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B-737 FLIGHT TEST OF CURVED-PATH AND STEEP-ANGLE APPROACHES USING MLS GUIDANCE

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DEFINITIONS, ABBREVIATIONS, AND ACRONYMS

Definitions shown in this list apply to the NASA/FAA Tests of the Time Reference Scanning Beam, Microwave Landing System. The special terms and abbreviations are listed to explain their meaning and application to procedures and criteria used in this test program and are not, necessarily, accepted terminology.

ACD	Analysis and Computation Division. NASA Langley's data processing facility.
ADI	Attitude Director Indicator.
ADL	FAA Office of Development and Logistics.
AFO	FAA Office of Flight Operations.
ATD	Along Track Distance. The distance to go to GPI is measured along the datum flight path.
ATOPS	Advanced Transport Operating System (generally referring to the NASA Boeing 737 aircraft or TSRV).
ATOPSPO	ATOPS Program Office.
AVN	FAA Office of Aviation Standards.
AZ	MLS Azimuth Beam. Navigation Computer Input.
B-STD	Biased Standard Deviation (computed statistic).
B-VAR	Biased Variance (computed statistic).
CG-X (or Xcg)	Actual longitudinal position of the aircraft's center of gravity referenced to the system axes in Fig. 7.2.
CG-Y (or Ycg)	Actual lateral (or crosstract) position of the aircraft's center of gravity referenced to the system axes in Fig. 7.2.
CG-Z (or Zcg)	Actual vertical position of the aircraft's center of gravity referenced to the system axes in Fig. 7.2.
CLS	Centerline Segment.
CP	Curved Path. Any MLS approach utilizing one or more curved segments with positive course guidance.
CPS01	Label for offset parallel curved path (Fig. 2.16).
CP131	Label for two-turn curved path (120-degree course reversal and 30-degree turn to full) (Fig. 2.15).
CP181	Label for 180-degree curved-path approach with Final Approach Point (FP) prior to Turn Point (TP), Fig. 4.6.

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CP191	Label for 90-degree curved-path approach with Minimum Centerline Segment, Fig. 4.9.
CP902	Label for 90-degree curved-path approach with Optimum Centerline Segment, Fig. 4.10.
CP131	Label for curved-path approach studying non-centerline segments, Fig. 4.11.
CPS01	Label for parallel offset curved-path approach, Fig. 4.12.
DAS	Data Acquisition System (B-737 airborne package).
DES PT	Design Point for 50-meter interval partitioning.
DH	Decision Height. The decision height is 200 feet above the GPI.
DME	Distance Measuring Equipment. The DME distance (slant) from the GPI to the aircraft, in nautical miles.
DME/P	Precision Distance Measuring Equipment associated with MLS.
DOT	Department of Transportation.
DTU	Data Translator Unit.
EL	MLS Elevation Beam. Navigation Compute Input.
ERCL	Extended Runway Centerline.
FAA	Federal Aviation Administration.
FAP	Final Approach Point. The point at which the computed glide path intersects the intermediate approach altitude.
FAS	Final Approach Segment. The segment from the final approach point to DH.
FFD	Forward Flight Deck of the TSRV/B-737.
FLIGHT	A flight consists of several runs during the time period from initial takeoff to the termination landing.
FPS-16	Wallops tracking radar/laser facility.

FTE	Flight Technical Error. The accuracy with which the pilot controls the aircraft. (Pilot success in causing the aircraft position to match the indicated command on the instrument display).
FTP	Final Turn Point. The last turn point from any curved or straight segment.
FY	Fiscal Year.
GPI	Ground Point of Intercept.
HSI	Horizontal Situation Indicator.
HT LOSS	Calculated value for height loss equal to value of Decision Height minus LOW AVG Z.
ICAO	International Civil Aeronautics Organization.
ILS	Instrument Landing System. System currently used for precision instrument approach procedures.
Initial Approach Segment	The segment from the initial approach fix (IAF) to the intermediate approach fix or point. In the initial segment, the aircraft has transitioned to an MLS approach either from the en route phase of flight by radar vector or from other terminal area facilities (VOR, TACAN), and is maneuvering to enter the intermediate segment. There can be multiple initial segments.
Intermediate Segment	The connecting segment between the initial and final approach segment. It begins at the intermediate fix or point and ends at the final approach point. Positive course guidance is provided by MLS.
KURTOSIS	Kurtosis (computed statistic).
LAT DEV	Lateral deviation (flight technical error).
LNSE	Lateral Navigation System Error.
LOW AVG Z	Lowest altitude of aircraft prior to go-around or low approach.
LTS	Laser Tracking System. Primary tracking facility at Wallops.
MCLS	Minimum Centerline Segment. The minimum operational straight line segment length along the extended runway centerline that may be used in designing a curved-path MLS approach.
MLS	Microwave Landing System. An air-derived system in which ground-based equipment transmits position information signals to a receiver in the aircraft. (Time reference scanning beam in azimuth and elevation, plus precision DME.)
NASA	National Aeronautics and Space Administration.

NCDU — Navigation Control and Display Unit. Used to program the various NCU modes.

NCLS — Non-centerline Segment. The minimum operational straight line segment length between turns that may be used in designing a curved-path MLS approach.

NCU — Navigation Computer Unit. Basic guidance system for the B-737.

OCLS — Optimum Centerline Segment. The most practical operational straight line segment length along the extended runway centerline to be used in the design of curved-path MLS approach.

PADS — Piloted Aircraft Data System. The primary data collection system used onboard the TSRV/B-737.

PCM — Pulse-code Modulation. Technique used for combining airborne data parameters for recoding.

RADL ERROR — Lateral Position Error.

RAGS — Research Aircraft Ground Station. Used for preliminary processing of airborne data.

RCLS — Runway Centerline Segment.

RNAV — Airborne area navigation (as applied to system, algorithm, or procedure).

RP — Rollout Point. The completion point of a turn with positive course guidance. The last RP in the final approach segment is identified as the Final Rollout Point (FRP).

RTCA — Radio Technical commission for Aeronautics.

RUN — Flying one complete profile for a data record.

SDC — Systems Development Corporation. Providing data reduction services under contract to NASA Langley.

SGS35 — Label for steep-angle approach having a 3.5 degree glide slope.

SGS38 — Label for steep-angle approach having a 3.8 degree glide slope.

SGS40 — Label for steep-angle approach having a 4.0 degree glide slope.

SKEW — Skewness (computed statistic).

STAR — Standard Terminal Arrival Route.

STEP — Service Test and Evaluation Program. (FAA)

STRU — Servo Transmit-Receive Unit (for airborne DAS channels).

DEFINITION, ABBREVIATIONS, AND ACRONYMS (continued)

TERPS	U.S. Standard Terminal Instrument Procedures. (Also, a FAA handbook).
TP	Turn Point. Points within the intermediate and/or final segment where transition occur in the horizontal plane (azimuth). The last TP in the segment is identified as the (FTP) Final Turn Point.
TSRB	Time Reference Scanning Beam. ICAO-accepted technique for MLS signal format.
TSRV	Transport Systems Research Vehicle. A specially-equipped Boeing 737-100 operated by NASA Langley for advanced flight research.
UNB-STD	Unbiased Standard Deviation (computed statistic).
UNB-VAR	Unbiased Variance (computed statistic).
USAF	United States Air Force.
VERT DEV	Vertical deviation (flight technical error).
VHF	Very High Frequency.
VNSE	Vertical Navigation System Error.
VPOS ERROR	Vertical Position Error.

1.0 INTRODUCTION

This report describes a flight test project undertaken jointly by the Federal Aviation Administration and the NASA Langley Research Center to create a statistical data base for the design of complex (i.e., computed curved path) approaches using MLS guidance. This report documents the systems and procedures used for profile development and evaluation during both ground simulation and flight tests, and is intended to complement the data report containing detailed data analysis and statistics, Reference 1.

The primary interest in conducting these tests was to measure the lateral and vertical deviations along various curved flight paths as flown by a typical jet transport aircraft. During the course of the project, a total of 432 approaches (consisting of 7 different curved-path and 3 steep-angle profiles) were flown for data in Langley's B-737.

The approach profiles were developed during piloted simulator sessions prior to actual flight testing, in order to reduce the expenses and inevitable time delays involved with actual flight operations. The simulator was also used for training subject pilots prior to flying the approaches in the aircraft, and for studying the effects of severe adverse winds on the flight paths.

1.1 OBJECTIVES

The overall objectives of this project were twofold, the first being to evaluate the system parameters of a "full-capability" MLS installation in a jet transport aircraft equipped with conventional cockpit displays and flight controls. (Full capability implies the ability to compute aircraft position, and subsequently, issue guidance commands for executing a complex approach.) The additional airborne equipment required to accomplish this task consisted of an MLS azimuth and elevation angle receiver, a precision DME interrogator, and a flight path computer.

The second major objective was to establish a data base of performance criteria that FAA Procedures Specialists could access in order to determine obstacle clearance requirements for complex approaches. From this data base, terminal instrument procedures (TERPS) may be written for MLS complex approaches as they apply to this category of aircraft. Results from this series of flight tests will provide the initial input to this data base with regard to curved flight paths and steep-angle glide slopes.

Specifically, the objectives of the test were to:

a. design and test MLS curved-path approaches that are practical to fly,

b. evaluate the operational use of "steep-angle" glide paths (between 3.0 and 4.0 degrees) which may be required at certain MLS installations,

c. collect data on flight technical error resulting from a group of subject pilots flying these approaches, and

d. observe the performance and ability of the MLS hardware and software to provide acceptable guidance for these types of approaches.

The project also provided an early opportunity to evaluate a format for the depiction of curved-path flight profiles on instrument approach procedure charts used by pilots. In addition, a practical application of a complex approach was demonstrated at the conclusion of the project by flying a version of the Washington National "River Approach" at the Wallops Flight Facility using MLS curved-path guidance.

1.2 BACKGROUND

The Microwave Landing System (MLS) concept has been adopted by the International Civil Aviation Organization (ICAO) as the world standard to replace the current Instrument Landing System (ILS). Numerous advantages in instrument meteorological condition (IMC) operations will be afforded by converting to MLS. Foremost among these will be the flexibility in approach path design due to the large volumetric coverage of MLS as compared to the single straight-line path of the ILS. This may provide improved traffic flow in major terminal areas where delays and congestion have become a serious problem. Figure 1.1 compares the signal coverage volume envisioned for a typical wide-angle MLS installation with the single course radiated by the currently used ILS.

The need for precision, curved approach paths stems from several requirements aimed at improved flight operations in the terminal area. These include increased airport capacity by providing tailored approach paths for various categories of aircraft, the design of special paths to reduce noise over sensitive areas, and the ability to provide navigation around physical obstructions or mountainous terrain.

The simplified siting requirements and reduced multi-path interference afforded by MLS will allow installation at locations where it is now difficult to provide precision ILS approaches. Examples of these would be mountain valley sites where multipath is a problem, and hilltop locations where the lack of adequate terrain for siting an ILS exists. MLS can provide the precision guidance necessary to satisfy the full range of operational requirements for all types of aircraft in all approach categories from heavy jet transports to STOL aircraft and helicopters. Implementation of MLS in the U.S. is scheduled to begin in the late 1980's and include equippage of approximately 1200 runways at airports across the country, nearly double the number of instrument landing systems now in use.

Extensive testing of MLS has been conducted by the FAA, NASA, and the U.S. Air Force. However, the objectives of most previous tests have been oriented toward answering technical issues involved with system development, signal format determination, or demonstrating the inherent capabilities of MLS. This flight test was the first major effort specifically conducted to collect performance data on the flyability of MLS complex approaches by airline pilots. Heretofore, most flight testing had been limited to the use of research and development test pilots, and little data useful for approach design had been collected.

Currently, there exists no criteria in the "United States Standards for Terminal Instrument Procedures" (commonly referred to as TERPS) that can be applied by Procedures Specialists to the design of curved-path MLS approaches. As a result, existing TERPS ILS procedures have been extended for use with the interim-standard MLS straight-in approaches. Criteria are likewise lacking for any type of approach having more than a nominal 3.0-degree glide slope. Hence, this particular project targeted these two areas in which to enhance TERPS development.

1.3 METHODOLOGY

Prior to initiation of the project, the FAA Office of Aviation Standards had identified four basic curved-path approaches (Figure 1.2) for study from the standpoint of determining the average pilot's ability to fly these profiles using MLS guidance. Inherent in each of the candidate profiles were a number of variables, such as turn rate, bank angle, segment length, and intercept offset distance, that required definition prior to further development of TERPS for MLS complex approaches. A flight test matrix (Table 1.1) was assembled to define the specific approach configurations that would be studied in this test.

After surveying a number of options for implementing this study, the decision was made to combine the attributes of flight simulation and actual airborne flight testing to accomplish the goals of this project. Due to the large number of variables involved, it was considered advantageous to screen the profiles using a ground-based simulator prior to conducting an actual flight test; hence approach profiles would be developed in the simulator and validated in flight. As things turned out, a synergistic effect was realized by using simulation to complement the flight test. Envisioned primarily to conserve resources, use of the simulator added a tremendous degree of flexibility in designing the approaches, thus permitting a wider range of flight path parameters to be compared and studied.

For many years NASA and the FAA have maintained a cooperative agreement aimed at improving terminal area operations by the development, evaluation, and demonstration of systems and procedures that provide for more effective operations in the increasingly congested terminal area. As part of this effort, NASA Langley operates an aircraft known as the "Transport Systems Research Vehicle," hereafter referred to as "TSRV." The TSRV consists of a Boeing 737-100, which is specially equipped with advanced navigation and guidance equipment, displays, and flight controls necessary for conducting research (Figure 1.3). In addition to the TSRV, a sophisticated flight simulation facility exists at Langley, including the Visual Motion Simulator, or VMS, which has a jet transport cab, a six-degree-of-freedom motion base, and out-the-window visual scene (Figure 1.4).

Accomplishment of this project relied heavily on the close cooperation of numerous people within the FAA, NASA, and from Piedmont Airlines. The primary interface for management of the project was between the FAA Langley Development and Logistics Field Office and NASA Langley's Advanced Transport Operating Systems Program Office (ATOPSPO). FAA had the primary responsibility for providing: (1) approach designs, (2) instrumentation requirements, (3) test and subject pilots, (4) data reduction guidelines, and (5) general management of the project. Langley had the primary responsibility of providing: (1) simulation facilities, (2) aircraft modifications, (3) data collection and processing, (4) interfacing with Wallops Flight Facility for tracking data, and (5) scheduling of Langley and Wallops resources.

The cockpit of the VMS was modified to incorporate the same instrumentation that would be used in the TSRV during the flight test phase. The simulator's navigation algorithms were likewise modified and programmed to permit "flying" curved-path procedures as done in the aircraft. Cockpit instrumentation chosen for the display of flight path information was intended to represent what was currently in use by the airline industry, and consisted basically of an electro/mechanical flight director and horizontal situation indicator. The use of sophisticated electronic flight displays (such as those installed in the TSRV's aft flight deck) was precluded in an attempt to (1) provide an easy transition to the new MLS procedures by pilots, and

(2) help the air carriers make the necessary aircraft modifications at the least cost.

In the VMS, the parameters for each of the proposed profiles were subjected to numerous permutations, including worst-case wind conditions. Each of the 4 profiles was exhaustively flown by FAA and NASA test pilots, studying various combinations of parameters until reaching what was collectively considered to be a flightworthy set of approaches. The final versions of these profiles were then programmed in the TSRV flight computers for flight testing.

Transition from the simulator to the aircraft was accomplished with relative ease for both pilots and programmers. The flight test evolved in three phases: (1) flight systems checkout, (2) approach profile validation, and (3) data collection. All flights were conducted (with the TSRV) at NASA's Wallops Flight Facility, where a prototype Bendix MLS (having a ± 60 degree azimuth coverage) was installed on Runway 22. During the first phase, a flight check was conducted to test all modifications made to the aircraft navigation and guidance equipment to accommodate the MLS approaches. After assuring proper systems operation, each of the candidate approaches was reevaluated in flight by the same FAA and NASA test pilots who had been involved in their development during the simulation study.

Meanwhile, subject pilots had been solicited from the airline industry to participate in the data collection phase of the flight test. Piedmont Airlines responded to the request by providing volunteers from their Norfolk domicile. Over the course of the program, fourteen captains and first officers--all currently flying Boeing 737's--participated in the flight tests with the support of their Regional Headquarters in Winston-Salem. While the final versions of the profiles were undergoing validation in the aircraft, the subject pilots were training in the simulator to gain familiarity with the concept of flying curved-path approaches and learning the basic characteristics of the Microwave Landing System.

Culmination of the project was achieved when the subject pilots flew the approaches during the data collection phase. According to the Test Matrix, each of the approaches was to be flown with 48 replications in order to achieve the statistical confidence needed to reliably develop TERPS criteria. The original scheme was to have eight pilots fly an approach six times, generally in succession, to attain this goal; however, due to scheduling conflicts, additional pilots were brought in to round out the total. Data, primarily on flight technical error, was collected on the overall performance of the man/machine system. Subjective questionnaires (see sample - Appendix A) were answered by the pilots at the completion of each set of approaches, and were subsequently analyzed by Flight Standards personnel, with results compiled in Reference 2.

While in the midst of flying the curved-path approaches, the need arose within FAA to obtain information that would allow Procedures Specialists to operationally evaluate the feasibility of "steep-angle" glide paths in excess of 3.0 degrees. This requirement stemmed from the installation of non-federal, microwave landing systems by state and local governments at locations requiring a steeper-than-normal glide path due to high underlying terrain. Profile Number 1, having a 180° course reversal path and with descent beginning at the turn point, was modified to accommodate three different steep-angle glide paths of 3.5, 3.8, and 4.0 degrees.

Data collected during the flight test consisted of aircraft position data from the Wallops radar/laser tracking system and airborne flight parameters recorded onboard the aircraft. Personnel from the Systems Development Corporation (SDC), under contract to Langley, processed the data from the 432 successfully completed data runs flown by the subject pilots. The data was reduced in accordance with FAA requirements (Appendix B) which called for partitioning an approach path into 50-meter intervals and combining data from all runs of a particular profile forming a composite data base for statistical analysis. Standard statistics were calculated for the parameters relevant to flight path deviations in both the horizontal and vertical planes. The resulting data base, in the form of computer records and isocontour plots, was forwarded to the FAA Aviation Standards National Field Office for analysis and interpretation to determine obstacle clearance requirements.

2.0 SIMULATOR DESCRIPTION

Langley's Visual Motion simulator (VMS), using Boeing 737 aircraft dynamics, was employed for the profile development phase of the project and for subject pilot training. Augmenting the cockpit simulator was the Visual Landing Display System (VLDS) a terrain model board which provided the visual scene needed for landing. The flight director algorithms used in the simulator, as well as the MLS signals used for guidance, were represented by software models resident in Langley's simulation library. While each of these software packages had been developed and employed individually for prior simulation studies, this project marked the first time that all of them had been linked together in a simulation effort of this magnitude.

2.1 VISUAL MOTION SIMULATOR

The Visual Motion Simulator (VMS), shown in Figure 1.4 was a general purpose simulator and consisted of a generic two-man cockpit mounted on a six-degee-of-freedom motion base. Time lags for the simulator were on the order of 50 msec and compatible with the attendant display system. A software model of the Boeing 737's flight dynamics was programmed to drive the simulator motion base and interfaced with the cockpit controls and instrumentation systems. Motion cues were provided, in the simulator, by the relative extension or retraction of the six hydraulic actuators on the motion base. Washout techniques were used to return the motion base to the neutral point once the onset motion cues had been commanded.

The cockpit of the VMS was configured as a generic transport aircraft as seen in Figure 2.1. During the simulation runs, the development and subject pilots flew from the left seat while a researcher occupied the right seat to monitor the test and perform co-pilot duties for the subject pilot. Action of the simulator's rudder pedals, control wheel, and column was augmented by a programmable, hydraulic, control loading system. The flight deck's console provided typical transport control features and, although not used for this simulation, an auto-throttle capability with forward and reverse thrust modes. For realism, a collimated video display provided an out-the-window, color, visual scene for both seats. The display could accept inputs from several sources of image generation but, for this test, the VLDS (described below) was employed.

2.2 VISUAL LANDING DISPLAY SYSTEM

The Visual Landing Display System (VLDS), Figure 2.2, was used in conjunction with the VMS to generate a realistic landing scene for the pilots. The visual cues associated with the runway environment were deemed especially useful in providing orientation while maneuvering near the ground. The VLDS consisted of a relief-type model terrain board having features representing both metropolitan and general aviation airports. A total of five runways and a heliport were included along with appropriate approach lighting systems. Two scale factors were used to accommodate the landing of both large and small aircraft; this was necessary because of the minimum height required by the optical probe above the board surface. The major portion of the model was scaled at 1500:1, with a minor portion scaled 750:1. Terrain features were "faired-in" between the two sections to avoid a discernable change in appearance when traversing sections during long approach profiles. Overall board measurements were 60 ft. long by 24 ft. high.

The landscape was viewed by a color television camera, fitted with a rotating optical probe, and mounted on a translation system that traversed the entire model board. Lighting for the board was set to represent daylight conditions, although dusk or nighttime scenes could be programmed. An adjustable skyplate was incorporated which was used to set predetermined ceiling heights and vary the visibility conditions. A reflective surface, mounted normal to the model board and running around the perimeter, extended the apparent horizon in the televised display to infinity.

2.3 FLIGHT DECK INSTRUMENTS

The simulator was modified to include flight deck instruments that were as similar to those onboard the TSRV as possible. A close-up view of the instrument panel, Figure 2.3, shows the major instruments used in this project to conduct flight maneuvers and navigation. Predominant on the panel was a dual cue flight director (F/D) having pitch and bank steering command bars. The customary HSI was replaced with a functionally similar one having both a course indicator and bearing pointer that were capable of being servo-driven by the navigation computer. The bearing pointer, located on the periphery of the HSI, was automatically driven to point to the MLS azimuth (AZ) site on the ground. The bearing pointer was functionally analogous to that of a typical RMI (radio magnetic bearing indicator). The instrument panel also included two digital mileage readouts: one indicating "along-track distance" (ATD), i.e. the distance along the flight path to the touchdown point or ground point of intercept (GPI); the second indicating the straight-line distance to the AZ site (used primarily for orientation). Mode annunciators for the flight director indicated to the pilot which navigation mode was selected and operating. An annunciator lamp, labelled TURN, was illuminated prior to the beginning of a turn to help the pilot anticipate upcoming flight director commands. Standard electro-mechanical and pneumatic indicators were used for airspeed, altitude, vertical speed, turn and bank, and the basic engine functions.

2.4 MLS GUIDANCE MODEL

A software model of the Microwave Landing System emulated the azimuth and elevation angle coordinates needed to simulate aircraft position. "Pure" MLS signals generated by the model were subsequently corrupted with system noise errors (using the Hazeltine model) to represent the signal characteristics that would typically be received by an aircraft. This was done to ensure a more realistic simulation.

Linkage was made to the "path generation" program, wherein were stored the waypoint coordinates and flight path parameters needed to construct the various test profiles. Aircraft position from the MLS simulation program, when compared with the stored profile data, yielded deviation from the prescribed flight path. Separated into horizontal and vertical components, these deviations were used to generate the flight director commands and drive the horizontal situation indicator.

3.0 AIRCRAFT DESCRIPTION

For the flight tests, Langley's Transport Systems Research Vehicle was used. The TSRV consisted of a Boeing 737-100 airframe, powered by two Pratt & Whitney JT-8D-7 engines, to which a sophisticated experimental navigation and guidance system had been added. The aircraft required an average crew complement of 10 people for piloting and equipment operation while having a maximum seating capacity for 32 persons. Figure 1.3 shows an overall view of the aircraft's exterior while Figure 3.1 shows a cutaway view of the interior indicating the layout of all major systems. Except for minor modifications to the flight director displays, the TSRV's forward flight deck was equipped with the customary Boeing 737 flight controls and engine instruments. (A technical description of the basic TSRV systems can be found in Reference 3.)

In addition to the forward flight deck employed for this test, the TSRV had an "aft flight deck" (AFD), as shown in Figure 3.1, equipped with a complete set of operational controls. Designed for advanced flight research projects, the AFD incorporated two cathode-ray tubes for the display of primary flight information. The first one portrayed the horizontal situation and was integrated with an electronic map; the second was used to display attitude information. Control panels for the navigation and display equipment were located in the AFD, where they were operated by systems personnel during the flight test to select the approach profiles to be flown. Navigation references provided by the video map display were especially useful in positioning the aircraft at the starting point of a new run. (A research practice routinely employed in lieu of radar vectoring.)

3.1 NAVIGATION AND GUIDANCE SYSTEM

The TSRV employed a single-thread (nonredundant) system of sensors, computers, control/display units, and related peripheral equipment to determine aircraft position and compute flight director commands. An overall block diagram of the system is shown in Figure 3.2. The navigation computer unit (NCU), a Litton C-4000 computer, performed the majority of navigation and guidance computations. Inputs to the NCU came from a number of different sources: receivers for MLS, DME, and ILS/VOR, as well as the INS. Inputs from the air data computer and magnetic compass were also fed to the NCU after pre-processing in the flight control computer (FCC). The NCU was controlled by the navigation control display unit (NCDU) and the advanced guidance and control system (AGCS) control mode panel (located on the AFD). In addition to flight path deviations, roll, pitch, and speed commands were generated in the NCU which were used to drive the flight director. The NCU memory provided the capability for storing the MLS curved-path data and computing the flight path. (Advanced features of the TSRV, such as INS and the autopilot/autothrottle system, however, were not used in this test since all approaches were flown manually.)

Due to the unique programming requirements of the TSRV, the navigation and guidance algorithms used in this test were implemented in two distinct modes designated RNAV and LAND, each covering specific portions of the flight path. The RNAV mode covered that portion of flight path from the beginning of an approach until intersecting the final (straight-in) approach course at which point transition was made to the LAND mode.

When operating in the RNAV mode, aircraft position estimates were computed in the NCU based on MLS coordinates (AZ, EL, and DME) and compared with the predefined curved-path stored in memory. The subsequent flight path deviations were computed and used to drive the flight director which provided primary guidance cues for the pilot. Transition was made to the LAND mode automatically upon rolling out of the final turn on a heading closely aligned with the runway centerline. The LAND mode was derived from AUTOLAND algorithms previously designed by NASA and flown in the TSRV. In the LAND mode "raw" azimuth and elevation deviations from the MLS ground stations became the primary inputs to the flight director in lieu of the computed-path deviations employed in the RNAV mode. This implementation was deemed desirable since, by deleting the additional step of computing position, another source of failure was eliminated.

Flight path deviations, whether computed by the RNAV algorithms or from raw AZ and EL data in the LAND mode, were displayed to the pilots via indicators integral with both the HSI and the F/D. The deviation displays served to augment the F/D command information.

To accommodate these two new navigation modes in the TSRV, a number of hardware and software modifications were required in the navigation system chain in order to properly drive the subject pilot's displays in the forward flight deck. A switch designated "MLS Select" was added to the aft flight to be engaged manually when all three MLS signals (AZ, EL, and DME) gave valid indications <u>and</u> the aircraft was geographically located in a position to begin a test run. This procedure was a necessary precaution to insure proper initialization of the computers upon starting a run. A variable labeled "STEP Distance-To-Go" (commonly referred to as "along track distance" or ATD) was computed to show the distance from present position to touch down. ATD was displayed to the pilot on a digital display added to the FFD and located just below the HSI. This parameter was used by pilots in conjunction with waypoint distances shown on the approach charts to provide rapid orientation during an approach.

Some of the more notable changes made to the TSRV navigation system for the STEP flight test are noted below:

Discrete outputs computed by the Navigation Computer (NCU) and sent to the Forward Flight Deck (FFD):

TURN ANTICIPATION -- computed to indicate onset of a defined turn in the flight path (illuminates light on pilot's annunciator panel)

MLS/VHF SWITCHING -- pilot initiated selection of the guidance mode to be used in driving the flight director

GO AROUND SWITCHING -- signaling the end of an approach and transferring F/D mode, also re-initializes computations

Synchro outputs computed by the NCU and sent to the FFD:

TRUE HEADING -- to drive HSI compass card

HEADING PATH -- to drive HSI course pointer

AZIMUTH BEARING -- to drive the secondary HSI bearing pointer

Digital outputs computed by the NCU and sent to the FFD: (ARINC 561, for digital display)

STPDTG -- distance to GPI (AKA: Along-Track-Distance)

HRAD -- radio altitude

GS -- ground speed

Discrete NCU outputs sent to the Flight Control Computers:

MLS3D -- indicating 3-D guidance possible

MLS/VHF -- flight director navigation source selection

LOCFD -- flight director localizer MLS mode engaged

GSFD -- flight director glide slope MLS mode engaged

FLARE -- flare mode indicated

MLS VALID & SELECTED -- (as stated)

FCC data words added (for interchange with NCU):

DTG FCC -- distance to GPI

MLSAZ - MLS azimuth

3.2 MLS SIGNAL PROCESSING

Signals transmitted from the MLS ground stations serving Runway 22 at the NASA Wallops Flight Facility were received onboard the TSRV utilizing receivers manufactured for the FAA by Bendix (referred to as STEP series). (The geometry of the Wallops MLS ground installation is described in Chapter 6.)

The primary MLS signals consisted of azimuth angle (AZ), elevation angle (EL), and precision range (DME/P) data. Angle data referenced to the MLS AZ and EL ground stations was available on the digital output bus of the airborne MLS receiver. Range (i.e. distance) information was derived from a DME/P interrogator onboard the aircraft and was referenced to the precision DME transponder co-located with MLS AZ ground station. Both angle and range data were required in order to compute aircraft position along the curved paths. Together, these two sets of data were used to feed the navigation and guidance system. A conventional CDI and DME indicator were located on the safety pilot's panel, along with the MLS control head, to monitor the MLS for reception of (raw) azimuth and elevation data and proper station selection. (The safety pilot's CDI display operated directly from the analog outputs of the MLS angle receiver without processing through the NCU, and thus could not be used for curved-path navigation.)

A data translator unit (DTU) was required to interface the digital MLS data with the TSRV navigation system which, otherwise, could not accept the MLS digital data bus inputs without extensive modifications. The primary purpose of the DTU was to multiplex the data streams coming from the MLS angle and DME/P receivers and format them properly for use by the Flight Control Computer (FCC) in order to compute position. Additionally, the DTU provided an extensive monitoring capability for the digital AZ, EL, and DME/P signals.

Angle and range data (transmitted by the MLS ground system in conical coordinates) were converted, by the FCC, to rectangular coordinates in order to calculate MLS-based estimates of position, velocity, and acceleration. The position parameters were subsequently transformed into values representing latitude, longitude, and altitude for input to the navigation computer. Flight path tracking errors were computed in the NCU by comparing aircraft position with the stored approach-determined profile. The resulting lateral and vertical error signals were used as inputs to the flight director for generating roll and pitch steering commands and flight path deviations.

The MLS subsystem is shown in block form in the upper left-hand portion of Figure 3.2. Two sets of antennas were used on the TSRV for angle and range reception, one set mounted on the fuselage section just above the cockpit and the second set mounted on the lower fuselage section aft of the cabin (see Figure 3.3). Automatic antenna switching was provided to prevent loss of coverage on the profiles requiring turns away from the runway. Circuitry in the MLS angle receiver continuously sampled the signal levels present at both the forward and aft antennas during the transmission of each azimuth data function. An antenna-select command was generated which switched both the angle receiver and the DME/P interrogator to the pair of antennas receiving the stronger signal. (A DME/P receiver with independent switching was unavailable in time for the test, hence, a suitable device was fabricated to switch DME/P antenna simultaneously with the angle receiver.) In processing the MLS signals, no corrections were made for differences in position attributed to switching antenna locations, cable length, or the rotational dynamics involved with flight maneuvers. (Reference 3 provides additional detail on the MLS signal processing functions.)

While some filtering of the MLS signal was routinely performed in the angle receiver, additional filtering was performed in the FCC. Here the signal first passed through an α-β prefilter and then through a third-order complementary filter. (The complementary filter was retained since major software changes would have been required in the TSRV computer programs to eliminate it.) Proper initialization of the complementary filter was dependent on an input parameter for aircraft acceleration which in prior tests had been supplied by the inertial navigation system (INS). While the TSRV carried INS equipment onboard, its use was prohibited in this test due to the feeling (prevalent at the time) that, in order to make the flying of MLS complex approaches a viable option for conventional jet transports, implementation should not be based on INS equippage. Therefore, in lieu of acceleration data from the INS, a suitable parameter was synthesized using data available from other onboard sensors. Provisions were made to use a body-mounted accelerometer in the event the synthesized data was inadequate. Comparisons made during the systems checkout phase of the flight test showed no significant differences between the three methods (synthesized, INS, or accelerometer) which would have contributed adversely to the manual flyability of any of the approaches.

MLS azimuth and elevation path deviation sensitivities, associated with the indicators on the flight deck instruments, were patterned after those used for ILS.

Angular deviation limits (i.e., an ever increasing course width as the distance from the AZ and EL antenna sites increases) were followed out to the point where linear course width limits were defined. (See illustration, Figure 3.4.) In the azimuth plane, course width was "tailored" to provide a full scale needle deflection of ±2 dots at a distance of ±350 feet either side of the runway centerline at the threshold. This formed the basis for an angular sensitivity of ±1.85 degrees which extended from the azimuth site out to the point where a course width of ±1,500 feet (for ±2 dots) was reached. From this point outward to the starting point on the approach, course width remained constant. Similarly, in the elevation plane, vertical sensitivity was established at ±0.75 degrees, which provided full-scale needle deflection from the elevation site until a (vertical) path width of ±500 feet (for ±2 dots) was attained. From this point on, the vertical width remained constant.

3.3 FLIGHT DIRECTOR AND COCKPIT DISPLAYS

The flight director (F/D) employed for this test was a hybrid design which combined a commercial Sperry Z-14 F/D with an experimental F/D algorithm resident in the NCU. Commands for the non-MLS modes, such as heading hold, altitude hold, and go-around, were generated in the Sperry unit while the curved-path guidance commands were generated by the NCU software. Logic and gain schedules for this algorithm were analogous to those found in commercial DC-9 and B-737 flight directors. To retain the navigation features of the original TSRV flight director for use in other projects, a mode/source switch was added to select either "MLS" - for MLS guidance, or "VHF" - for ILS/VOR guidance. A functional block diagram of the flight director implemented for this test is depicted on the right-hand side of Figure 3.2, while Table 3.1 lists the flight director modes and associated signal sources.

The NCU flight director algorithms (for both the pitch and roll axes) were implemented in two stages: an RNAV mode and the LAND mode, as described in Section 3.1. The algorithms used for the roll axis are depicted in Figure 3.5 including both the RNAV and the LAND modes. In a similar manner, Figure 3.6 describes the algorithms used in the pitch flight director, again showing both modes. Configuration and operation employed in the aircraft were essentially identical to that used in the simulator.

With respect to the cockpit displays in the TSRV, only minor modifications were made to an otherwise conventionally-equipped instrument panel. The main change was to replace the existing Sperry HSI with a similar unit, an Astronautics AQU-2/A, having a remote course select capability. This feature permitted automatic slewing of the course arrow so that it would remain properly oriented with respect to the desired course while negotiating a curved path. In addition, the AQU-2/A incorporated a slaved bearing pointer which was driven to indicate the relative bearing to the MLS azimuth ground station at all times when in MLS coverage.

The subject pilot's annunciator panel was modified to display the new MLS flight director model instead of the aircraft's previous autopilot modes. The "RNAV" or "computed-path" mode was indicated by illuminating the "MLS C/P" annunciator when flying along non-centerline segments; illumination of separate "AZ" and "EL" indicators (while extinguishing "MLS C/P") showed that transition had been made to the "LAND" mode. In addition to calling attention to the fact that a mode change-over had been accomplished, this distinction gave visibility to the status of the individual MLS ground stations. It was felt that separate indicators would be desirable should the need arise to accommodate an AZ-only approach in the event EL data was lost on short final. (This was envisioned to serve the same function as the "localizer-only" approach does in today's ILS-operational scenario.) A "TURN" annunciator was included to alert the pilot that a (computed) turn was about to commence when operating in the RNAV mode. A detailed view of the primary pilot displays is shown in Figure 3.7.

A multi-purpose digital display was added directly beneath the HSI to read either: (1) the computed "along-track distance" (ATD); (2) the straight-line distance to the DME/P site; or (3) the height above GPI, in feet. The display function was selectable by the pilot, but generally was set for a continuous readout of ATD.

3.4 AIRBORNE DATA ACQUISITION SYSTEM

All airborne flight parameters were recorded onboard the aircraft using the TSRV's data acquisition system (DAS). The heart of the DAS was the "piloted aircraft data system" (PADS) designed and built by Langley Research Center, capable of accepting and digitizing up to 104 analog signals at a 40-sample per-second rate. Signals for recording came from the navigation and guidance system, the flight control interface, and from dedicated instrumentation transducers located throughout the aircraft. A patch panel was used to select the desired airborne sensors. Digitized signals (9-bits) from the sensors were formatted into a serial pulse code modulation (PCM) data stream and recorded on a wideband magnetic tape-recorder utilizing one of four available tracks. Data from the flight-control computer (capable of 82 channels at a 20 Hz rate) and the navigation computer (capable of 32 channels at 8 Hz) were recorded on the three additional tracks. The entire list of parameters selected for recording is tabulated in Table 3.2.

After each flight, a set of key parameters from the airborne data tape were processed through the Research Aircraft Ground Station (RAGS), at Langley, where a "quick-look" capability was used to scan the data to assure that no gross errors or data dropouts were encountered. All channels requiring calibration or scaling were subsequently processed through the RAGS facility and reformatted making them compatible with the formal data reduction routines.

Parameters from the RAGS tapes, along with the data contained on the remaining three tracks of data on the original airborne tapes, were later merged with the Wallops radar tracking tapes to produce a comprehensive time-history tape for each flight. This tape, recorded at a 20 Hz rate, was used for the statistical processing (see Section 7).

Additional data on the TSRV's airborne data system can be found in Reference 4.

4.0 PROFILE DEVELOPMENT AND SIMULATOR EVALUATION

During the flight simulation phase of the project, the four profiles and their associated parameters were sequentially analyzed using a flow-charted process depicted along with the respective profiles in Figures 4.1-4.4. Specific parameters were identified within each of the candidate profiles, such as turn rate, bank angle, segment length, and parallel offset distance which required definition prior to further development of Terminal Instrument Procedures Standards (TERPS). (It was envisioned that selected parameters drawn from each of these profiles could be combined to accommodate most approaches anticipated in the near future.) Together, FAA operations inspectors and NASA test pilots sifted through a myriad of flight path parameters to determine those that should be considered for actual flight testing. The flexibility afforded by the simulator permitted a methodical progression through the various combinations.

Strip chart recordings showing pilot performance were compared and evaluated after each of the simulator runs. Subjective comments, relating the "flyability" of the approaches, were discussed among the test pilots and Flight Standards personnel. Where necessary, modifications where made to the profiles which were subsequently retested. This iterative process continued until everyone was in agreement as to a final set of values. Tables showing the final parameter values resulting from the simulation are included with each profile depiction.

Each of the profiles will be discussed in detail following a brief discussion of some of the limitations placed on the flight tests and the methods used for path construction. It should be noted that throughout the simulation phase every effort was made to retain flight test fidelity.

4.1 TEST CONDITIONS

In the attempt to make the flight tests as useful as possible while constrained to one particular aircraft, a carefully thought-out set of aircraft performance requirements was formulated. In deference to the vehicle chosen, aircraft operations were conducted at the high end of the FAA's approach "Category C" speed range to render the results of this test as applicable as possible to a wide range of aircraft. Flights were planned for an approach airspeed of 140 knots on the downwind leg (relatively fast for the 737) with full flaps deployed.

On all approaches decision height (DH) was set at 200 feet and the touchdown zone located approximately 1,000 feet down the runway. Approaches would terminate in one of three ways, either in: (1) a go-around initiated at the DH, (2) a low approach, or (3) a landing; the particular scenario called by the safety pilot at DH according to a prearranged sequence not known to the subject pilots. Missed approaches were executed manually by flying along the runway heading and climbing to 2,000 feet. At this point the run was terminated and a left turnout made to set up for the next approach.

To simulate the lateral navigation position errors anticipated during routine transitioning from radar vectors to MLS guidance, intercept of the approach path was offset by 0.8 n.mi. for all of the approaches - during both simulator and flight tests. Flight test runs were initiated using barometric altitude settings requiring pilots to make the (vertical) transition to MLS-derived altitude upon entering the MLS coverage area.

To corroborate the MLS algorithms being used in the simulator with the actual MLS coverage limits at Wallops, several preliminary flights were made with the TSRV using a rudimentary version of Profile No. 1 and the pre-existing MLS equipment onboard the aircraft. Flying the profile in a reverse direction confirmed that MLS azimuth coverage existed out to approximately 61 degrees. However, when flying the approach in the proper direction to verify the time required to initialize the TSRV's RNAV computer algorithms, upon entering MLS coverage, an unforeseen problem was discovered. The initialization process required approximately 10 seconds after receiving valid signals from all three components of the MLS (i.e., AZ, EL, and DME ground stations).

The fact that all three signals were simultaneously required to compute valid navigation solution posed a problem in designing several of the approach profiles. Since the AZ and EL MLS ground sites were physically separated by approximately the length of the runway (9,218 ft.), it was not possible to receive the EL signal reliably until the aircraft reached an area falling between 44 and 55 degrees of AZ coverage while on the downwind leg (the actual angle was dependent on the lateral offset distance from the runway). This imposed a particular hardship on Profile No. 1, which was based on a 180-degree turn and required early acquisition of MLS guidance. To achieve a consistent starting point, the decision was made to begin an approach upon intercepting the 60-degree radial downwind of the EL site. (Accomplishment of this technique involved having the navigation engineer manually inhibit MLS computations until reaching a designated "start" point for each approach.)

As an unfortunate consequence of this system design, it was necessary to lengthen the downwind segment of Profile No. 1 by 1.5 n.mi., which had the result of increasing the final runway centerline segment by an equal length. Profiles 2, 3, and 4 were not so encumbered since they received reliable EL coverage on all portions of their paths.

4.2 CURVED-PATH GUIDANCE TECHNIQUE

The approach profiles were defined using "curved-path" construction techniques which, for the lateral path, consisted of straight line segments connected by circular arcs around waypoints where turns were required. The circular arcs were an integral part of the path, yielding a single, precise path over the ground for all aircraft. For a turn, an arc of fixed radius was struck from a point located along the line bisecting the angle formed by the intersection of the two straight-line segments. (See Figure 4.5A.) A radius of 8,464 feet was chosen based on previous flight tests and verified in the simulator.

In the vertical plane, a constant-angle glide path was computed for the entire approach starting at the descent point (labelled FAP on the charts) and continuing to touchdown. The actual ground path distance (i.e. ATD), measured around the curves, was used in the calculations. (Round earth coordinates were employed in all path computations.)

The lateral and vertical position errors (LAT DEV and VERT DEV, respectively) were defined as perpendicular displacements from the flight path and were ultimately used to drive the flight director. Lateral errors were computed and displayed with respect to a smooth continuous path with the HSI course arrow always indicating a heading tangent to the desired course, and the deviation needle remaining centered when on course in a turn. (Figure 4.5 gives a sequential portrayal of the instrument displays for curved-path guidance around a turn.) Vertical deviation was calculated and displayed with respect to a constant-angle glide path, beginning at the descent point (FAP) and continuing to the ground point of intercept (GPI).

The calculations for LAT DEV and VERT DEV are shown along with the design equations for the various approach paths in Appendix C.

4.3 CURVED-PATH APPROACHES AND SIMULATOR RESULTS

Profile Number 1

Approach Profile Number 1 (Figure 4.1A) consisted of a 180-degree turn to a final centerline intercept while descending on a 3-degree glide path. The accompanying flow chart (Figure 4.1B) was used during the simulator sessions to step through the various design parameters.

This profile was primarily designed to determine where the descent point, designated the "final approach point" or "FAP" on the charts, should be located. Three different scenarios were examined with the FAP located (1) prior to the turn point (TP), (2) coincident with the TP, or (3) after the TP. The intent here was to see if any significant differences were encountered between the different techniques when making a descent along a curved path.

Additionally, the profile was used to investigate the minimum time required to capture the MLS signal and receive positive course guidance upon entering the coverage and prior to commencing the approach. The minimum time required between the task of initiating path tracking and starting a descent and/or making a turn was likewise investigated.

The optimum turn rate for normal operations (in association with determining the nominal turn radius) was also studied during the simulator evaluation of this profile. Since operational constraints, based on maximum permissable bank angle and aircraft category, generally fix the minimum turn radius, the value selected for this profile remained the same for all turns in subsequent profiles.

Simulator findings showed that the minimum "time in coverage" required to capture the MLS signal and become established on course was 95 seconds prior to reaching the final approach point (FAP) or the turn point (TP). With respect to the time interval required between maneuvers, 25 seconds was found to be marginally acceptable for transitioning between the FAP and TP or vice versa; 45 seconds, however, was preferred. Pilots voiced a preference for having the FAP precede the turn; however, no problems were encountered when the FAP and TP were coincident.

Maximum bank-angle and turn-rate determinations were based on the results of previous tests conducted by the Air Force between 1975 and 1977, which indicated that a turn rate of 2.25 degrees/second was feasible. (This yielded bank angles which never exceeded 30 degrees - Reference 5.) The steepest bank angles encountered were the result of the maneuvering required to intercept the approach course upon entering the MLS coverage area from en route navigation or radar vectors. A turn rate of 1.8 degrees per second was initially tested which was subsequently varied until an optimum rate was found following the flow-charted procedures in Figure 4.1B. Considerable emphasis was given to finding a value that would sustain the aircraft in a stable condition during an approach encountering a maximum crosswind component of 50 knots. Turn rates higher than 1.8 degrees per second were not tested, since it was felt that bank-angle margins would be exceeded in coping with the high crosswinds. Based on the simulation results, a turn rate of 1.6 degrees per second was considered to be optimum by the test pilots.

The resulting three subprofiles became known as "CP181," "CP182," and "CP183" to distinguish between the various descent locations. They are respectively portrayed in approach chart form in Figures 4.6-4.8.

Profile Number 2

Approach Profile No. 2, Figrue 4.2A, consisted of a 90-degree (base-leg) turn to intercept the runway centerline with the FAP located along the approach course 90 degrees to the runway heading. The profile was designed to determine the minimum and optimum times required along the runway centerline segment prior to touchdown. These segments were designated minimum and optimum centerline segments, MCLS and OCLS, respectively.

Two imprortant questions were addressed by this profile: (1) what was the minimum segment length that could be used to gain an operational advantage, and (2) what was an acceptable (optimum) segment length to be used as a practical limit in the design of a typical approach. The flow chart, Figure 4.2B, was used as a guide for varying times on the final approach segment during simulator analysis.

The method used to accomplish this objective was to fly a profile having a 90-degree intercept to the final approach course (FAC). The initial intercept point tested was based on a wings-level distance along the FAC 0.4 n.mi. (or approximately 10 seconds) prior to DH using the optimum operational turn rate determined for the first profile. Successive intercept points varied the segment time by 15 seconds (approximately 0.6 n.mi.) outward or 5 seconds (0.2 n.mi.) inward until the minimum flyable segment was established. The minimum segment length was then increased as required to establish the optimum segment length.

Findings from the simulator test showed that an absolute minimum time of 60 seconds was required along the runway centerline segment prior to DH and that 90 seconds was considered nominal. Centerline segment distances corresponding to 3 and 4 n.mi. were ultimately chosen for the airspeeds used in these tests.

The resulting two profiles used in the flight test were designated "CP901" and "CP902," respectively; see Figures 4.9 and 4.10 for the approach charts used.

Profile Number 3

Approach Profile No. 3, Figure 4.3A, consisted of two turns along the final approach course, first a 120-degree turn for course reversal followed by a straight non-centerline segment (NCLS) and a 30-degree turn to intercept the runway centerline. This profile was designed to determine the minimum time required between consecutive turns while descending on the glide path. It also was used to reevaluate the time-in-coverage requirement previously looked at in Profile No. 1.

Design of this profile was based on the aircraft entering MLS coverage at a distance sufficient to acquire valid MLS signals, establish the descent, accomplish the 120-degree turn, and fly a straight non-centerline segment prior to making final turn (30 degrees) onto the extended runway centerline (ERCL). At no time was a bank angle of 30 degrees to be exceeded. Using the flow-charted procedures in Figure 4.3B, the time alloted to fly the NCLS was intially chosen to be the same as that determined for the MCLS in Profile No. 2. This time increment was subsequently varied, increasing in 15-second increments or decreasing in 5-second increments, until the minimum NCLS time was established. The same value for MLS "time in coverage" determined during Profile No. 1 testing was used for entry.

Two versions of profile No. 3 were tested in the simulator, the first having the FAP located prior to the TP and the second with the FAP following the TP. This was done to determine whether or not a particular case would cause a change in NCLS length.

Considering the findings from Profile No. 1 for placement of the final approach point and the turn point with respect to each other, a case could not be made for flying both variations. Thus, the profile was implemented having the FAP prior to the TP.

Simulator findings for Profile No. 3 showed the minimum time required between successive turns (while descending on the glide slope along a non-centerline segment - NCLS) to be 25 seconds; a value of 45 seconds was considered to be the optimum value. For flight test, a segment length of 0.9 n.mi. (corresponding to 25 sec.) was used for the NCLS. Time-in-coverage was reevaluated and confirmed the value of 95 seconds, found for Profile No. 1.

This profile was designated CP131 and the approach chart used for flight test is shown in Figure 4.11.

Profile Number 4

Profile No. 4, Figure 4.4A, consisted of a "parallel offset" approach with transition to the extended runway centerline accomplished by making a pair of opposing or reverse turns of equal magnitude. The approach was designed to determine the minimum and maximum intercept angles to the runway centerline, and was tested with and without a straight non-centerline segment (NCLS) between the pair of reverse turns.

A fan of intercept angles varying from 15 to 90 degrees was tested during the simulation sessions utilizing the parameters previously chosen for the optimum turn rate, OCLS, and NCLS. Parallel offset approaches with angles of 15, 45, 75, and 90 degrees were flown and all except the 15-degree approach were acceptable. While flying the minimum offset angle of 15 degrees, centerline capture occurred prematurely due to the close proximity of the offset and centerline courses.

The length of the intermediate or noncenterline segment was studied using different wind vectors to judge their effect, per the flow chart, Figure 4.4B. Tests for the minimum time required on the intermediate segment between reverse turns was determined to be 60 seconds. A 10-second NCLS was attempted and found to be too short, therefore, the 25-second NCLS was reinstated as used for Profile No. 3. (The turn rate, 1.6 deg./sec. as previously determined, was considered to be adequate for this approach.) Initial intercept of the offset path, itself, was made at an angle of 60 degrees to the parallel course; this technique was introduced to determine the time required on the intermediate NCLS prior to FAP or TP.

This profile was designated CPSO1. The approach chart shown in Figure 4.12 was used in the flight test.

4.4 STEEP-ANGLE APPROACHES

The steep-angle approaches were designed to look at the maneuverability of a typical transport aircraft on a variety of glide-slope angles starting at 3.5 degrees and progressing to a maximum operational angle determined from the simulator evaluation. A flow chart giving the variations used in the simulator study is shown in Figure 4.13. Based on this simulator evaluation, 3 nominal values were selected for flight testing: 3.5, 3.8, and 4.0 degrees.

Four approaches were flown for each of the three angles by eight subject pilots for a total of 96 approaches. To accomplish the maximum number of approaches in a given time period, the lateral path of Profile No. 1, CP182 (Figure 4.2) was used since it returned the aircraft to the starting point in the most expedient manner. The entry altitude was increased for each angle tested as neccessary to intercept the glide slope at the final approach point (FAP). The following items were taken into account in determining the maximum angle during simulation:

- Flyability of the approach
- Airspeed/groundspeed/vertical-velocity envelope
- Segment lengths
- Decision height
- Landing dispersion
- Height loss on initiating a missed approach
- Sensitivity of the FD
- Engine response

For the three angles selected, all were determined to be practical candidates for the flight test. However, reservations were held with respect to the 4.0-degree glide slope which had descent rates often greater than 1,000 feet per minute. There was a feeling that this approach angle might exceed the pilot's workload limit.

4.5 RIVER APPROACH

To demonstrate the overall utility of MLS in meeting a "real-world" problem, the "River Approach" to Washington National Airport was programmed for testing in the simulator. See Figure 4.14. Several variations of the River Approach were programmed in the TSRV aircraft and flown at the Wallops Flight Facility. The variations allowed for both manual, hands-on, flying of the approach as well as an automatic flight mode. Although the approach presented a heavy workload for the pilot and required additional attention by the copilot, the hands-on version was determined to be feasible to fly. Several attempts were made to fly the actual River 18 Approach at Washington National, but each was thwarted by an opposing traffic flow at the airport. Scheduled repairs to the aircraft precluded any further experimental flights.

4.6 APPROACH CHARTS

Distinctive approach plates were designed for this test which depicted the curved paths in three dimensions and applied the new terminology associated with MLS. Terms such as "AZ" and "EL" (for azimuth and elevation, respectively) replaced the customary ILS terminology of "localizer" and "glide slope."

On the curved-path charts the turn point (TP) and rollout point (RP) were marked by distances associated with "along-track distance" on both the plan and profile views. The designation "final approach point" (FAP) replaced the terminology "final approach fix" (FAF). Throughout the flight tests, the approach plates were evaluated by the subject pilots and were generally well liked. Final versions of the charts are depicted in Figures 4.6-4.12.

4.7 SUBJECT PILOT TRAINING

Each of the subject pilots chosen to fly in the data collection phase received two sessions (a total of approximately 4 hours) of training in the simulator. This practice time was useful for introducing the concept flying of curved-path approaches and acquainting the pilots with the fundamentals of MLS operation and its terminology. Sufficient time was allowed for each pilot to feel comfortable with the profiles prior to flying in the aircraft. Table 4.1 shows the sequence of profiles and wind conditions flown for practice by the subject pilots.

5.0 FLIGHT TEST AND DATA COLLECTION PHASE

During the flight test phase of this study, conducted at NASA's Wallops Flight Facility, data was collected on the seven curved-path and three steep-angle approaches. The flight test entailed recruiting a cadre of subject pilots to fly each of the approaches a number of times in NASA Langley's Boeing 737 (TSRV) while data on flight track dispersions was recorded. In making the test relevant to present-day practices, subject pilots were sought having backgrounds which encompassed a wide range of experience. Also the flight test aircraft was deployed with controls and instrumentation similar to what is found in conventional jet transports. The flight test progressed through three stages: aircraft systems modification and checkout, approach profile validation, and data collection.

The first stage involved making the necessary modifications to the aircraft navigation and guidance system to accommodate the flying of curved paths. A description of the aircraft subsystems (navigation computer, flight director, and data collection subsystems, as modified) was reported in Chapter 3. A number of checkout flights were flown to make sure the experimental flight systems aboard the TSRV were fully functional and capable of sustaining the curved-path procedures. This series of flights was flown by NASA test pilots. Time was also allocated for final checkout of the airborne and ground-tracking data systems prior to the actual data collection flights.

During the "profile validation" stage, the profile parameters obtained during the simulation phase were validated in flight by four test and evaluation pilots, two from NASA Langley and two from the FAA. They checked the profiles for any discrepancies in areas pertaining to: time in MLS coverage (assuring a stabilized condition prior to beginning an approach), location of the final approach (descent) points, turn points, turn rate, and the adequacy of the experimentally determined path lengths for both centerline and non-centerline segments. A final determination on the suitability of each profile was made by the evaluation pilots prior to release for flight by the subject pilots.

Original plans for the "data collection" stage of the flight test, called for eight airline pilots to fly the candidate profiles in accordance with the statistical confidence requirements set by the FAA. This entailed having every subject pilot fly each of the curved-path and steep-angle approaches six times, generally in succession. As the flight test progressed, additional Piedmont pilots were indoctrinated and put in the cockpit to support the data collection effort, replacing their peers whose airline commitments interposed.

The data gathered during this flight test was the first statistically meaningful data base of its kind ever collected. As such, it will be used to establish obstacle clearance criteria to further the development of Terminal Instrument Procedures Standards (TERPS) for MLS approaches as applicable to jet transports having conventional instrumentation.

5.1 GENERAL FLIGHT TEST PROCEDURES

A detailed flight test plan was prepared in advance of each deployment, defining the approach profiles and procedures to be used for individual test runs. Prior to flying, the subject pilots and crew were briefed on the objectives of the day's flight, during which time any questions were answered in regard to the approaches and test procedures contained in the flight plan.

The special approach charts, previously described, depicting the curved paths were used for reference by the subject pilots during the test. Subject pilots, wearing hoods to restrict outside visual cues, flew all approaches manually making use of the flight director, HSI, and supporting instruments for reference. "Along-track-distance," prominently shown on the charts and indicated by a digital readout on the panel, was the key parameter used for profile orientation during the approaches. The bearing pointer on the HSI (remotely slaved to indicate the relative bearing to the MLS azimuth ground station) was deemed especially helpful in maintaining a general situational awareness with respect to the runway location throughout the approach.

