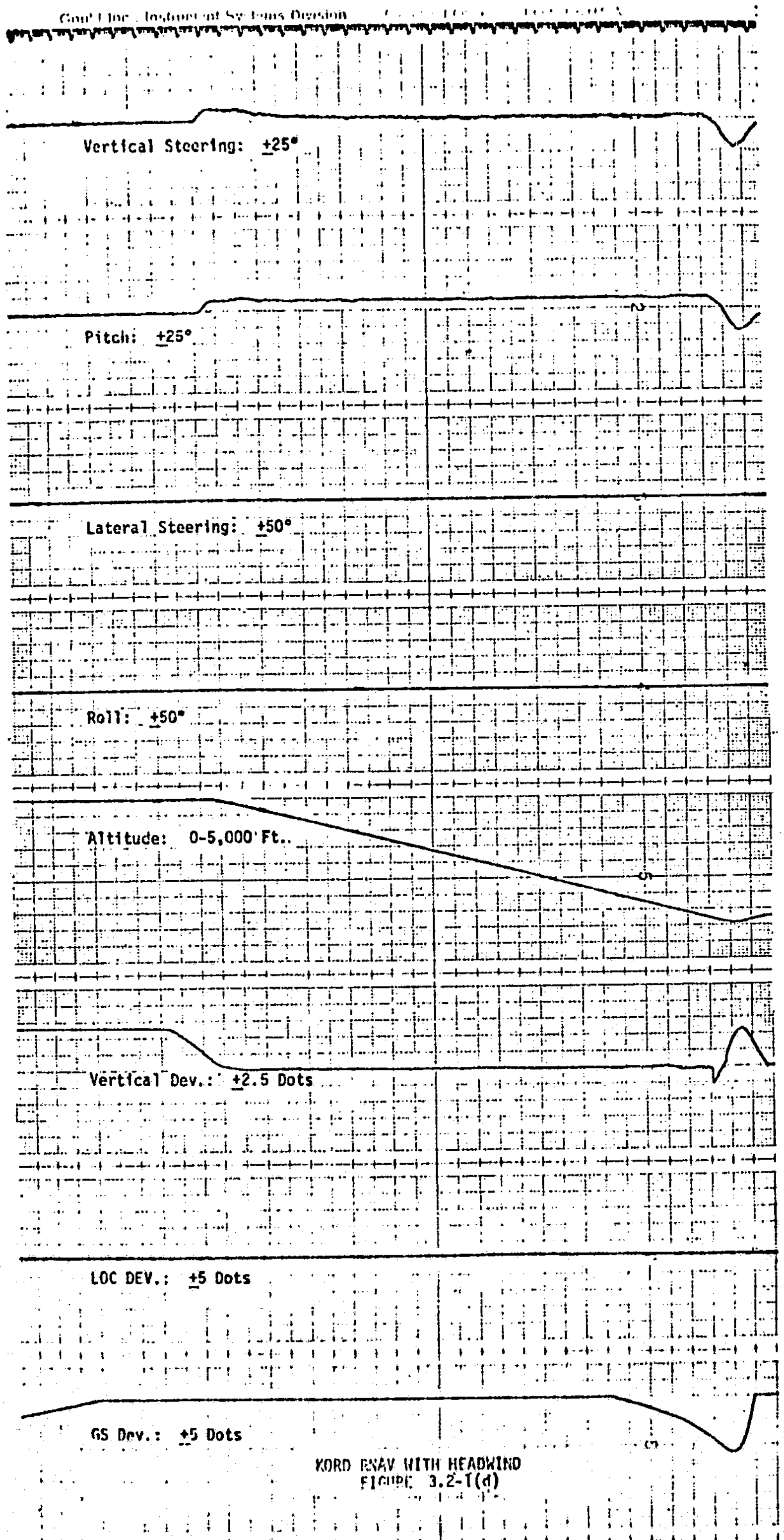
KORD ILS NO NOISE
FIGURE 3.2-1(a)



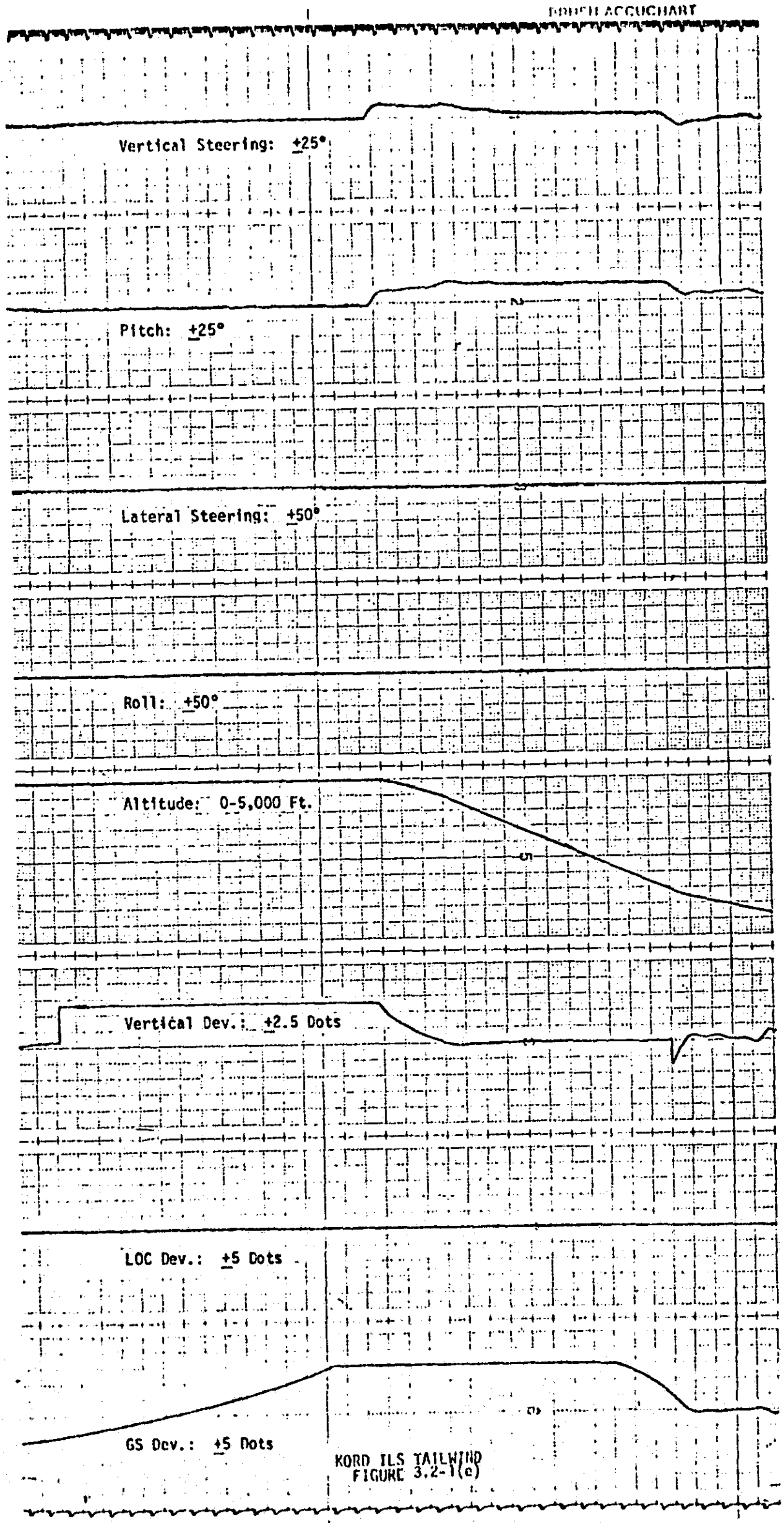
KOPD PHAV NO NOISE
FIGURE 3.2-1(b)



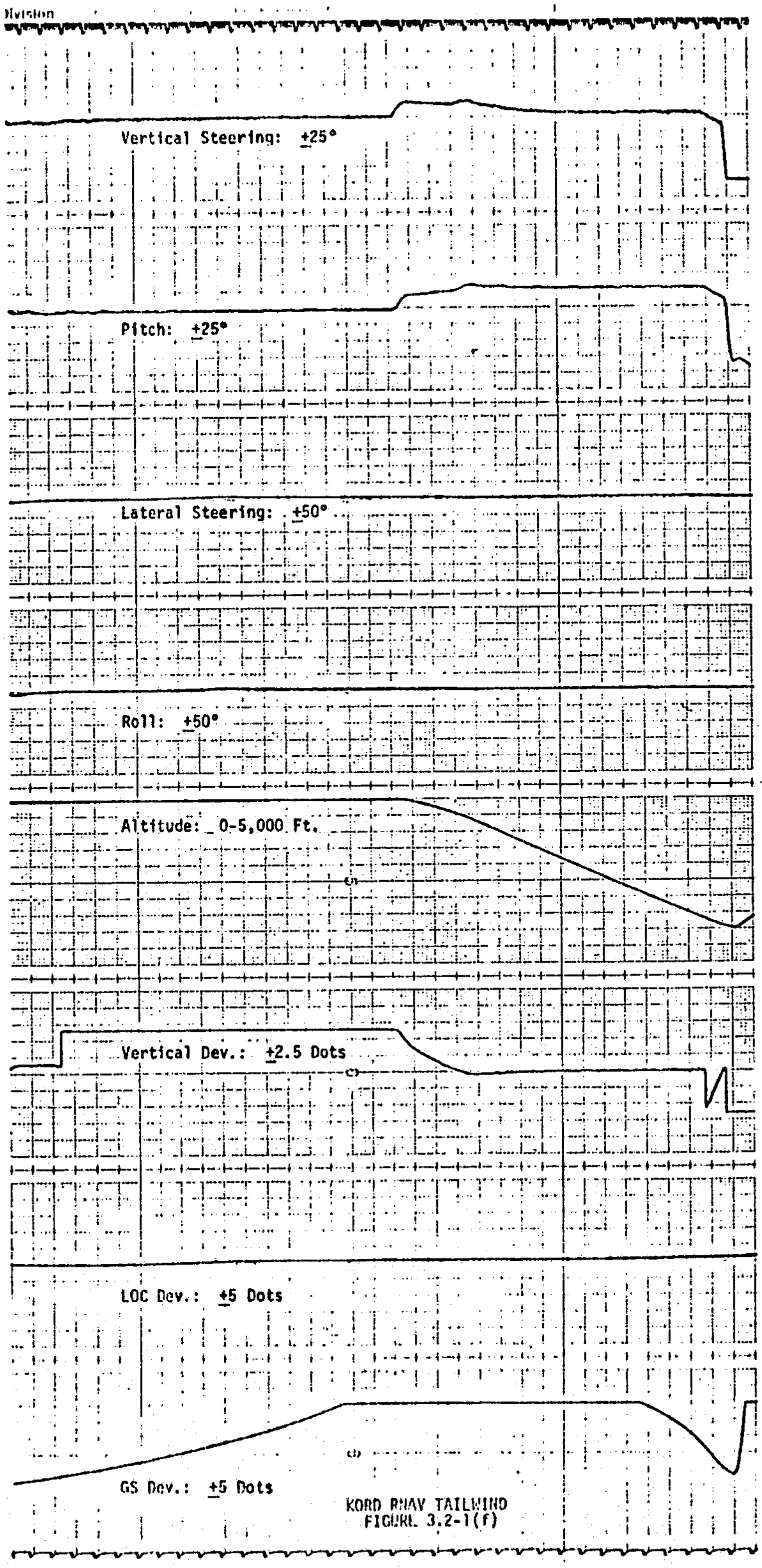
KORD ILS WITH HEADWIND
FIGURE 3.2-1(c)



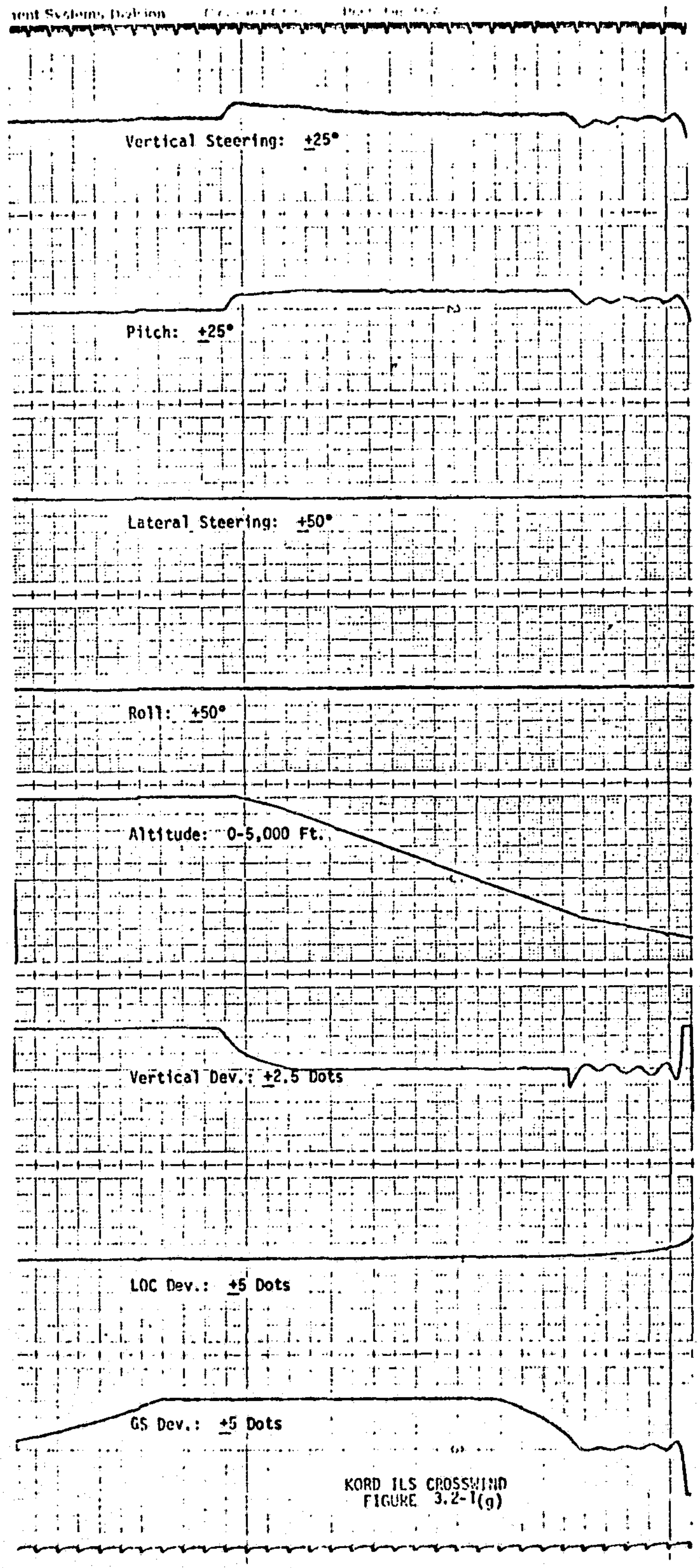
KORD RNAV WITH HEADWIND
FIGURE 3.2-1(d)



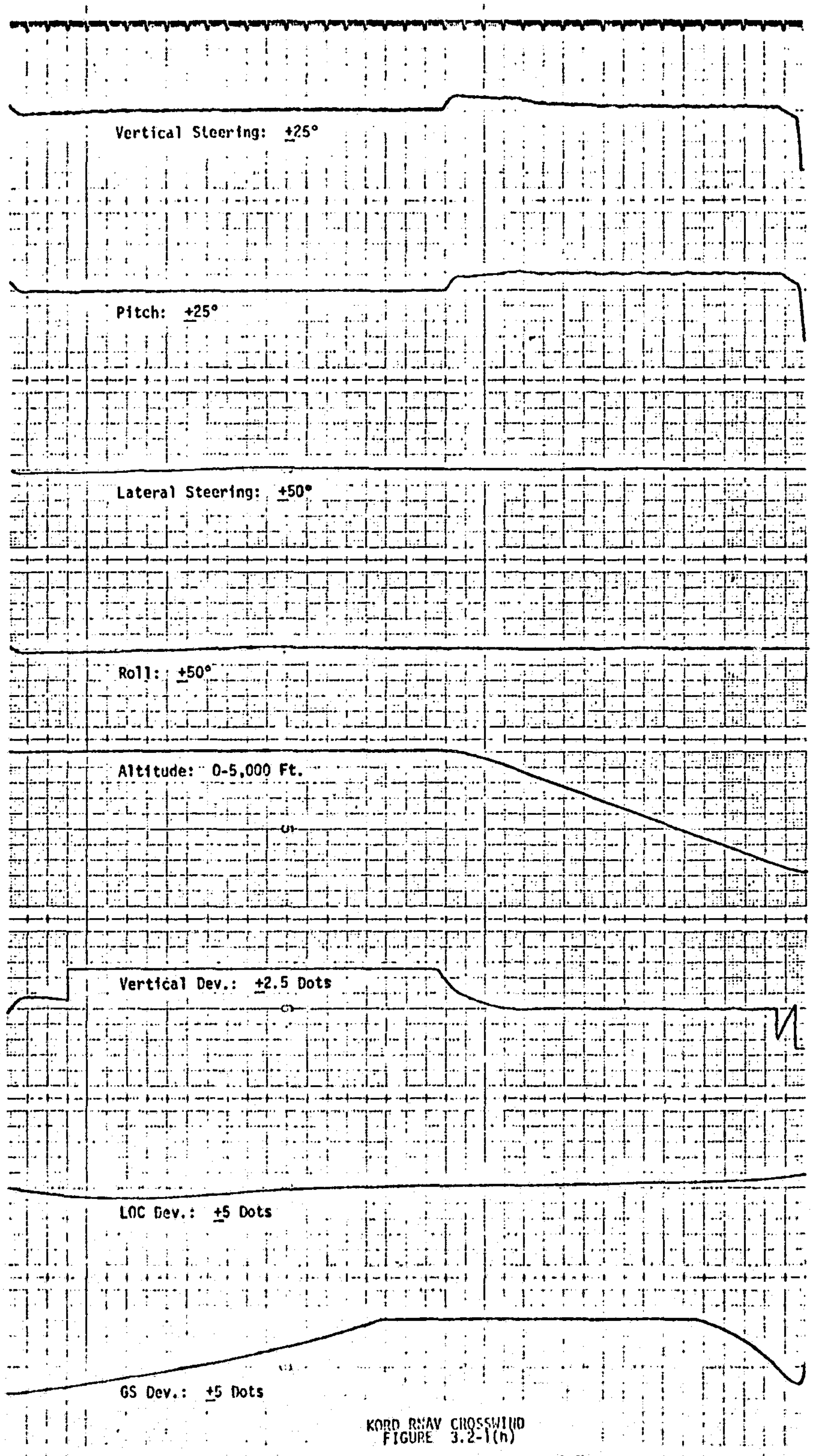
KORD ILS TAILWIND
FIGURE 3.2-1(e)



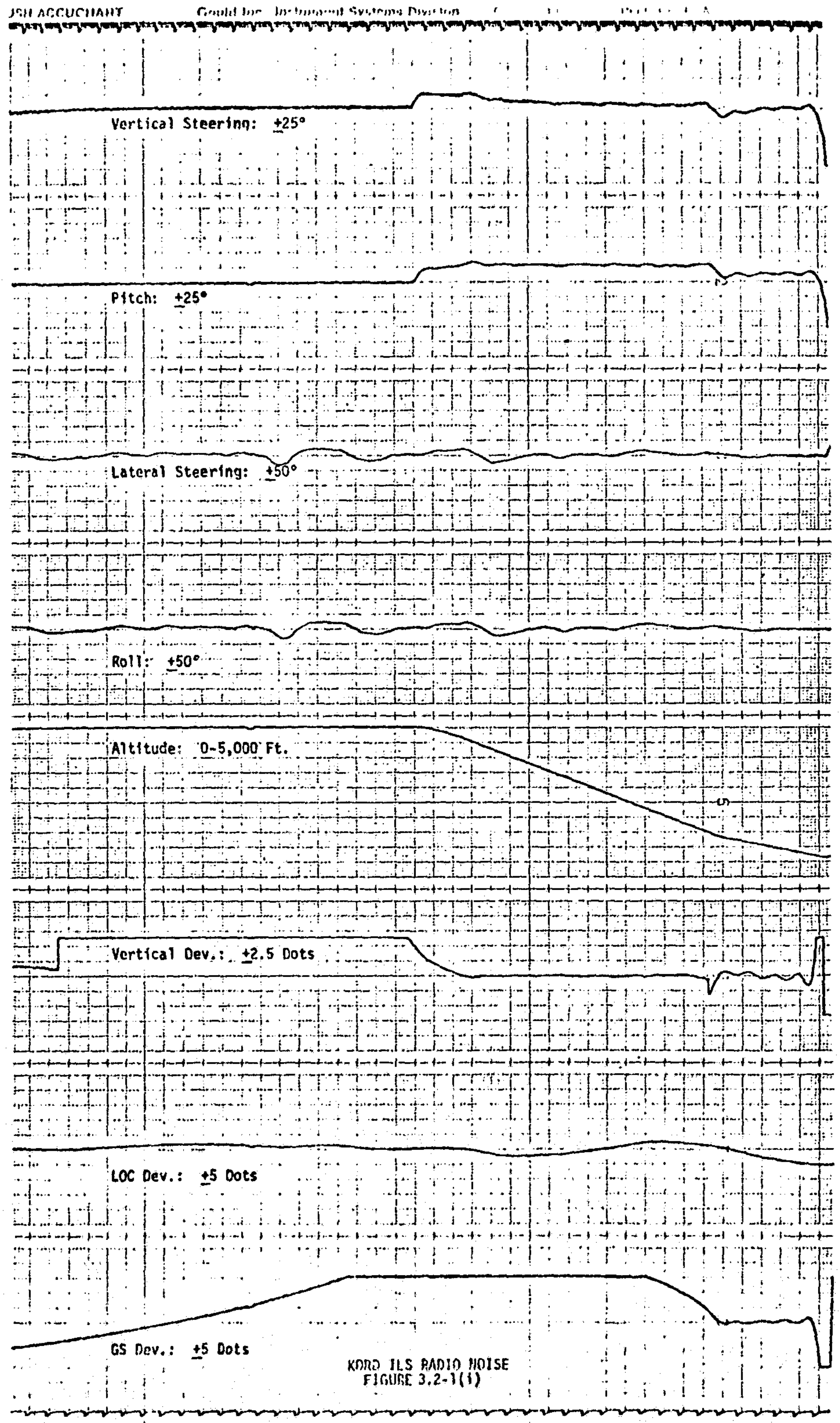
KORD RWAY TAILWIND
FIGURE 3.2-1(f)



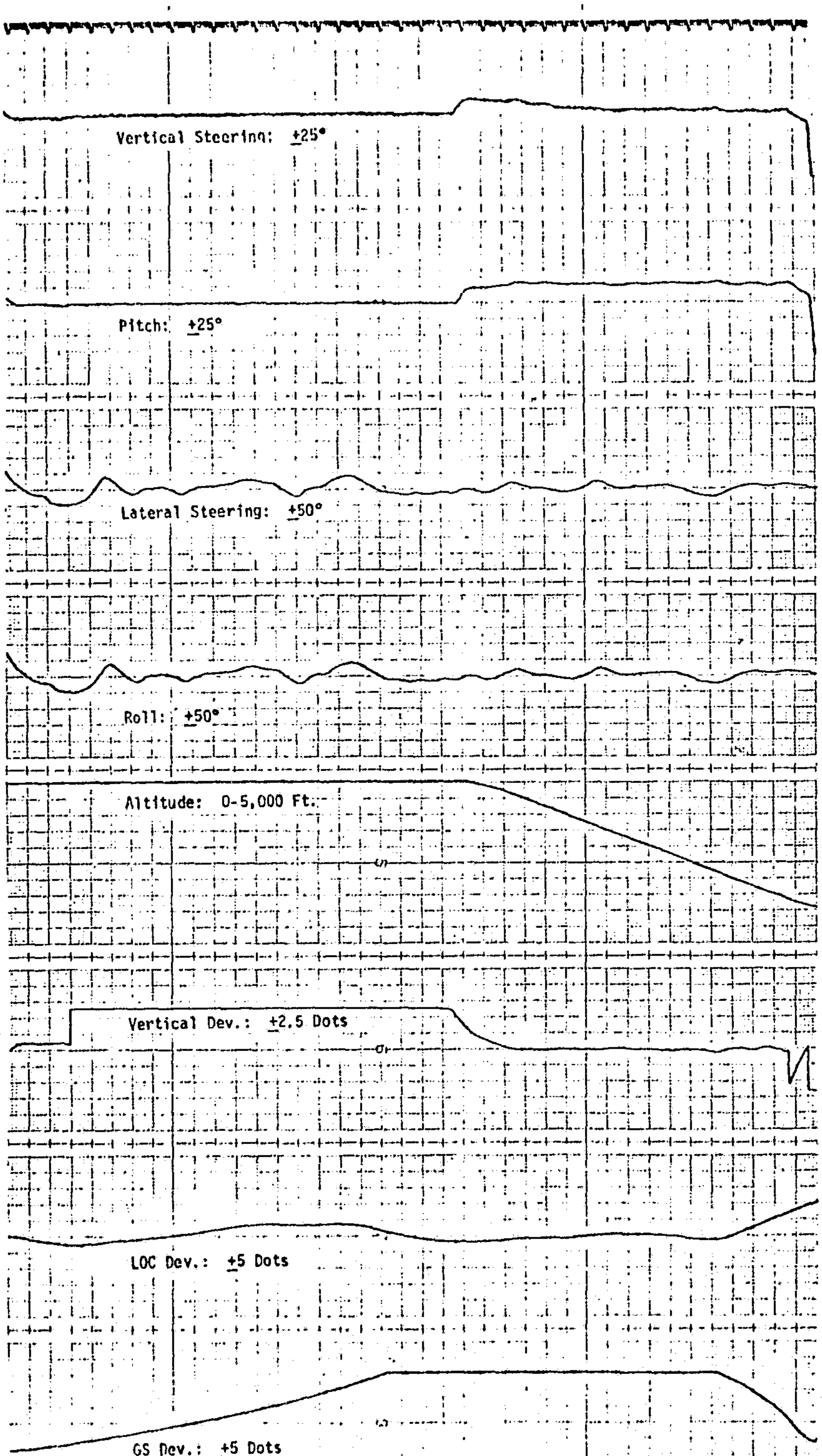
KORD ILS CROSSWIND
FIGURE 3.2-1(g)



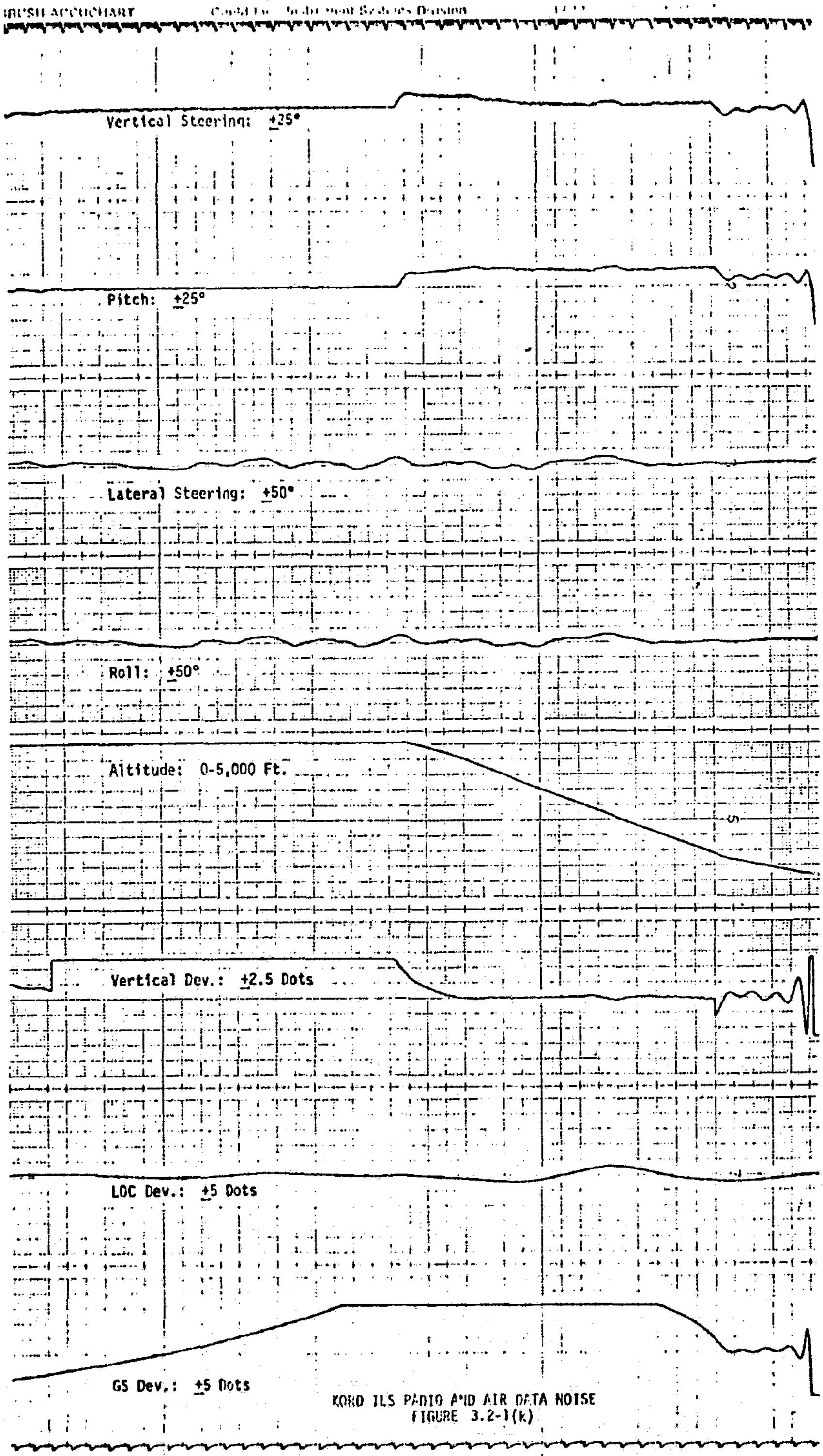
KORD RNAV CROSSWIND
FIGURE 3.2-1(h)



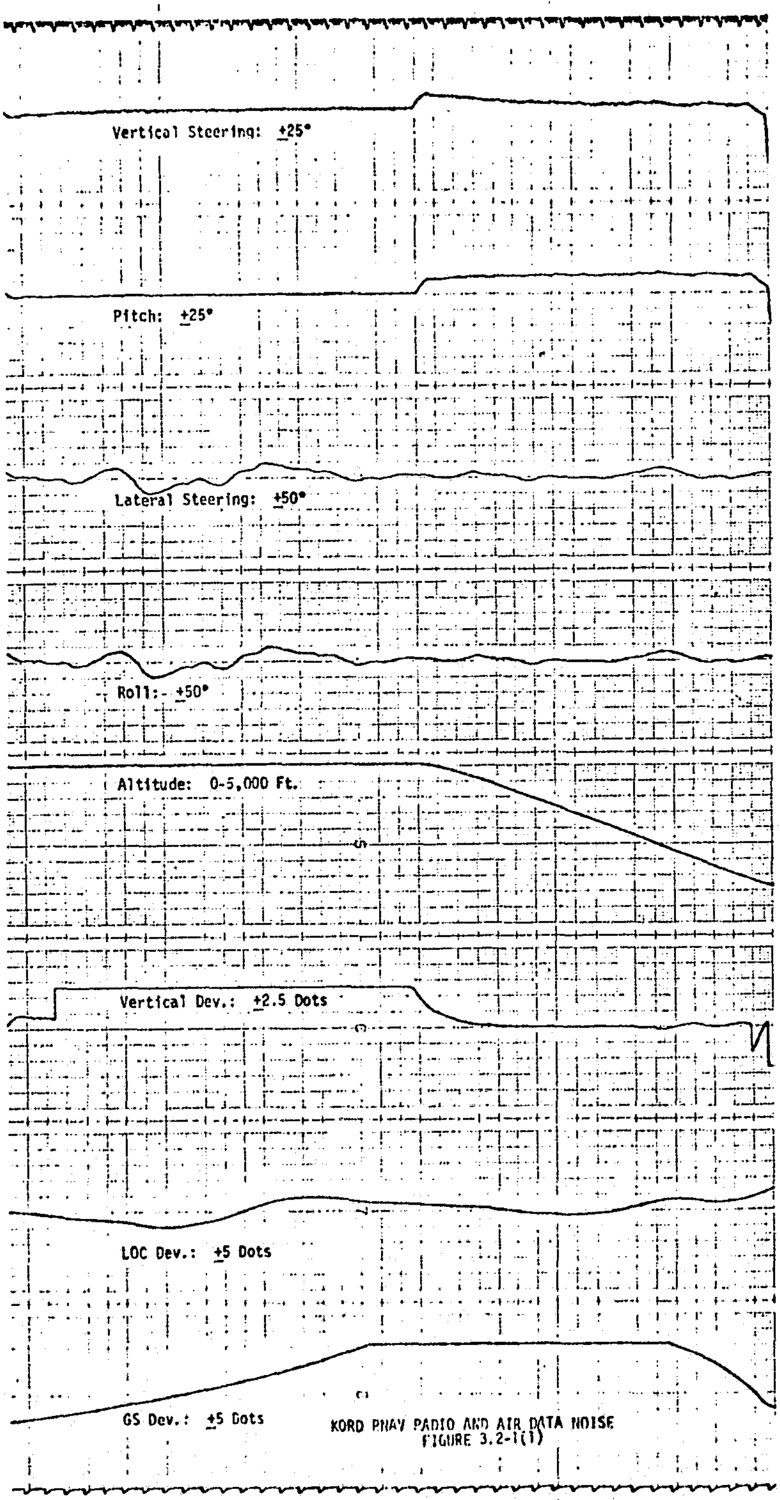
KORD ILS RADIO NOISE
FIGURE 3.2-1(i)



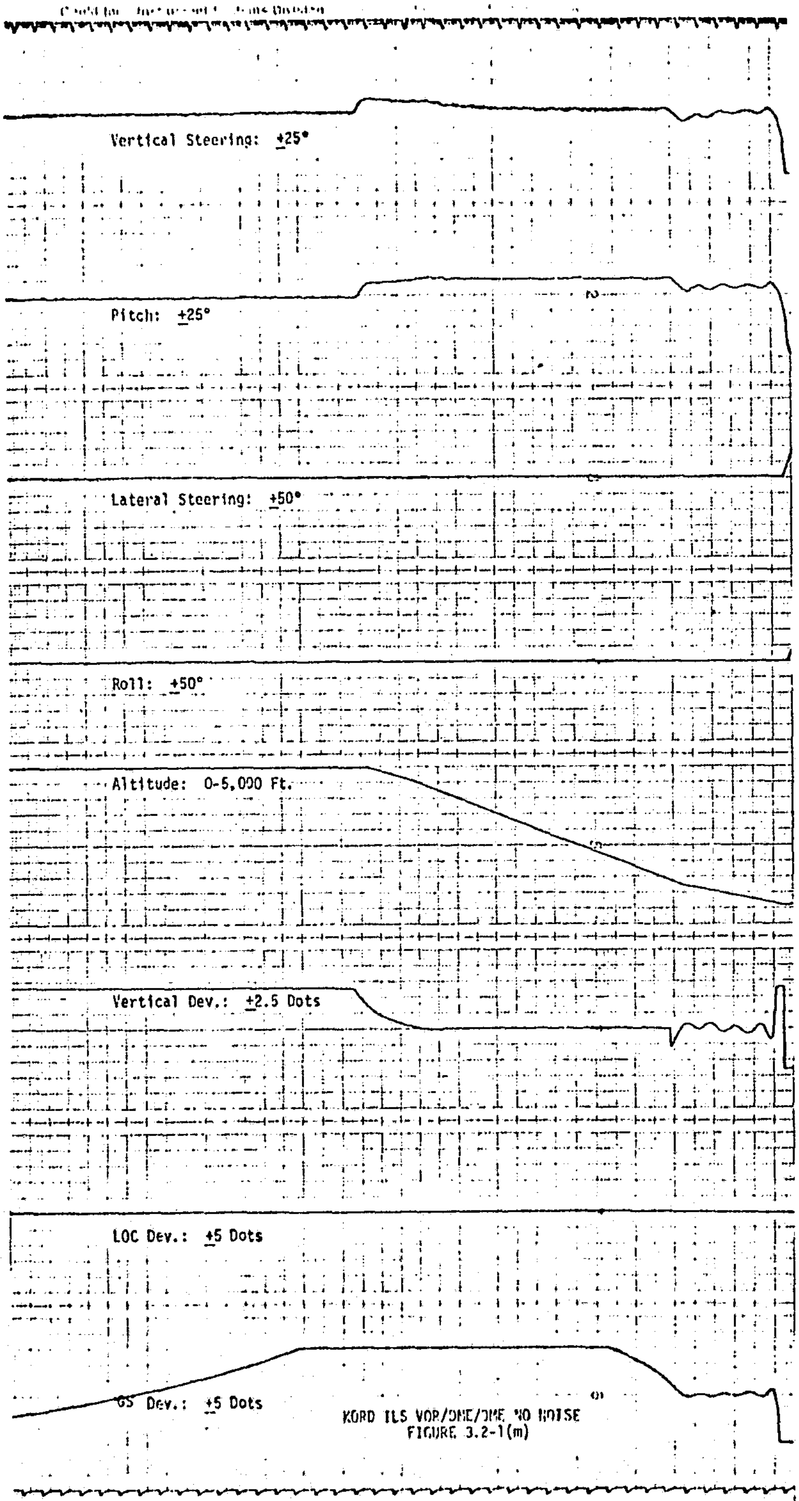
KORD RNAV RADIO NOISE
FIGURE 3.2-1(j)