All approaches terminated in one of three ways, either by: (1) executing a missed-approach procedure at Decision Height (DN), (2) making a low approach, followed by a wave-off or (3) continuing to a landing. The determination of how an approach would end was made in advance and announced to the subject pilot at an appropriate time in order to minimize complacency due to the repetitive nature of the runs. Most of the runs (approximately 80%), terminated by having the safety pilot call for a missed approach; approximately ten percent of the runs ended in an actual landing, and another ten percent in a low approach.

For the purposes of expediency, the published missed-approach procedures indicated on the charts were not used. Instead, the pilot was instructed to maintain runway heading and climb to an altitude of 2,000 feet. After reaching the desired altitude, a left-hand turn was made and the safety pilot took over control of the aircraft and proceeded to position the aircraft for the next run. Preparation for the start of a run was accomplished with assistance from personnel in the TSRV's aft flight deck who provided heading vectors, for the pilot to navigate by, based on the electronic map displays which portrayed the approach paths and navigation aids.

During the time the aircraft was being maneuvered in preparation for the next approach, the subject pilot answered in a brief questionnaire on the approach just completed. At the conclusion of all slated runs for a given profile, each pilot answered a more comprehensive questionnaire. The short questionnaires answered after each run served as refreshers for the longer form. At the end of a day's flying, the subject pilots were debriefed at Langley where they were encouraged to discuss any problems or items not addressed by the questinnaire. Videotapes made from the aft flight-deck video displays were available for review and served as a stimulus for discussion during the debriefing session.

5.2 SUBJECT PILOTS AND FLIGHT CREW MEMBERS

The data collection phase relied heavily on the efforts of the captains and first officers from the Norfolk hub of Piedmont Airlines who voluntarily served as subject pilots. It was desired to involve pilots whose backgrounds encompassed a wide range of experience and flight time so that conclusions drawn from the flight test would be based on "average" pilot ability. This was expected to provide a better overall estimation of any difficulties that might be encountered while flying curved-path approaches. Individual subject pilots' qualifications are shown in Table 5.1; the minimum requirement established for pilots was that each be actively flying B737-type aircraft.

Prior to flying approaches in the TSRV for data collection, the subject pilots were given individual briefings on the primary objectives of the test, on the peculiarities of the cockpit displays, and on MLS in general. Afterwards, they were given the opportunity to fly the profiles in the simulator to get a feel for flying curved-path approaches using MLS guidance.

For all flights in the TSRV, a NASA safety pilot occupied the left-hand seat of the aircraft while the evaluation or subject pilots flew the approaches from the right-hand seat. (Only the flight director right-hand side of the cockpit had been modified to display the computed MLS command information.) The safety pilots were responsible for ferrying the airplane to and from Wallops and for maneuvering the plane into a position for the start of each data run. The NASA safety pilot performed the customary copilot duties for the FAA evaluation pilots during the pretest phase and for the Piedmont subject pilots during the data collection phase. The safety pilot also handled ATC communications, checklists, and other cockpit duties. At the conclusion of a day's flight, the NASA pilots remained on hand to assist the subject pilots during the debriefing session.

An FAA test observer was present in the cockpit during the tests to monitor the approaches and record any discrepancies. He also administered the subject pilot questionnaires and conducted debriefing sessions.

NASA personnel in the TSRV's aft flight deck operated the experimental avionics systems, selected the profiles to be flown, and recorded the airborne data. They also had the responsibility for coordinating and communicating with Wallops project personnel on the ground.

5.3 TYPICAL FLIGHT SCENARIO

The following flight procedures were generally adhered to during both the profile evaluation and data collection phases of the test:

A. Initial Set Up: The aircraft was flown "down wind" by the safety pilot and roughly positioned for the start of a run using pseudo radar vectors given over the intercom from personnel reading the electronic map displays in the aft flight deck. Once a heading was secured that would allow interception of the approach path control was passed to the subject pilot. This occurred near the starting point of the procedure, designated "SP" on the profile charts. The starting point was intentionally offset 0.8 n.mi. laterally to either the left or right of the MLS approach path to simulate worst case ATC radar vectoring errors.

Aircraft Configuration at Entry:

Gear -- up
Flaps -- 15 deg.
IAS -- 160 kts.

Flight Director:

RADIO --Position manually selected, arming F/D for "RNAV" mode. Aircraft continues to fly as configured in "altitude/heading hold" mode until reliably capturing the MLS signals.

(Refer to Figure 3.7 for F/D and annunciator layout and Table 3.1 for F/D logic.)

Annunciator Indications:

HEADING and ALTITUDE -- Green (engaged)
MLS C/P, AZ, and EL -- Amber (armed)

B. Start Point (SP): Upon entering MLS coverage and having confirmed reception of valid MLS signals, the flight director would command a roll ("fly left" or "fly right") providing guidance for making the transition to the MLS approach course. A pitch command ("fly up" or "fly down") could also be expected, resulting from the transition to MLS-derived altitude after flying the initial approach using barometric altitude.

Annuciator Indications:

HEADING and ALTITUDE -- Extinguished
MLS C/P -- Green (indicating a RNAV, i.e. computed-path, mode engaged)
AZ, EL -- Amber (armed)
Along-Track Distance -- Readout "Alive" (counting down the distance, in n.mi., to the GPI)

C. Final Approach Point (FAP): Approximately one mile prior to the FAP (or when a one dot vertical deviation was noted prior to glide-slope intercept) the aircraft was configured for flying the approach:

Gear -- Down
Flaps -- 25-30 deg.
IAS -- Slow to 140 kts.

D. Turn Point (TP): Five seconds prior to reaching a turn point depicted on the chart (identified by along-track distance) the turn would be announced by illumination of the turn anticipation light and followed by a flight director command for the turn.

Flight Director:

Bank steering bars indicate appropriate roll command for right or left turn.

Annuciator Indications:

MLS C/P -- Green (RNAV mode engaged)
TURN -- Green (illuminated 5 seconds prior to F/D command for initiating a turn and throughout turn)

E. Roll-Out Point (RP): When rolling out of an intermediate turn the F/D would command a return to course and the TURN light would be extinguished.

When rolling out of the last turn onto the final centerline segment, the flight director control algorithms transitioned from the "RNAV" mode to the "LAND" mode. This allowed the aircraft to navigate the runway centerline and glide path using raw AZ and EL data without relying on a computed solution for aircraft position.

Flight Director:

LAND mode automatically engaged after rolling out of final turn and meeting criteria for final segment capture. Flight guidance now referenced to (raw) AZ and EL deviation data.

Annuciator Indications:

TURN -- Extinguished (at roll-out point)
AZ and EL -- Green (LAND mode engaged upon joining the final straight segment)
MLS C/P -- Extinguished (cancelling RNAV mode)
FLARE -- Amber (armed)

Cockpit Procedures:

Landing Checklist -- Executed
Normal Call-outs -- Executed
Reset HDG Bug for Go-around

F. Decision Height (DH, 236 Ft. MSL): At the decision height the subject pilot was instructed to (1) execute a missed approach, (2) continue for a low approach with a last minute wave-off, or land. (This was done according to a predetermined sequence unknown to the subject pilot).

G. Missed Approach: Upon executing the missed approach option, the aircraft was configured and flown as follows:

Flight Director -- Follow command once reset with palm switch
EPR -- 1.8
Flaps -- 15°
Positive Rate of Climb -- Gear up
Climb on runway centerline to 2,000 feet and initiate left turn

At the end of the missed approach procedure, control of the aircraft was given back to the safety pilot to set up the next run, while the subject pilot filled out a short questionnaire on the approach.

6.0 GROUND SUPPORT SYSTEMS

All flight testing was done at NASA's Wallops Flight Facility (formerly Wallops Flight Center) located on Virginia's Eastern Shore. The airport is operated primarily to assist in NASA's aeronautical research and development programs; thus it had the requisite facilities to conduct this test, including an MLS ground system, radar/laser tracking system, the project coordination facilities. In addition, the airport had all of the essential safety and support equipment found at both civilian and military airports. An ASR-7 Airport Surveillance Radar is also located on the field with display and controls remoted to the Project Control Center. Figure 6.1 shows a composite view of the airport detailing the runway and service facilities.

6.1 MLS GROUND STATION

A Bendix pre-production Microwave Landing System was installed on Runway 22 at Wallops. The MLS employed the ICAO standard "Time Reference Scanning Beam" (TRSB) format current at the time of the test, and was configured as a "basic-wide" system (implying a wide AZ antenna aperture yielding a narrow, more precision, beam). The signal coverage characteristics of the system were as follows (see Fig. 1.1 for illustration):

Azimuth -- ±60 degrees
Elevation -- 1.52 to 20 degrees
Range -- 0 to 20 nautical miles
Beamwidth -- azimuth -- 1 degree
elevation -- 1.5 degrees

Figure 6.2 shows the location of the azimuth, elevation, and precision DME components with respect to the geometry of Runway 22.

6.2 AIRCRAFT TRACKING

Tracking services were provided by the Aeronautical Research Radar Complex (ARRC) which is located northeast of the intersection of Runways 10-28 and 17-35 at Wallops. The ARRC offered a host of tracking and data services for flight research, including the FPS-16 radar/laser tracking system (LTS) used for these tests. Figure 6.3 shows a block diagram of the overall ARRC capabilities.

The FPS-16 radar and laser tracker were co-located and shared a common rotational mount. Together, they were capable of tracking the same target (in this case, the TSRV) with each generating independent range information. "Angular" data for the azimuth and elevation planes were derived from sensors located on the mount; hence, these data were common to both laser and radar computations. "Angle-error" signals, which controlled the directional rotation of the mount, were derived independently by the radar and laser systems, with the operating mode capable of being selected either manually or automatically. The preferred mode of operation utilized the laser computations since it provided greater range accuracy at close-in ranges (0.6 ft., compared with three yards average error for the radar) and more accurate tracking at lower elevation angles. Figure 6.4 shows a block diagram of the FPS-16 radar/laser tracking system.

Tracking of the aircraft was done via a laser retroreflector located at the top of the tail fin. A C-band transponder co-located with the retroreflector provided a single, fixed tracking point on the TSRV. The transponder was used to facilitate initial radar acquisition of the target and enhanced the range capability of the radar.

Housed in the ARRC were the computers and associated peripherals used for formatting and recording digital data from the tracking system. Data recorded for off-line processing included range data from both radar and laser systems, tracking angle data (azimuth and elevation from the mount), run identification data, time of day, and auxiliary data from the radar. Aircraft position plots were made during each run from the real-time tracking data to give an indication of overall system performance. Plots were obtained for the X-Y and X-Z axes using the same data that was digitized for analysis. (See Figure 6.5.)

Further information on the FPS-16 radar and laser tracking system can be found in Reference 5.

6.3 TRACKING DATA - INITIAL PROCESSING

The raw data from the FPS-16 radar/laser tracking system was processed through a series of programs at Wallops before being transmitted to Langley for subsequent merging with the airborne data. A brief description of the data manipulation follows.

A program called PASS-1 processed the FPS-16 tape (coded with time, radar and laser range, and both the azimuth and elevation angles) checking it for any obvious errors and making the conversion into engineering units. Another program, P1 COPY, selected the laser as the preferred data source and made the necessary correction for the physical difference in mounting location such that its data would correspond with that from the radar. The program also made adjustment for any bias in the system. The next program, DATA PROC, accomplished three things; first, the range, AZ, and EL data were edited by removing a record whenever an anomalous data point was noted and replacing it with a linearly interpolated value. Second, the program corrected known bit errors in the data by making card entry changes; and third, any of the parameters could be scaled or biased to correct for, known problems if required. Yet another program, SMAD - for SMoothing And Differentiating, was used to filter the tracking data. A "9-point" filter was generally used on range data while a "21-point" filter was used on angle data during the curved approach test (a "41-point" filter was available if needed).

The program, TCV-1, accomplished the transformation of range, AZ, and EL from polar to rectangular coordinates and translated the data to the GPI reference system. This program also computed x, y, and z velocities. Finally, a program called TCV MERGE formated and recorded the tapes to be used in Langley's data reduction process.

7.0 COMPREHENSIVE FLIGHT DATA PROCESSING

The basic requirements for data reduction and presentation were set forth by the FAA's Office of Aviation Standards to include graphical and numerical representation of flight path errors and certain airborne flight parameters. (Details of the FAA requirement are included as Appendix B to this report.)

An overview of the data processing scheme is shown in Figures 7.1 and 7.2. Quantitative data were collected from two primary sources: the airborne parameters via the TSRV Data Acquisition System (DAS); and aircraft position information from the Wallops laser/radar tracking system (FPS-16). The data reduction process involved stripping four tracks of multiplexed data from the airborne data tape and applying the required sensor calibrations and scaling factors. Afterwards the airborne and ground-tracking data were merged together, record for record, creating a data set based on a time reference. Once merged, lateral and vertical flight path errors were computed and corresponding profile plots were made for each run. Next, data from similar segments of the individual runs were combined to create "composite" profile plots for each of the (seven) different paths. The composite data set was subsequently rearranged according to along-track distance (instead of time) and partitioned in 50 meter intervals from which to compute standard statistics. Per FAA requirements, the deliverable products consisted of a statistical analysis of the flight path errors and associated parameters presented in tabular and graphical form form of isocontour plots with standard deviation limits superimposed.

7.1 DATA MERGE ROUTINE

The first major effort involved merging the flight test data with the ground tracking data. As a practical matter, both airborne and ground-tracking data were recorded in a "time-history" format for ease in collection and the initial merging process. The 4-track DAS analog tape containing the airborne parameters required several intermediate steps in order to retrieve the parameters in a usable form. First the tape was played back with the PCM data being converted to a digital format. This operation yielded three individual tapes containing data for the aircraft sensors (PADS), navigation Computer (NCU), and flight-control computers (Formatter). These tapes, in turn, were processed applying the appropriate parameter calibrations to the PADS data and the applicable scale factors to the NCU and Formatter data. This step produced tapes having readable engineering units, that could be combined (merged) with each other and with the Wallops tracking tapes.

Prior to initiating the merge routine, for each test run, a visual inspection of printed records was made of the data on each of the three airborne tapes and the radar tracking tape. This was done to assure that each constituant part of the data set had exactly the same starting and ending times, without which the computer could not properly perform the merge process.

Table 7.1 shows a sample listing from the "corrected" merged data tape, delineating all of the parameters requested by AVN. Corrections were made to some of the raw data parameters in order to facilitate their use. A discussion of some key parameters follows. (The sign convention used for parameter tagging is shown in Figure 7.3, where the axes are referenced to the ground point of intercept (GPI) physically located along the centerline of Runway 22, opposite the EL antenna, see Figure 6.2.)

1. Ground tracking parameters for aircraft position (X, Y, and Z) as originally recorded were referenced to the Wallops runway coordinate system and measured with respect to the laser retroreflector located atop the aircraft's tail. These parameters were geometrically translated to coincide with the aircraft's CG position; the point to which the airborne parameters were referenced. This yielded the new tracking coordinate parameters labelled Xcg, Ycg, and Zcg.

2. The parameter labelled DISTANCE-TO-GO (commonly known as "along-track-distance") was computed to show the actual length of the flight path. This value corresponded with the parameter "L" as determined for each profile according to the equations in Appendix C. Values for this parameter were computed in both feet and meters.

3. Parameters representing lateral and vertical deviation (labelled LAT DEV and VERT DEV, respectively) required conversion into units typically identified with flight technical error, feet and "dots". In the RNAV mode, path deviation was computed (by the NCU) in the units of feet; conversion was made to show the equivalent displacement in dots. In the LAND mode, where path deviation was obtained directly

from the MLS, the raw data already existed in the form of dots, hence, a complementary conversion from dots to feet was required.

4. Parameters representing lateral and vertical position error, RADL ERROR, and V POS ERROR were calculated as described in Section 7.2, based on the flight path equations in Appendix C.

5. A new parameter labelled DES POINT was calculated (as described in Section 7.3) to permit subsequent partitioning of the data into 50-meter intervals for the statistical analysis. Also in this column are listed any way points (e.g. DH, RP, TP, FAP) that were not coincident with one of the 50-meter intervals.

6. Height above touchdown, HTDZ, was calculated from the MLS altitude, ZHAT, for use in statistical analysis (i.e., HTDZ = ZHAT - 8 feet).

7. Barometric altitude, H BARO, (used by the navigation computer) was corrected on an hourly basis using Wallops meteorological information. The corrected value is denoted H BARO CORR on the printout.

8. Incremental normal acceleration, NORM ACC (the synthesized input required by the complementary filter) was converted to a non-dimensional quantity and represented as DEL NOR AC.

7.2 CALCULATION OF AIRCRAFT POSITION ERRORS

In the data reduction process, aircraft position errors for both the lateral and vertical paths were computed using the flight path design equations found in Appendix C. These equations show the error as the difference between the aircraft's position, obtained from the Wallops tracking data, and the design flight-path. At any particular point, lateral and vertical position errors were defined as perpendicular displacements of the aircraft relative to a tangent drawn with respect to the flight path. Lateral position error is listed as RADL ERROR in the equations and subsequent tabulations, while vertical positon error is listed as VPOS ERROR. These parameters became the primary factors used in the statistical computations for mean path error, flight technical error, and navigation system error.

Aircraft position obtained from the laser-tracker system was measured with respect to the retro-reflector located atop the TSRV's vertical stabilizer. X, Y, and Z position coordinates taken from this location were translated during the subsequent data processing to coincide with the aircraft's center-of-gravity (CG) and were labelled Xcg, Ycg, and Zcg. These terms were used in the equations to compute lateral and vertical errors. (A constant CG of 18.5% mean aerodynamic chord (MAC) was assumed throughout the entire program. The choice of a constant value greatly simplified the computation when making the position translation from the retroreflector to the aircraft CG.)

Onboard the TSRV, aircraft position and flight path deviation were derived from MLS parameters for navigation and display purposes. Since two sets of antennas (both forward and aft mounted) were used for angle and DME reception, a specific aircraft reference point was not defined. Instead, for data derived directly from the MLS, the point of reference used for flight navigation (and in subsequent data reduction) was simply taken to be the location of whichever antenna happened to be feeding the receiver at any particular moment. No translation of antenna coordinates was made to accommodate a common datum point as was done for the laser-tracker position data. As a consequence, a small error may be found between the aircraft position data computed and recorded onboard the aircraft and the aircraft position data recorded by the ground tracking system. Any error present would be most noticable on the cross-wind leg of an approach and limited in magnitude to a maximum of 35 feet, the distance between the farthest MLS antenna and the aircraft's CG.

7.3 FIFTY-METER INTERVAL PARTITIONING

Processing of the data to obtain statistics on aircraft position errors required correlating the tracking data with the designed flight path. This entailed converting both ground and airborne data, originally recorded in time-history formats, to a reference system which would conform to the curved path of each profile. The parameter chosen to provide this reference was "along-track distance" (DIST TO GO in Table 7.1).

To remain consistent with other FAA flight test programs, the interval spacing along the flight path was set at fifty meters. The geographic origin for the 50-m intervals was located at the point along the X-axis where the glide path attained a height of 50 ft. above the theoretically computed value for the runway threshold (see Figure 7.3). Interpreted mathematically for the 3° glide slope, used for the curved-path test, this point was located 954 feet from the GPI, (i.e., $X_{cg} = 50'/\tan 3^\circ$. For the steep-angle tests, the reference point changed in accordance with the glide path angle flown (3.5, 3.8, or 4.0 degrees).

Fifty-meter intervals were measured from the GPI backwards along the flight path to the starting point (SP) of the profile, and forward of the reference point until termination of the test run. The actual number of points varied according to profile length and type of termination (go-around, low approach, or landing). This yielded roughly 400 bins for the shortest approach and 600 bins for the longest (corresponding to along-track-distances of between 20,000 and 30,000 meters).

The column labelled DES POINT in Table 7.1 shows the exact 50-meter interval used for data analysis. Data for discrete way-points (SP, TP, RP, etc.) were included with the 50-meter interval data in the printouts since, in general, these points were not coincident with any of the 50-meter partition points. As such, they appear as non-sequential entries in the DES POINT column. The values for flight data keyed to these intervals were taken from the database to be those lying closest to the DES POINT; no interpolation was done.

7.4 STATISTICS

Standard statistics were computed using a Langley program called "BDS" which computes: the mean; the second, third, and fourth moments about the mean; the biased and unbiased variance and standard deviation; and the skewness and Kurtosis for a one-dimensional array of data.

In combining the data from individual runs, three separate groupings were established based on how a particular approach terminated. These distinctions were made since each group required a unique processing routine in order to extract certain data of interest. (The segment from the beginning of an approah down to DH remained common to all runs.) The three groups consisted of data for approaches ending in (1) a go-around, (2) low approach, or (3) a landing. Sample statistical printouts are reproduced in Table 7.2 showing the different treatments used in each of the three cases. A summary of the various approaches, listed by profile type and the way in which they terminated, is given in Table 7.3.

The parameters for which statistics were calculated are described below:

1. DES POINT or DES PT - Design Point, one of a series of consecutive points spaced at 50-meter intervals along the flight path where data was reported. Also included are those discrete points (e.g. SP, TP, DH, etc.) deemed of interest when not coincident with a 50-meter point.

2. VPOS ERROR - the aircraft's position error with respect to the desired vertical flight path (see Appendix C for calculation).

3. RADL ERROR - the aircraft's position error perpendicular to the desired lateral flight path (see Appendix C for calculation).

4. VERT DEV - deviation from the desired vertical path as indicated to the pilot via cockpit displays (also referred to as vertical flight technical error.

5. LAT DEV - deviation from desired lateral path as indicated to the pilot via cockpit displays (also referred to as lateral flight technical error).

6. CG Y - aircraft lateral positon obtained from tracking data, corrected and translated to the aircraft CG.

7. CG Z - aircraft vertical position obtained from tracking data, corrected and translated to the aircraft CG.

8. LNSE - lateral navigation system error - computed as the difference between RADL ERROR and LAT DEV.

9. VNSE - vertical navigation system error - computed as the difference between VPOS ERROR and VERT DEV.

7.5 COMPUTATIONS FOR GO-AROUNDS, LOW APPROACHES, AND LANDINGS

Go-Arounds and Low Approaches

For those approaches terminating in a go-around, data collection continued until turnout to assess missed approach performance. At the onset of the program, data was gathered until reaching an altitude of 2,000 feet; about halfway through the program, however, the decision was made to change the cut-off point to 1,000 feet in the interest of conserving time. For approaches ending in a low approach, data collection was terminated upon wave-off.

For all runs in these two categories, a height-loss analysis was performed looking for the lowest point on the flight path after reaching DH. A subroutine was written to scan the aircraft's vertical position (Zcg) using a moving window technique (called the "3-point moving average") to establish the lowest point (LOWACG Z) for each run ending in a go-around or low approach. Once found, the "decision height" altitude (DH = 200 ft.) was subtracted from each of these points to compute the actual height lost (HTLOSS).

Landings

To determine the touchdown point for those approaches terminating in a landing, the"raw" flight data tapes were scanned during the RAGS "quick-look" process to find the point where the normal acceleration (NORM ACC) trace showed the first sign of excitation. This point was correlated with both the "wheel spin up" and "squat switch" discrete channels to verify a touchdown. The coordinates of the airplane taken at the time and location chosen for actual touchdown constituted the population used for the statistical evaluation of the touchdown point.

7.6 GRAPHICAL PRESENTATION

Plan and Profile Views

Plan view (X-Y) and profile view (L-Z) plots were compiled for each individual run using tracking data corrected for the aircraft CG (i.e., Xcg, Ycg, and Zcg). In the profile view Zcg was plotted versus L (along-track-distance) so there would be no doubling back of the plot during the turns. Each data point from the time history merge was plotted from the start of run to completion. The actual flight path was drawn against the design path (dotted lines) for each view. Sample plan and profile plots are shown in Figures 7.4 and 7.5, respectively.

Composite Plots

Composite plots were made by overlaying plots of the individual runs in order to visually show the spread of the data. Plots were grouped as described in Section 7.4 for statistical processing, i.e. from the beginning of the approach to DH, DH to go-around, DH to low approach, and DH to land. Sample plots are shown in Figures 7.6 and 7.7.

Select Flight Parameters

From the merged data, plots were generated for certain aircraft parameters deemed of interest by researchers to aid in overall data reduction and subsequent analysis. The list of select parameters consisted of: airspeed, flap position, pitch angle, engine pressure ratio, vertical velocity, normal acceleration, and landing gear position. See Figures 7.8a and b for examples. Wind speed and direction were recorded for many of the later flights using data derived from the inertial navigation system (INS) onboard the aircraft.

7.7 FLIGHT TECHNICAL AND NAVIGATION SYSTEM ERRORS

Flight Technical Error

Flight technical error (FTE) was defined as the difference between the path commanded by the flight director and the desired flight path, (showing the accuracy to which pilots flew the commanded track). Both vertical and lateral deviations were computed by the navigation computer and displayed on the cockpit deviation indicators. This data was plotted in units of feet and dots, and is labelled herein as Vertical (VERT DEV) and Lateral Deviation (LAT DEV). See Figures 7.9 and 7.10 for sample plots.

Navigation System Error

Navigation system error (NSE) was calculated by subtracting the path deviation errors (representative of flight technical error, above) from the ground tracking errors obtained via the laser tracker system. These errors included both MLS errors and flight path errors attributable to the flight director computer. Navigation system errors for both the vertical and lateral paths were computed and referred to as VNSE and LNSE, respectively: (Note: VPOS ERROR is labelled VERT POS ERROR in Fig. 7.11 and RADL ERROR is labelled LAT POS ERROR in Fig. 7.12.)

VNSE = VPOS ERROR - VERT DEV
LNSE = RADL ERROR - LAT DEV

7.8 ISOCONTOUR PLOTS

Based on the statistics previously computed, isocontour plots were generated to graphically show the mean and standrd deviation ($\pm 2\sigma$) limits for: total (aircraft) position error, flight technical error, and navigation system error. Aircraft position error and FTE were plotted alongside each other on the same chart; sample data is shown in Figures 7.11 and 7.12, respectively, for the vertical and lateral planes. The navigation system errors, VNSE and LNSE, were similarily plotted; see sample data, Figure 7.13. (These data were plotted from the start of a run to DH.) Isocontour plots of aircraft position were generated for approaches ending in a go-around. Sample plots for vertical and lateral position (Zcg and Ycg, respectively) are shown in Figure 7.14.

7.9 DATA TAPES AND ARCHIVAL

Both the original flight test tapes and the merged data tapes have been archived at Langley for future reference. The raw airborne data tapes and the tracking data tapes from Wallops will be retained by the ATOPS Program Office. The merged data tapes will be archived in the ACD library. A list of these tapes is given in Appendix D.

Transmittal tapes containing the merged data for 50-meter intervals and tapes containing the statistics used in creating the plots and listings were delivered to AVN. The tape format and a summary of those tapes are reproduced herein as Appendix E. These tapes are written in a serial, binary format for use on a Cyber computer operating with the NOS 1.4 operating system.

In the future, should a need be identified for use of this data a request can be made through the FAA's Langley Field Office for access.

8.0 RESULTS AND DISCUSSION

In summation, the flight test was completed in an orderly and expeditious manner with much new knowledge gained throughout the course of events. A total of 336 curved-path and 96 steep-angle approaches were flown. The resulting data was reduced at Langley, and forwarded to AVN for their analysis and entry into the TERPS data base. A cursory analysis of the data has been conducted and published in Reference 1.

A tabulation of the profiles flown during the course of this flight test is shown in Table 7.3. This table indicates the total number of data runs accomplished, the number of successful vs. unsuccessful runs, and how the runs terminated.

8.1 PILOT COMMENTS

The subject pilots had no trouble getting used to the concept of flying curved-path approaches, and they appeared comfortable even on the first runs. They liked the smoothness (i.e., freedom from course bending the scalloping) of the approaches flown with MLS guidance as compared with the roughness experienced on many ILS approaches.

One comment that rang universal among the pilots was their appreciation for the situational awareness provided by the bearing pointer on the HSI which gave constant bearing information to the runway. The single most useful display for profile orientation was considered to be the readout of "along-track-distance." This information, in conjunction with waypoints depicted on the approach charts, afforded a convenient means of locating the aircraft's present position during an approach.

When it came to flying the steep-angle approaches, pilots appeared to have no problems with any of the steep-angle glide paths, even at 4.0 degrees. However, general consensus among the pilots indicated that a glide-path angle of 3.8 degrees should be considered the maximum for a fixed DH of 200 ft. to allow for the combined effect of variations found in operating conditions and individual pilot skills. Offering an alternative, the pilots felt that, by using a "sliding scale" for determining Decision Height, steeper angles might be acceptable (e.g., a glide slope of 4.0° having a DH of 200 ft., 3.8° having a DH of 150 ft., and 3.5° having a DH of 100 ft.). Concern was expressed that safety could be compromised in cases where pilots, having lesser experience, were required to fly a 4.0-degree approach in adverse weather conditions. Consensus also indicated that a descent rate of 1,000 fpm should not be exceeded since it would result in an "unstable" and/or "unspooled" approach in certain types of jet aircraft.

With respect to the cockpit instrumentation, pilots would have preferred the digital readout for "Along-Track-Distance" to have been more closely integrated with the pilot's normal instrument scanning pattern. This also applied to the F/D mode annunciators, especially the TURN indicator, which was located considerably outside the normal scan area.

The subjective data obtained from the subject pilots, via the individual questionnaires, were forwarded to the FAA's Civil Aeromedical Institute (CAMI) for analysis. CAMI conducted a statistical study of the pilots' responses to the questions and have documented their findings in the report listed in Reference 2.

8.2 OPERATIONAL ISSUES

It should be noted that most of the approaches flown in this test were conducted in calm atmospheric conditions or with light-quartering tail winds. (This was primarily due to the orientation of the MLS-instrumented runway with respect to a prevailing sea breeze.) Consequently, with little headwind or crosswind components, the resulting bank angles - while in the turns - were quite shallow since the paths were designed to accommodate a maximum "adverse" wind component of 50 knots (as noted in the Profile Development Section).

On several occasions during the course of the tests, inadvertant system anomalies were encountered by the subject pilots. How they coped with them - without comment or advice on how to proceed - spoke well for their intuitive skills as pilots, and on the ease with which the complex approaches could be flown on incomplete information. During a couple of runs where both the roll and pitch steering F/D bars were lost due to computer malfunction, subject pilots were able to complete the flying of a curved-path approach using only computed deviation (lateral and vertical) cues. Such runs were subsequently repeated for inclusion in the statistical data base, but were noteworthy in themselves. Additionally, in spite of a more-or-less generic flight director (which was not finely-tuned to the aircraft's dynamics, and gave somewhat balky pitch commands) the subject pilots had virtually no trouble navigating any of the curved paths.

It should be pointed out that this test was not intended to determine the minimum instrumentation required for flying complex paths, but instead, to provide data on pilot performance using instrumentation representative of that currently used by the airline industry. It will be left to other studies underway by FAA and NASA to determine the merits of specific guidance and display techniques.

One of the resulting display issues that needs to be addressed in future studies is when and how to cope with the vertical transition required between en route flight, using barometric altitude as a reference, and terminal guidance based on MLS elevation. It is understandably confusing for a pilot to have cockpit instruments in disagreement with each other due to different reference criteria. Allied with this issue is one of determining what type of guidance a pilot should be given for intercepting the glide path or making a vertical transition while flying along a straight or curved segment.

For this flight test, a "pseudo" glide path was computed and displayed in a manner similar to that encountered when intercepting the glide slope during a typical ILS approach. That is, the glide slope indicator was biased out of sight, at the top of the instrument, prior to the glide slope intercept; the needle then moved slowly downward as the computed path was intercepted. The aviation community will have to decide whether this should become an accepted practice or whether there is a better means of providing the appropriate lead information to the pilot.

8.3 DATA ANALYSIS

With respect to analyzing the data collected from this test, several observations are in order to properly interpret the results. Since oscillations were observed in the flight director's pitch axis, it is possible that the vertical error observed is somewhat exaggerated over what it might have been had a more refined F/D algorithm been available. Hence, some of the problems encountered in the vertical regime during these flight tests can be directly attributed to the simplicity of the F/D algorithm used in the RNAV mode and will no doubt be improved upon by the manufacturers. (See F/D description in Section 3.3.)

The results obtained for FTE will probably appear to be better than what has been familiarly observed in the past using ILS. This is due to the fact that course guidance based on MLS has much lower susceptibility to bends and scalloping in the course than does ILS.

In looking over the plotted data, a number of the runs may show places where data is nonexistent over a short portion of the flight path. Investigation has shown these gaps were due to dropouts in the radar tracking data furnished by Wallops. The dropouts are attributable to the fact that no data was recorded during the 4-10 second period that elapsed between the time when one data recorder would run out of tape and a second recorder came on line. These dropouts generally have no effect on the overall usefulness of the final product since only a couple of runs had any significant amount of data missing. However, this placed an additional burden on personnel reducing the data since an accounting had to be made for every interval of missing tracking data during the merge process. (The total number of valid data runs used in computing the statistical confidence for a particular path segment are indicated in the column labelled "Points" on the statistical printouts, see Table 7.2.)

8.4 CONCLUDING REMARKS

As this report goes to publication, a number of projects related to the deployment of MLS are in progress. Three of these which are closely related to work associated with this project are given a brief discussion below.

(1) FAA and the USAF have just completed a flight test designed to obtain TERPS data on MLS approaches for larger category aircraft. Called the "Joint MLS Operational Test," a C-141 aircraft was flown to collect data on curved, multiple-segment, and offset-angle approaches. Departure patterns and holding procedures, using MLS RNAV-type guidance, were also included in the test. In addition to using the "curved-path" guidance technique described herein, a second scheme referred to as "segmented-data" guidance was investigated. In this technique, the path was defined by a sequence of waypoints connected by straight lines. Turns were defined using a circular "fillet" between the two straight segments.

(2) The Radio Technical Commission for Aeronautics (RTCA) has convened a special committee (SC-151) which is drafting "Minimum Operational Performance Standards (MOPS) for Airborne MLS Area Navigation Equipment." This document will provide guidance to manufacturers designing commercial equipment used to fly complex MLS approaches. The European community, through EUROCAE, also has formed a working group (WG-27) for the same purpose. Both groups are in correspondence with each other.

(3) With the implementation of MLS underway in the United States and in other countries worldwide, attention is being given to use of complex paths to solve problems at existing aerodromes. Currently, facility analyses are being conducted by each of the FAA regions, under the auspices of the Office of Air Traffic Operations, to take a close look at what operational advantages can be gained by using MLS curved paths to ease congestion and noise at the nation's busiest terminals.

8.5 CONTRIBUTORS

Special thanks are due to the following people who assisted in the overall project effort and made contributions to this report: Sharon Paulson and Connie Basnette, Systems Development Corportion - flight data reduction; Arlene Guenther, Sperry Corporation - simulation programming; and Paul Baldasare, Kentron International - flight data management.

9.0 REFERENCES

1. Moon, B.: B-737 Microwave Landing System Flight Test Program Report, FAA report, FAA-AVN-200-27, June 1986.

2. Moon, B; Juhlin, D; and Pate, D.: NASA/FAA B-737 MLS Flight Test Pilot Evaluation of Curved Path and CTOL Steep Angle Approaches. FAA memorandum report, FAA-AVN-200-25, October 1984.

3. White, William F.: Flight Demonstrations of Curved, Descending Approaches and Automatic Landings Using Time References Scanning Beam Guidance. NASA Technical Memorandum 78745, May 1978.

4. Baldasare, Paul: Experimenter's Guide to the TCV B-737 Data Acquisition System. NASA's Terminal Configured Vehicle Program Document No. V-19100/OLTR-373, Kentron International.

5. Eastman, D., et. al.: Profile Investigation for Microwave Landing System - Phase II Report. AFFDL-TM-77-8, February 1977.

6. Wallops Airport Facilities. NASA Wallops Flight Center operations document, August 1978.

TABLE 1.1 - FLIGHT TEST MATRIX

Profile	Test		Variation	Star	No. of Approaches	Flight Test
1	180^{o} Trombone Optimum Operational Turn Rate	1	Final Approach Point (FP) Prior to Turn (TP)	CP181	48 (6/pilot)	144
		2	Final Approach Point (FP) at Turn (TP)	CP182	48 (6/pilot)	
		3	Final Approach Point (FP) After Turn (TP)	CP183	48 (6/pilot)	
2	90^{o} Intercept Minimum/Optimum Operational Centerline Segment	1	Minimum (MCLS)	CP901	48 (6/pilot)	96
		2	Optimum (OCLS)	CP902	48 (6/pilot)	
3	120^{o} Turn Minimum Operational Noncenterline Segment	1	NCLS FAP Prior to TP	CP131	48 (6/pilot)	48
4	Parallel Offset 15^{o}, 45^{o} 75^{o}, 90^{o}	1	Maximum Angle Not Requiring NCLS		(6/pilot)	48
		2	Maximum Angle With NCLS	CPS01	48 (6/pilot)	
SUBTOTAL - Curved-Path Approaches						(336)
Steep Angle Approach Assessment for Category "C" Criteria (on Centerline Segment)		1	3.5^{o}	SGS35	32 (4/pilot)	32
		2	3.0^{o}	SGS38	32 (4/pilot)	32
		3	4.0^{o}	SGS40	32 (4/pilot)	32
SUBTOTAL - STEEP-ANGLE APPROACHES						(96)
TOTAL ALL APPROACHES						432

TABLE 3.1 - ꞌLS-STEP FLIGHT DIRECTOR MODES

NAVIGATION MODE	MLS STATUS	F/D MODE SELECTOR	F/D RADIO SOURCE SW	F/D ANNUNCIATOR	ADI COMMAND SOURCE	LATERAL DEVIATION	VERTICAL DEVIATION	HSI COURSE SELECTION	DISTANCE READOUT	HSI BEARING POINTER
VECTORS	NO MLS OR LESS THAN ALL THREE FUNCTIONS VALID	HEADING	MLS	HEADING, ALT HOLD	SPERRY Z14	-- -	----	PILOT SELECT	FLAG	DEAD OR ROTATING
VECTORS	AZ, EL, AND PDME VALID	HEADING	MLS	HEADING, ALT HOLD	SPERRY Z14	COMPUTED LINEAR OR ANGULAR*	COMPUTED LINEAR OR ANGULAR*	AUTO SLEWED TO REQUIRED GROUND TRACK	ATD OR HTDZ (PILOT SELECTED)	MAG BRG TO AZ ANT SITE
VECTORS	NO MLS OR LESS THAN ALL THREE FUNCTIONS VALID	RADIO	MLS	HDG, ALT MLS C/P ARM AZ ARMED EL ARMED	SPERRY Z14	-- -	----	PILOT SELECT	FLAG	DEAD OR ROTATING
MLS 3-D RNAV (OFF RWY CL)	AZ, EL, AND PDME VALID	RADIO	MLS	MLS ENG AZ ENGAGED EL ENG**	NAV COMPUTER FLIGHT DIR IN RNAV MODE	COMPUTED LINEAR OR ANGULAR*	COMPUTED LINEAR OR ANGULAR*	AUTO SLEWED TO REQUIRED GROUND TRACK	ATD OR HTDZ (PILOT SELECTED)	MAG BRG TO AZ ANT
MLS 3-D RNAV (OFF RWY CL)	LOSS OF AZ, EL OR PDME WHILE IN MLS C/P MODE	RADIO	MLS	MLS C/P ARM AZ ARM EL ARM	HIDE ROLL AND PITCH COMMAND BARS FROM VIEW	--	----	REMAINS AT LAST VALUE	FLAG	DEAD OR ROTATING
MLS FINAL APPR (ILS-EQUIV) DEV	AZ, EL AND PDME VALID	RADIO	MLS	AZ ENG EL ENG	NAV COMPUTER FLIGHT DIR IN LAND MODE	MLS AZ DEV	MLS EL DEV	AUTO SLEWED TO RWY HDG	ATD OR HTDZ (PILOT SELECTED)	MAG BRG TO AZ ANT
MLS FINAL APPR (ILS-EQUIV) DEV	AZ AND EL ONLY VALID	RADIO	MLS	AZ ENG EL ENG	NAV COMPUTER FLIGHT DIR IN LAND MODE	MLS AZ DEV	MLS EL DEV	AUTO SLEWED TO RWY HDG	FLAG	MAG BRG TO AZ ANT
MLS FINAL APPR (ILS-EQUIV) DEV	AZ ONLY OR AZ AND PDME	RADIO	MLS	AZ ENG EL ARM	NAV COMP FOR ROLL COMMAND, HIDE PITCH BAR	MLS AZ DEV	----	AUTO SLEWED TO RWY HDG	FLAG	MAG BRG TO AZ ANT
MLS FINAL APPR (ILS-EQUIV) DEV	LOSS OF AZ AFTER LAND MODE ENGAGED	RADIO	MLS	AZ ARM EL ARM	HIDE ROLL AND PITCH COMMAND BARS FROM VIEW	-- -	----	REMAINS AT LAST VALUE	FLAG	DEAD OR ROTATING
VOR OR ILS	ANY STATUS	RADIO	VHF	VOR/LOC & G/S OR ALT	SPERRY Z14	VOR/LOC DEV	G/S DEV OR ALT SELECT	PILOT SELECT	BLANK	DEAD OR SAME AS RMI
MISSED APPR	SAME AS BEFORE GO-AROUND INITIATED	G/A BUTTON PUSHED	MLS	WINGS LEVEL OR HDG, G/A	SPERRY Z14	SAME AS BEFORE G/A INITIATED	SAME AS BEFORE G/A INITIATED	SAME AS BEFORE G/A INITIATED	SAME AS BEFORE G/A INITIATED	SAME AS BEFORE G/A INITIATED
MISSED APPR	ANY STATUS	G/A BUTTON PUSHED	VHF	DEPENDS ON PILOT SELECTION	SPERRY Z14	VOR/LOC	PILOT SEL	PILOT SEL	BLANK	DEAD OR SAME AS RMI

* { LATERAL DEVIATION 1.85 DEGREES FULL SCALE (2 DOTS) OR 1500 FEET, WHICHEVER IS MORE SENSITIVE
VERTICAL DEVIATION 0.75 DEGREES FULL SCALE (2 DOTS) OR 500 FEET, WHICHEVER IS MORE SENSITIVE } (see Figure 3-4)

** A "TURN" ANNUNICATION IS GIVEN 15 SEC. IN ADVANCE OF A F/D STEERING COMMAND

*** ATD IS THE ALONG TRACK DISTANCE TO GPI, HTDZ IS ATD x TAN OR GLIDESLOPE ANGLE + ALTITUDE ERROR (RANGE 0 to 999 FEET)

TABLE 3.2A - AIRBORNE PARAMETER LIST FOR DATA COLLECTION

PARAMETER	MNEMONIC	RESOLUTION/RANGE	SOURCE
TIME	TIME/t	0.025 SEC	
COPILOT'S INDICATED AIRSPEED	COMPTD A/S 2B	0.4 KT, 50-200 KT	PCM
COPILOT'S VERTICAL VELOCITY	BAR HDOT 2	0.3 FPS, +-4000 FPS	PCM
AIRCRAFT HEADING	MAG HEAD	0.75 DEG, 0-360 DEG	PCM
BAROMETRIC ALTITUDE	BAR ALT F2B	5 FT, -500 TO 2000 FT	PCM
RADIO ALTITUDE	RAD ALT 2B	1 FT, 0-500 FT	PCM
COPILOT'S VERTICAL DEVIATION	G'S DEV 2	FT OR DEG AS F(POSITION)	PCM
VERTICAL DEVIATION, LINEAR	HER	1 FT	NCU
COPILOT'S LATERAL DEVIATION	LOC DEV 2	FT OR DEG AS F(POSITION)	PCM
LATERAL DEVIATION, LINEAR	XTK	1 FT	NCU
MLS AZIMUTH	MLS AZ	0.005 DEG	FMT
MLS EL1	MLS EL1	0.005 DEG	FMT
MLS RANGE	MLS RANGE	5 FT	FMT
X CL POSITION	XHAT	1 FT	FMT
Y CL POSITION	YHAT	1 FT	FMT
HEIGHT ABOVE MLS REF PLANE	ZHAT	1 FT	FMT
HEIGHT ABOVE TD FROM EL1	HTDZ	1 FT, 0-1000 FT	NCU
ALONG TRACK DISTANCE	STPDTG	1 FT	NCU
ALONG TRACK DISTANCE	DME	N. M.	NCU
CORRECTED BARO ALTITUDE	HBARO CORR	1 FT	NCU
MLS FLAGS	MLS VALID FLAGS	DISCRETES	MLS
LEFT AILERON POSITION	AIL POS L	0.1 DEG	PCM
LEFT ELEVATOR POSITION	ELEV POS L	0.1 DEG	PCM
RUDDER POSITION	RUD POS	0.15 DEG	PCM
ROLL RATE	ROLL RTE 2	0.1 DEG/SEC	PCM
PITCH RATE	PITCH RTE 2	0.1 DEG/SEC	PCM
YAW RATE	YAW RATE	0.1 DEG/SEC	PCM
ROLL ATTITUDE	ROLL ATT 2	0.2 DEG	PCM
PITCH ANGLE	PITCH 2	0.1 DEG	PCM
ANGLE OF ATTACK	ALPHA	0.2 DEG	PCM
THROTTLE POSITION	FTH HDL 2	0.5 DEG	PCM

TABLE 3.2A - (continued)

PARAMETER	MNEMONIC	RESOLUTION/RANGE	SOURCE
FLAP POSTION	T E FLAP	0.5 DEG	PCM
EVENT MARKER	EVENT MARK	DISCRETE	PCM
NORMAL ACCELERATION	NORM ACC	0.004 G	PCM
F/D PITCH COMMAND	FDVC	--	PCM
F/D ROLL COMMAND	FDLC	--	PCM
ROLL COMMAND BAR DISCRETE	--	DISCRETE	F/D
PITCH COMMAND BAR DISCRETE	--	DISCRETE	F/D
AZ ARM ANNUNCIATION	AZ ARM	DISCRETE	NCU
TURN ANNUNCIATION	ALG FLG	DISCRETE	NCU
EL ARM ANNUNCIATION	EL ARM	DISCRETE	NCU
AZ ENGAGE ANNUNCIATION	AZ ENGAGE	DISCRETE	NCU
EL ENGAGE ANNUNCIATION	EL ENGAGE	DISCRETE	NCU
MLS C/P ARM ANNUNCIATION	MLS C/P ARM	DISCRETE	NCU
MLS C/P ENGAGE ANNUNCIATION	MLS C/P ENGAGE	DISCRETE	NCU
MLS ANGLE ANTENNA SWITCH	ID1M	DISCRETE	PCM
DME ANTENNA SWITCH	ID2M	DISCRETE	PCM
NOSE GEAR POSITION	N G POS	DISCRETE	PCM
SMOOTHED VERTICAL SPEED	HDCF	FPS	
GROUND SPEED	GS	0 KT	NCU (INS)
SIDESLIP ANGLE	BETA	DEG	PCM
FLIGHT PATH ANGLE	GAMMA	DEG	PCM
SPEED BRAKE POSITION	F SPD BRK	POSITION	PCM
LONGITUDINAL TRIM	STAB POS	PILOT UNIT	PCM
ENGINE PRESSURE RATIOS	EPR1, EPR2	.01, RATIO, 1-2	PCM

*Data Source Sample Rate:
PCM - 20/sec
NCU - 10/sec
Formatter - 8/sec
Tracking - 10/sec

**Calculated Parameter

-- Internal Commands

TABLE 3.2B - AIRBORNE STRIP CHART RECORDER

PARAMETER	UNITS	APPROX SCALING
COPILOT'S LATERAL DEVIATION	DOTS OF DEVIATION	1 INCH = 1 DOT
COPILOT'S VERTICAL DEVIATION	DOTS OF DEVIATION	1 INCH = 1 DOT
AIRCRAFT HEADING	DEGREES MAGNETIC	1 INCH = 90 DEGREES
VERTICAL VELOCITY	FEET/MINUTE	1 INCH = 2000 FT/MIN
COPILOT'S INDICATED AIRSPEED	KNOTS	1 INCH = 50 KT (NONLINEAR)
BAROMETRIC ALTITUDE	FEET	1 INCH = 625 FT (-500 to 2000)
RADIO ALTITUDE	FEET	1 INCH = 125 FEET (NONLINEAR)
DISTANCE TO GO	NAUTICAL MILES	1 INCH = 1.25 N. MI.
THROTTLE POSITION	DEGREES	1 INCH = 57 DEG (NONLINEAR)
FLAP POSITION	DEGREES	1 INCH = 25 DEG (NONLINEAR)
F/D PITCH BAR COMMAND		
F/D ROLL BAR COMMAND		

TABLE 4.1 - SUBJECT PILOT TRAINING - SIMULATOR RUNS

Run No.	Profile	Conditions
1	103	Practice - no wind, no turbulence, no offset. (Do not collect data on practice runs.)
2	103	30 knot wind blowing to 040°, 3 ft/sec turb, 0.8NM right offset.
3	103	35K wind blowing to 310°, 3 ft/sec turb, 0.8NM right offset.
1A	103	Repeat Run 1 for second subject pilot.
2A	103	Repeat Run 2 for second subject pilot.
3A	103	Repeat Run 3 for second subject pilot.
4	433	50K wind, to 350°, 3 ft/sec turb, right offset.
5	433	50K wind, to 330°, 6 ft/sec turb, right offset.
4A	433	Repeat Run 4 for second subject pilot.
5A	433	Repeat Run 5 for second subject pilot.
6	441	50K wind, to 350°, 3 ft/sec turb, right offset.
7	441	50K wind, to 330°, 6 ft/sec turb, right offset.
6A	441	Repeat Run 6 for second subject pilot.
7A	441	Repeat Run 7 for second subject pilot.
8	843	Practice - no wind, to turbulence, no offset.
9	843	25K wind, to 310°, 5 ft/sec turb, 0.8NM left offset.
10	843	35K wind, to 265°, 5 ft/sec turb, left offset.
8A	843	Repeat Run 8 for second subject pilot.
9A	843	Repeat Run 9 for second subject pilot.
10A	843	Repeat Run 10 for second subject pilot.
11	845	25K wind, to 310°, 5 ft/sec turb, left offset.
12	845	35K wind, to 265°, 5 ft/sec turb, left offset.
11A	845	Repeat Run 11 for second subject pilot.
12A	845	Repeat Run 12 for second subject pilot.

TABLE 5.1 - SUBJECT PILOT QUALIFICATIONS

Pilot	Hours	Instrument Hours	TOTAL
1	3500	3000	17000
2	2800	620	15000
3	1700	420	13500
4	1400	250	6000
5	1500	320	6000
6	400	250	3680
7	500	1000	8000
8	1600	Not Available	10000
9	1250	200	4500
10	2000	600	7500
11	470	432	8030
12	2300	850	9200
13	2100	120	9600
14	1600	1200	9800
AVERAGE	1651	712	9129

TABLE 7.1 - MERGED DATA LISTING - SAMPLE

(A) SHOWING ALL AIRBORNE AND GROUND PARAMETERS

ATOPS FLT R-401 MERGE RUN 3WA

TIME SECONDS	X FT	Y FT	Z FT	ALCFLG N/A	HBARD FT	HER FT	XTK FT	STPDTG FT	GAMMA DEG
60500.0000	39654.000	-36.000	1741.000	0.000	1580.000	-156.000	-52.000	30289.109	.059
60500.7000	39487.400	-31.100	1742.400	0.000	1577.534	-160.000	-47.397	30146.794	-.092
60501.4000	39321.200	-26.600	1743.800	0.000	1580.000	-160.000	-34.953	29985.906	-.178
60502.1000	39155.200	-22.600	1745.000	0.000	1580.000	-160.000	-40.000	29816.441	-.233
60502.8000	38988.600	-19.800	1745.000	0.000	1580.000	-160.000	-33.681	29624.406	-.372
60503.4000	38846.200	-17.400	1745.000	0.000	1580.000	-160.000	-32.000	29504.544	-.481
60504.1000	38680.100	-14.700	1745.100	0.000	1580.000	-160.000	-20.656	29319.279	-.546
60504.8000	38512.800	-12.600	1745.800	0.000	1584.000	-160.000	-20.000	29159.022	-.552
60505.5000	38346.000	-11.500	1746.000	0.000	1580.000	-160.000	-32.000	29001.122	-.527
60506.2000	38179.800	-11.200	1745.800	0.000	1582.592	-156.000	-24.225	28855.550	-.591
60506.9000	38014.600	-11.900	1745.100	0.000	1580.000	-156.000	-29.845	28695.900	-.630
60507.6000	37847.600	-13.200	1743.800	0.000	1580.000	-160.000	-20.000	28549.063	-.627
60508.3000	37680.300	-14.900	1742.700	0.000	1576.969	-160.000	-32.000	28384.844	-.605
60509.0000	37513.000	-17.000	1742.000	0.000	1576.000	-160.000	-29.281	28238.031	-.533
60509.6000	37369.600	-20.600	1741.400	0.000	1576.000	-164.000	-46.636	28095.750	-.472
60510.3000	37202.600	-24.500	1740.700	0.000	1576.000	-152.000	-35.062	27868.688	-.430
60511.0000	37036.000	-28.000	1740.000	0.000	1576.000	-144.594	-40.000	27703.125	-.305
60511.7000	36868.700	-32.200	1739.300	0.000	1576.000	-136.000	-48.156	27548.313	-.164
60512.4000	36701.800	-36.800	1739.000	0.000	1575.156	-124.844	-52.000	27373.063	-.166
60513.1000	36535.100	-41.300	1739.000	0.000	1572.000	-112.000	-57.938	27218.719	-.269
60513.2000	36511.200	-41.600	1739.000	0.000	1572.000	-111.844	-52.000	27189.969	-.283
60513.8000	36367.800	-43.400	1739.000	0.000	1576.000	-100.000	-60.000	27034.563	-.275
60514.4000	36224.000	-45.600	1739.400	0.000	1576.000	-88.000	-64.969	26892.406	-.199
60515.1000	36056.200	-48.300	1740.000	0.000	1572.469	-76.000	-72.000	26732.219	-.077
60515.8000	35889.600	-50.400	1740.000	0.000	1572.000	-64.000	-72.000	26559.781	.041
60516.5000	35723.000	-52.000	1739.500	0.000	1572.000	-48.721	-78.557	26384.656	.148
60517.2000	35556.800	-53.000	1738.600	0.000	1572.000	-40.000	-74.312	26220.531	.199
60517.9000	35391.600	-53.000	1737.200	0.000	1572.000	-28.970	-80.000	26041.817	.241
60518.6000	35228.800	-51.800	1735.800	0.000	1572.000	-19.094	-78.189	25885.134	.244
60519.3000	35067.900	-49.800	1734.400	0.000	1569.219	-5.219	-74.438	25715.313	.263
60520.0000	34909.000	-47.000	1733.000	0.000	1568.000	4.656	-80.000	25563.469	.282
60520.7000	34745.900	-44.200	1732.300	0.000	1564.000	16.000	-64.410	25392.819	.212
60521.4000	34583.600	-42.200	1730.800	0.000	1564.000	28.000	-72.000	25238.755	.065
60522.2000	34398.600	-40.200	1727.400	0.000	1560.000	37.403	-60.000	25047.581	-.158
60522.9000	34236.200	-37.400	1721.800	0.000	1556.000	44.000	-60.000	24888.663	-.424
60523.6000	34073.800	-34.000	1717.400	0.000	1556.000	52.000	-54.306	24733.081	-.814
60524.3000	33909.600	-30.200	1713.200	0.000	1548.000	56.000	-52.000	24564.000	-1.394
60525.0000	33743.000	-26.000	1709.000	0.000	1543.097	60.000	-49.291	24391.872	-2.043
60525.7000	33580.600	-24.600	1705.500	0.000	1537.222	64.000	-40.000	24247.331	-2.568
60526.4000	33421.400	-22.400	1700.000	0.000	1528.000	67.347	-50.041	24092.163	-2.873

TABLE 7.1 - MERGED DATA LISTING - SAMPLE

(B) SHOWING ALL AIRBORNE AND GROUND PARAMETERS

ATOPS FLT R-401 MERGE RUN 3WA

TIME SECONDS	GS KNOTS	WD DEG/180	WS KNOTS	HBARO CORR FT	MLS RANGE NAUT MI	MLS AZ DEG	XHAT+1 FT	YHAT+1 FT	ZHAT+1 FT
60500.0000	140.781	352.305	8.359	1865.000	6.521	.031	39561.030	-13.378	1720.929
60500.7000	140.591	352.473	8.328	1862.534	6.495	.025	39395.713	-9.150	1720.391
60501.4000	140.422	351.509	8.266	1865.000	6.467	.010	39231.034	-5.185	1720.162
60502.1000	140.260	351.793	8.306	1865.000	6.440	.010	39065.785	-1.477	1719.607
60502.8000	140.201	352.394	8.391	1865.000	6.410	0.000	38900.357	.998	1719.531
60503.4000	140.359	351.469	8.234	1865.000	6.387	-.000	38757.036	2.767	1719.531
60504.1000	140.639	351.469	8.234	1865.000	6.361	-.001	38589.031	4.969	1719.813
60504.8000	140.658	354.205	8.695	1869.000	6.333	-.010	38422.161	6.273	1720.898
60505.5000	140.585	358.066	9.344	1865.000	6.305	-.010	38255.609	7.195	1722.377
60506.2000	140.777	354.916	8.453	1867.592	6.279	-.005	38087.646	7.515	1723.373
60506.9000	140.938	354.916	8.453	1865.000	6.252	-.005	37920.144	7.224	1723.707
60507.6000	140.986	356.983	8.453	1865.000	6.224	-.005	37753.890	6.318	1723.479
60508.3000	140.890	356.983	8.453	1861.969	6.197	0.000	37588.157	4.584	1722.648
60509.0000	140.786	357.289	8.234	1861.000	6.170	.005	37422.729	1.934	1721.071
60509.6000	140.641	356.274	8.141	1861.000	6.147	.010	37281.101	-.646	1719.178
60510.3000	140.498	355.564	8.069	1861.000	6.119	.012	37116.362	-4.328	1716.939
60511.0000	140.413	353.526	7.953	1861.000	6.092	.025	36950.784	-8.286	1714.994
60511.7000	140.307	353.027	7.859	1861.000	6.064	.034	36785.353	-12.958	1714.375
60512.4000	140.422	352.687	8.078	1860.156	6.036	.044	36618.537	-18.183	1714.530
60513.1000	140.813	352.687	8.078	1857.000	6.009	.040	36449.843	-23.663	1715.080
60513.2000	140.814	352.616	8.092	1857.000	6.005	.042	36425.768	-24.380	1715.265
60513.8000	141.034	350.865	8.422	1861.000	5.981	.045	36281.511	-28.332	1716.424
60514.4000	141.229	350.865	8.422	1861.000	5.958	.055	36137.286	-31.559	1718.175
60515.1000	141.461	351.723	9.016	1857.469	5.929	.060	35969.025	-34.995	1719.864
60515.8000	141.679	352.146	9.844	1857.000	5.902	.065	35799.935	-38.120	1721.241
60516.5000	141.913	352.146	9.844	1857.000	5.875	.070	35630.553	-40.205	1721.820
60517.2000	141.960	352.980	10.246	1857.000	5.847	.065	35462.158	-41.567	1721.414
60517.9000	141.816	355.029	11.234	1857.000	5.820	.065	35295.163	-42.172	1721.375
60518.6000	141.342	354.509	11.484	1857.000	5.795	.064	35129.777	-41.735	1721.242
60519.3000	140.946	354.356	11.422	1854.219	5.769	.060	34965.870	-40.751	1721.367
60520.0000	140.222	354.356	11.422	1853.000	5.740	.055	34803.825	-38.851	1722.206
60520.7000	139.628	353.056	11.117	1849.000	5.712	.055	34641.248	-36.069	1722.375
60521.4000	139.063	353.640	10.875	1849.000	5.687	.045	34478.409	-32.813	1721.477
60522.2000	138.376	355.084	10.828	1845.000	5.655	.043	34555.992	-28.901	1719.284
60522.9000	137.858	355.084	10.828	1841.000	5.630	.031	34132.072	-25.349	1716.255
60523.6000	137.290	355.691	10.344	1841.000	5.602	.030	33971.104	-21.305	1712.056
60524.3000	136.769	355.691	10.344	1833.000	5.577	.030	33810.916	-17.785	1706.758
60525.0000	136.026	355.943	9.531	1828.097	5.552	.020	33652.422	-14.814	1700.258
60525.7000	135.430	351.078	8.297	1822.222	5.525	.010	33495.131	-11.666	1692.647
60526.4000	134.862	351.078	8.297	1813.000	5.496	.010	33337.556	-8.218	1684.619

TABLE 7.1 - MERGED DATA LISTING - SAMPLE

(C) SHOWING ALL AIRBORNE AND GROUND PARAMETERS

ATOPS FLT R-401 MERGE RUN 3WA

TIME SECONDS	EL-1 DEG	MLS MODE N/A	VPOS ERROR FEET	ALPHA DEGREES	BETA DEGREES	CMPTDAS 2B KNOTS	MAG HEAD DEGREES	F TH HDL 2 DEGREES	YAW RATE DEG/SEC
60500.0000	3.259	1.000	-176.887	8.452	-1.224	133.967	229.141	15.600	-.041
60500.7000	3.280	1.000	-175.736	8.438	-.885	133.776	229.141	15.424	-.378
60501.4000	3.295	1.000	-174.462	8.503	-.855	134.396	228.407	15.600	-.491
60502.1000	3.315	1.000	-173.621	8.452	-.682	133.633	228.407	15.376	-.378
60502.8000	3.340	1.000	-174.119	8.039	-.855	134.205	228.407	15.600	-.266
60503.4000	3.360	1.000	-174.289	8.155	-.788	134.837	227.674	15.200	-.329
60504.1000	3.381	1.000	-174.581	8.104	-.682	133.967	227.674	14.976	-.491
60504.8000	3.405	1.000	-174.196	8.090	-.142	133.776	226.941	15.024	-.378
60505.5000	3.425	1.000	-174.409	7.974	-.345	133.800	226.207	14.976	-.266
60506.2000	3.445	1.000	-174.972	8.155	-.075	133.872	226.207	15.600	-.153
60506.9000	3.465	1.000	-175.817	8.039	-.142	134.134	226.207	15.600	-.041
60507.6000	3.480	1.000	-177.370	8.039	-.277	134.003	226.207	15.424	-.041
60508.3000	3.495	1.000	-178.622	8.220	-.480	134.432	226.207	15.600	-.041
60509.0000	3.505	1.000	-179.462	8.503	-.615	134.229	225.474	15.376	-.153
60509.6000	3.516	1.000	-180.205	8.503	-.547	134.134	225.474	15.376	-.153
60510.3000	3.535	1.000	-181.071	8.735	-.480	134.062	224.741	15.600	-.041
60511.0000	3.558	1.000	-181.711	8.851	-.412	133.645	224.741	15.600	.072
60511.7000	3.580	1.000	-182.775	8.735	-.345	134.039	224.741	15.200	.135
60512.4000	3.605	1.000	-183.546	8.206	-.345	133.538	224.741	14.800	.297
60513.1000	3.635	1.000	-183.793	8.090	-.277	134.538	224.741	14.800	.297
60513.2000	3.635	1.000	-182.464	8.155	-.277	134.360	224.741	14.576	.410
60513.8000	3.665	1.000	-172.358	8.155	-.210	134.503	224.741	13.024	.523
60514.4000	3.684	1.000	-161.900	8.039	-.315	133.633	224.741	12.400	.572
60515.1000	3.710	1.000	-149.447	8.155	-.412	135.099	225.474	12.224	.523
60515.8000	3.725	1.000	-137.682	8.336	-.615	134.503	226.207	11.424	.523
60516.5000	3.743	1.000	-126.490	8.503	-.682	133.872	226.207	11.024	.410
60517.2000	3.770	1.000	-115.604	8.735	-.682	133.240	226.941	10.800	.234
60517.9000	3.790	1.000	-105.443	8.735	-.682	132.738	226.941	10.176	.072
60518.6000	3.811	1.000	-95.544	8.916	-.885	132.570	226.941	9.785	.410
60519.3000	3.845	1.000	-85.545	9.199	-.953	132.785	226.941	10.000	.297
60520.0000	3.865	1.000	-75.985	9.199	-.817	131.553	227.674	10.000	-.041
60520.7000	3.885	1.000	-65.407	9.199	-.547	130.953	227.674	10.224	-.041
60521.4000	3.901	1.000	-55.523	9.315	-.615	130.942	227.351	10.000	.022
60522.2000	3.927	1.000	-46.209	9.315	-.682	130.750	227.351	10.176	-.041
60522.9000	3.940	1.000	-40.637	9.496	-.817	129.307	226.941	10.176	-.041
60523.6000	3.955	1.000	-34.155	9.083	-.817	128.873	226.941	10.000	-.153
60524.3000	3.975	1.000	-27.491	8.684	-.615	129.114	226.941	10.224	-.216
60525.0000	3.985	1.000	-20.445	8.568	-.547	130.017	226.941	10.224	-.203
60525.7000	4.000	1.000	-12.585	8.851	-.345	129.776	226.207	10.176	.072
60526.4000	4.010	1.000	-7.130	8.851	-.450	128.704	226.207	10.224	.072

TABLE 7.1 - MERGED DATA LISTING - SAMPLE

(D) SHOWING ALL AIRBORNE AND GROUND PARAMETERS

ATOPS FLT R-401 MERGE RUN 3WA

TIME SECONDS	NORM ACC FT/SEC/SEC	RADL ERROR FEET	T E FLAP DEGREES	F SPD BRK POSITION	N G POS POS	ROLL ATT 2 DEGREES	FDVC DEGREES	PTCH RTE 2 DEG/SEC	ROLL RTE 2 DEG/SEC
60500.0000	31.858	-29.116	23.949	7.000	-1.000	-1.485	-.135	-.025	1.401
60500.7000	32.176	-24.599	23.949	7.000	-1.000	-.683	.133	.153	.562
60501.4000	31.883	-20.530	23.949	7.000	-1.000	-.965	.206	.148	-1.529
60502.1000	31.704	-15.810	23.949	7.000	-1.000	-2.490	.474	-.367	-2.197
60502.8000	31.500	-12.559	23.949	7.000	-1.000	-3.472	1.083	-.135	-.169
60503.4000	31.773	-10.851	23.949	7.000	-1.000	-3.212	1.351	.089	.885
60504.1000	31.052	-8.466	23.949	7.000	-1.000	-2.569	1.424	-.101	.973
60504.8000	31.828	-7.152	23.949	7.000	-1.000	-2.129	1.692	.034	.527
60505.5000	30.527	-6.583	23.949	7.000	-1.000	-2.230	1.424	-.308	-.681
60506.2000	31.883	-6.078	23.949	7.000	-1.000	-2.670	1.692	.017	-.881
60506.9000	31.416	-6.553	23.949	7.000	-1.000	-3.133	1.692	.089	-.559
60507.6000	31.455	-7.730	23.949	7.000	-1.000	-3.393	1.692	.110	-.222
60508.3000	31.913	-9.340	24.585	7.000	-1.000	-3.574	1.083	.376	.301
60509.0000	32.131	-12.267	24.449	7.000	-1.000	-3.032	.474	.262	1.121
60509.6000	32.280	-16.346	23.949	7.000	-1.000	-2.027	.474	.203	1.872
60510.3000	32.588	-21.338	23.949	7.000	-1.000	-.944	.474	.414	1.671
60511.0000	33.254	-25.302	24.585	7.000	-1.000	.039	-.135	.317	1.077
60511.7000	32.946	-29.729	23.949	7.000	-1.000	.501	-.135	-.367	.493
60512.4000	31.634	-34.500	23.949	7.000	-1.000	.839	.206	-.367	.291
60513.1000	31.510	-39.135	23.949	7.000	-1.000	1.118	.742	.093	.405
60513.2000	31.570	-39.440	23.949	7.000	-1.000	1.118	.815	.089	.493
60513.8000	32.300	-41.410	23.949	7.000	-1.000	1.477	.474	.098	.571
60514.4000	31.704	-43.696	23.949	7.000	-1.000	1.656	.474	.203	.301
60515.1000	31.580	-45.991	23.949	7.000	-1.000	2.014	-.135	.207	.379
60515.8000	32.022	-47.770	23.949	7.000	-1.000	2.551	-.135	.224	.728
60516.5000	31.758	-49.541	23.949	7.000	-1.000	2.910	-.744	.279	.728
60517.2000	31.744	-50.130	23.949	7.000	-1.000	3.268	-.744	.203	-.525
60517.9000	31.316	-49.699	23.949	7.000	-1.000	2.372	-.744	.110	-1.529
60518.6000	31.788	-48.245	23.949	7.000	-1.000	1.835	-1.085	.144	-.247
60519.3000	31.744	-46.238	23.949	7.000	-1.000	1.835	-.744	.072	.056
60520.0000	31.813	-42.870	23.949	7.000	-1.000	1.835	-.744	-.130	-.335
60520.7000	31.292	-39.733	23.949	7.000	-1.000	1.118	-.744	-.042	-1.305
60521.4000	31.331	-37.552	25.085	7.000	-1.000	.220	-.135	-.042	-1.417
60522.2000	31.277	-35.045	25.085	7.000	-1.000	-.864	.474	-.135	-.837
60522.9000	31.068	-32.439	25.085	7.000	-1.000	-1.146	.474	-.595	-.213
60523.6000	30.290	-29.111	25.085	7.000	-1.000	-1.045	1.692	-.878	.527
60524.3000	29.787	-25.517	25.085	7.000	-1.000	-.683	2.301	-.840	.257
60525.0000	29.560	-21.339	25.085	7.000	-1.000	-.683	2.910	-.367	-.013
60525.7000	32.022	-20.537	26.263	7.000	-1.000	-.604	3.519	.072	.144
60526.4000	32.449	-18.394	27.400	7.000	-1.000	-.503	3.178	-.320	-.144

TABLE 7.1 - MERGED DATA LISTING - SAMPLE

(E) SHOWING ALL AIRBORNE AND GROUND PARAMETERS

ATOPS FLT R-401 MERGE RUN 3WA

TIME SECONDS	BAR HDOT 2 FT/SEC	EVENT MARK EVENT	RUD POS 1 DEGREES	STAB POS PILOT UNIT	RAD ALT 2B FEET	FDLC DEGREES	VERT DEV DOT	LAT DEV DOT	EPR 2 RATIO
60500.0000	-.454	0.000	1.732	7.255	579.263	-1.827	-1.190	-.105	1.356
60500.7000	1.635	0.000	1.937	7.335	579.263	-2.589	-1.148	-.099	1.361
60501.4000	1.538	0.000	1.435	7.255	579.263	-3.078	-1.117	-.071	1.366
60502.1000	1.234	0.000	1.217	7.184	579.263	-1.338	-1.081	-.081	1.368
60502.8000	.760	0.000	1.160	7.325	579.263	.614	-1.039	-.069	1.364
60503.4000	1.368	0.000	1.069	7.264	579.263	1.102	-1.003	-.069	1.370
60504.1000	.323	0.000	1.332	7.139	579.263	.888	-.959	-.064	1.370
60504.8000	.894	0.000	1.378	7.219	579.263	.888	-.924	-.053	1.361
60505.5000	.190	0.000	.658	7.290	579.263	.614	-.893	-.059	1.359
60506.2000	-1.329	0.000	.748	7.344	579.263	1.863	-.851	-.053	1.353
60506.9000	-.891	0.000	.600	7.255	579.263	2.780	-.815	-.059	1.364
60507.6000	-2.144	0.000	.966	7.264	579.263	3.541	-.785	-.058	1.370
60508.3000	-2.752	0.000	.966	7.255	579.263	4.244	-.760	-.071	1.378
60509.0000	-2.411	0.000	1.538	7.344	579.263	4.029	-.742	-.064	1.368
60509.6000	-.588	0.000	1.789	7.175	579.263	3.541	-.724	-.071	1.373
60510.3000	.020	0.000	1.789	7.335	579.263	2.839	-.687	-.076	1.366
60511.0000	-.758	0.000	1.571	7.219	579.263	1.805	-.665	-.099	1.368
60511.7000	-.320	0.000	1.583	7.264	579.263	1.590	-.616	-.104	1.366
60512.4000	.323	0.000	1.481	7.344	579.263	1.375	-.568	-.110	1.360
60513.1000	-.320	0.000	1.571	7.299	579.263	1.590	-.519	-.110	1.375
60513.2000	-.150	0.000	1.641	7.299	579.263	1.863	-.513	-.122	1.363
60513.8000	.020	0.000	1.526	7.255	579.263	1.590	-.459	-.115	1.361
60514.4000	-.454	0.000	1.481	7.255	579.263	1.317	-.428	-.133	1.319
60515.1000	.420	0.000	1.526	7.335	579.263	1.044	-.385	-.133	1.296
60515.8000	.117	0.000	1.674	7.504	579.263	.614	-.355	-.138	1.271
60516.5000	-1.913	0.000	1.789	7.575	579.263	-.146	-.326	-.139	1.250
60517.2000	-.624	0.000	1.230	7.415	579.263	-1.123	-.276	-.139	1.248
60517.9000	-1.706	0.000	1.744	7.459	579.263	-1.123	-.238	-.139	1.222
60518.6000	-1.025	0.000	1.789	7.699	579.263	-.088	-.204	-.138	1.196
60519.3000	-.661	0.000	1.160	7.744	579.263	-.361	-.145	-.133	1.197
60520.0000	-.150	0.000	1.423	7.699	579.263	-.361	-.108	-.127	1.183
60520.7000	-2.484	0.000	1.275	7.940	579.263	-.635	-.077	-.128	1.176
60521.4000	-3.360	0.000	.966	7.940	579.263	-.146	-.046	-.122	1.182
60522.2000	-5.319	0.000	.966	7.940	579.263	1.102	-.005	-.116	1.176
60522.9000	-5.891	0.000	1.127	7.994	579.263	1.590	.026	-.110	1.176
60523.6000	-7.278	0.000	1.275	7.904	579.263	1.375	.056	-.099	1.176
60524.3000	-8.835	0.000	1.114	7.975	579.263	.614	.085	-.092	1.176
60525.0000	-9.176	0.000	1.493	8.055	579.263	.341	.104	-.087	1.172
60525.7000	-10.051	0.000	1.230	7.940	579.263	.127	.135	-.082	1.173
60526.4000	-12.010	0.000	.761	7.869	579.263	-.088	.146	-.076	1.173

TABLE 7.1 - MERGED DATA LISTING - SAMPLE

(F) SHOWING ALL AIRBORNE AND GROUND PARAMETERS

ATOPS FLT R-401 MERGE RUN 3WA

TIME SECONDS	LAT DEV FEET	ELEV POS L DEGREES	AIL POS L DEGREES	BAR AL F2B FEET	PITCH 2 DEGREES	ID1M FORW ANT	ID2M AFT ANT	DEL NOR AC N/A	CG X FT
60500.0000	-67.000	7.057	3.814	1565.956	6.072	256.000	0.000	-.010	30396.329
60500.7000	-62.000	6.898	6.170	1565.956	6.072	256.000	0.000	.000	30229.675
60501.4000	-44.000	7.771	6.250	1565.956	6.214	256.000	0.000	-.009	30063.356
60502.1000	-50.000	7.918	4.880	1565.956	6.032	256.000	0.000	-.014	29897.522
60502.8000	-43.000	7.057	1.768	1565.956	5.669	256.000	0.000	-.021	29731.128
60503.4000	-43.000	7.567	2.729	1565.956	5.720	256.000	0.000	-.012	29588.604
60504.1000	-40.000	6.853	3.289	1568.747	5.538	256.000	0.000	-.035	29422.542
60504.8000	-32.000	8.179	3.369	1565.956	5.447	256.000	0.000	-.011	29255.181
60505.5000	-36.000	7.759	4.605	1570.940	5.215	256.000	0.000	-.051	29088.414
60506.2000	-32.000	7.147	3.885	1568.149	5.033	256.000	0.000	-.009	28922.308
60506.9000	-36.000	7.306	3.049	1565.956	5.124	256.000	0.000	-.023	28757.091
60507.6000	-35.000	7.045	2.249	1565.956	5.084	256.000	0.000	-.022	28590.118
60508.3000	-42.000	7.000	2.569	1560.973	5.175	256.000	0.000	-.008	28422.789
60509.0000	-38.000	7.249	.478	1560.973	5.305	256.000	0.000	-.001	28255.347
60509.6000	-42.000	7.000	.181	1560.973	5.396	256.000	0.000	.003	28111.873
60510.3000	-45.000	6.738	1.253	1558.780	5.487	256.000	0.000	.013	27944.752
60511.0000	-58.000	7.261	2.889	1560.973	5.850	256.000	0.000	.034	27777.976
60511.7000	-61.000	7.918	2.729	1560.973	5.669	256.000	0.000	.024	27610.736
60512.4000	-65.000	7.306	3.289	1560.973	5.345	256.000	0.000	-.017	27443.958
60513.1000	-64.000	7.057	1.928	1560.973	5.305	256.000	0.000	-.021	27277.267
60513.2000	-71.000	7.102	1.928	1558.780	5.124	256.000	0.000	-.019	27253.442
60513.8000	-67.000	7.000	2.889	1560.973	5.215	256.000	0.000	.004	27109.994
60514.4000	-77.000	6.796	3.369	1560.973	5.215	256.000	0.000	-.014	26966.189
60515.1000	-77.000	6.898	3.369	1555.990	5.356	256.000	0.000	-.018	26798.347
60515.8000	-79.000	6.898	3.529	1555.990	5.487	256.000	0.000	-.005	26631.706
60516.5000	-80.000	6.840	4.339	1558.182	5.527	256.000	0.000	-.013	26465.075
60517.2000	-79.000	6.796	6.090	1555.990	5.720	256.000	0.000	-.013	26298.816
60517.9000	-79.000	6.342	4.000	1555.990	5.760	256.000	0.000	-.027	26133.641
60518.6000	-78.000	6.840	3.939	1555.990	5.669	256.000	0.000	-.012	25970.902
60519.3000	-75.000	6.796	5.370	1553.199	5.850	256.000	0.000	-.013	25809.929
60520.0000	-71.000	6.796	5.370	1553.797	5.669	256.000	0.000	-.011	25651.151
60520.7000	-71.000	6.796	5.290	1551.006	5.527	256.000	0.000	-.027	25488.146
60521.4000	-67.000	7.306	5.290	1551.006	5.578	256.000	0.000	-.026	25325.846
60522.2000	-64.000	7.000	4.249	1546.023	5.305	256.000	0.000	-.028	25141.013
60522.9000	-60.000	7.816	4.009	1543.830	5.073	256.000	0.000	-.034	24978.686
60523.6000	-54.000	7.612	3.849	1541.040	4.488	256.000	0.000	-.058	24816.525
60524.3000	-50.000	7.612	4.570	1533.266	3.721	256.000	0.000	-.074	24652.634
60525.0000	-47.000	6.898	3.564	1528.282	3.216	256.000	0.000	-.081	24486.253
60525.7000	-44.000	6.898	4.330	1521.106	3.216	256.000	0.000	-.005	24323.794
60526.4000	-40.000	5.775	5.290	1516.123	2.995	256.000	0.000	.009	24164.687

TABLE 7.1 - MERGED DATA LISTING - SAMPLE

(G) SHOWING ALL AIRBORNE AND GROUND PARAMETERS

ATOPS FLT R-401 MERGE RUN 3WA

TIME SECONDS	CG Y FT	CG Z FT	DIST TO GO METERS	DIST TO GO FEET	VERT DEV FEET	DES POINT METERS	
60500.0000	-29.116	1726.031	9267.173	30396.329	-156.000	9267.900	
60500.7000	-24.599	1727.424	9216.364	30229.675	-160.000	9217.900	
60501.4000	-20.530	1728.937	9165.657	30063.356	-160.000	9167.900	
60502.1000	-15.810	1730.016	9115.098	29897.522	-160.000	9117.900	
60502.8000	-12.559	1729.755	9064.368	29731.128	-160.000	9067.900	
60503.4000	-10.851	1729.787	9020.916	29588.604	-160.000	9017.900	
60504.1000	-8.466	1729.729	8970.287	29422.542	-160.000	8967.900	
60504.8000	-7.152	1730.349	8919.262	29255.181	-160.000	8917.900	
60505.5000	-6.583	1730.369	8868.419	29088.414	-160.000	8867.900	
60506.2000	-6.078	1730.036	8817.777	28922.308	-156.000	8817.900	
60506.9000	-6.553	1729.418	8767.406	28757.091	-156.000	8767.900	
60507.6000	-7.730	1728.094	8716.500	28590.118	-160.000	8717.900	
60508.3000	-9.340	1727.070	8665.484	28422.789	-160.000	8667.900	
60509.0000	-12.267	1726.458	8614.435	28255.347	-160.000	8617.900	
60509.6000	-16.346	1725.907	8570.693	28111.873	-164.000	8567.900	
60510.3000	-21.338	1725.265	8519.742	27944.752	-152.000	8517.900	
60511.0000	-25.302	1724.847	8468.895	27777.976	-144.594	8467.900	
60511.7000	-29.729	1724.005	8417.907	27610.736	-136.000	8417.900	
60512.4000	-34.500	1723.453	8367.060	27443.958	-124.844	8367.900	
60513.1000	-39.135	1723.424	8316.240	27277.267	-112.000	8317.900	
60513.2000	-39.440	1723.282	8308.976	27253.442	-91.442	8312.200	< FAP
60513.8000	-41.410	1723.357	8265.242	27109.994	-81.435	8267.900	
60514.4000	-43.696	1723.759	8221.399	26966.189	-75.539	8217.900	
60515.1000	-45.991	1724.476	8170.228	26798.347	-67.519	8167.900	
60515.8000	-47.770	1724.589	8119.422	26631.706	-61.956	8117.900	
60516.5000	-49.541	1724.128	8068.621	26465.075	-56.458	8067.900	
60517.2000	-50.130	1723.389	8017.932	26298.816	-47.528	8017.900	
60517.9000	-49.699	1721.999	7967.573	26133.641	-40.777	7967.900	
60518.6000	-48.245	1720.518	7917.958	25970.902	-34.603	7917.900	
60519.3000	-46.238	1719.261	7868.881	25809.929	-24.421	7867.900	
60520.0000	-42.870	1717.718	7820.473	25651.151	-18.180	7817.900	
60520.7000	-39.733	1716.898	7770.776	25488.146	-12.901	7767.900	
60521.4000	-37.552	1715.433	7721.295	25325.846	-7.688	7717.900	
60522.2000	-35.045	1711.822	7664.943	25141.013	-.787	7667.900	
60522.9000	-32.439	1706.043	7615.453	24978.686	4.279	7617.900	
60523.6000	-29.111	1701.186	7566.014	24816.525	9.043	7567.900	
60524.3000	-25.517	1696.389	7516.047	24652.634	13.744	7517.900	
60525.0000	-21.339	1691.801	7465.321	24486.253	16.675	7467.900	
60525.7000	-20.537	1688.300	7415.791	24323.794	21.497	7417.900	
60526.4000	-18.394	1682.630	7367.283	24164.687	23.047	7367.900	

TABLE 7.1 - MERGED DATA LISTING - SAMPLE

(H) SHOWING ALL AIRBORNE AND GROUND PARAMETERS

THE MAX,MIN,MEAN, AND RMS VALUES FOR EACH CHANNEL OF SERIAL NUMBER 3 FOLLOWS:

CHANNEL	UNITS	HIGH	LOW	MEAN	RMS	STD	POINTS
TIME	SECONDS	60620.000	60473.500	60545.77299	60545.78823	43.06646	211.
X	FT	46037.000	12096.000	29101.98107	30743.81197	9936.02342	211.
Y	FT	96.000	-154.000	-17.85687	42.43052	38.58154	211.
Z	FT	1846.000	221.000	1257.85545	1364.32918	529.64447	211.
ALCFLG	N/A	0.000	-1.000	-.03318	.18214	.17952	211.
HBARO	FT	1708.000	-33.634	1067.12846	1206.26194	563.74723	211.
HFR	FT	116.000	-164.000	-9.03754	78.59021	78.25450	211.
XTK	FT	55.174	-112.000	-39.35173	53.42225	36.21594	211.
STPDTG	FT	36702.392	2790.194	19774.54378	22115.99320	9927.31802	211.
GAMMA	DEG	.386	-6.232	-2.76183	3.32606	1.85777	211.
GS	KNOTS	146.547	129.985	137.45754	137.52566	4.33822	211.
WD	DEG/180	359.708	.294	230.23792	280.85199	161.21867	211.
WS	KNOTS	13.484	5.953	9.43615	9.58314	1.67597	211.
HBARO CORR	FT	1993.000	251.366	1352.12846	1464.43029	563.74723	211.
MLS RANGE	NAUT MI	7.573	1.982	4.78432	5.05509	1.63614	211.
MLS AZ	DEG	.185	-.224	.01634	.08594	.08457	211.
XHAT+1	FT	45956.111	12022.740	29013.07660	30660.32363	9938.05369	211.
YHAT+1	FT	121.257	-120.720	-6.44207	40.99715	40.58414	211.
ZHAT+1	FT	1841.802	200.357	1237.26020	1346.61302	532.62202	211.
EL-1	DEG	4.225	2.865	3.75883	3.77980	.39862	211.
MLS MODE	N/A	1.000	1.000	1.00000	1.00000	0.00000	211.
VPOS ERROR	FEET	61.116	-183.793	-49.88416	86.82321	71.23122	211.
ALPHA	DEGREES	11.134	6.647	8.50996	8.55483	.87705	211.
BETA	DEGREES	1.575	-2.811	-.47099	.80140	.64993	211.
CMPTDAS 2B	KNOTS	138.472	121.242	129.69259	129.76804	4.43523	211.
MAG HEAD	DEGREES	241.648	216.674	225.36274	225.39320	3.71387	211.
F TH HDL 2	DEGREES	16.000	8.462	10.89993	11.11138	2.16250	211.
YAW RATE	DEG/SEC	1.539	-2.291	-.03972	.67606	.67650	211.
NORM ACC	FT/SEC/SEC	35.514	28.317	32.06341	32.08778	1.25326	211.
RADL ERROR	FEET	117.829	-71.151	-8.67832	46.16672	45.45155	211.
T E FLAP	DEGREES	28.392	23.949	26.78596	26.86623	2.08028	211.
F SPD BRK	POSITION	7.000	7.000	7.00000	7.00000	0.00000	211.
N G POS	POS	1.000	-1.000	-.91943	.98808	.36273	211.
ROLL ATT 2	DEGREES	6.950	-15.676	-.88692	4.54833	4.47163	211.
FDVC	DEGREES	5.345	-5.006	1.24083	2.10658	1.70640	211.
PTCH RTE 2	DEG/SEC	1.705	-1.566	.11619	.46604	.45240	211.
ROLL RTE 2	DEG/SEC	7.144	-6.547	.08274	1.86724	1.86984	211.
BAR HDOT 2	FT/SEC	1.635	-29.006	-11.49291	13.92836	7.88715	211.
EVENT MARK	EVENT	0.000	0.000	0.00000	0.00000	0.00000	211.
RUD POS 1	DEGREES	4.039	-.481	1.33395	1.47393	.62842	211.
STAB POS	PILOT UNIT	9.265	7.015	8.37414	8.41696	.84988	211.
RAD ALT 2B	FEET	579.263	223.723	546.13099	552.93849	86.70373	211.
FDLC	DEGREES	10.097	-9.157	.94930	3.57639	3.45631	211.
VERT DEV	DOT	.529	-2.230	-.29773	.76806	.70969	211.
LAT DEV	DOT	.194	-.277	-.08327	.12639	.09530	211.
EPR 2	RATIO	1.378	1.119	1.19615	1.19919	.08550	211.
LAT DEV	FEET	72.000	-136.000	-36.32227	52.39505	37.85134	211.

TABLE 7.1 - MERGED DATA LISTING - SAMPLE

(I) SHOWING ALL AIRBORNE AND GROUND PARAMETERS

ELEV POS L	DEGREES	8.939	5.367	7.01028	7.04098	.65835	211.
AIL POS L	DEGREES	7.851	-3.775	2.90144	3.90362	2.61769	211.
BAR AL F2B	FEET	1693.331	-56.087	1048.00039	1190.87601	566.92513	211.
PITCH 2	DEGREES	6.759	-1.278	2.59081	3.28142	2.01860	211.
ID1M	FORW ANT	256.000	256.000	256.00000	256.00000	0.00000	211.
ID2M	AFT ANT	0.000	0.000	0.00000	0.00000	0.00000	211.
DEL NOR AC	N/A	.104	-.120	-.00331	.03901	.03896	211.
CG X	FT	36783.853	2839.768	19845.59452	22183.30299	9935.75226	211.
CG Y	FT	106.602	-134.036	-14.32870	41.74841	39.30573	211.
CG Z	FT	1830.332	202.561	1240.27771	1348.50553	530.57756	211.
DIST TO GO	METERS	11214.589	865.783	6050.48613	6763.20213	3029.19276	211.
DIST TO GO	FEET	36775.666	2839.768	19845.04631	22182.41388	9934.85790	211.
VERT DFV	FEET	64.331	-164.000	-25.29958	69.33197	64.70468	211.
DES POINT	METERS	11217.900	867.900	6050.66209	6763.44901	3029.39346	211.
THE NUMBER OF FRAMES IN SERIAL		3 =	211				

TABLE 7.2 - STATISTICAL DATA - SAMPLE

(A) 50-METER INTERVAL DATA

START OF APPROACH TO D.H.

CHANNEL SUMMARIES FOR
FIFTY METER INTERVAL AND WAYPOINTS CP902 TO DH

CHANNEL	UNIT	HIGH	LOW	MEAN	B-VAR	UNB-VAR	B-STD	UNB-STD	SKEW	KURTOSIS	POINTS
DES PT	METERS	17140.8000	17140.8000	17140.8000	0.0000	0.0000	0.0000	0.0000	0.0000	9999999999	48.
VPOS ERROR	FEET	132.9457	-133.4309	.5769	2771.8134	2830.7882	52.6460	53.2052	-.0816	-.1789	48.
RADL ERROR	FEET	266.6397	-5831.9951	-2471.5502	9999999999	9999999999	1662.1515	1679.7409	-.3468	-.7574	48.
VERT DEV	FEET	-261.7246	-550.0000	-544.4109	1468.1729	1499.4105	38.3167	38.7222	6.7098	43.0213	48.
LAT DEV	FEET	131.0000	-1650.0000	-1392.6750	262550.0677	268136.2394	512.3964	517.8187	1.8211	1.9173	48.
CG Y	FEET	-19653.2439	-26333.7619	-26162.5373	921175.0830	940774.5528	959.7787	969.9353	6.5077	41.0387	48.
CG Z	FEET	2412.3698	2145.9882	2280.1865	2759.2454	2817.9527	52.5285	53.0844	-.0875	-.1573	48.
LNSF	FEET	436.4793	-4181.9951	-1078.6752	9999999999	9999999999	1367.4472	1381.9180	-.8851	-.4666	48.
VNSF	FEET	662.9457	247.6264	544.9879	4627.5889	4726.0483	68.0264	68.7463	-1.6282	5.6299	48.

CHANNEL SUMMARIES FOR
FIFTY METER INTERVAL AND WAYPOINTS CP902 TO DH

CHANNEL	UNIT	HIGH	LOW	MEAN	B-VAR	UNB-VAR	B-STD	UNB-STD	SKEW	KURTOSIS	POINTS
DES PT	METERS	17090.8000	17090.8000	17090.8000	0.0000	0.0000	0.0000	0.0000	0.0000	9999999999	48.
VPOS ERROR	FEET	133.5875	-88.5440	2.2563	2403.5144	2454.6530	49.0257	49.5445	.1955	-.5151	48.
RADL ERROR	FEET	234.9365	-5742.2413	-2405.0845	9999999999	9999999999	1652.4372	1669.9238	-.3797	-.7794	48.
VERT DEV	FEET	-260.2503	-550.0000	-544.1557	1484.1967	1515.7774	38.5253	38.9330	6.6935	42.8746	48.
LAT DEV	FEET	102.0000	-1650.0000	-1381.0208	271695.2287	277680.2336	521.4357	526.9537	1.7271	1.5305	48.
CG Y	FEET	-19628.2513	-26171.1155	-26005.6957	879743.8492	898461.6034	937.9466	947.8723	6.5527	41.5346	48.
CG Z	FEET	2413.2156	2191.0985	2262.0625	2390.9284	2441.7992	48.8971	49.4146	.1928	-.4995	48.
LNSF	FEET	510.6550	-4092.2413	-1024.0636	9999999999	9999999999	1353.5140	1367.8373	-.9116	-.4599	48.
VNSF	FEET	672.8104	246.5967	546.4120	4232.3508	4322.4008	65.0565	65.7450	-1.8422	7.1406	48.

CHANNEL SUMMARIES FOR
FIFTY METER INTERVAL AND WAYPOINTS CP902 TO DH

CHANNEL	UNIT	HIGH	LOW	MEAN	B-VAR	UNB-VAR	B-STD	UNB-STD	SKEW	KURTOSIS	POINTS
DES PT	METERS	17040.8000	17040.8000	17040.8000	0.0000	0.0000	0.0000	0.0000	0.0000	9999999999	48.
VPOS ERROR	FEET	133.4417	-128.3955	.6113	2660.9899	2717.6067	51.5848	52.1307	-.0603	-.2147	48.
RADL ERROR	FEET	209.6245	-5651.7664	-2337.4738	9999999999	9999999999	1642.0923	1659.4694	-.4131	-.7933	48.
VERT DEV	FEET	-278.3741	-550.0000	-543.9057	1509.0582	1541.1659	38.8466	39.2577	6.6509	42.4801	48.
LAT DEV	FEET	85.0000	-1650.0000	-1367.3542	283189.0204	289214.3187	532.1551	537.7865	1.6484	1.2251	48.
CG Y	FEET	-19603.1966	-26004.8804	-25847.4625	839483.8601	857345.2189	916.2335	925.9294	6.5949	41.9460	48.
CG Z	FEET	2413.2700	2151.4338	2280.6146	2649.8878	2706.2684	51.4771	52.0218	-.0660	-.1954	48.
LNSF	FEET	500.4455	-4001.7664	-970.1197	9999999999	9999999999	1337.4863	1351.6400	-.9425	-.4417	48.
VNSF	FEET	662.5393	245.2679	544.5169	4435.9672	4530.3494	66.6031	67.3079	-1.8239	6.3228	48.

CHANNEL SUMMARIES FOR
FIFTY METER INTERVAL AND WAYPOINTS CP902 TO DH

CHANNEL	UNIT	HIGH	LOW	MEAN	B-VAR	UNB-VAR	B-STD	UNB-STD	SKEW	KURTOSIS	POINTS
DES PT	METERS	16990.8000	16990.8000	16990.8000	0.0000	0.0000	0.0000	0.0000	0.0000	9999999999	48.
VPOS ERROR	FEET	131.6965	-125.0952	1.0356	2619.1195	2674.8455	51.1773	51.7189	-.0580	-.2850	48.
RADL ERROR	FEET	161.0817	-5560.0666	-2270.3615	9999999999	9999999999	1631.4060	1648.6700	-.4443	-.8061	48.
VERT DEV	FEET	-273.5493	-550.0000	-543.5605	1572.9249	1606.3914	39.6601	40.0798	6.5761	41.7625	48.
LAT DEV	FEET	71.0000	-1650.0000	-1352.7500	290635.6458	296819.3830	539.1063	544.8113	1.5653	.9320	48.
CG Y	FEET	-19578.2298	-25841.7057	-25688.3070	800545.3676	817581.3116	894.7337	904.2020	6.6328	42.3091	48.
CG Z	FEET	2411.7513	2154.9370	2281.2361	2608.9537	2664.4634	51.0779	51.6184	-.0634	-.2067	48.

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TABLE 7.2 - STATISTICAL DATA - SAMPLE

(B) 50-METER INTERVAL DATA

START OF APPROACH TO D.H.

CHANNEL SUMMARIES FOR
FIFTY METER INTERVAL AND WAYPOINTS

CHANNEL	UNIT	HIGH	CP902 LOW	DH TO MEAN	LAND B-VAR	UNB-VAR	B-STD	UNB-STD	SKEW	KURTOSIS	POINTS
DES PT	METERS	1163.2000	1163.2000	1163.2000	0.0000	0.0000	0.0000	0.0000	0.0000	**********	7.
Z CG	FEET	202.4042	158.5693	190.8252	200.3908	233.7893	14.1559	15.2902	-1.5413	.9680	7.
Y CG	FEET	16.1519	-46.6244	-10.9321	623.9030	734.8868	25.0979	27.1088	-.3239	-1.6188	7.

CHANNEL SUMMARIES FOR
FIFTY METER INTERVAL AND WAYPOINTS

CHANNEL	UNIT	HIGH	CP902 LOW	DH TO MEAN	LAND B-VAR	UNB-VAR	B-STD	UNB-STD	SKEW	KURTOSIS	POINTS
DES PT	METERS	1140.8000	1140.8000	1140.8000	0.0000	0.0000	0.0000	0.0000	0.0000	**********	7.
Z CG	FEET	199.8362	152.7326	187.3812	232.3342	271.0565	15.2425	16.4638	-1.5277	.9332	7.
Y CG	FEET	17.5209	-44.4387	-9.3196	621.4594	725.0360	24.9291	26.9265	-.3555	-1.6298	7.

CHANNEL SUMMARIES FOR
FIFTY METER INTERVAL AND WAYPOINTS

CHANNEL	UNIT	HIGH	CP902 LOW	DH TO MEAN	LAND B-VAR	UNB-VAR	B-STD	UNB-STD	SKEW	KURTOSIS	POINTS
DES PT	METERS	1090.8000	1090.8000	1090.8000	0.0000	0.0000	0.0000	0.0000	0.0000	**********	7.
Z CG	FEET	195.3920	142.9424	180.4479	278.0155	324.3514	16.6738	18.0098	-1.4451	.8051	7.
Y CG	FEET	20.4959	-40.3467	-6.0355	599.3684	687.5964	24.2769	26.2221	-.3692	-1.6268	7.

CHANNEL SUMMARIES FOR
FIFTY METER INTERVAL AND WAYPOINTS

CHANNEL	UNIT	HIGH	CP902 LOW	DH TO MEAN	LAND B-VAR	UNB-VAR	B-STD	UNB-STD	SKEW	KURTOSIS	POINTS
DES PT	METERS	1040.8000	1040.8000	1040.8000	0.0000	0.0000	0.0000	0.0000	0.0000	**********	7.
Z CG	FEET	190.3001	133.6824	173.1297	321.7965	375.4293	17.9387	19.3760	-1.2838	.5487	7.
Y CG	FEET	23.2966	-38.0165	-2.4262	573.7836	669.4142	23.9538	25.8730	-.3481	-1.6129	7.

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TABLE 7.2 - STATISTICAL DATA - SAMPLE

(C) 50-METER INTERVAL DATA

START OF APPROACH TO D.H.

CHANNEL SUMMARIES FOR
FIFTY METER INTERVAL AND WAYPOINTS CP902 DH TO LOW APPROACH

CHANNEL	UNIT	HIGH	LOW	MEAN	B-VAR	UNB-VAR	B-STD	UNB-STD	SKEW	KURTOSIS	POINTS
DES PT	METERS	1163.2000	1163.2000	1163.2000	0.0000	0.0000	0.0000	0.0000	0.0000	**********	4.
CG Z	FEET	202.0518	180.5274	193.6549	73.1081	97.4775	8.5503	9.8731	-.5484	-1.2806	4.
CG Y	FEET	32.7253	-14.8778	8.3113	380.6515	507.5354	19.5103	22.5285	.0461	-1.7567	4.

CHANNEL SUMMARIES FOR
FIFTY METER INTERVAL AND WAYPOINTS CP902 DH TO LOW APPROACH

CHANNEL	UNIT	HIGH	LOW	MEAN	B-VAR	UNB-VAR	B-STD	UNB-STD	SKEW	KURTOSIS	POINTS
DES PT	METERS	1140.8000	1140.8000	1140.8000	0.0000	0.0000	0.0000	0.0000	0.0000	**********	4.
CG Z	FEET	193.4553	176.0938	189.6769	78.2667	104.3556	8.8468	10.2155	-.5491	-1.2732	4.
CG Y	FEET	31.0118	-19.1360	6.3891	426.3515	568.4657	20.6483	23.8426	-.0659	-1.7643	4.

CHANNEL SUMMARIES FOR
FIFTY METER INTERVAL AND WAYPOINTS CP902 DH TO LOW APPROACH

CHANNEL	UNIT	HIGH	LOW	MEAN	B-VAR	UNB-VAR	B-STD	UNB-STD	SKEW	KURTOSIS	POINTS
DES PT	METERS	1090.8000	1090.8000	1090.8000	0.0000	0.0000	0.0000	0.0000	0.0000	**********	4.
CG Z	FEET	188.4532	168.3638	180.9759	60.2256	80.3008	7.7605	8.9611	-.7648	-.9646	4.
CG Y	FEET	26.1516	-25.4677	4.2183	492.0451	656.0602	22.1821	25.6137	-.2015	-1.7338	4.

CHANNEL SUMMARIES FOR
FIFTY METER INTERVAL AND WAYPOINTS CP902 DH TO LOW APPROACH

CHANNEL	UNIT	HIGH	LOW	MEAN	B-VAR	UNB-VAR	B-STD	UNB-STD	SKEW	KURTOSIS	POINTS
DES PT	METERS	1040.8000	1040.8000	1040.8000	0.0000	0.0000	0.0000	0.0000	0.0000	**********	4.
CG Z	FEET	180.0725	160.0121	172.6940	57.8315	77.1087	7.6047	8.7812	-.9009	-.6311	4.
CG Y	FEET	25.5718	-31.9624	1.2699	563.2022	750.9363	23.7319	27.4032	-.2841	-1.6072	4.

TABLE 7.2 - STATISTICAL DATA - SAMPLE

(D) 50-METER INTERVAL DATA

START OF APPROACH TO D.H.

CHANNEL SUMMARIES FOR
FIFTY METER INTERVAL AND WAYPOINTS CP902 DH TO GO AROUND

CHANNEL	UNIT	HIGH	LOW	MEAN	B-VAR	UNB-VAR	B-STD	UNB-STD	SKEW	KURTOSIS	POINTS
DES PT	METERS	1163.2000	1163.2000	1163.2000	0.0000	0.0000	0.0000	0.0000	0.0000	**********	29.
Z CG	FEET	217.9813	174.4667	198.2067	100.8563	104.4583	10.0427	10.2205	-.0335	-.3353	29.
Y CG	FEET	48.7136	-96.3394	-7.8317	932.7888	966.1027	30.5416	31.0822	-.6406	.5746	29.

CHANNEL SUMMARIES FOR
FIFTY METER INTERVAL AND WAYPOINTS CP902 DH TO GO AROUND

CHANNEL	UNIT	HIGH	LOW	MEAN	B-VAR	UNB-VAR	B-STD	UNB-STD	SKEW	KURTOSIS	POINTS
DES PT	METERS	1140.8000	1140.8000	1140.8000	0.0000	0.0000	0.0000	0.0000	0.0000	**********	29.
Z CG	FEET	214.4700	170.2255	195.2330	107.0457	110.8687	10.3463	10.5294	-.0361	-.1608	29.
Y CG	FEET	49.5169	-97.0649	-7.8677	947.3305	981.1637	30.7787	31.3235	-.6362	.5840	29.

CHANNEL SUMMARIES FOR
FIFTY METER INTERVAL AND WAYPOINTS CP902 DH TO GO AROUND

CHANNEL	UNIT	HIGH	LOW	MEAN	B-VAR	UNB-VAR	B-STD	UNB-STD	SKEW	KURTOSIS	POINTS
DES PT	METERS	1090.8000	1090.8000	1090.8000	0.0000	0.0000	0.0000	0.0000	0.0000	**********	29.
Z CG	FEET	219.7803	160.1304	188.7955	137.2947	142.1981	11.7173	11.9247	.1078	.7172	29.
Y CG	FEET	52.4085	-99.9236	-8.0631	1007.8823	1043.8781	31.7472	32.3091	-.6388	.6597	29.

CHANNEL SUMMARIES FOR
FIFTY METER INTERVAL AND WAYPOINTS CP902 DH TO GO AROUND

CHANNEL	UNIT	HIGH	LOW	MEAN	B-VAR	UNB-VAR	B-STD	UNB-STD	SKEW	KURTOSIS	POINTS
DES PT	METERS	1040.8000	1040.8000	1040.8000	0.0000	0.0000	0.0000	0.0000	0.0000	**********	29.
Z CG	FEET	223.8580	150.1655	184.0133	209.6470	217.1344	14.4792	14.7355	.5969	1.8122	29.
Y CG	FEET	55.1051	-101.7176	-8.2126	1055.6512	1093.3530	32.4908	33.0659	-.6600	.7699	29.

TABLE 7.2 - STATISTICAL DATA - SAMPLE

(E) LANDING DISPERSION

CHANNEL SUMMARIES FOR
CP 902 OBSTACLE CLEARANCE ANALYSIS LANDINGS

CHANNEL	UNIT	HIGH	LOW	MEAN	B-VAR	UNB-VAR	B-STD	UNB-STD	SKEW	KURTOSIS	POINTS
TIME	SECS	75782.5000	52591.2000	66124.3000	***********	***********	8944.9273	9661.6258	-.3861	-1.6016	7.
L CG	FEET	-44.5060	-1441.3460	-732.6540	234609.2633	273710.6072	484.3648	523.1738	-.3172	-1.2085	7.
Z CG	FEET	12.7010	9.8250	11.7951	.8152	.9510	.9029	.9752	-1.2142	.4890	7.
Y CG	FEET	14.1750	-14.5410	-1.0611	97.7446	114.0354	9.8866	10.6787	.0987	-1.4199	7.

(F) HEIGHT LOSS ANALYSIS - FOR LOW APPROACHES

CHANNEL SUMMARIES FOR
SELECTED POINTS PROFILE 902 DH TO LOW APPROACH

CHANNEL	UNIT	HIGH	LOW	MEAN	B-VAR	UNB-VAR	B-STD	UNB-STD	SKEW	KURTOSIS	POINTS
TIME	SECS	73156.1000	53501.1000	64194.1250	***********	***********	8687.2742	10031.2002	-.0866	-1.6768	4.
LOWAVG Z	FT	48.4742	24.4652	36.5504	99.7247	132.9663	9.9862	11.5311	-.0108	-1.8016	4.
HTLOSS	FT	175.5348	151.5258	163.4496	99.7247	132.9663	9.9862	11.5311	.0108	-1.8016	4.
DIST TO GO	FT	674.6364	197.7126	457.7702	44530.1016	59373.4689	211.0216	243.6667	-.0863	-1.8759	4.
CG Y	FT	21.4666	-35.2007	-.4647	456.8974	609.1965	21.3752	24.6819	-.7609	-.9562	4.

(G) HEIGHT LOSS ANALYSIS - FOR GO-AROUND

CHANNEL SUMMARIES FOR
SELECTED POINTS PROFILE 902 DH TO GO AROUND

CHANNEL	UNIT	HIGH	LOW	MEAN	B-VAR	UNB-VAR	B-STD	UNB-STD	SKEW	KURTOSIS	POINTS
TIME	SECS	76049.1000	51552.0000	67235.3000	***********	***********	8275.6744	8403.9871	-.6957	-1.0812	33.
LOWAVG Z	FT	213.7209	106.6369	165.8699	507.8518	523.7222	22.5356	22.8850	-.3000	-.0241	33.
HTLOSS	FT	93.3631	-13.7209	34.1301	507.8518	523.7222	22.5356	22.8850	.3000	-.0241	33.
DIST TO GO	FT	3747.0430	1983.3391	2982.4813	171153.0318	176501.5640	413.7065	420.1209	-.3840	-.0914	33.
CG Y	FT	53.2428	-108.1302	-5.7965	1269.1759	1308.8377	35.6255	36.1779	-.9576	1.0560	33.

TABLE 7.3 - CURVED-PATH APPROACH SUMMARY

PROFILE	NO. OF PRETEST RUNS	NO. OF DATA RUNS	NO. OF GOOD APPROACHES	NO. OF LANDINGS	NO. OF APPROACHES	NO. OF GO-AROUNDS
CP181	21	54	48	2	1	45
CP182	12	53	48	2	8	38
CP183	6	55	48	6	7	35
CP901	6	52	48	7	9	32
CP902	4	55	48	9	5	34
CP131	2	48	48	4	5	39
CPS01	2	49	48	3	2	43
TOTALS	53	366	336	33	37	226
PERCENT	-	108.93	100.00	9.82	11.01	79.17

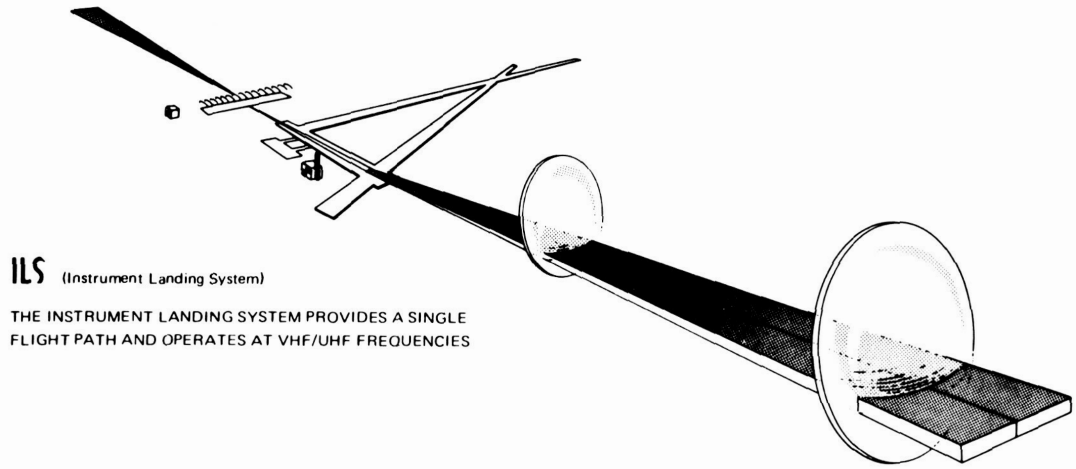
STEEP ANGLE APPROACH SUMMARY

SGS40	8	32	32	17	0	15
SGS38	3	32	32	15	0	17
SGS35	1	33	32	16	0	16
TOTALS	12	97	96	48	0	48
PERCENT	-	101.04	100	50.00	0.00	50.00

TOTAL MLS STEP APPROACHES

NUMBER	65	463	432	81	37	314
PERCENT	-	106.70	100	18.75	8.56	72.69

INSTRUMENT LANDING SYSTEM (ILS)



MICROWAVE LANDING SYSTEM (MLS)

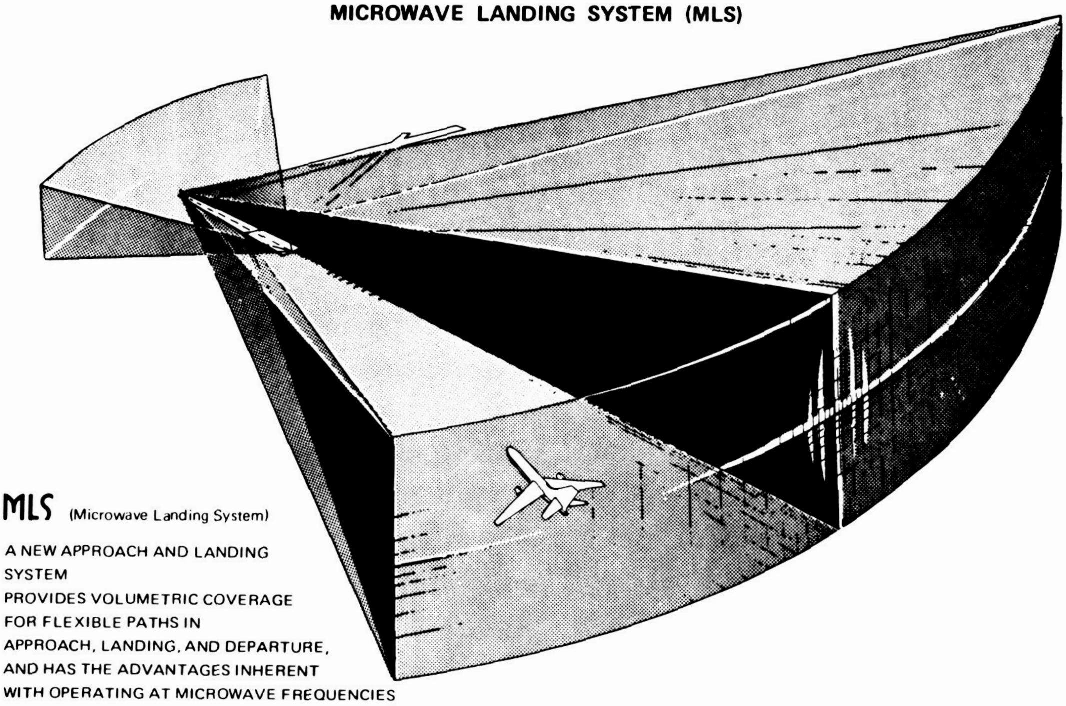


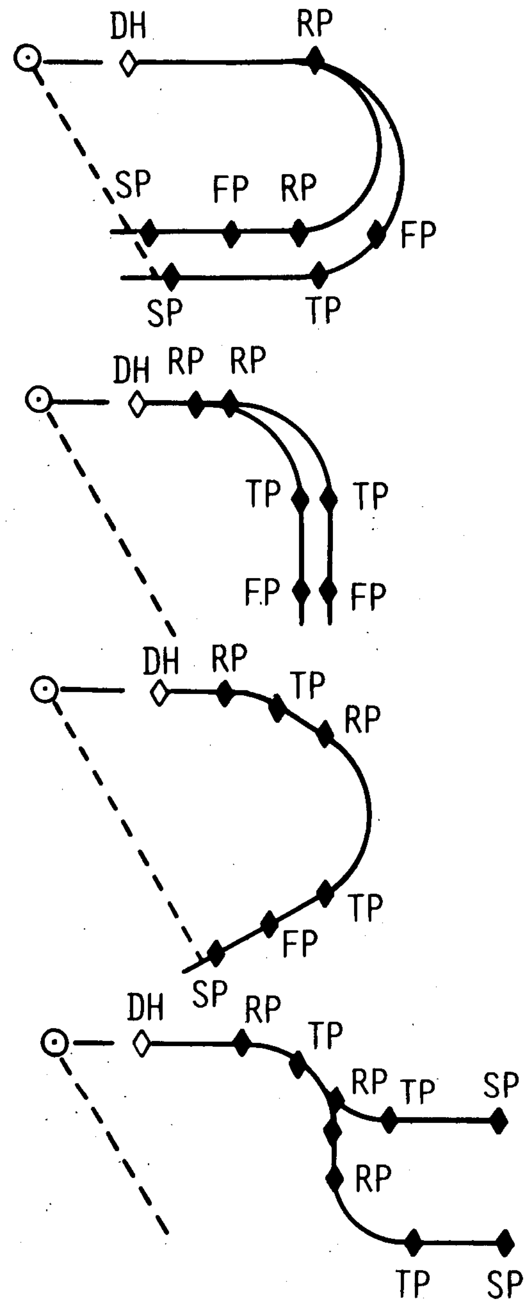
FIGURE 1.1 - MLS VOLUMETRIC COVERAGE

A. Profile No. 1 — to study MLS coverage areas and optimum turn rates using a 180°-curved path. 3 variations allow for turn (TP) and descent points (FP) to be interchanged.