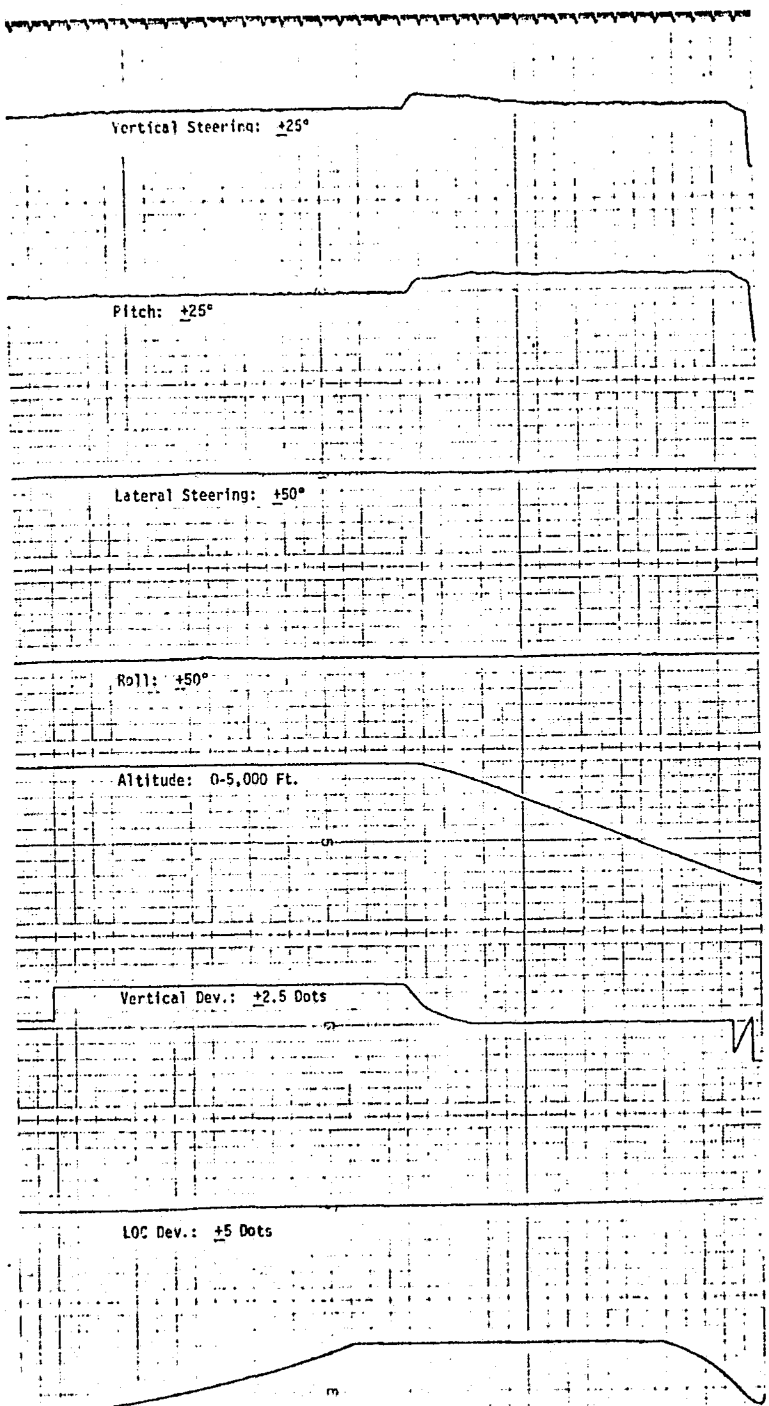
KORD ILS RADIO AND AIR DATA NOISE
FIGURE 3.2-1(k)



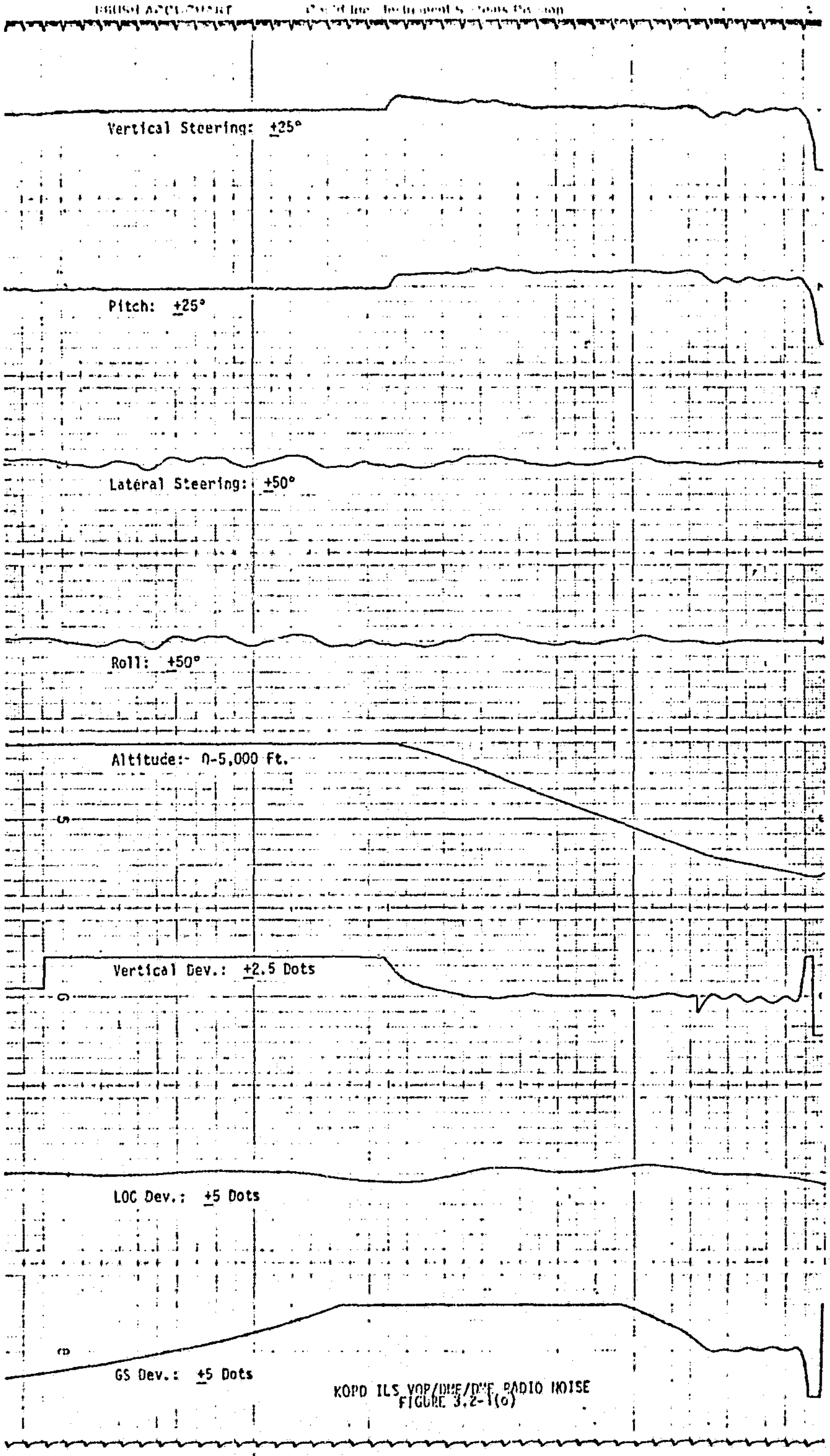
KORD RNAV RADIO AND AIR DATA NOISE
FIGURE 3.2-1(1)



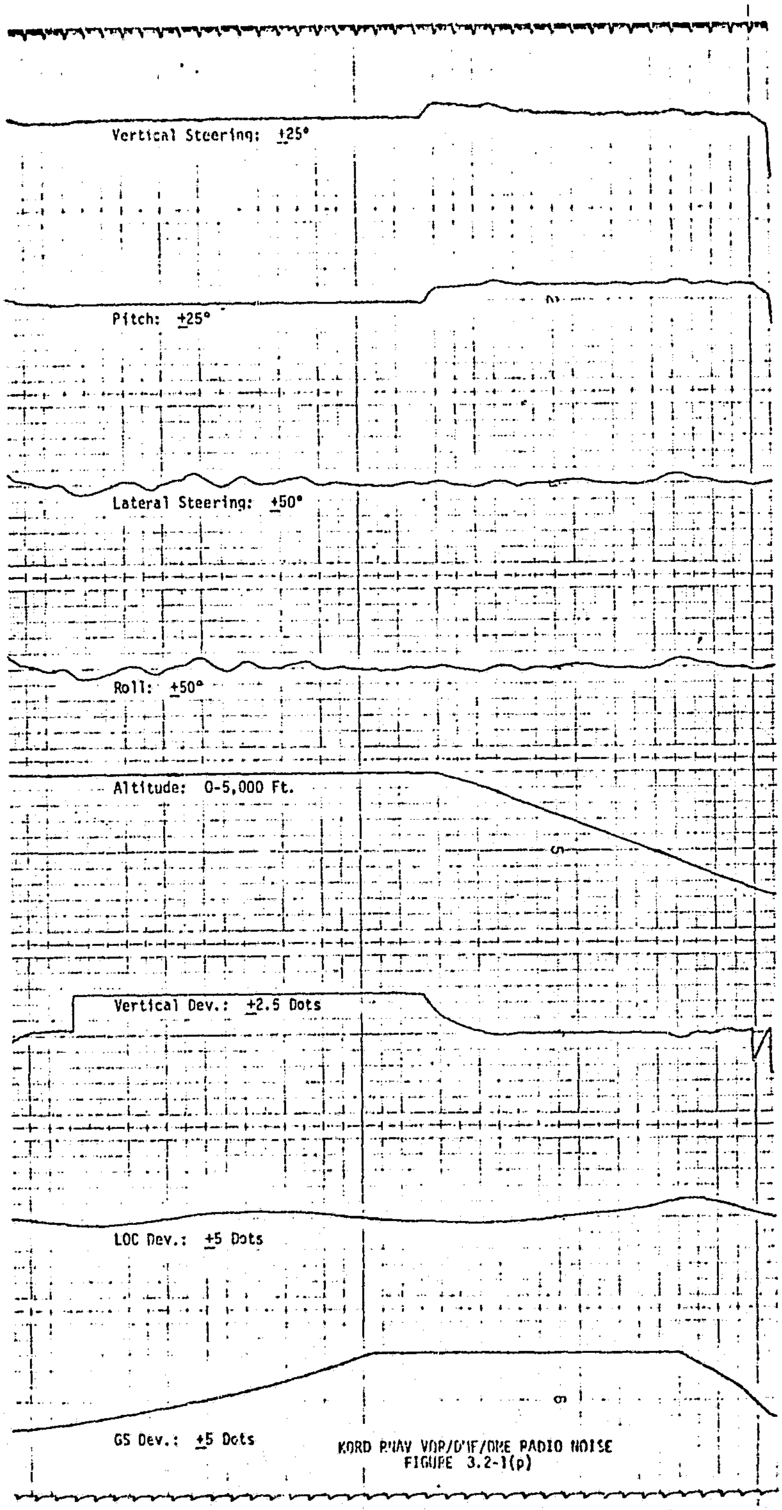
KORD ILS VOR/DME/DME NO NOISE
FIGURE 3.2-1(m)



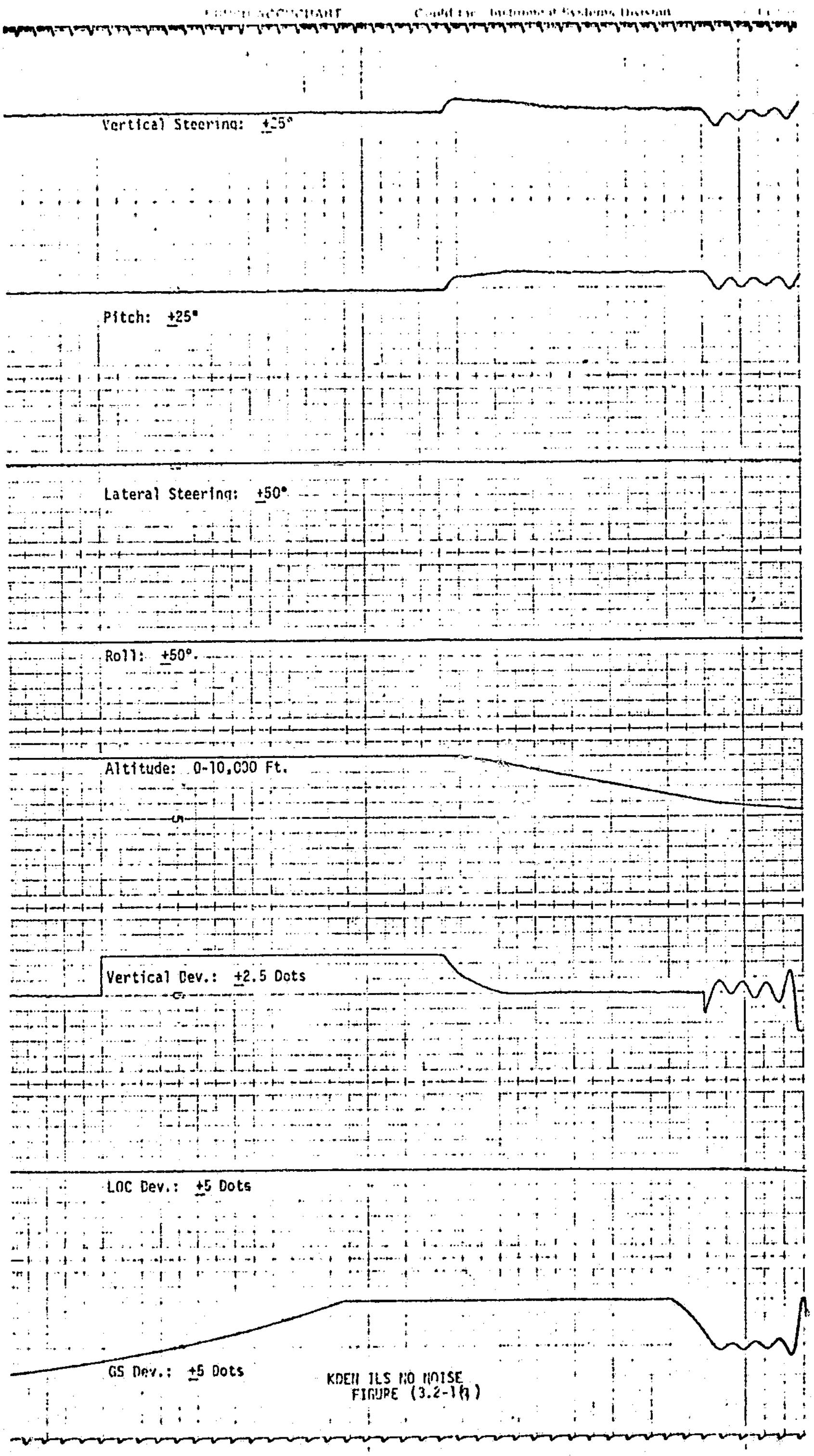
KOPD RNAV VOR/DME/DME NO NOISE
FIGURE 3.2-1(n)



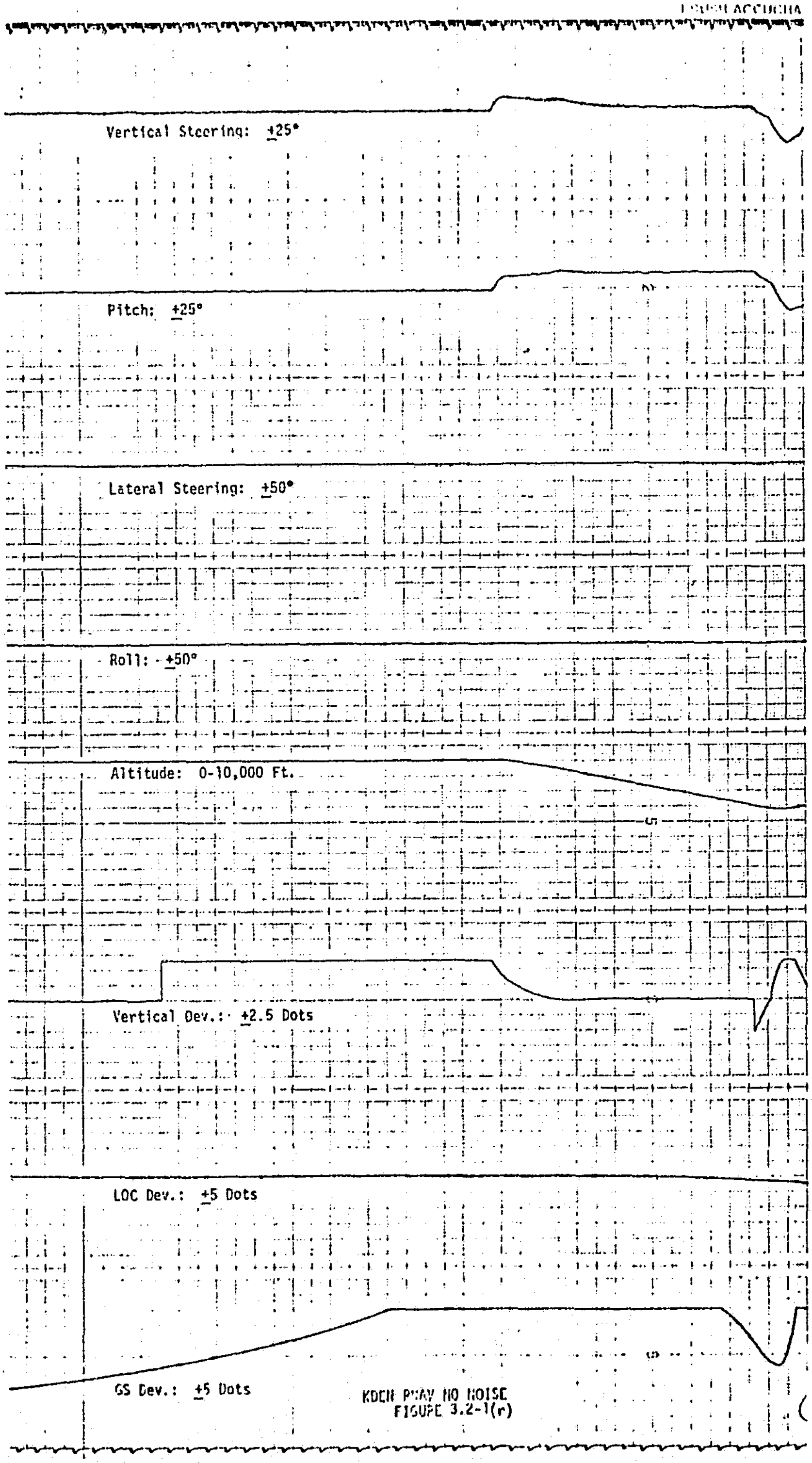
KOPD ILS VOR/DME/DME RADIO NOISE
FIGURE 3.2-1(o)



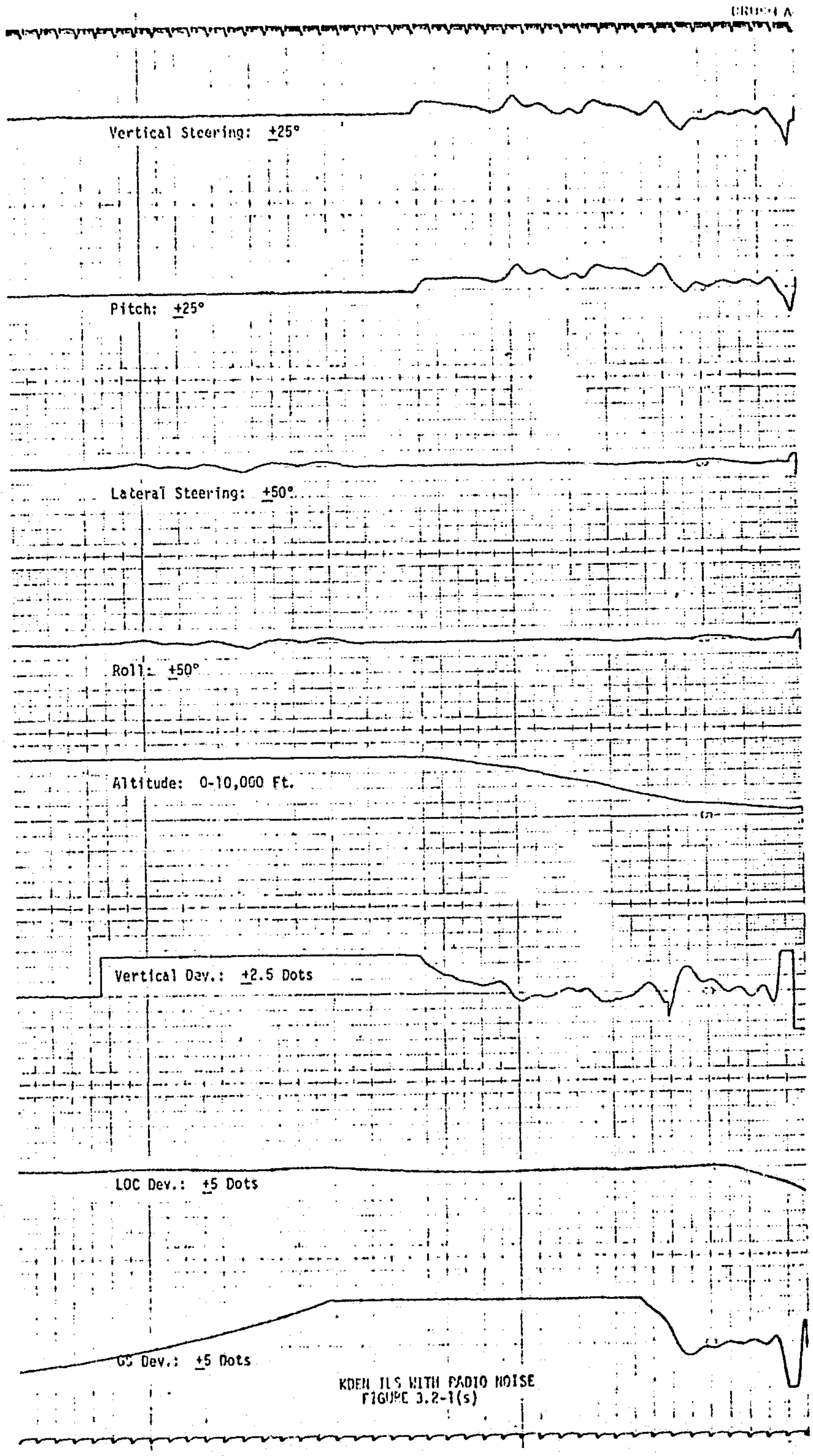
KORD RNAV VOR/DME/DME RADIO NOISE
FIGURE 3.2-1(p)



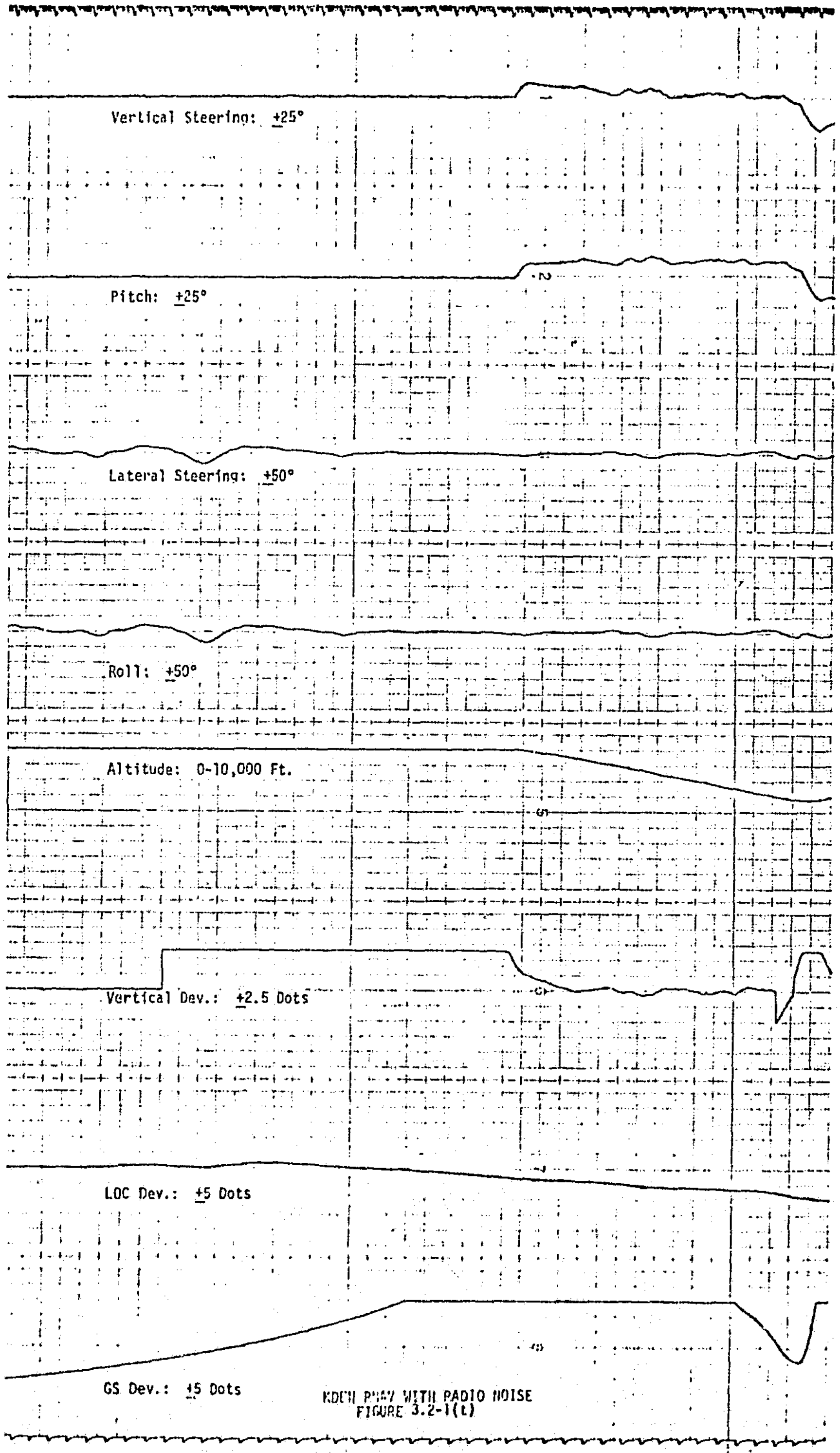
KDEN ILS NO NOISE
FIGURE (3.2-1(?))



KDEN RWY NO NOISE
FIGURE 3.2-1(r)



KDEN ILS WITH RADIO NOISE
FIGURE 3.2-1(s)



KDEN RWY WITH RADIO NOISE
FIGURE 3.2-1(t)

sor for determining along-track position. For these tests, DEN was used for approaches to runway 26L at Denver.

The ground station geometries for these tests are shown in Figures 3.2-2 and 3.2-3.

In the case of ILS approaches, the localizer deviation, lateral steering, and roll are indicative only of what could be expected if the RNAV steering was used throughout the approach. In actual flight, the lateral steering was transferred to the flight director and autopilot.

In the noiseless, no wind, cases, the most noticeable phenomena is the small oscillation in the vertical axis while tracking the glide slope signal. This oscillation does not appear to be present in the actual aircraft performance.

In the presence of a tailwind, the upper capture commences to show a slight overshoot and a two-stage pitch down that was visible in actual flight.

The effect of the cross-wind shear on the RNAV approach can be seen in the localizer deviation (used for reference only) in Figure 3.2-1(h).

The degradation in performance in the presence of sensor noise can easily be seen in Figures 3.2-1(i) through 3.2-1(l). The degradation is due almost entirely to the VOR noise with the station geometry being used and there is relatively little effect on the along-track and hence the vertical axis. The presence of a second DME signal in Figures 3.2-1(o) and 3.2-1(p) has little effect due to the closeness of the VOR station.

The effect of a noisy VOR signal from a station perpendicular to the approach path can be seen clearly in Figures 3.2-1(s) and 3.2-1(t). With this station geometry, the VOR noise has only a slight effect on

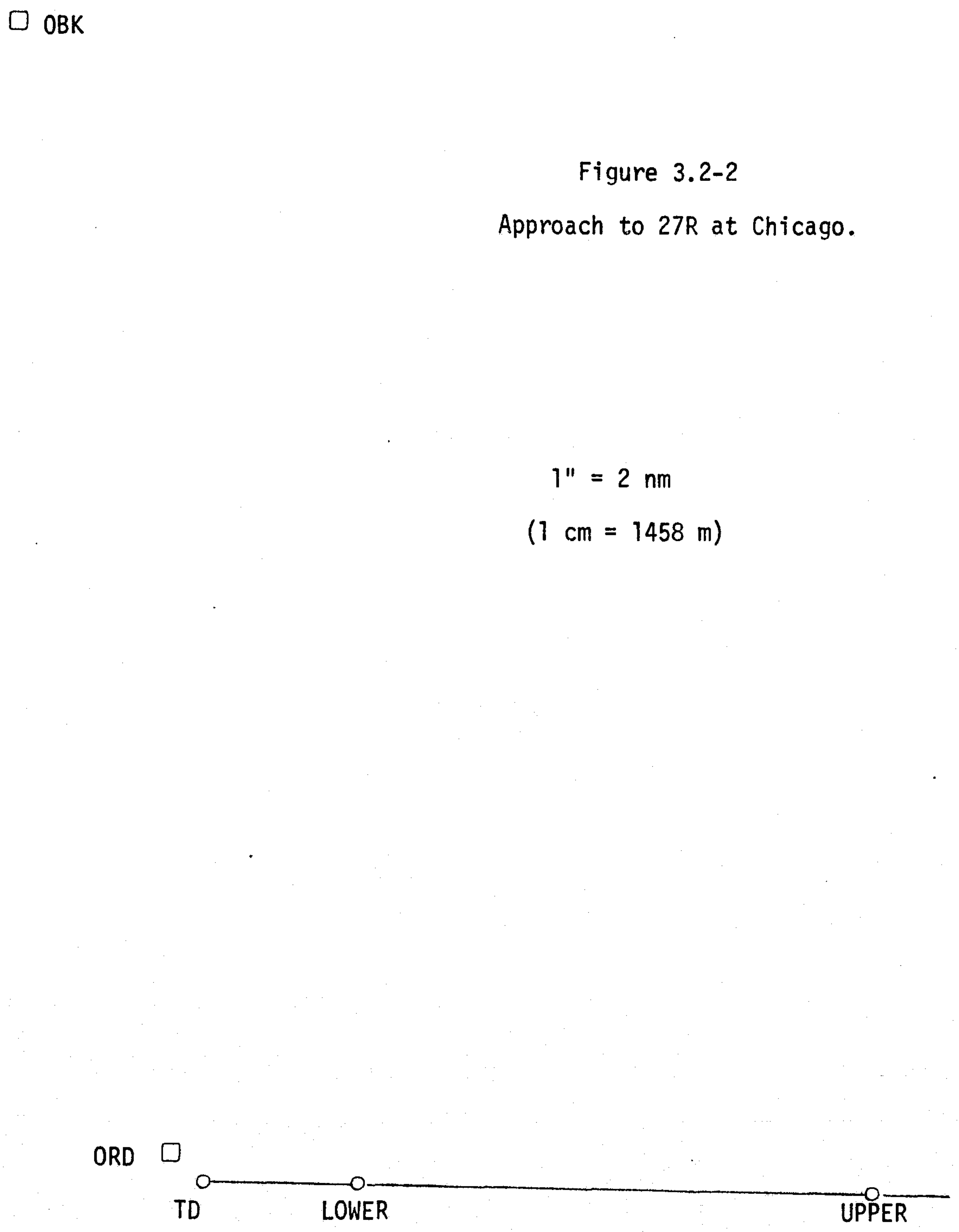


Figure 3.2-2

Approach to 27R at Chicago.

1" = 2 nm

(1 cm = 1458 m)

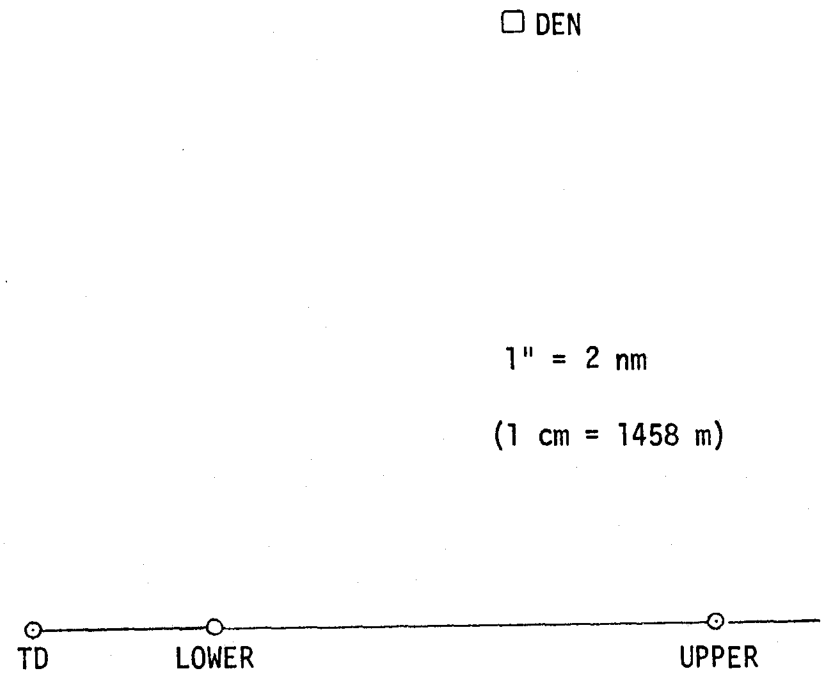


Figure 3.2-3

Approach to 26 L at Denver

lateral position, but by affecting the along-track position estimate it has a dramatic effect upon pitch activity during descent. In the RNAV approach shown in Figure 3.2-1(t), the effect of DME bias on lateral position is visible.

The RFP required that there be no significant overshooting of the upper segment or sinking below the standard glide slope. Collins indicated in their proposal that the following performance would be achieved:

1. The intercept altitude would be tracked to within ±25 feet.
2. Overshoot on the upper segment would not exceed 50 feet, and the upper segment would be tracked to within ±50 feet.
3. Capture of the normal glide slope would not result in more than one overshoot, which would not exceed 45μa.
4. Glide slope tracking would be within ±35μa or ±12 feet, whichever is larger.

The simulation results (assuming wind shear, but no radio sensor noise) met those requirements, with the exception of the glide slope profiles, where the beam is tracked within the ±35μa limits, but where there are multiple overshoots (oscillation).

4.0 RELIABILITY ANALYSIS

As one of the program tasks, a Failure Mode and Effect Analysis (FMEA) was performed on the retrofit kit system and its elements, and a copy of the system level analysis is attached as appendix D.

UAL maintained operational time and removal records on the retrofit kit system equipments during the line service evaluation phase of the program, and these are compared below with the predicted MTBF's. The comparison, it should be noted, is between values derived from large number theory and values measured on single equipments over a few months of operation.

Equipment	Predicted MTBF (hours)	Measured MTBF (hours)
Flight Data Storage Unit	8550	>855:37
Control Display Unit	8900	>855:37
RNAV Switching Unit	4450	>2233:25
Tuning Line Adapter	8300	>2233:25
Navigation Computer Unit	2350	171:07

Specific problems encountered during the program are discussed below. None are two-segment related.

1. Flight Data Storage Unit

The FDSU installed at the beginning of the line evaluation period remained on board throughout the remainder of the program. A cartridge clamp was broken on this unit while trying to remove a tightly engaged cartridge, but was replaced on board the aircraft without removal of the FDSU.

During the engineering evaluation phase a different unit was removed when it was found to be writing on the tapes. The write-enable strap in the aircraft wiring was subsequently removed, but the direct mechanism which caused the unit to write on tape was not identified. That unit was subsequently tested at Collins and no malfunction was found.

2. Control Display Unit

Until a change was made late in the program, sticking CDU keys resulted in on-board operator delays and several equipment removals. The removed equipments generally operated properly when returned to Collins, but the keys were known to be a problem. The original key switches were operated "dry," and although presumably designed for such application, would develop very high contact resistance.

When the switches were replaced with new units, they were "wetted" by increasing the contact current to 100 ma.

3. Magnetic Tape Units

One cartridge failed during the line evaluation phase. During test it was found to generate tape read errors and have a worn bearing. Both the tape and the bearing were replaced.

At the beginning of the program, considerable trouble was experienced with the life of the cartridges. The primary problem was a low signal-to-noise ratio in the system, which was cured by going to a chromium oxide tape with a higher output level and lower friction, and by using a smoother finish on the tape guides.

4. RNAV Switching Units

These units were reworked several times during the engineering evaluation phase due to system design changes. The only fault experienced with the final configuration was a solder fleck short on a unit during that period. No problems were noted during line evaluation.

5. Tuning Line Adapter

No trouble was experienced with this unit during the line service evaluation. A relay was replaced during the engineering evaluation phase. An analysis of the unit showed particulate contamination on a contact surface.

6. Navigation Computer Unit

Early in the engineering evaluation phase, a rash of failures was encountered in various discrete flag inputs. These were found to be due to failures of a new multiple gate input thin film. Contamination during the manufacturing process resulted in rapid degradation with time. The problem was solved by replacing the defective units with ones having a different design.

The most chronic problem was inability to withstand power transients on board the aircraft, a condition that could rarely be duplicated in factory tests. The problem was ultimately traced to a shorted power supply monitor transistor which was not being caught in factory card tests. The test procedure was modified. The defective transistor resulted in failure of the NCU to perform a proper shutdown sequence when primary power was lost.

During line service evaluation, there were five confirmed failures of the NCU, three on one computer and two on the other.

One failure was a re-occurrence of the power transient problem noted above. In this case, however, the cause was found to be a faulty power supply filter capacitor. The failure mode in the capacitor was high leakage due to poor design. The units were subsequently replaced with ones having a better design.

The same failure mode in a different capacitor of the same family also occurred in the spare NCU. In this case, however, the failure resulted in a leakage path within the NCU that grounded the frequency common of one set of 2 x 5 tuning lines.

Two of the NCU failures were associated with an intermittent in the compass input circuits. The synchro-to-digital converter card and an associated transformer were replaced in the troubleshooting process, but no component failure was confirmed and the intermittent may have been due to a card or solder contact.

The fifth failure was the loss of a shift register stage in one of the memory cards, which resulted in false data in one byte of the data words. This ultimately led to a conflict in system logic and system shutdown.

5.0 FLEET RETROFIT

5.1 Dual Systems

The system installed on the UAL aircraft for this program was single-sided. It is probable, however, that should such a system come into widespread operational use that dual systems would be employed by many operators.

The impact of dual system operation would depend heavily upon the isolation and operational philosophy of the user. In most of our dual RNAV installations today, each computer is fed directly from each of the dual radio sensors, while each computer is fed singly by one of the dual CADC systems, but can obtain altitude data from the other computer via a cross-talk bus if its own CADC is flagged invalid. The cross-talk bus also serves to exchange flight plan data and to compare position and computed output data for monitoring. Some users would probably prohibit cross-coupling of raw sensors and some would probably even prohibit cross-talk transactions of any sort.

Total isolation would impose flight plan discipline requirements in order to guarantee display and steering coherence, and the requirement for identical altitude, waypoints and courses would present a similar but more comprehensive task than that presented by dual flight director system today. If at least cross talk monitoring is allowed, the computers themselves can be given the task of warning of data or flight plan and progress discrepancies.

Considered only as a retrofit task, most of the above questions would already have been resolved.

5.1 Continued

Generally, the autopilot is coupled only to the pilot's system, and in any case is coupled to only one system so no conflict results. The user must decide when the second system is on whether it be allowed to simply warn of inconsistencies or to disconnect. With dual flight directors it is unlikely that one system would be allowed to abort the other, but as is common with such independent dual systems today, the slight differences between systems could result in one system capturing slightly ahead of the other and momentarily creating conflicting steering commands.

In the case of RNAV/RNAV approaches, the impact of adding two-segment capability lies in the areas of approach progress annunciation and safety protection. In the case of RNAV/ILS approaches, there is the added requirement of performing the ILS capture and tracking or transferring those tasks to the flight director and autopilot systems. There is also the task of informing the system that the upcoming series of waypoints is a two-segment approach.