B. Profile No. 2 — to study the minimum and optimum centerline segment lenths (MCLS & OCLS), using a 90° turn to final.

C. Profile No. 3 — the minimum non-centerline segment length (NCLS) between curved segments.

D. Profile No. 4 — offset parallel approaches to study the minimum NCLS at varying angles and offset distances.



Notes:

RP = roll-out point
SP = starting point
TP = turn point
FP = final approach point

FIGURE 1.2 - MLS COMPLEX APPROACH STUDY - PROFILE TYPES

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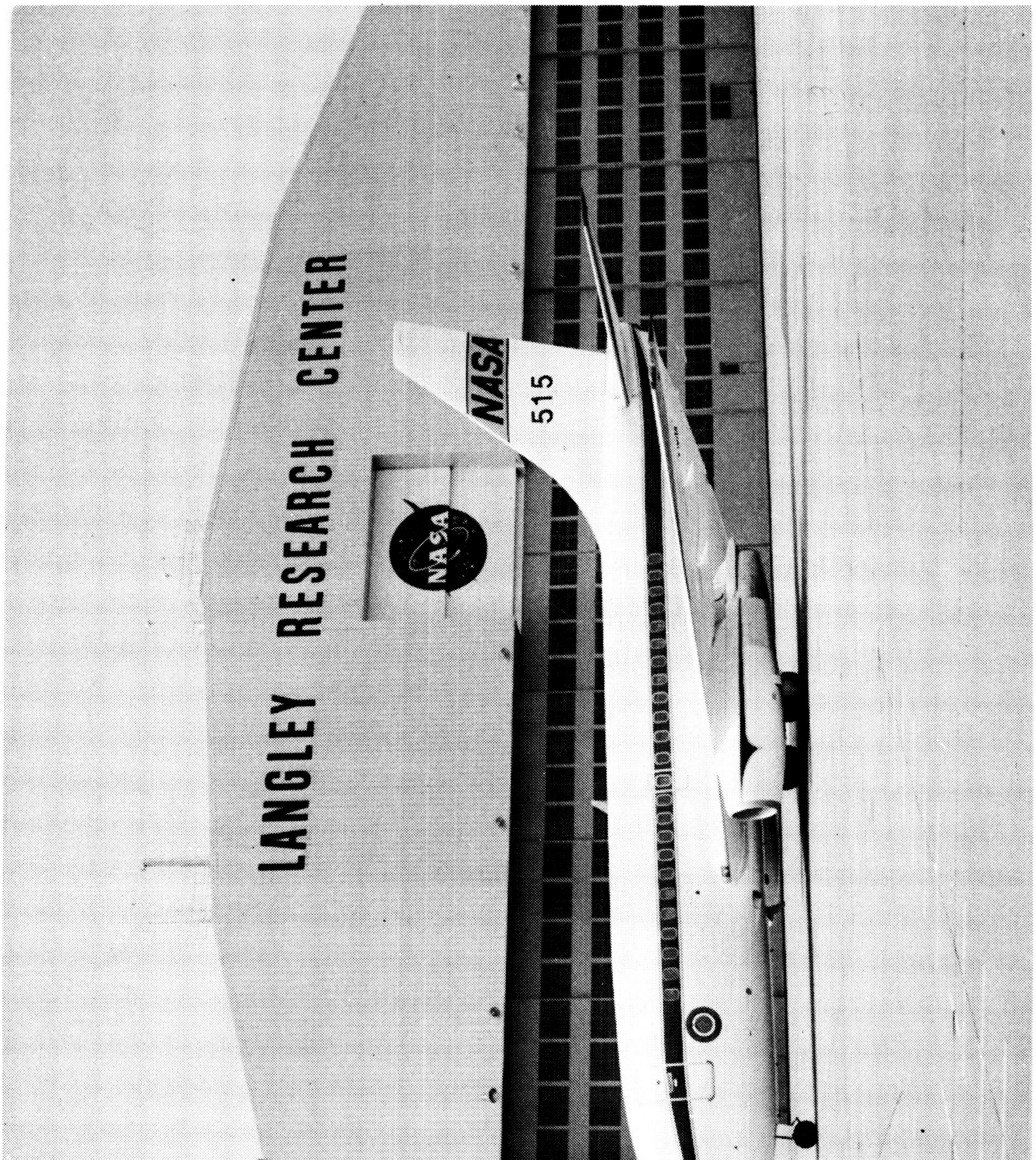

FIGURE 1.3 - NASA LANGLEY TSRV (B-737) RESEARCH AIRCRAFT

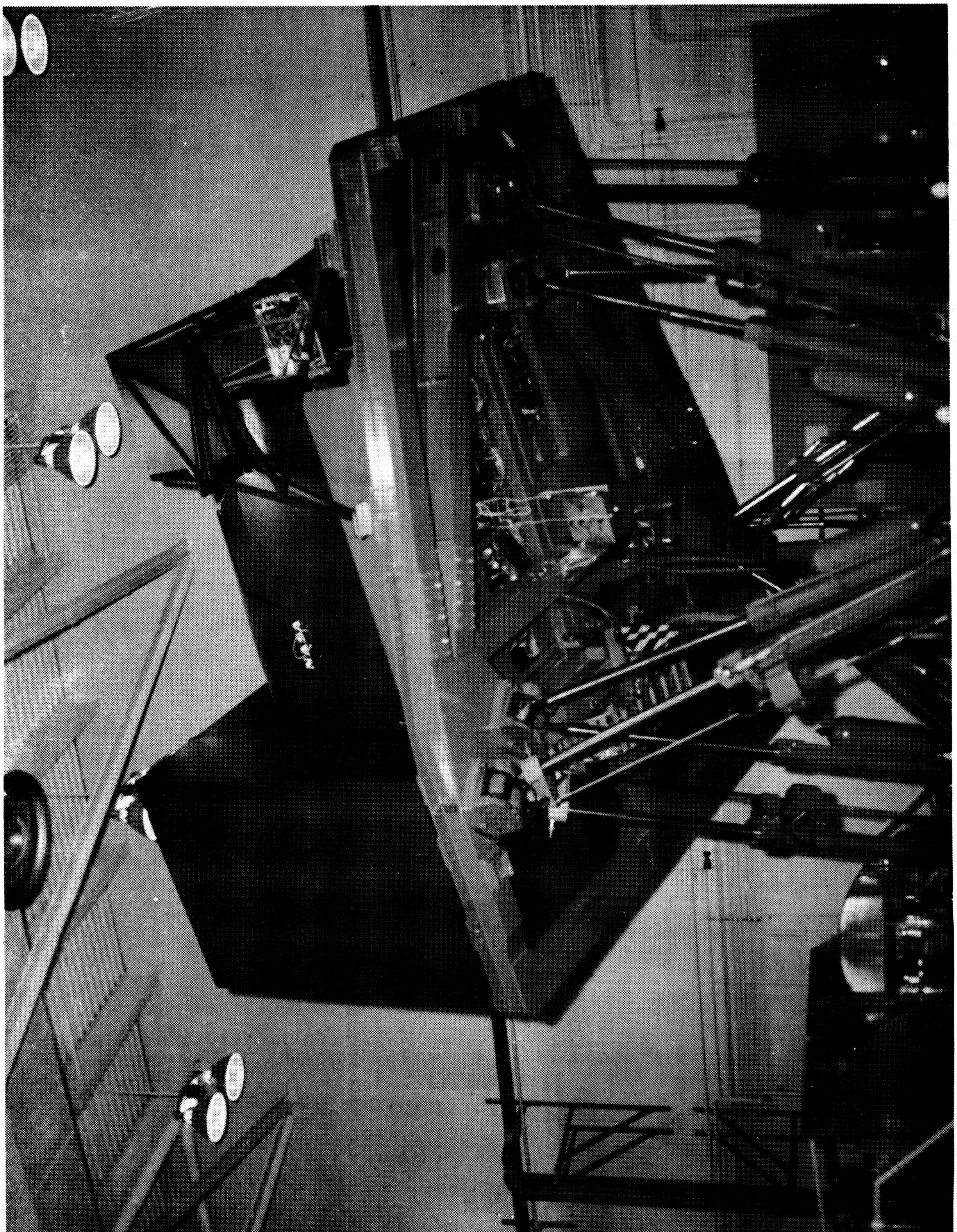

FIGURE 1.4 - VISUAL MOTION SIMULATOR (VMS) - (Exterior View)

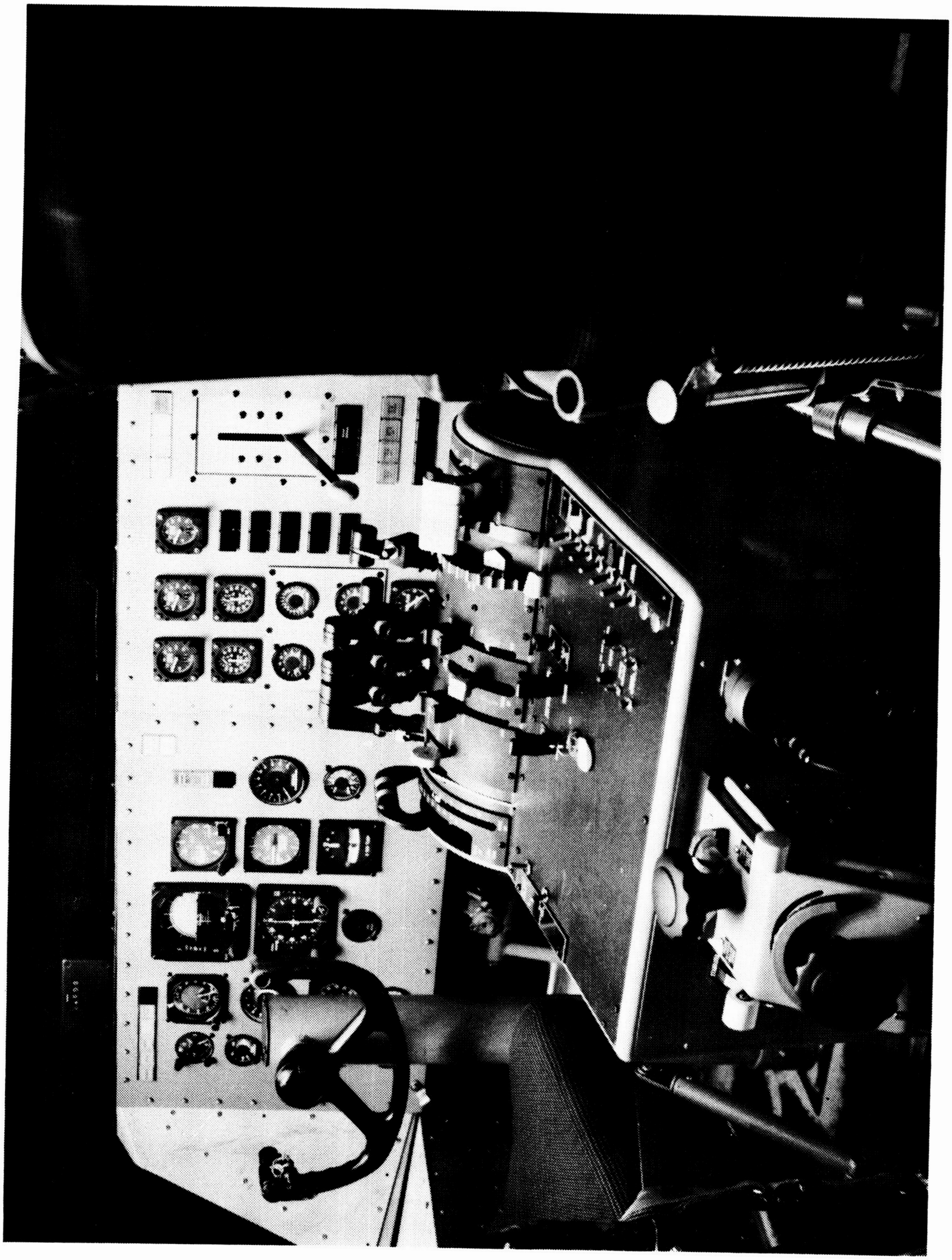

FIGURE 2.1 - VISUAL MOTION SIMULATOR (VMS) - (Interior View)

FIGURE 2.2 - VISUAL LANDING DISPLAY SYSTEM (VLDS)

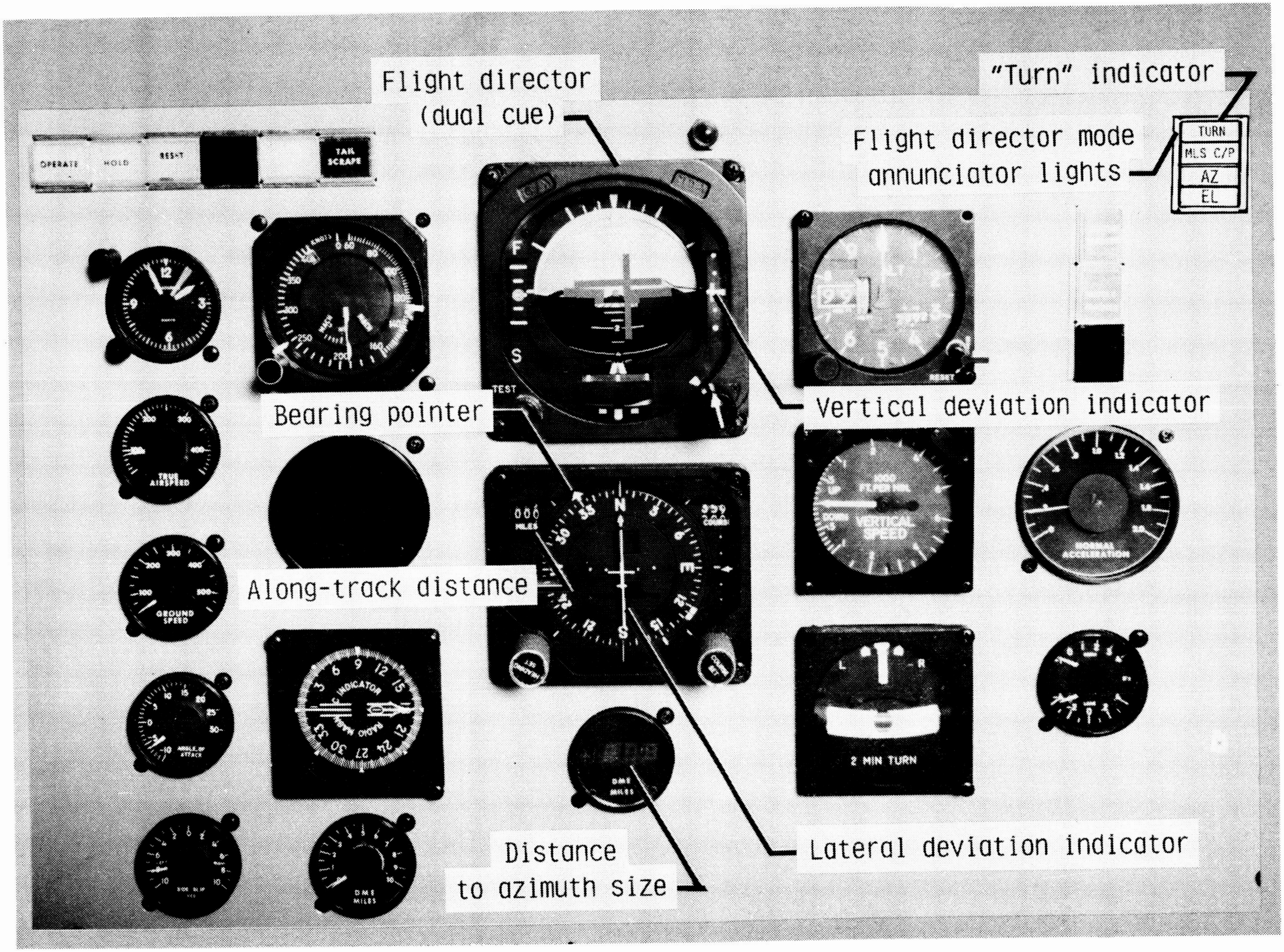

FIGURE 2.3 - VISUAL MOTION SIMULATOR - COCKPIT INSTRUMENTATION

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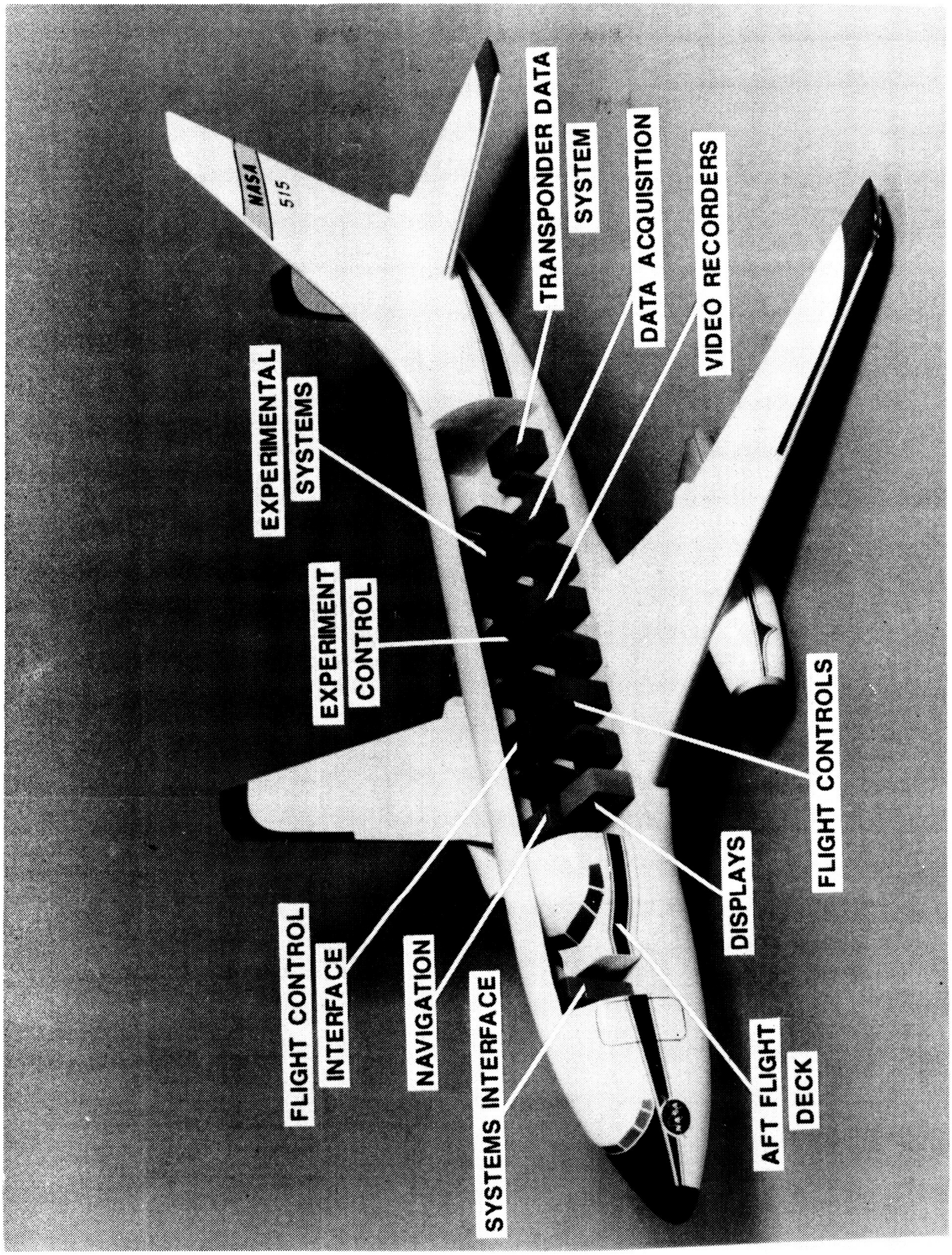
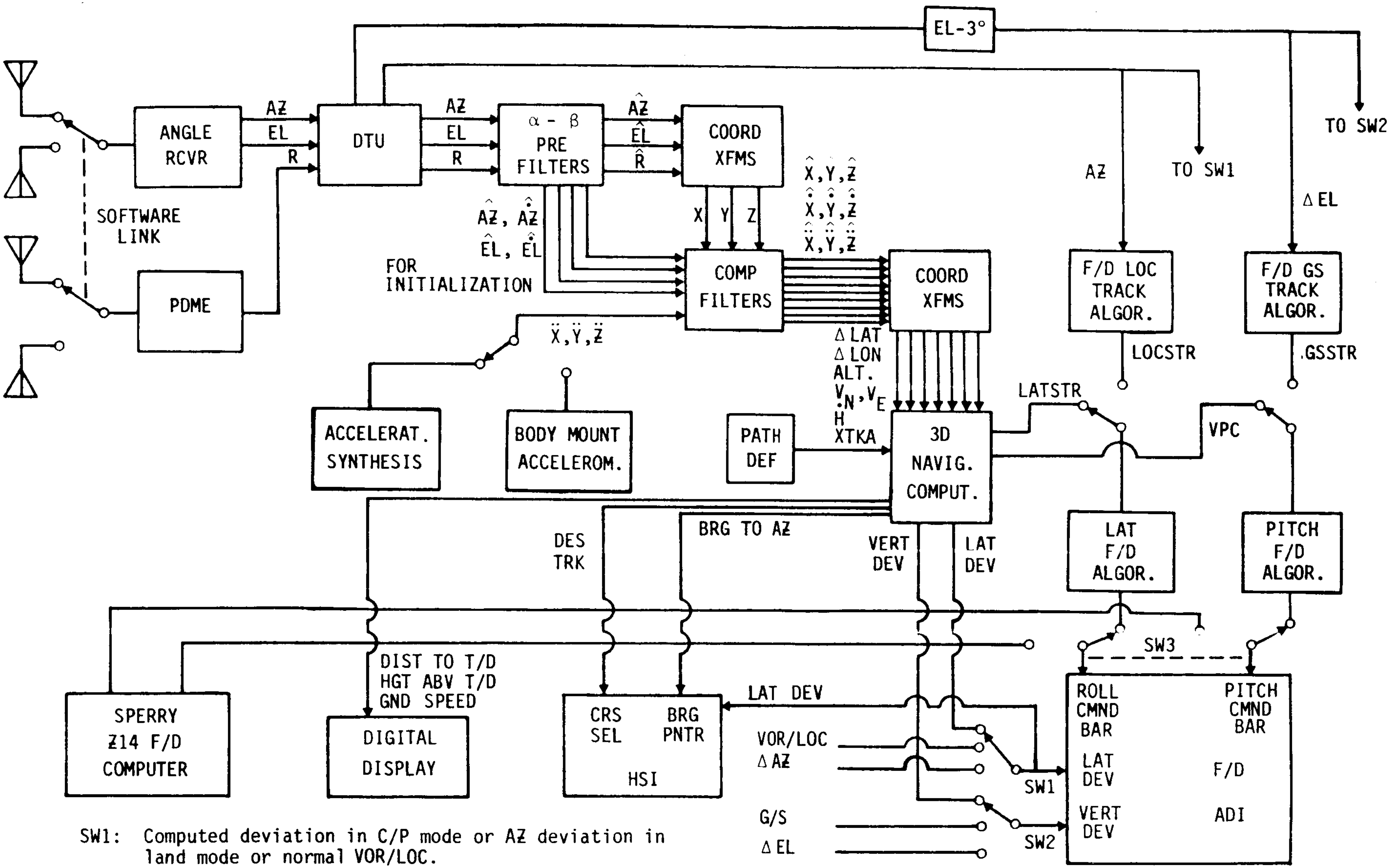


FIGURE 3.1 - TSRV CUTAWAY VIEW SHOWING MAJOR SYSTEMS



SW1: Computed deviation in C/P mode or AZ deviation in land mode or normal VOR/LOC.
SW2: Computed deviation in C/P or EL deviation in land mode or normal G/S.
SW3: MLSVLD·$\overline{\text{HDG}}$·$\overline{\text{GOARND}}$·$\overline{\text{VHF}}$

FIGURE 3.2 - NAVIGATION AND GUIDANCE SYSTEM (Functional Block Diagram)

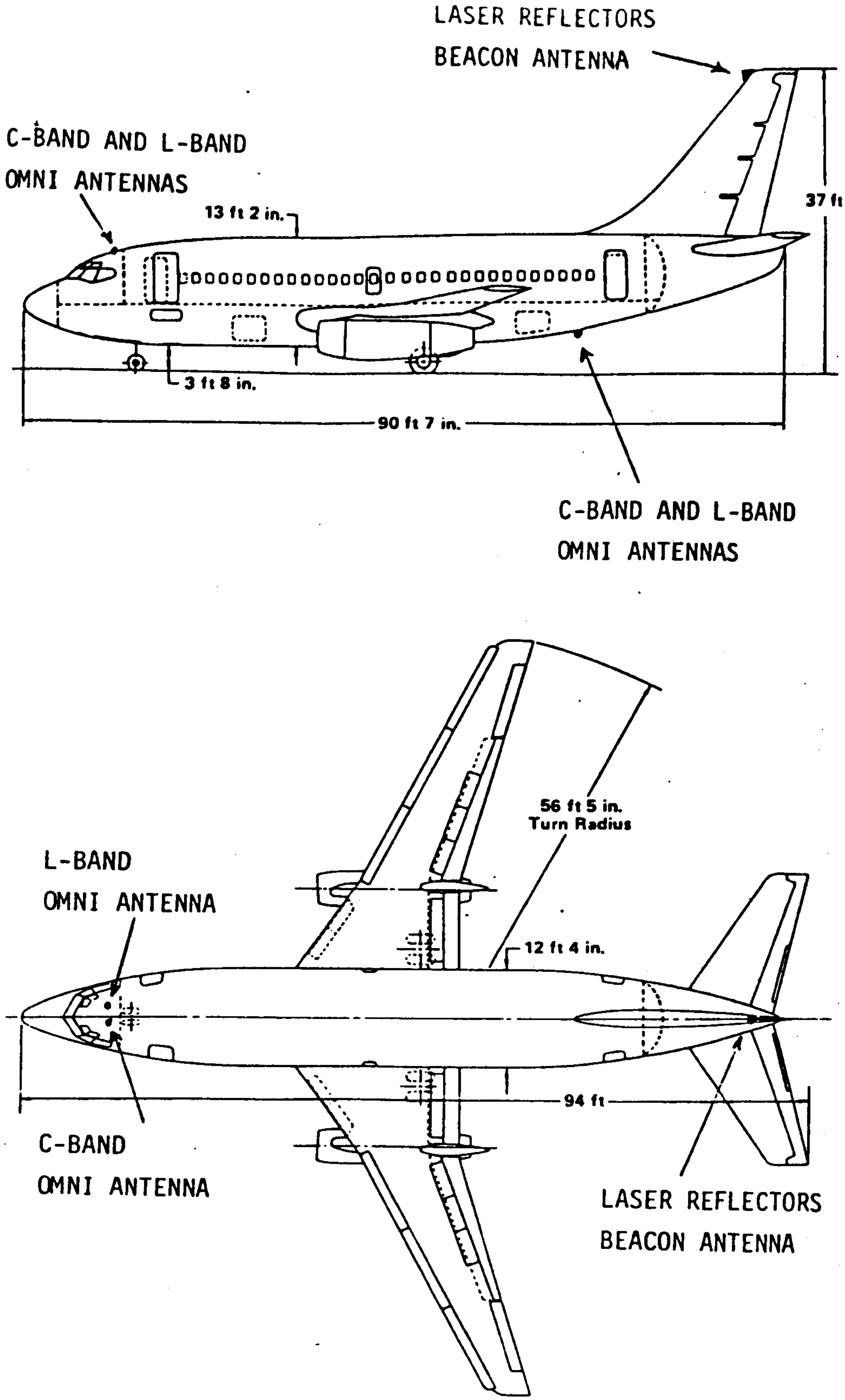
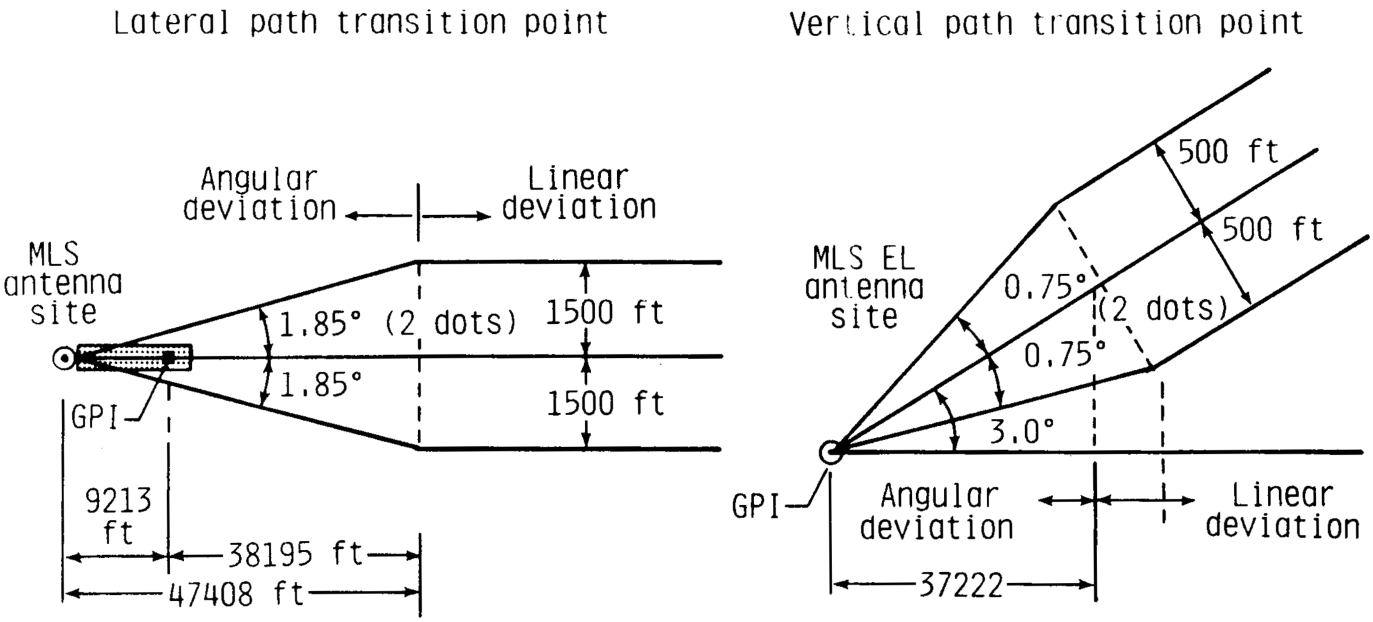


FIGURE 3.3 - MLS ANTENNA LOCATIONS AND TRACKING POINT



Deviation display conversions for dots to feet

- Azimuth
  - For "distance to go" (L) > 38,195 feet:
    Lateral deviation = (± dots) * 750 ft/dot
  - For "distance to go" (L) < 38,195 feet:
    Lateral deviation = (L + 9213) tan [(± dots)(+0.925°/dot)]
- Elevation
  - For L > 37,222 feet:
    Vertical deviation = (± dots) * 250 ft/dot
  - For L < 37,222 feet:
    Vertical deviation = Ltan [(± dots)(0.375°/dot)]

FIGURE 3.4 - FLIGHT DIRECTOR TRANSITION POINTS AND AZ/EL DEVIATION SENSITIVITIES

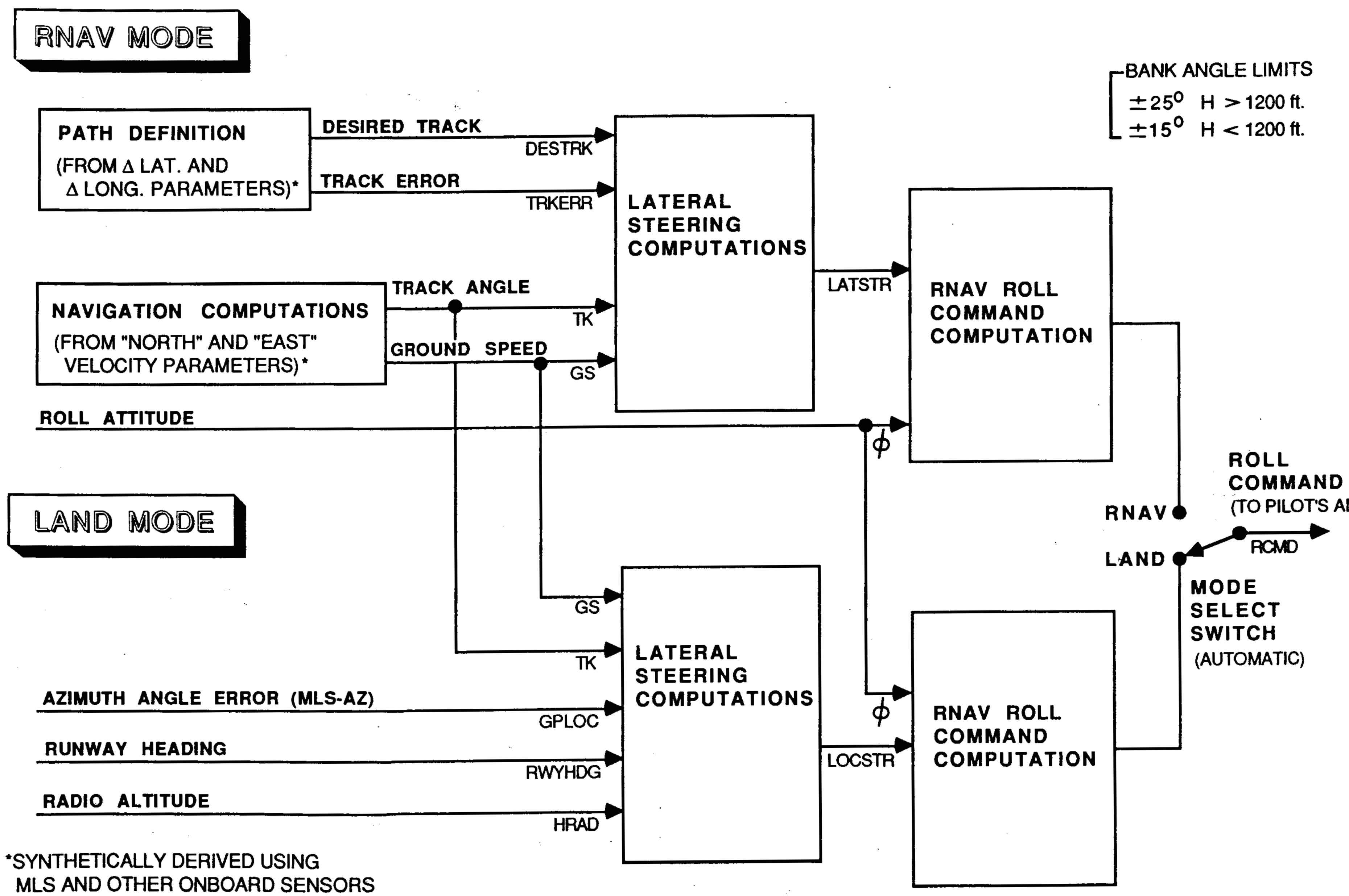


FIGURE 3.5 - ROLL AXIS FLIGHT DIRECTOR

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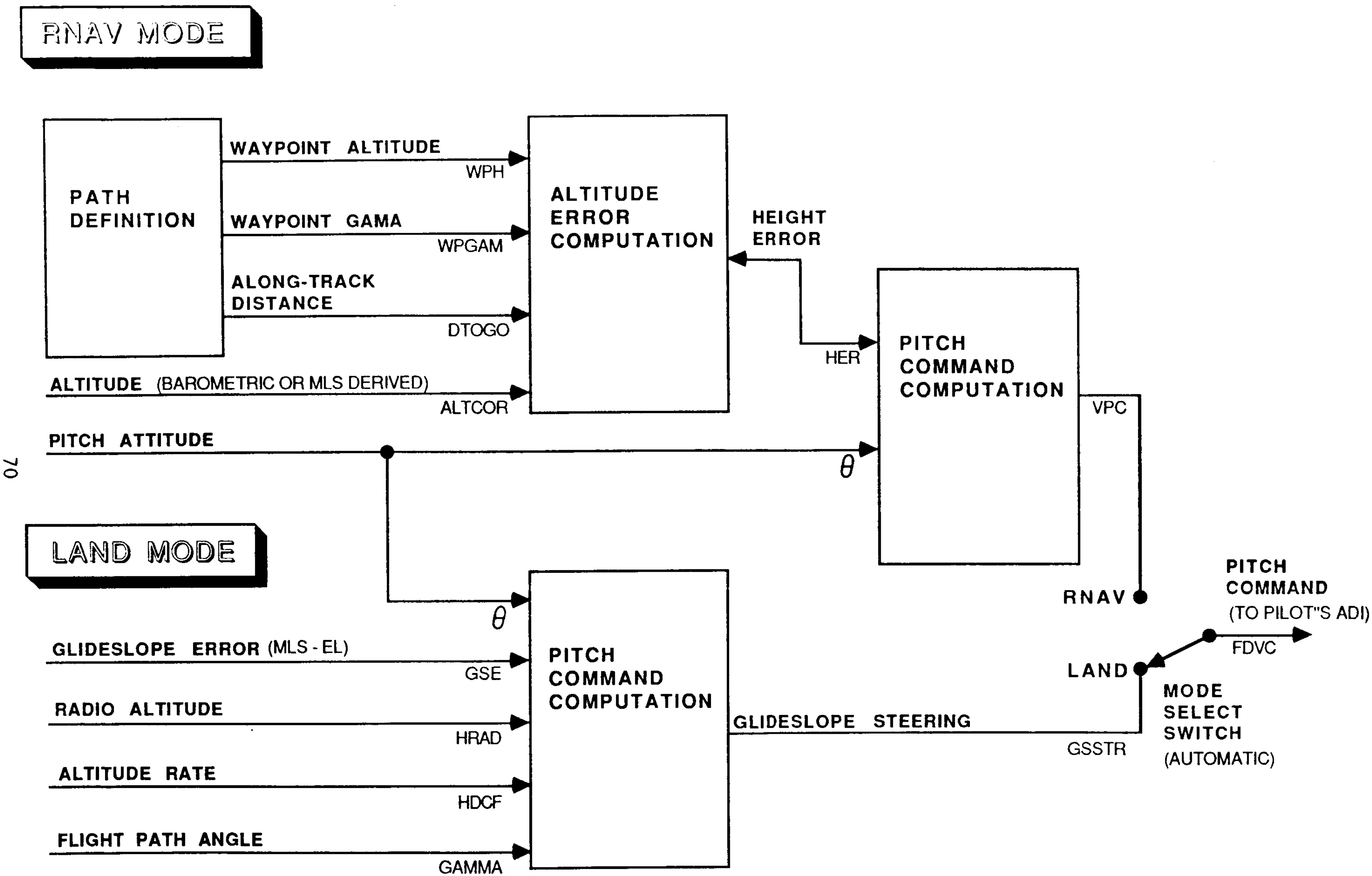


FIGURE 3.6 - PITCH AXIS FLIGHT DIRECTOR

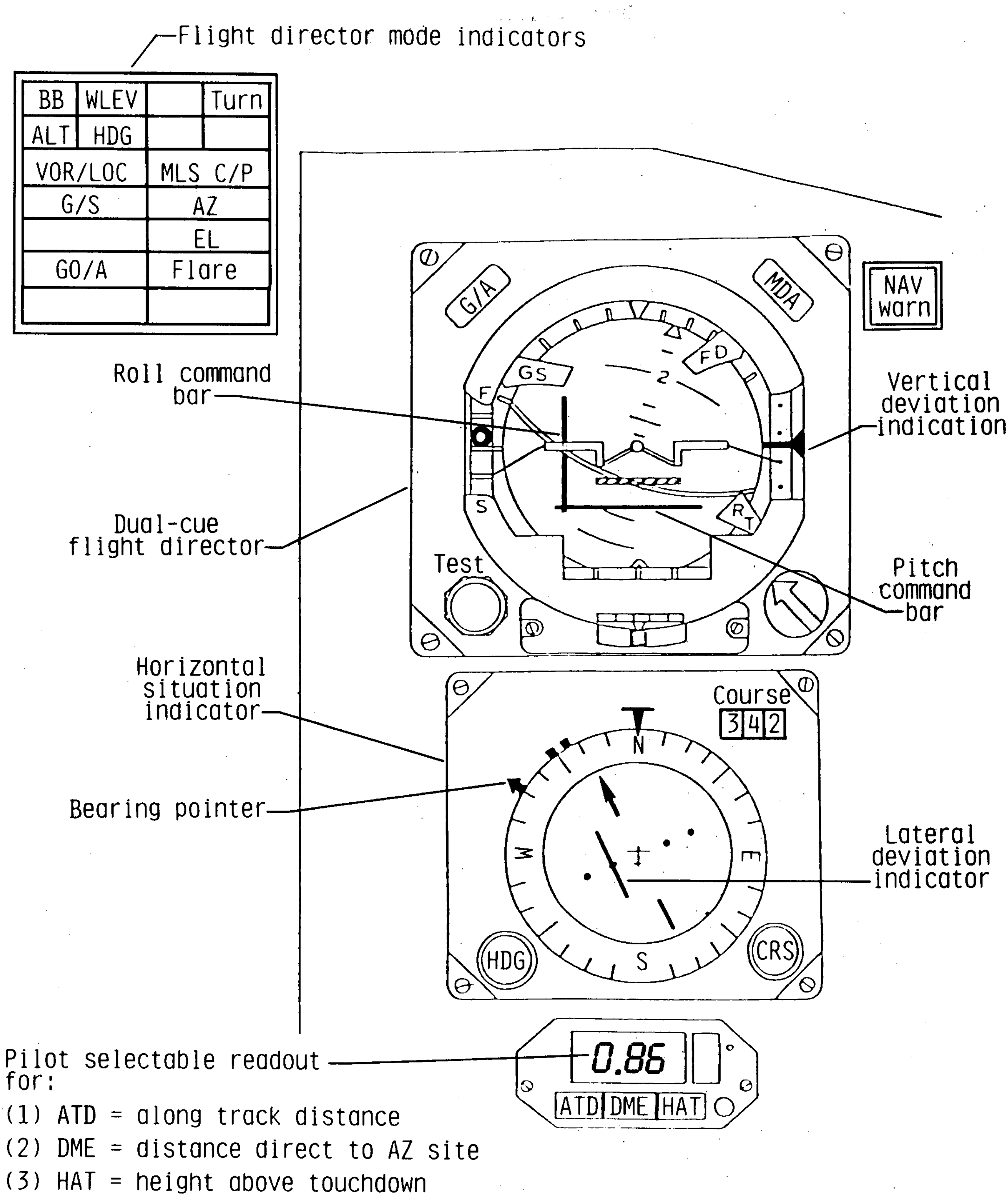
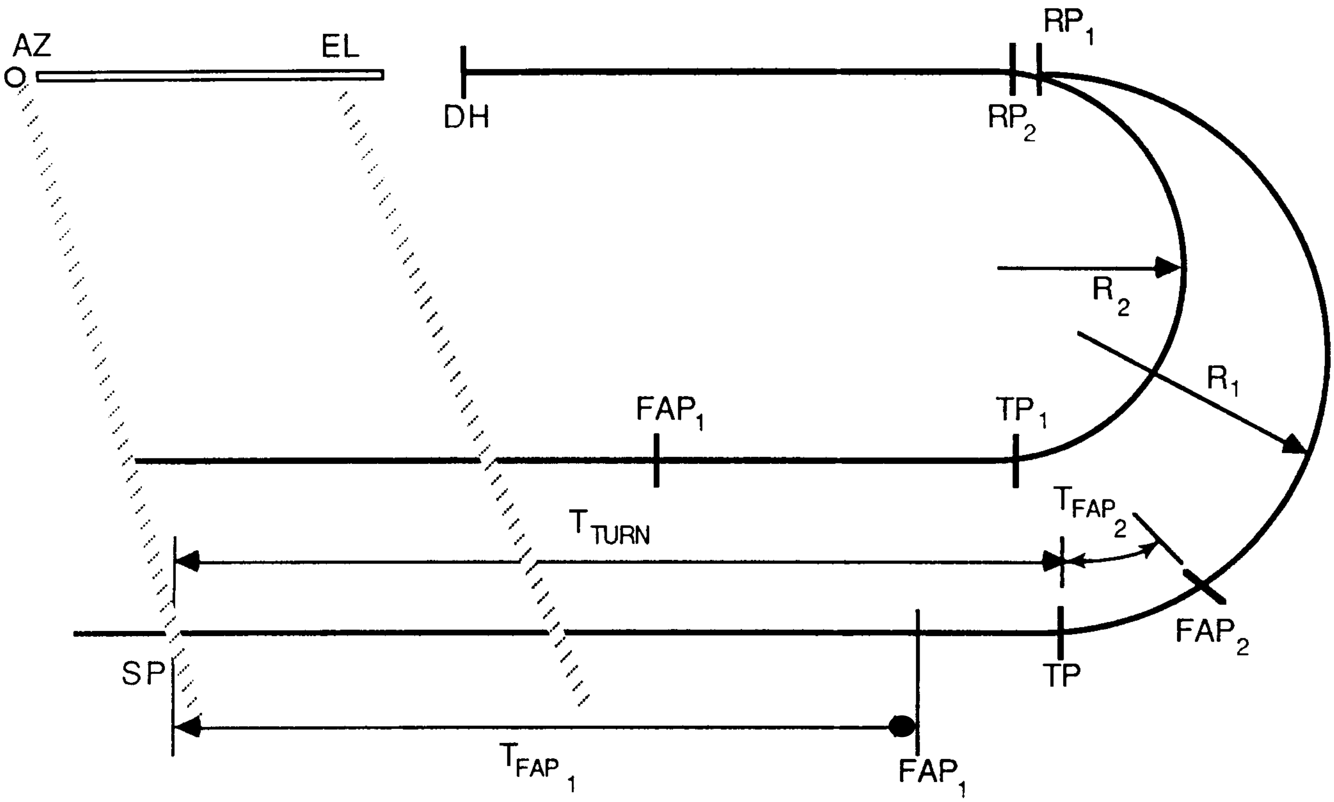


FIGURE 3.7 - PILOT DISPLAYS USED FOR FLIGHT TEST



SUB PROFILE	SP			FAP			TP			RP		
	ALT. (FT-MSL)	A.T.D. (NMi)	IAS (KTS)	ALT. (FT-MSL)	A.T.D. (NMi)	IAS (KTS)	ALT. (FT-MSL)	A.T.D. (NMi)	IAS (KTS)	ALT. (FT-MSL)	A.T.D. (NMi)	IAS (KTS)
CP-181	3883	16.1	160	3883	12.0	140	3586	11.0	140	2192	6.6	140
CP-182	3278	14.2	160	[SAME AS TP]			3278	10.1	140	1884	5.7	140
CP-183	2981	14.2	160	[LOCATED AFTER TP] 2981	9.2	140	2981	10.1	140	1884	5.7	140

NOTES: FAP = FINAL APPROACH POINT
RP = ROLLOUT POINT
SP = START POINT
TP = TURN POINT
DH = DECISION HEIGHT
R = TURN RADIUS - T.B.D.
T = SEGMENT TIME - T.B.D.
AZ = MLS AZIMUTH SITE
EL = MLS EVALUATION SITE

3 VARIATIONS: CP-181 - FAP PRIOR TO TP
CP-182 - FAP AND TP COINCIDENT
CP-183 - FAP AFTER TP

FIGURE 4.1A - PROFILE 1. 180 DEGREE COURSE REVERSAL

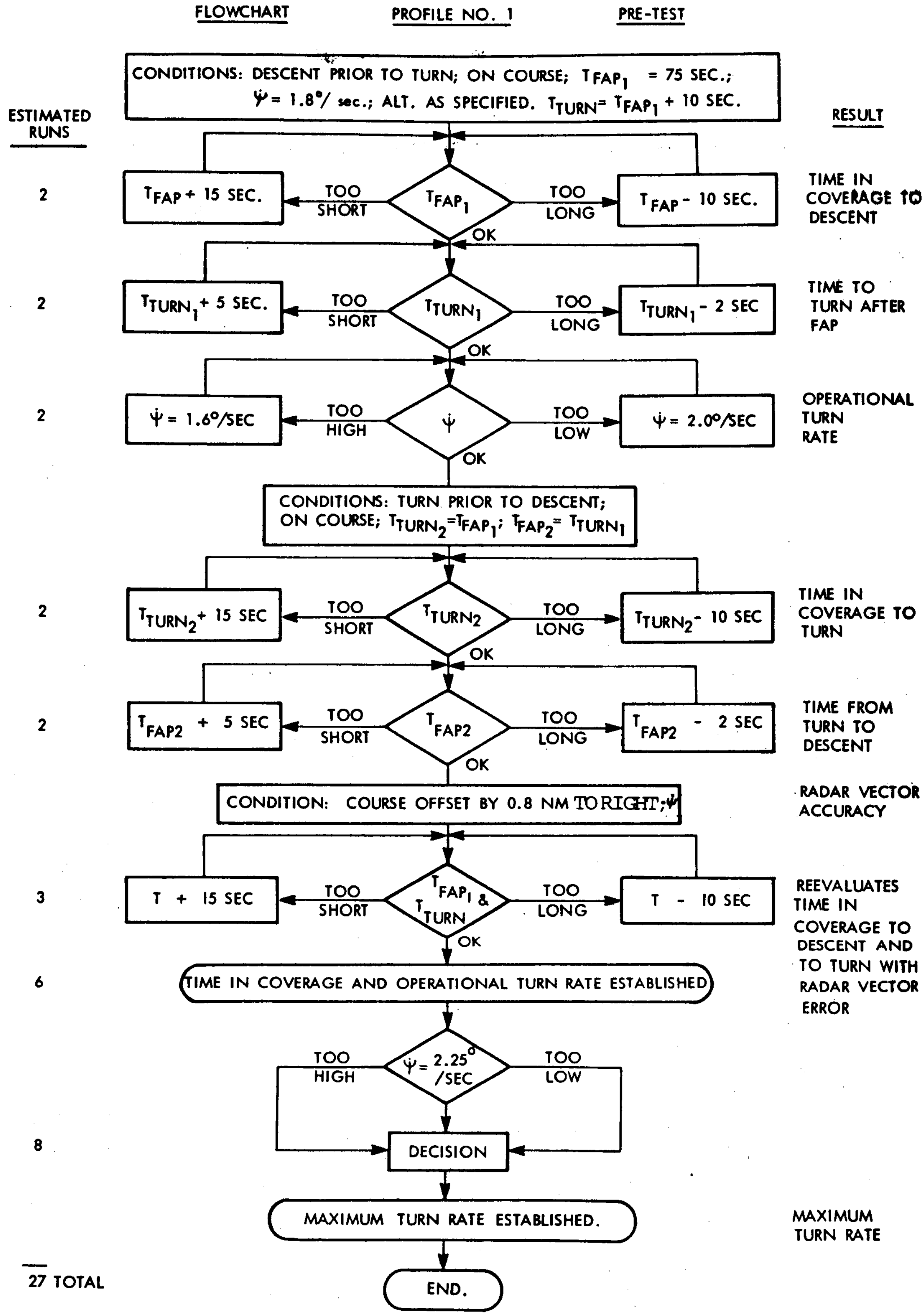
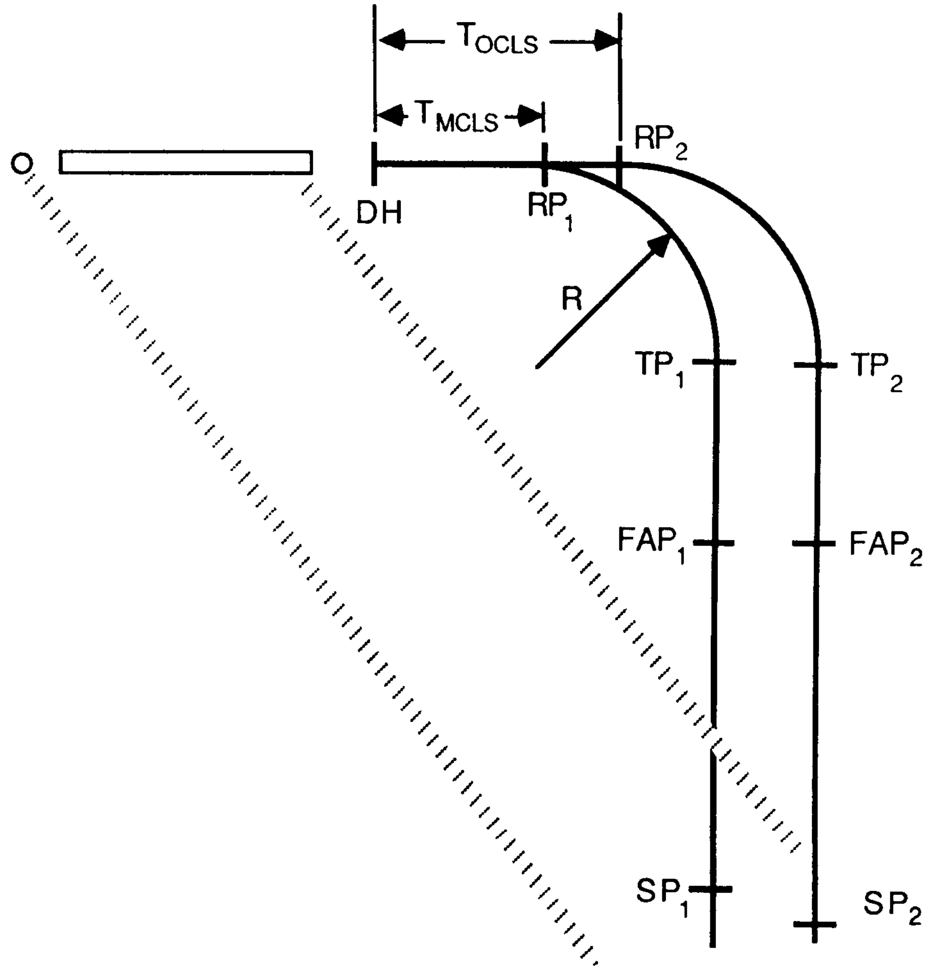


FIGURE 4.1B - FLOW CHART FOR TESTING PROFILE NO. 1



SUB PROFILE	SP			FAP			TP			RP		
	ALT. (FT-MSL)	A.T.D. (NMi)	IAS (KTS)	ALT. (FT-MSL)	A.T.D. (NMi)	IAS (KTS)	ALT. (FT-MSL)	A.T.D. (NMi)	IAS (KTS)	ALT. (FT-MSL)	A.T.D. (NMi)	IAS (KTS)
CP-901	1981	10.0	160	1981	6.1	140	1684	5.2	140	987	3.0	140
CP-902	2359	11.2	160	2359	7.2	140	2062	6.3	140	1366	4.1	140

NOTES: MCLS = MINIMUM CENTERLINE SEGMENT
OCLS = OPTIMUM CENTERLINE SEGMENT
DH, RP, TP, FAP, SP = (see notes for Fig. 4.1A)