5.2 Maintenance

The maintenance costs of RNAV systems with and without two-segment capability should be essentially the same. Failures in the major elements of the system are more likely to occur in enroute operations than in approach operations because more time is spent in the enroute regime.

Because the RNAV system interfaces with many other aircraft sensor and display systems, and has both memory and compact display capability, it has considerable potential as an aid to maintenance. The addition of two-segment capability to the system would presumably be accompanied by expanded capability to self-test the unique two-segment features

5.2 Continued

and to identify (as was done in this program with an abort code display on the CDU) many operational or sensor fault conditions.

5.3 Retrofit Kit Costs

The possible variations in an RNAV 2-segment approach system "retrofit kit" are so large that costs are meaningless unless the conditions are quite specific. They will be greatly affected by the specific reversionary switching, display, and operational requirements of the user, by the characteristics of the existing aircraft avionics, and the characteristics of the RNAV system being used. Because aircraft down time and modification costs represent a large portion of any retrofit program, the net cost is also strongly affected by the growth provisions provided for by the user at the time the RNAV system was originally installed.

If the basic RNAV system is designed to provide both lateral and vertical steering and deviation outputs, it is likely that the addition of 2-segment approach capability would be involved with only the addition of special progress annunciators and the addition of the ILS inputs to the computer insofar as direct costs are concerned.

The following estimated cost of adding 2-segment approach capability to an existing RNAV system is based on these assumptions:

1. Dual ILS receivers are part of the basic RNAV installations. While not true of the test aircraft, it is common practice to add separate ILS receivers and VOR only receivers when RNAV is installed.

5.3 Continued

2. The aircraft is wired for the two-segment option at the time of the RNAV installation. This assumption is less sure because there is no general commitment to 2-segment approaches at this time. The ARINC Mark II and Mark 13 specifications, however, reserve pins for ILS augmentation inputs to the computer. It is probable that some costs would be incurred by most retrofit customers to add annunciator and ILS interface wiring.
3. The aircraft has dual RNAV capability of the ARINC Mark II variety.
4. The RNAV system has the growth space to accommodate the additional ILS inputs in the form of plug-in cards.
5. A fleet of 100 aircraft is assumed.
6. No installation costs or aircraft down-time costs are included.
7. No pilot or maintenance training costs are included.
8. No special data base is required. The assumption here is that in a two-segment approach system fully defined by the FAA, no user would have to create his own special data base.
9. No certification costs are included.
10. The approach progress annunciators required would cost $200 per aircraft.
11. The ILS input cards required for the RNAV system would cost $1,000 per aircraft.
12. The software development costs would be written off at $1,000 per aircraft.

5.3 Continued

Under the above assumptions, the "retrofit kit" would cost $2,200 per aircraft, which is obviously much less than the cost excluded by the above assumptions. The largest variable in the estimated cost involves the software. It becomes very expensive very rapidly to add software to a computer that is approaching saturation.

The cost also hinges upon the definition of what constitutes a two-segment approach.

6.0 OBSERVATIONS AND RECOMMENDATIONS

6.1 Alternate Approaches to the RNAV Two-Segment System

Although the two-segment approaches were flown in this program using a general purpose digital computer programed for three-dimensional RNAV, RNAV two-segment approaches do not require any of these features. Any two-dimensional RNAV can provide distance-to-go information from a specified point, which could be the runway touchdown point. This information could then be used with a special purpose computer of digital or analog form like the one used on the 727 program to fly two-segment approaches.

6.2 Limiting Performance Factors

The bounds on system performance are established primarily by the nature of the sensor systems used to determine the aircraft's position. Although the aircraft equipment contibutes errors, they are small compared to the possible bias and noise on the signals received from the ground (particularly VOR signals) due to propagation and station location. Also, like the basic RNAV concept, the accuracy of the system is dependent upon the absolute positions of the stations and the aircraft's stored knowledge of those locations. Presumably the station location/ data base problem can be made negligible, but it always represents a potential problem that does not occur in relative navigation systems.

6.3 RNAV in the Present ATC Environment

Without an RNAV system, the pilot presently navigates or maintains his orientation in the terminal area through VOR/DME bearing and distance displays. Vectoring by ATC will be done by heading commands, commands to fly specified VOR radials, or commands to maintain some relative position to a known navigation aid.

With an RNAV system, the pilot is presented with valid steering, deviation, bearing, and distance information with regard to his course into the upcoming waypoint until an ATC vector occurs. At that time, with the increased terminal area workload, the method of modifying the flight plan or departing and returning to it efficiently is of considerable importance.

As far as orientation is concerned, the bearing and distance to any point could always be obtained (in this system) via the CDU. It could also be displayed on the RMI pointer and the HSI distance readout by making the selected point the "TO" waypoint in the flight plan. To ensure that the desired waypoint remained the "TO" waypoint, however, requires that automatic waypoint passage be inhibited, which could be done by going to the heading select mode of the RNAV system.

A return to the flight plan could be made by either: (1) deleting the heading command, which generated an intercept course to the nearest leg of the flight plan, (2) going to the heading arm mode of the RNAV system, which resulted in the specified heading being flown until a flight plan leg was intercepted, or (3) performing a "DIRECT TO". Only (3) was used by UA.

Operations in the terminal area were complicated by the following factors:

1. The RNAV heading mode required that the selected heading be input through the CDU keyboard.

2. No altitude hold mode was available. Because no RNAV lateral-only mode was available, the vertical steering could be misleading.
3. The vertical "DIRECT TO" profile was not based on present aircraft position (see 6.5.3).
4. The RNAV/flight director/autopilot controls and displays were more expedient than coordinated.

Recommendation

1. Selection of the heading command mode should freeze the RNAV flight plan, using an overall system mode selection and display.
2. The heading selection should be done in the manner normal to the aircraft (the HSI in this aircraft).
3. RNAV vertical steering should be eliminated in the heading select mode, except for altitude held. Altitude hold should be an overall system mode/display.

6.4 Displays

6.4.1 Vertical Deviation

Recommendation

The displayed vertical deviation from the flight plan should always reference the leg being flown.

For this program, the vertical deviation displayed on the HSI started to reference the extended upper segment of the approach when the aircraft reached a point 8 nautical miles (14.8 km) from UPPER. The deviation bar would thus go off scale to the top and ultimately descend as UPPER was approached. This was entirely appropriate for this program, where the RNAV system was not used en route and where the action of the deviation bar was similar to that experienced by the pilots when making a standard ILS approach. It would also appear appropriate for RNAV systems which do not display deviation en route.

If, as would normally be the case, this RNAV system were used en route and deviation from the leg being flown was continuously displayed, it is believed that the sudden switch of the vertical deviation display to a reference unrelated to the leg presently being flown and thus no longer tied to the steering display would be very disconcerting. It is believed that sufficient warning of the impending pitch down manuever can be provided by progress annunciators and the distance to waypoint data.

6.4.2 Mode Annunciation

Recommendation

Provide the pilot with clear and continuous annunciation of flight system status.

The RNAV system could be placed in the heading select or vertical speed mode by using the line select keys on a specific page of the CDU but the annunciation was visible only on the CDU and only on that page.

6.5 Guidance

6.5.1 ILS Guidance

Recommendation

Transfer steering to the flight director and autopilot computers as soon as feasible on ILS approaches. Use RNAV only to intercept the ILS beams.

RNAV systems are not normally designed to use ILS signals, while existing flight directors and autopilots are. It would appear desirable therefore not to burden the RNAV system with the duplication of existing functions and not to penalize the reliability of the flight director or autopilot by placing the reliability of the RNAV system in series with them.

The implementation of the above philosophy is complicated by the nature of the existing systems. Many flight directors and autopilots are not designed to intercept glide slope beams from above, so the RNAV system would still have the task of making the capture manuever even if it could then transfer the steering task.

In the case of the lateral axis, some systems (such as the autopilot on this aircraft) could not be armed for localizer capture in the heading select mode used for RNAV steering, so transfer could not be made until the RNAV system could insure that the capture would take place immediately. It was further complicated (on this aircraft) by the lack of mode annunciations to verify that the capture had actually taken place. Although the localizer signal was used in the RNAV steering signal, and the RNAV computer monitored the deviation for gross errors, there was no monitor except the pilot that the flight director or autopilot was actually tracking the signal.

Another problem is that of obtaining proper ILS gain programming, which is typically done with radio altimeter signals which would not be the same for standard and two-segment approaches.

To the extent possible, however, it is recommended that capture and tracking of the ILS beams be given to the autopilot and flight director.

6.5.2 False Glide Slope Capture

Recommendation

Examine the problem of false glide slope capture.

On an approach to Denver, a bad vertical profile was flown when another aircraft momentarily deflected the glide slope beam and forced beam capture while the aircraft was well above the normal beam center. False glide slope capture, because of a deflected beam, is not unique to two-segment approaches, but the result is more serious because of the already steep descent of the aircraft and the fact that the beam is below rather than above the aircraft. A possible solution would be to disengage the system if the glide slope deviation exceeded a given value after capture, or to change the steering law so that descent rate could not exceed a given value after upper segment capture and would provide a proper pitch up when the beam was closed on the second time.

6.5.3 Navigation Logic

Recommendation

1. Permit capture of the upper segment at variable altitudes.

   In this system, all of the two-segment STAR waypoints were three-dimensional and fixed. This was compatible with the basic RNAV system, but it posed a restriction on the interception of the upper segment not present in the system used on the 727 program, where the intercept could be made at any altitude. How severe this restriction is depends upon the ultimate ATC environment, but the restriction can be avoided.

2. Allow editing of the course into UPPER over a sector that would permit intercept of the runway centerline at angles up to 90 degrees.

   In this system, the pilot was prohibited from editing the sequence or parameters of the waypoints that established the upper corner, lower transition, touchdown, and go-around waypoints of noise abatement STAR. He was also prohibited from editing the courses into those waypoints and from making a "DIRECT TO" to any of the waypoints except UPPER. To establish a given course into UPPER, a waypoint had to be created outside UPPER, which unnecessarily complicated the terminal area operations.

3. Improve flight plan handling in the terminal area.

   Probably the most troublesome problem was created by the complex rules used in the RNAV system to capture and pass lateral and vertical events. The rules were adopted to provide coordination between lateral and vertical steering and were adequate when waypoints were not closely spaced and deviations from the desired flight path were small. When operating in the terminal area under ATC vectoring, large deviations could occur and the switching point for a vertical event could occur prior to passage of a preceeding lateral event. The problem was attacked operationally by going into the heading select mode to inhibit waypoint passage when deviations had to be incurred in the terminal area, but the waypoint passage rules need to be reviewed to see if they can be improved for terminal area operation.

One method of returning to the flight plan was to perform a "DIRECT TO", which generated a direct course to the selected point. The "DIRECT TO" function in the software used deleted the flight plan prior to the selected point and generated a course to that point, but generated a vertical profile that was a function of the altitude of the previous waypoint. Any new implementation should create a vertical profile from the aircraft's present position to the selected waypoint.

6.5.4 Pilot Interfaces

Recommendation

Review all pilot-computer transactions

This is a general recommendation for all systems which share tasks with the pilot. Typical was the problem of ILS tuning. In the original design, a check-list type message "TUNE ILS (FREQ)" was presented on the CDU and had to be acknowledged by the pilot prior to a given point in the approach or the system would abort. Failure to acknowledge the message caused numerous aborts during the "racetrack" series of engineering test flights and was dropped at UA's request on the grounds that ILS tuning was standard procedure anyway. Occasional aborts were still experienced in line service, however, due to failure to actually tune the ILS receiver.

It was (and is) felt desirable to have the pilot set the manual frequency controller to the ILS frequency so that no fumbling is involved if the RNAV system fails. If the computer has sufficient capability, however, it would be desirable to have it monitor the ILS tuning and flash a "TUNE ILS (FREQ)" message until the pilot has actually tuned the radio to the correct frequency.

6.5.5 Steering

Recommendation

Modify approach deviation and steering gains

A problem which caused concern as the flight evaluation progressed was a slow build-up of cross-track deviation on some RNAV approaches as the aircraft came down the upper segment. As displayed on the HSI, this deviation would sometimes amount to more than two dots when the aircraft reached LOWER.

Analysis of the present lateral steering equation and the aircraft dynamics showed that lateral deviations of the type seen could occur if the aircraft was subjected to crosswind shear, and the analysis was confirmed by testing on the hybrid computer simulation facility.

Wind shear acting on the aircraft accelerates it in the cross-track direction, but the aircraft can sense the acceleration only when the resultant displacement shows up as a radio displacement. The system must decide if the deviations sensed are due to actual displacement of the aircraft by wind shear or are due to radio sensor noise. If the steering is allowed to respond with high gain to the deviation, the displacement due to wind shear will be kept low, but the roll activity will also increase in an attempt to keep up with any radio noise which shares the same spectrum.

On the basis of the performance seen in the field, it appears that the VOR noise model is unrealistically large in the terminal area for most locations, and that it would be feasible to increase the cross-track gain and decrease the wind estimation time in order to improve the performance in wind shear.

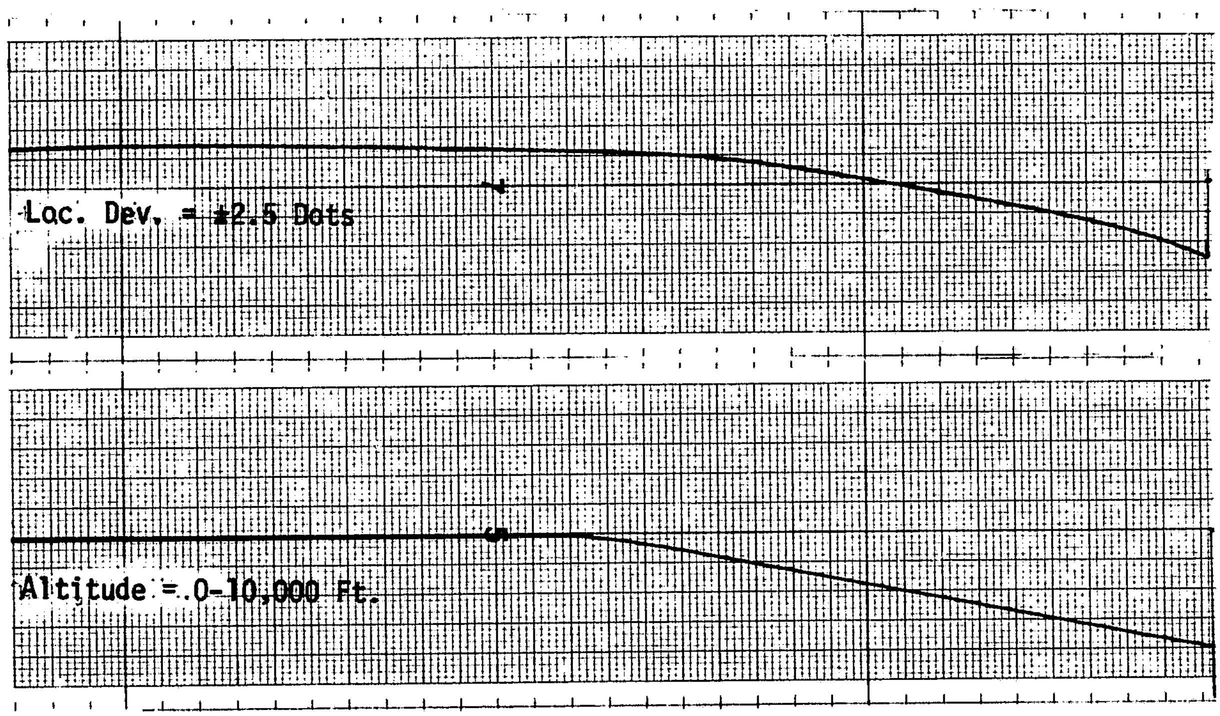
Regardless of the steering, it is unacceptable to display to the pilot any large deviations to which the system does not appear to be responding, or which are too rapid or too large for him to track normally.

To the extent that the system tracking gain can be increased, as suggested above, the apparent deviation is decreased. Beyond that, the displayed deviation should be filtered to a rate compatible with the pilot and aircraft response time, and scaled to be compatible with the overall system accuracy so that the pilot does not chase insignificant displacements.

In the present system design, the pilot's deviation display corresponds to standard ILS sensitivity, while the basic radio noise input to the system is closer to that of a VOR beam.

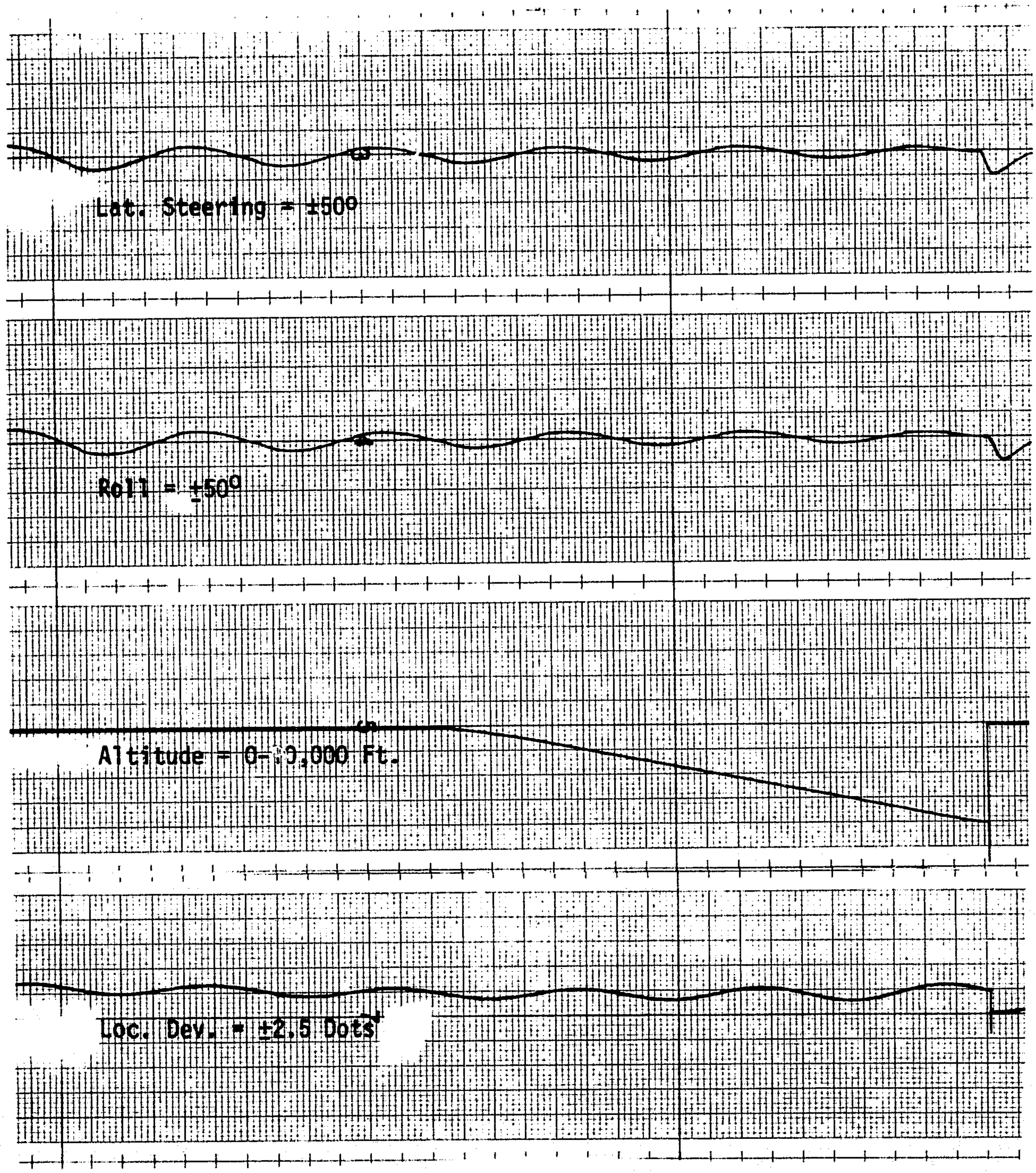
Figures 6.5-1 through 6.5-6 show some of the simulation runs with the present and some modified software.

Figure 6.5-1 shows the deviation on an RNAV approach with a cross-wind shear of 10 fps per 1000 feet (3.05 mps per 305 m), starting at 5000 feet (1524 m). Figure 6.5-2 shows the roll activity resulting from a 1 degree peak sine wave VOR error with a 1 minute period, the VOR/DME located on the field and no secondary DME present. These were RNAV/RNAV approaches, and the apparent localizer deviation bias is due



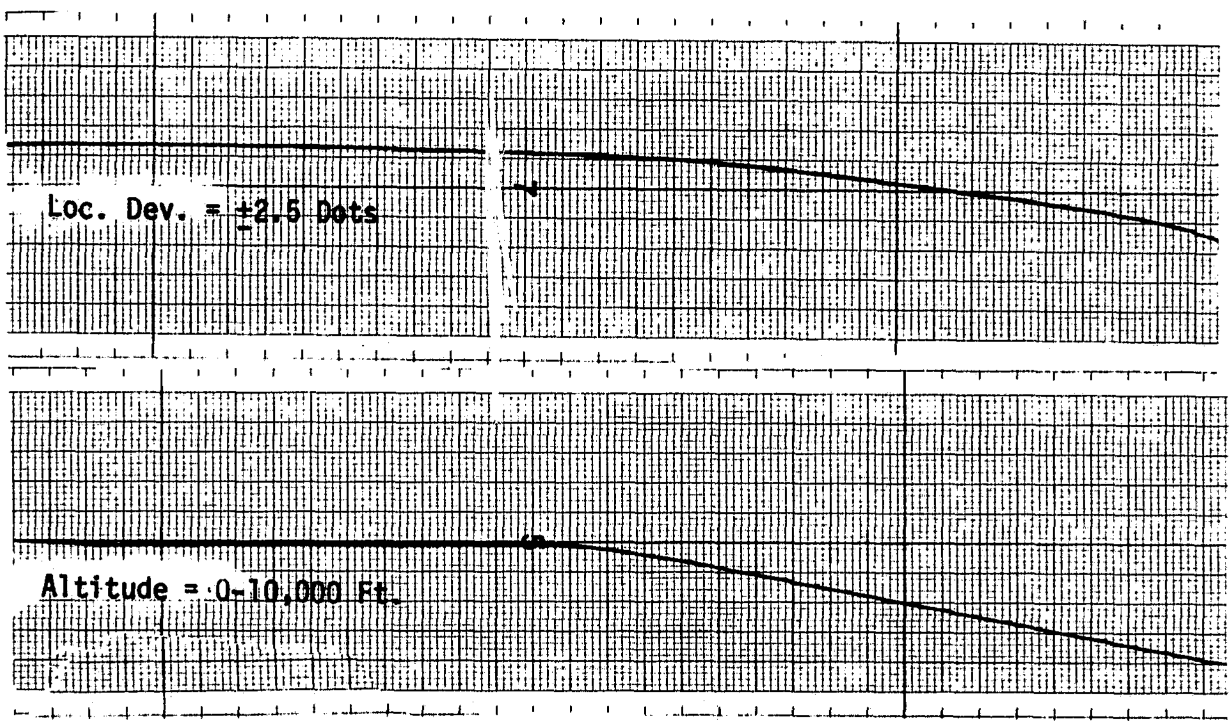
20 sec/cm
Wind Shear
(Standard Software)

FIGURE 6.5-1



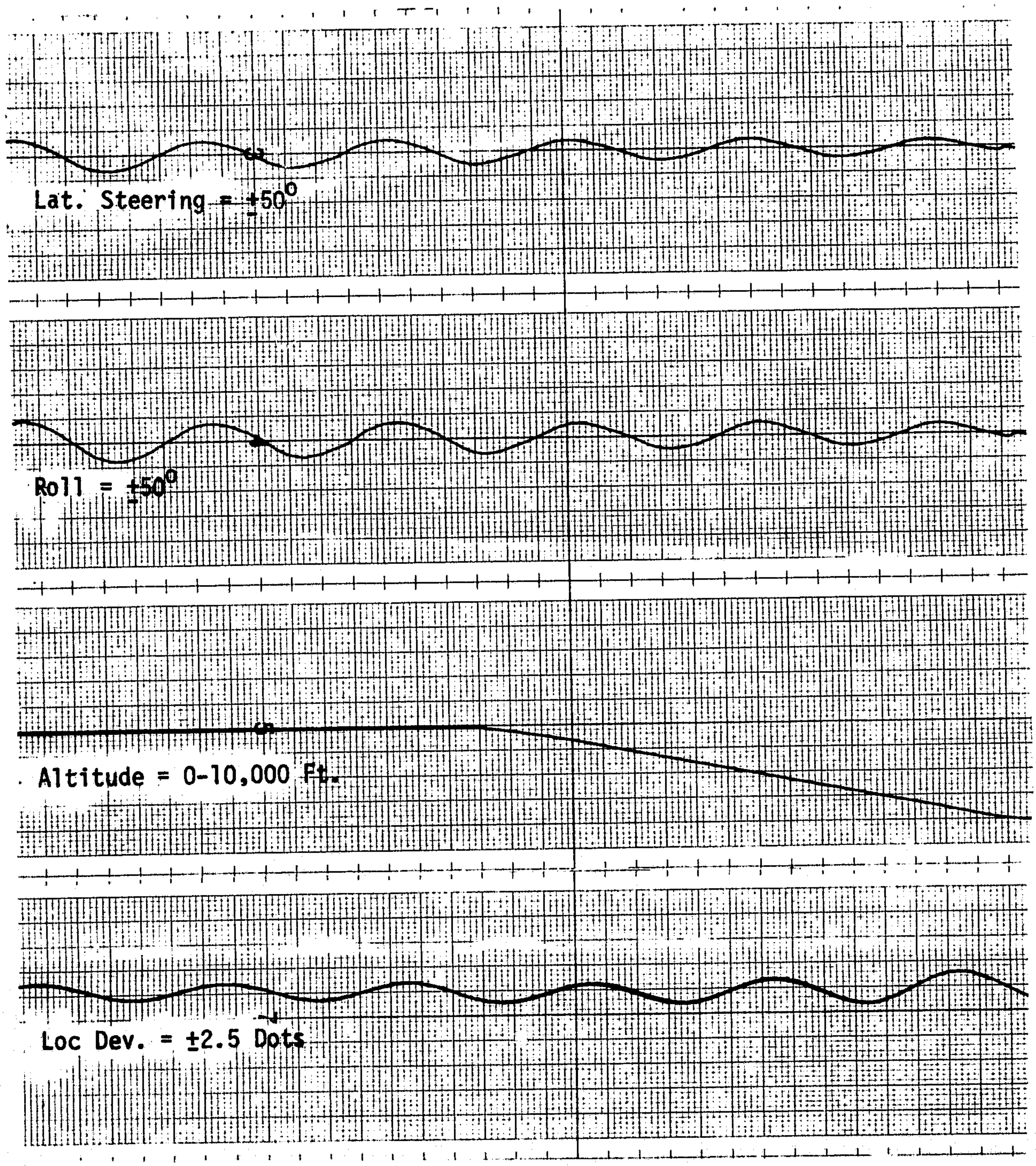
20 sec/cm
VOR Noise (Standard Software)

FIGURE 6.5-2



20 sec/cm
Wind Shear
(Increased Deviation Gain)

FIGURE 6.5-3

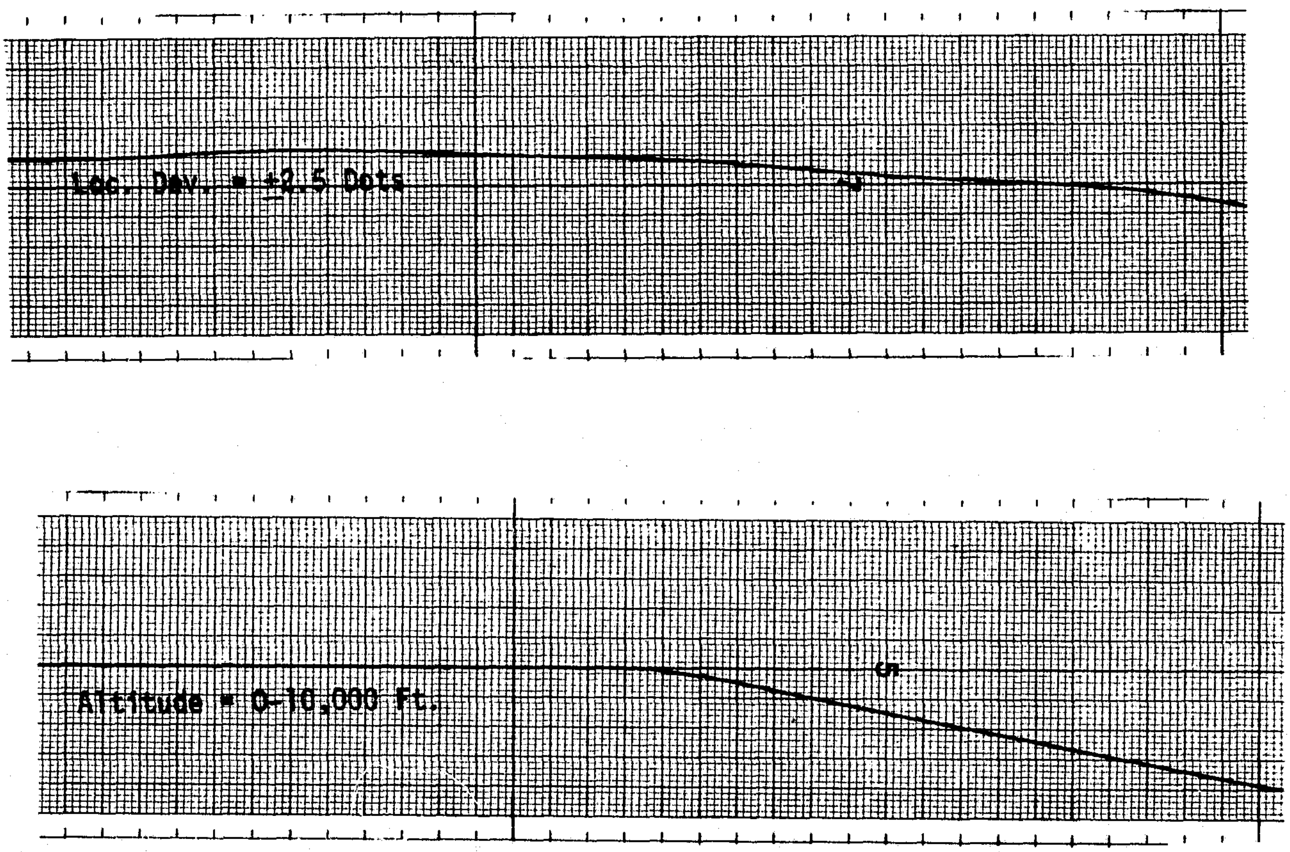


20 sec/cm

VOR Noise

(Increased Deviation Gain)

FIGURE 6.5-4

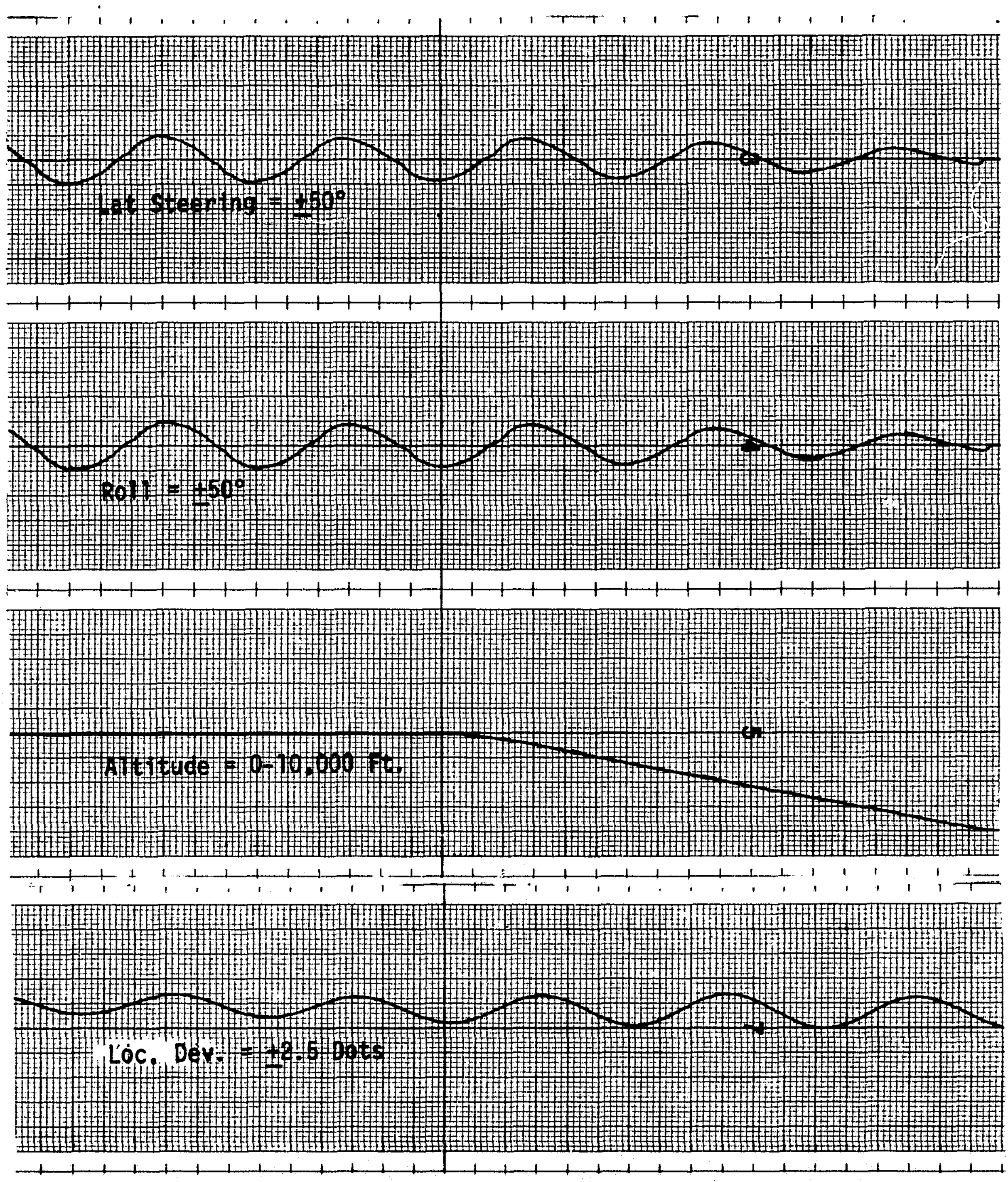


20 sec/cm

Wind Shear

(Decreased Wind Estimation Time)

Figure 6.5-5



20 sec/cm

VOR Noise
(Decreased Wind Estimation Time)
Figure 6.5-6

to the difference between the lat/long waypoint in the data base and the simulator localizer beam.

Figure 6.5-3 shows the decrease in deviation when the cross-track gain is changed from 47.7 degrees per nautical mile (1852 m) to 73.5 degrees per nautical mile, while Figure 6.5-4 shows the corresponding increase in roll activity.

Figure 6.5-5 shows the decrease in deviation when the wind estimation time was reduced from approximately 82 seconds (65%), to approximately 45 seconds. Figure 6.5-6 is the corresponding VOR noise case.

6.6 Software

Recommendation

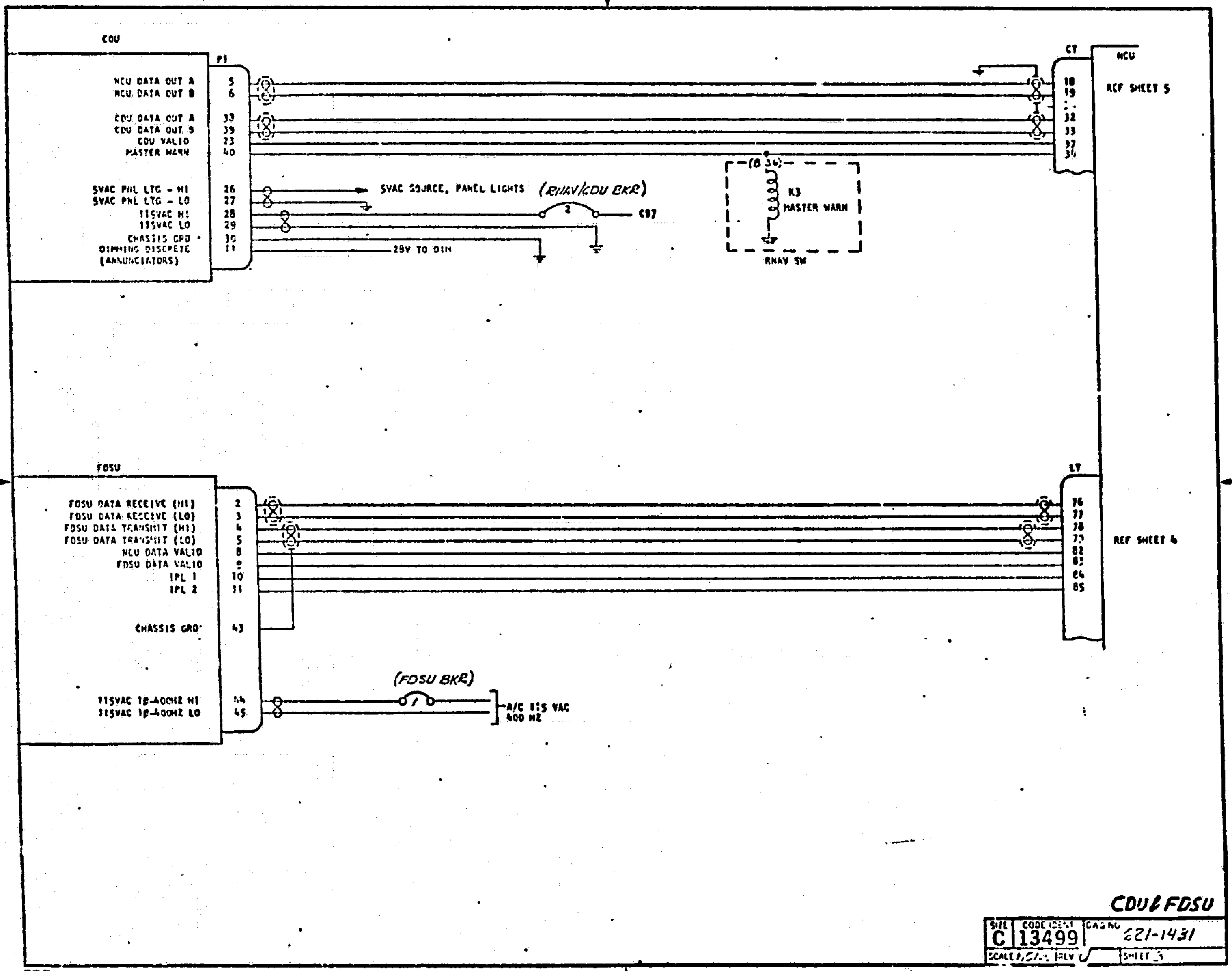
1. Use a software architecture that will allow functions such as the two-segment approach to be added with minimum impact on existing functions.
2. Provide adequate memory to accommodate added functions.
3. Provide thorough ground testing of software prior to deployment on aircraft.