2 VARIATIONS: CP-901 - MINIMUM TIME ON R/Y CENTERLINE
CP-902 - OPTIMUM TIME ON R/Y CENTERLINE

FIGURE 4.2A - PROFILE 2. 90 DEGREE INTERCEPT

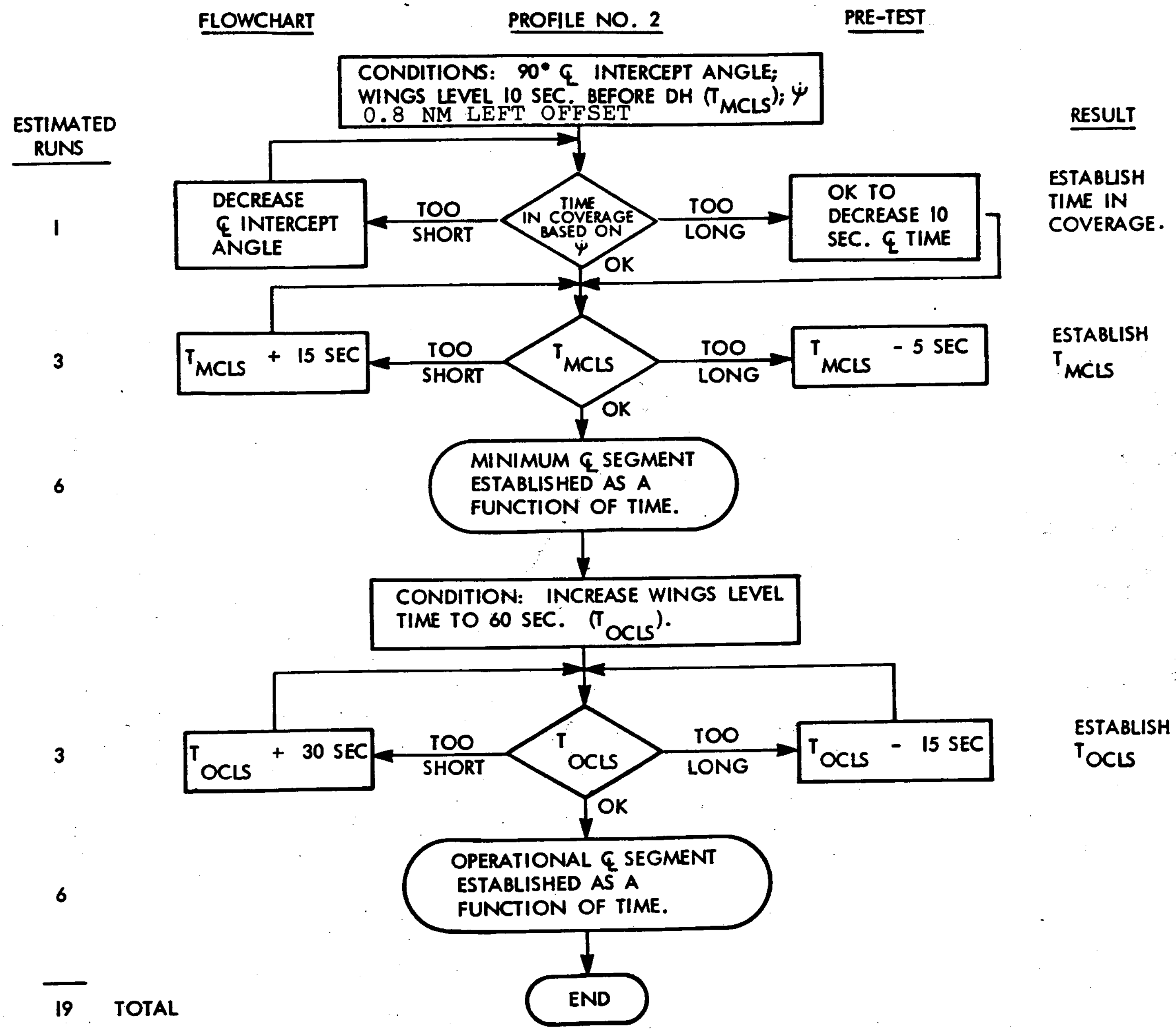
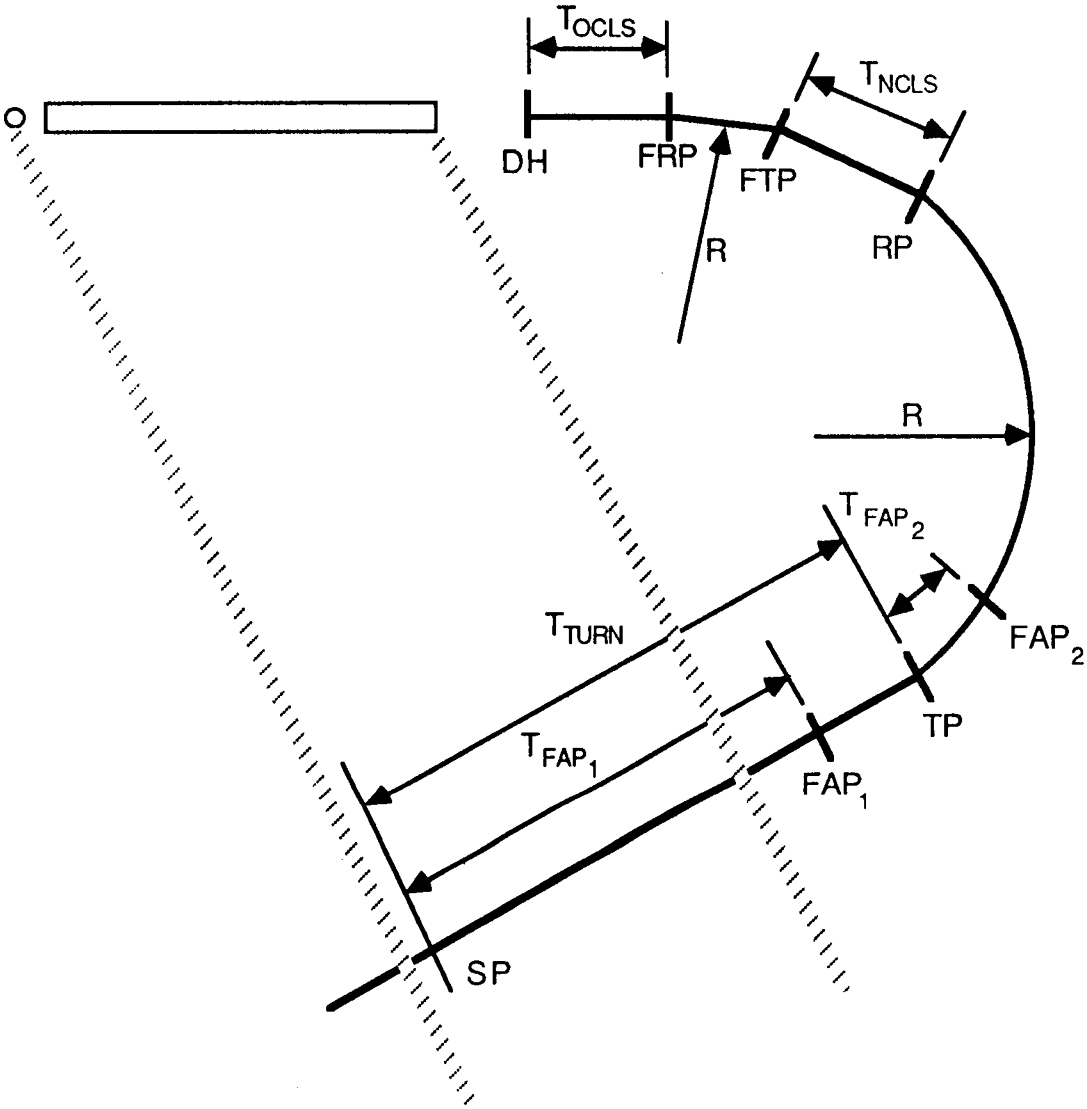


FIGURE 4.2B - FLOW CHART FOR PROFILE NO. 2



PARAMETERS FOR CP-131

FAP			TP			RP			FTP			FRP		
ALT. (FT MSL)	A.T.D. (NMi)	IAS (KTS)	ALT. (FT-MSL)	A.T.D. (NMi)	IAS (KTS)	ALT. (FT-MSL)	A.T.D. (NMi)	IAS (KTS)	ALT. (FT-MSL)	A.T.D. (NMi)	IAS (KTS)	ALT. (FT-MSL)	A.T.D. (NMi)	IAS (KTS)
3752	11.6	140	3455	10.6	140	2526	7.7	140	2229	6.8	140	1997	6.1	140

NOTES: NCLS = NON-CENTERLINE SEGMENT
FRP = FINAL ROLLOUT POINT
FTP = FINAL TURN POINT
OCLS, FAP, RP, SP, TP, DH, T = (see notes for Fig. 4.2A)

FIGURE 4.3A - PROFILE 3. DUAL TURN (120 AND 30 DEGREE) COURSE REVERSAL

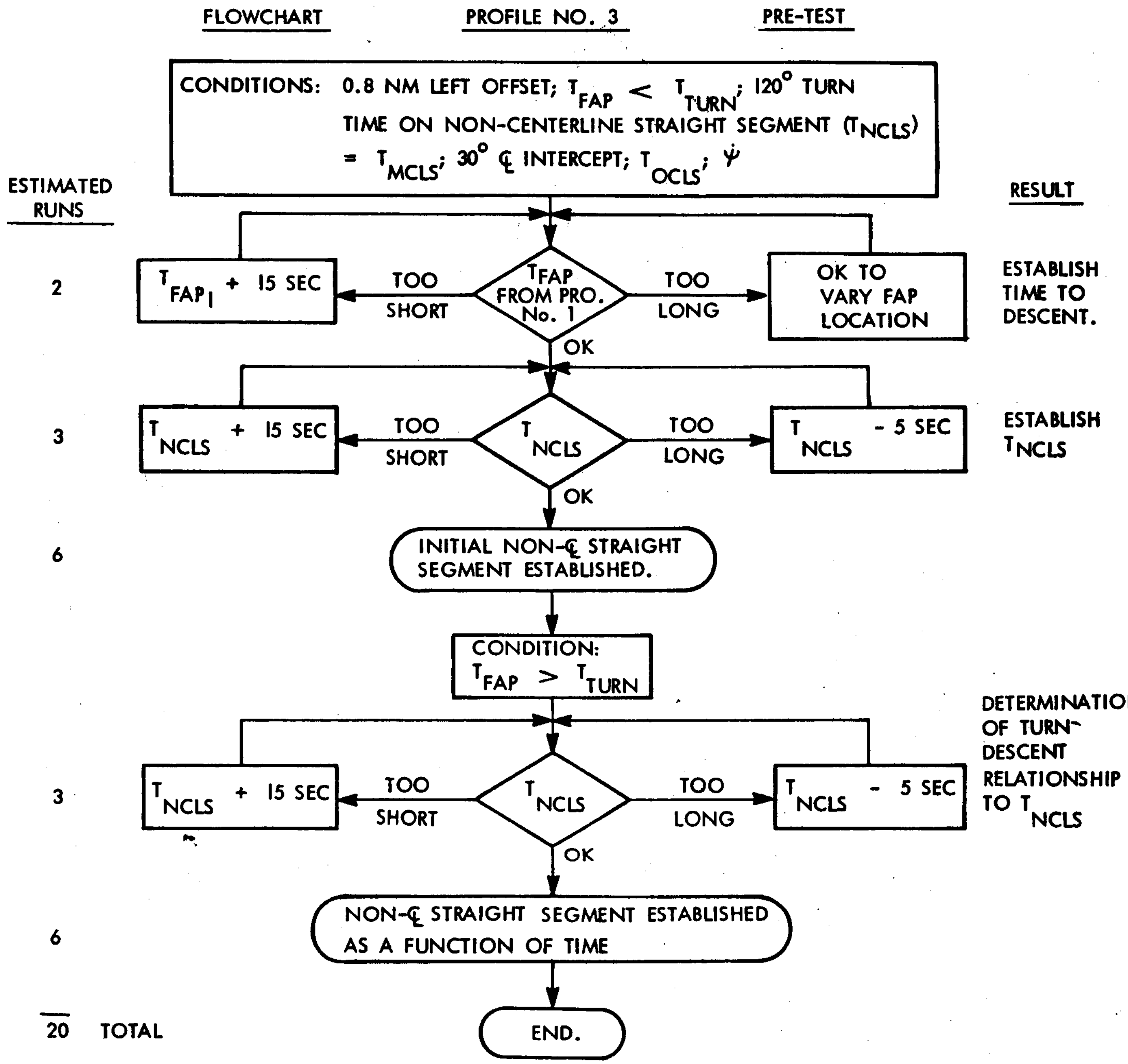
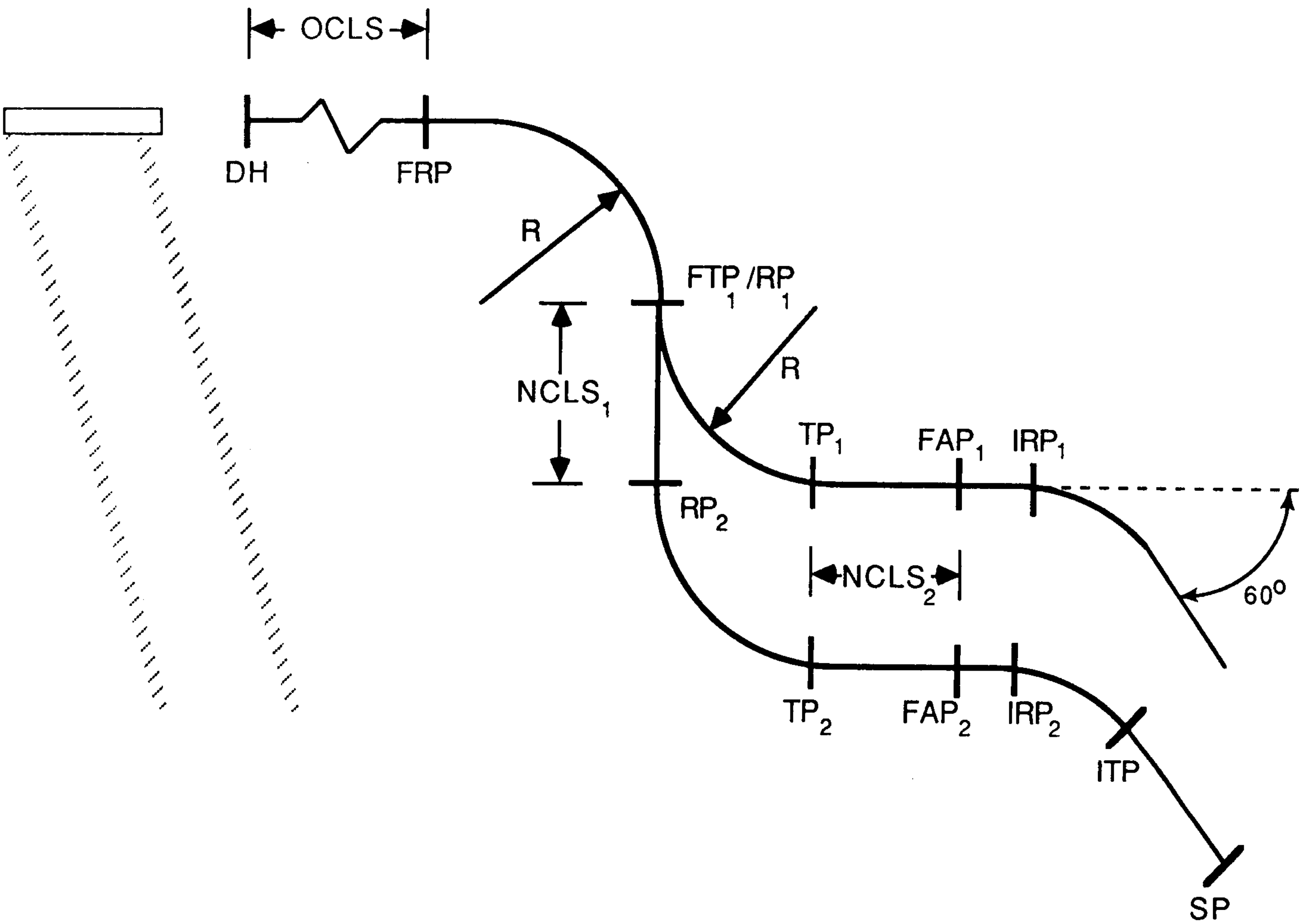


FIGURE 4.3B - FLOW CHART FOR PROFILE NO. 3



PARAMETERS FOR CP-S01

SP			TP			RP			FTP			FRP		
ALT. (FT-MSL)	A.T.D. (NMi)	IAS (KTS)	ALT. (FT-MSL)	A.T.D. (NMi)	IAS (KTS)	ALT. (FT-MSL)	A.T.D. (NMi)	IAS (KTS)	ALT. (FT-MSL)	A.T.D. (NMi)	IAS (KTS)	ALT. (FT-MSL)	A.T.D. (NMi)	IAS (KTS)
3354	14.3	140	3057	9.4	140	2360	7.3	140	2063	6.3	140	1366	4.1	140

NOTES: ITP = INTERCEPT TURN POINT
IRP = INTERCEPT ROLL POINT
FP, RP, SP, TP, FRP, FTP, OCLS, NCLS, DH = (see notes for Fig. 4.3A)

FIGURE 4.4A - PROFILE 4. PARALLEL OFFSET

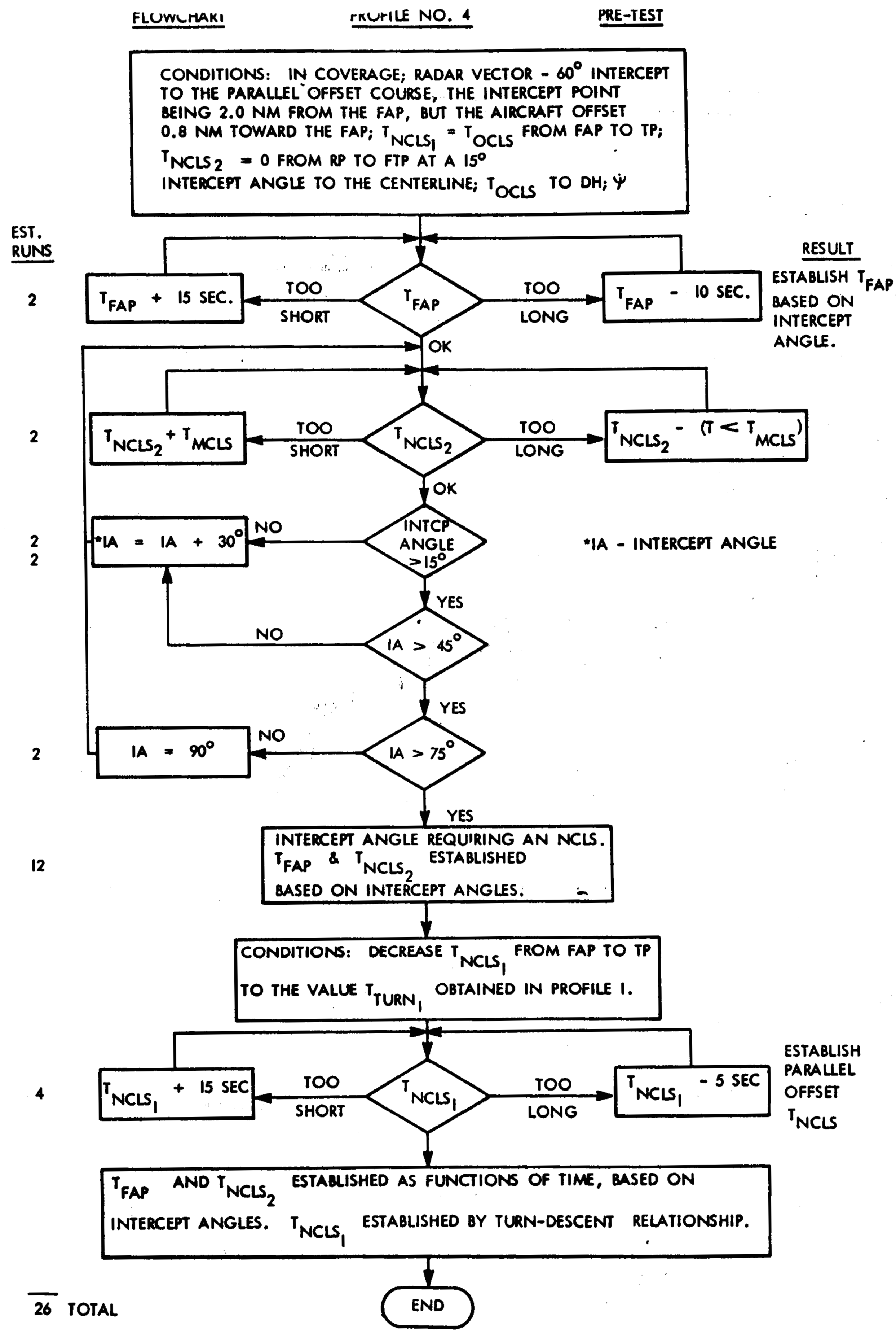
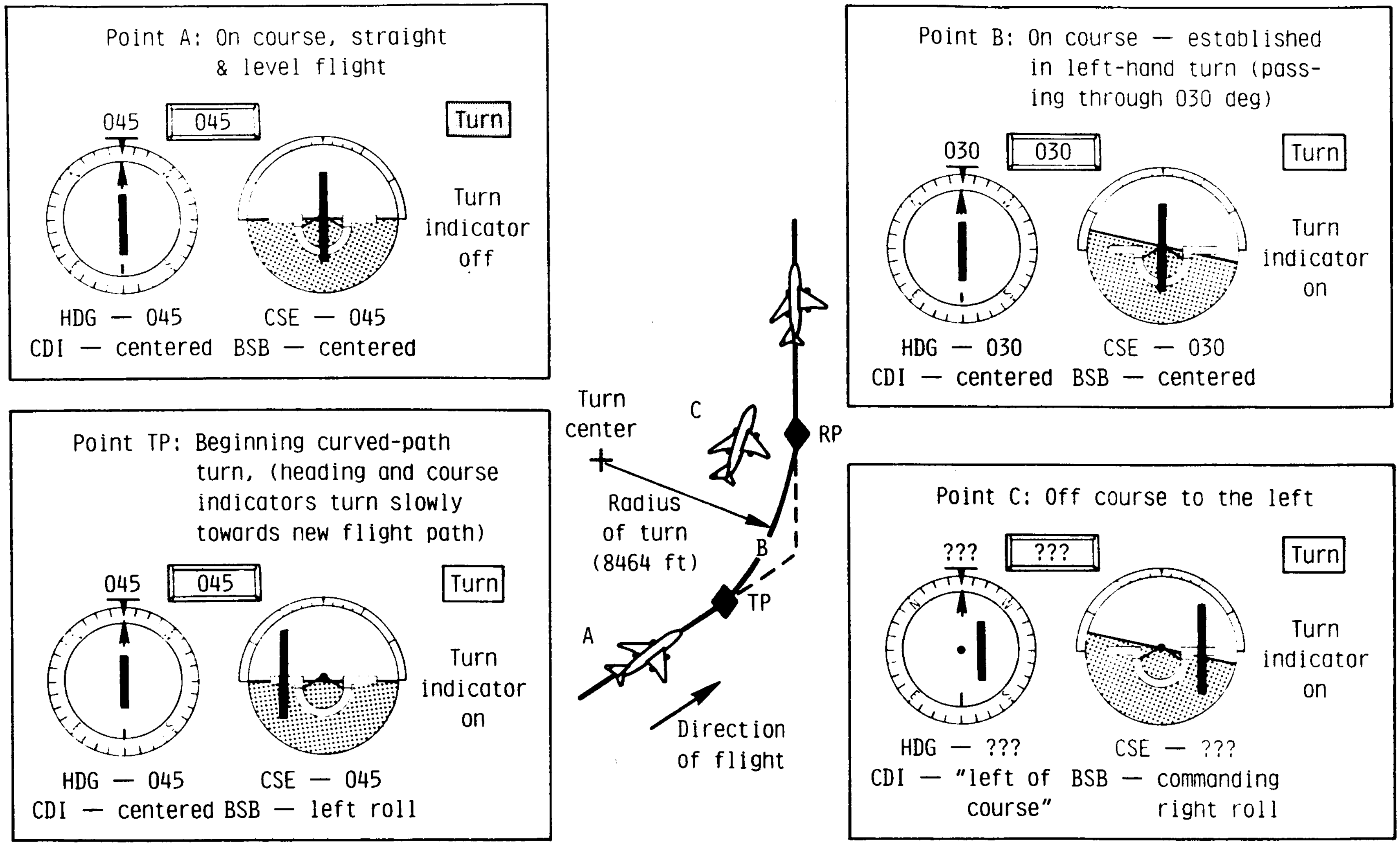
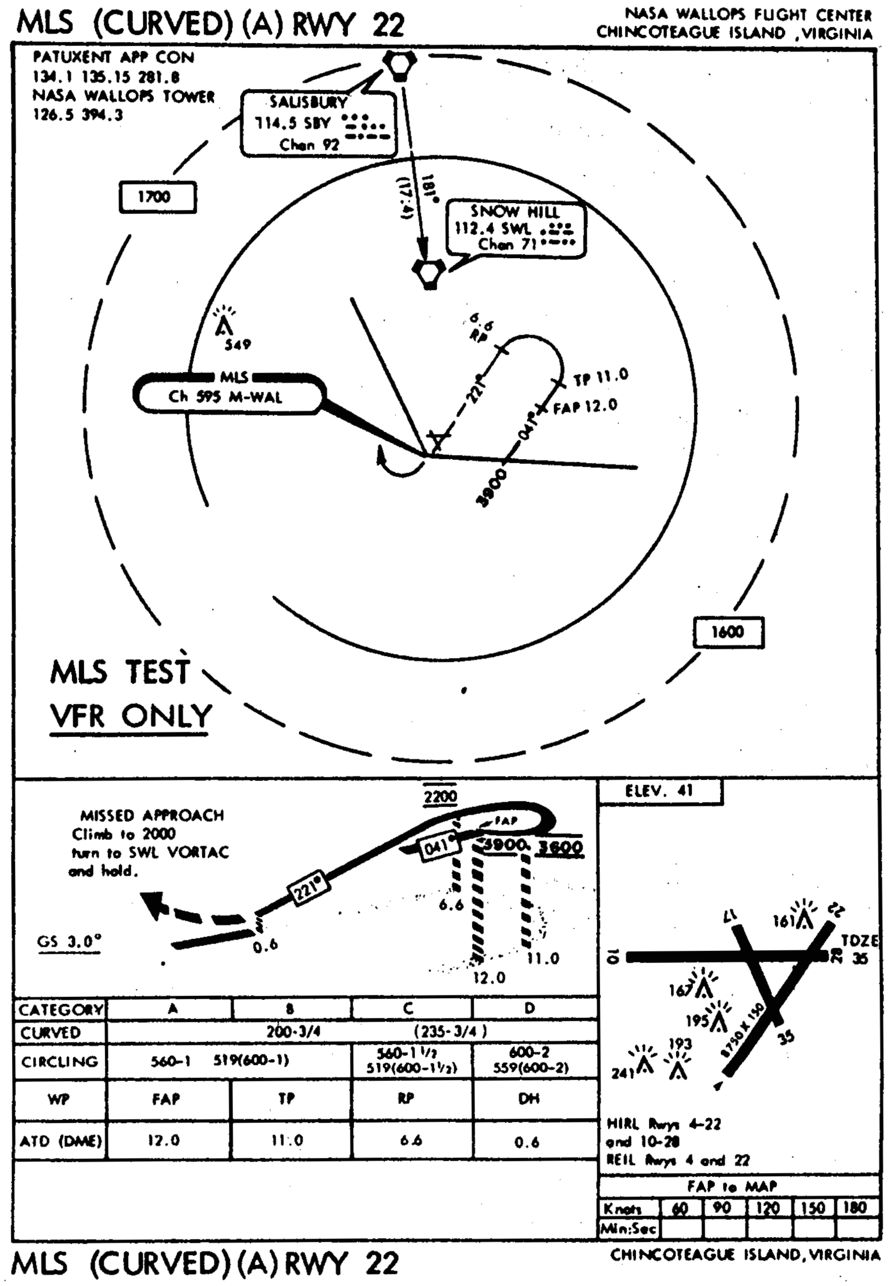


FIGURE 4.4B - FLOW CHART FOR PROFILE NO. 4



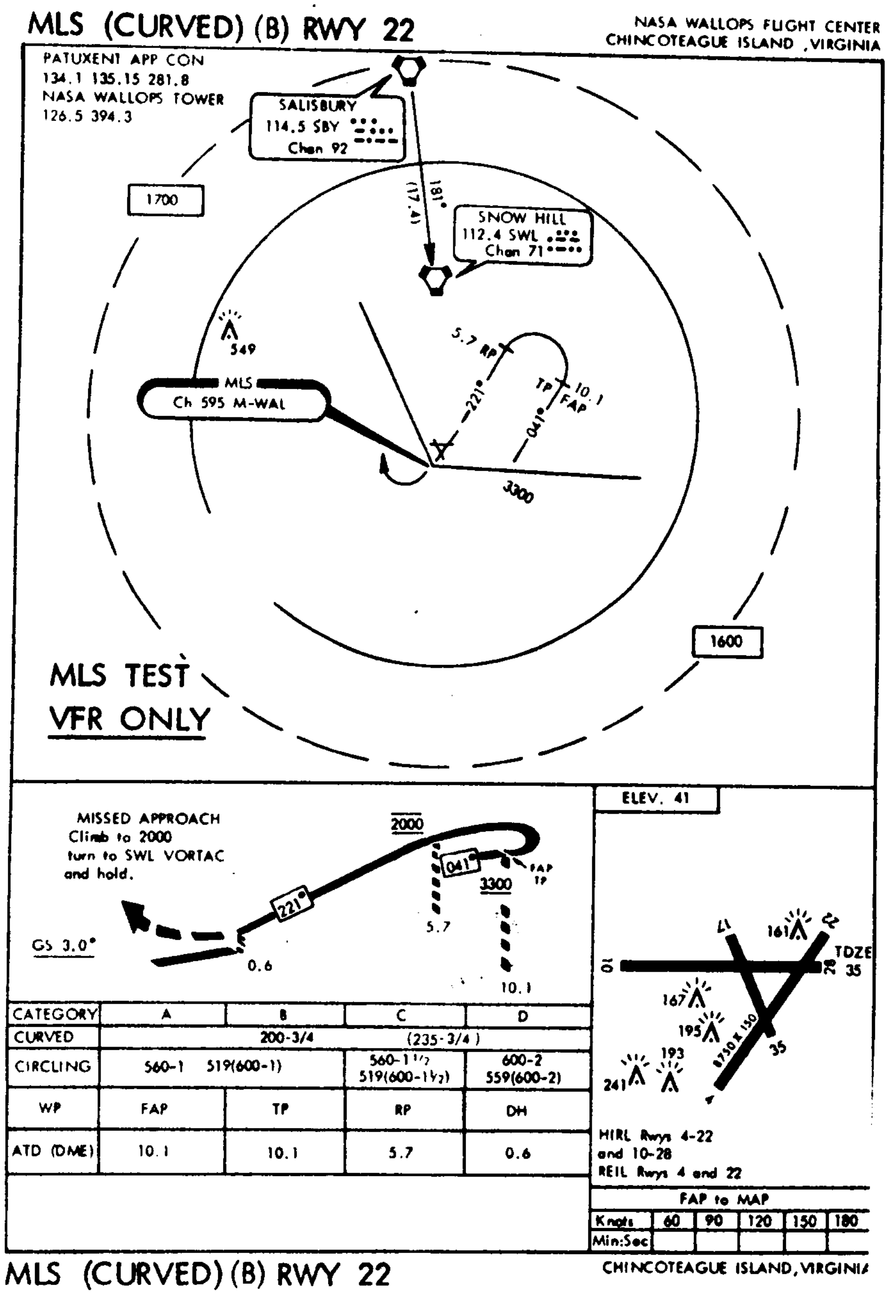
Note: CDI = Course Deviation Indicator
BSB = Bank Steering Bar

FIGURE 4.5 - CURVED-PATH CONSTRUCTION TECHNIQUE AND CORRESPONDING FLIGHT DIRECTOR INDICATIONS



CATEGORY	A	B	C	D
CURVED	200-3/4		(235-3/4)	
CIRCLING	560-1 519(600-1)		560-1 1/2 519(600-1 1/2)	600-2 559(600-2)
WP	FAP	TP	RP	DH
ATD (DME)	12.0	11.0	6.6	0.6

FIGURE 4.6.- CURVED-PATH APPROACH CHART FOR CP-181



CATEGORY	A	B	C	D
CURVED	200-3/4		(235-3/4)	
CIRCLING	560-1 519(600-1)		560-1½ 519(600-1½)	600-2 559(600-2)
WP	FAP	TP	RP	DH
ATD (DME)	10.1	10.1	5.7	0.6

FIGURE 4.7 - CURVED-PATH APPROACH CHART FOR CP-182

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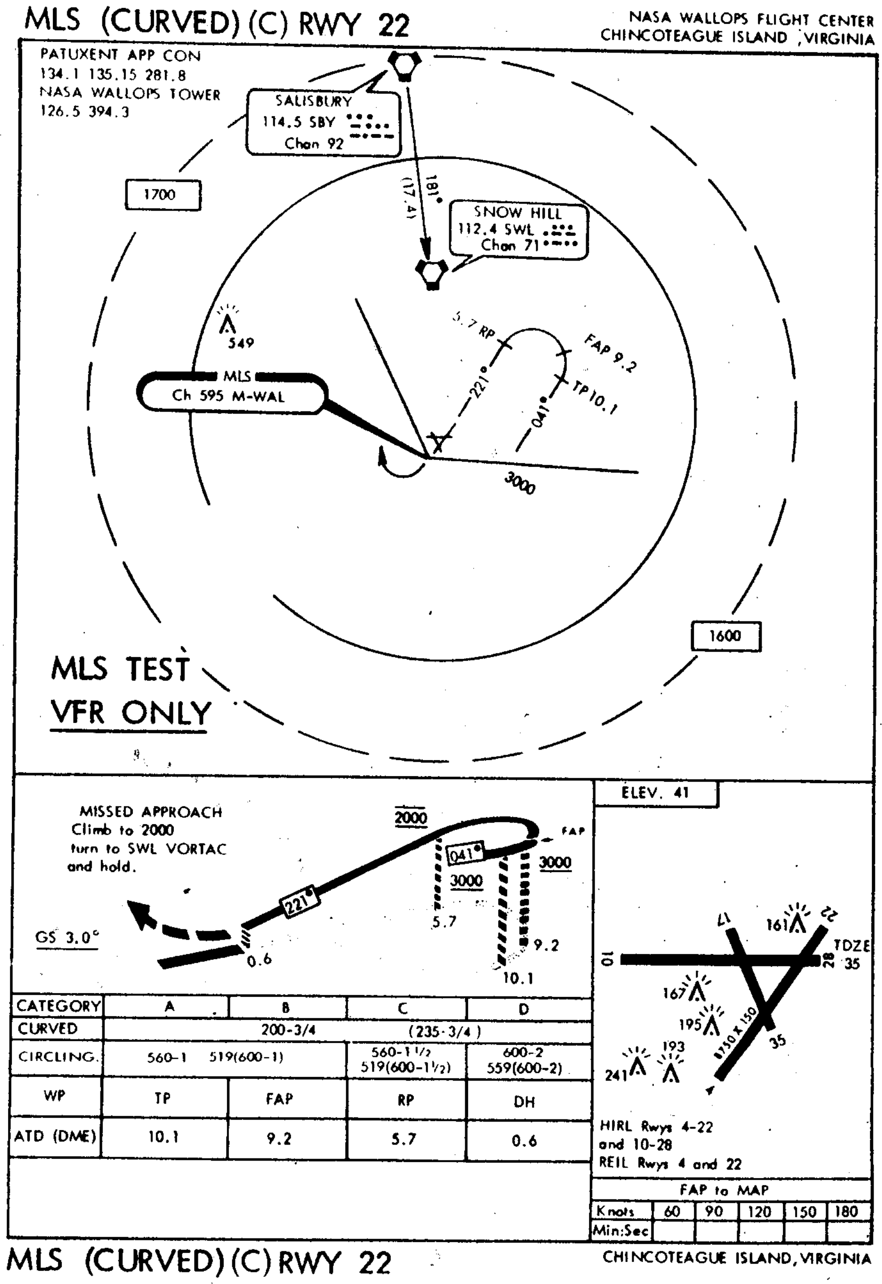


CATEGORY	A	B	C	D
CURVED	200-3/4		(235-3/4)	
CIRCLING	560-1 519(600-1)		560-1 1/2 519(600-1 1/2)	600-2 559(600-2)
WP	TP	FAP	RP	DH
ATD (DME)	10.1	9.2	5.7	0.6

FIGURE 4.8 - CURVED-PATH APPROACH CHART FOR CP-183

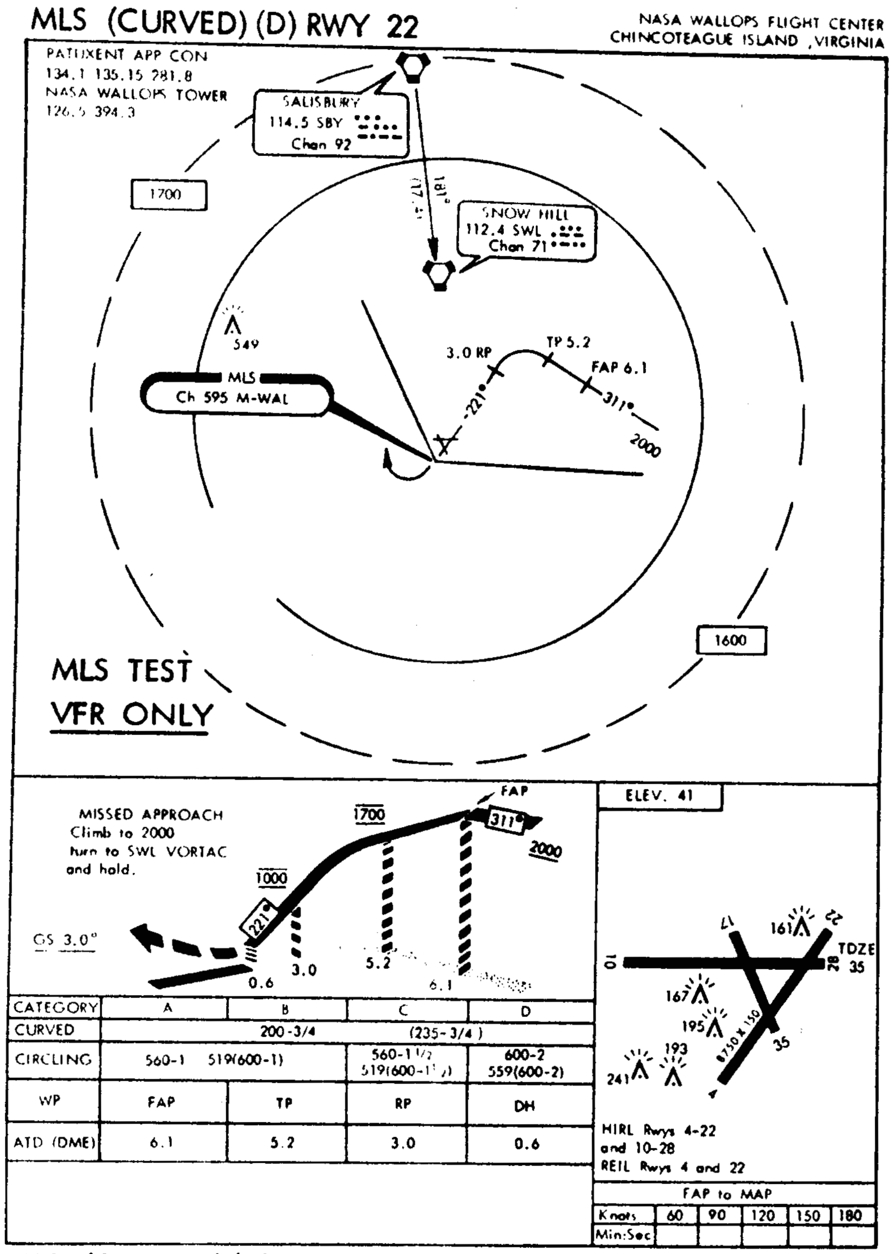


FIGURE 4.9 - CURVED-PATH APPROACH CHART FOR CP-901

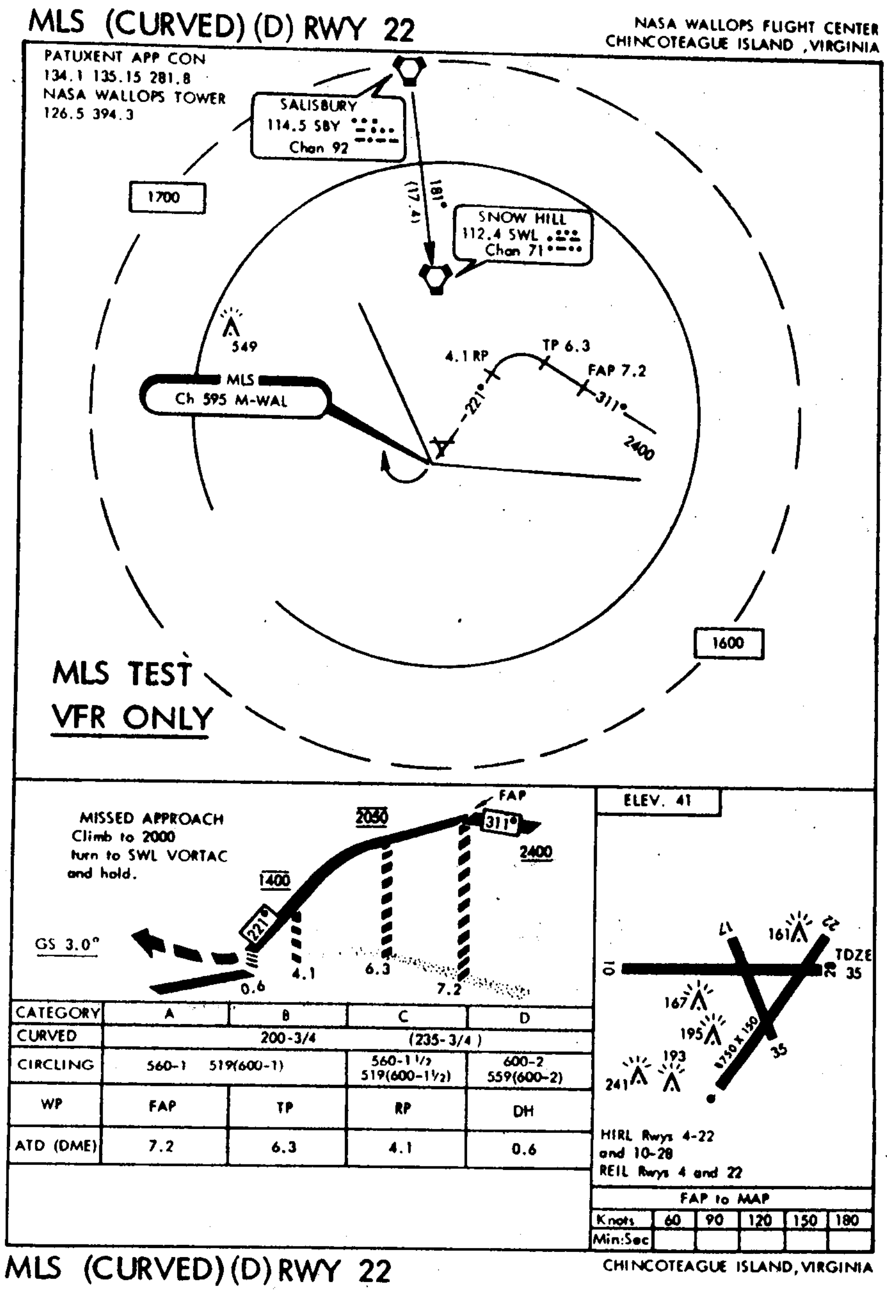


FIGURE 4.10 - CURVED-PATH APPROACH CHART FOR CP-902

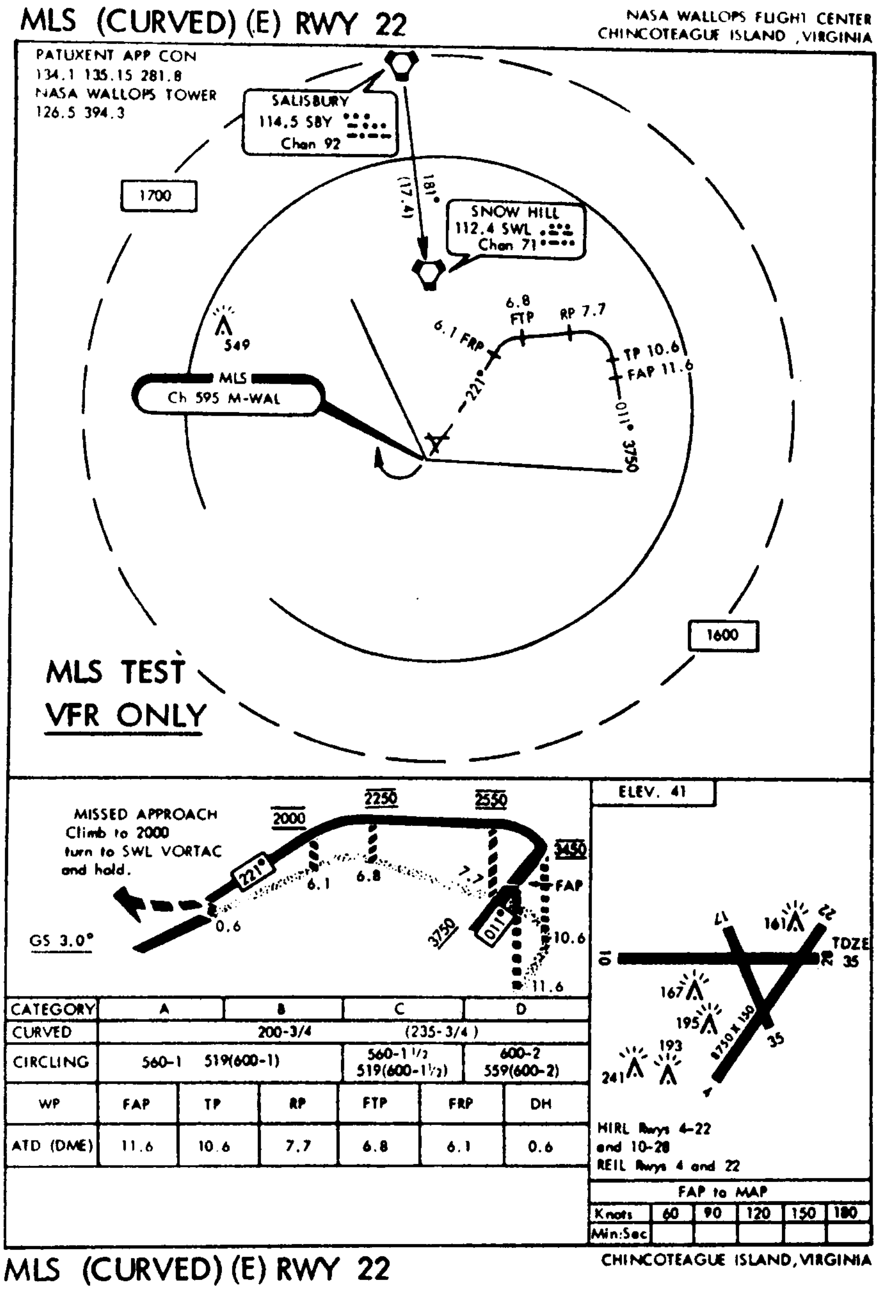
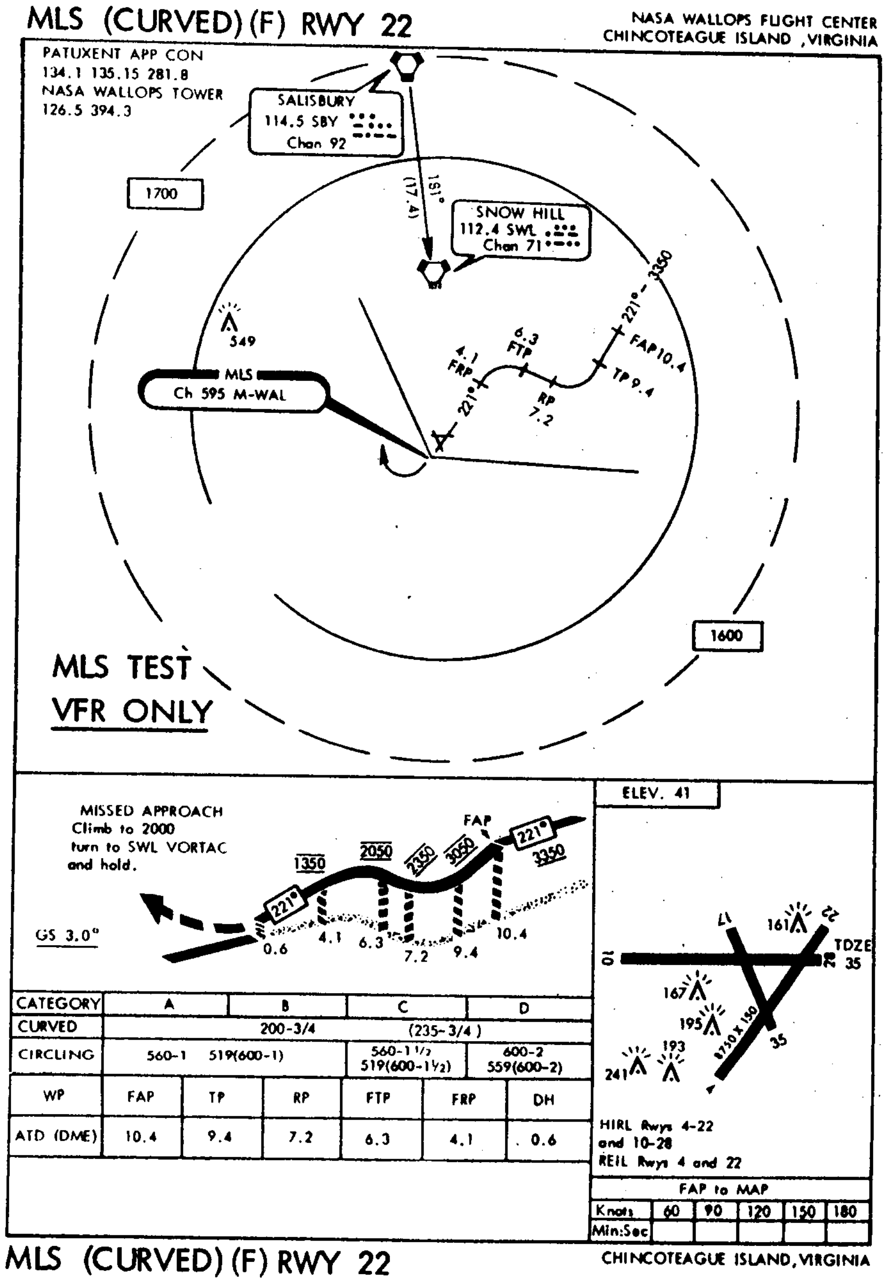


FIGURE 4.11 - CURVED-PATH APPROACH CHART FOR CP-131



CATEGORY	A	B	C	D
CURVED	200-3/4		(235-3/4)	
CIRCLING	560-1 519(600-1)		560-1 1/2 519(600-1 1/2)	600-2 559(600-2)

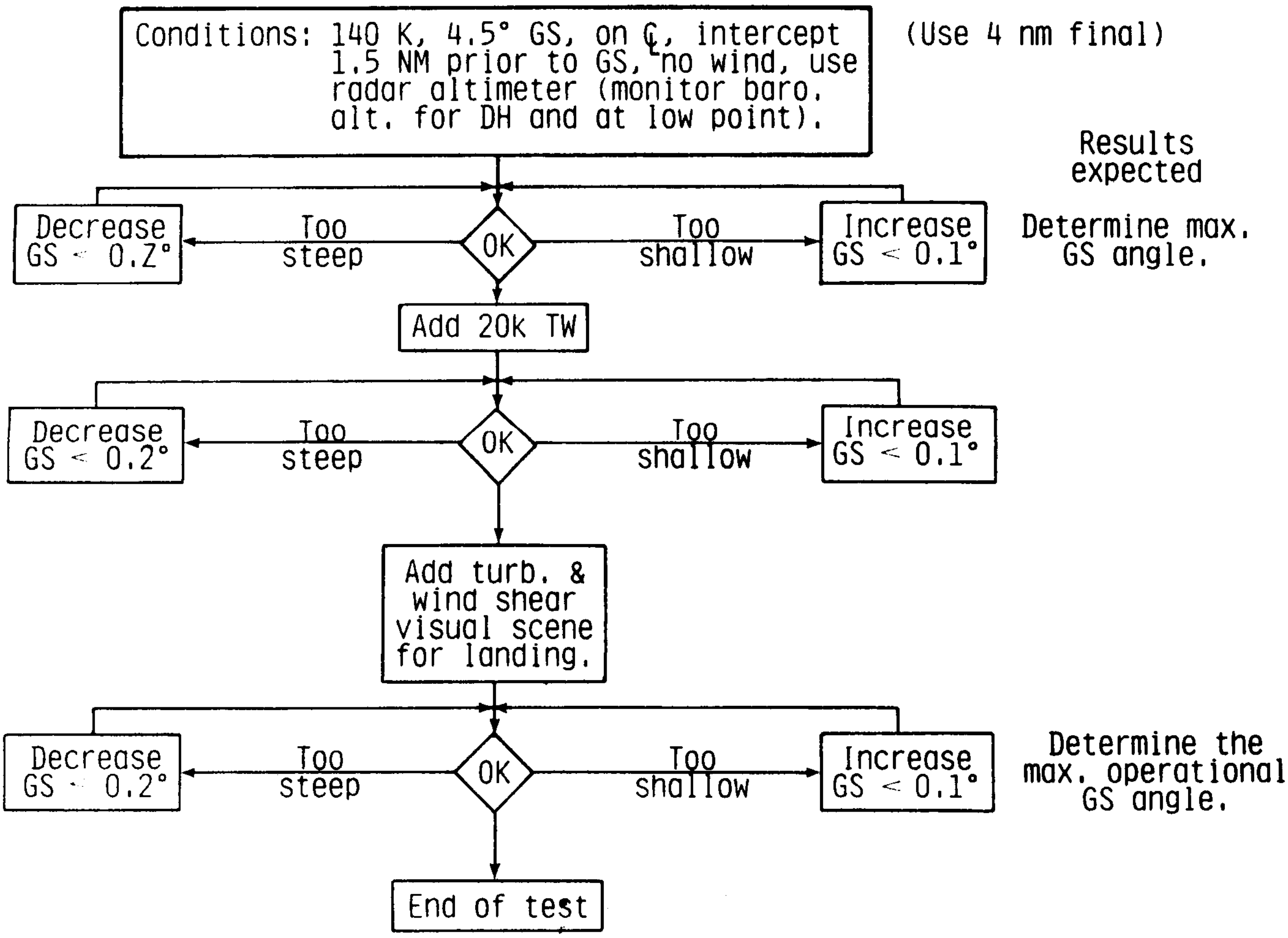
WP	FAP	TP	RP	FTP	FRP	DH
ATD (DME)	10.4	9.4	7.2	6.3	4.1	0.6

FIGURE 4.12 - CURVED-PATH APPROACH CHART FOR CP-S01

C-2

Simulator evaluation

Steep angle approaches



Data collection on 96 approaches

8 pilots will fly four approaches on each of three angles: 3.5, 3.8 & 4.0 deg

FIGURE 4.13 - FLOW CHART FOR STEEP ANGLE EVALUATION

STAR

RIV01

(WALLOPS)