The above recommendations are repeated despite their common usage as guidelines. If added functions such as two-segment are envisioned, the growth should be liberally allowed for in the basic system design.

Item 3 simply reflects the cost of actual aircraft operation. The availability of a facility such as the Collins hybrid computer complex to enable the RNAV computer and aircraft model to be exercised in real time was invaluable in reducing actual aircraft flight time. Even so, it is very difficult to exactly duplicate the conditions in the aircraft, and even more difficult to envision all the test sequences necessary to adequately exercise the software program.

APPENDIX 1

RNAV NOISE ABATEMENT APPROACH SYSTEM INTERFACE WIRING FOR THE DC-8-61 AIRCRAFT



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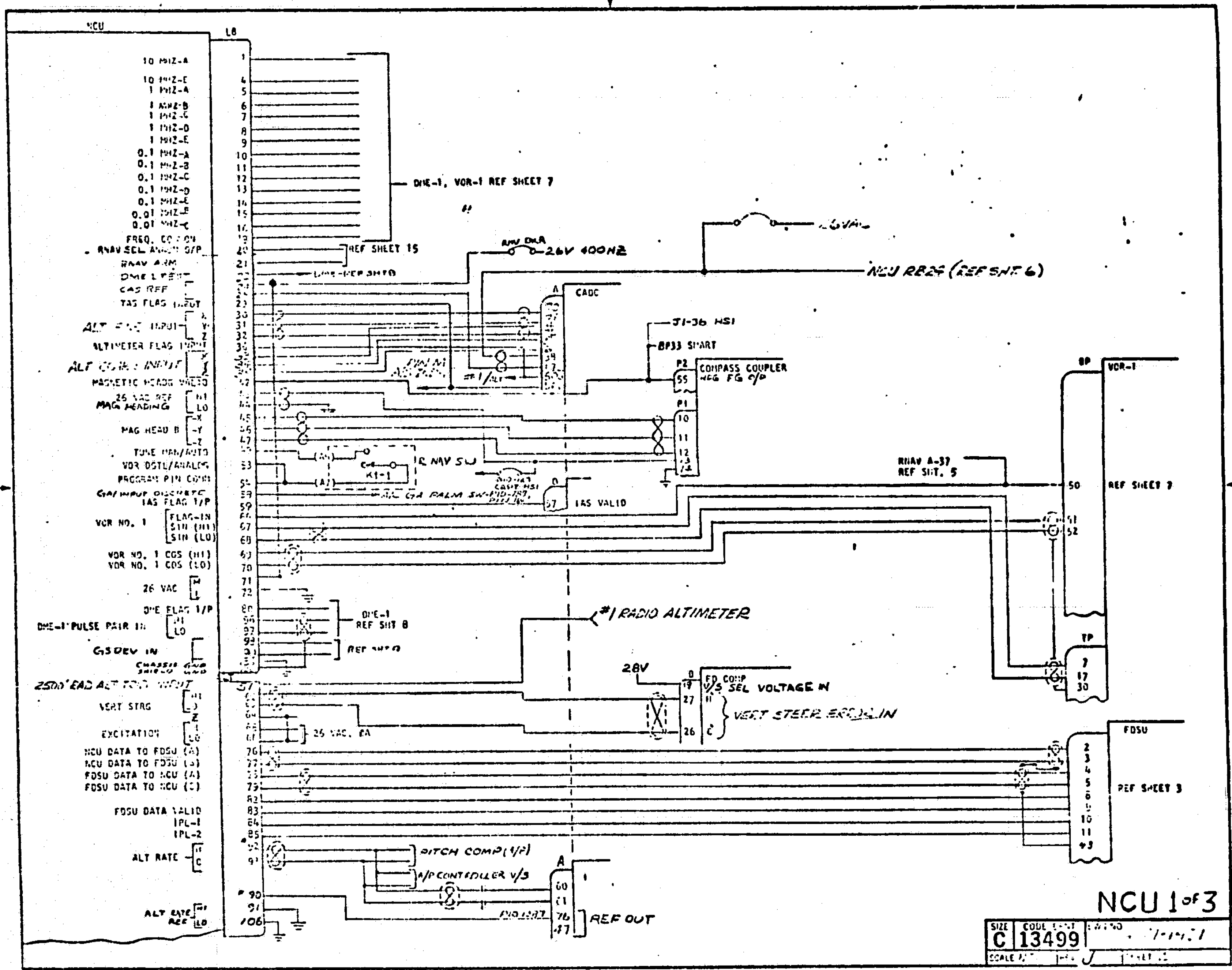
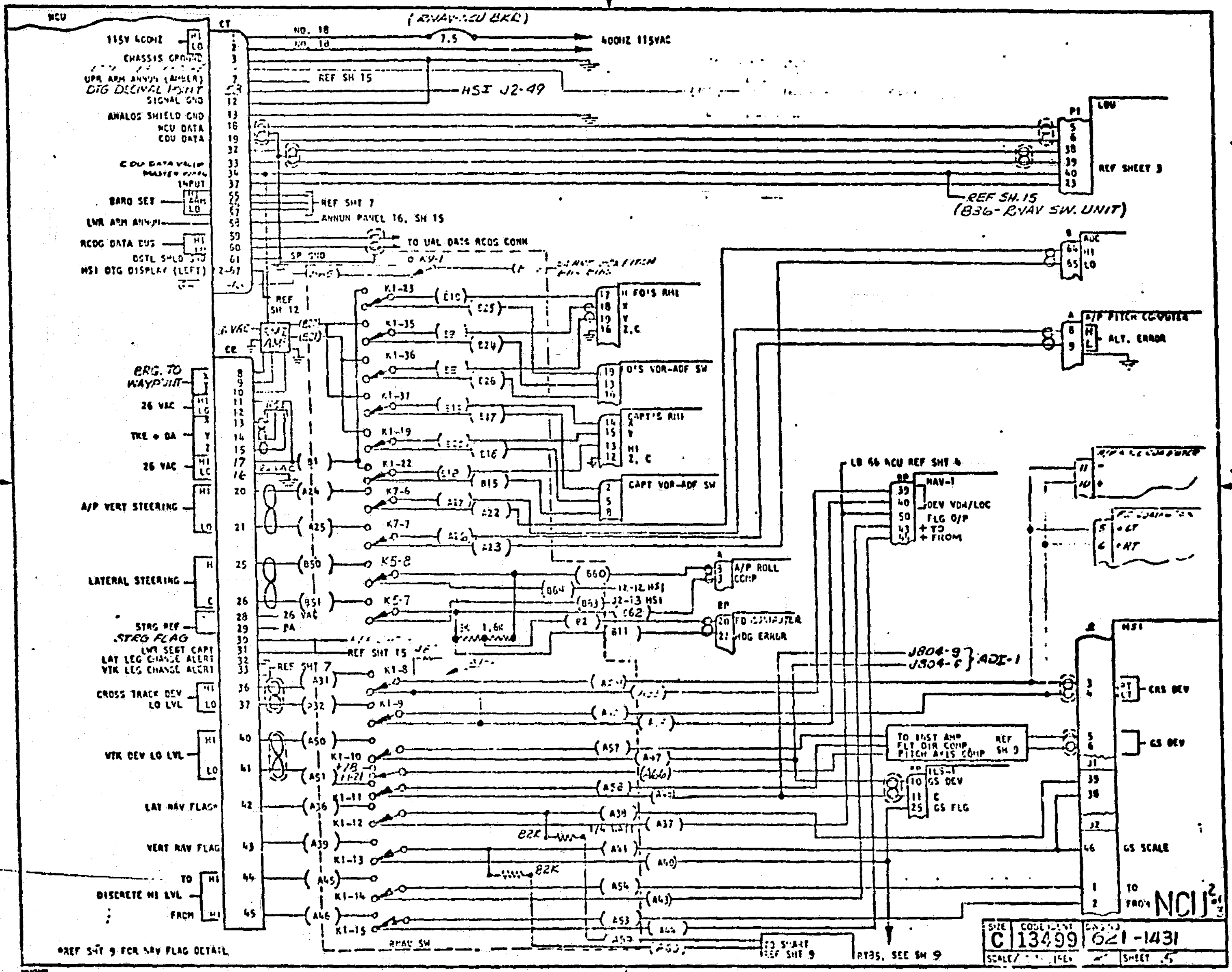
OF POOR QUALITY


NCU
L8
10 MHZ-A
10 MHZ-E
1 MHZ-A
1 MHZ-B
1 MHZ-D
1 MHZ-E
0.1 MHZ-A
0.1 MHZ-B
0.1 MHZ-C
0.1 MHZ-D
0.1 MHZ-E
DME-1, VOR-1 REF SHEET 7
REF SHEET 15
26V 400HZ
NCU RB24 (REF SHT 6)
CADC
J1-36 HSI
COMPASS COUPLER
RNAV SW
K1-1
IAS VALID
RNAV A-37
REF SHT. 5
VOR-1
REF SHEET 7
ALTIMETER FLAG INPUT
MAGNETIC HEADG VALID
MAG HEAD B
TUNE MAN/AUTO
VOR DGTL/ANALOG
PROGRAM PIN COMM
TAS FLAG I/P
VOR NO. 1
VOR NO. 1 COS (HI)
VOR NO. 1 COS (LO)
26 VAC
DME FLAG I/P
DME-1 PULSE PAIR IN
DME-1
REF SHT 8
GS DEV IN
#1 RADIO ALTIMETER
28V
V/S SEL VOLTAGE IN
VERT STEER ERROR IN
VERT STRG
EXCITATION
26 VAC, EA
NCU DATA TO FDSU (A)
NCU DATA TO FDSU (B)
FDSU DATA TO NCU (A)
FDSU DATA TO NCU (B)
FDSU DATA VALID
IPL-1
IPL-2
FDSU
REF SHEET 3
ALT RATE
PITCH COMP (I/P)
A/P CONTROLLER V/S
REF OUT
ALT RATE REF
NCU 1 of 3
SIZE C
13499



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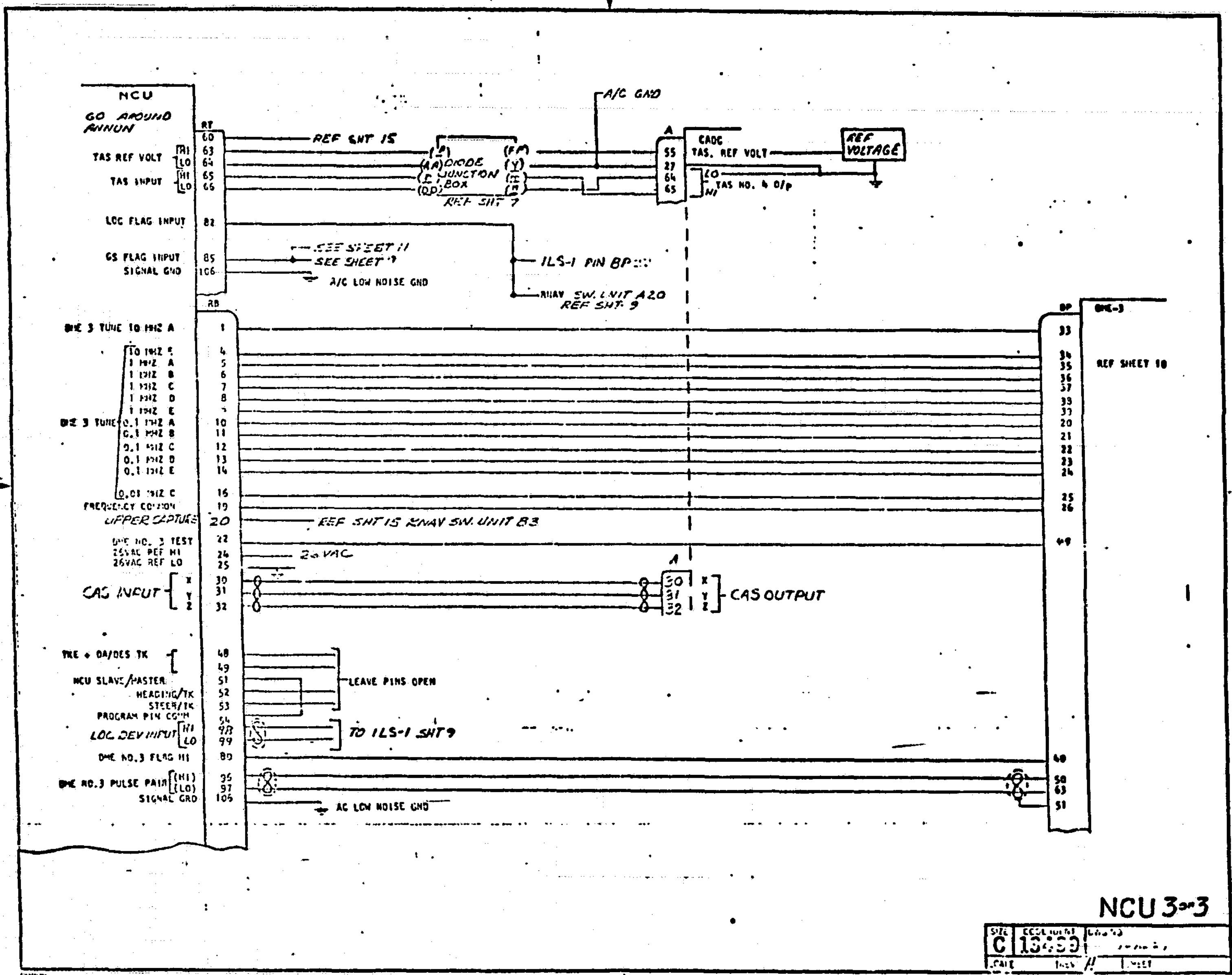
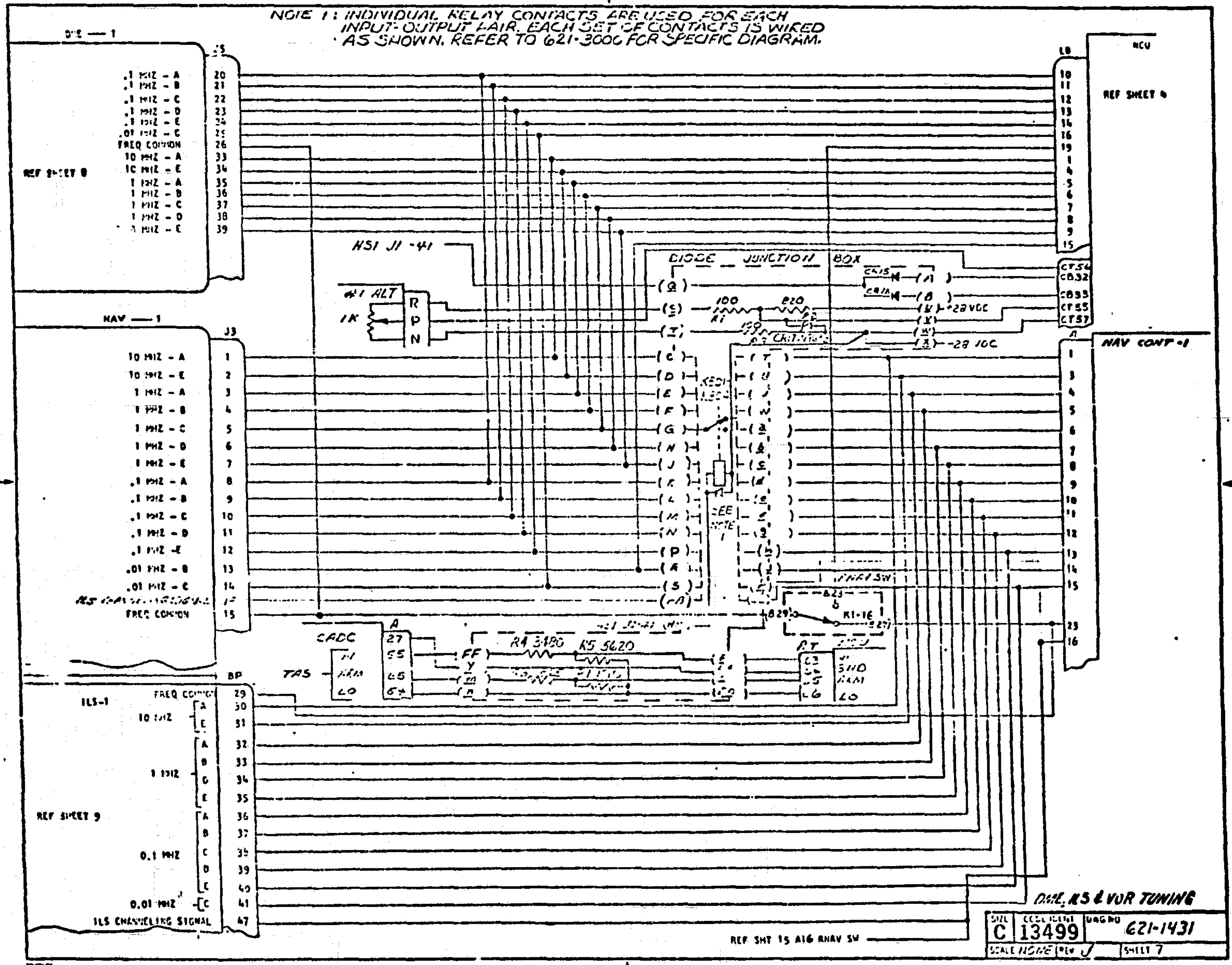
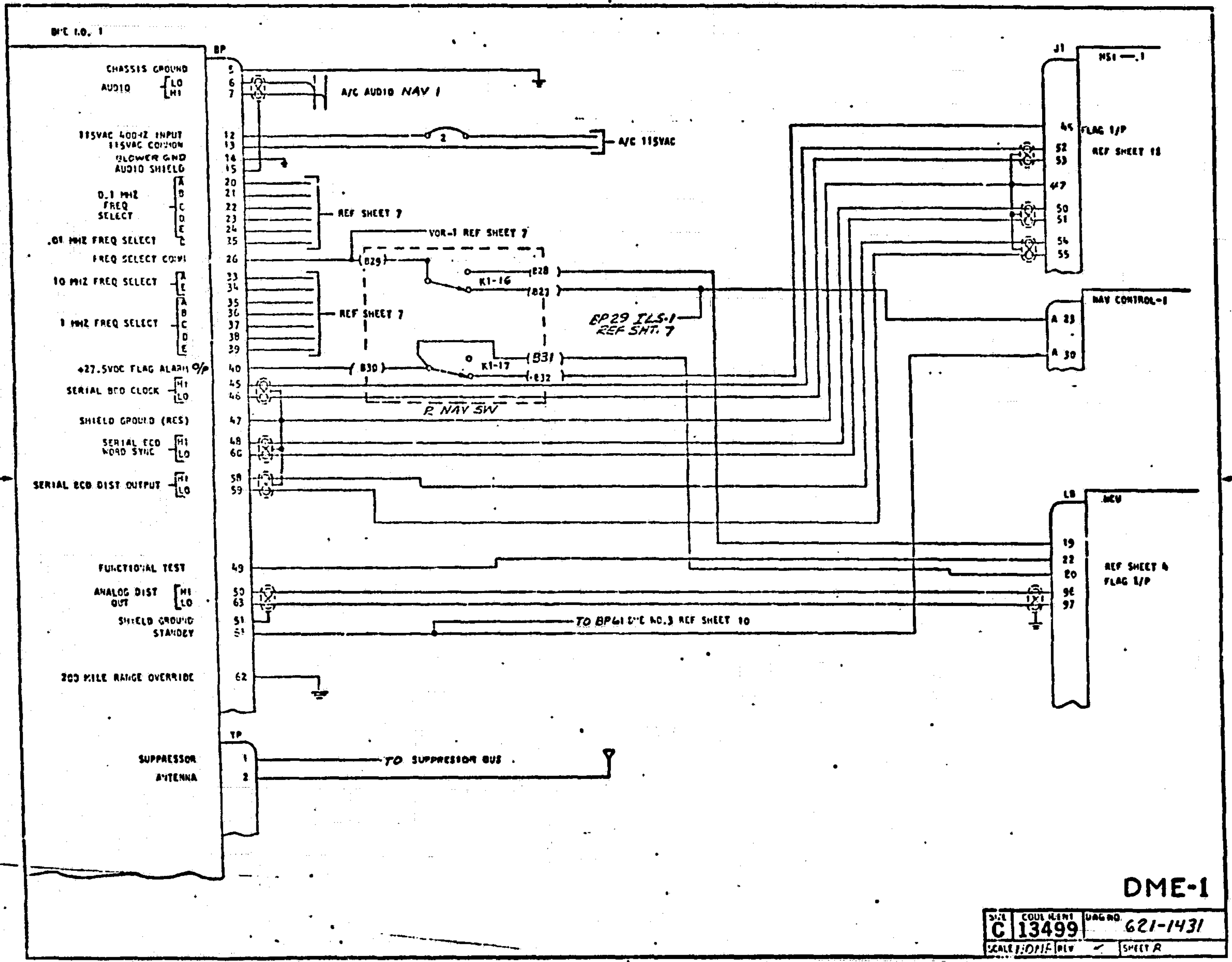
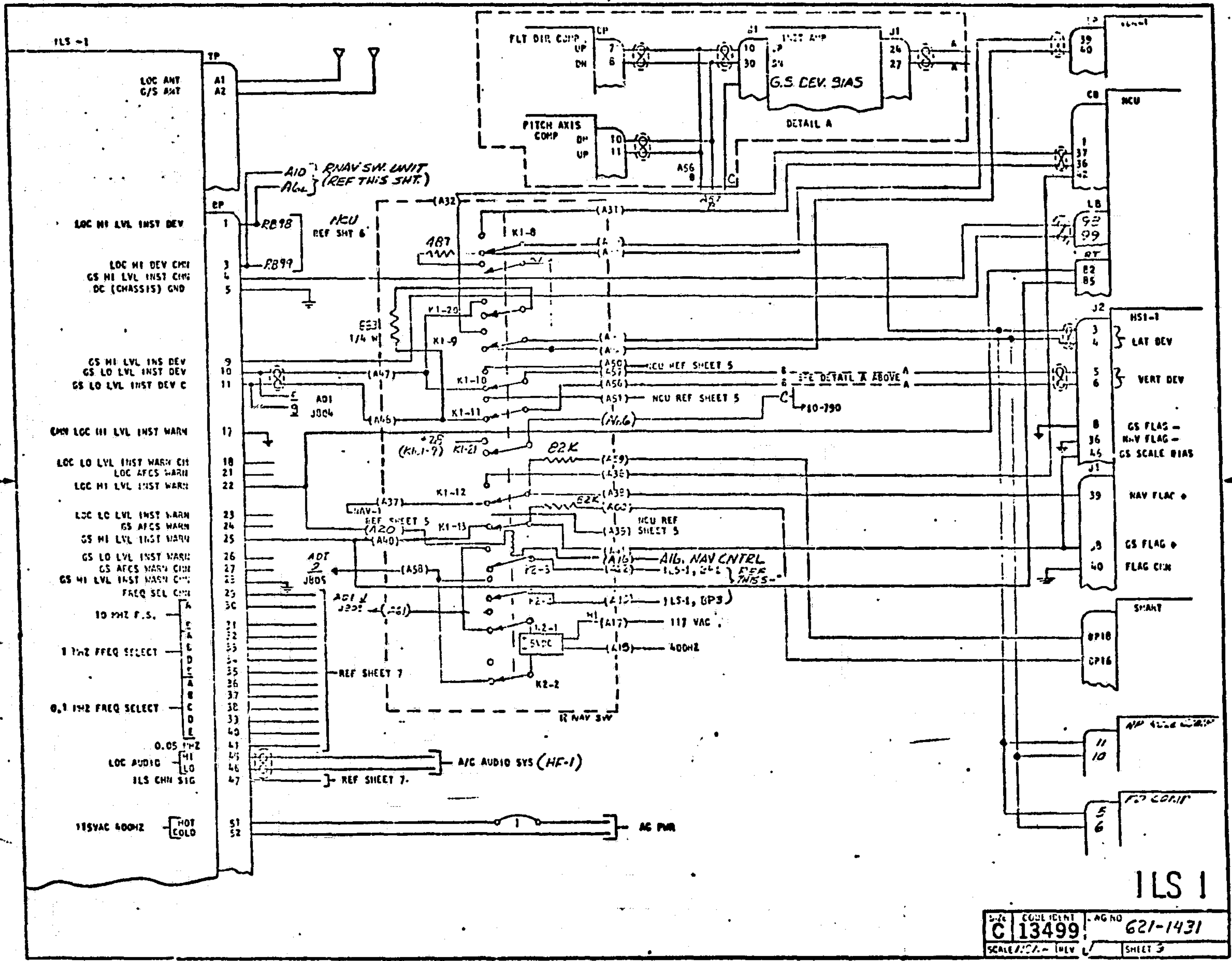


NCU
GO AROUND ANNUN
TAS REF VOLT
TAS INPUT
LOC FLAG INPUT
GS FLAG INPUT
SIGNAL GND
REF SHT 15
DIODE JUNCTION BOX
REF SHT 7
A/C GND
CADC
TAS. REF VOLT
REF VOLTAGE
TAS NO. 4 O/P
SEE SHEET 11
SEE SHEET 9
A/C LOW NOISE GND
ILS-1 PIN BP
RNAV SW. UNIT A20 REF SHT 9
DME 3 TUNE 10 MHZ A
DME 3 TUNE
FREQUENCY COMMON
UPPER CAPTURE
REF SHT 15 RNAV SW. UNIT B3
DME NO. 3 TEST
26VAC REF HI
26VAC REF LO
26VAC
CAS INPUT
CAS OUTPUT
LEAVE PINS OPEN
NCU SLAVE/MASTER
HEADING/TK
STEER/TK
PROGRAM PIN COMM
LOC DEV INPUT
TO ILS-1 SHT 9
DME NO. 3 FLAG HI
DME NO. 3 PULSE PAIR
SIGNAL GRD
AC LOW NOISE GND
DME-3
REF SHEET 10
NCU 3 of 3

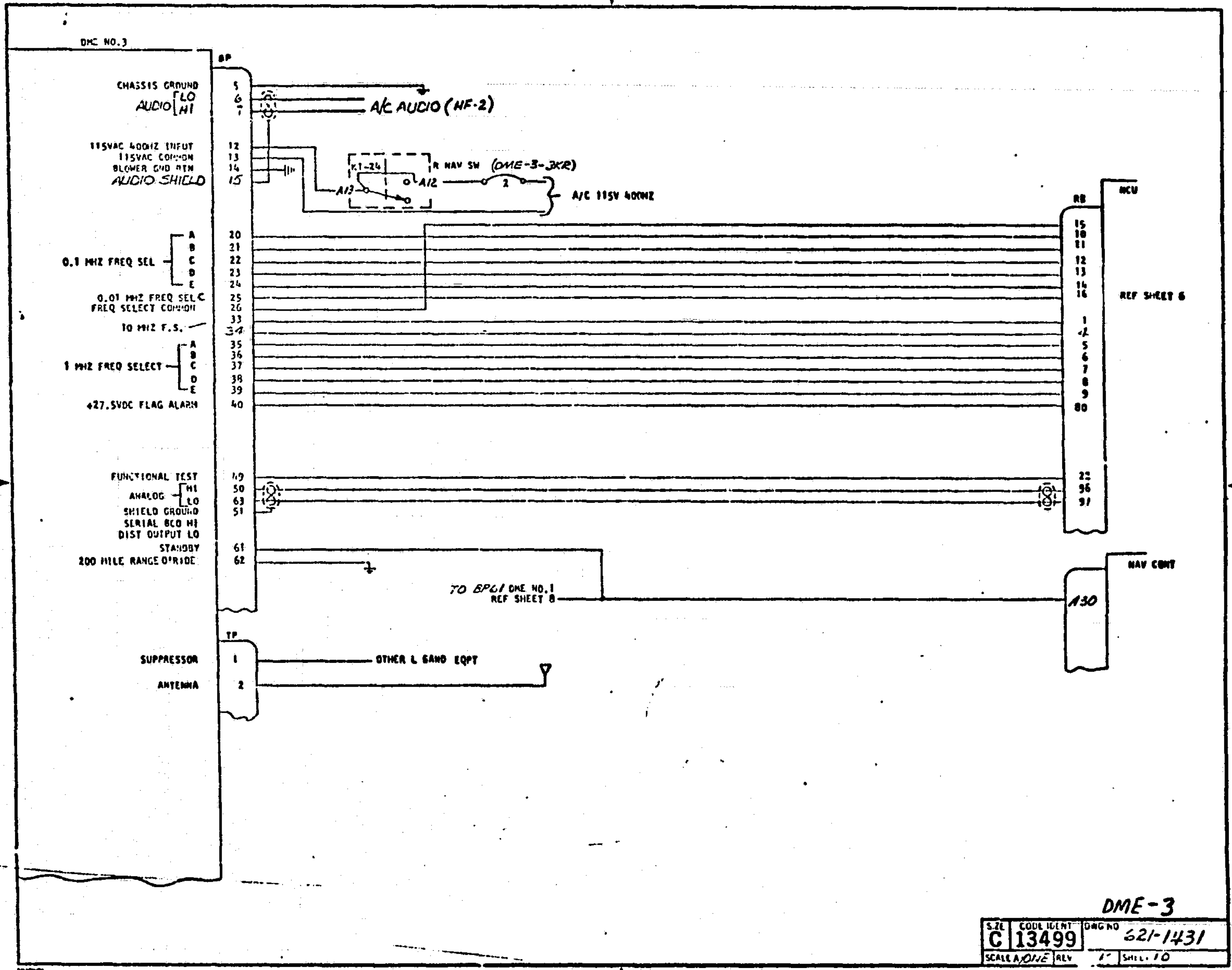

NOTE 1: INDIVIDUAL RELAY CONTACTS ARE USED FOR EACH INPUT-OUTPUT PAIR. EACH SET OF CONTACTS IS WIRED AS SHOWN. REFER TO 621-3000 FOR SPECIFIC DIAGRAM.
REF SHEET 8
NAV — 1
REF SHEET 4
HSI J1-41
DIODE JUNCTION BOX
NAV CONT-1
CADC
TAS
R4 3480
R5 5620
ILS-1
REF SHEET 9
FREQ COMMON
ILS CHANNELING SIGNAL
REF SHT 15 A16 RNAV SW
DME, ILS & VOR TUNING
C 13499 621-1431
SCALE NONE REV J SHEET 7

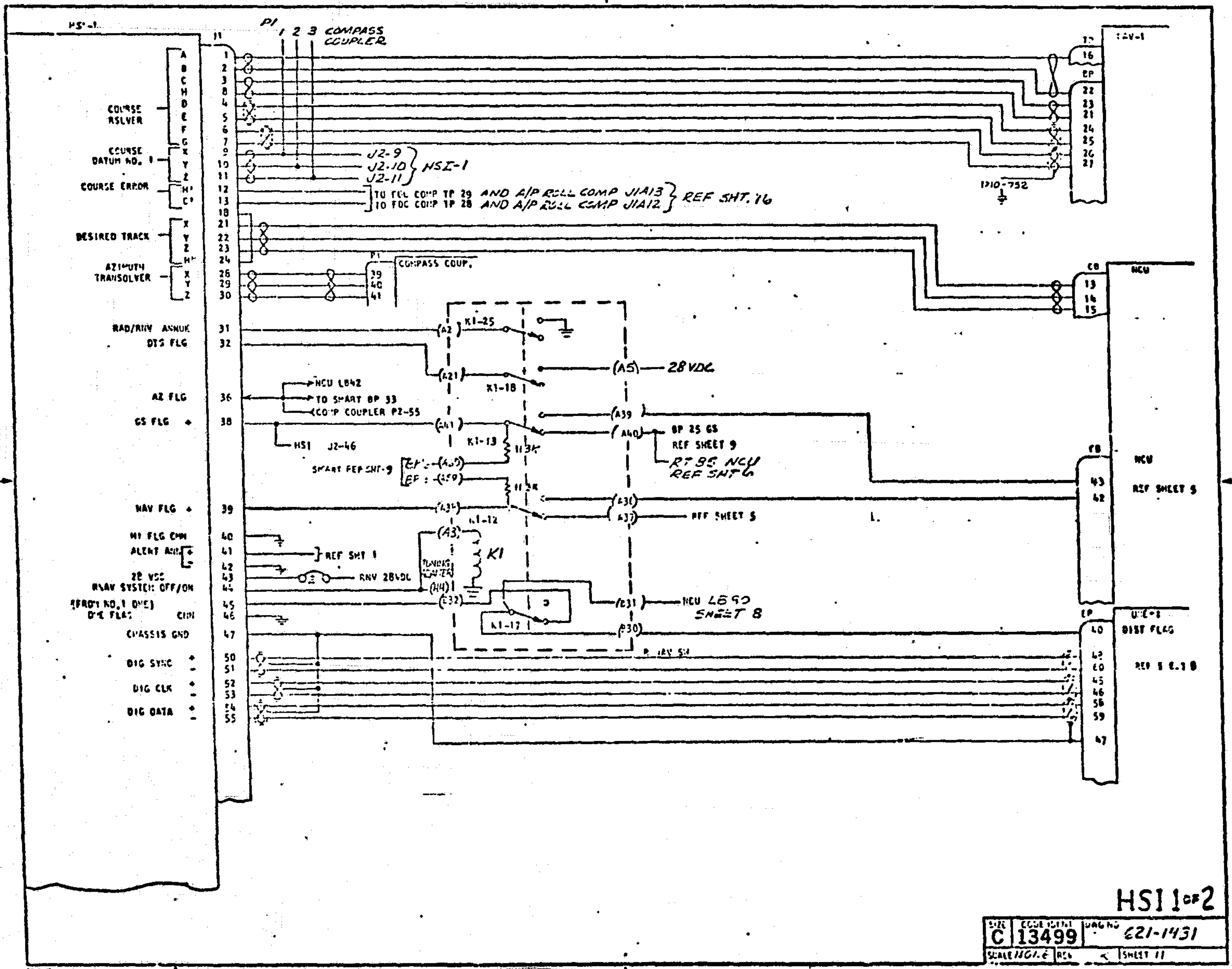

DME I.O. 1
BP
CHASSIS GROUND
AUDIO LO HI
A/C AUDIO NAV 1
115VAC 400HZ INPUT
115VAC COMMON
BLOWER GND
AUDIO SHIELD
A/C 115VAC
0.1 MHZ FREQ SELECT
.01 MHZ FREQ SELECT
REF SHEET 7
VOR-1 REF SHEET 7
FREQ SELECT COMM
10 MHZ FREQ SELECT
1 MHZ FREQ SELECT
K1-16
K1-17
EP29 ILS-1 REF SHT. 7
+27.5VDC FLAG ALARM O/P
SERIAL BCD CLOCK
R NAV SW
SHIELD GROUND (RES)
SERIAL BCD WORD SYNC
SERIAL BCD DIST OUTPUT
FUNCTIONAL TEST
ANALOG DIST OUT
SHIELD GROUND
STANDBY
TO BP61 DME NO.3 REF SHEET 10
200 MILE RANGE OVERRIDE
TP
SUPPRESSOR
ANTENNA
TO SUPPRESSOR BUS
J1
HSI-1
FLAG I/P
REF SHEET 11
NAV CONTROL-1
L8
MCU
REF SHEET 4 FLAG I/P
DME-1
C 13499 621-1431
SHEET 8

A-8

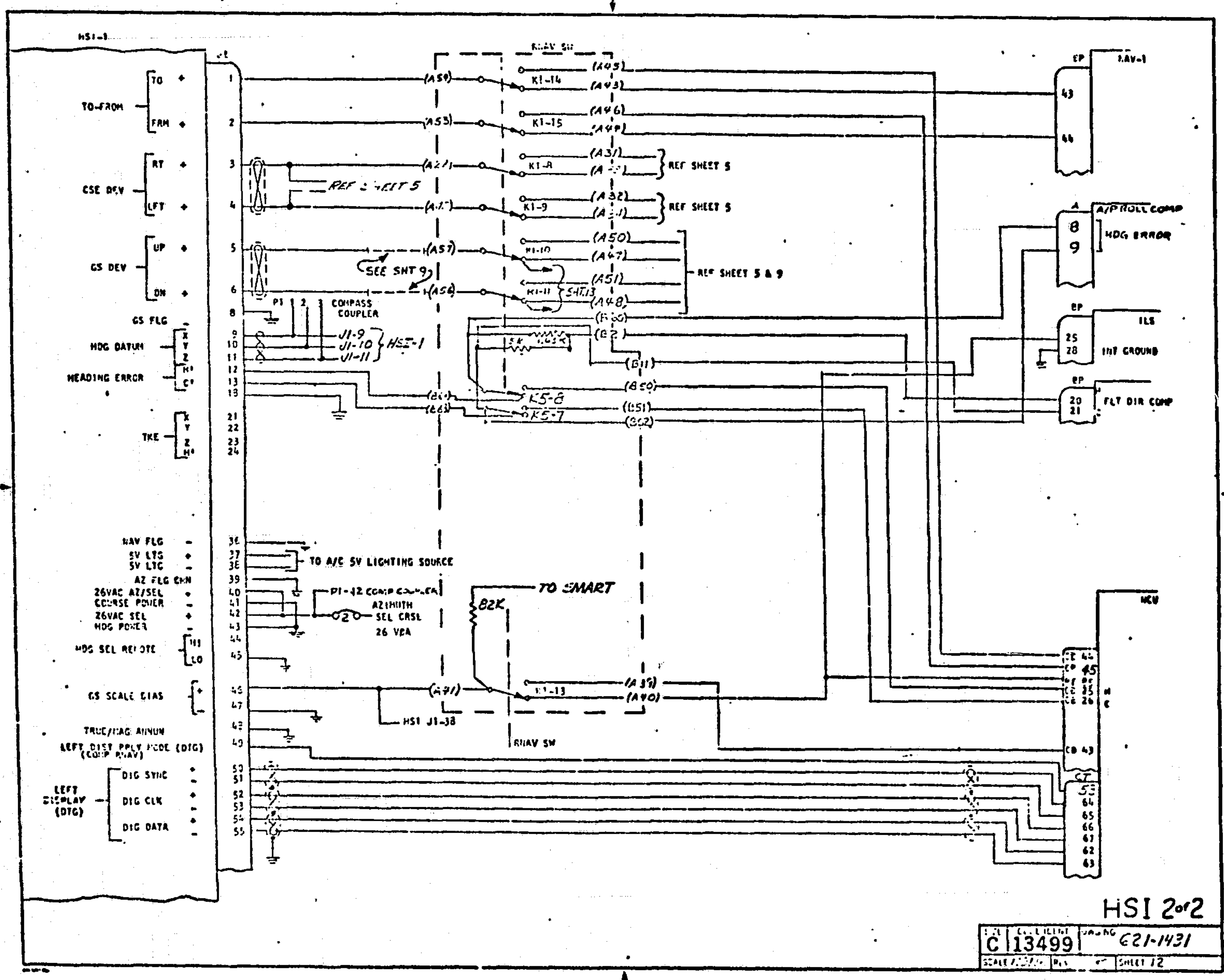


ILS-1
LOC ANT
G/S ANT
LOC HI LVL INST DEV
LOC HI DEV CMN
GS HI LVL INST CMN
DC (CHASSIS) GND
GS HI LVL INS DEV
GS LO LVL INST DEV
GS LO LVL INST DEV C
LOC LO LVL INST WARN
LOC AFCS WARN
LOC HI LVL INST WARN
GS AFCS WARN
GS HI LVL INST WARN
GS LO LVL INST WARN
FREQ SEL CMN
10 MHZ F.S.
1 MHZ FREQ SELECT
0.1 MHZ FREQ SELECT
0.05 MHZ
LOC AUDIO
ILS CMN SIG
115VAC 400HZ
HOT
COLD
RNAV SW. UNIT (REF THIS SHT.)
NCU REF SHT 6
REF SHEET 7
A/C AUDIO SYS (HF-1)
REF SHEET 7
AC PWR
FLT DIR COMP
PITCH AXIS COMP
G.S. DEV. BIAS
DETAIL A
NCU
LAT DEV
VERT DEV
GS FLAG -
NAV FLAG -
GS SCALE BIAS
NAV FLAG +
GS FLAG +
FLAG CMN
SHAFT
NCU REF SHEET 5
SEE DETAIL A ABOVE
NCU REF SHEET 5
AIL NAV CNTRL
117 VAC
400HZ
R NAV SW
82K
487
K1-8
K1-9
K1-10
K1-11
K1-12
K1-13
K2-2
ADI J804
ADI J805
ILS 1
C
13499
621-1431


DME NO.3
BP
CHASSIS GROUND
AUDIO LO HI
A/C AUDIO (HF-2)
115VAC 400HZ INPUT
115VAC COMMON
BLOWER GND RTN
AUDIO SHIELD
K1-24
R NAV SW
(DME-3-3KR)
A13
A12
A/C 115V 400HZ
0.1 MHZ FREQ SEL
0.01 MHZ FREQ SEL C
FREQ SELECT COMMON
10 MHZ F.S.
1 MHZ FREQ SELECT
+27.5VDC FLAG ALARM
FUNCTIONAL TEST
ANALOG HI LO
SHIELD GROUND
SERIAL BCD HI
DIST OUTPUT LO
STANDBY
200 MILE RANGE O'RIDE
TO BP61 DME NO.1
REF SHEET 8
RB
NCU
REF SHEET 6
NAV CONT
A30
TP
SUPPRESSOR
ANTENNA
OTHER L BAND EQPT
DME-3
SIZE C
CODE IDENT 13499
DWG NO 621-1431
SCALE NONE
SHEET 10


COURSE RSLVER
COURSE DATUM NO. 1
COURSE ERROR
DESIRED TRACK
AZIMUTH TRANSOLVER
RAD/RNV ANNUC
DTS FLG
AZ FLG
GS FLG
NAV FLG
ALERT ANN
28 VDC
RNAV SYSTEM OFF/ON
CHASSIS GND
DIG SYNC
DIG CLK
DIG DATA
P1 1 2 3 COMPASS COUPLER
J2-9
J2-10
J2-11
HSI-1
TO FDC COMP TP 29 AND A/P ROLL COMP J1A13
TO FDC COMP TP 28 AND A/P ROLL COMP J1A12
REF SHT. 16
COMPASS COUP.
K1-25
K1-18
28VDC
NCU L842
TO SMART BP 33
COMP COUPLER P2-55
HSI J2-46
K1-13
BP 25 GS
REF SHEET 9
RT 85 NCU
REF SHT 6
REF SHEET 5
K1-12
K1
REF SHT 1
RNV 28VDC
K1-17
NCU L690
SHEET 8
NCU
NCU
REF SHEET 5
DIST FLAG
HSI 1 of 2
C 13499 621-1431
SHEET 11

A-10

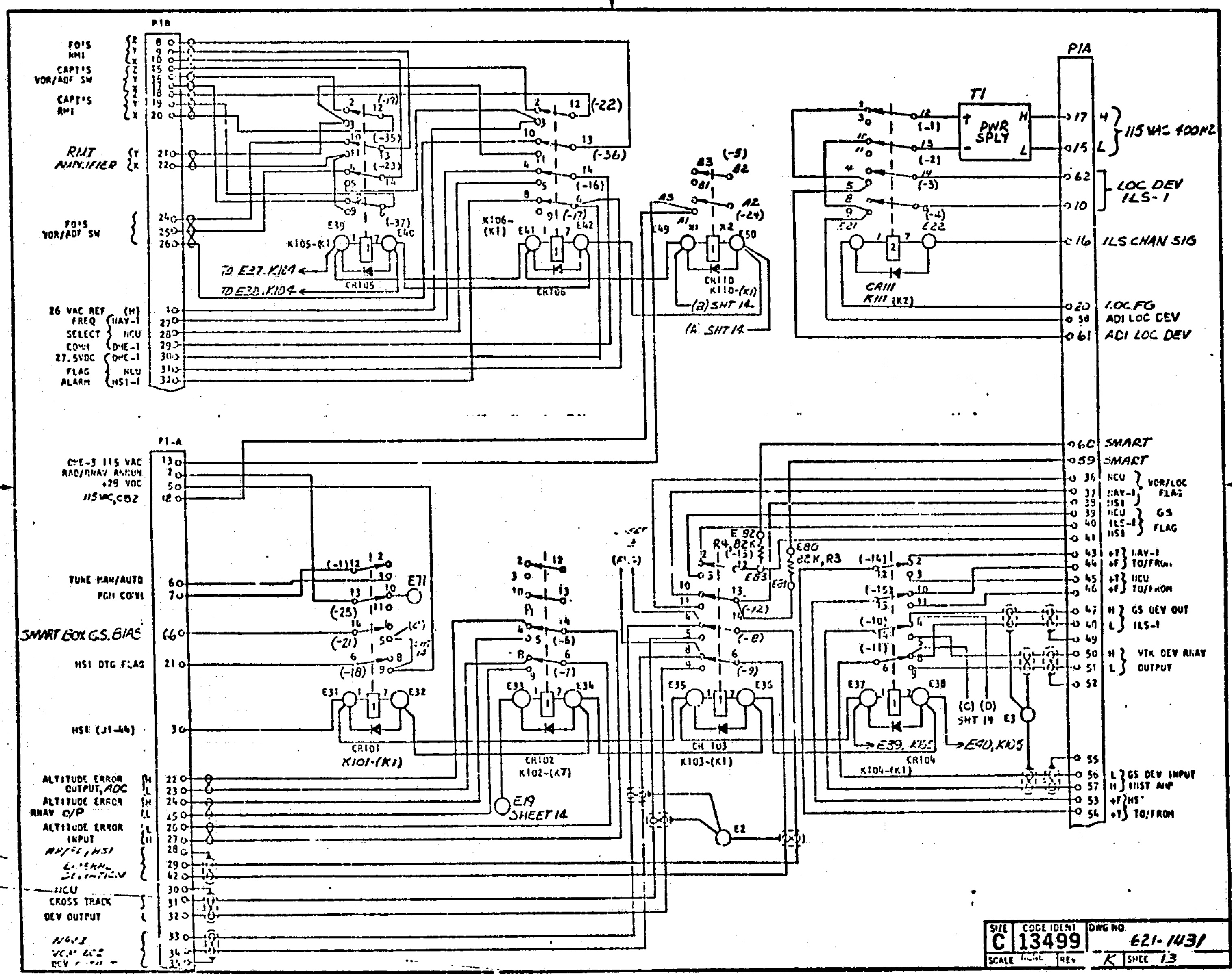


HSI 2 of 2

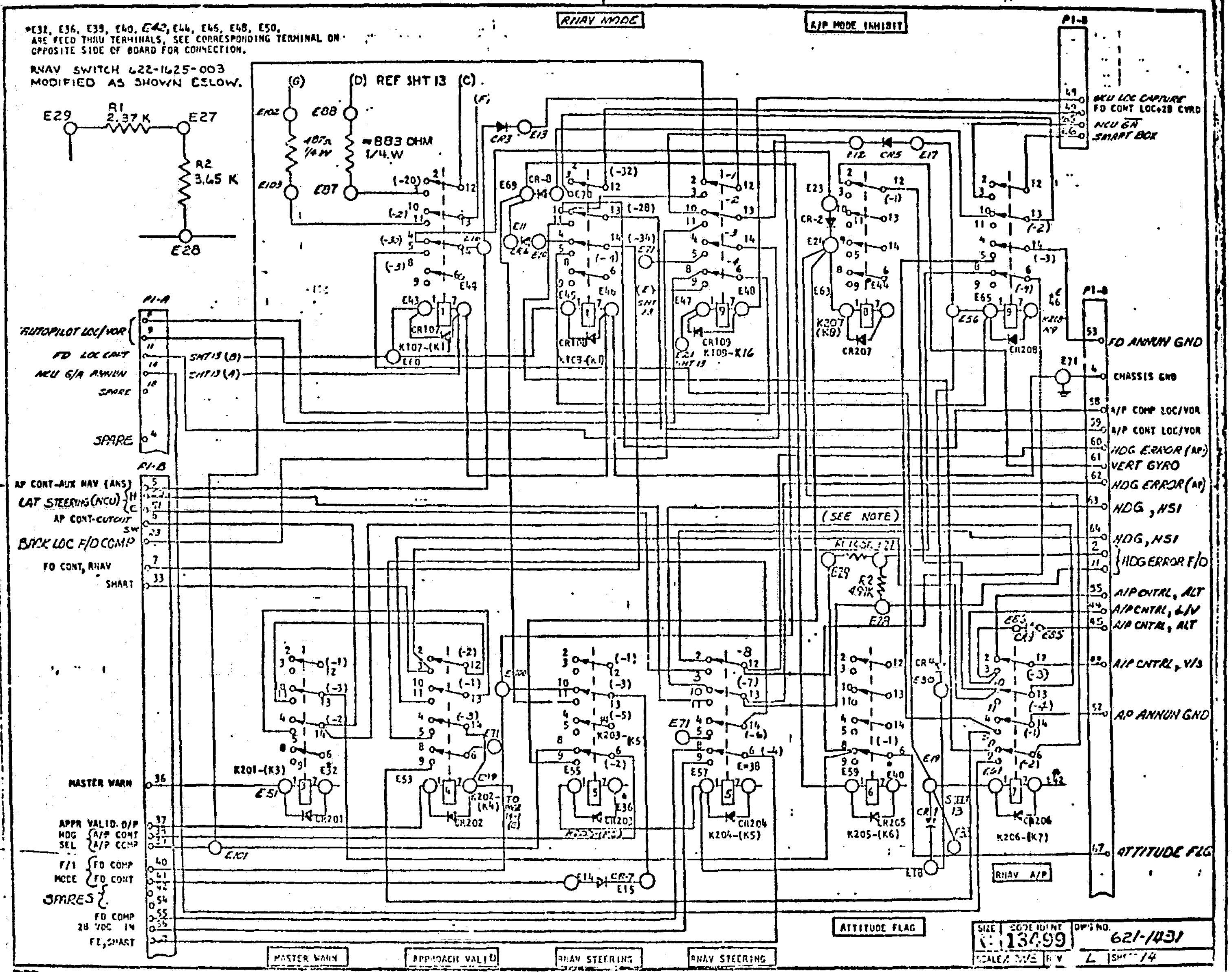
SIZE	CODE IDENT	DWG NO
C	13499	621-1431

SHEET 12

A-11

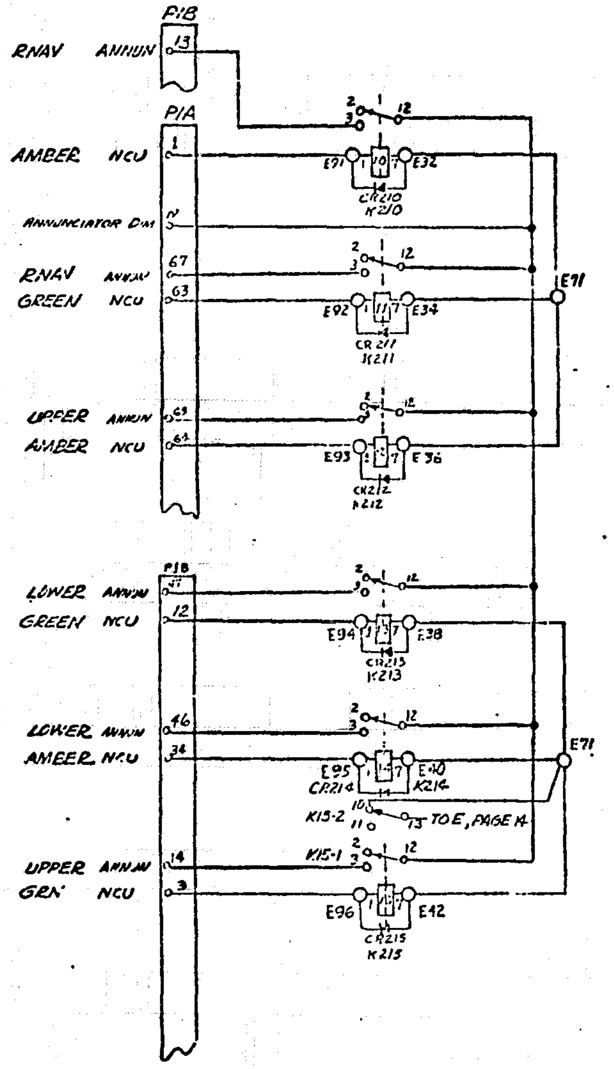


P1B
FO'S RMI
CAPT'S VOR/ADF SW
CAPT'S RMI
RNT AMPLIFIER
FO'S VOR/ADF SW
26 VAC REF FREQ SELECT COMM
27.5VDC FLAG ALARM
K105-(K1)
K106-(K1)
K110-(K1)
CR105
CR106
CR110
TO E37, K104
TO E38, K104
(a) SHT 14
T1
PWR SPLY
P1A
115 VAC 400HZ
LOC DEV ILS-1
ILS CHAN SIG
CR111
K111 (K2)
LOC FG
ADI LOC DEV
ADI LOC DEV
P1-A
DME-3 115 VAC
RAD/RNAV ANNUN
+28 VDC
115VAC, CB2
TUNE MAN/AUTO
PGM COMM
SMART BOX G.S. BIAS
HSI DTG FLAG
HSI (J1-44)
ALTITUDE ERROR OUTPUT, ADC
ALTITUDE ERROR RNAV O/P
ALTITUDE ERROR INPUT
NCU
CROSS TRACK
DEV OUTPUT
E71
CR101
K101-(K1)
CR102
K102-(K7)
E19 SHEET 14
CR103
K103-(K1)
CR104
K104-(K1)
E39, K105
E40, K105
(C) (D) SHT 14
R4, 82K
82K, R3
SMART
SMART
NCU
NAV-1
HSI
VOR/LOC FLAG
ILS-1
GS FLAG
NAV-1 TO/FROM
NCU TO/FROM
GS DEV OUT ILS-1
VTK DEV RNAV OUTPUT
GS DEV INPUT HIST AMP
HSI TO/FROM
SIZE C
CODE IDENT 13499
DWG NO. 621-1431
SCALE NONE
REV K
SHEET 13



*E32, E36, E39, E40, E42, E44, E46, E48, E50, ARE FEED THRU TERMINALS, SEE CORRESPONDING TERMINAL ON OPPOSITE SIDE OF BOARD FOR CONNECTION.
RNAV SWITCH 622-1625-003 MODIFIED AS SHOWN BELOW.
E29
R1 2.37 K
E27
R2 3.45 K
E28
(G)
(D) REF SHT 13
(C)
≈883 OHM 1/4 W
RNAV MODE
A/P MODE INHIBIT
P1-B
P1-A
AUTOPILOT LOC/VOR
FD LOC CAPT
SPARE
AP CONT-AUX NAV (ANS)
LAT STEERING (NCU)
AP CONT-CUTOUT
BACK LOC F/D COMP
FD CONT, RNAV
SMART
FD ANNUN GND
CHASSIS GND
A/P COMP LOC/VOR
A/P CONT LOC/VOR
HDG ERROR (AP)
VERT GYRO
HDG, HSI
HDG ERROR F/D
A/P CNTRL, ALT
A/P CNTRL, V/S
A/P ANNUN GND
ATTITUDE FLG
(SEE NOTE)
MASTER WARN
K201-(K3)
K202-(K4)
K203-(K5)
K204-(K5)
K205-(K6)
K206-(K7)
K107-(K1)
K207 (K8)
RNAV A/P
ATTITUDE FLAG
MASTER WARN
APPROACH VALID
RNAV STEERING
RNAV STEERING
SPARES
CODE IDENT 13499
DWG NO. 621-1431
SHEET 14

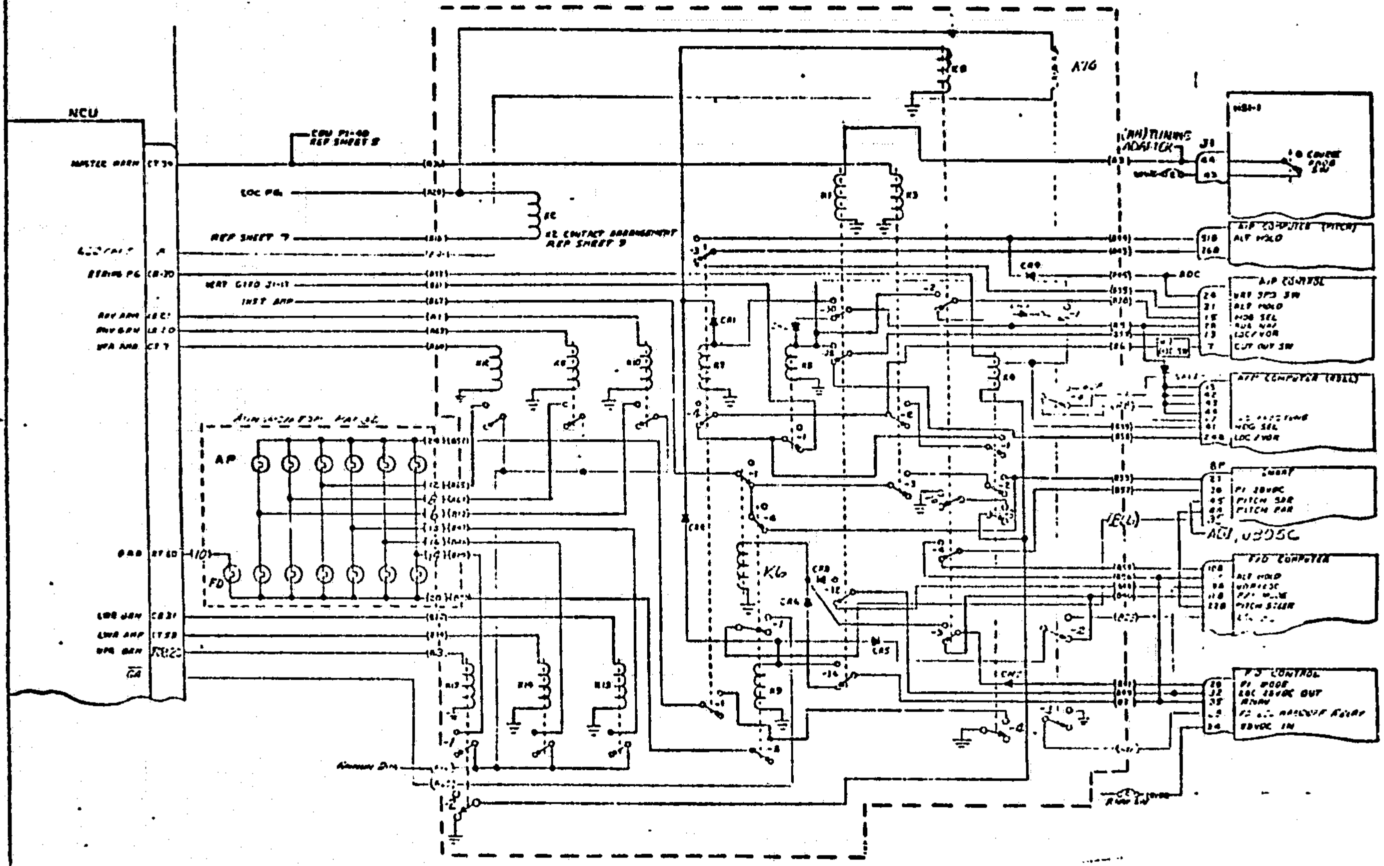
A-14



ORIGINAL PAGE IS
OF POOR QUALITY

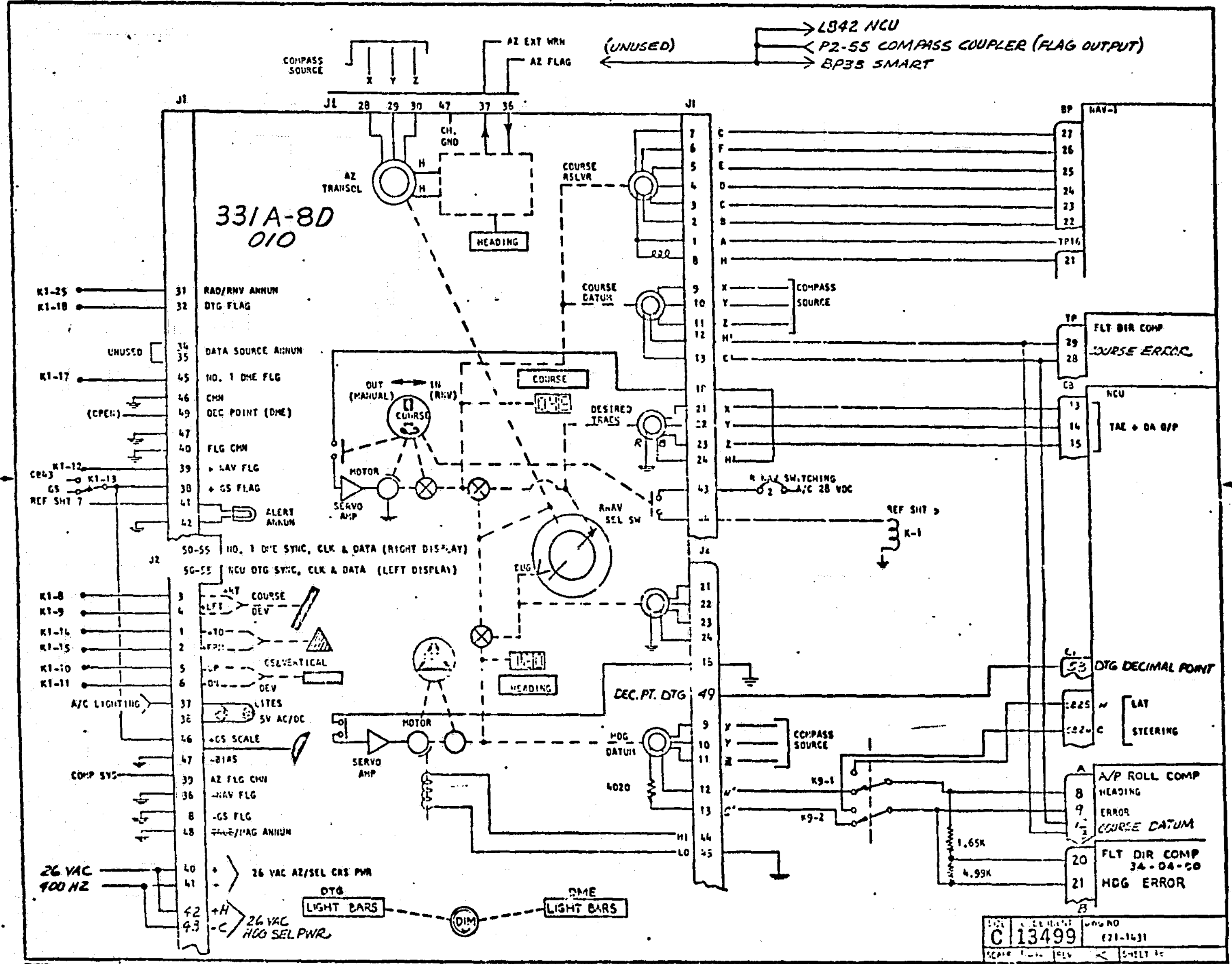
RNAVØ2

SIZE	CODE IDENT	DWG NO
C	13499	621-1431
SCALE	REV	SHEET 14-1



RNAV, Ø 2

SIZE	CODE IDENT	DWG NO.
C	13499	621-1431
SCALE NONE	REV A	SHEET 15



331A-8D
010
COMPASS SOURCE
AZ EXT WRN
AZ FLAG
(UNUSED)
L842 NCU
P2-55 COMPASS COUPLER (FLAG OUTPUT)
BP35 SMART
AZ TRANSOL
HEADING
COURSE RSLVR
COURSE DATUM
NAV-1
FLT DIR COMP
COURSE ERROR
NCU
TAE + DA O/P
RAD/RNV ANNUN
DTG FLAG
DATA SOURCE ANNUN
NO. 1 DME FLG
DEC POINT (DME)
FLG CMN
+ NAV FLG
+ GS FLAG
ALERT ANNUN
COURSE
DESIRED TRACK
MOTOR
SERVO AMP
RNAV SEL SW
RNAV SWITCHING
A/C 28 VDC
REF SHT 7
NO. 1 DME SYNC, CLK & DATA (RIGHT DISPLAY)
NCU DTG SYNC, CLK & DATA (LEFT DISPLAY)
COURSE DEV
GS/VERTICAL DEV
LITES 5V AC/DC
+GS SCALE
BIAS
AZ FLG CMN
-NAV FLG
-GS FLG
A/C LIGHTING
COMP SYS
26 VAC 400 HZ
26 VAC AZ/SEL CRS PWR
26 VAC HDG SEL PWR
DTG LIGHT BARS
DIM
DME LIGHT BARS
DEC. PT. DTG
HDG DATUM
DTG DECIMAL POINT
LAT STEERING
A/P ROLL COMP
HEADING ERROR
COURSE DATUM
FLT DIR COMP 34-04-00
HDG ERROR
1.65K
4.99K
K9-1
K9-2
C
13499

APPENDIX 2

TWO-SEGMENT DIGITAL COMPUTER SYSTEM FUNCTIONAL DESCRIPTION

FUNCTIONAL DESCRIPTION
OF THE
NASA - AMES
NOISE ABATEMENT
2-SEGMENT DIGITAL COMPUTER SYSTEM

REVISION 1

28 SEPTEMBER 1973

COLLINS RADIO COMPANY

CEDAR RAPIDS, IOWA

1.0 INTRODUCTION

This document describes both the components and the operation of the retrofit kit which Collins will supply to meet the requirement for an aircraft digital computer system which will enable noise abatement approaches to be made into airports equipped with a DME which is co-located with the ILS glideslope facility.

2.0 GENERAL SYSTEM DESCRIPTION

The proposed noise abatement retrofit kit, in conjunction with existing aircraft avionics, will permit noise abatement approaches to be made to runways which are ILS-equipped and which have a DME which is colocated with the glideslope facility and paired in frequency with that facility. The system will provide both vertical deviation and vertical steering signals for the flight director and autopilot.

The system interfaces only with the pilot's sensors and displays, the copilot's sensors and displays operating in their normal manner. In the event that the noise abatement approach system is not engaged, the pilot will have available to him all of his normal flight director and autopilot functions. Availability of these functions is dependent only upon the switch/relay unit of the retrofit kit, and all other elements of the kit may be removed without affecting them. A block diagram of the system is shown in Figure 2-1.

2.1 Retrofit Kit Components

The equipment which will be added to the aircraft as part of this system includes units and functions which will ultimately permit the system to be configured to provide full three-dimensional RNAV capability and RNAV/ILS noise abatement approach capability.

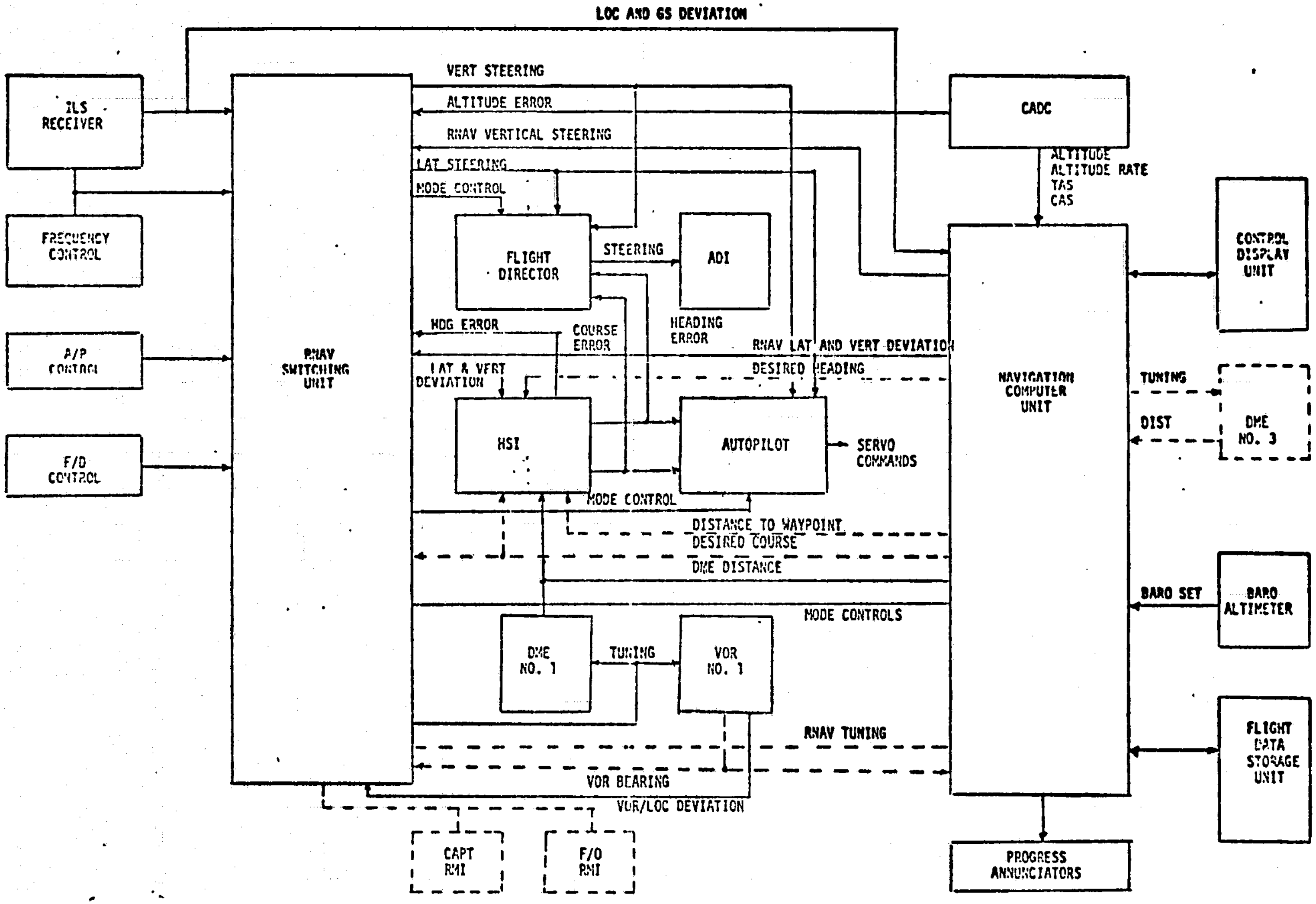


FIGURE 2-1

2-SEGMENT DIGITAL COMPUTER SYSTEM

1. 8564B-2X Navigation Computer Unit (NCU)

The NCU includes the general purpose digital computer which performs the vertical steering and deviation calculations, and the aircraft systems coupler (ASC), which provides the I/O conversion between the digital computer and the multiple analog and digital aircraft sensors and displays.

The NCU has the following features:

a. Data words of 32 bits, plus parity bit.

b. 16,384 word core memory.

c. Half-word (16 bit) instruction format.

d. Instruction set of 78 instructions with direct, lateral, indexed, and indirect addressing.

e. Sixteen accumulator/index registers implemented as 60 ns access time scratch pad memory.

f. Program control of I/O operations, providing efficient memory utilization, realistic reversionary modes, and subsystem isolation.

g. Buffered aircraft systems interfaces, with monitoring of sensor validity signals and of output conversions.

h. Real time system executive control, providing efficient allocation of processing time.

The NCU utilizes 390 watts of 400 Hz, single-phase power, and is housed in a 1 ATR long package. It has a maximum weight of 44 pounds and requires 250 lbs/hr of forced air cooling.

2. 813H-1C Control Display Unit (CDU)

The CDU provides the CRT display and control interface between the pilot and the NCU. Via this unit, the pilot assembles his flight plan and is informed as to system status, flight progress and performance. (Limited data entry for this program.)

The CDU provides a CRT display of 6 label lines, 6 data lines, and a scratchpad line with 16 characters per line. Data displayed on the label and data lines originates in the NCU. The scratchpad line displays data entered by the pilot via the keyboard. This data may then be modified or transferred to the computer and/or data lines (via the computer) by using the various line select or special function keys.

The keyboard provides full alphanumeric data capability. Operational use of the CDU is covered in the following sections. The CRT display is updated by the NCU three times a second, while a local refresh memory updates the display 88 times per second to eliminate flicker. Both manual and automatic brightness control is provided, and the display is legible in an ambient light level of 10,000 foot candles.

The unit is shaped to fit the DC-8-61 pedestal, and has a front panel which is 5.75 inches wide and 9.0 inches high.

The maximum weight is 18 pounds, and the unit uses 125 watts of 400 Hz single-phase power. An internal blower provides cooling in free-flow cockpit air.

3. 8848D-2 Flight Data Storage Unit (FDSU) and 7520A-1 Magnetic Tape Unit (MTU)

The FDSU and its replaceable tape cartridge provide the bulk data storage and transfer mechanism for the system. The computer diagnostics and operational programs are stored on the cartridge.

The FDSU provides a 2-motor, reel drive, constant reel speed tape drive system under control of the NCU. Data is transferred to the NCU at 23.7 kHz. Write as well as playback capability is provided by the FDSU, however, only the playback capability will be used in the proposed system.

The MTU is a pocket-sized sealed cartridge containing 160 feet of 1 mil computer-grade tape on which can be stored 12 million bits of data. The cartridge also contains the tape heads and the center and end of tape sensors. The tape is always rewound to center after data is accessed in order to minimize data access time. The MTU can be quickly installed and removed from the FDSU without the use of tools.

The FDSU is a 1/2 ATR short unit weighing 14.6 pounds, and is convection cooled. It requires 19.5 watts of 400 Hz single-phase power.

4. 161E-12 RNAV Switching Unit

The RNAV switching unit is basically an assembly of relays which transfers signal and control circuits between the normal aircraft sensors, displays, flight director and autopilot computers, and the elements of the RNAV system.

The unit is housed in a 1/4 ATR short low case, weighs four pounds, has a maximum power dissipation of 25 watts, and is convection cooled. It utilizes 28 VDC power.

5. Diode Isolation Unit

The diode isolation unit is a small unit housing isolation diodes for radio manual/automatic tuning lines and resistors associated with miscellaneous signal lines. It requires no power.

2.2 Modification to Standard Avionics

To permit full utilization of the RNAV system, certain modifications to the standard avionic units are required as follows:

1. VOR Receiver (Modification not required for this system)

The pilot's VOR receiver will be modified to provide sine and cosine station bearing outputs for use by the RNAV computer. Existing functions will not be affected.

2. DME

The pilot's existing DME will be replaced with an ARINC 568 DME, to permit the RNAV computer to tune it with ARINC 2X5 control lines, and to provide a distance readout compatible with the RNAV computer input. (In this program, the RNAV computer will not tune the DME.) In addition, to enable the RNAV system to obtain DME-DME position fixes, an additional DME will be added to the pilot's side of the aircraft. This unit would not be operable when the RNAV system is off. (The additional DME is not needed for this program.)

3. HSI

The pilot's existing HSI will be replaced with a new unit having the following additional capability:

a. ARINC 6-wire digital input to accept DME or RNAV distance data. (DME only used in this system.)

b. A course arrow drive system which permits either local or remote control of its position. (Local only used in this system.)

c. A heading bug drive system which permits either local or remote control of its position. (Local only used in this system.)

4. Air Data System

The air data system will be modified to provide the RNAV computer with true air speed, indicated air speed, barometric altitude referenced to 29.92 in. of Hg and baro altitude rate.

5. Baro Altitude

A potentiometer pick-off will be provided on the pilot's altimeter to indicate the baro-setting to the RNAV computer.

6. ILS Receiver

Since the present navigation receiver must operate in the VOR mode during the approach, an independent ILS receiver will be added to provide the localizer and glideslope signals. This unit will also operate as the glideslope receiver in the normal or non-RNAV mode. (The glideslope only will be utilized in this system.)

7. Flight Director Controller

An RNAV mode position will be added to the pilot's flight director controller.

8. Autopilot Controller

The AUX NAV position on the autopilot controller, not presently used, will be used as the RNAV mode for the autopilot.

9. Progress Annunciators

These annunciators have been added to provide visual indication of proper flight director and autopilot mode selection and of the flight progress during approach operations. They include:

a. RNAV ARM/CAPTURE Annunciators - Provide separate annunciators for the flight director and autopilot of proper mode selection and commencement of terminal area operations. (Not used in this system.)

b. UPPER ARM/CAPTURE Annunciators - Provide arm and capture annunciation of the upper segment flight path when the system is operating.

c. LOWER ARM/CAPTURE Annunciators - Provide arm and capture annunciation of the glideslope segment of the approach.

d. GO AROUND Annunciators (flight director only) - Provide an indication that the GO AROUND mode has been selected.

3.0 ENROUTE OPERATIONS

The course selector on the pilot's HSI will ultimately function as the switch to engage the RNAV system. For operation of this interim system, the course selector should always be pulled out, in which position the course selector may be set to the desired course.

When power is applied to the system, the CDU will display the page shown in Figure 3-1, and the system can be engaged or disengaged by pressing the top line select key. When the system is off, the top line will read 2-SEGMENT OFF.

When the system is off, the operation of the flight director and autopilot will be the same as in the unmodified aircraft.

4.0 APPROACH OPERATIONS

In order to use the system for a two-segment approach, the pilot must enter the correct field elevation and switch the system ON. The field elevation is entered by using the keyboard to write the elevation in the scratchpad and then pressing the line select key adjacent to the elevation data line to transfer the data to that line. This can be done only when the top line on the CDU reads 2-SEGMENT OFF.

When the system is switched ON by using the top line select key, the UPPER annunciators will go to amber if the following conditions are met and maintained.

a. Pilot's frequency controller tuned to an ILS frequency.