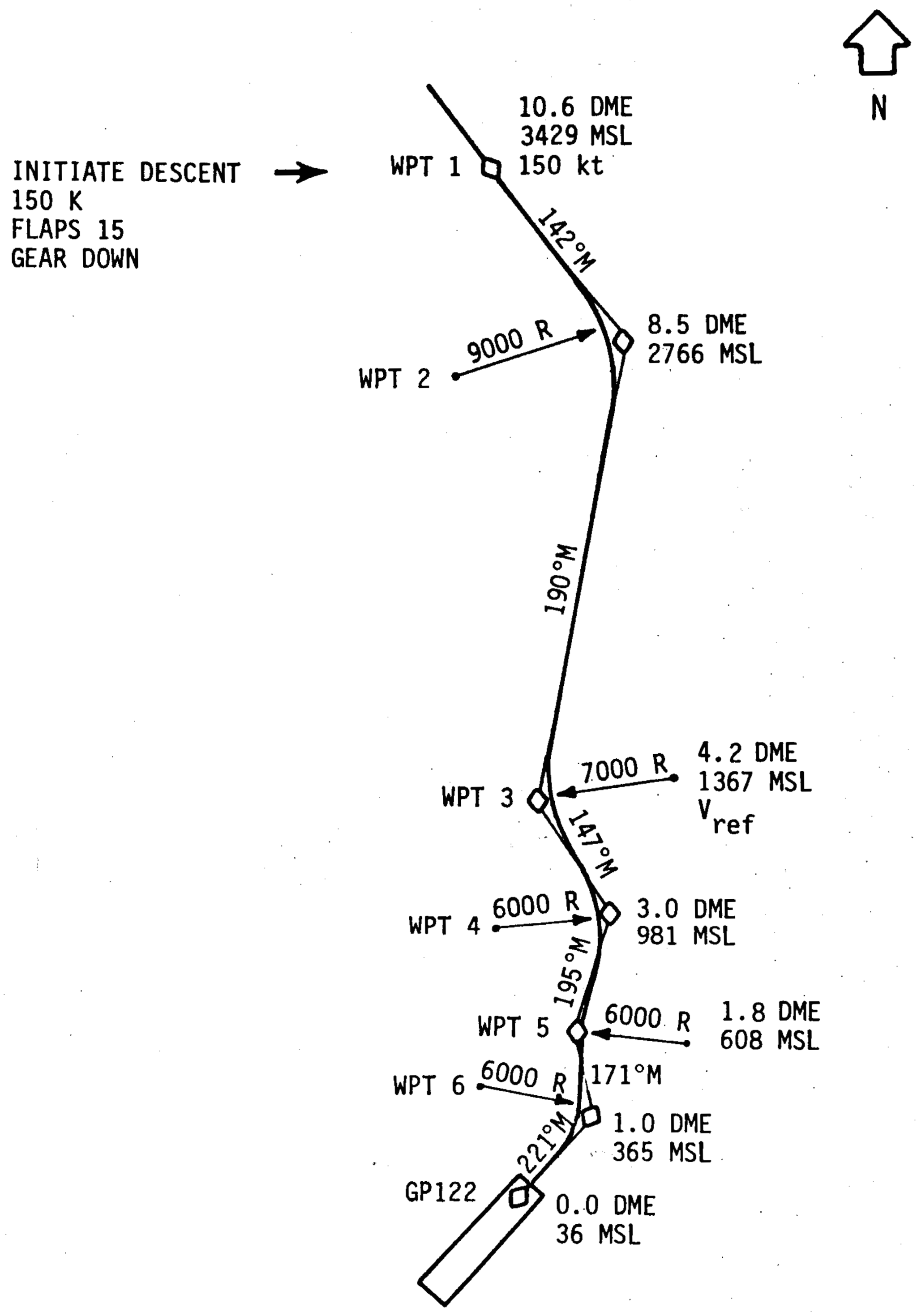
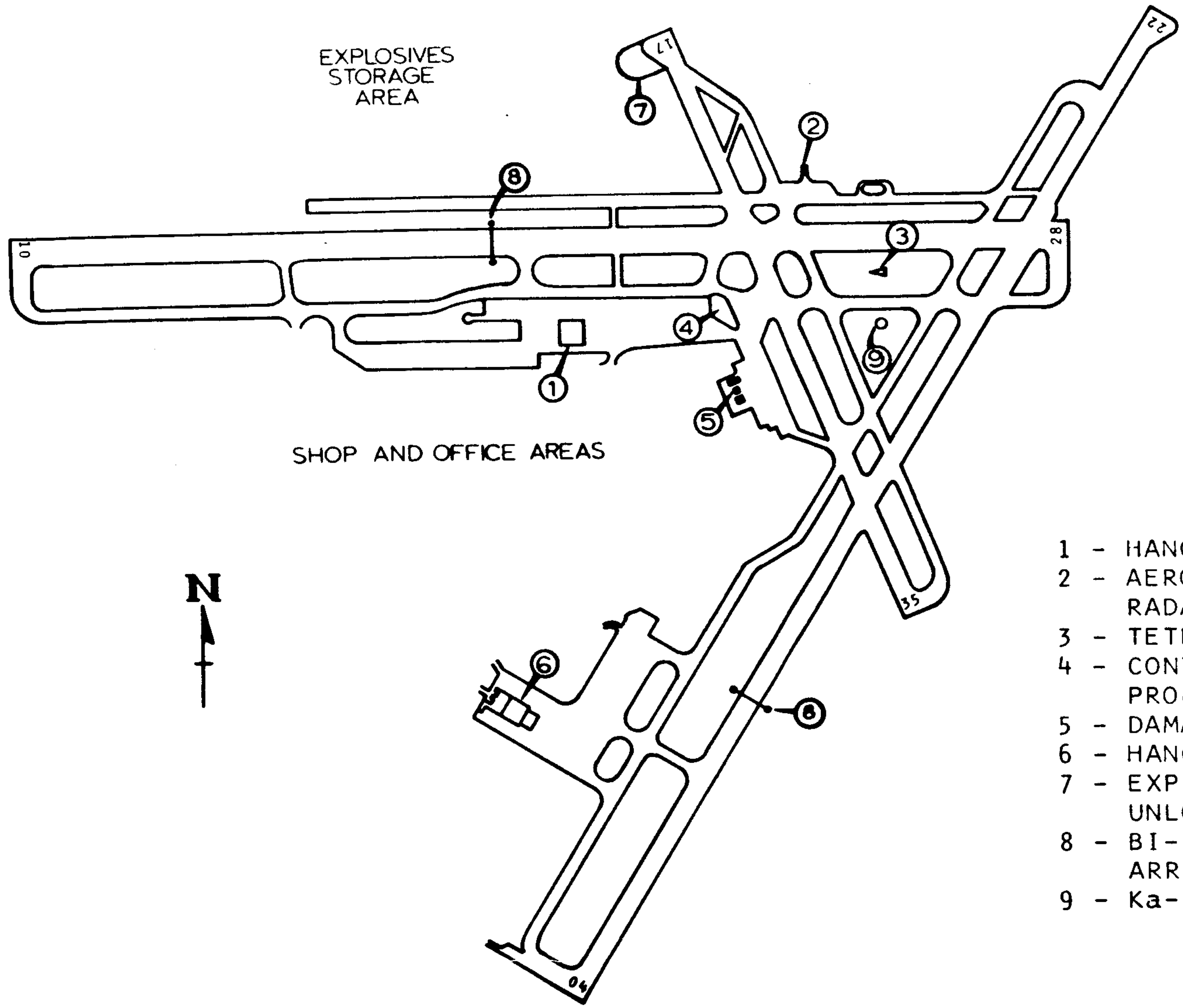


FIGURE 4.14 - WASHINGTON NATIONAL RIVER APPROACH



1 - HANGAR (BLDG D-1)
2 - AERONAUTICAL RESEARCH RADAR COMPLEX (A-41)
3 - TETRAHEDRON
4 - CONTROL TOWER AND PROJECT CONTROL CENTER
5 - DAMAGE CONTROL (B-129)
6 - HANGAR (BLDG N-159)
7 - EXPLOSIVES LOADING & UNLOADING APRON
8 - BI-DIRECTIONAL, E-28, ARRESTING GEAR (2)
9 - Ka-BAND RADAR

FIGURE 6.1 - WALLOPS RUNWAY FACILITY LAYOUT

Antenna	Lat.	Long.	h_{MSL}
AZ	37.9240058°	-75.4737087°	41.1 ft
DME	37.924110°	-75.473880°	49.7 ft
EL	37.944799°	-75.455469°	34.7 ft
FPS-16	37.943985°	-75.4645740	____

True runway heading = 212.1978° (magnetic variation = -9.09°)

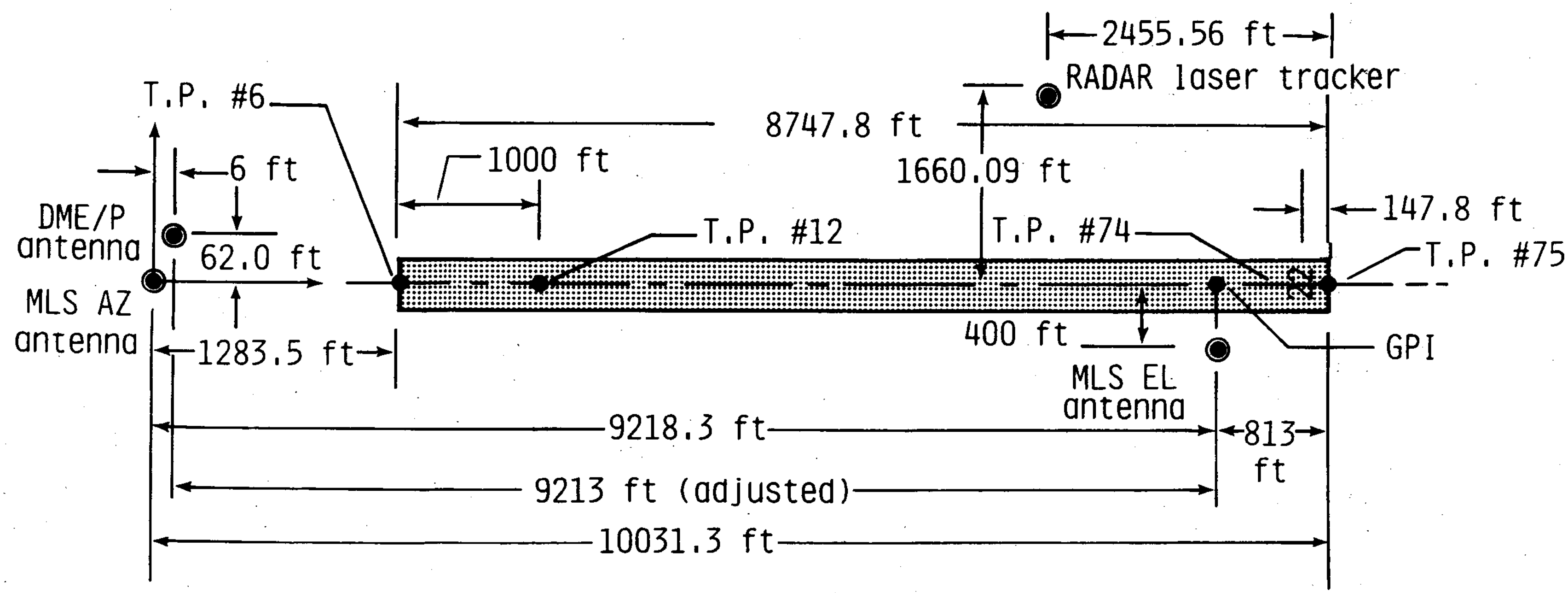


FIGURE 6.2 - MLS ANTENNA LOCATIONS ON RUNWAY 22

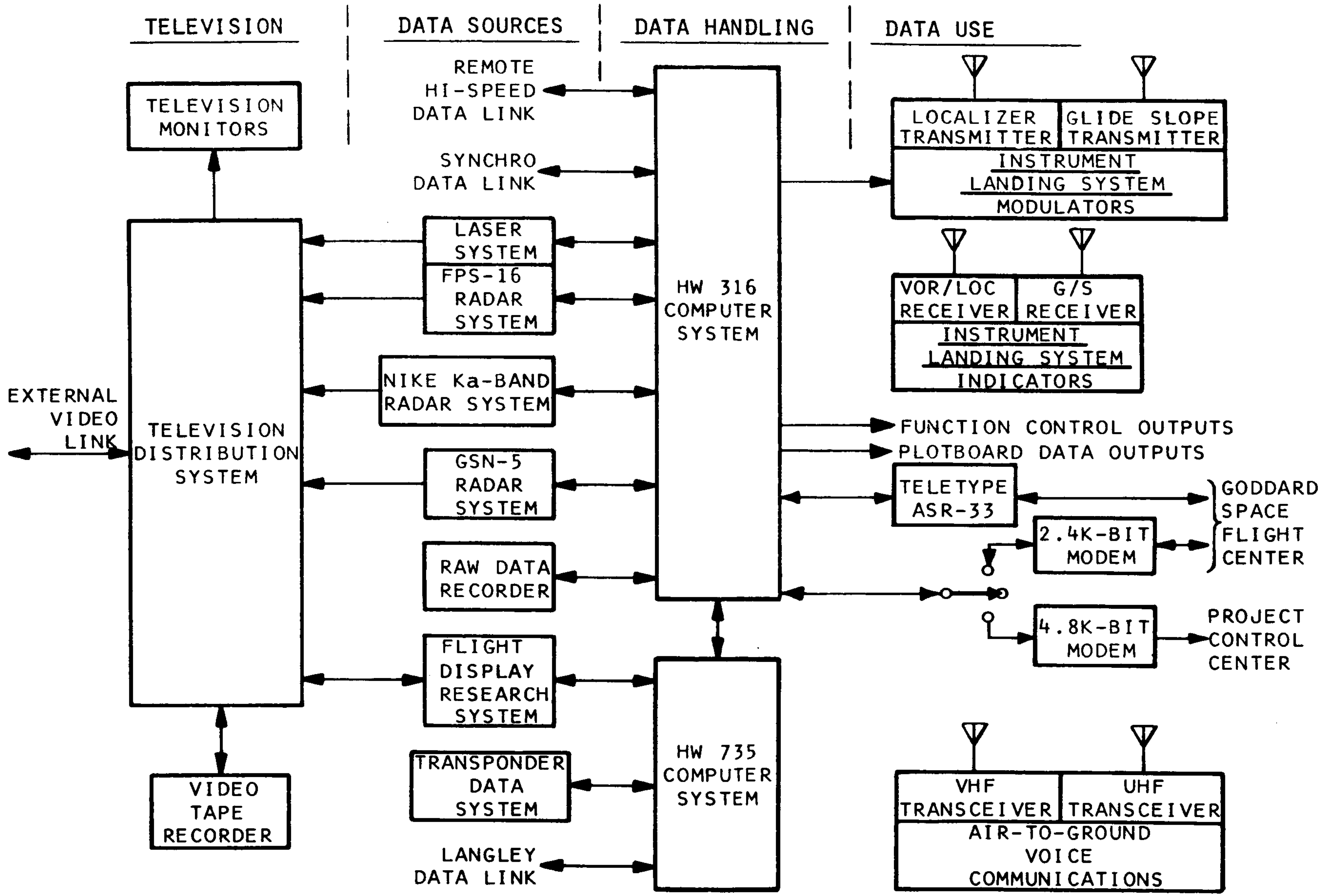


FIGURE 6.3 - AERONAUTICAL RESEARCH RADAR COMPLEX

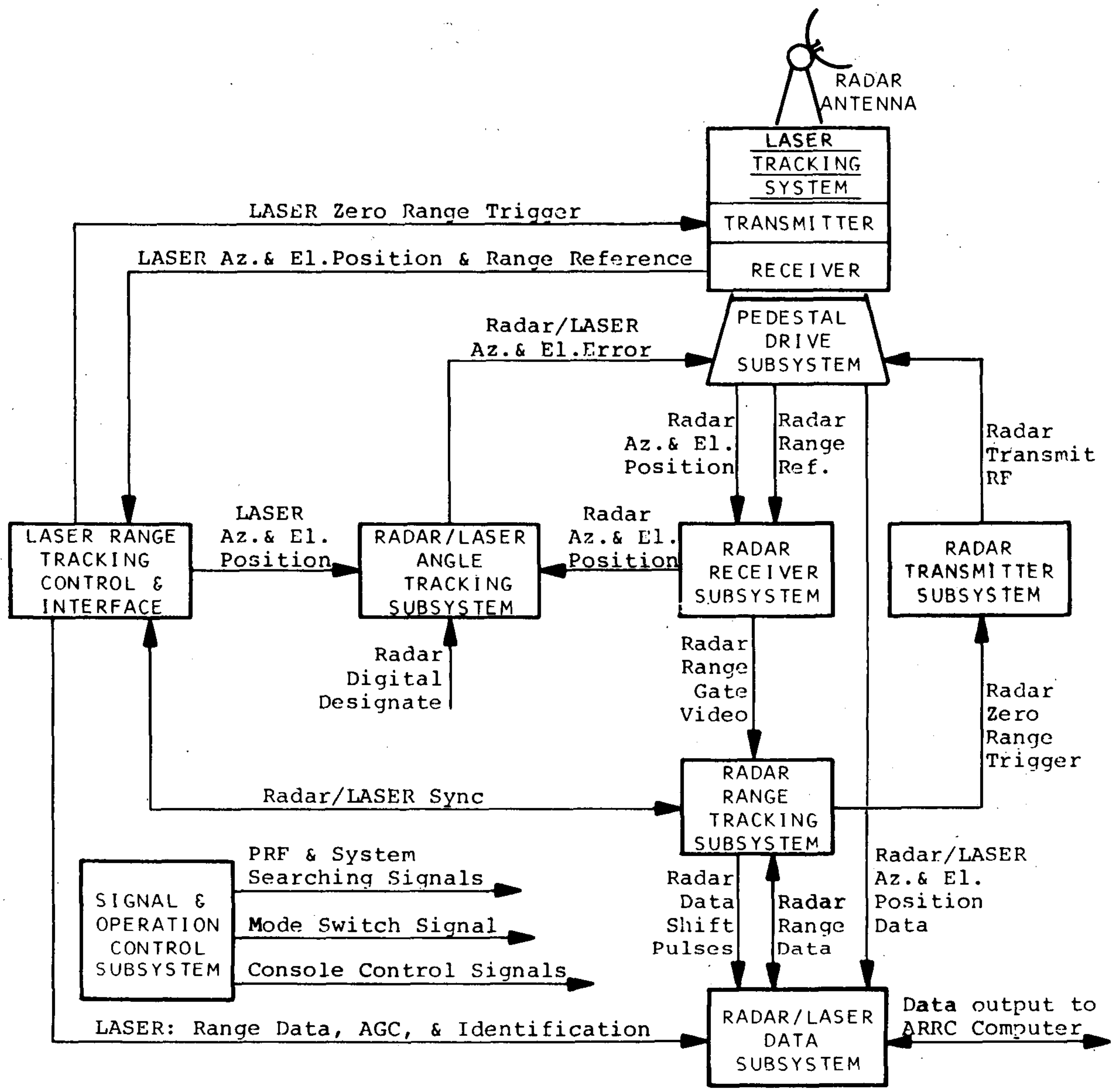


FIGURE 6.4 - WALLOPS AN/FPS-16 RADAR/LASER TRACKING SYSTEM

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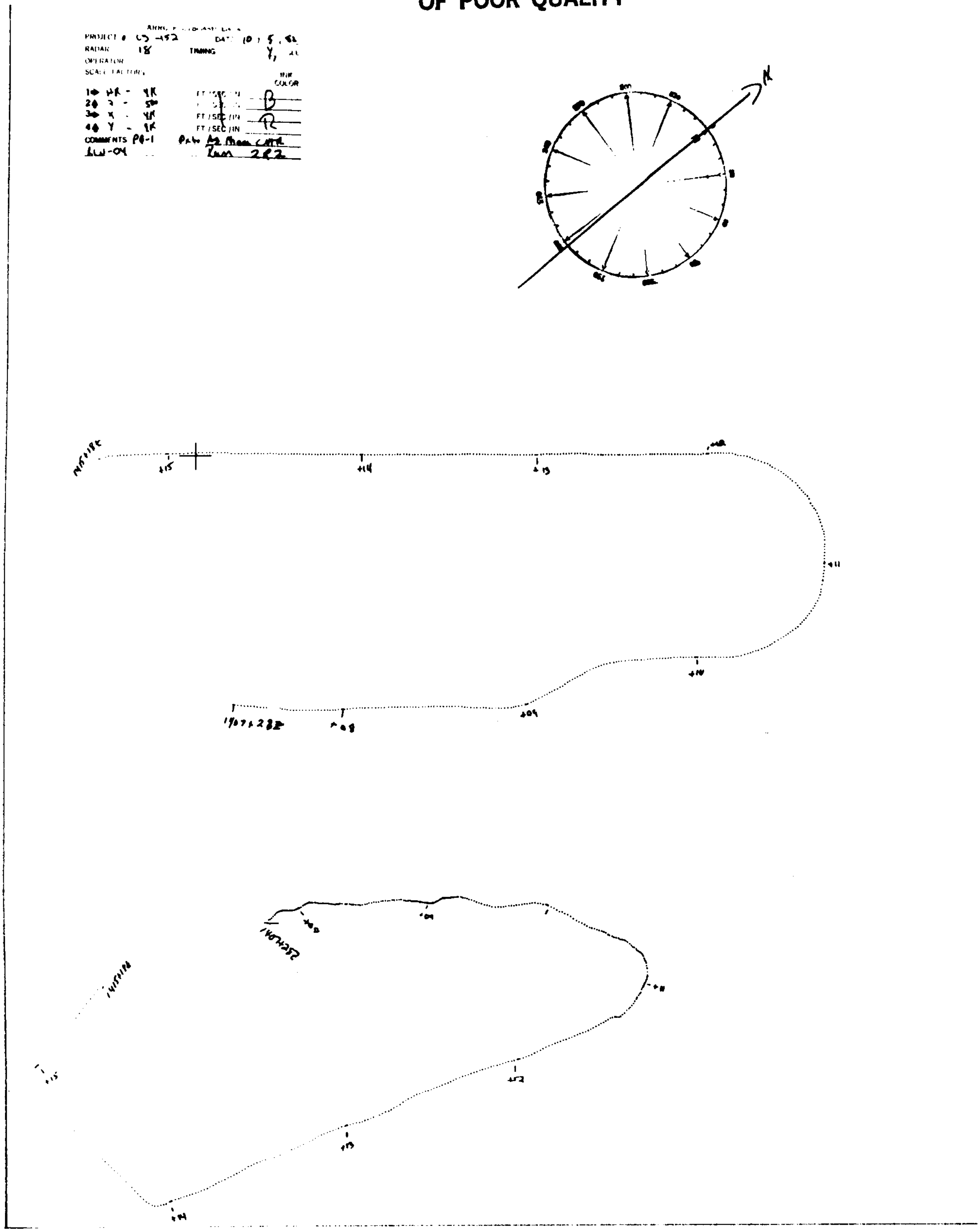

FIGURE 6.5 - PLOTBOARD REPRESENTATION OF APPROACH FROM WFF TRACKING

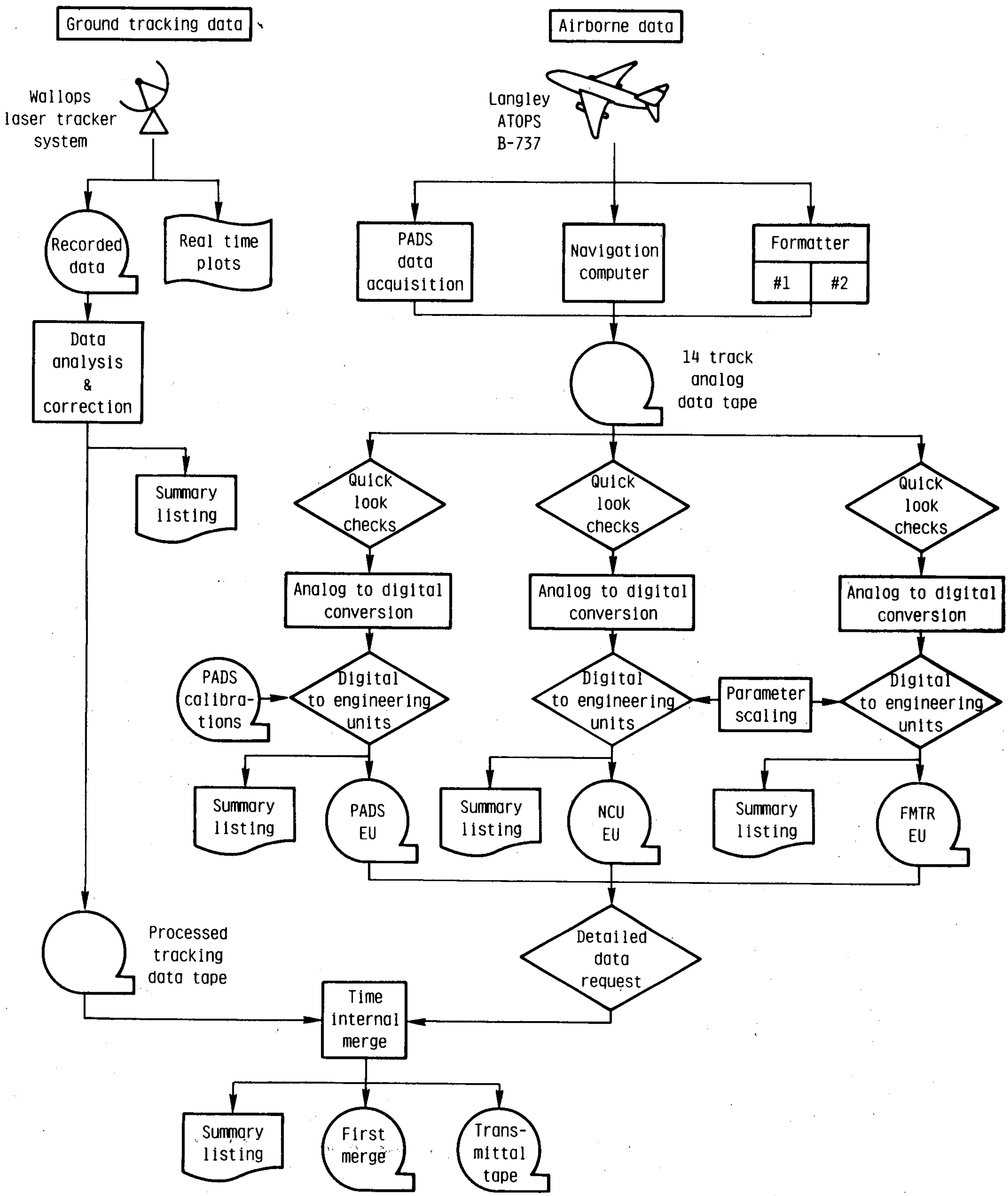

FIGURE 7.1 - DATA COLLECTION AND MERGE PROCESS

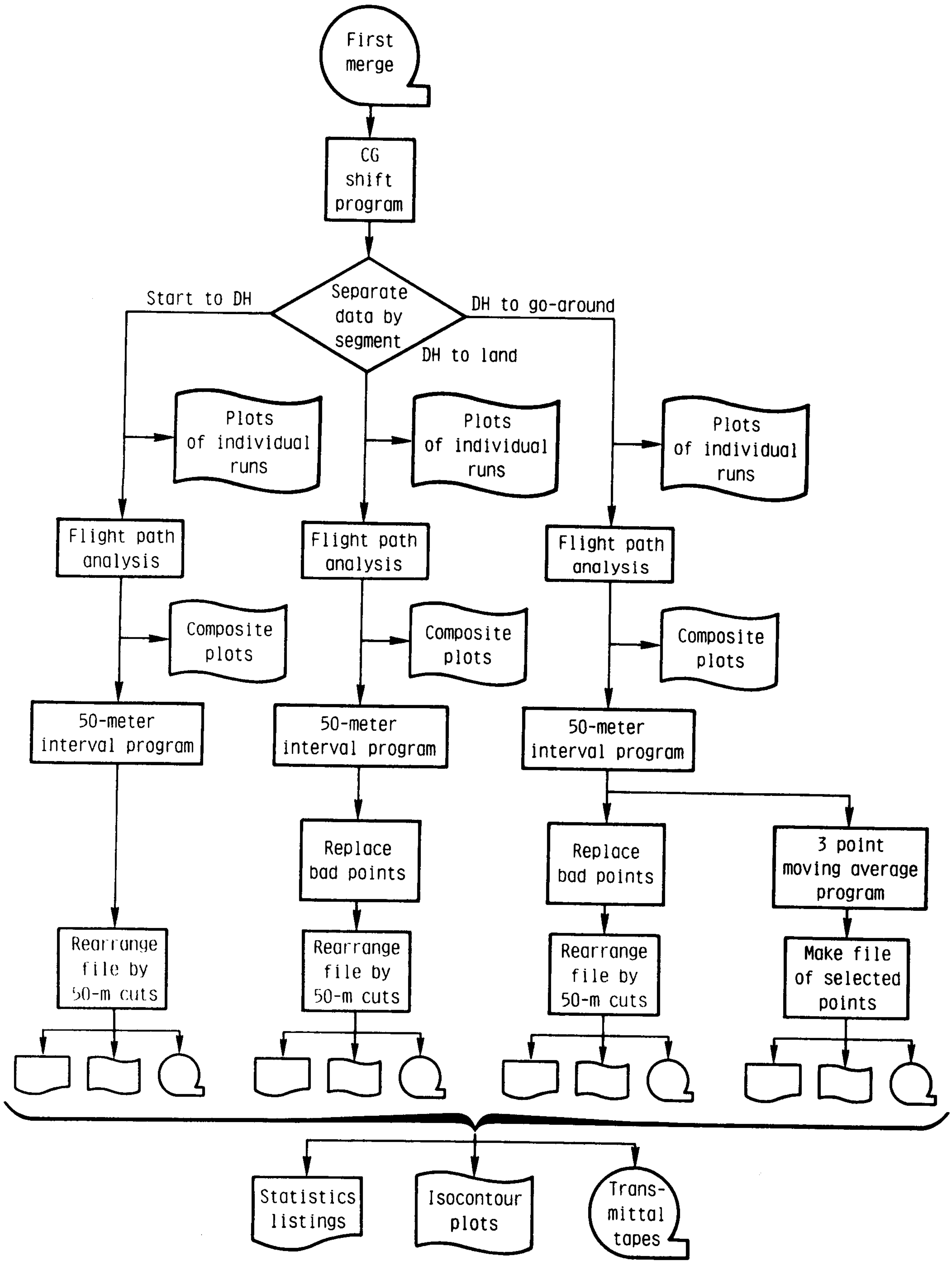

FIGURE 7.2 - DATA REDUCTION PROCESS

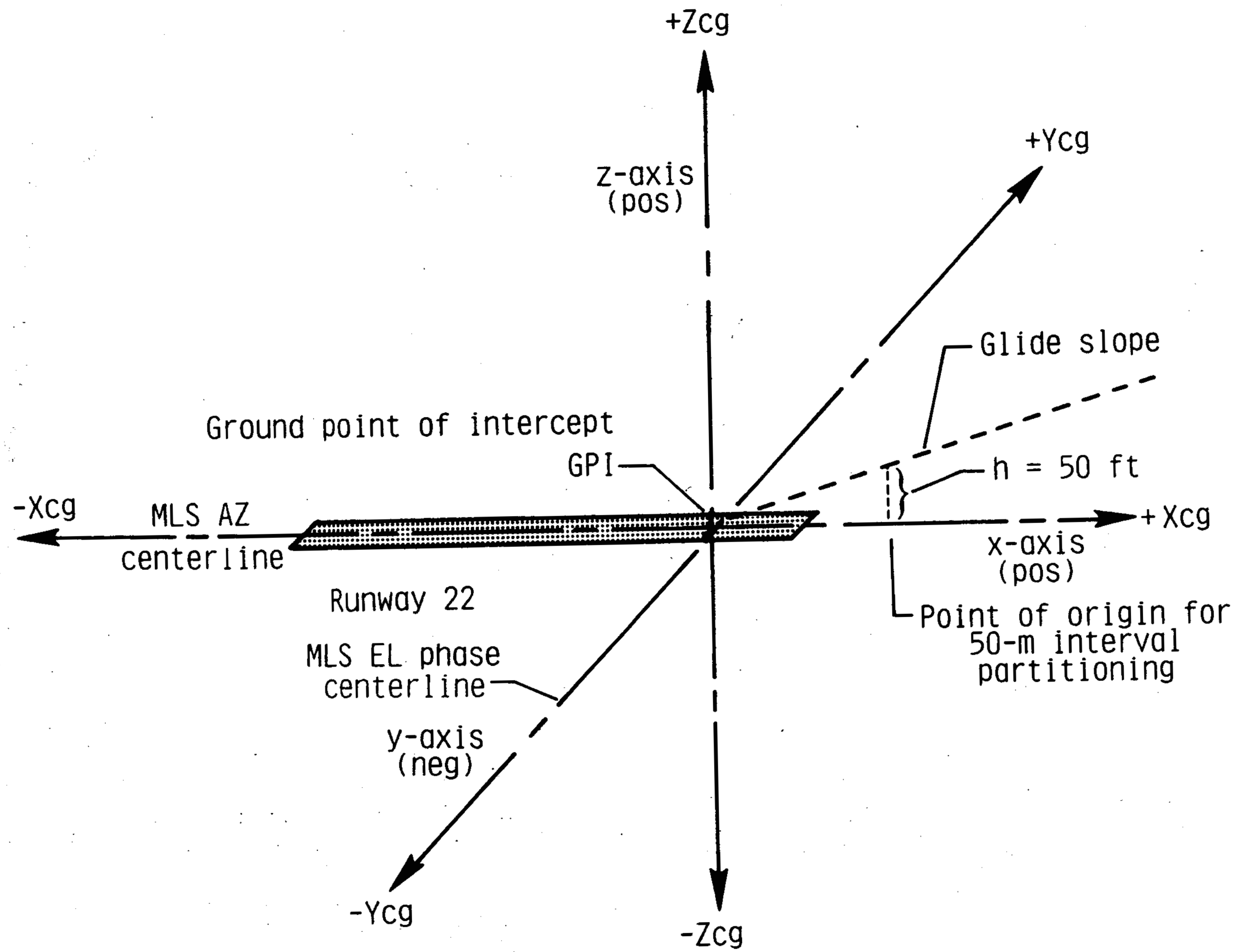

FIGURE 7.3 - SIGN CONVENTION USED IN DATA ANALYSIS

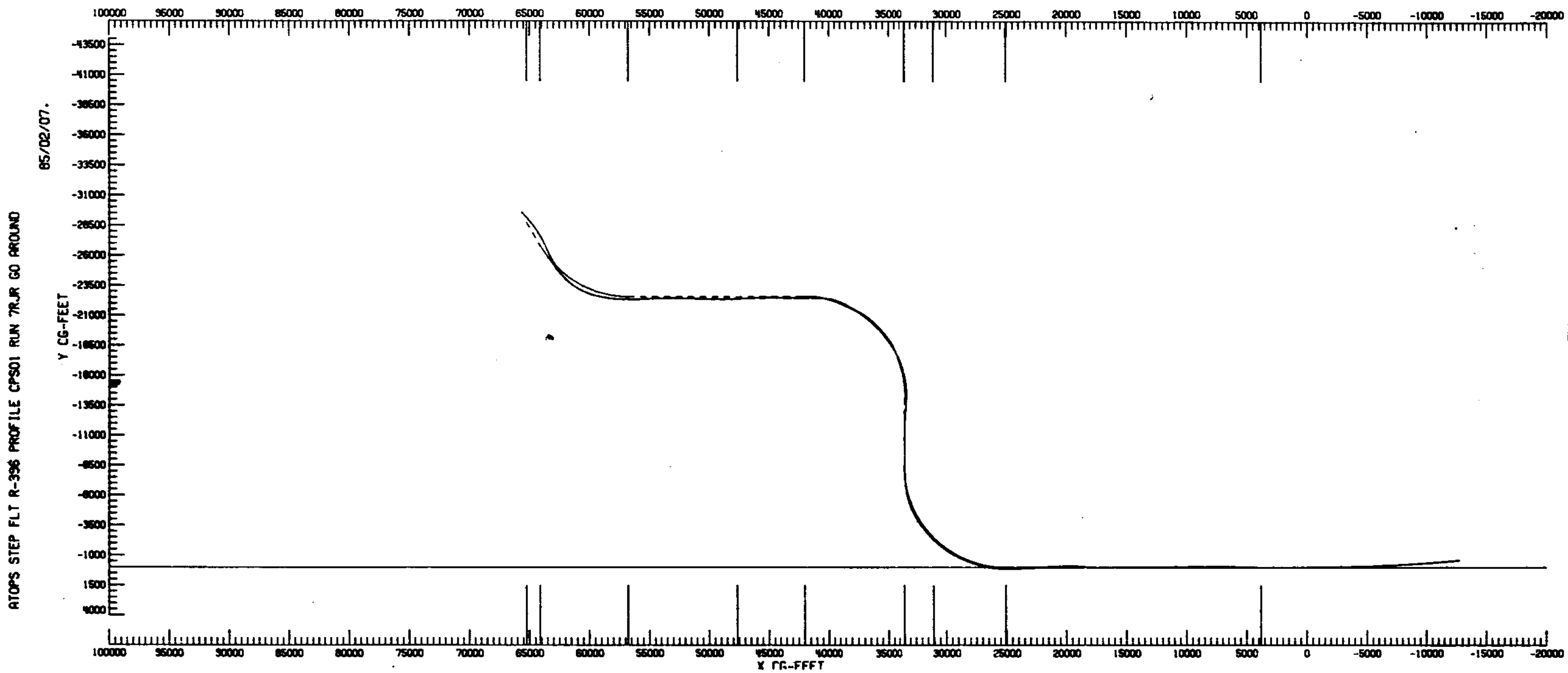

FIGURE 7.4 - SAMPLE APPROACH - PLAN VIEW

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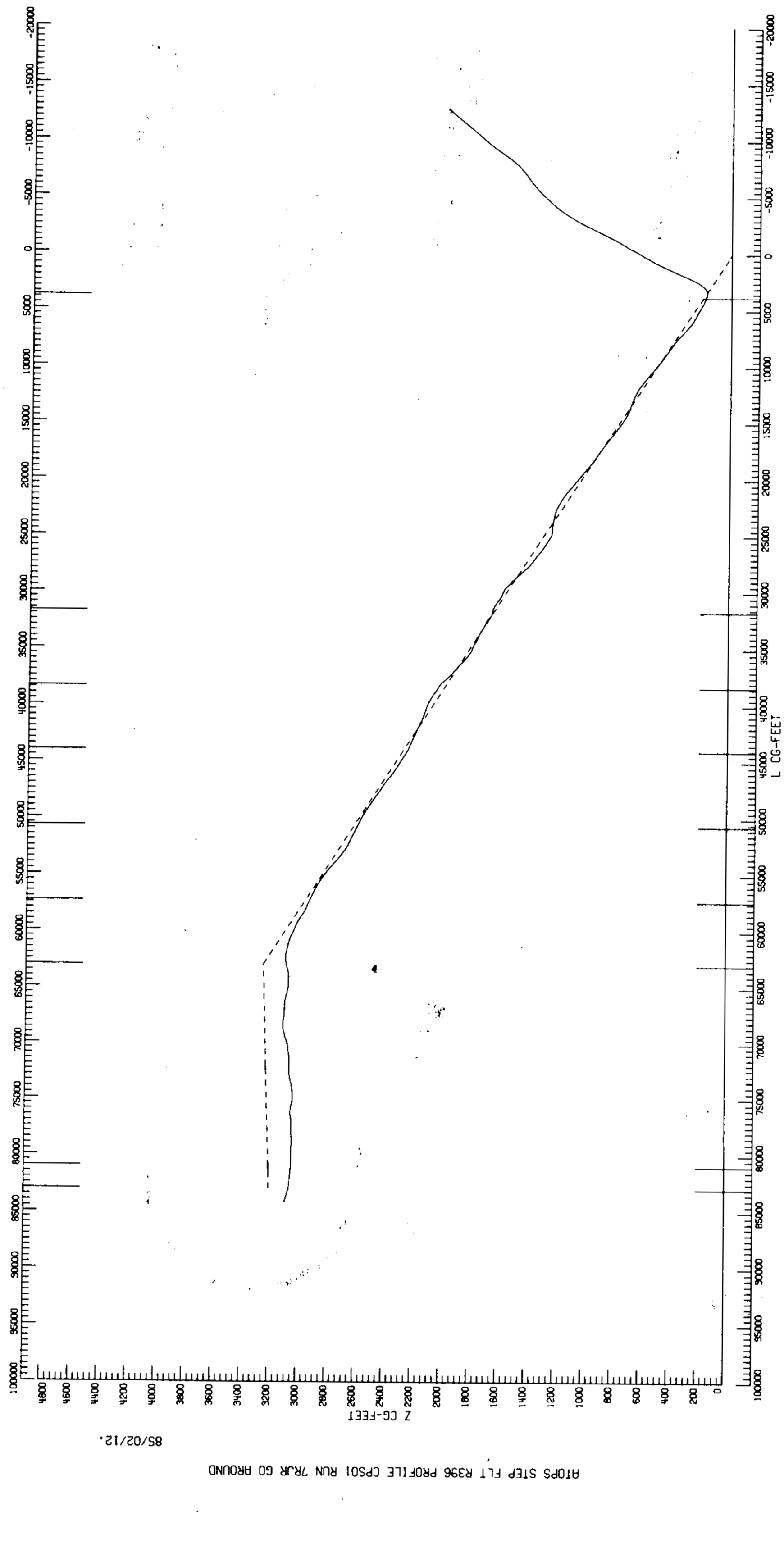
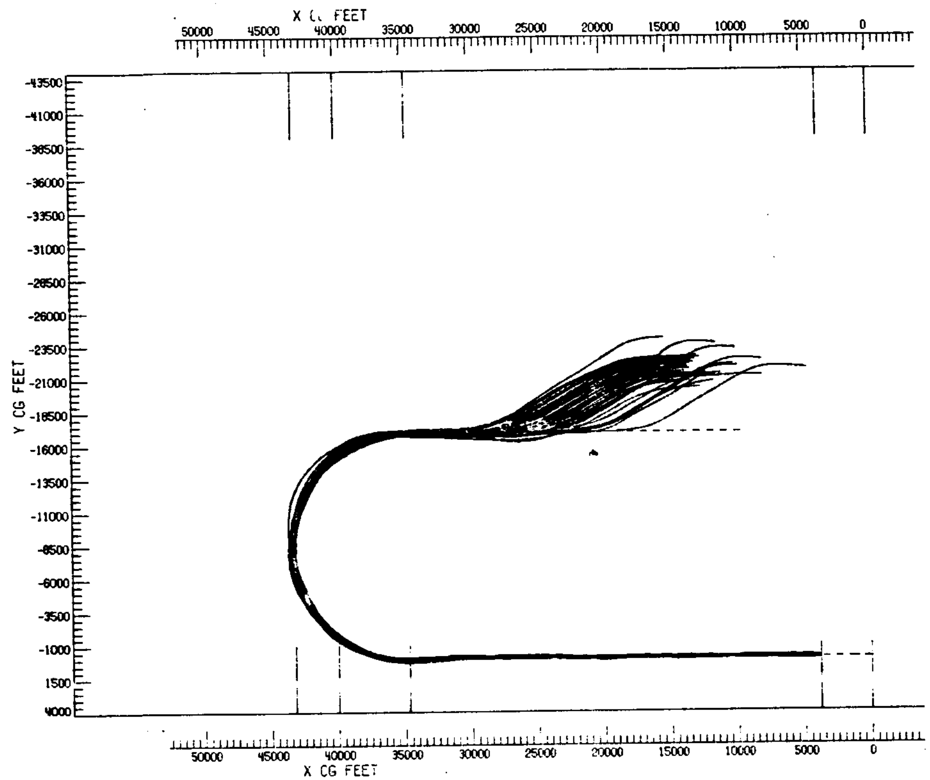
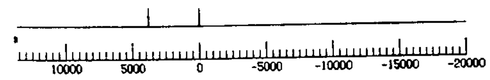
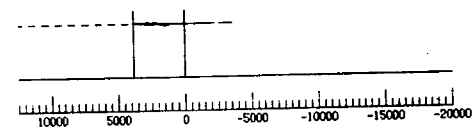


FIGURE 7.5 - SAMPLE APPROACH - PROFILE VIEW

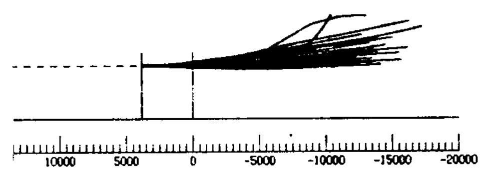




(a) Landing Dispersion



(b) Low Approach Dispersion



(c) Go-around Dispersion

FIGURE 7.6 - SAMPLE COMPOSITE PLOT - PLAN VIEW WITH TERMINATIONS:

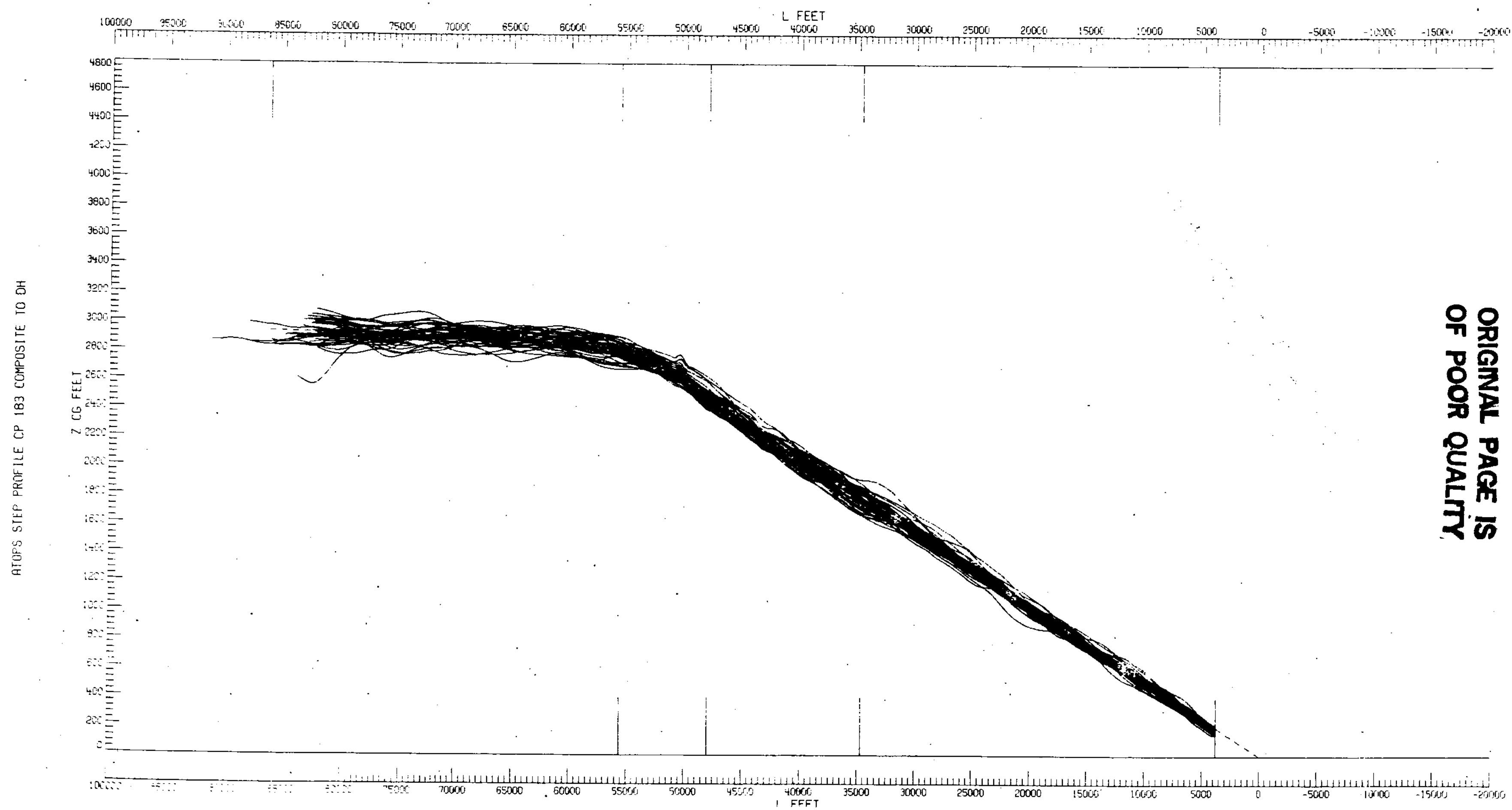


FIGURE 7.7A - SAMPLE COMPOSITE PLOT - PROFILE VIEW TO DECISION HEIGHT

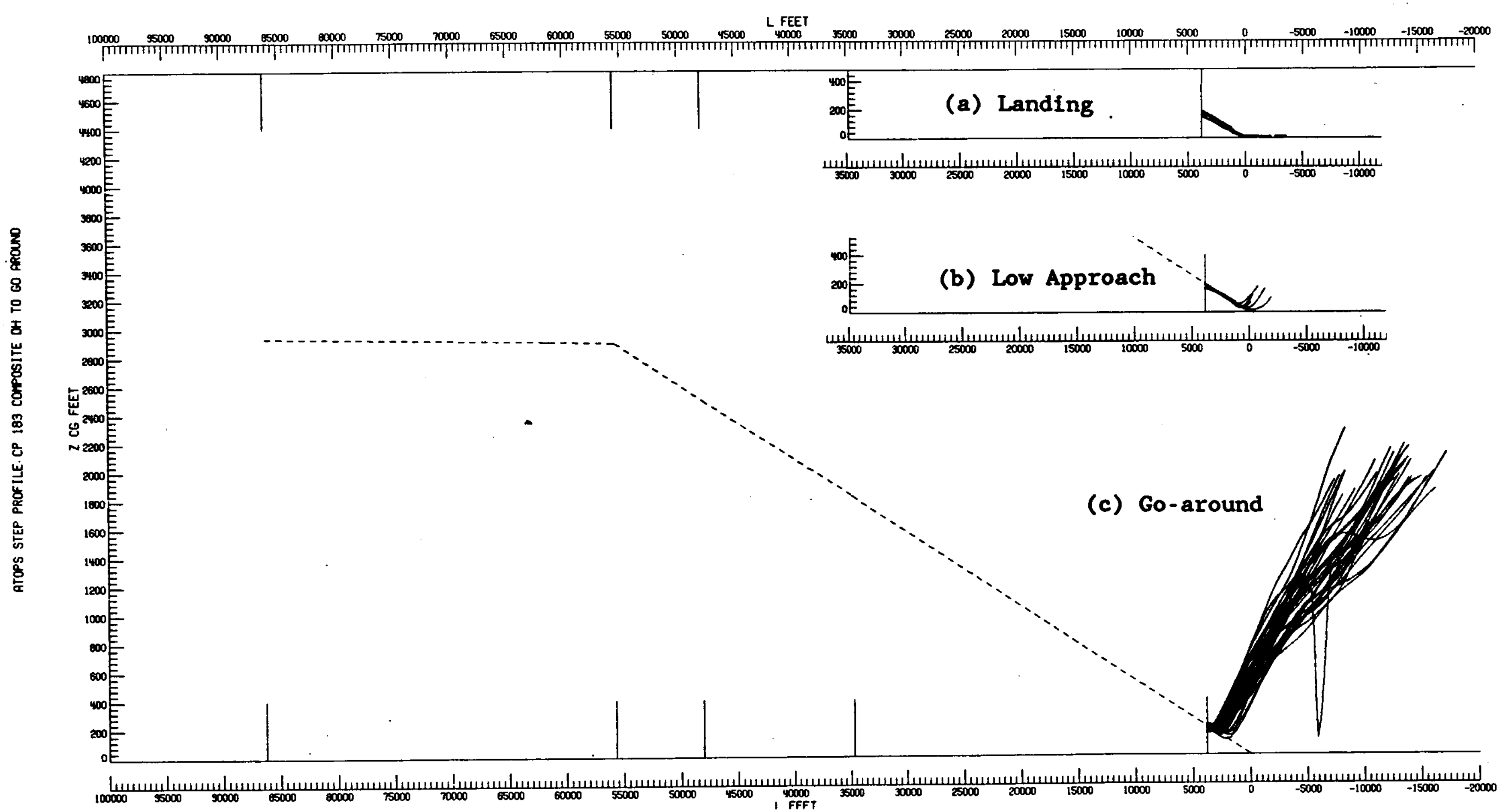


FIGURE 7.7B - SAMPLE COMPOSITE PLOT - PROFILE VIEW OF VARIOUS TERMINATIONS:

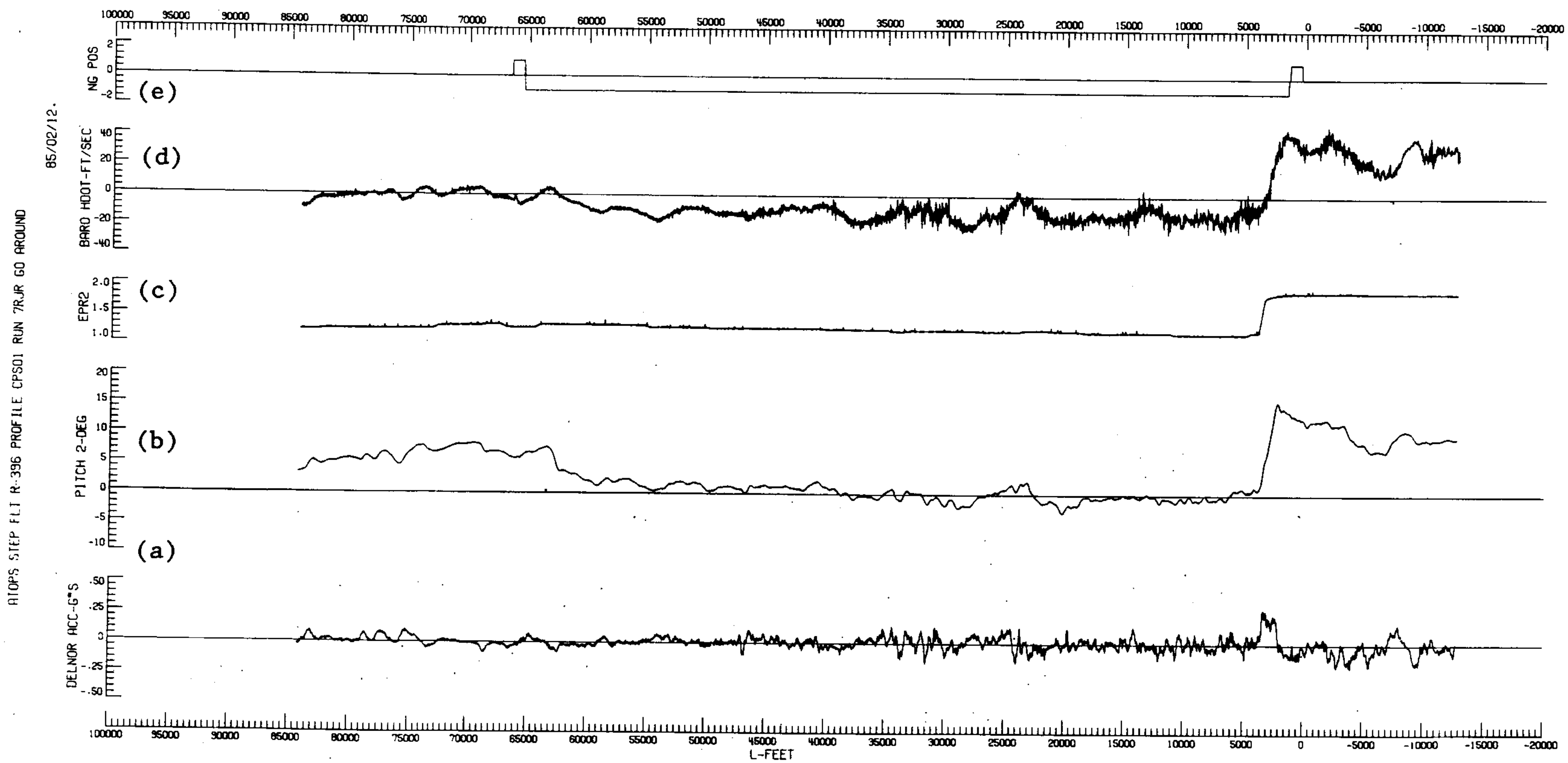


FIGURE 7.8A - SAMPLE PLOT - SELECT FLIGHT PARAMETERS: (a) Normal Acceleration, (b) Pitch Attitude, (c) EPR, (d) Vertical Rate, (e) Nose Gear Position

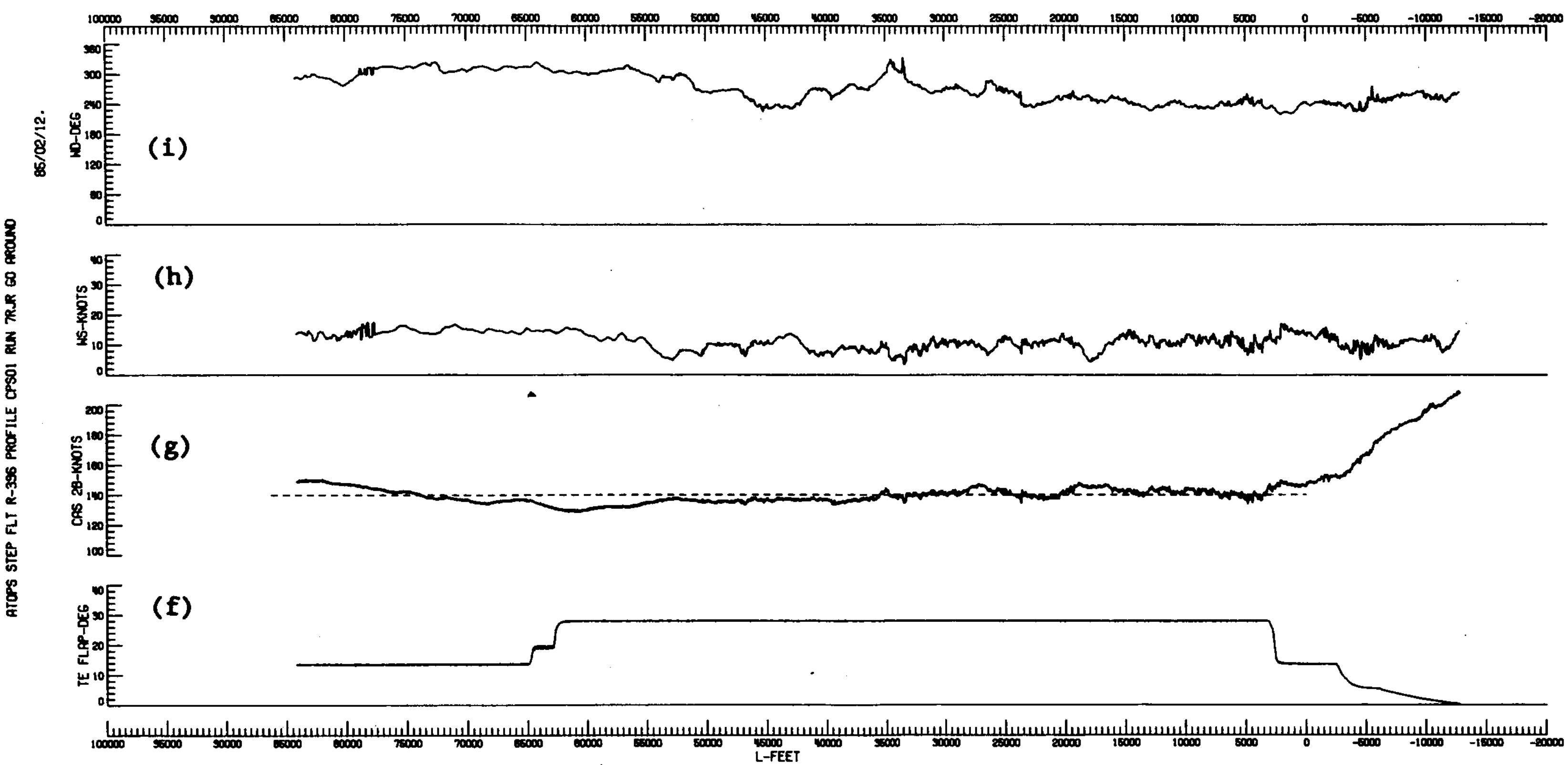


FIGURE 7.8B - SAMPLE PLOT -SELECT FLIGHT PARAMETERS (cont) - (f) Flap Position, (g) Calibration Air Speed, (h) Wind Speed, (i) Wind Direction (from INS)