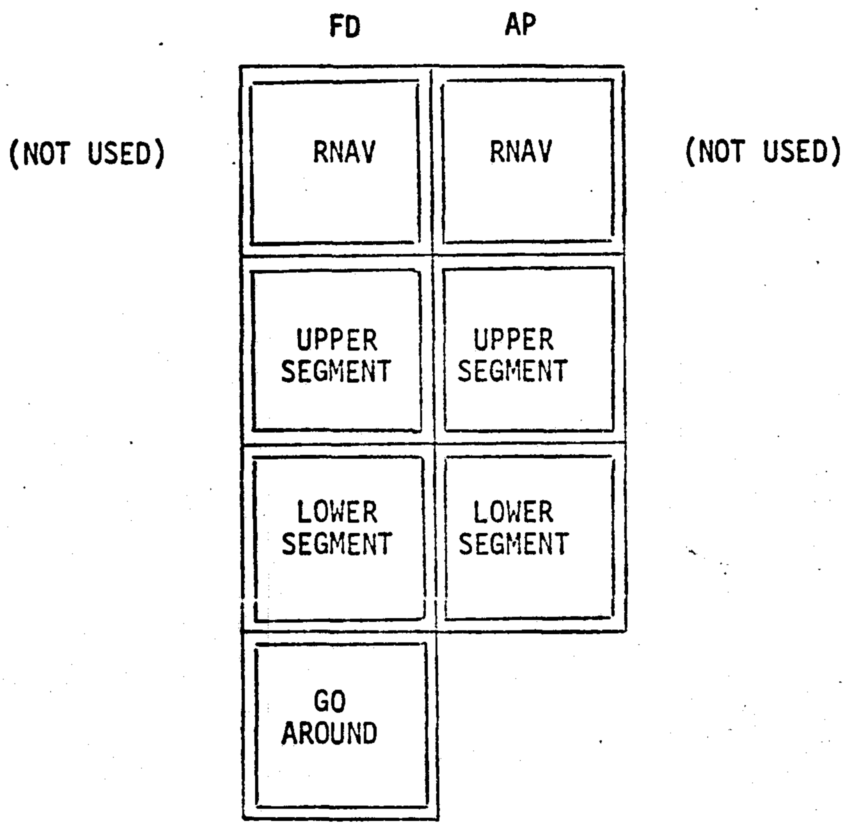
b. DME input valid.

c. CADC input valid.

d. Baroset monitor valid.

e. Computer self-tests valid.

The FD lights will operate only if the FD controller is set to the RNAV position and the AP lights will operate only if the AP controller is set to the AUX NAV position.



AMBER (ARM) AND GREEN (CAPTURE)

GO AROUND GREEN ONLY

FIGURE 4-1

INSTRUMENT PANEL ANNUNCIATORS

The AP controller must be set to VERT SPEED prior to UPPER green. The HSI vertical deviation needle will be displaying deviation from the upper segment during upper amber.

At the computed upper segment capture point, the UPPER annunciator will go to green if the system was previously in the upper amber mode. UPPER GREEN will not occur if the aircraft is above the upper segment or is flying away from the DME.

Throughout the approach, lateral steering will be provided by means of standard flight director and autopilot modes (heading or localizer) and raw glideslope and localizer signals will be displayed on the ADI. The HSI lateral deviation needle will display raw localizer deviation. The selection of RNAV on the flight director or AUX NAV on the autopilot will place the respective systems in the VOR/LOC lateral mode.

At UPPER GREEN, the HSI vertical deviation needle will display deviation from the upper segment with a sensitivity of 250 feet per dot, and the FD and AP steering will be to the computed vertical flight path.

After UPPER GREEN, the AP vertical speed wheel will automatically track the aircraft's vertical speed and the vertical speed override function will not be available.

After UPPER GREEN, LOWER amber will come on if the DME distance is less than 5 nautical miles, and the glideslope, DME, and CADC signals are valid.

LOWER green will occur once the glideslope capture starts, at which time the HSI vertical deviation indicator will once again display raw glideslope deviation.

If LOWER green does not occur before the altitude decreases to a value of the intercept altitude (IHT) plus 50 feet (above field evaluation), or before the DME reaches a value of (IHT + 50)/6076 tan GS nautical miles of less, or before the glideslope deviation reaches a value of less than one-half dot high, the autopilot will be disengaged, the steering biased from view, and the vertical deviation flagged.

If go-around is selected, all progress annunciators will be extinguished and the system will be switched to the OFF state

4.1 Failure and Recovery Modes

During enroute operations, the CDU will normally read 2-SEGMENT OFF, plus the last field elevation and engineering data entered into the system. The NCU will continually run self-tests when power is on the system and if a fault is detected, a MASTER WARN will occur and the system cannot be turned on.

If a power interrupt occurs for less than two seconds, the system will continue to operate. If the interruption is longer, the computer will shut down. When power is restored, the system will revert to the 2-SEGMENT OFF mode. The system can then be turned on, but the annunciation and system operation will not start until the conditions for upper amber are met.

In the upper amber mode, the annunciation will be lost if the frequency controller is moved to a non-ILS frequency, if the DME, CADC or baroset data becomes invalid, if an NCU master warn occurs, or if the respective FD or AP controller is moved out of RNAV or AUX NAV position.

After upper green and prior to glideslope capture, the system continuously examines the validity of the computer, the CADC signals, the baroset input, and the DME. Loss of any of these will cause the autopilot to be disengaged, the pitch steering to be driven from view, and the HSI vertical deviation to be flagged.

All annunciators will be extinguished. After LOWER amber, glide-slope validity will also be required.

5.0 ENTRY OF ENGINEERING DATA

The next to the bottom data line on the CDU will display the approach profile parameters: the upper segment angle (US<), the altitude at which the upper segment and the glideslope intercept (INT), and the angle of the glideslope beam (GS<).

The parameters may be changed at any time the top line on the CDU reads 2-SEGMENT OFF by entering the desired values in the scratch-pad (with the slash marks to separate the three data fields) and then pressing the line select key adjacent to the parameter data line. If the parameters are not within the allowable ranges, the data will not be accepted by the computer and an ERROR message will be displayed on the CDU. The ERROR message can be deleted by clearing the erroneous data from the scratchpad.

The acceptable data ranges are:

a. Glideslope angle: NMT 3 dgreees, NLT 2.5 degrees

b. Intercept altitude: NMT 999 feet, NLT 350 feet

c. Upper segment angle: NMT 6.5 degrees, NLT 4.0 degrees

6.0 RNAV SWITCH UNIT FUNCTIONS

In addition to the switching performed within the NCU, both logic and function switching is performed by the RNAV switch unit. A brief description of the major functions is provided in the following section.

6.1 Annunciator Switching

A block diagram of the annunciator switching is shown in Figure 6-1. The flight director and autopilot annunciators are individually controlled by the closure of their own mode validity relay contacts. The mode relays (see Figures 6-2 and 6-3) are dependent upon the selection of an ILS frequency, VNAV and MASTER WARN validity signals from the NCU, and selection of the RNAV or AUX NAV modes on the respective flight director or autopilot controllers.

For any of the annunciators to be illuminated, the NCU must supply valid VNAV and MASTER WARN signals to the RNAV switch, and the pilot's frequency control must be on an ILS frequency. The flight director and autopilot annunciators are then individually controlled by selection of the RNAV or AUX NAV positions on their respective controllers.

6.2 FD Mode Control

The RNAV switch functions involving the flight director are shown in Figure 6-2.

Selection of the RNAV position on the FD controller will place the FD computer in the VOR/LOC mode.

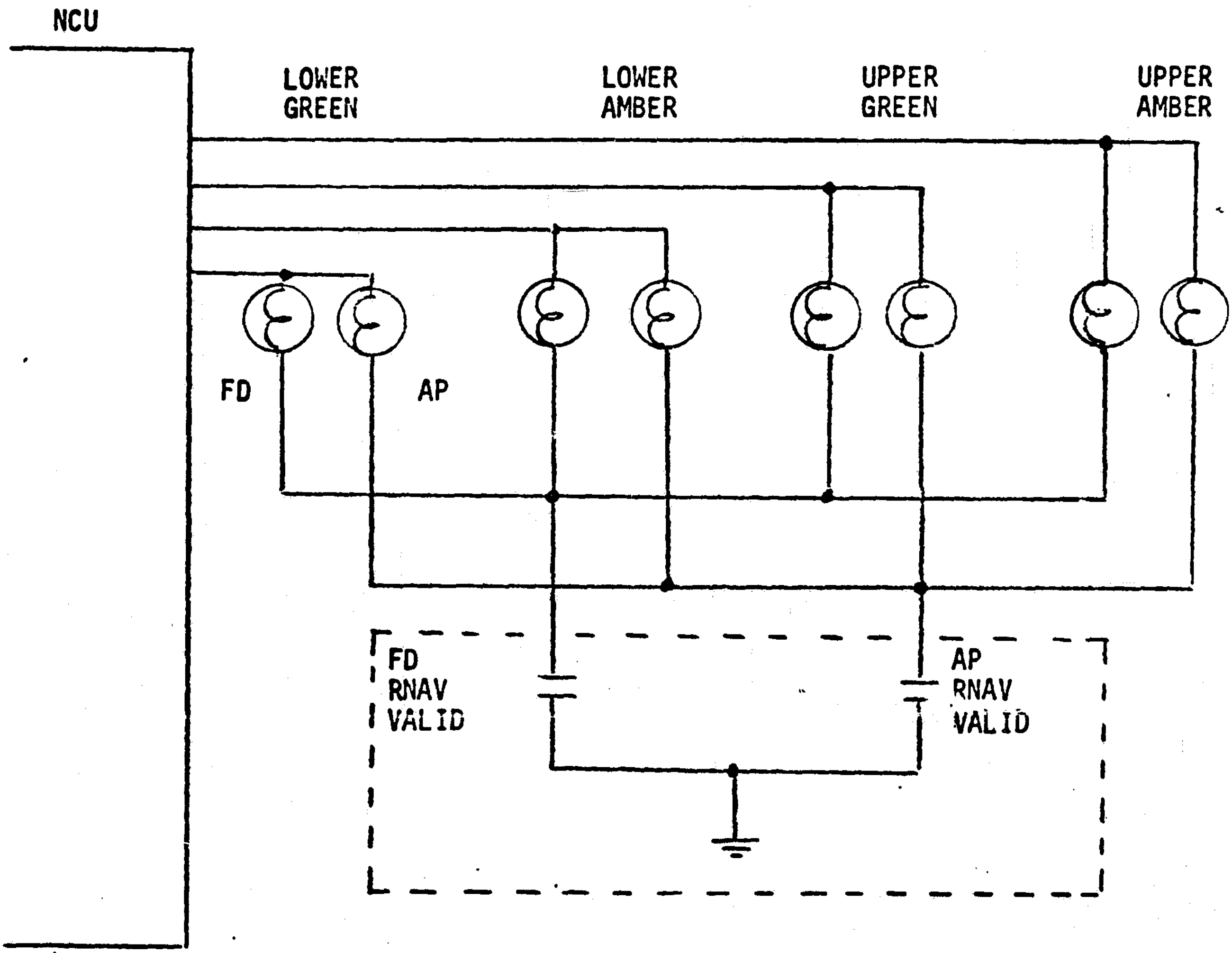


FIGURE 6-1

ANNUNCIATOR SWITCHING

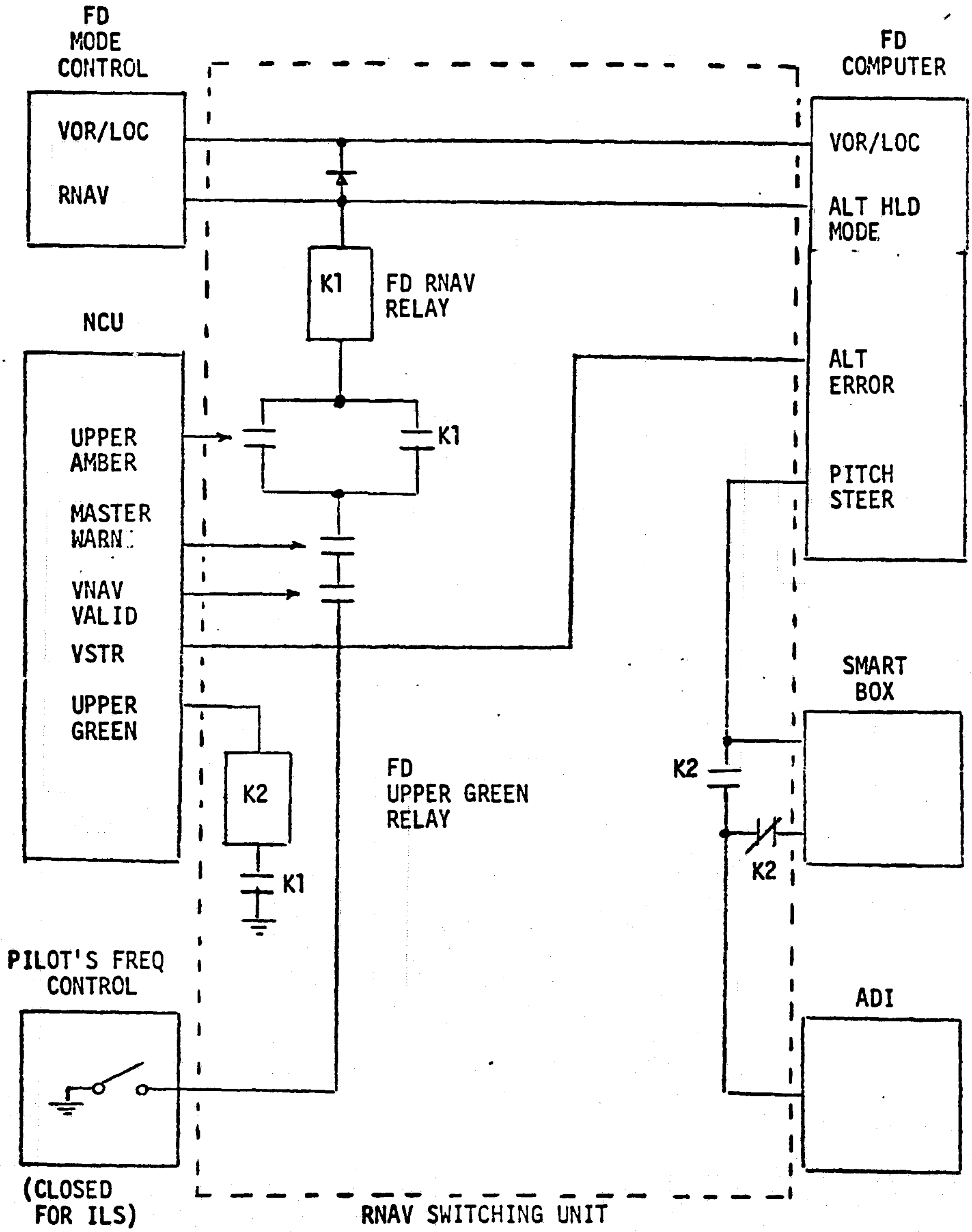


FIGURE 6-2

FD MODE CONTROL

If the VNAV, MASTER WARN, and UPPER AMBER validity signals are present from the NCU, and if an ILS frequency is tuned, the FD RNAV relay will pull in and lock out the requirements for UPPER AMBER through its own contacts. This circuit, in conjunction with NCU logic which always requires UPPER AMBER before any other annunciation, prevents the system from being engaged in a status other than UPPER AMBER, but keeps it engaged thereafter.

When UPPER GREEN occurs, K2 will be energized (if the FD mode is valid) and will bypass the SMART box to place the FD pitch steering signal on the ADI. (The pitch bar is normally biased out of view by the SMART box when the flight director is in the VOR/LOC mode.)

In the event that any of the mode validity signals are lost, K2 will be de-energized and return control of the pitch bar to the SMART box, which will bias it from view.

6.3 AP Mode Control

A block diagram of the RNAV switch function involving the autopilot is shown in Figure 6-3.

Selection of the AUX NAV mode on the autopilot controller will place the roll computer in the LOC/VOR mode and cause K4 to energize. This will remove the shunt on the MASTER WARN, ILS, and VNAV validity contacts in the disengage circuit, and will also permit voltage to be applied to K3 if the pitch channel is engaged and ILS, VNAV, MASTER WARN, and UPPER AMBER are valid. When K-3 energizes it will lock out the UPPER AMBER requirement.

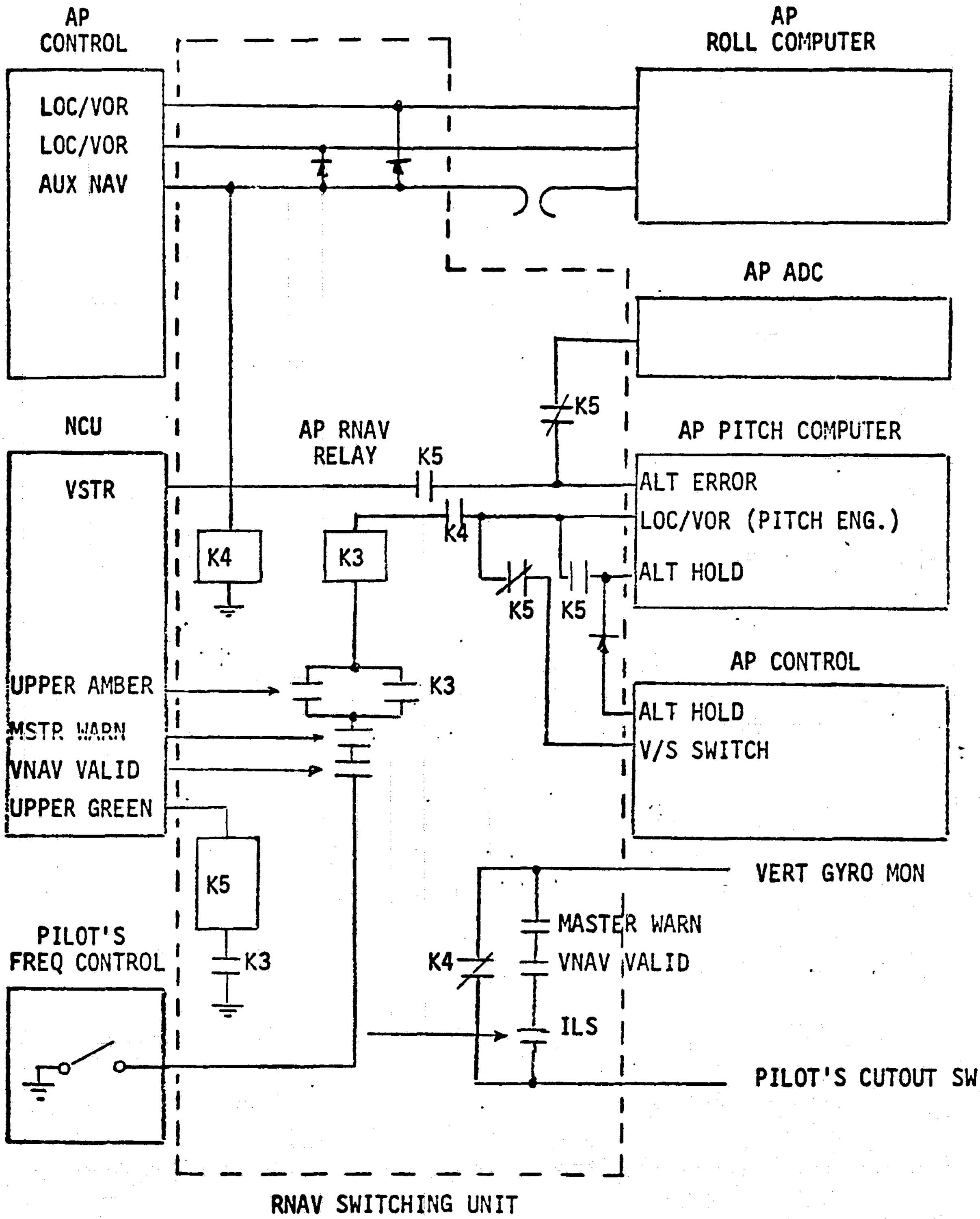


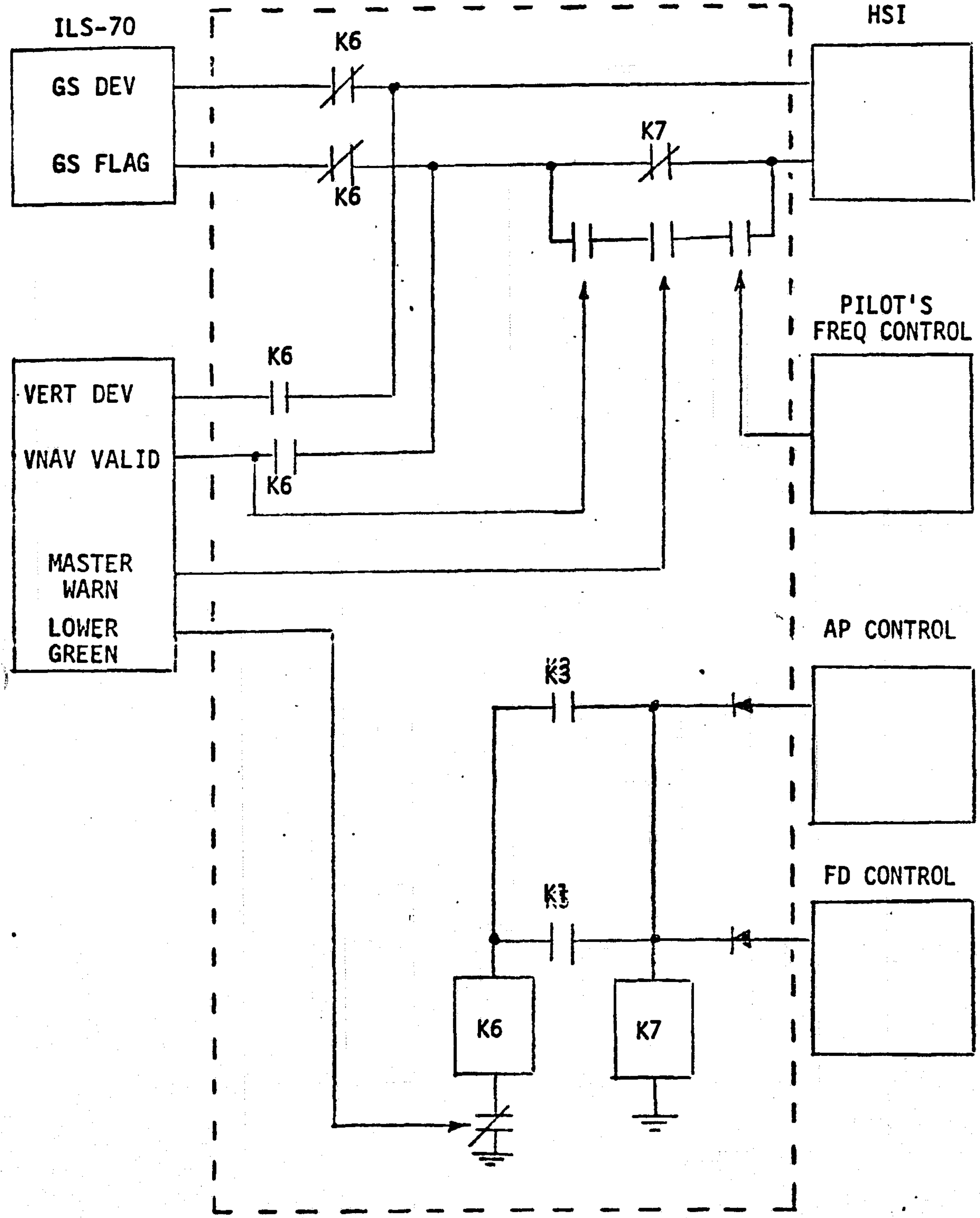
FIGURE 6-3

AP MODE CONTROL

When UPPER GREEN occurs, K-5 will pull in, transferring the pitch computer altitude error input from the air data computer to the NCU vertical steering output, and will also remove voltage from the V/S switches in the AP controller and apply voltage to the pitch computer to place it in the altitude hold mode. The removal of V/S switch voltage will cause the speed wheel clutch to engage, so that it will track the aircraft's vertical speed.

6.4 HSI Deviation Switching

A block diagram of the RNAV switch unit functions involving the HSI are shown in Figure 6-4. When either the FD or AP controller is placed in the RNAV or AUX NAV position, K7 is energized, which makes the HSI glideslope flag dependent upon MASTER WARN, VNAV validity, and ILS tuning. Whenever K1 or K3 closes, signifying a valid UPPER amber condition, K6 will be energized, transferring the HSI glideslope deviation and flag inputs from the ILS-70 to the outputs from the NCU. When LOWER GREEN occurs, K6 will be released, restoring the raw glide-slope signals to the HSI.



RNAV SWITCHING UNIT

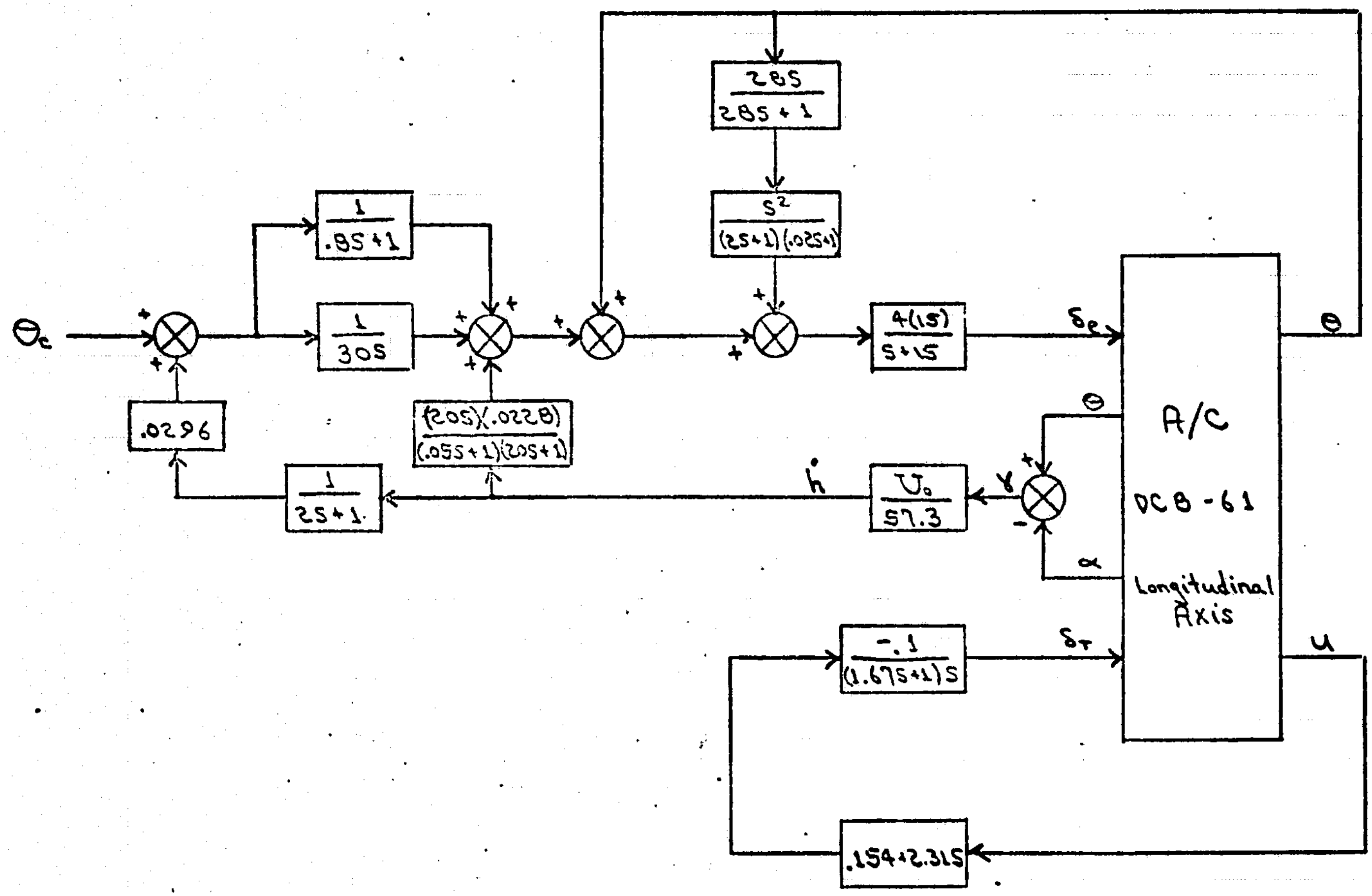
FIGURE 6-4
HSI SWITCHING

APPENDIX 3

DC-8-61 AND SP-30AL LATERAL AND LONGITUDINAL SIMULATION

This appendix documents the DC-8-61 longitudinal and lateral axis simulation as implemented on the EAI 680 analog computer. Figures 1 through 4 show thw block diagrams and analog circuit board diagrams for the pitch and roll axes.

Appendix A contains the basic aircraft equations. Appendix B contains the worksheets used to determine the transfer functions for the autopilot roll loop, based on data supplied by UA. Appendix C contains data on the pitch loop, and Appendix D data on the yaw damper. Appendix E contains the spoiler/aileron data.



DC 8-61 Pitch Axis Block Diagram

Figure 1

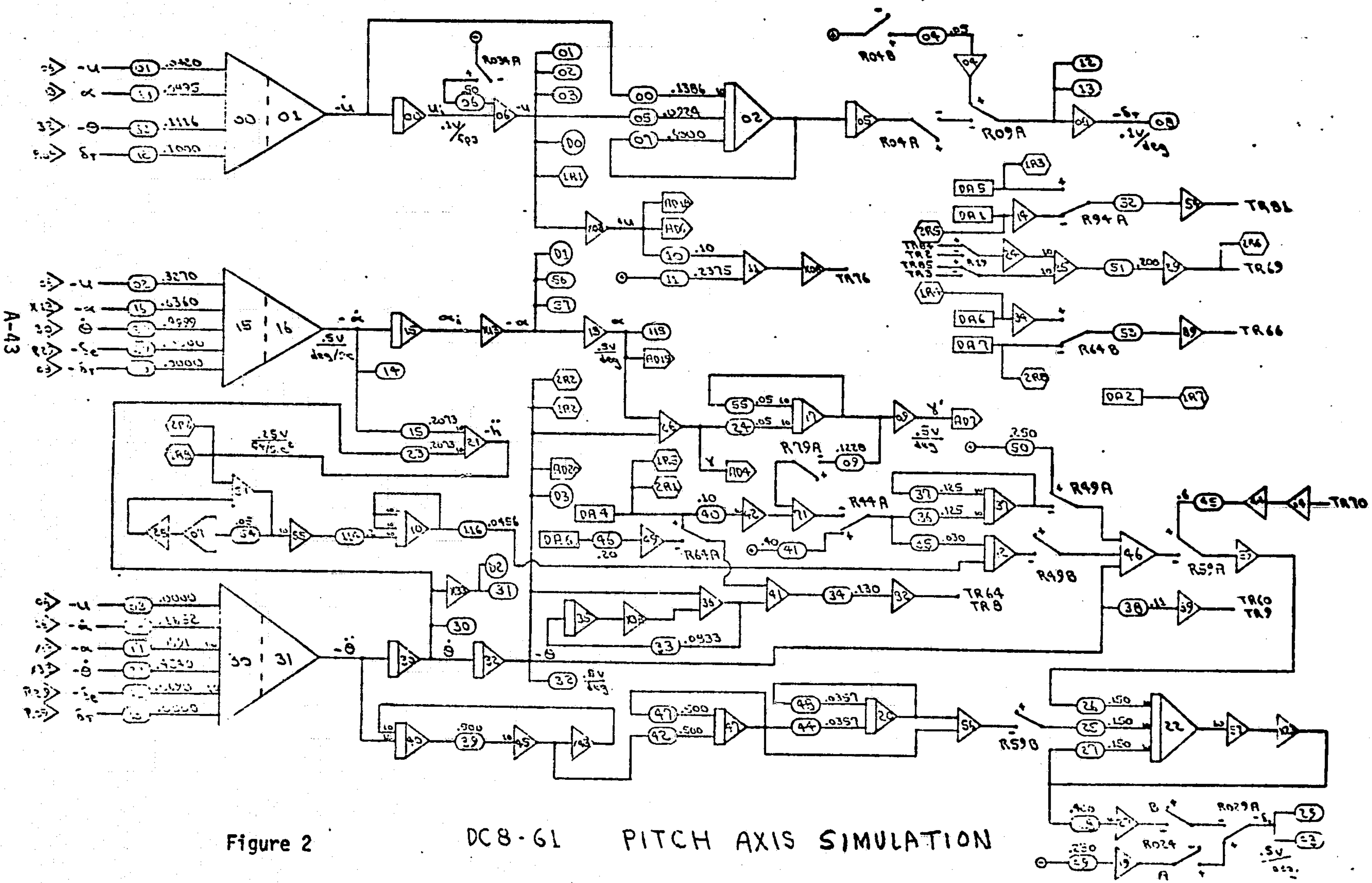
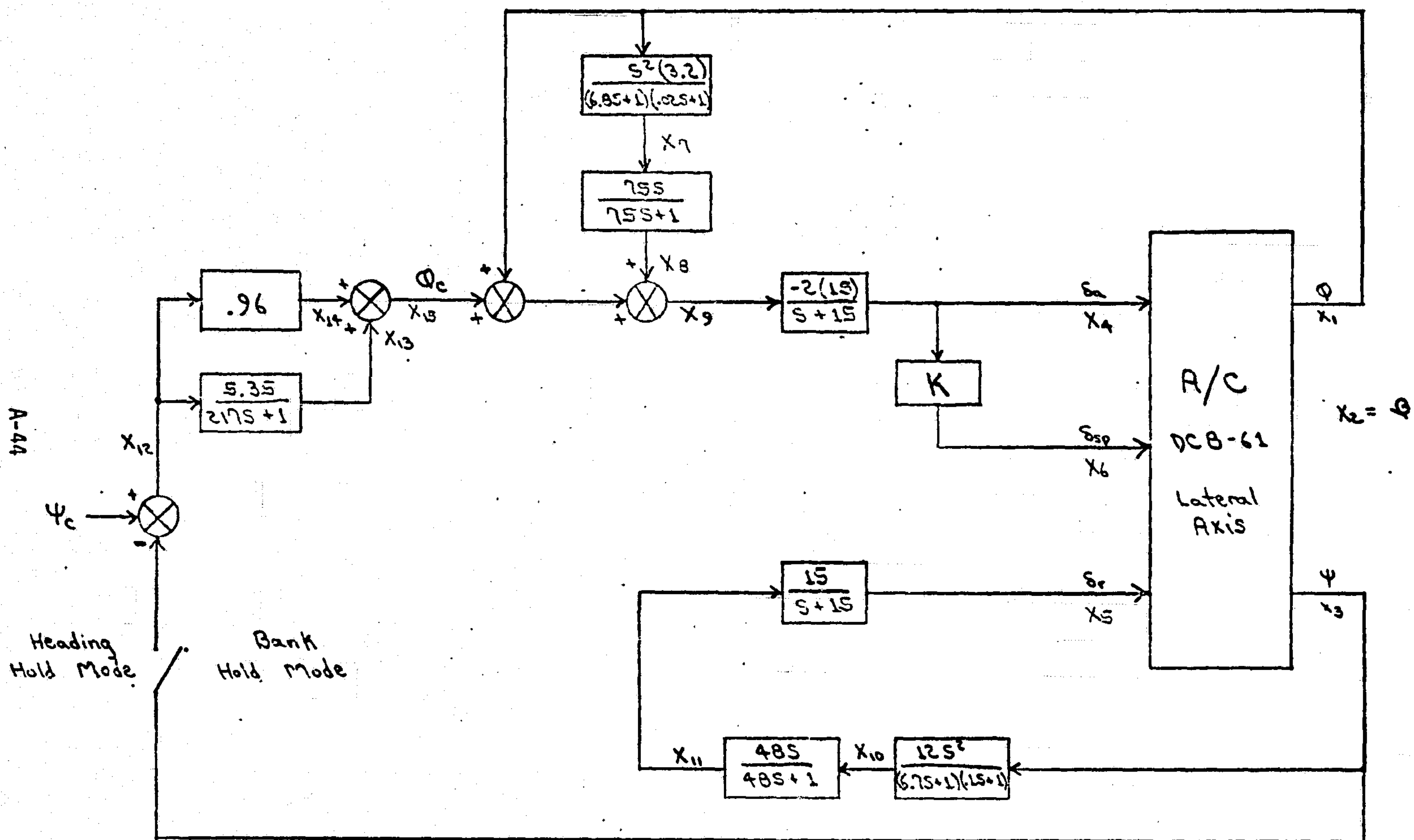


Figure 2 DC8-61 PITCH AXIS SIMULATION



DC8-61 Roll Axis Block Diagram

Figure 3

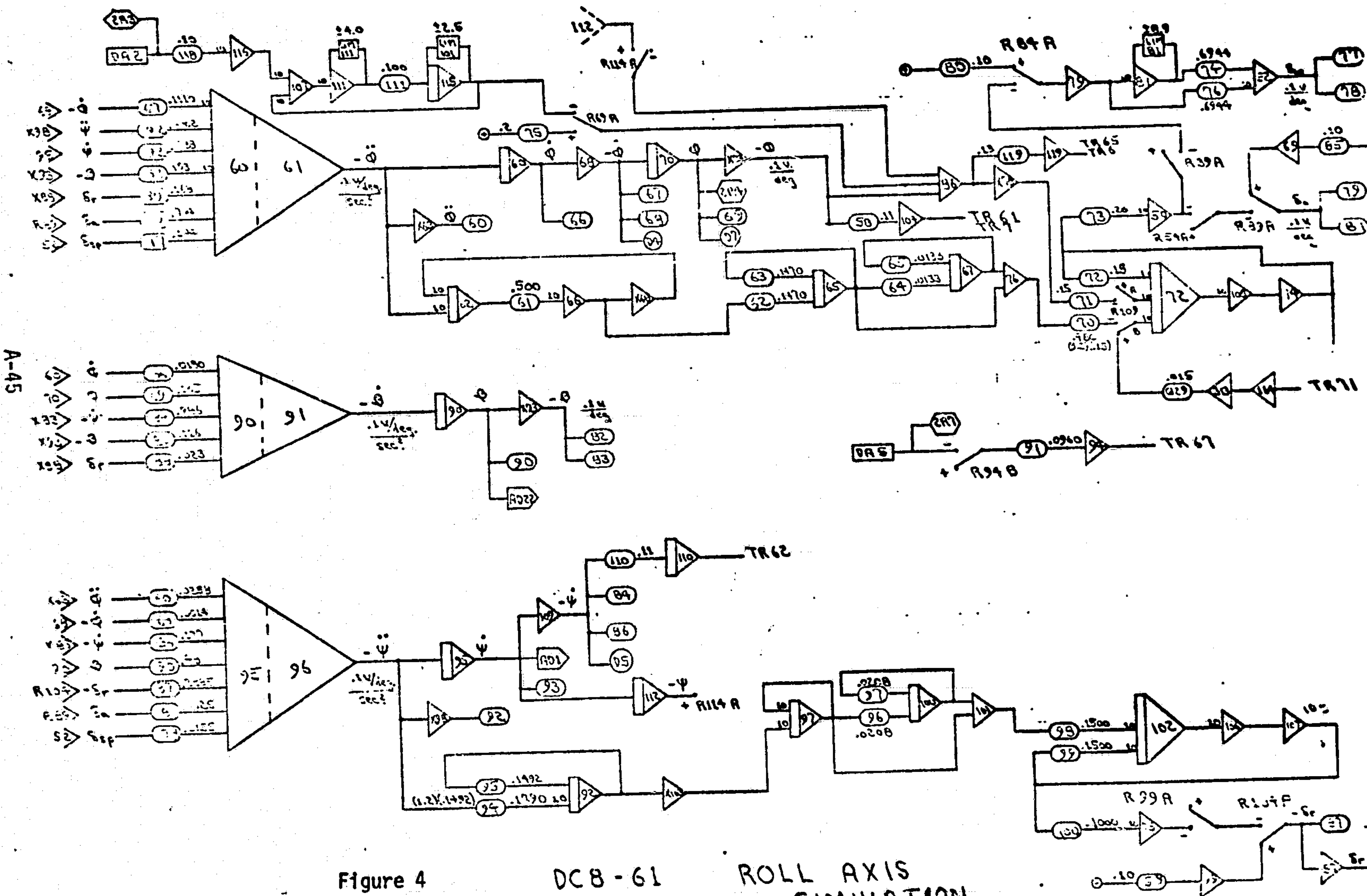


Figure 4 DC8 - 61 ROLL AXIS SIMULATION

APPENDIX A

DC8-61 AIRCRAFT EQUATIONS

A-47

V equivalent (knots)	V true = U ft./sec.	Mach no	Altitude K feet	Weight (pounds)	q (lbs./ft.²) dynamic pressure	Mass (slugs)	I_y pitch inertia (slug ft.²)	Flaps				Flight condition
												I
												II
												III
	238	.213	0	200,000				50°				IV
												V
												VI
												VII
												VIII

AIRFRAME TRANSFER FUNCTIONS —

Flt. cond.	f(s)	s^4	s^3	s^2	s^1	s^0	f(s)	s^4	s^3	s^2	s^1	s^0
IV	D.N.	1.000	1.292	1.049	.0545	.0252						
	$N_u - \delta_e$				.2141	.2449						
	$N_\alpha - \delta_e$			-.6900	-.0290	-.0252						
	$N_\theta - \delta_e$		-.6900	-.4622	-.0236	0.0						

$$\dot{U} = \frac{Sq}{mU} C_{x_u} u + \frac{Sqc}{2mU}\frac{1}{57.3} C_{x_{\dot\alpha}} \dot\alpha + \frac{Sq}{m}\frac{1}{57.3} C_{x_\alpha}\alpha + \frac{Sqc}{2mU}\frac{1}{57.3} C_{x_q}\dot\theta + \left[\text{[illegible]}\right]\theta + \frac{Sq}{m}\frac{1}{57.3} C_{x_{\delta_e}}\delta_e$$

Longitudinal force	P48	Q43 Q40	P41(X) Q42(X)	P45(X) P47(X)	P46 (X)	Q39 Q38
Sign	−	+ or −	+ or −	+ or −	−	+ or −
I						
II						
III						
IV	-.042		.2477		-.558	1.0
V						
VI						
VII						
VIII						

$$f_1 = \left(1 - \frac{Sqc}{2mU^2} C_{z_{\dot\alpha}}\right) \cong 1.0 \qquad f_2 = \left(1 + \frac{Sqc}{2mU^2} C_{z_q}\right) \cong 1.0$$

$$\dot\alpha = \frac{Sq}{mU^2 f_1} 57.3\, C_{z_u} u + \frac{Sq}{mU f_1} C_{z_\alpha}\alpha + \frac{f_2}{f_1}\dot\theta + \left[\frac{g}{U f_1}(\sin\theta_0)\right]\theta + \frac{Sq}{mU f_1} C_{z_{\delta_e}}\delta_e$$

Vertical force	Q44	P42 (X)	Q45	Q46(X)	P38	
Sign	−	−	+	+ or −	−	
I						
II						
III	-.0654	-.635	1.0			
IV						
V						
VI						
VII						
VIII						

$$\ddot\theta = \frac{Sqc}{I_y}\frac{57.3}{U} C_{m_u} u + \frac{Sqc^2}{2UI_y} C_{m_{\dot\alpha}}\dot\alpha + \frac{Sqc}{I_y} C_{m_\alpha}\alpha + \frac{Sqc^2}{2UI_y} C_{m_q}\dot\theta + \frac{Sqc}{I_y} C_{m_{\delta_e}}\delta_e$$

Pitch moment	Q49 P49	P43(X) P40(X)	Q41 (20)	Q47 (X)	Q36 (X)	
Sign	+ or −	+ or −	−	−	−	
I						
II						
III						
IV		-.1652	-.691	-.454	-.69	
V						
VI						
VII						
VIII						

a = a.²

c = a.

Coefficients are based on Douglas memo CL-250-Aero-66-485 dated 19 July, 1966

COLLINS RADIO COMPANY

DC-9(61)

	V EQUIVALENT (knots)	V TRUE = U FT/SEC	MACH NO.	ALTITUDE K FEET	WEIGHT (pounds)	$S\rho U^2/2$ DYNAMIC PRESSURE	MASS (slugs)	I_x ROLL INERTIA (slug ft.²)	I_z YAW INERTIA (slug ft.²)	I_{xz} INERTIAL COUPLING (slug ft.²)	FLAPS	FLIGHT CONDITION
												I
												II
												III
		233	.213	0	200,000						50°	IV
												V
												VI
												VII
												VIII

AIRFRAME TRANSFER FUNCTIONS –

FLT. COND.	f(s)	s^4	s^3	s^2	s^1	s	f(s)	s^4	s^3	s^2	s^1	s
I	DEN.						DEN.					
	$N_\phi - \delta_a$						$N_\phi - \delta_r$					
	$N_\psi - \delta_a$						$N_\psi - \delta_r$					
	$N_\beta - \delta_a$						$N_\beta - \delta_r$					
II	DEN.						DEN.					
	$N_\phi - \delta_a$						$N_\phi - \delta_r$					
	$N_\psi - \delta_a$						$N_\psi - \delta_r$					
	$N_\beta - \delta_a$						$N_\beta - \delta_r$					
III	DEN.						DEN.					
	$N_\phi - \delta_a$						$N_\phi - \delta_r$					
	$N_\psi - \delta_a$						$N_\psi - \delta_r$					
	$N_\beta - \delta_a$						$N_\beta - \delta_r$					
IV	DEN.	.9977	1.383	.8030	.8067	.0080	DEN.	.9977	1.338	.8030	.8067	.0080
	$N_\phi - \delta_a$		.7242	.2341	.3970	0.0	$N_\phi - \delta_r$		.1420	.1668	.4871	0.0
	$N_\psi - \delta_a$		.0230	.0643	.0022	.0521	$N_\psi - \delta_r$		.2842	.3435	.0324	.0643
	$N_\beta - \delta_a$			.0054	.1041	.0192	$N_\beta - \delta_r$		.0219	.3120	.3472	.0189
V	DEN.						DEN.					
	$N_\phi - \delta_a$						$N_\phi - \delta_r$					
	$N_\psi - \delta_a$						$N_\psi - \delta_r$					
	$N_\beta - \delta_a$						$N_\beta - \delta_r$					
VI	DEN.						DEN.					
	$N_\phi - \delta_a$						$N_\phi - \delta_r$					
	$N_\psi - \delta_a$						$N_\psi - \delta_r$					
	$N_\beta - \delta_a$						$N_\beta - \delta_r$					
VII	DEN.						DEN.					
	$N_\phi - \delta_a$						$N_\phi - \delta_r$					
	$N_\psi - \delta_a$						$N_\psi - \delta_r$					
	$N_\beta - \delta_a$						$N_\beta - \delta_r$					
VIII	DEN.						DEN.					
	$N_\phi - \delta_a$						$N_\phi - \delta_r$					
	$N_\psi - \delta_a$						$N_\psi - \delta_r$					
	$N_\beta - \delta_a$						$N_\beta - \delta_r$					

$$\ddot{\phi} = \frac{S\rho b^2}{2UI_x} C_{l_p} \dot{\phi} + \frac{I_{xz}}{I_x} \ddot{\psi} + \frac{S\rho b^2}{2UI_x} C_{l_r} \dot{\psi} + \frac{S\rho b}{I_x} C_{l_\beta} \beta + \frac{S\rho b}{I_x} C_{l_{\delta_r}} \delta_r + \frac{S\rho b}{I_x} C_{l_{\delta_a}} \delta_a + \frac{S_1 b}{I_x} C_{l_{\delta_{sp}}} \delta_{sp}$$

ROLL MOMENT	P23 (X)	P28 P29	P25 (X)	Q21 (10/X)	Q34 (X)	Q32 (X)	P05
SIGN	−	+ OR −	+	−	+	+	
I							
II							
III							
IV	-1.11	.0902	.588	-1.93	.168	.794	.394
V							
VI							
VII							
VIII							

$$k_1 = \left(1 - \frac{S\rho b}{2mU^2} C_{y_{\dot\beta}}\right) \cong 1.0 \qquad k_2 = \left(\frac{S\rho b}{2mU^2} C_{y_r} - 1\right) \cong -1.0$$

$$\dot{\beta} = \frac{S\rho b}{2mU^2 k_1} C_{y_p} \dot{\phi} + \frac{g}{Uk_1}\left[\cos\theta_o\right]\phi + \frac{k_2}{k_1}\dot{\psi} + \frac{g}{Uk_1}\left[\sin\theta_o\right]\psi + \frac{S\rho}{mUk_1} C_{y_\beta}\beta + \frac{S\rho}{mUk_1} C_{y_{\delta_r}}\delta_r + \frac{S\rho}{mUk_1} C_{y_{\delta_a}}\delta_a$$

SIDE FORCE	Q20 Q22	Q26	P27 (X)	NO POT	Q24	P34 (X)	P32 P31
SIGN	+ OR −	+	−	+	−	+	+ OR −
I							
II							
III							
IV	.01804	.135	-.986		-.116	.023	
V							
VI							
VII							
VIII							

$$\ddot{\psi} = \frac{I_{xz}}{I_z}\ddot{\phi} + \frac{S\rho b^2}{2UI_z} C_{n_p}\dot{\phi} + \frac{S\rho b^2}{2UI_z} C_{n_r}\dot{\psi} + \frac{S\rho b}{I_z} C_{n_\beta}\beta + \frac{S\rho b}{I_z} C_{n_{\delta_r}}\delta_r + \frac{S\rho b}{I_z} C_{n_{\delta_a}}\delta_a + \frac{S_1 b}{I_z} C_{n_{\delta_{sp}}}\delta_{sp}$$

YAW MOMENT	Q29 Q23	P20(X) P22(X)	Q27	P21 (X)	Q33 (X)	P30 Q31	P09
SIGN	+ OR −	+ OR −	−	+	−	+ OR −	
I							
II							
III							
IV	.02582	-.001416	-.177	.48	-.2985	.002506	.01552
V							
VI							
VII							
VIII							

S ft.
b ft.
c.g.

Coefficients are based on Douglas memo CL-250-AERO-56-485 dated 19, July, 1966

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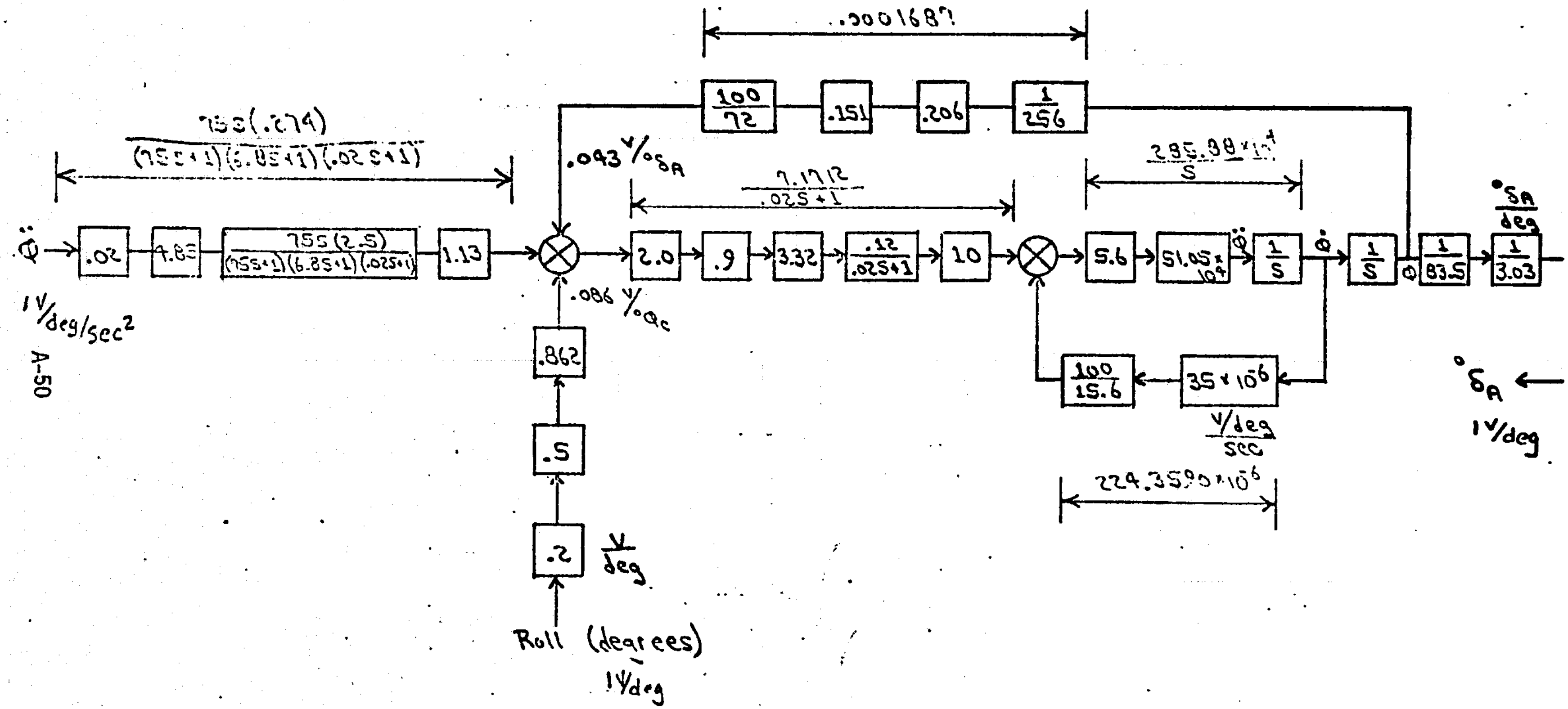
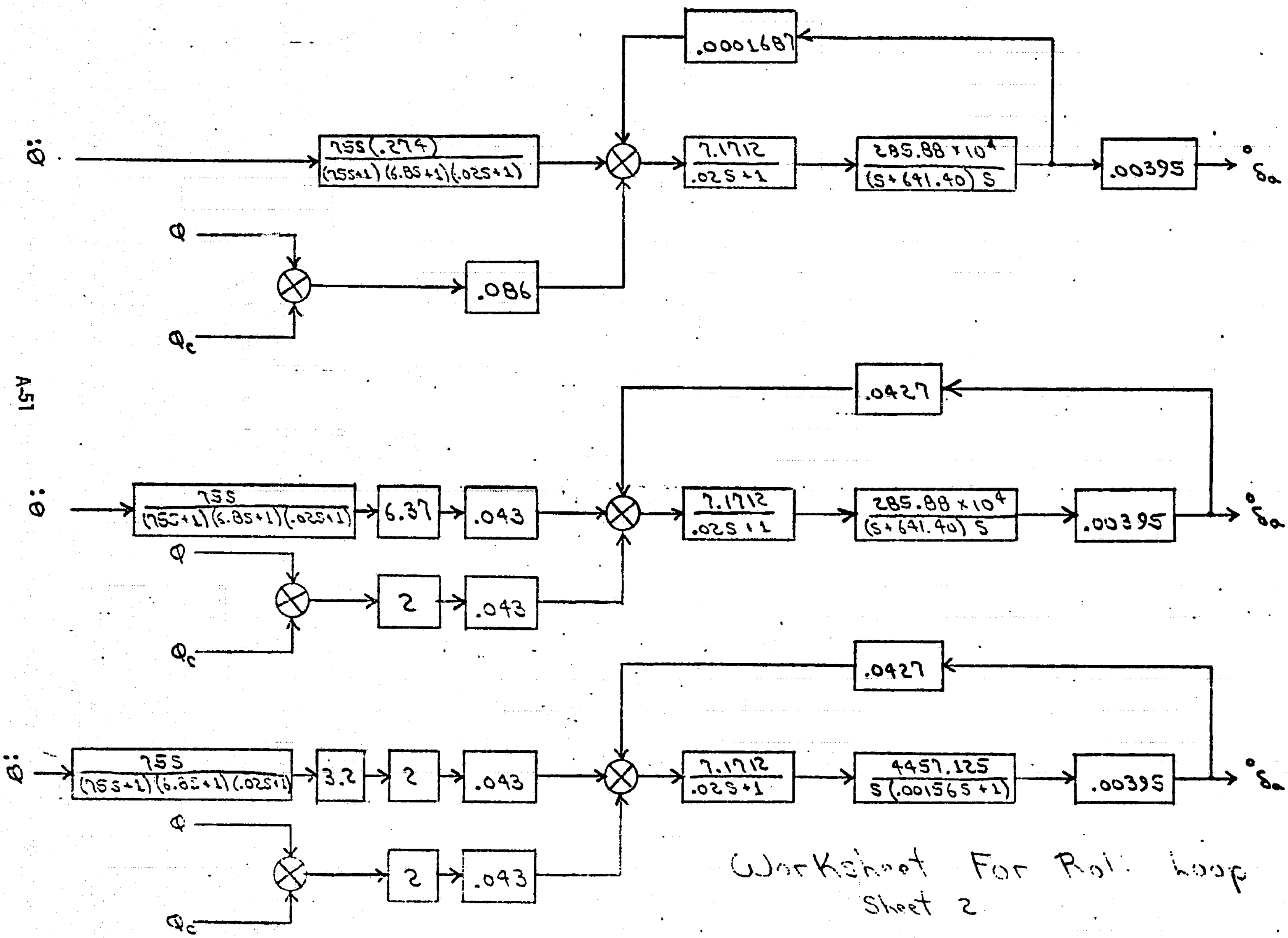
APPENDIX B

SP-30AL/DC8 ROLL AXIS AUTOPILOT DATA AND WORKSHEETS



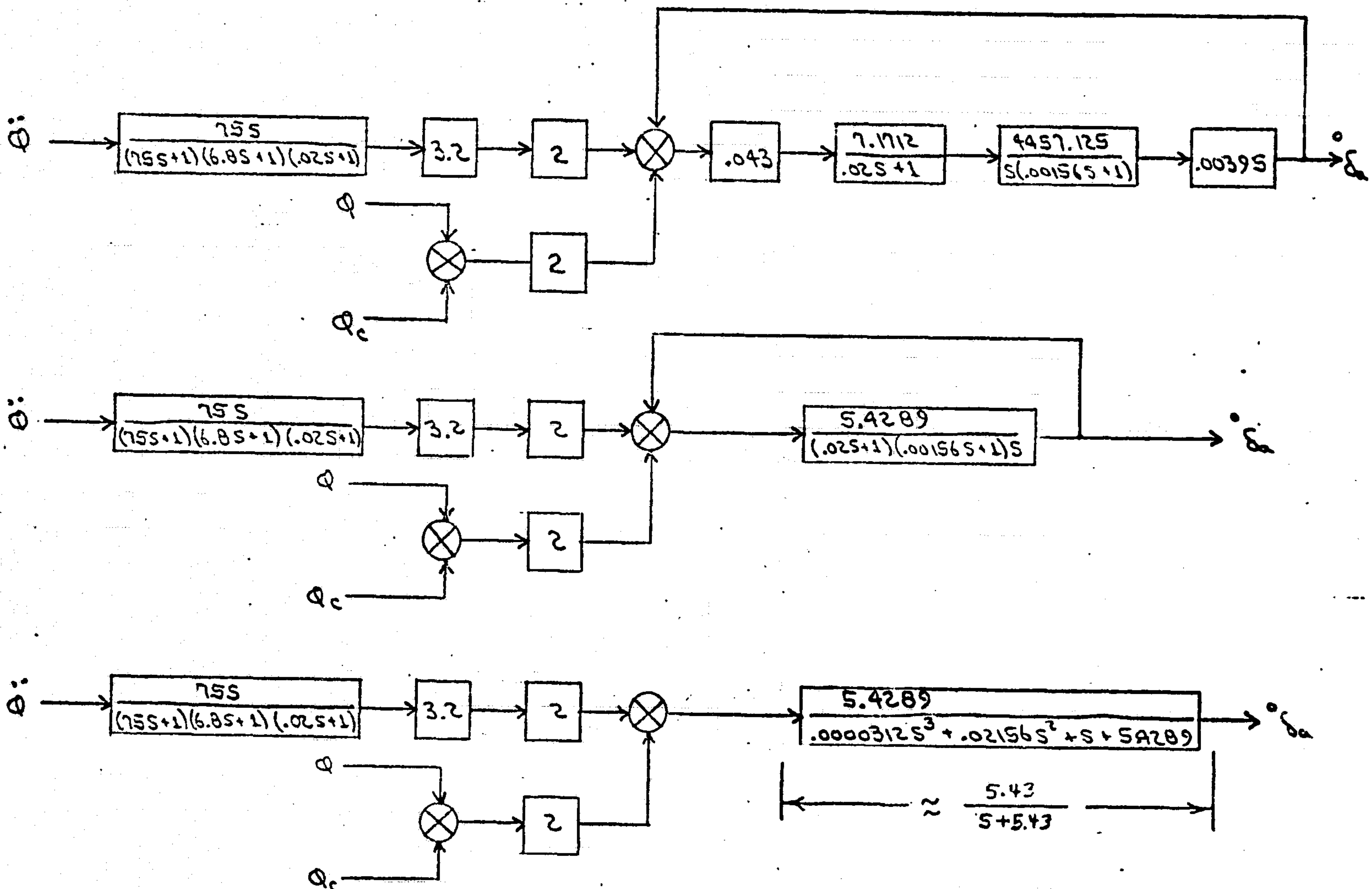
A-50

SP-30 AL / DC 8
Roll Axis Basic Stabilization
Sheet 1



Worksheet For Roll Loop

Sheet 2



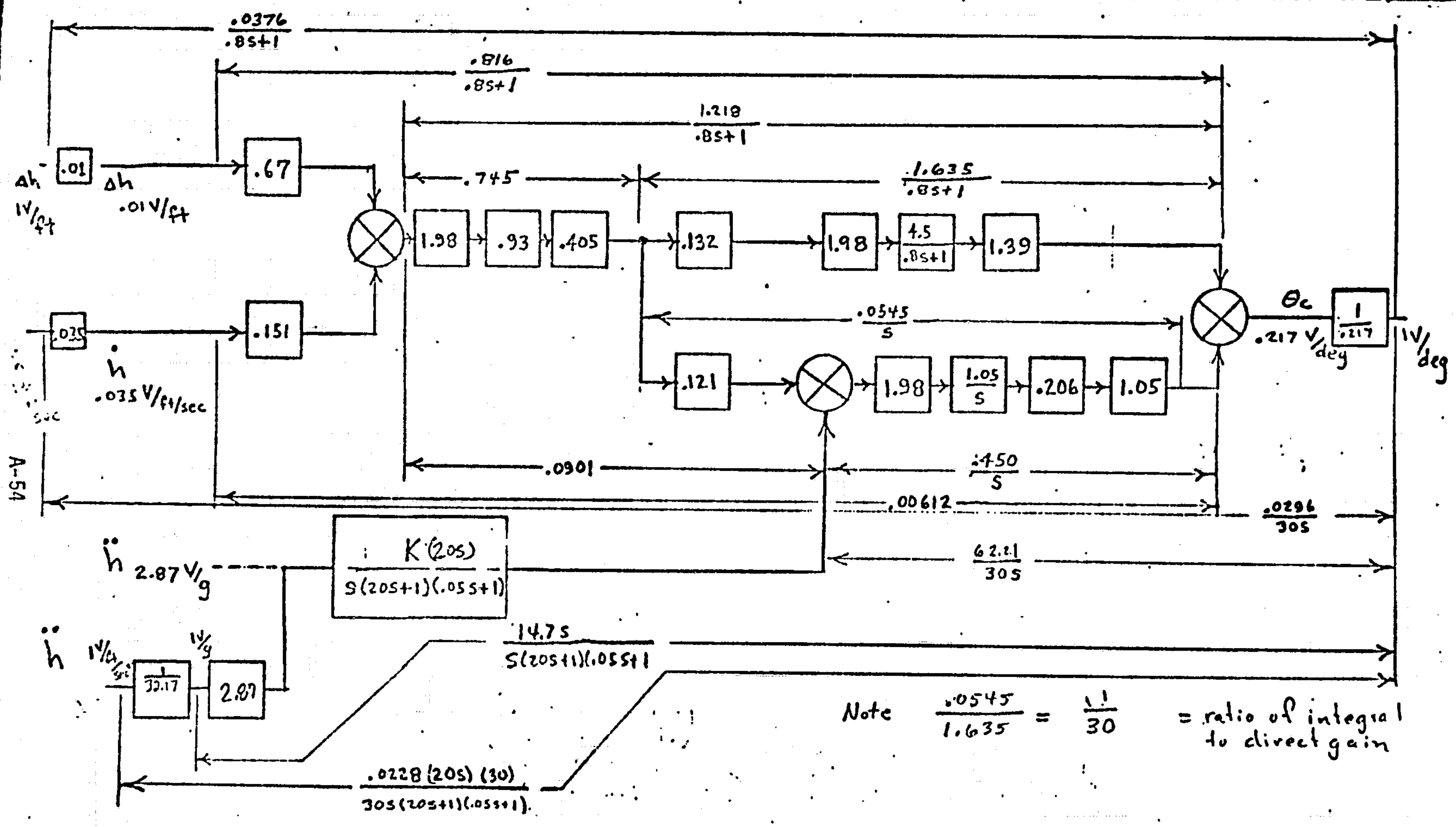
Worksheet For Roll Loop

Sheet 3

APPENDIX C

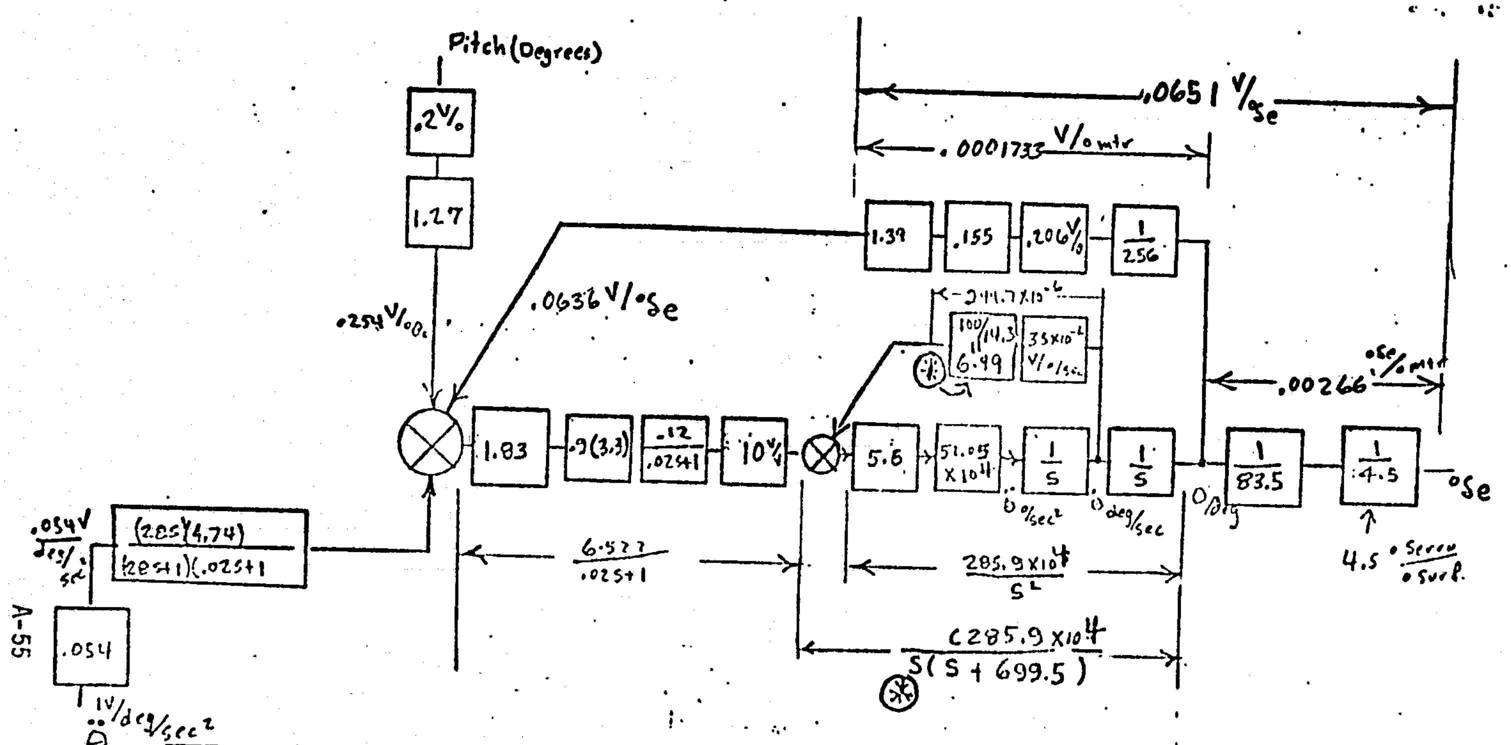
SP-30AL/DC-8 PITCH AXIS

AUTOPILOT DATA AND WORKSHEETS



Worksheet for Reduction of Altitude Hold Mode to Block Diagram

A-54



Worksheet for Reduction of Pitch Loop to Block Diagram (Sheet 1)

MOTOR: $T = .98$ in LB/AMP

$J = 1.1 \times 10^{-4}$ in LB/rad/sec²

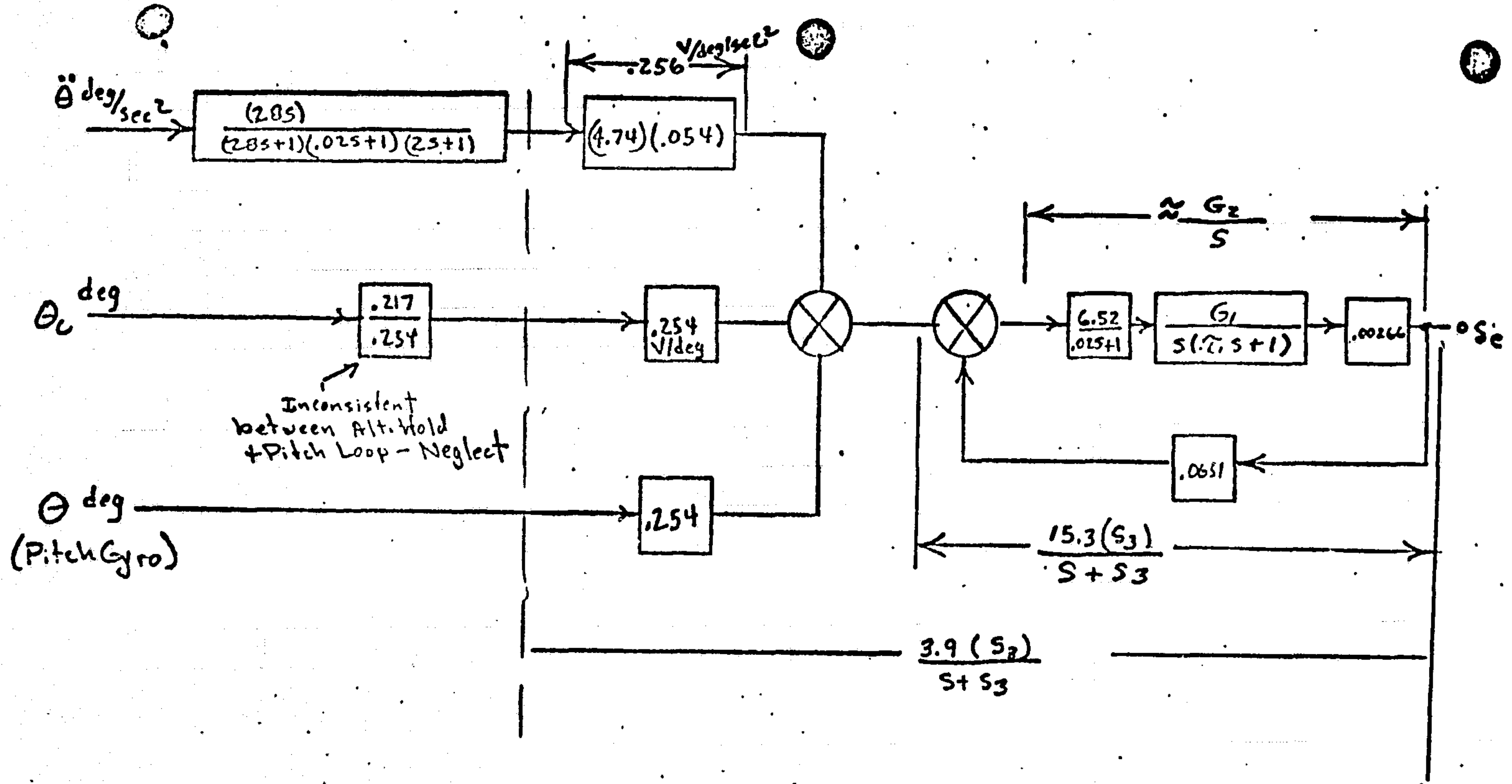
$T = J\ddot{\theta} \Rightarrow \ddot{\theta} = \frac{.98}{1.1 \times 10^{-4}} = .8909 \times 10^{4}$ rad/sec² $\times \frac{57.3^\circ}{rad} = 51.05 \times 10^{4}$ °/sec²/AMP

$\ddot{\theta} = 51.05 \times 10^{4}$ $\frac{deg/sec^2}{AMP}$

(*) Alternate Values

$\frac{100K}{37K} = 2.70$

$\frac{285.9 \times 10^{4}}{S + 270.18}$



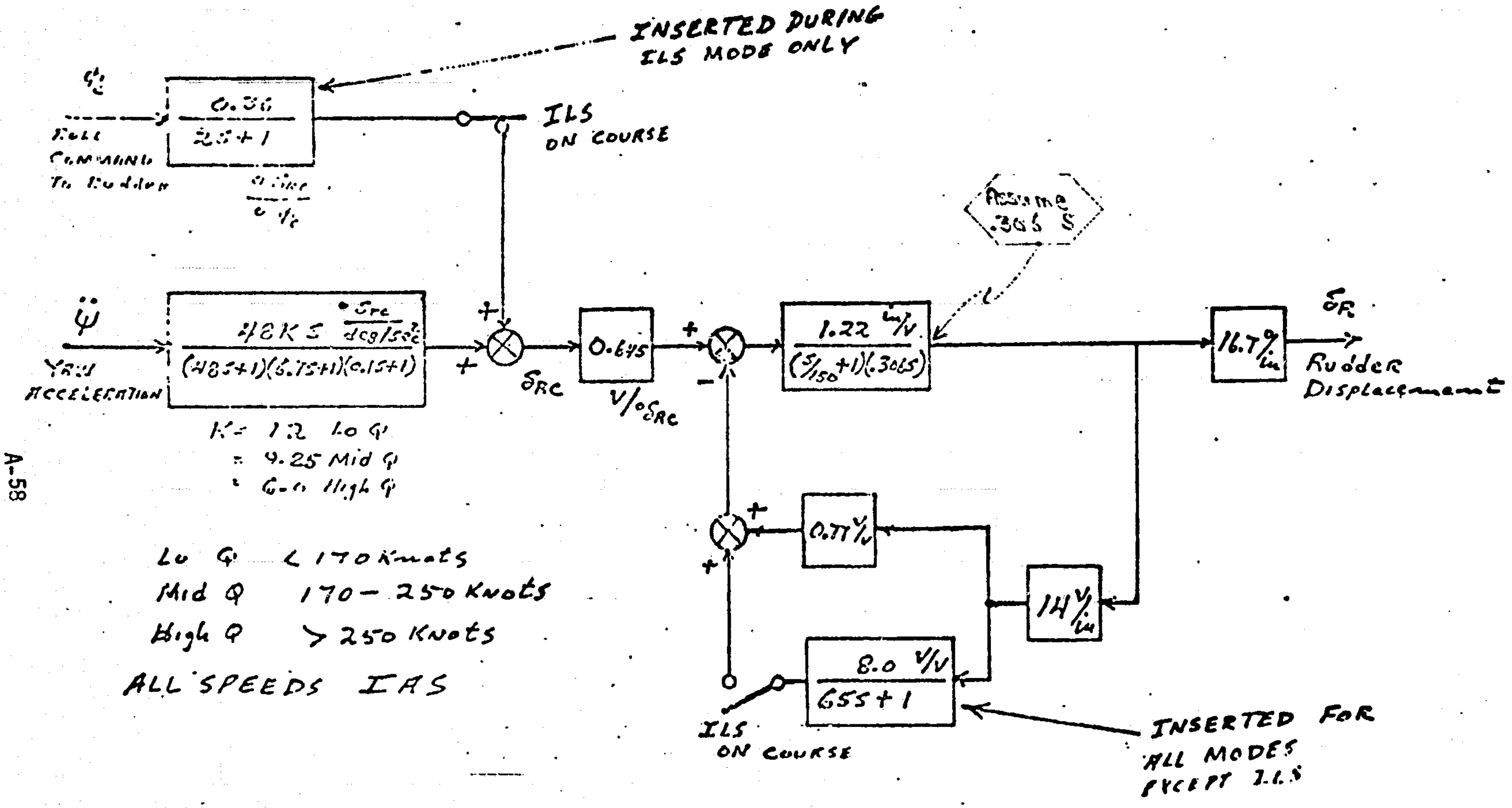
A-56

Worksheet for Reduction of Pitch Loop to Block Diagram (Sheet 2)

Servo Tach F.B. Gain	6.99	2.70
G_1	4087.2	10581.8
τ_1	.0014	.0037
G_2	70.91	183.58
S_3	4.62	12.0

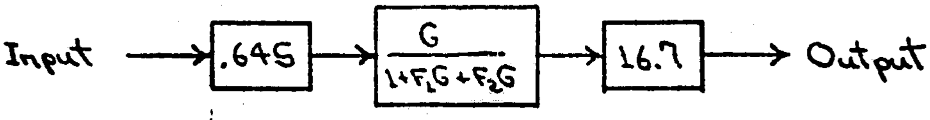
APPENDIX D

YAW DAMPER



YAW DAMPER BLOCK DIAGRAM
FOR
DC-8 60 SERIES AIRCRAFT

15 Aug 6?
P.R.S.



$$G = \frac{1.22}{(S/150+1)(.306\,S)} = \frac{(.306\,S)(S+150)}{183}$$

$$F_1 = \frac{8(14)}{65S+1} = \frac{112}{65S+1}$$

$$F_2 = 14(.77) = 10.78$$

$$\frac{G}{1+F_1G+F_2G} = \frac{1}{1/G + F_1 + F_2}$$

$$\text{Output} = \text{Input} * \left[\frac{(.645)(16.7)}{\frac{(.306S)(S+150)}{183} + \frac{112}{65S+1} + 10.78}\right]$$

$$\text{Output} = \text{Input} * \left[\frac{10.7715\,(183)\,(65S+1)}{(.306\,S)(S+150)(65S+1) + 112\,(183) + 10.78(183)(65S+1)}\right]$$

$$\text{Output} = \text{Input} * \left[\frac{128126.7\,S + 1971.18}{19.89\,S^3 + 2983.81\,S^2 + 128279\,S + 22468.74}\right]$$

$$\text{Output} \approx \text{Input} * \left[\frac{S + .015}{.00015\,S^3 + .023\,S^2 + S + .175}\right]$$