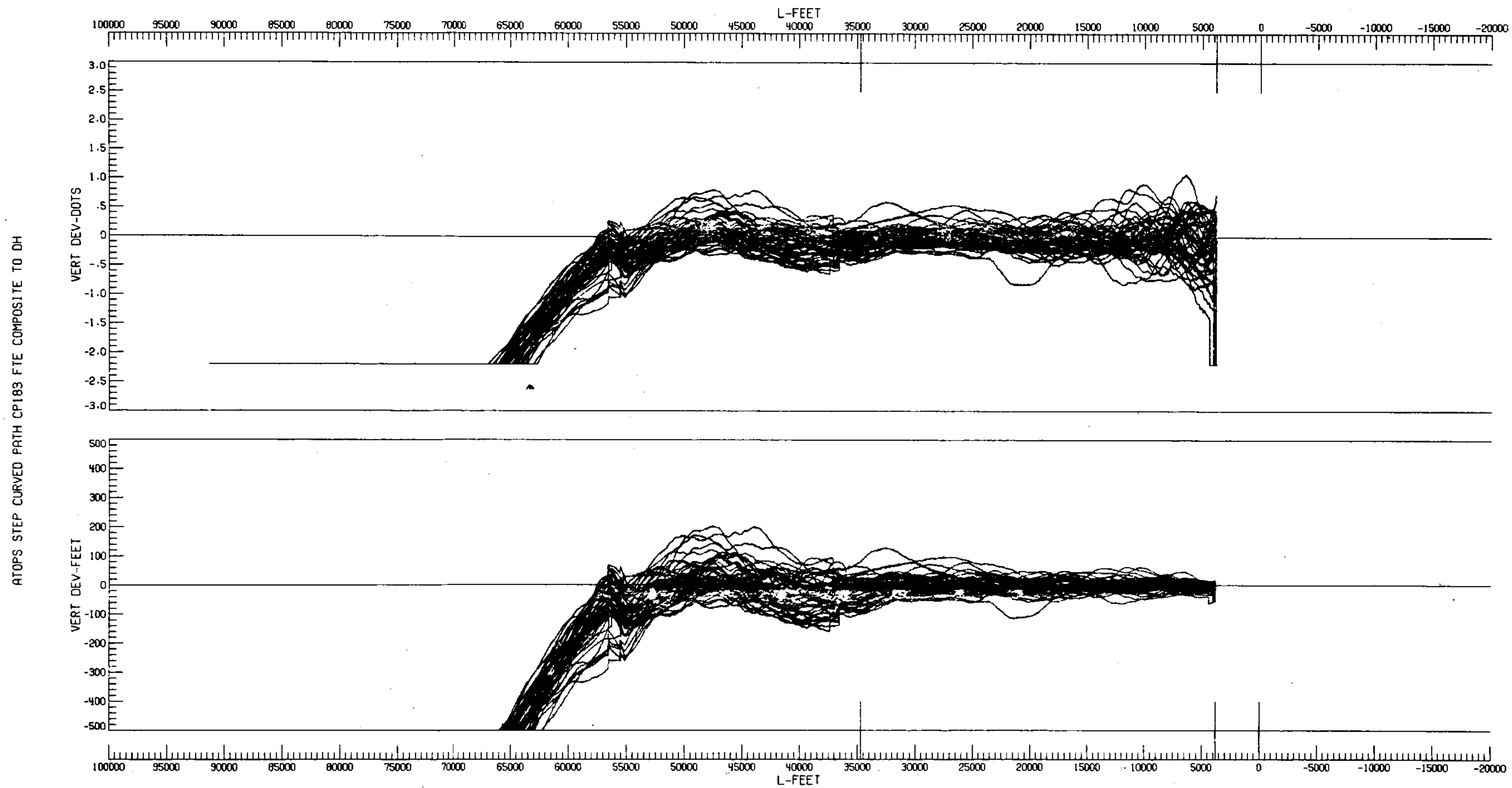


FIGURE 7.9 - SAMPLE COMPOSITE PLOT - FLIGHT TECHNICAL ERROR - VERTICAL REGIME

ATOPS STEP CURVED PATH CP183 FTE COMPOSITE TO DH

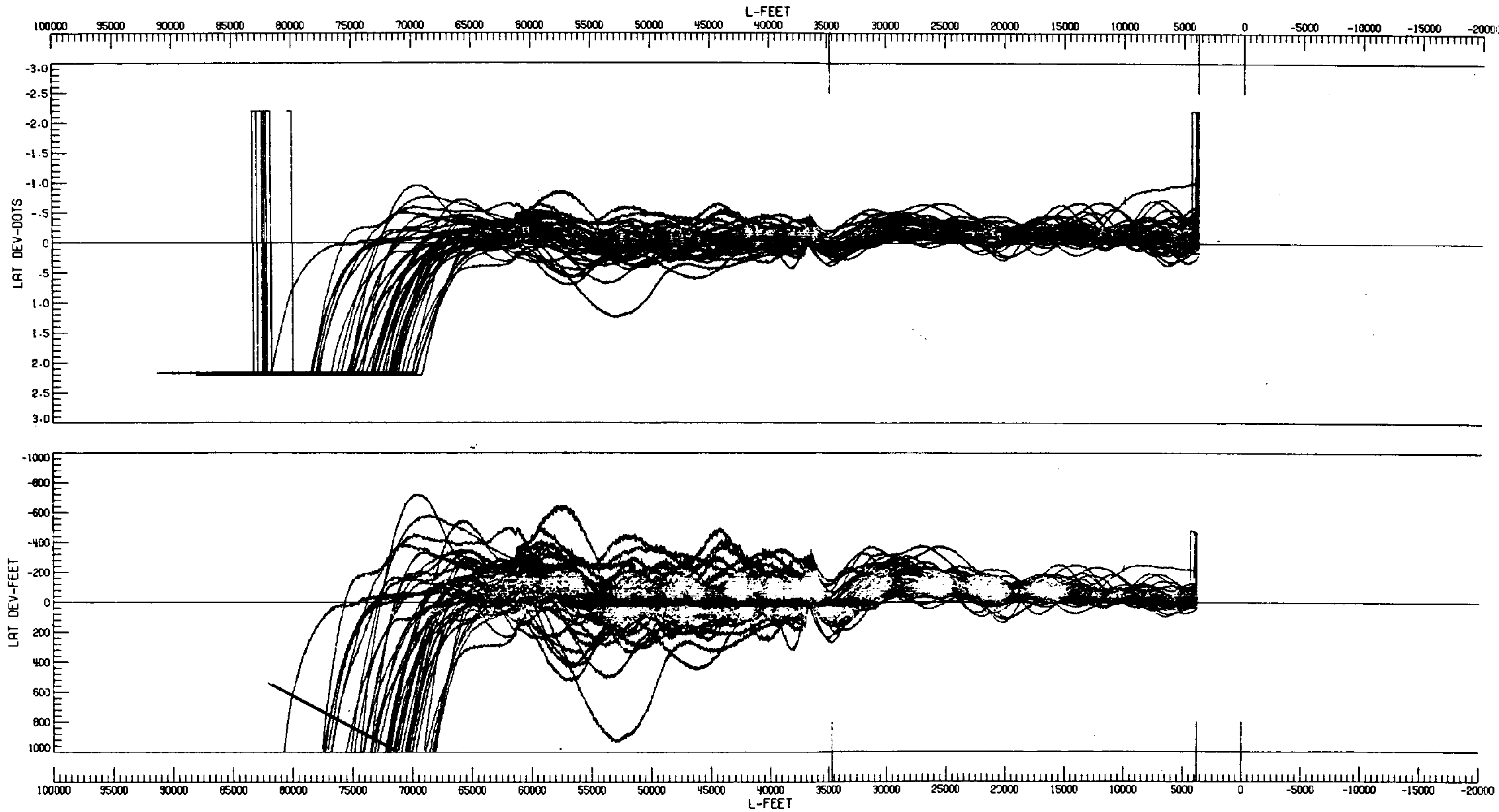


FIGURE 7.10 - SAMPLE COMPOSITE PLOT - FLIGHT TECHNICAL ERROR - LATERAL REGIME

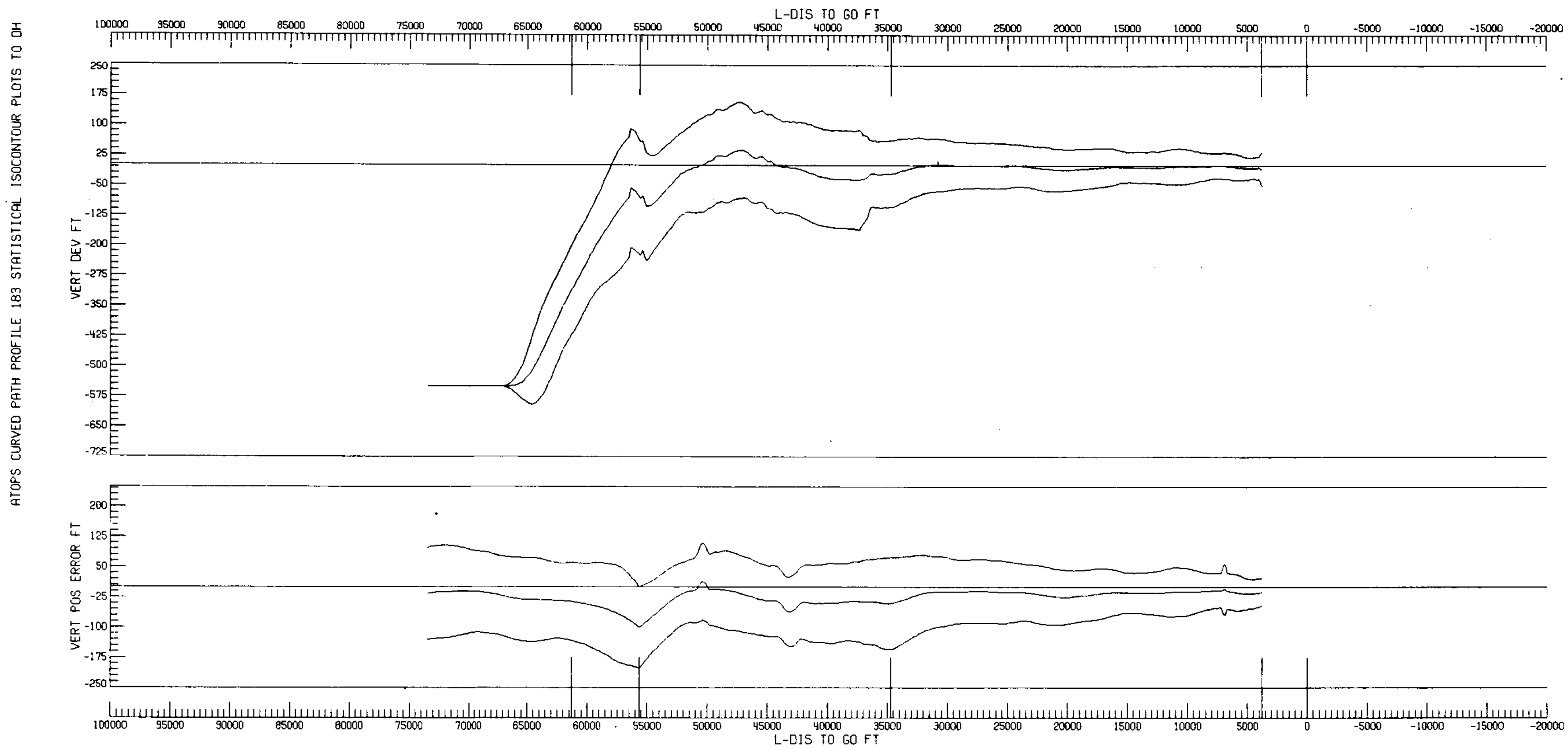


FIGURE 7.11 - SAMPLE ISOCONTOUR PLOT - VERTICAL FTE (DEV) AND POSITION (POS) ERRORS

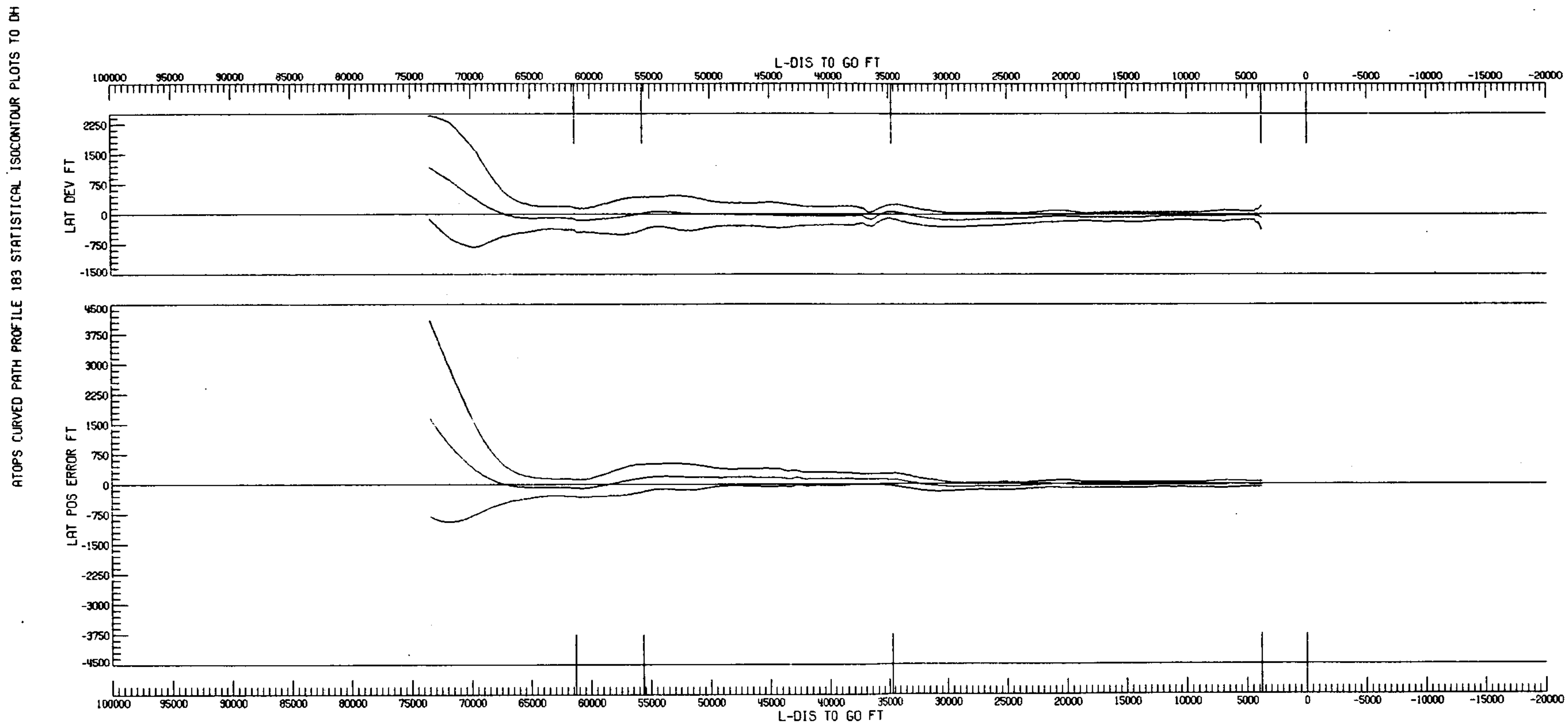


FIGURE 7.12 - SAMPLE ISOCONTOUR PLOT - LATERAL FTE (DEV) AND POSITION (POS) ERRORS

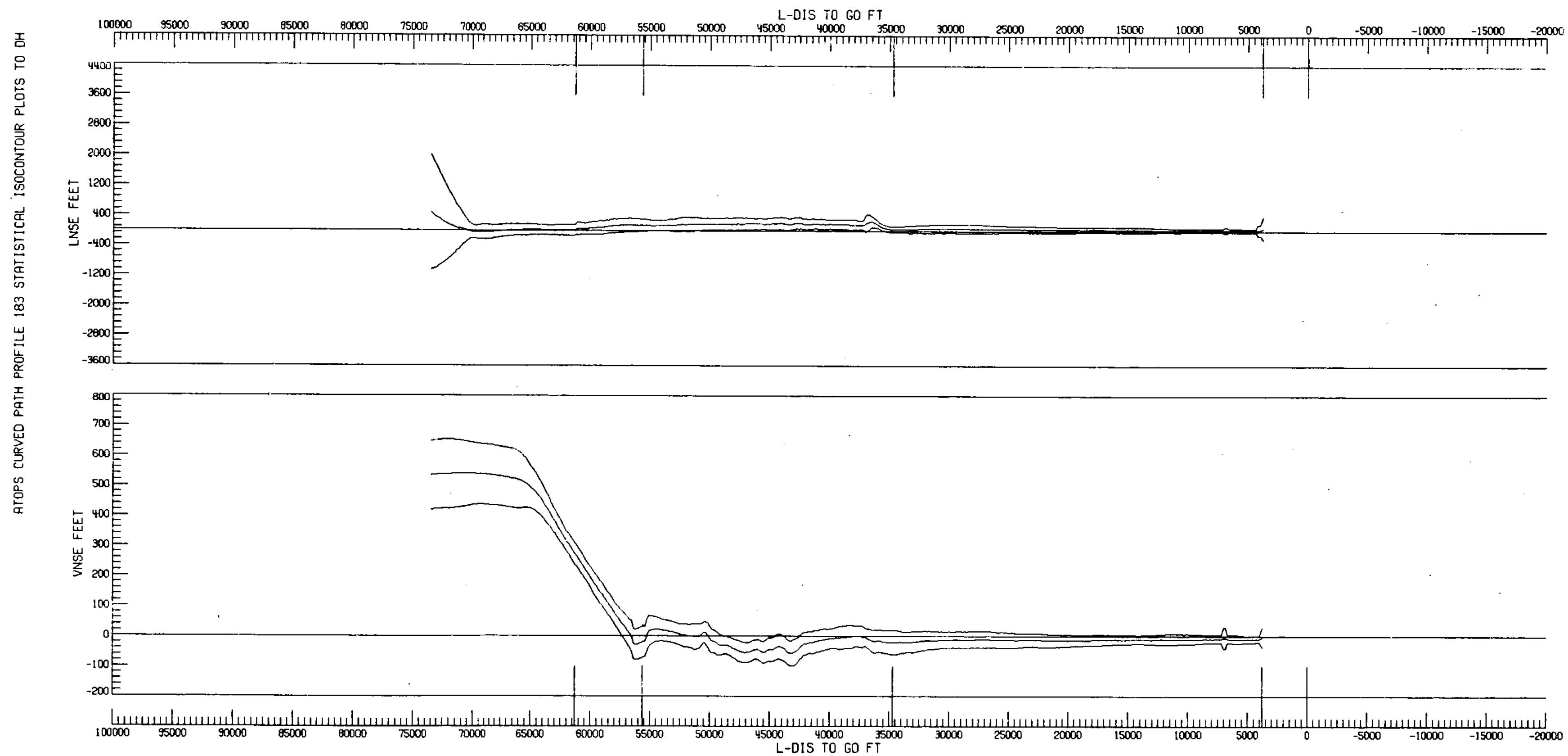


FIGURE 7.13 - SAMPLE ISOCONTOUR PLOT OF VERTICAL AND LATERAL NAVIGATION SYSTEM ERRORS

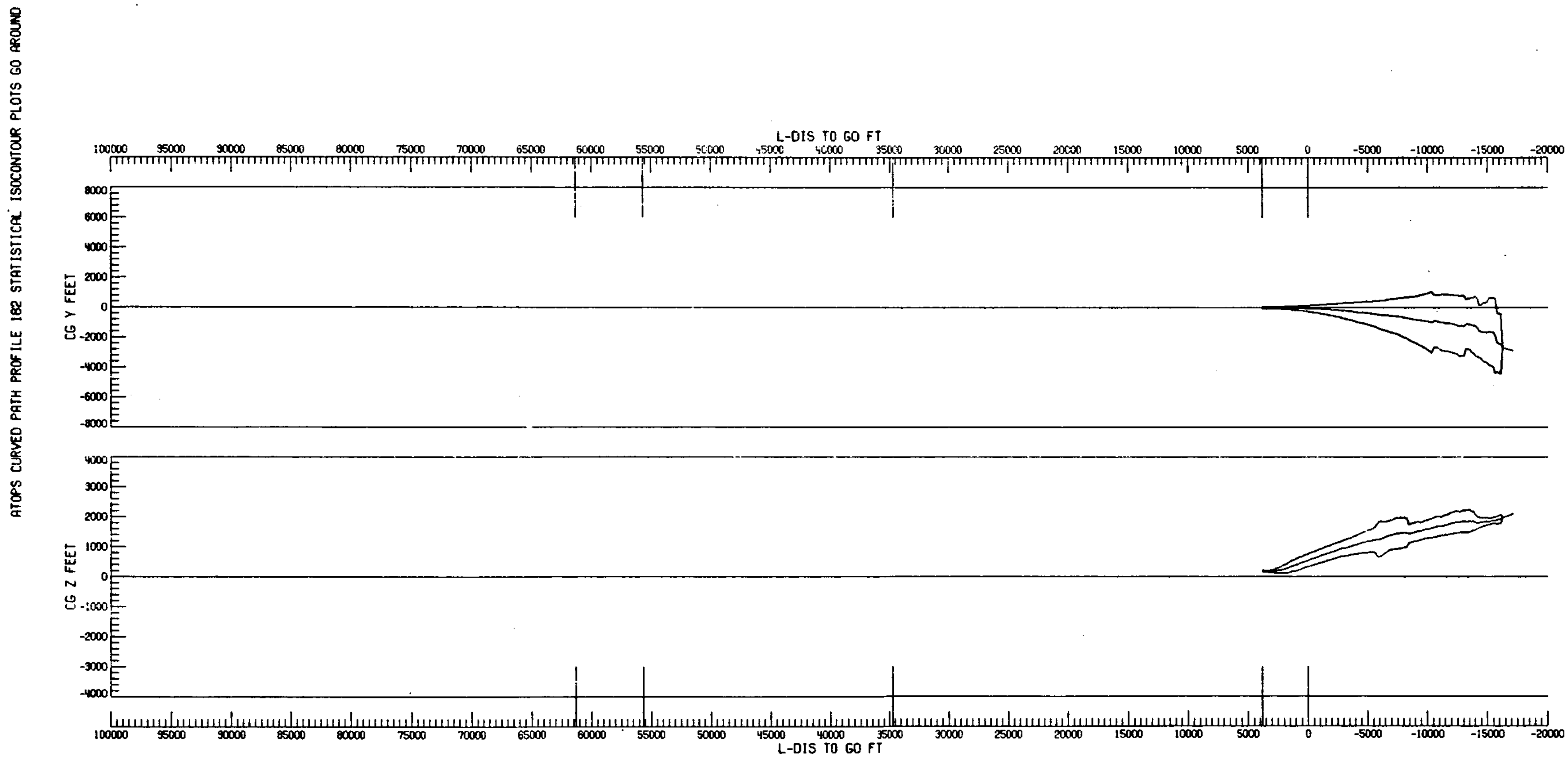


FIGURE 7.14 - SAMPLE ISOCONTOUR PLOT OF VERTICAL AND LATERAL POSITION ERRORS ON GO-AROUND RUNS

APPENDIX A

SUBJECT PILOT QUESTIONNAIRES - SAMPLE

A.1 - Overall pilot questionnaire (completed at conclusion of a series of similar profiles.

A.2 - "Refresher" questionnaires (completed after an individual run).

(A) Profile No. 1 (CP-181, CP-182, and CP-183)
(B) Profile No. 2 (CP-901 and CP-902)
(C) Profile No. 3 (CP-131)
(D) Profile No. 4 (CP-S01)

A.3 - Steep angle questionnaire.

APPENDIX A.1 - OVERALL PILOT QUESTIONNAIRE

NASA/FAA B737 MLS

PILOT QUESTIONNAIRE

PILOT NO. PROFILE: SUB-PROFILE: RUN: DATE:

1. Using the scales presented below, circle the number that represents **your estimate of the overall workload involved in this approach.**

				AVERAGE				
Demanding	1	2	3	4	5	6	7	Undemanding
No Planning Needed	1	2	3	4	5	6	7	Much Planning Needed
Difficult	1	2	3	4	5	6	7	Easy

Comments: ____________________

2. In your opinion, how adequate was the flight director in providing computed course guidance for this approach?

1	2	3	4	5	6	7
More than Adequate						Inadequate

3. Rate the sensitivity of the flight director for this approach profile.

A) **Roll**

1	2	3	4	5	6	7
Insufficient Sensitivity			About Right			Overly Sensitive

B) **Pitch**

1	2	3	4	5	6	7
Insufficient Sensitivity			About Right			Overly Sensitive

4. For each of the instruments listed below, provide an evaluation of the amount of information provided for this approach.

HSI	1	2	3	4	5	6	7
FDI	1	2	3	4	5	6	7
RMI	1	2	3	4	5	6	7
	More Than Sufficient						Insufficient

5. If you are dissatisfied with either the information available or the instrumentation, please indicate how you would modify the cockpit configuration and displays to improve conditions.

   a) Additional Information?

   b) Rearrange Instruments?

   c) Other

6. Which instrument(s) aided you most in orientation during this approach?

7. The information provided on the approach plate was:

   ☐ Considerably more than required

   ☐ More than required

   ☐ About right

   ☐ Less than required

   ☐ Considerably less than required

8. What information or format changes would you recommend for the approach plate?

9. How difficult do you believe this approach would be if flown in:

a) Larger aircraft?

1	2	3	4	5	6	7
Difficult						Easy

b) Smaller aircraft?

1	2	3	4	5	6	7
Difficult						Easy

c) Faster aircraft?

1	2	3	4	5	6	7
Difficult						Easy

d) Slower aircraft?

1	2	3	4	5	6	7
Difficult						Easy

10. Were any approaches not completed? Yes No

Reason for noncompletion of the approach: (e.g. System failure, traffic, conflict, etc.)

11. Circle the number that indicates the extent to which you were distracted during the approach.

1	2	3	4	5	6	7
Not at All						Very Much

What distracted you?

12. Check the appropriate box below to indicate your evaluation of the amount of time necessary to stabilize on the indicated segment of the approach prior to the turn or descent.

Intermediate		Centerline
☐	Considerably more than enough	☐
☐	More than enough	☐
☐	About right	☐
☐	Less than enough	☐
☐	Considerably less than enough	☐

14. Indicate the type of approach used; ☐ turn and descent or ☐ descent and turn, then indicate your evaluation of the amount of time allowed between the two points.

- ☐ Considerably less time than needed
- ☐ Less time than needed
- ☐ About right
- ☐ More time than needed
- ☐ Considerably more time than needed

15. Which of the following do you prefer?

- ☐ The descent should precede the turn
- ☐ The turn should precede the descent
- ☐ Turn and descend at the same time
- ☐ It doesn't make any difference to me

16. How would you evaluate the turn rate?

1	2	3	4	5	6	7
Excessively low			About Right			Excessively high

17. How would you evaluate the bank angle?

1	2	3	4	5	6	7
Excessively shallow			About Right			Excessively steep

18. Using the scales below, how does the amount of effort required in flying this curved path MLS approach compare to an ILS approach in terms of:

a) Tracking; azimuth vs localizer

1	2	3	4	5	6	7
Considerably more						Considerably less

b) Tracking; elevation vs glide slope

1	2	3	4	5	6	7
Considerably more						Considerably less

c) Workload; MLS vs ILS

1	2	3	4	5	6	7
Considerably more						Considerably less

d) Airspeed Control; MLS vs ILS

1	2	3	4	5	6	7
Considerably more						Considerably less

19. Using the following scale, to what extent did you experience disorientation while flying the approach?

1	2	3	4	5	6	7
Not at all						Considerable

What recommendation would you have to lessen the disorientation?

20. Would you recommend this type of approach for single pilot IMC operations? Yes No

Comment:

21. Comments Section:

(1) Describe your average position at the DH, relative to a normal landing for these approaches.

(2) What is the lowest DH you would recommend for this type approach?

(3) What is your opinion concerning the maneuvering during the descending turns?

(4) What would you consider the lowest altitude for maneuvering prior to stabilizing on the runway extended centerline?

(5) Additional Comments

APPENDIX A.2 - 'REFRESHER' QUESTIONNAIRE

(A) PROFILE 1 (CP-181, CP-182, AND CP-183)

PILOT NAME________________ DATE_______ PROFILE_______ RUN_______

PROFILE 1 VARIATION____

1. Was the time in coverage allowed to capture and track the course

1	2	3	4	5
Too Long				Too Short

2. Was the time to turn after the FAP

1	2	3	4	5
Too Long				Too Short

3. Was the turn rate

1	2	3	4	5
Too Low				Too High

4. Was the bank angle

1	2	3	4	5
Too Shallow				Too Steep

5. Was the time from the turn to the FAP

1	2	3	4	5
Too Long				Too Short

6. When offset from the course, was the time in coverage

1	2	3	4	5
Too Long				Too Short

<u>COMMENTS</u> Feel free to comment on any aspect of the run; profile itself, approach plates, how you would feel flying this approach under ATC with passengers, etc.....

(B) PROFILE 2 (CP-901 AND CP-902)

PILOT NAME______________ DATE__________ PROFILE ☐ CP901 RUN__________
☐ CP902

PROFILE 2 90 degree turn to final.

1. Was the time in cdverage allowed to capture and track the course

1	2	3	4	5
Too Long				Too Short

2. Was the time to turn after the FAP

1	2	3	4	5
Too Long				Too Short

3. Was the turn rate

1	2	3	4	5
Too Low				Too High

4. Was the bank angle

1	2	3	4	5
Too Shallow				Too Steep

5. Was the 3/4 mile final (centerline) segment length

1	2	3	4	5
Too Long				Too Short

6. If a low approach was made - do you feel that you would have been able to execute a safe landing from your go-around position

☐ Yes ☐ No

COMMENTS: (Feel free to comment on any aspect of this particular run.)

APPENDIX A.2 - 'REFRESHER' QUESTIONNAIRE

(C) PROFILE 3 (CP-131)

PILOT_______________________DATE__________PROFILE 3 RUN NO.______

PROFILE 3 (150 degree approach)

1. Was the the time in coverage to the FAP

1	2	3	4	5
Too Long				Too Short

2. Was the non-centerline segment (NCLS) length

1	2	3	4	5
Too Long				Too Short

3. Was the workload during this approach

1	2	3	4	5
Too Little				Too Much

COMMENTS:

(D) PROFILE 4 (CP-S01)

PROFILE 4

1. Was the FAP too close to the intersect point using the 60° intercept angle?

   ☐ Yes ☐ No

   If yes, how much farther should the intersect point be moved from the FAP?

   ☐ 1/2 NM ☐ 1 NM ☐ 1 1/2 NM ☐ 2 NM

2. Was the time from the FAP to the turn point

1	2	3	4	5
Too Long				Too Short

3. What was the highest usable intercept angle after the turn without an NCLS ?

   ☐ 15° ☐ 45° ☐ 75° ☐ 90°

4. Do you think there is a requirement to have a straight non-centerline line segment between the two turns?

   ☐ Yes ☐ No

Why? (Please Comment)

APPENDIX A.3 - STEEP-ANGLE QUESTIONNAIRE

PILOT QUESTIONNAIRE
B-737 STEEP ANGLE APPROACHES

Date________________

Pilot________________

1. Was the GS angle too steep? VMC ☐ yes ☐ no

   IMC ☐ yes ☐ no

2. Could it have been steeper? VMC ☐ yes ☐ no

   IMC ☐ yes ☐ no

   Please comment:____

   ____

3. Was any difficulty experienced in intercepting the GS and maintaining the angle?____

   Please comment:____

   ____

4. Was any difficulty experienced in keeping the localizer centered due to the glide slope angle? ☐ yes ☐ no

   Please comment:____

   ____

5. Was the stablized power setting too low to execute a normal landing or missed approach?____

   Please comment:____

   ____

6. Could a normal landing be made from this angle when transitioning from

   - 200'DH ☐ yes ☐ no
   - 100'DH ☐ yes ☐ no

   Please comment:____

   ____

7. Would you feel comfortable in making a missed approach from 200' DH?______ 100' DH?______

   Please comment:____

APPENDIX A.3 - STEEP-ANGLE QUESTIONNAIRE

1. Compare the workload of a __________ GS to a normal 3 degree ILS.

1	2	3	4	5	6	7
Much Less			Same			Much More

2. Was the GS intercept distance from DH

1	2	3	4	5	6	7
Too Short			About Right			Too Long

3. What is your recommendation for the maximum allowable rate of descent?

   ______________fpm.

4. What is your recommendation for a minimum at DH?

   ☐ 100 ☐ 150 ☐ 200 ☐ 250 ☐ 300 ☐ Other

   What?______ft.

APPENDIX B

FAA DATA ANALYSIS REQUIREMENTS

(As specified by FAA Office of Aviation Standards.)

APPENDIX B - FAA DATA ANALYSIS REQUIREMENTS

(From Original Project Plan)

5. DATA HANDLING

This paragraph describes the quantitative data that will be obtained from the airborne and ground data collection systems.

5.1 DATA COLLECTION. There are five sources of data: airborne Data Acquisition System (DAS), airborne "quick look" visicorder, flight observer logs, pilot questionnaires, and Wallops ground data collection system. The DAS, visicorder, and ground data system are discussed in this paragraph.

5.1.1 Airborne Data Acquisition System (DAS).

The specifications for the data obtained from the airborne DAS are presented in ~~Table 5.1.~~ Table 3.2A

5.1.2 Airborne Visicorder. - Not used.

The analog traces provided by the visicorder will be utilized as a "quick look" verification of selected data elements. Table 5.2 provides a list of the selected parameters. The project engineer or flight observer should verify and mark each output with date, time, approach identification, and any observed flight discrepancies.

5.1.3 Wallops Ground Data Collection System.

There are three categories of data from this system: approach documentation, meteorological data, and aircraft position.

5.1.3.1 Approach Documentation.

Approach identification, start and stop time of each approach shall be recorded.

5.1.3.2 Meteorological Data.

The specifications for the meteorological data are given in Table 5.3.

5.1.3.3 Aircraft Position.

A rectangular coordinate reference system shall be established with origin at the elevation angle ground point of intercept (GPI) with the runway along the runway centerline. This axis extending along the runway centerline is designated the x-axis, positive on

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the approach side, negative beyond the origin. The y-axis is drawn perpendicular to the x-axis at the GPI within the runway plane. The z-axis is drawn perpendicular to the x-y plane at the GPI, positive above, and negative below the ground plane. See ~~Figure 5.1.~~ Figure 7.1 The position of the aircraft in space as determined by by the ground tracking system should be recorded to the nearest foot with respect to this rectangular coordinate system. The position of the aircraft should be established to 5 feet.

The x,y,z coordinates should be sampled at a minimum rate of 10 per second and with time, recorded on magnetic tape for outlier removal, smoothing, and merging with airborne data.

5.2 DATA REDUCTION.

5.2.1 All magnetic tapes obtained from the airborne DAS and Wallops ground tracking system shall be processed by an outlier routine and an appropriate smoothing filter (for example Wallops forty-one point filter for the tracker data).

5.2.2 All data shall be converted to the engineering units specified in ~~Table 5.1.~~ Table 3.2

5.2.3 A mathematical function which describes the geometric approach path for each test profile shall be generated. Based on this analytical function, and the x,y,z tracker position, vertical and crosstrack deviation from the intended geometric path shall be generated, and with along-track distance, recorded on magnetic tape in feet to the nearest whole foot.

5.2.4 The vertical/crosstrack deviation with along-track data described in Paragraph 5.2.3 and airborne DAS described in Paragraph 5.1.1 shall be time merged into a common magnetic tape file.

5.2.5 The magnetic tapes shall have the following characteristics.

5.2.5.1 Nine track, 6250 bits per inch.

5.2.5.2 File input ASCII sequential.

5.2.5.3 Character set on tape: EBCDIC (8 bit)

5.2.5.4 Character set after input: ASCII

5.2.5.5 Maximum record length: 158 characters/record

5.2.6 The merged data tape shall be columnar in form. That is, for any given time a line of data would contain time, x,y,z, vertical/crosstrack deviation, IAS, vertical velocity, etc.

5.3 DATA ANALYSIS. This paragraph will present a summary of the statistical analysis to be applied to the data.

5.3.1 Standard Statistics.

Throughout this paragraph, reference will be made to computation of standard statistics. Such reference indicates that standard statistics will be computed for the data set in question.

5.3.2 Graphical Presentation.

Graphical plots, using airborne and ground tracker data as the source, should be presented for various sets of data including:

5.3.2.1 Plan view of each approach (x,y).

5.3.2.2 Profile view of each approach (x,z).

5.3.2.3 Vertical composite plot by range for each profile type to DH window (i.e. all 5.3.2.2 raw data overlaid).

5.3.2.4 Crosstrack composite plot by range for each profile type to DH window (5.3.2.1 data overlaid).

5.3.2.5 Vertical composite, similar to 5.3.2.3, by range for each profile type from DH window.

5.3.2.5.1 To landing for all landings.

5.3.2.5.2 To missed approach climb altitude or turn, whichever occurs first, for all missed approaches.

5.3.2.6 Ninety-five percent isoprobability contour curves (mean ± 2 sigma) about:

5.3.2.6.1 The vertical track deviation for each profile type.

5.3.2.6.2 The crosstrack deviation for each profile type.

5.3.2.7 Ninety-five percent isoprobability contour curves:

5.3.2.7.1 Above and below the missed approach climb gradient.

5.3.2.7.2 About the crosstrack deviation of the missed approach, referenced to the runway centerline.

5.3.2.8 Composite plot by range for each profile type. (Signal deviation, not flight director commands.)

5.3.2.8.1 Vertical FTE.

5.3.2.8.2 Crosstrack FTE.

5.3.2.9 Ninety-five percent isoprobability contour curve by range about:

5.3.2.9.1 Vertical FTE.

5.3.2.9.2 Crosstrack FTE.

5.3.3 Obstacle Clearance Analysis.

This analysis will be used in conjunction with other data to establish MLS obstacle clearance criteria for TERPS. The following paragraphs identify the type of statistical summary required.

5.3.3.1 Based on the theoretically computed range for the runway threshold (THR), i.e., where the glide path is 50 feet above the THR, partition the data (y,z deviation, and airborne DAS information) at 50 meter intervals. (At ranges THR, THR + 50, THR + 100, --- and THR - 50, THR - 100 ---, continuing throughout the approach and missed approach, to missed approach altitude). Additionally, partition the data at the following specific ranges: azimuth intercept, final approach point, turn point, rollout point, missed approach point altitude, low point in missed approach, and if landing, the touchdown point.

5.3.3.2 Compute standard statistics at each range interval specified in Paragraph 5.3.3.1 for each profile type:

5.3.3.2.1 Vertical deviation from intended vertical position.

5.3.3.2.2 Crosstrack deviation from intended horizontal position.

5.3.3.3 Partition missed approach data (y,z, and DAS) as in Paragraph 5.3.3.1. The data should be limited to missed approach climb altitude or turn whichever occurs first.

5.3.3.4 Compute standard statistics at each range interval specified in Paragraph 5.3.3.3 for each profile type:

5.3.3.4.1 Vertical position.

5.3.3.4.2 Horizontal position.

5.3.3.5 Partition landing data (y,z, and DAS) as in Paragraph 5.3.3.1 beginning at 200 ft. DH, and continuing to touchdown.

5.3.3.6 Compute standard statistics at each range interval specified in Paragraph 5.3.3.5 for each profile type:

5.3.3.6.1 Vertical position.

5.3.3.6.2 Horizontal position.

5.3.4 Minima Analysis.

The height loss (HL) will be analyzed to determine the effects of profile type on decision height.

5.3.4.1 From the missed approach data determine the coordinates (x,y,z) low of the lowest altitude achieved in the go around for each profile type.

5.3.4.2 Compute HL by substracting z_{low} from 200 ft. (DH).

5.3.4.3 Compute standard statistics by profile type.

5.3.4.3.1 Height Loss (HL).

5.3.4.3.2 Range at low point (X_{low}).

5.3.4.3.3 Crosstrack deviation at low point (Y_{low}).

5.3.5 Profile Type 1 Analysis.

Profile type 1 has four subprofiles, including two Final Approach Points (FAP) and two turn rates. Analysis of this profile type is to determine the effects of (1) the FAP location and (2) turn rate.

5.3.5.1 Effect of FAP location.

Compute standard statistics of vertical and crosstrack deviation error, at FAP and at 50 meter intervals to and including DH window for:

5.3.5.1.1 FAP preceding turn.

5.3.5.1.2 FAP during turn.

5.3.5.1.3 Generate a time history trace for yaw, pitch, roll, power, rate of climb/descent, heading, and speed. (Show movement and magnitude; show control surface position. Trace should also show flap, gear, and trim position.)

5.3.5.1.3.1 FAP preceding turn.

5.3.5.1.3.2 FAP during turn.

5.3.5.1.4 Using appropriate statistical tests (such as an F-test), determine if a statistically significance of difference exists between level of performance for the two FAP locations.

5.3.5.2 Effect of turn rate.

Repeat Paragraph 5.3.5.1 for each turn rate.

5.3.6 Profile Type Two Analysis.

There are two basic subprofiles in type two approaches. The basic parameter to be measured is the effect of time on centerline segment for minimum centerline segment and optimal centerline segment. Repeat Paragraph 5.3.5.1 for each segment length.

5.3.7 Profile Type Three.

There are two subprofile types and the effect of FAP location is evaluated with noncenterline segment on each profile. Repeat Paragraph 5.3.5.1 for each FAP location.

5.3.8 Profile Type Four.

There are two subprofiles included in this profile type. The effects of an intermediate intercept angle and no noncenterline segment versus a large intercept angle (derived at pretest), and a required centerline segment. Repeat Paragraph 5.3.5.1 for each intercept angle.

APPENDIX C

PATH DEFINITION AND POSITION ERROR EQUATIONS

FIGURES ACCOMPANYING TABLES

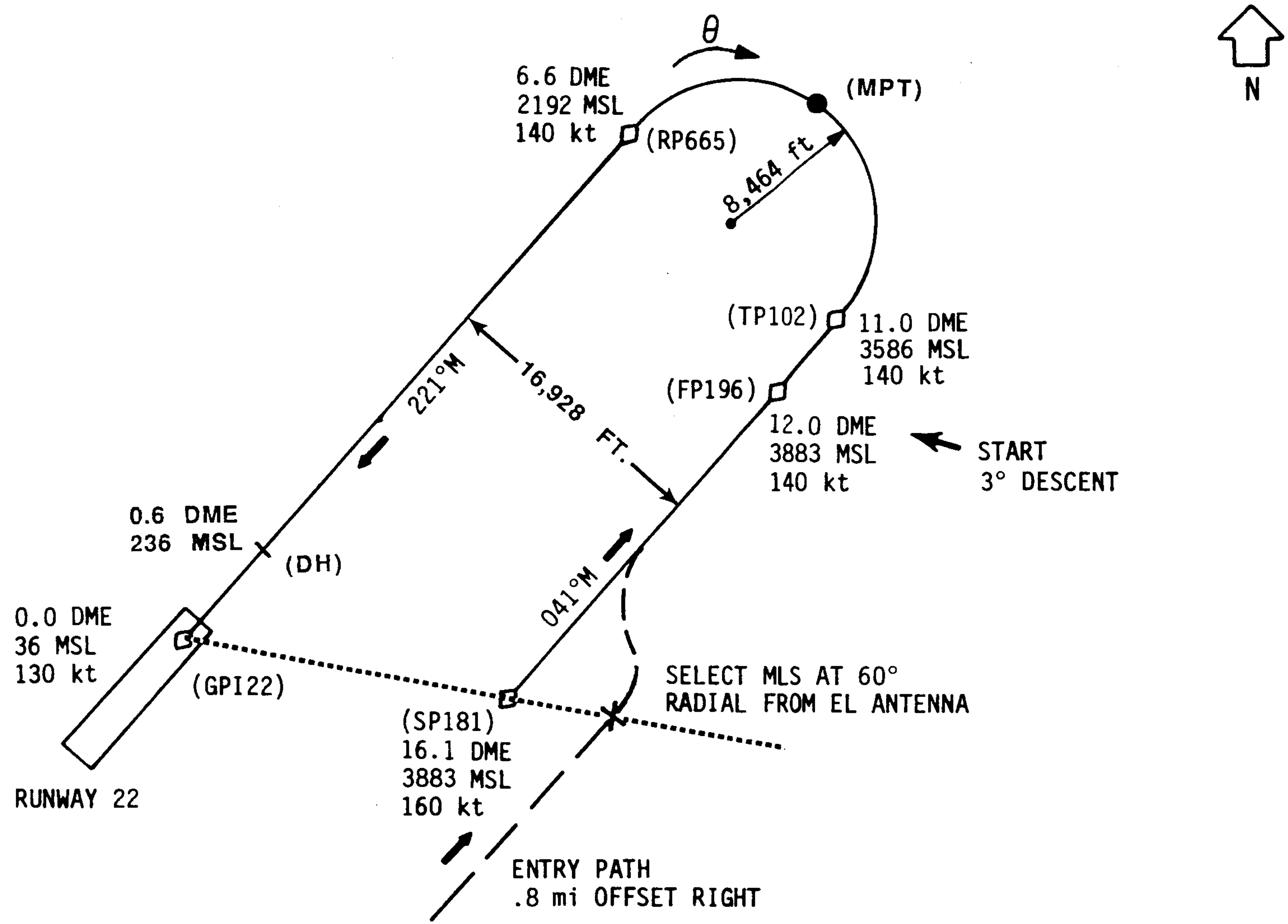


FIGURE C-1 - FLIGHT PATH DEFINITION FOR CP-181

TABLE C-1(A) – PATH DEFINITION AND WAYPOINT DATA FOR CP181

Waypoint	X	Y	Z*	h_{MSL}	L
	(all units in feet, referenced to GPI 22, Fig. C-1)				
GPI22	0	0	0	36	0
TCH	954	0	50	86	954
DH	3816	0	200	236	3816
RP665	40391	0	2117	2192	40391
MPT	48855	-8464	2804	2889	53686
TP102	40391	-16928	3504	3586	66981
FP196	34720	-16928	3811	3883	72652
SP181***	9768	-16928	3838	3883	97604

*<u>Height Calculations</u>

For leg RP665 to GP122:

$$Z = X \tan 3^{\circ} \qquad \text{(or } L \tan 3^{\circ}\text{)}$$

Elsewhere, calculate Z from h_{MSL}:

$$Z = h_{MSL} - 36 - 2.39137067 * 10^{-8} (X^2 + Y^2)$$

In turn, TP102 to RP665:

$$h_{MSL} = 2192 + 1394 \left(\frac{\Theta}{180}\right) \begin{cases} \Theta = 0^{\circ} @ \text{ RP665} \\ \Theta = 180^{\circ} @ \text{ TP102} \end{cases}$$

On leg FP196 to TP102:

$$h_{MSL} = 3556 + 297 \left(\frac{L - 66981}{5671}\right)$$

On leg SP181 to FP196:

$$h_{MSL} = 3883 \text{ ft.}$$

TABLE C–1(B) – POSITION ERROR CALCULATION FOR CP181

(NOTE: All distances are in feet; Θ is in radians.)

For leg SP181 to FP196: $(97604 > L > 72652)$

$L = 107372 - X_{cg}$ $(X_{cg} \leq 34720)$

RADL ERROR $= -Y_{cg} - 16928$

VPOS ERROR $= Z_{cg} - 3840 + 2.39137 * 10^{-8} X^2_{cg}$

From FP196 to TP102: $(72652 > L > 66981)$:

$L = 107372 - X_{cg}$ $(40391 \geq X_{cg} > 34720)$

RADL ERROR $= -Y_{cg} - 16928$

VPOS ERROR $= Z_{cg} - 5658.5 + 0.0523717X_{cg} + 2.39137 * 10^{-8} X^2_{cg}$

In turn TP102 to RP665: (66981 > L > 40391)

$$L = 40391 + 8464\,\Theta$$

$$\Theta = 1.570796 - \tan^{-1}\left(\frac{Y_{cg} + 8464}{X_{cg} - 40391}\right) \qquad (X_{cg} > 40391)$$

$$\text{RADL ERROR} = \left[\,(X_{cg} - 40391)^2 + (Y_{cg} + 8464)^2\,\right]^{\frac{1}{2}} - 8464$$

$$\text{VPOS ERROR} = Z_{cg} - 2156 - 443.724\,\Theta + 2.39137 * 10^{-8}\,\left[\,(40391 + 8464 \sin\Theta)^2 + (8464\,(1 - \cos\Theta))^2\,\right]$$

On leg RP665 to GPI22:

$$L = X_{cg} \qquad (X_{cg} \leq 40391 \text{ ft.})$$

$$\text{RADL ERROR} = Y_{cg}$$

$$\text{VPOS ERROR} = Z_{cg} - 0.0524078\,X_{cg}$$

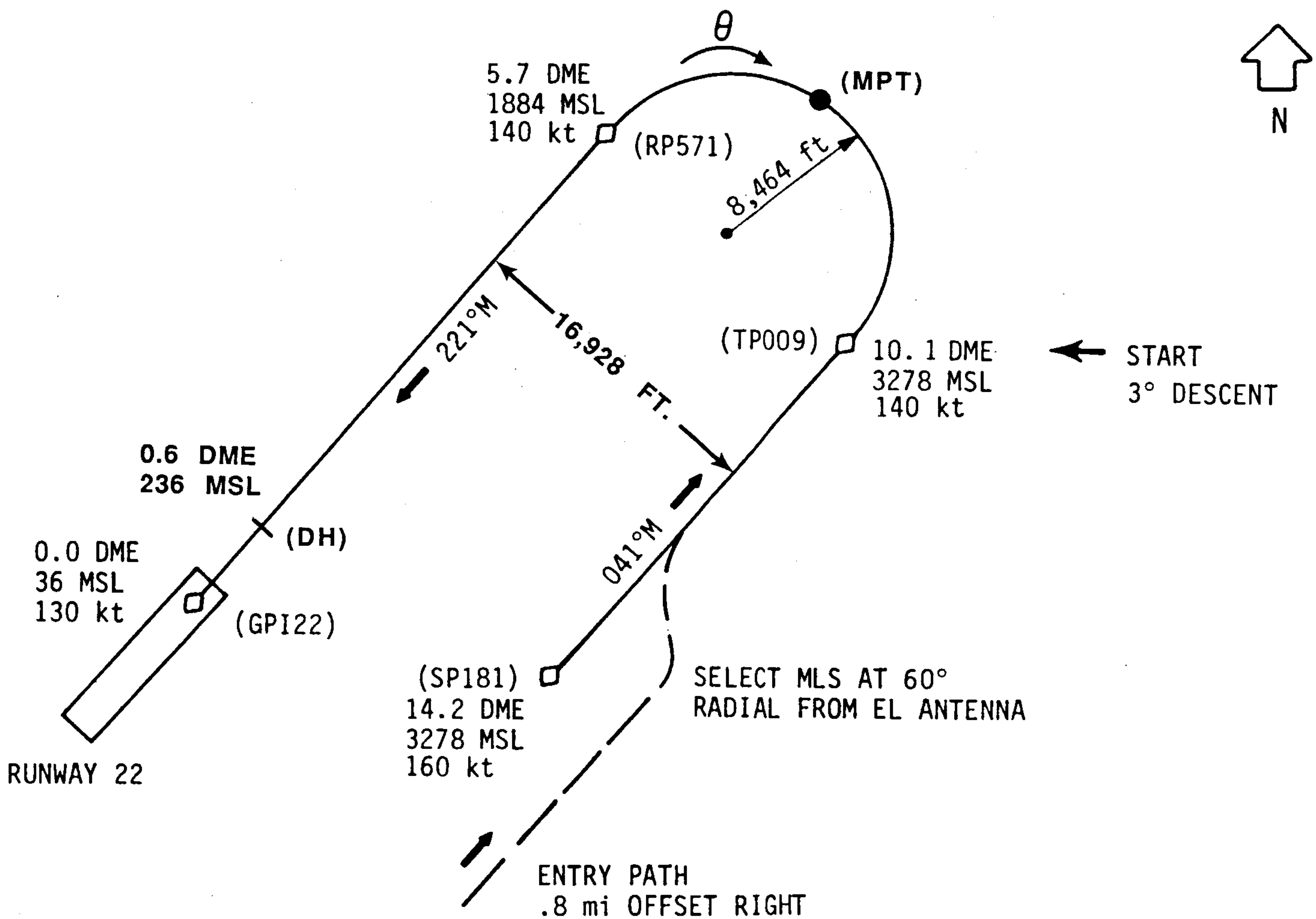


FIGURE C-2 - FLIGHT PATH DEFINITION FOR CP-182

TABLE C–2(A) – PATH DEFINITION AND WAYPOINT DATA FOR CP182

Waypoint	X	Y	Z*	h_{MSL}	L
	(all units in feet, referenced to GPI, Fig. C–2)				
GP122	0	0	0	36	0
TCH	954	0	50	86	954
DH	3816	0	200	236	3816
RP571	34720	0	1820	1884	34720
MPT	43184	–8464	2499	2581	48015
TP009	34720	–16928	3206	3278	61310
SP181	9768	–16928	3233	3278	86262

*Height Calculations

For leg RP571 to GP122:

$$Z = X \tan 3^{\circ} \qquad \text{(or } L \tan 3^{\circ}\text{)}$$

Elsewhere, calculate Z from h_{MSL}:

$$Z = h_{MSL} - 36 - 2.39137067 * 10^{-8} (X^2 + Y^2)$$

In turn, TP009 to RP571:

$$h_{MSL} = 1884 + 1394 \left(\frac{\theta}{180}\right) \qquad (\theta \text{ in degrees})$$

On leg SP181 to TP009:

$$h_{MSL} = 3278 \text{ ft.}$$

TABLE C-2(B) - POSITION ERROR CALCULATION FOR CP182

(NOTE: All distances are in feet; Θ is in radians.)

From SP181 to TP009: $(86262 > L > 61310)$:

$L = 96030 - X_{cg}$ $(X_{cg} \leq 34720)$

RADL ERROR $= -Y_{cg} - 16928$

VPOS ERROR $= Z_{cg} - 3235 + 2.39137 * 10^{-8} X^2_{cg}$

In turn, TP009 to RP571: $(61310 > L > 34720)$

$L = 34720 + 8464\ \Theta$

$$\Theta = 1.570796 - \tan^{-1}\left(\frac{Y_{cg} + 8464}{X_{cg} - 34720}\right) \qquad (X_{cg} > 34720)$$

RADL ERROR $= [\,(X_{cg} - 34720)^2 + (Y_{cg} + 8464)^2\,]^{\frac{1}{2}} - 8464$

VPOS ERROR $= Z_{cg} - 1848 - 443.724\ \Theta +$
$2.39137 * 10^{-8}\ [\,(34720 + 8464 \sin\Theta)^2 + (8464\,(1 - \cos\Theta)\,)^2\,]$

On leg RP571 to GPI22:

$L = X_{cg}$ $(X_{cg} \leq 34720$ ft.)