Worksheet For Yaw Damper

(SUMS OF PRODUCTS)/(SUMS OF PRODUCTS) DIRECTIVE
1/2

NUMERATOR

1.00000 S + .150000-01

ROOTS OF NUMERATOR

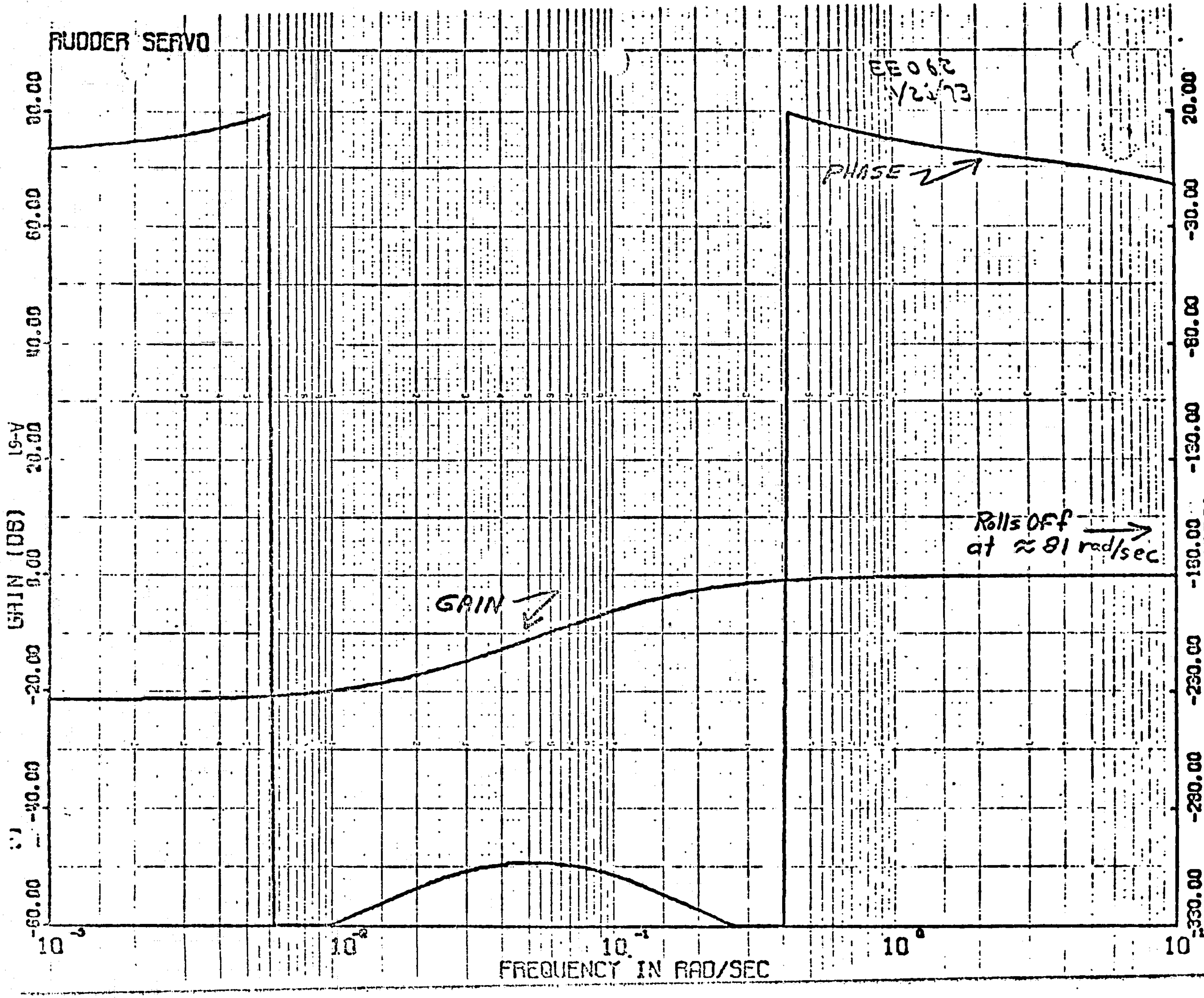
REAL	IMAGINARY	ZETA	OMEGA
-.15000000-001	.00000000	*****	*******

DENOMINATOR

.150000-03S** 3 + .230000-01S** 2 + 1.00000 S + .175000

ROOTS OF DENOMINATOR

REAL	IMAGINARY	ZETA	OMEGA
-.76578814+002	.27846743+002	.940	81.485
-.76578814+002	-.27846743+002	.940	81.485
-.17570928+000	.00000000	*****	*******

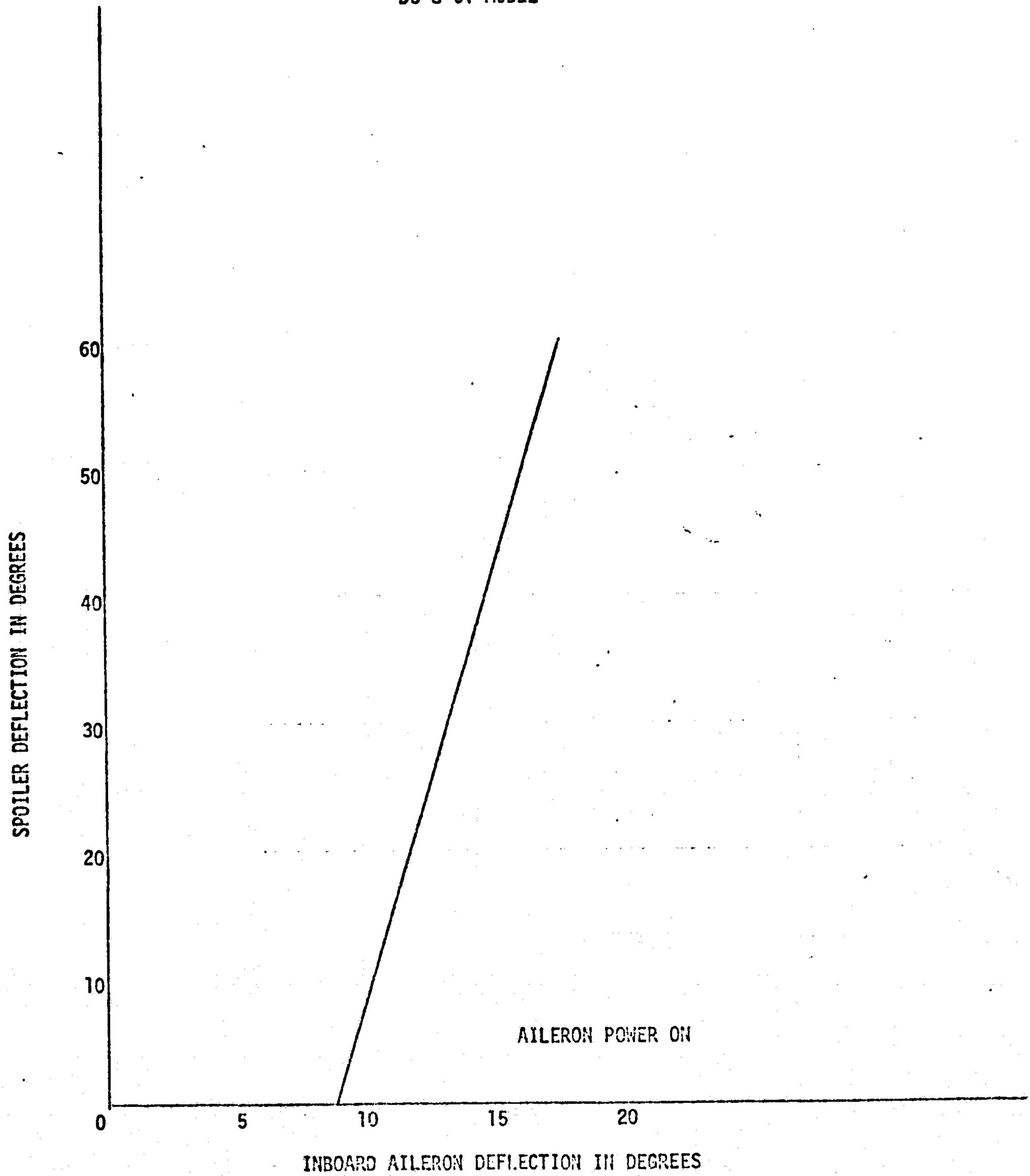

RUDDER SERVO
EE062
1/22/73
PHASE
GAIN
Rolls Off at ≈ 81 rad/sec
GAIN (DB)
FREQUENCY IN RAD/SEC
A-61
80.00
60.00
40.00
20.00
0.00
-20.00
-40.00
-60.00
20.00
-30.00
-80.00
-130.00
-180.00
-230.00
-280.00
-330.00
10^-3
10^-2
10^-1
10^0
10^1

APPENDIX E

RELATION BETWEEN SPOILER AND INBOARD AILERON DEFLECTIONS

SPOILER DEFLECTION VS. INBOARD AILERON DEFLECTION

DC-8-61 MODEL



APPENDIX 4

FAILURE MODES AND EFFECT ANALYSIS ON THE NASA AREA NAVIGATION NOISE ABATEMENT APPROACH SYSTEM

FAILURE MODES AND EFFECTS ANALYSIS
ON THE
NASA-AMES AREA NAVIGATION NOISE
ABATEMENT APPROACH SYSTEM

12 SEPTEMBER 1974

COLLINS RADIO GROUP
ROCKWELL INTERNATIONAL
CEDAR RAPIDS, IOWA

1.0 SCOPE

This document covers the Failure Mode and Effect Analysis (FMEA) of the NASA-Ames Area Navigation Noise Abatement Approach System. The system, for the purposes of this FMEA, consists of the following equipments:

1) 8564B-2X Navigation Computer Unit
2) 813H-1C Control Display Unit
3) 8848D-2 Flight Data Storage Unit
4) 161E-12 RNAV Switching Unit
5) Tuning Line Adapter, CPN 621-8612-001

These are the equipments supplied by Collins for the Noise Abatement program, but it should be noted that the total "system" includes many other equipments on board the aircraft which are required for both execution of the noise abatement approaches and detection of fault conditions. These inlcude sensor equipments such as the VOR and DME radios, display equipment such as the ADI and HSI, and monitoring equipment such as the "SMART BOX."

2.0 SUMMARY

The FMEA shows that on an overall aircraft basis no undetectable failure mode exists, assuming the specified functional failure modes. Since the installation in the UAL DC-8-61 is single-sided, the flight officer's system provides a completely independent source of data, and raw data displays are available to the pilot. The fault detection process relies heavily upon pilot detection, using the independent displays.

A great deal of the reliance upon pilot observation could be removed in a dual installation, where the two computers could be used to cross check each other and where the reversionary switching complexity could probably be reduced.

In terms of present line operations, the most critical units are the RNAV Switching Unit and the Tuning Line Adapter, as both of these units are at least partially in-line to normal (nonRNAV) functions. A failure in the Tuning Line Adapter can cause the pilot to lose his navigation radio.

Failures in the RNAV Switching Unit can cause false zero deviation display on the pilot's ADI raw localizer display (RNAV mode), cause loss of the pilot's flight director or autopilot functions, and give false HSI glideslope and localizer deviation and flag displays. These are inherent in the use of the unit to switch between raw and RNAV sensors and common displays.

The FMEA has considered only the effect of hardware failures. Just as a hardware design can fail because the design (and test) process fails to recognize an overstress condition, so can a complicated software design fail because the design (and test) process fails to recognize or exercise all possible states that the logic can reach. This is especially true when the initial conditions and subsequent inputs are time-dependent. Since the error is not recognized, the probability of encountering it cannot be calculated for either the hardware or software case.

Because it is normally executed in a machine with a vanishingly small error rate, software is not normally considered to have a statistical failure ratein the sense that such a rate exists for hardware. This does not mean that two software programs written to execute the same task may not have different "failure rates" when machine errors occur, but the calculation of such a time dependent function is generally not feasible.

3.0 ANALYTIC APPROACH

An FMEA was conducted at the piece part level for each of the five equipments listed in Section 1. The effect of each piece part failure mode operation at the LRU and system level was examined, and the method of fault detection was determined. The details of the FMEA's for the individual equipments have been included in the attached reports.

The analyses were performed on the system with the following assumptions:

1) Only single failure occur-multiple failures were not considered.
2) All inputs to the system from the other aircraft systems are valid.
3) The piece part failure modes and rates are those outlined in the LRU FMEA's.
4) The pilot and F.O. perform the same instrument monitoring that they would normally do during a normal ILS or nonprecision approach, for the RNAV/ILS and RNAV/RNAV modes respectively.

The FMEA details can be found in the following attached documents:

1. Failure Mode and Effect Analysis on the 8564B-2X Navigational Computer Unit CPN 622-1463-001, dated 1 June 1974.
2. Failure Mode and Effect Analysis on the 8848D-2/7520A-1 Flight Data Storage Unit, dated December 17, 1971.
3. Failure Mode and Effect Analysis on the 813H-1 Control Display Unit, dated January 10, 1972.
4. Failure Mode and Effect Analysis on the 161E-12 RNAV Switching Unit CPN 622-1625-002, dated 8 May 1974.
5. Failure Mode and Effect Analysis on the Tuning Line Adapter CPN 621-8612-001, dated 30 April 1974.

The FMEA for the 8564B-2X NCU is based upon that for the 8564B-2A which it closely resembles. The differences are detailed in the referenced FMEA.

The 813H-1C CDU used on this program is a mechanical modification of the 813H-1, but is electrically identical.

APPENDIX 5

SOFTWARE CHANGES DURING LINE EVALUATION

Software Changes During Line Evaluation

During the on-line evaluation, several modifications were made to the original STC software to correct deficiencies, improve performance, or modify the data base. These changes are summarized below:

Cartridge No.	Modifications
618-5312-001-01	Original STC version
618-5312-002-02	Truncated latitude and longitude words were added to the ARINC digital data for output with DADS labels so the data could be received by the UA flight recorder. The lateral deviation display gain was increased to the correct value. The radio tuning logic was modified to ensure automatic tuning en route and prevent unecessary secondary radio tuning in the terminal area. The data base was modified to eliminate Vancouver and add Denver, Los Angeles, San Francisco, San Diego, Norfolk, and Cleveland.
618-5312-003-03	The logic was modified to prevent two-segment events from being passed while in the heading mode. Errors in the ident for CLX (co-located DME at Cleveland) and the lat/long for SAZ (co-located DME at San Diego) were corrected.

618-5312-004-04 The data base was modified to correct the stored magnetic variation for CLE (Cleveland). A logic error which resulted in the deletion of a prior holding pattern in the flight plan if a STAR was deleted was corrected. Logic was also modified to reset the two-segment abort flags and the system state counter if a STAR was deleted. A logic error which eliminated the "NOT STORED" message was corrected. The logic was modified to prevent power interrupts prior to RNAV GREEN from causing later STAR aborts. The lateral deviation display for RNAV approaches was corrected to be angular after UPPER AMBER. The radio tuning logic was modified to restore automatic en route tuning after flying through a STAR.

618-5312-005-05 The minimum distance abort logic was modified to create the abort at 750 feet past LOWER. The vertical deviation display output was modified to prevent a computational overflow and deviation reversal if the aircraft was flown more than 3 dots above the path. The data base was modified to add a new STAR at Cleveland.

618-5312-005-06 This issue of the software modified only the data base. Two-segment approach data was added for Las Vegas, Windsor Locks, Dulles, and Richmond, Virginia. Denver, Pueblo, Newark, Seattle and San Francisco were deleted. The list of en route navigation aids was revised to cover the new UA route structure.

618-5312-005-07 The primary navigation aid for Los angeles was changed from LAX to SMO (Santa Monica). LAX was off the air.

618-5312-005-08 The data base was revised to add Denver and Milwaukee, and the navigation aid list modified to cover the new route structure.

618-5312-006-09 Due to erratic signals from the Hartford (HFD) station, the primary navigation aid for Windsor Locks was changed to Barnes (RNZ). The CDU deviation displays were changed to read in normal RNAV manner (present leg and linear) rather than being switched to match the HSI displays at UPPER AMBER. The navigation filter logic was modified to force reversion to the air data mode if only one radio sensor was available. The transfer of lateral steering to the autopilot and flight director was allowed to occur prior to LOWER AMBER if the conditions were valid.

618-5312-007-09 The lateral steering gain was increased to provide the correct gain in the terminal area.

APPENDIX 6

INSTALLATION DRAWINGS

ORIGINAL PAGE IS OF POOR QUALITY

C-SYSTEM GRAPHICS

NOTES

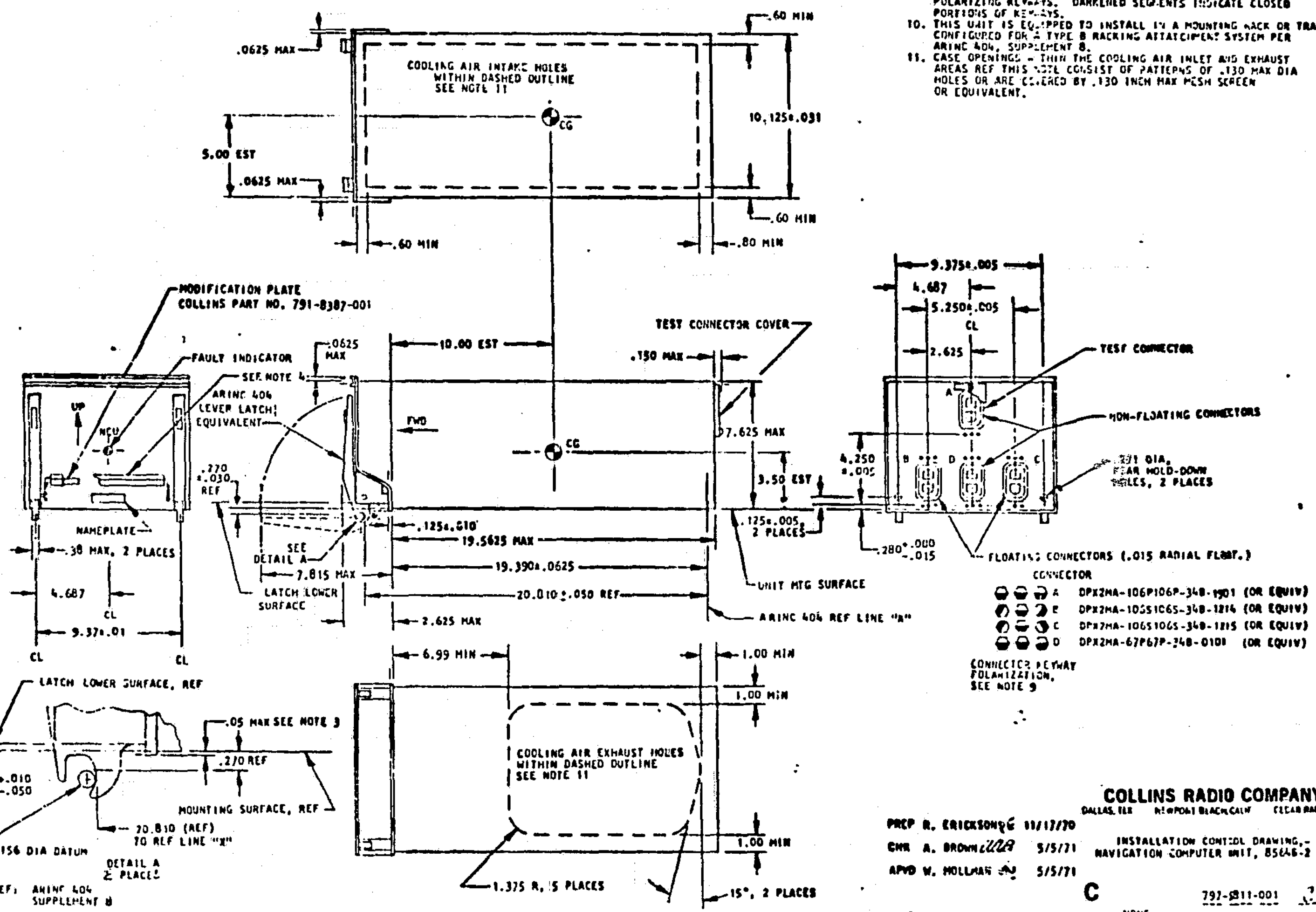
1. DIMENSIONS ARE IN INCHES.
2. UNLESS OTHERWISE SPECIFIED - TOLERANCES ON:
   DECIMAL DIMENSIONS - .XX = ±.02, .XXX = ±.008
   HOLE DIAMETERS - UNDER .251 DIA = + .005 - .005
   .251 TO .500 DIA = + .006 - .005
   OVER .500 DIA = + .008 - .005
   ANGLES = ± 1.0°
3. UNIT FRONT PANEL PROJECTION LIMIT AND LATCH LOWER SURFACE LIMIT WITH RESPECT TO UNIT MOUNTING SURFACE.
4. HANDLE IS SHOWN IN LATCHED OR STOWED POSITION. HANDLE FUNCTIONS AS UNIT CARRYING HANDLE IN UNLATCHED POSITION.

(NOTES CONT AT RIGHT)

5. THIS DRAWING IS APPLICABLE TO 8564B-2 EQUIPMENT IDENTIFIED BY COLLINS PART NUMBERS 792-6727-201, -202, -203, -299, -101, -102, -001 & -002.
6. ENVELOPE DIMENSIONS SHOWN ON THIS DRAWING ARE APPLICABLE TO 8564B-2 MOCKUPS IDENTIFIED BY COLLINS PART NUMBERS 792-6727-221 AND -231.
7. WEIGHT: [illegible] LBS MAX.
8. COOLING AIR REQUIREMENT: UNIT CONFIGURATION IS FOR ARINC COOLING. UNIT REQUIRES A NET FLOW OF 240 LBS/HR AT THE 125°F AMBIENT DESIGN CONDITION. UNIT PRESSURE DROP, ΔP IS 0.25 INCHES OF WATER MAX AT A FLOW RATE OF 240 LBS/HOUR, AND AIR DENSITY OF .075 LBS/CUBIC FOOT.

(NOTES CONT AT RIGHT)

9. CONNECTOR KEYWAY POLARIZATION-FACE VIEW OF ENGAGING END OF POLARIZING KEYWAYS. DARKENED SEGMENTS INDICATE CLOSED PORTIONS OF KEYWAYS.
10. THIS UNIT IS EQUIPPED TO INSTALL IN A MOUNTING RACK OR TRAY CONFIGURED FOR A TYPE B RACKING ATTACHMENT SYSTEM PER ARINC 404, SUPPLEMENT 8.
11. CASE OPENINGS - THIN THE COOLING AIR INLET AND EXHAUST AREAS REF THIS NOTE CONSIST OF PATTERNS OF .130 MAX DIA HOLES OR ARE COVERED BY .130 INCH MAX MESH SCREEN OR EQUIVALENT.



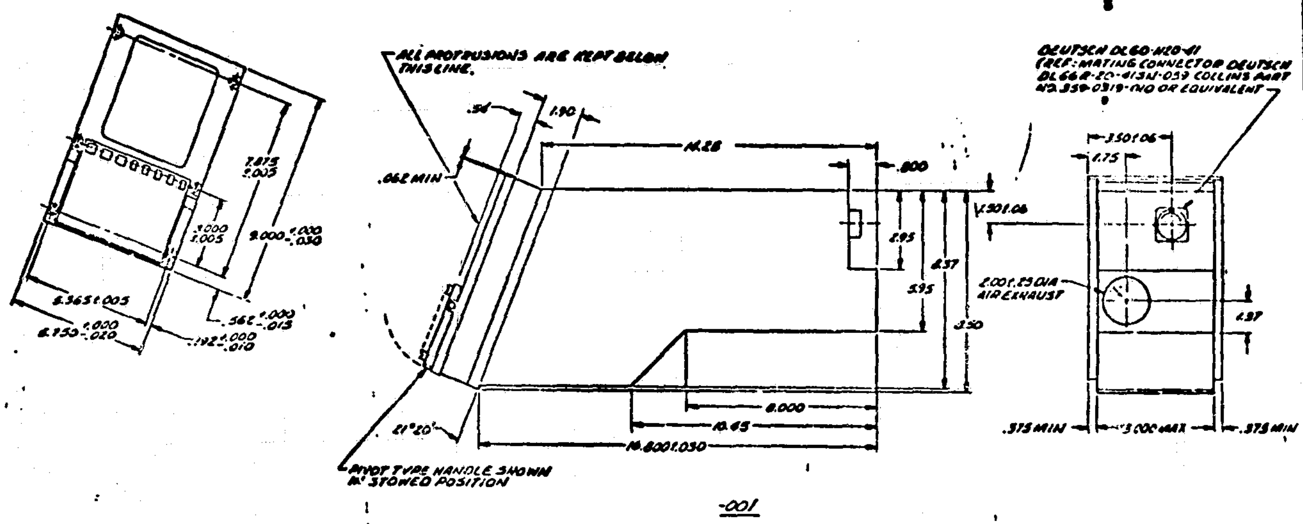
COLLINS RADIO COMPANY
DALLAS, TEX — NEWPORT BEACH, CALIF — CEDAR RAPIDS, IA

PREP R. ERICKSON 11/17/70
CHK A. BROWN 5/5/71
APVD W. HOLLMAN 5/5/71

INSTALLATION CONTROL DRAWING, NAVIGATION COMPUTER UNIT, 8564B-2

C — 792-5811-001 — NONE

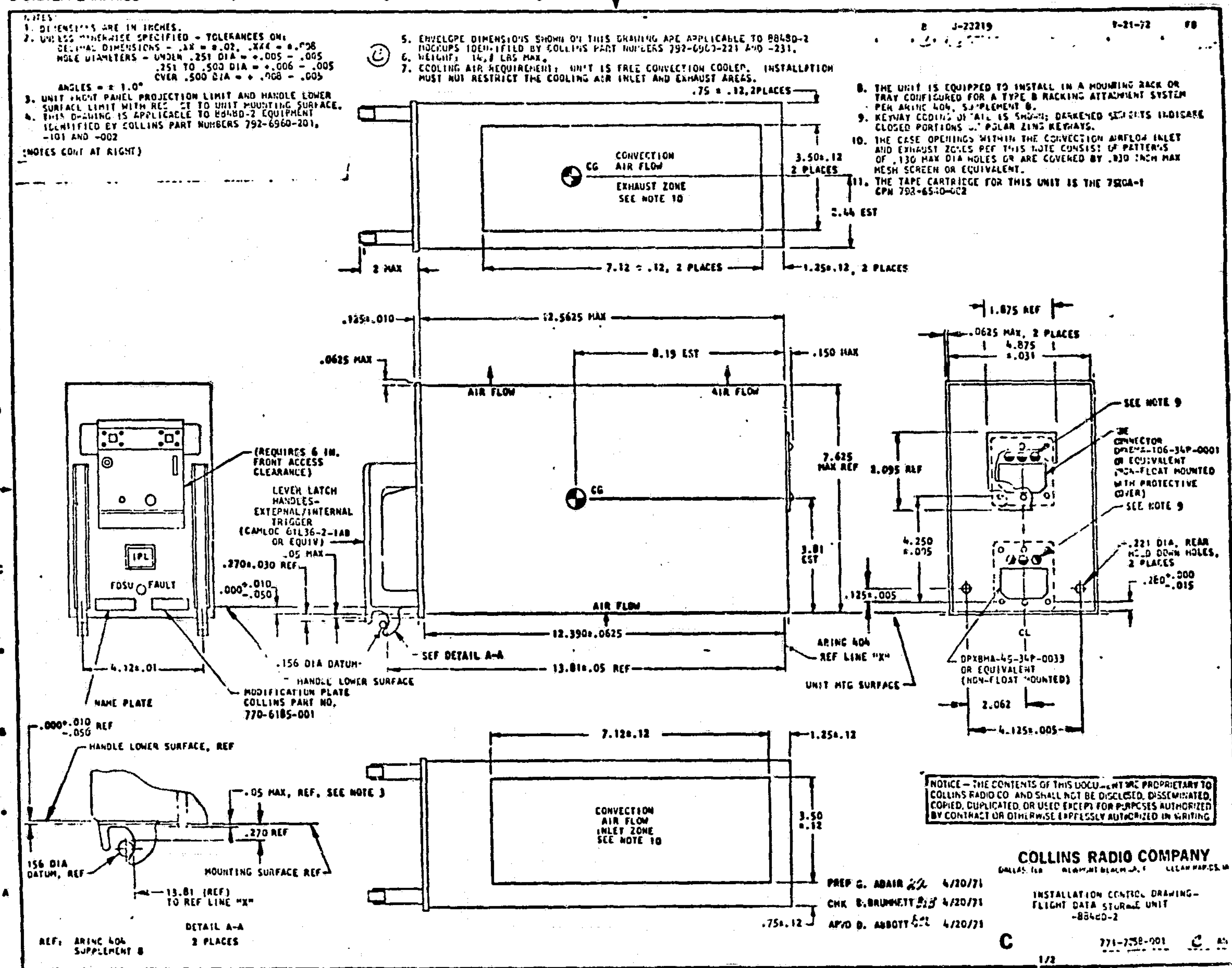
NOTE:
1. WEIGHT: 20 LBS MAX (EST).



-001

NONE	UNLESS OTHERWISE SPECIFIED	CONTRACT NO.	COLLINS RADIO COMPANY
NONE		C Tscnitncut 2/9/73	INSTALLATION CONTROL DWG (CDU) 813N-1C
		J H 2/9/73	D 13499 ( )-2455

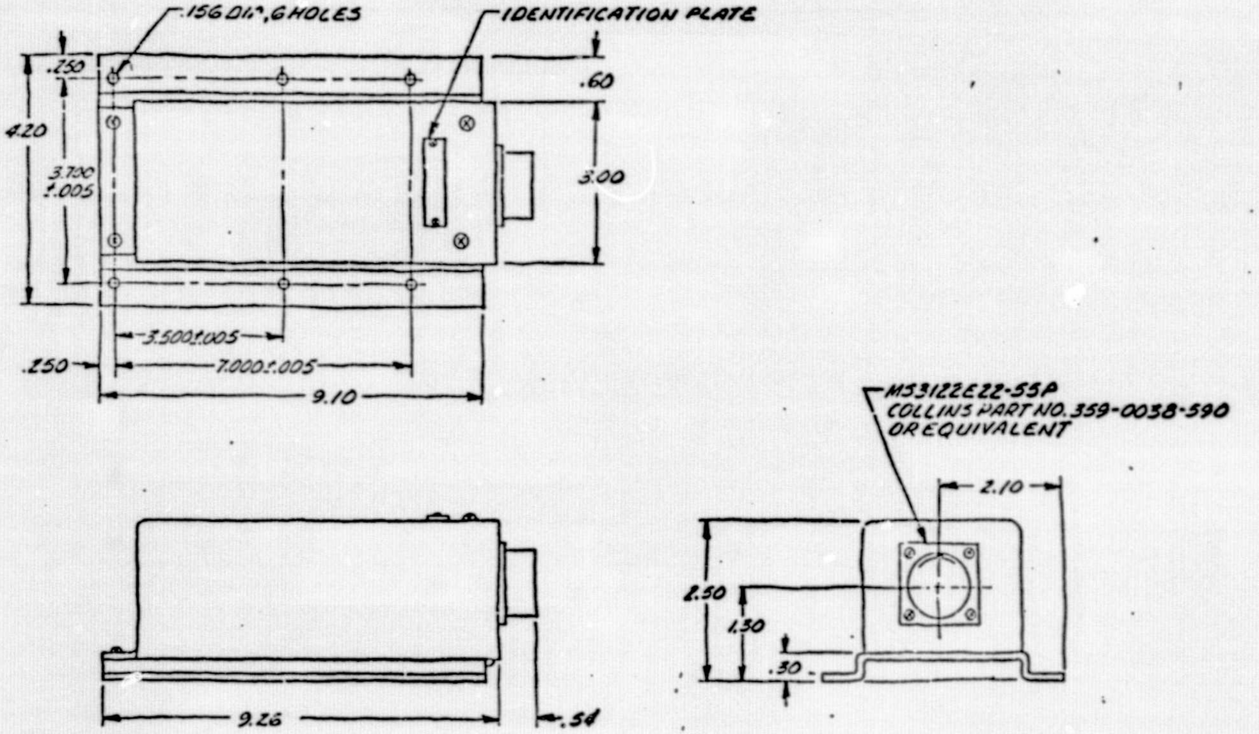
C-SYSTEM GRAPHICS



NOTES:

1. WEIGHT: 1.1 LB MAX (EST).

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED

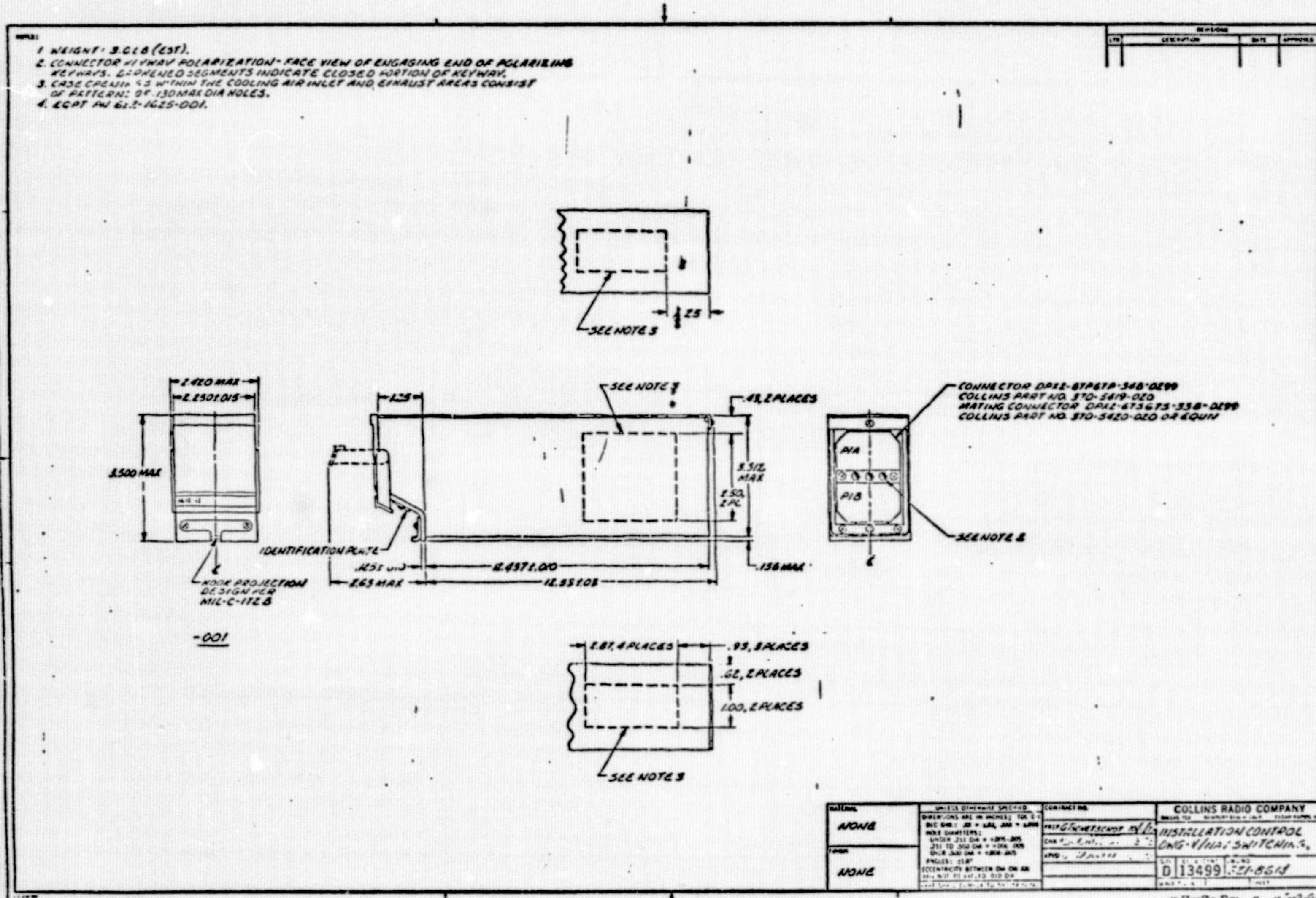


-001

A-78

MATERIAL	UNLESS OTHERWISE SPECIFIED	CONTRACT NO.	COLLINS RADIO COMPANY DALLAS TEX NEWPORT BEACH CALIF CEDAR RAPIDS, IA
NONE	DIMENSIONS ARE IN INCHES; DEC DIM.: .XX = ±.02, .XXX = ±.008 HOLE DIAMETERS: UNDER .251 DIA = +.005-.005 .251 TO .500 DIA = +.006-.005 OVER .500 DIA = +.008-.005 ANGLES: ±1.0° ECCENTRICITY BETWEEN DIA ON AN AXIS NOT TO EXCEED .010 DIA	PREP G. TSCHETSCHOT 9/[illegible] CHK R. JOHNSTON 3/29/73 APVD [illegible] 73	INSTALLATION CONTROL DWG-ADAPTER, TUNING LINE
NONE			SIZE C	CODE IDENT 13499	DWG NO 521-3213

C-3


NOTES:
1 WEIGHT: 3.0 LB (EST).
2. CONNECTOR KEYWAY POLARIZATION - FACE VIEW OF ENGAGING END OF POLARIZING KEYWAYS. DARKENED SEGMENTS INDICATE CLOSED PORTION OF KEYWAY.
3. CASE OPENINGS WITHIN THE COOLING AIR INLET AND EXHAUST AREAS CONSIST OF PATTERNS OF .130 MAX DIA HOLES.
4. EQPT PN 622-1625-001.
.25
SEE NOTE 3
2.420 MAX
2.250±.015
3.500 MAX
HOOK PROJECTION DESIGNED PER MIL-C-172B
-001
.125
SEE NOTE 3
.13, 2 PLACES
3.312 MAX
2.50, 2 PL
IDENTIFICATION PLATE
.156 MAX
12.437±.010
2.63 MAX
12.55±.03
CONNECTOR DPX2-87P67P-348-0299
COLLINS PART NO. 370-5419-020
MATING CONNECTOR DPX2-67S67S-338-0299
COLLINS PART NO. 370-5420-020 OR EQUIV
P1A
P1B
SEE NOTE 2
2.87, 4 PLACES
.93, 8 PLACES
.62, 2 PLACES
1.00, 2 PLACES
SEE NOTE 3
NONE
NONE
UNLESS OTHERWISE SPECIFIED
COLLINS RADIO COMPANY
INSTALLATION CONTROL DWG - V/HAI SWITCHING
D
13499

A-79