RADL ERROR $= Y_{cg}$

VPOS ERROR $= Z_{cg} - 0.0524078\ X_{cg}$

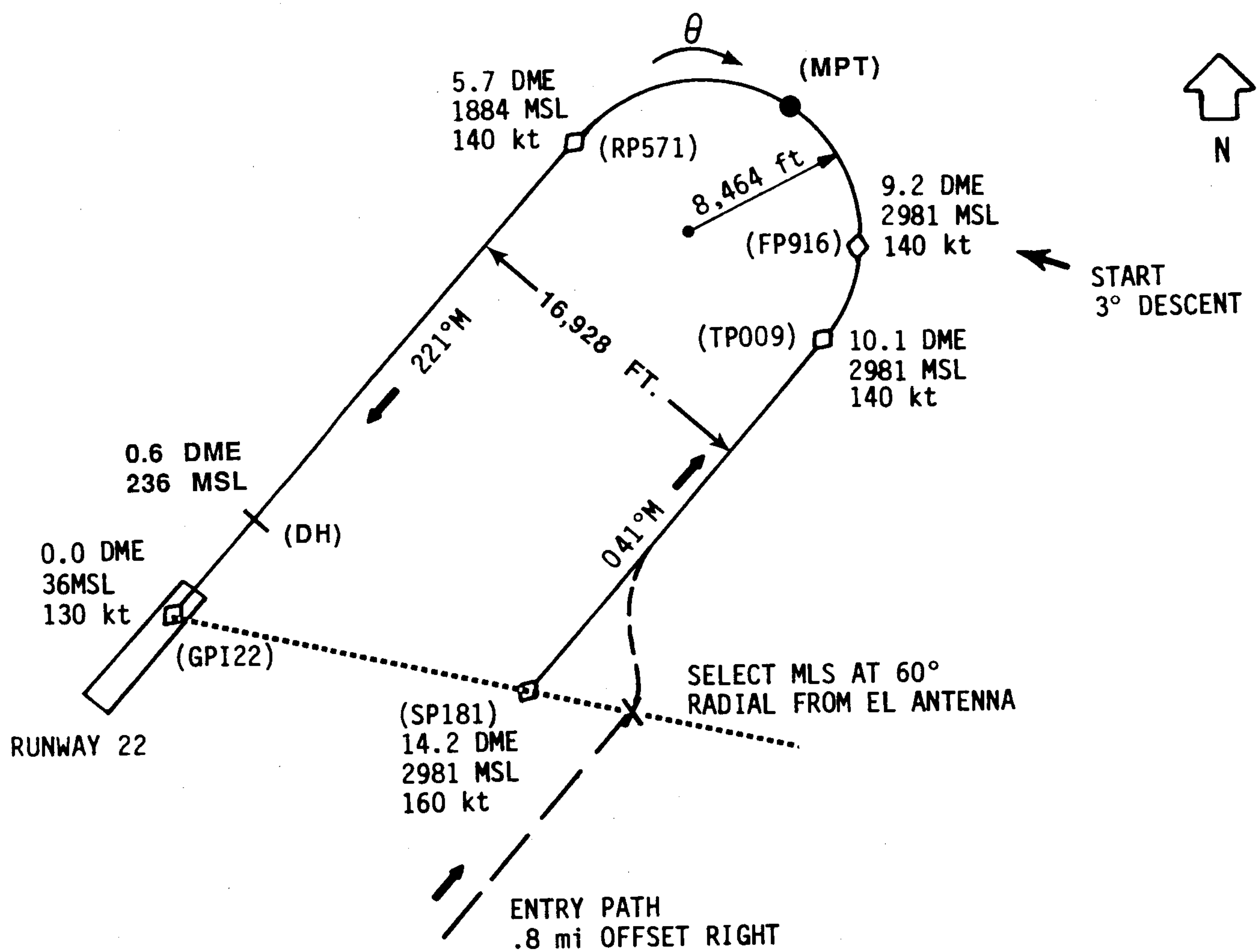


FIGURE C-3 - FLIGHT PATH DEFINITION FOR CP-183

TABLE C-3(A) – PATH DEFINITION AND WAYPOINT DATA FOR CP183

Waypoint	X	Y	Z*	h_{MSL}	L
	(all units in feet, referenced to GPI 22, Fig. C-3)				
GPI22	0	0	0	036	0
TCH	954	0	50	086	954
DH	3816	0	200	236	3816
RP571	34720	0	1820	1884	34720
MPT	43184	-8464	2499	2581	48015
FP916	39976	-15098	2901	2981	55639
TP009	34720	-16928	2909	2981	61310
SP181	9768	-16928	2936	2981	86262

*Height Calculations

For leg RP571 to GP122:

$$Z = X \tan 3^{\circ} \qquad \text{(or L Tan } 3^{\circ})$$

Elsewhere, calculate Z from h_{MSL}:

$$Z = h_{MSL} - 36 - 2.39137067 * 10^{-8} (X^2 + Y^2)$$

In turn, FP916 to RP571:

$$h_{MSL} = 1884 + 1394 \left(\frac{\Theta}{180}\right) \qquad (\Theta \text{ in degrees})$$

On leg SP181 to TP009:

$$h_{MSL} = 2981 \text{ ft.}$$

TABLE C-3(B) – POSITION ERROR CALCULATION FOR CP183

(NOTE: All distances are in feet; Θ is in radians.)

From SP181 to TP009: $(86262 > L > 61310)$

$$L = 96030 - X_{cg} \qquad (X_{cg} \leq 34720)$$

$$\text{RADL ERROR} = -Y_{cg} - 16928$$

$$\text{VPOS ERROR} = Z_{cg} - 2938 + 2.39137 * 10^{-8} X^2_{cg}$$

From TP009 to FP916: $(61310 > L > 55639)$;

$$L = 34720 + 8464\ \Theta$$

$$\Theta = 1.570796 - \tan^{-1}\left(\frac{Y_{cg} + 8464}{X_{cg} - 34720}\right) \qquad (X_{cg} > 34720)$$

$$\text{RADL ERROR} = [\,(X_{cg} - 34720)^2 + (Y_{cg} + 8464)^2\,]^{\frac{1}{2}} - 8464$$

$$\text{VPOS ERROR} = Z_{cg} - 2945 + 2.39137 * 10^{-8}\,(X_{cg}^{\;2} + Y_{cg}^{\;2})$$

In turn, FP916 to RP571: (55639 > L > 34720)

$$L = 34720 + 8464\,\Theta$$

$$\Theta = 1.570796 - \tan^{-1}\left(\frac{Y_{cg} + 8464}{X_{cg} - 34720}\right) \qquad (X_{cg} > 34720)$$

$$\text{RADL ERROR} = [\,(X_{cg} - 34720)^2 + (Y_{cg} + 8464)^2\,]^{\frac{1}{2}} - 8464$$

$$\text{VPOS ERROR} = Z_{cg} - 1848 - 443.724\,\Theta + 2.39137 * 10^{-8}\ [\,(34720 + 8464 \sin\Theta)^2 + (8464\,(1 - \cos\Theta)\,)^2\,]$$

On leg RP571 to GPI22:

$$L = X_{cg} \qquad (X_{cg} \leq 34720 \text{ ft.})$$

$$\text{RADL ERROR} = Y_{cg}$$

$$\text{VPOS ERROR} = Z_{cg} - 0.0524078\,X_{cg}$$

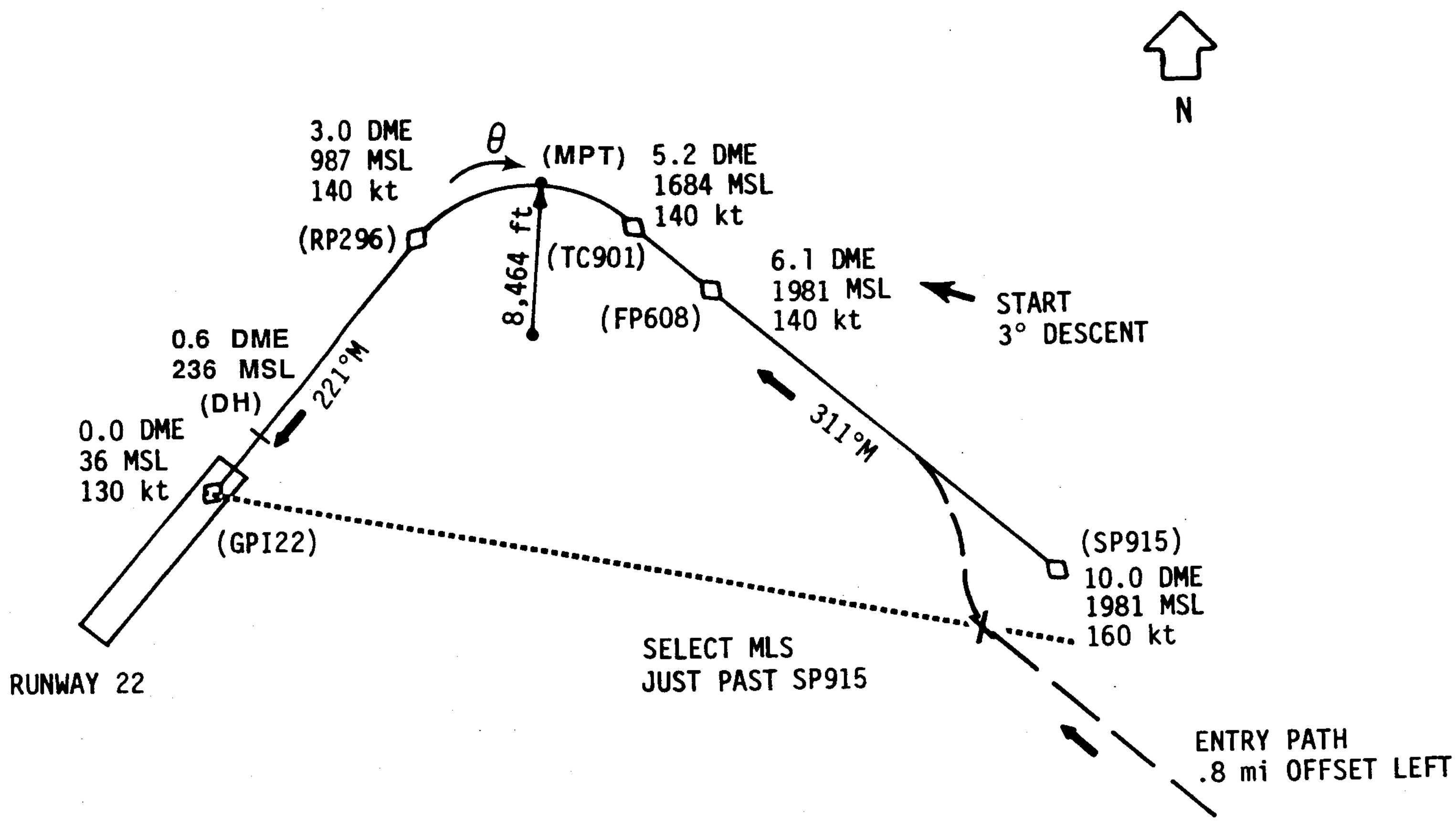


FIGURE C-4 - FLIGHT PATH DEFINITION FOR CP-901

TABLE C-4(A) – PATH DEFINITION AND WAYPOINT DATA FOR CP901

Waypoint	X	Y	Z*	h_{MSL}	L
	(all units in feet, referenced to GPI 22, Fig. C-4)				
GPI22	0	0	0	36	0
TCH	954	0	50	86	954
DH	3816	0	200	236	3816
RP296	17994	0	943	987	17994
MPT	23979	–2479	1285	1336	24642
TC901	26458	–8464	1629	1684	31289
FP608	26458	–14131	1936	1981	36956
SP915	26458	–38435	1905	1981	61260

*Height Calculations

For leg RP296 to GP122:

$$Z = X \tan 3^{o} \qquad \text{(or L Tan } 3^{o}\text{)}$$

Elsewhere, calculate Z from h_{MSL}:

$$Z = h_{MSL} - 36 - 2.39137067 * 10^{-8} (X^2 + Y^2)$$

In turn, TC901 to RP296:

$$h_{MSL} = 987 + 697 \left(\frac{\theta}{90}\right) \qquad (\theta \text{ in degrees})$$

On leg FP608 to TC901:

$$h_{MSL} = 1684 + 297 \left(\frac{L - 31289}{5667}\right)$$

On leg SP915 to FP608:

$$h_{MSL} = 1981 \text{ ft.}$$

TABLE C-4(B) - POSITION ERROR CALCULATION FOR CP901

(NOTE: All distances are in feet; θ is in radians.)

For leg SP915 to FP608: $(61260 > L > 36956)$

$L = 22825 - Y_{cg}$ $(Y_{cg} \leq -14131)$

$\text{RADL ERROR} = X_{cg} - 26458$

$\text{VPOS ERROR} = Z_{cg} - 1928.3 + 2.39137 * 10^{-8} Y^2_{cg}$

From FP608 to TC901: $(36956 > L > 31289)$:

$L = 22825 - Y_{cg}$ $(Y_{cg} > -14131)$

$\text{RADL ERROR} = X_{cg} - 26458$

$\text{VPOS ERROR} = Z_{cg} - 1187.7 + 0.0524087 X_{cg} + 2.39137 * 10^{-8} Y^2_{cg}$

In turn TC901 to RP296: (31289 > L > 17994)

$L = 17994 + 8464\,\Theta$

$$\Theta = 1.570796 - \tan^{-1}\left(\frac{Y_{cg} + 8464}{X_{cg} - 17994}\right) \qquad (X_{cg} > 17994)$$

$$\text{RADL ERROR} = [\,(X_{cg} - 17994)^2 + (Y_{cg} + 8464)^2\,]^{\frac{1}{2}} - 8464$$

$$\text{VPOS ERROR} = Z_{cg} - 951 - 443.724\,\Theta + 2.39137 * 10^{-8}\,[\,(17994 + 8464 \sin\Theta)^2 + (8464\,(1 - \cos\Theta)\,)^2\,]$$

On leg RP296 to GPI22:

$L = X_{cg}$ $\qquad (X_{cg} \leq 17994 \text{ ft.})$

$\text{RADL ERROR} = Y_{cg}$

$\text{VPOS ERROR} = Z_{cg} - 0.0524078\,X_{cg}$

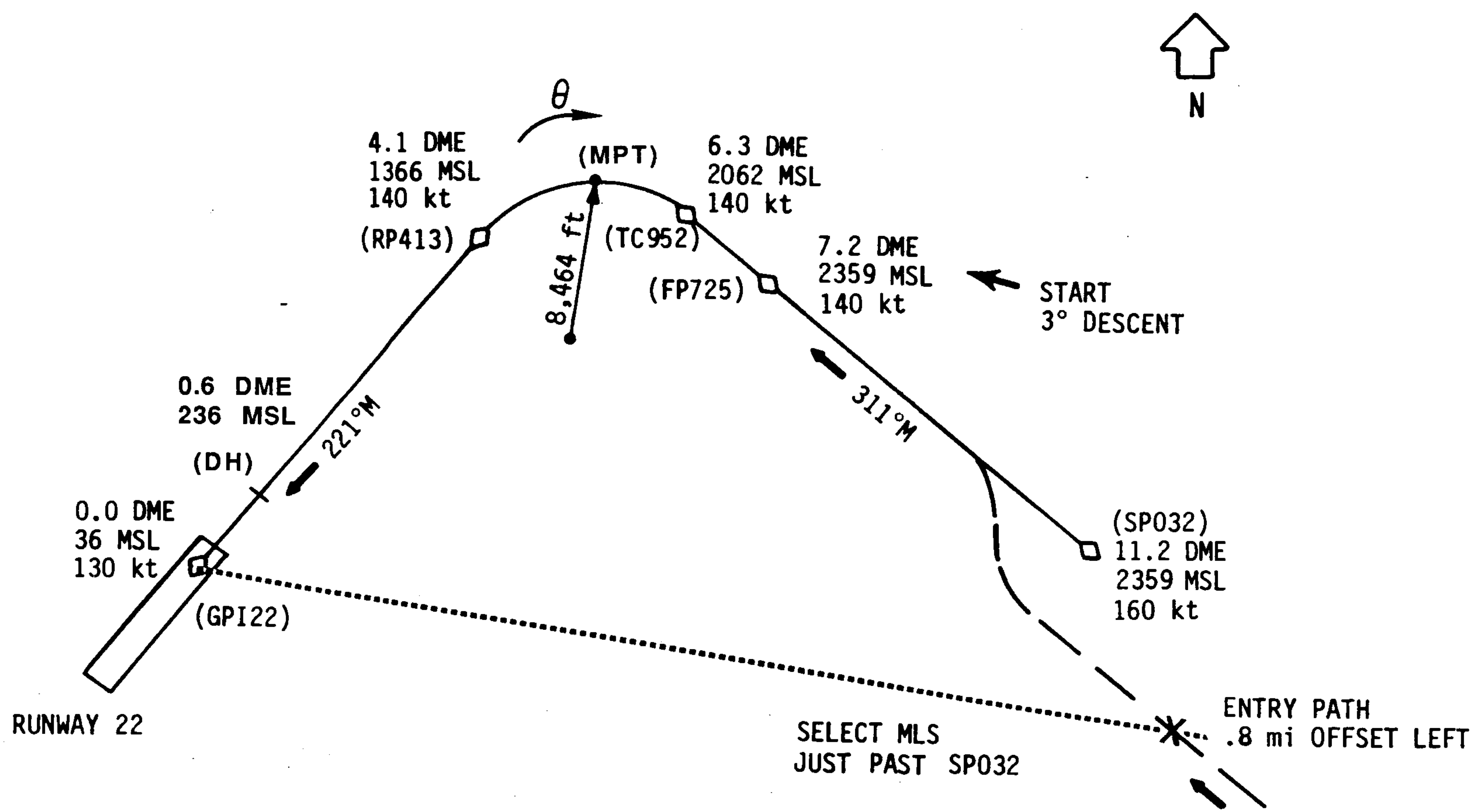


FIGURE C-5 - FLIGHT PATH DEFINITION FOR CP-902

TABLE C-5(A) – PATH DEFINITION AND WAYPOINT DATA FOR CP902

Waypoint	X	Y	Z*	h_{MSL}	L
	(all units in feet, referenced to GPI 22, Fig. C-5)				
GPI22	0	0	0	36	0
TCH	954	0	50	86	954
DH	3816	0	200	236	3816
RP413	25082	0	1314	1366	25082
MPT	31067	-2479	1654	1714	31730
TC952	33546	-8464	1998	2062	38378
FP725	33546	-14131	2307	2359	44045
SP032	33546	-38435	2277	2359	68349

*Height Calculations

For leg RP413 to GP122:

$Z = X \tan 3^{o}$ (or $L \tan 3^{o}$)

Elsewhere, calculate Z from h_{MSL}:

$$Z = h_{MSL} - 36 - 2.39137067 * 10^{-8} (X^2 + Y^2)$$

In turn, TC952 to RP413:

$$h_{MSL} = 1366 + 696 \left(\frac{\Theta}{90}\right) \quad (\Theta \text{ in degrees})$$

On leg FP725 to TC952:

$$h_{MSL} = 2062 + 297 \left(\frac{L - 38378}{5667}\right)$$

On leg SP032 to FP725:

$$h_{MSL} = 2359 \text{ ft.}$$

TABLE C-5(B) – POSITION ERROR CALCULATION FOR CP902

(NOTE: All distances are in feet; Θ is in radians.)

For leg SP032 to FP725: $(68349 > L > 44045)$

$L = 29914 - Y_{cg}$ $(Y_{cg} \leq -14131)$

$$\text{RADL ERROR} = X_{cg} - 33546$$

$$\text{VPOS ERROR} = Z_{cg} - 2296 + 2.39137 * 10^{-8}\, Y^2_{cg}$$

From FP725 to TC952: $(44045 > L > 38378)$:

$L = 29914 - Y_{cg}$ $(Y_{cg} > -14131)$

$$\text{RADL ERROR} = X_{cg} - 33546$$

$$\text{VPOS ERROR} = Z_{cg} - 1555.5 + 0.0524087\, Y_{cg} + 2.39137 * 10^{-8}\, Y^2_{cg}$$

In turn, TC952 to RP413: (38378 > L > 25082)

$$L = 25082 + 8464\,\Theta$$

$$\Theta = 1.570796 - \tan^{-1}\left(\frac{Y_{cg} + 8464}{X_{cg} - 25082}\right) \qquad (X_{cg} > 25082)$$

$$\text{RADL ERROR} = [\,(X_{cg} - 25082)^2 + (Y_{cg} + 8464)^2\,]^{\frac{1}{2}} - 8464$$

$$\text{VPOS ERROR} = Z_{cg} - 1330 - 443.724\,\Theta + 2.39137 * 10^{-8}\ [\,(25082 + 8464 \sin\Theta)^2 + (8464\,(1 - \cos\Theta)\,)^2\,]$$

On leg RP413 to GPI22:

$$L = X_{cg} \qquad (X_{cg} \le 25082 \text{ ft.})$$

$$\text{RADL ERROR} = Y_{cg}$$

$$\text{VPOS ERROR} = Z_{cg} - 0.0524078\,X_{cg}$$

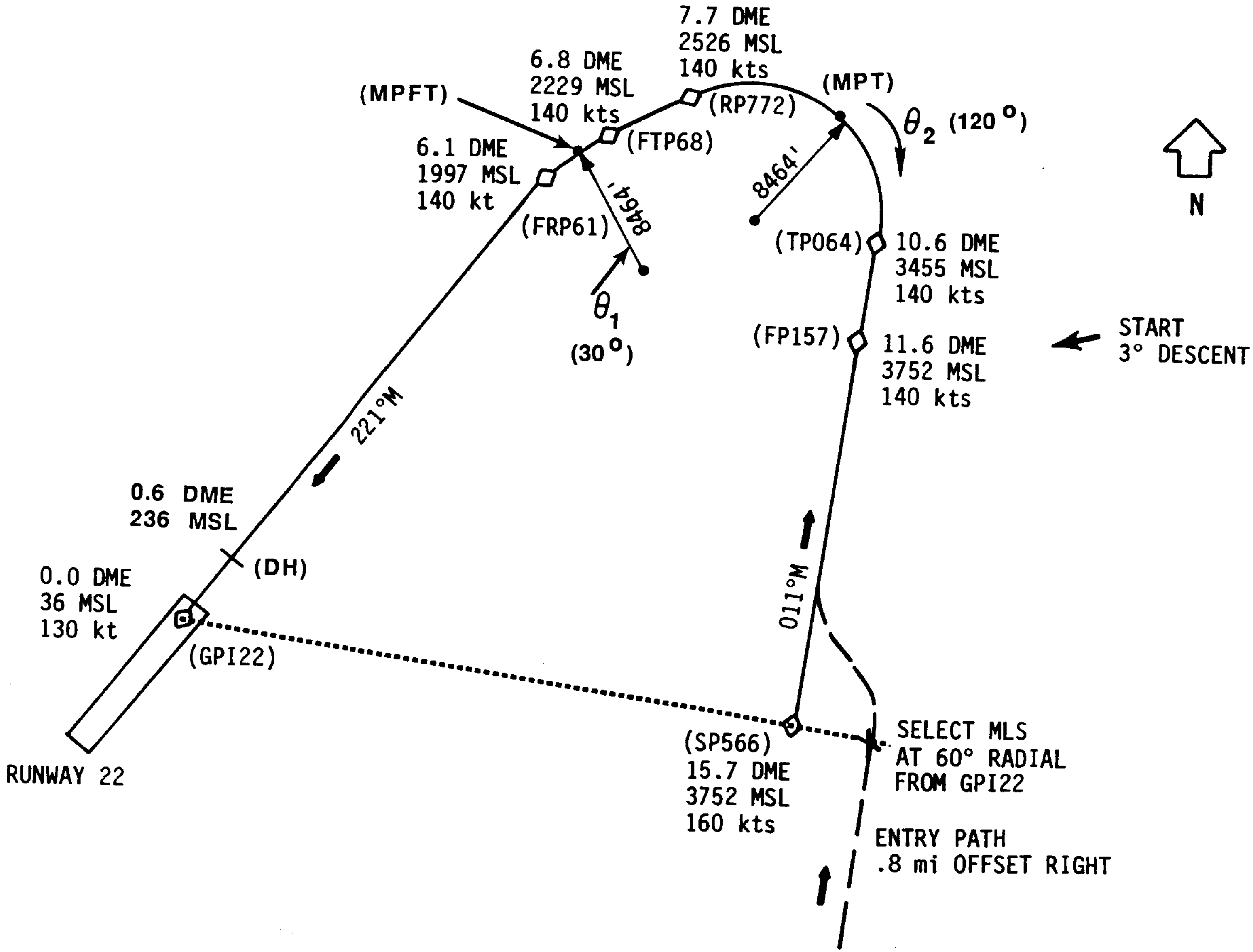


FIGURE C-6 - FLIGHT PATH DEFINITION FOR CP-131

TABLE C-6(A) - PATH DEFINITION AND WAYPOINT DATA FOR CP131

Waypoint	X	Y	Z*	h_{MSL}	L
	(all units in feet, referenced to GPI 22, Fig. C-6)				
GPI22	0	0	0	36	0
TCH	954	0	50	86	954
DH	3816	0	200	236	3816
FRP61	36809	0	1929	1997	36809
MPFT	39000	-288	2071	2113	39025
FTP68	41041	-1134	2153	2229	41241
RP772	45952	-3970	2439	2526	46912
MPT	50184	-11300	2891	2990	55776
TP064	45952	-18630	3360	3455	64639
FP157	41041	-21466	3648	3752	70310
SP566	19555	-33871	3679	3752	95120

*Height Calculations

For leg FRP61 to GP122:

$$h_{MSL} = X \tan 3^{o} \qquad \text{(or L Tan } 3^{o}\text{)}$$

Elsewhere, calculate Z from h_{MSL}:

$$Z = h_{MSL} - 36 - 2.39137067 * 10^{-8} (X^2 + Y^2)$$

In turn, FTP68 to FRP61:

$$h_{MSL} = 1997 + 232 \left(\frac{L-36809}{4432}\right)$$

On leg RP772 to FTP68:

$$h_{MSL} = 2229 + 297 \left(\frac{L - 41241}{5671}\right)$$

In turn, TP064 to RP772:

$$h_{MSL} = 2526 + 929 \left(\frac{L - 46912}{17727}\right)$$

On leg FP157 to TP064:

$$h_{MSL} = 3455 + 297 \left(\frac{L - 64639}{5671}\right)$$

On leg SP566 to FP157:

$$h_{MSL} = 3752 \text{ ft.}$$

TABLE C-6(B) - POSITION ERROR CALCULATION FOR CP131

(NOTE: All distances are in feet; Θ is in radians.)

On leg SP566 to FP157: $(95120 > L \geq 70310)$

$L = 95120 - H \cos(\phi_2 + 0.523599)$ (see Sketch 1 below)

$H = [(-33871 - Y_{cg})^2 + (X_{cg} - 19555)^2]^{1/2}$

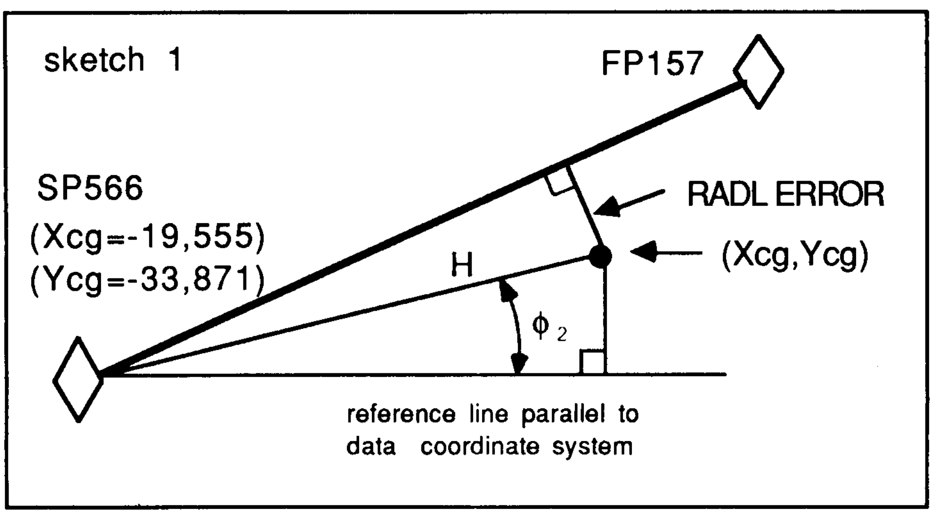
Calculate ϕ_2 for the off-axis, straight-line segment as follows:

$$\phi_2 = \tan^{-1}\left(\frac{-33871 - Y_{cg}}{X_{cg} - 19555}\right)$$

(Not valid for $X_{cg} \leq 19555$, but run should not start there anyway.)

RADL ERROR = $H \sin(\phi_2 + 0.523599)$

VPOS ERROR = $Z_{cg} - 3716 + 2.39137 * 10^{-8} [(41041 - 0.866025 (L - 70310))^2 + (-21466 - 0.5 (L - 70310))^2]$



On leg FP157 to TP064: $(70310 > L \geq 64639)$

(L and H as previously calculated.)

$$\text{RADL ERROR} = H \sin(\phi_2 + 0.523599)$$

$$\begin{aligned}\text{VPOS ERROR} = {} & Z_{cg} - 3419 - 0.0523717\,(L - 64639) + \\ & 2.39137 * 10^{-8}\ [\,(45952 - 0.866025\,(L - 64639)\,)^2 + \\ & (-18630 - 0.5\,(L - 64639)\,)^2\,]\end{aligned}$$

In turn #2, TP064 to RP772: $(64639 > L > 46912)$

$$L = 46912 + 8464\,\theta_2$$

$$\theta_2 = 1.570796 - \tan^{-1}\left(\frac{Y_{cg} + 11300}{X_{cg} - 41720}\right)$$

$$\text{RADL ERROR} = [\,(X_{cg} - 41720)^2 + (Y_{cg} + 11300)^2\,]^{1/2} - 8464$$

$$\begin{aligned}\text{VPOS ERROR} = {} & Z_{cg} - 2258 - 443.724\,\theta_2 + \\ & 2.39137 * 10^{-8}\ [\,(41720 + 8464 \sin\theta_2)^2 + \\ & (2836 + 8464\,(1 - \cos\theta_2))^2\,]\end{aligned}$$

On leg RP772 to FTP68: $(46912 \geq L \geq 41241)$

$$L = 46912 - H \cos \phi_1 \qquad \text{(see Sketch 2 below)}$$

$$H = [(-3970 - Y_{cg})^2 + (X_{cg} - 45952)^2]^{\frac{1}{2}}$$

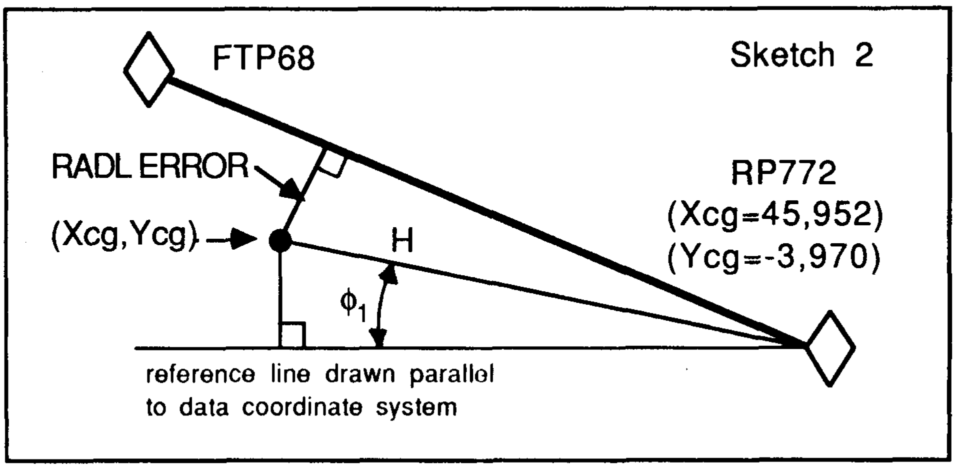
Calculate ϕ_1, for the off-axis, straight-line segment as follows:

$$\phi_1 = \tan^{-1}\left(\frac{-3970 - Y_{cg}}{X_{cg} - 45952}\right) - .523599 \qquad (X_{cg} < 45952)$$

$$\phi_1 = \tan^{-1}\left(\frac{X_{cg} - 45952}{+3970 + Y_{cg}}\right) + 1.047198 \qquad (X_{cg} > 45952)$$

$$\text{RADL ERROR} = H \sin \phi_1$$

$$\begin{aligned}\text{VPOS ERROR} = {} & Z_{cg} - 2193 - 0.0523717\,(L - 41241) + \\ & 2.39137 * 10^{-8}\,[\,(41041 + 0.866025\,(L - 41241)\,)^2 + \\ & (-1134 - 0.5\,(L - 41241)^2]\end{aligned}$$



In turn #1, FTP68 to FRP61: (41241 > L > 36809)

$L = 36809 + 8464\ \Theta_1$ (Final turn = 30° arc)

$$\Theta_1 = 1.570796 - \tan^{-1} \frac{Y_{cg} + 8464}{X_{cg} - 36809} \qquad (X_{cg} > 36809)$$

$$\text{RADL ERROR} = [\,(X_{cg} - 36809)^2 + (Y_{cg} + 8464)^2\,]^{1/2} - 8464$$

$$\text{VPOS ERROR} = Z_{cg} - 1961.4 - 443.724\ \Theta_1 + 2.39137 * 10^{-8}\,[\,(36809 + 8464 \sin \Theta_1)^2 + (8464\,(1 - \cos \Theta_1))^2\,]$$

On leg FRP61 to GPI22:

$L = X_{cg}$ ($X_{cg} \leq 36809$ ft.)

$\text{RADL ERROR} = Y_{cg}$

$\text{VPOS ERROR} = Z_{cg} - 0.0524078\ X_{cg}$

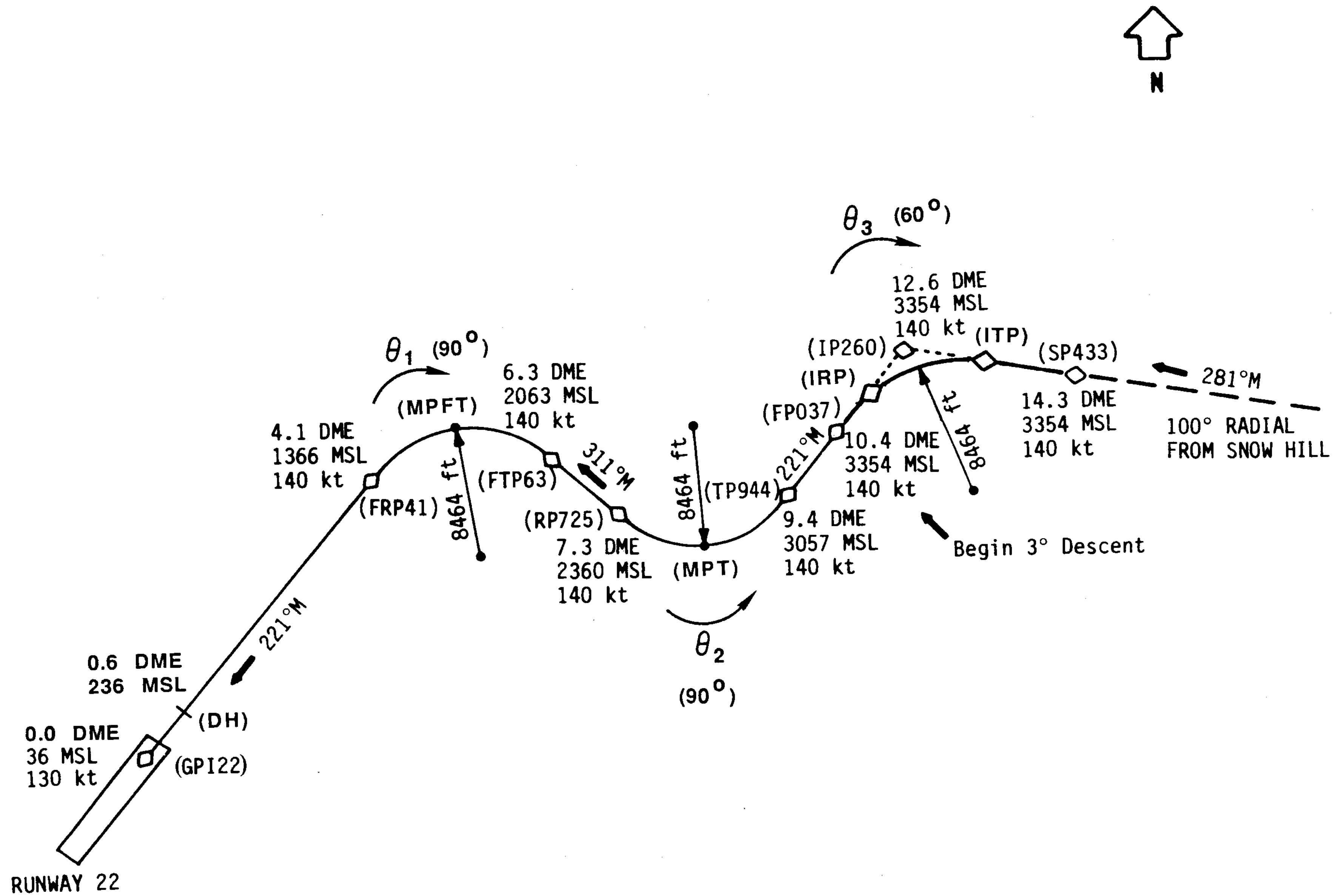


FIGURE C-7 - FLIGHT PATH DEFINITION FOR CP-S01

TABLE C-7(A) - PATH DEFINITION AND WAYPOINT DATA FOR CPS01

Waypoint	X	Y	Z*	h_{MSL}	L
	(all units in feet, referenced to GPI 22, Fig. C-7)				
GPI22	0	0	0	36	0
TCH	954	0	50	86	954
DH	3816	0	200	236	3816
FRP41	25082	0	1314	1366	25082
MPFT	31067	-5985	1654	1714	31730
FTP63	33546	-8464	1998	2063	38378
RP725	33546	-14135	2307	2360	44045
MPT	39531	-20120	2625	2708	50697
TP944	42010	-22599	2967	3057	57344
FP037	47681	-22599	3251	3354	63015
IRP	56795	-22599	3251	3354	72129
ITP	64125	-26831	3251	3354	80993

*<u>Height Calculations</u>

For leg FRP41 to GP122:

$Z = X \tan 3^{\circ}$ (or $L \tan 3^{\circ}$)

Elsewhere, calculate Z from h_{MSL}:

$$Z = h_{MSL} - 36 - 2.39137067 * 10^{-8} (X^2 + Y^2)$$

In turn, FTP63 to FRP41:

$$h_{MSL} = 1366 + 697 \left(\frac{\theta_1}{90}\right)$$ (θ_1 and θ_2 in degrees)

On leg RP725 to FTP63:

$$h_{MSL} = 2063 + 297 \left(\frac{L - 38378}{5671}\right)$$

In turn TP944 to RP725

$$h_{MSL} = 2360 + 697 \left(\frac{\Theta_2}{90}\right)$$

On leg FP037 to TP944:

$$h_{MSL} = 3057 + 297 \left(\frac{L - 57344}{5671}\right)$$

On leg SP433 to FP037:

$$h_{MSL} = 3354 \text{ ft.}$$

TABLE C-7(B) – POSITION ERROR CALCULATION FOR CPS01

(NOTE: All distances are in feet; Θ is in radians.)

On entry leg SP433 to ITP: (L > 80993)

$L = 80993 + H \cos \phi$ (see Sketch 3 below)

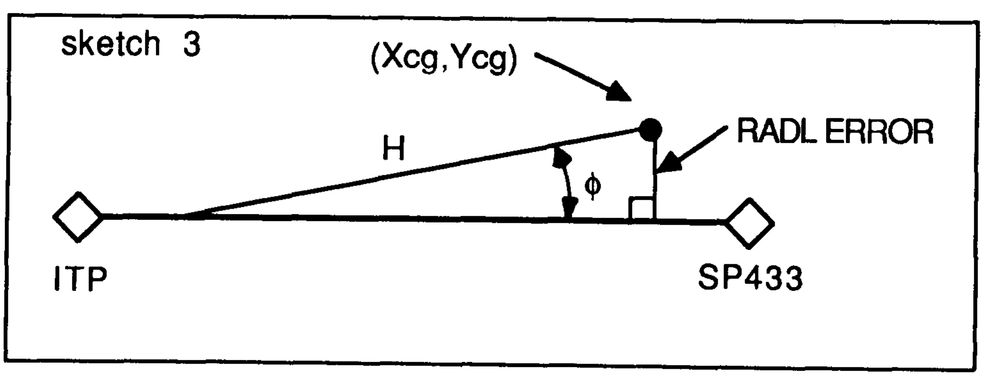
$$H = [\,(Y_{cg} + 26831)^2 + (X_{cg} - 64125)^2\,]^{\frac{1}{2}}$$

$$\phi = \tan^{-1}\left(\frac{Y_{cg} + 26831}{X_{cg} - 64125}\right) + 1.047198 \qquad (X_{cg} > 64125)$$

$$\phi = \tan^{-1}\left(\frac{64125 - X_{cg}}{Y_{cg} + 26831}\right) - 0.5235988 \qquad (X_{cg} < 64125)$$

$\text{RADL ERROR} = H \sin \phi$

$$\text{VPOS ERROR} = Z_{cg} - 3318 + 2.39137 * 10^{-8}\,[\,(64125 + 0.5\,(L - 80993)\,)^2 + (26831 + 0.866025\,(L - 80993)\,)^2]$$



In entry turn, ITP to IRP: $(80993 > L > 72129)$

$$L = 72129 + 8464\ \Theta_3 \qquad (\Theta_3 = 60^{\circ} \text{ max, total turn})$$

$$\Theta_3 = 1.570796 - \tan^{-1}\left(\frac{Y_{cg} + 31063}{X_{cg} - 56795}\right) \qquad (X_{cg} > 56795)$$

$$\text{RADL ERROR} = [\,(X_{cg} - 56795)^2 + (Y_{cg} + 31063)^2]^{\frac{1}{2}} - 8464$$

$$\text{VPOS ERROR} = Z_{cg} - 3318 + 2.39137 * 10^{-8}\,[\,(56795 + 8464 \sin\Theta_3)^2 + (22599 + 8464\,(1 - \cos\Theta_3))^2]$$

On leg IRP to FP037: $(72129 > L > 63015)$

$$L = 15334 + X_{cg} \qquad (X_{cg} > 47681)$$

$$\text{RADL ERROR} = Y_{cg} + 22599$$

$$\text{VPOS ERROR} = Z_{cg} - 3305 + 2.39137 * 10^{-8}\ X_{cg}^{\ 2}$$

On leg FP037 to TP944: $(63015 > L > 57344)$

$$L = 15334 + X_{cg} \qquad (X_{cg} \geq 42010)$$

$$\text{RADL ERROR} = Y_{cg} + 22599$$

$$\text{VPOS ERROR} = Z_{cg} - 808.7 - 0.0523717\ X_{cg} + 2.39137 * 10^{-8}\ X_{cg}^{\ 2}$$

In turn #2, TP944 to RP725: $(44045 > L < 57344)$

$$L = 57344 - 8464\,\Theta_2$$

$$\Theta_2 = 4.712389 + \tan^{-1}\left(\frac{Y_{cg} + 14135}{42010 - X_{cg}}\right) \qquad \begin{cases} X_{cg} < 42010 \text{ (start)} \\ Y_{cg} \leq -14135 \text{ (end)} \end{cases}$$

$$\text{RADL ERROR} = 8464 - [(X_{cg} - 42010)^2 + (Y_{cg} + 14135)^2]^{\frac{1}{2}}$$

$$\text{VPOS ERROR} = Z_{cg} - 4415 + 443.724\,\Theta_2 + 2.39137 * 10^{-8}$$
$$[(42010 + 8464 \sin\Theta_2)^2 + (-14135 + 8464 \cos\Theta_2)^2]$$

On leg RP725 to FTP63: $(44045 > L > 38378)$

$$L = 29914 - Y_{cg} \qquad (Y_{cg} \leq -8464)$$

$$\text{RADL ERROR} = X_{cg} - 33546$$

$$\text{VPOS ERROR} = Z_{cg} - 1556 + 0.0523717\,Y_{cg} + 2.39137 * 10^{-8}\,Y_{cg}^2$$

In turn #1, FTP63 to FRP41: $(38378 \geq L \geq 25082)$

$$L = 25082 + 8464\,\Theta_1$$

$$\Theta_1 = 1.570796 - \tan^{-1}\left(\frac{Y_{cg} + 8464}{X_{cg} - 25082}\right) \qquad (X_{cg} > 25082)$$

$$\text{RADL ERROR} = [\,(X_{cg} - 25082)^2 + (Y_{cg} + 8464)^2\,]^{\frac{1}{2}} - 8464$$

$$\text{VPOS ERROR} = Z_{cg} - 1329 - 443.724\,\Theta_1 + 2.39137 * 10^{-8}\ [\,(25082 + 8464 \sin\Theta_1)^2 + (8464\,(1 - \cos\Theta_1)\,)^2\,]$$

On leg FRP41 to GPI22:

$$L = X_{cg} \qquad (X_{cg} \leq 25082 \text{ ft.})$$

$$\text{RADL ERROR} = Y_{cg}$$

$$\text{VPOS ERROR} = Z_{cg} - 0.0524078\,X_{cg}$$

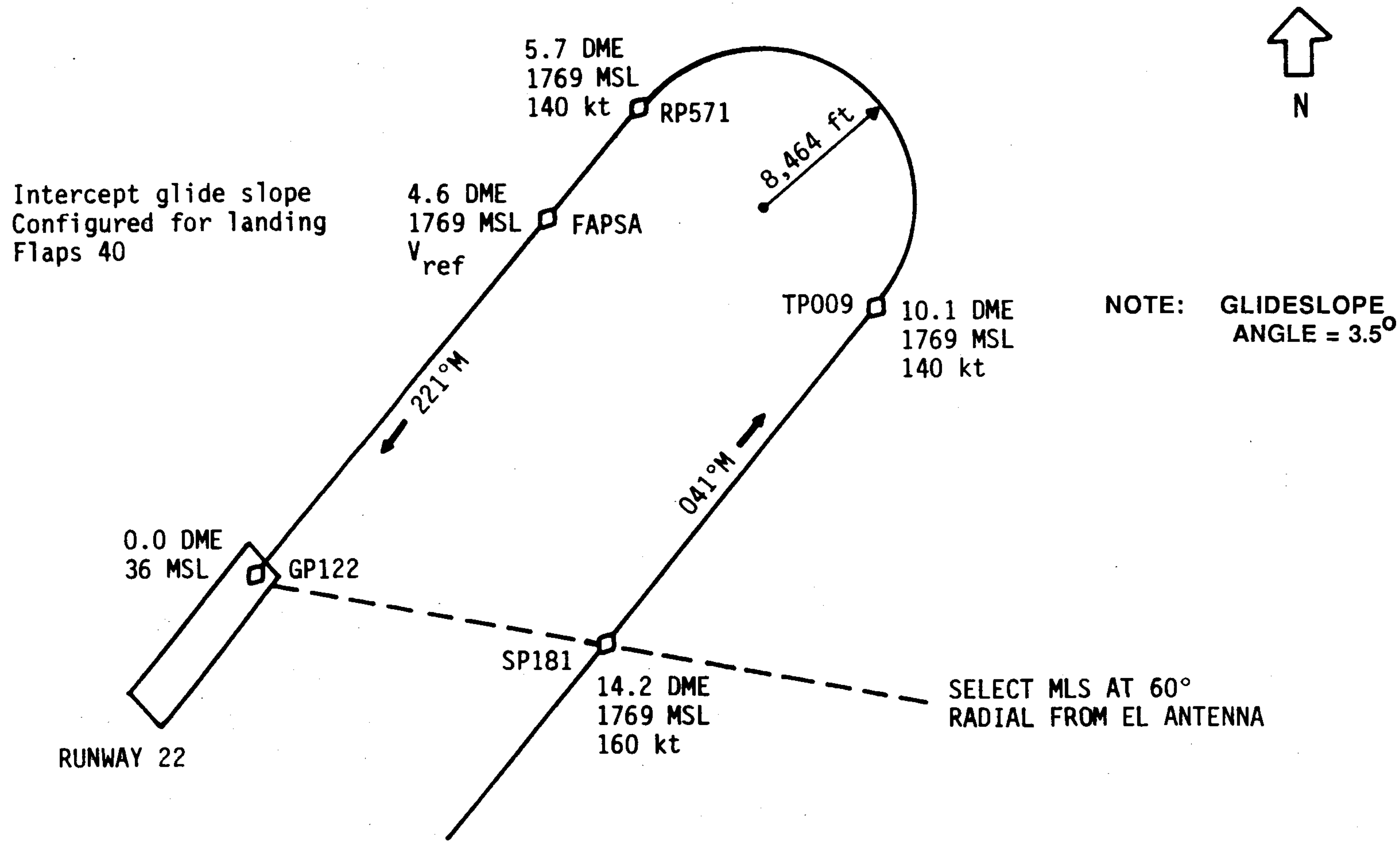


FIGURE C-8 - STEEP ANGLE FLIGHT PATH DEFINITION FOR SGS35

(see position error equations per CP-182)

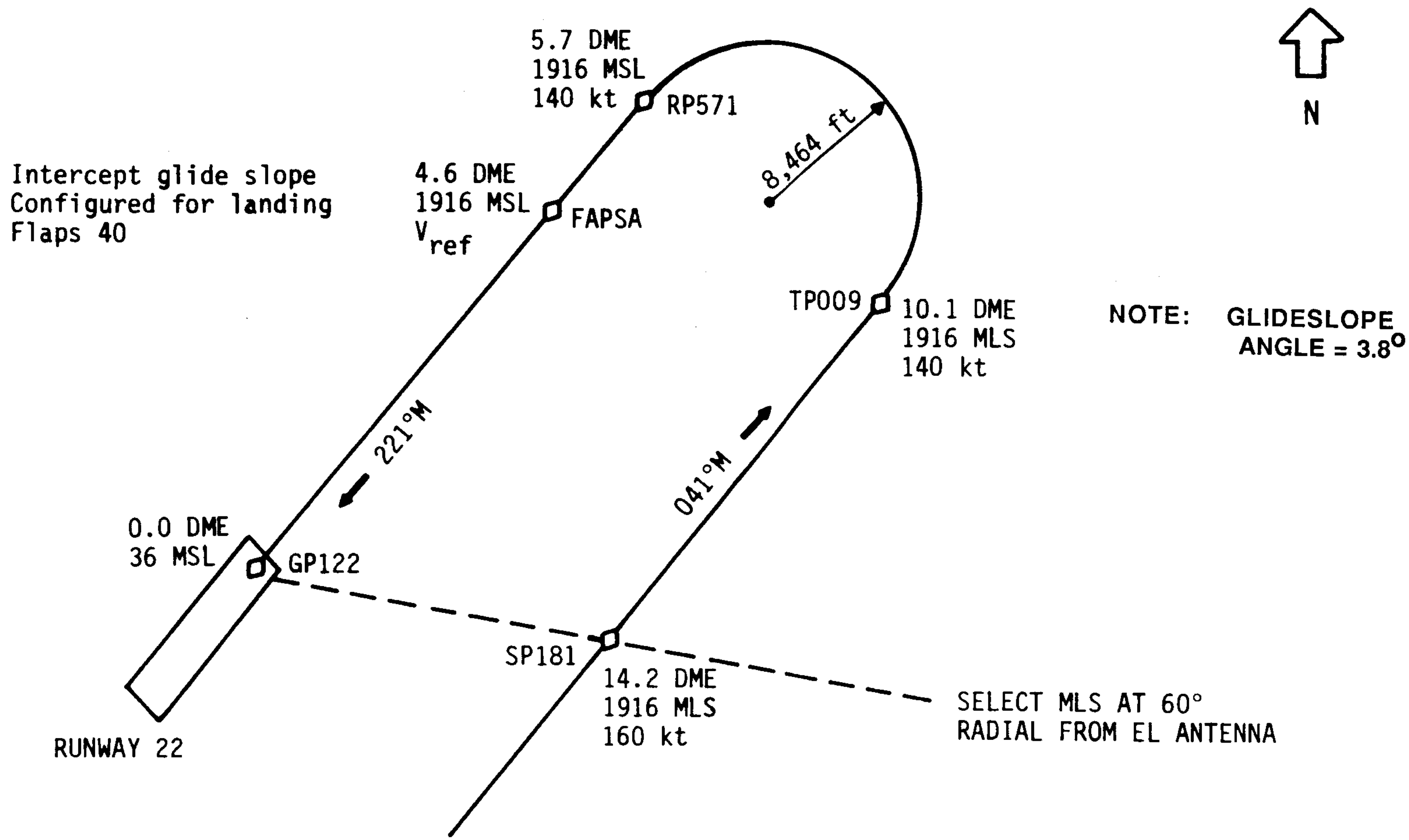


FIGURE C-9 - STEEP ANGLE FLIGHT PATH DEFINITION FOR SGS38

(see position error equations per CP-182)

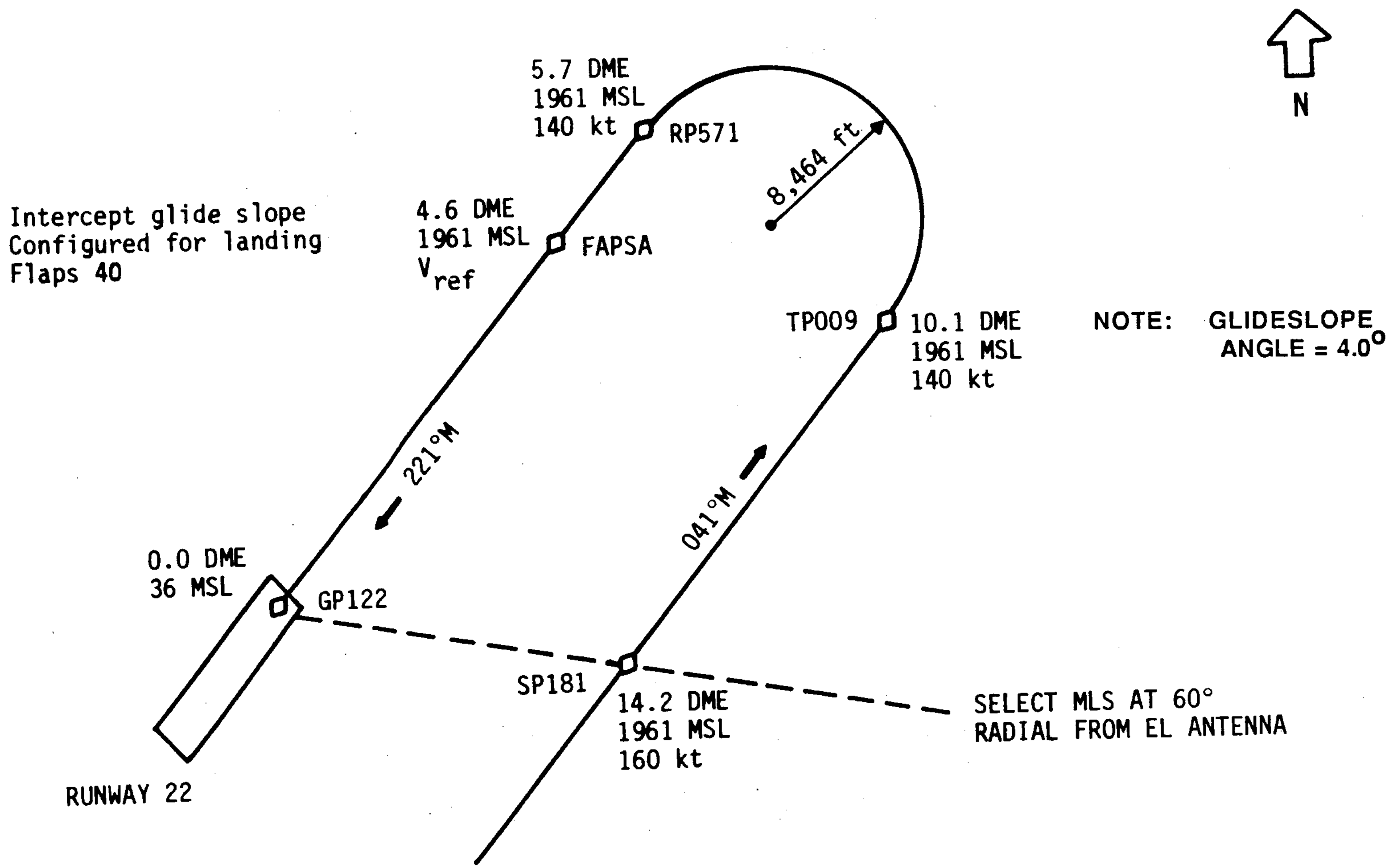


FIGURE C-10 - STEEP ANGLE FLIGHT PATH DEFINITION FOR SGS40

(see position error equations per CP-182)

APPENDIX D

ARCHIVED DATA TAPE LIST

The following document lists (by number and content) the tapes containing merged data for curved-path and steep-angle approaches that are archived in the NASA Langley tape library.

MEMORANDUM

DATE: 24 April 1985
MEMO NO. DRD-85-30

TO: J. Branstetter, FAA

FROM: S. Paulson

SUBJECT: List of STEP Nine Track Data Tapes - Merged Data

NK0580	"STEP - Profile 4.0 DH to 1000"
NK0539	"STEP - Profile 3.8 DH to 1000"
NK0535	"STEP - Profile 3.5 DH to 1000"
NK1048	"STEP - Profile 3.0 DH to LAND"
NK1035	"STEP - Profile 3.8 DH to LAND"
NK1149	"STEP - Profile 3.5 DH to LAND"
NX0919	"STEP - Profile 4.0 to DH"
NA0635	"STEP - Profile 3.8 to DH"
NE1288	"STEP - Profile 3.5 to DH"
NF1005/NN1070/NN1120	"CP181 - all runs"
NP0920/NR1017/NR1042	"CP182 - all runs"
NB0887/NB0987/NC0383	"CP183 - all runs"
NL1116/NL1121/NJ0137	"CP901 - all runs"
NG0139/NG0407	"CP902 - all runs"
NJ0871/NJ0873/NJ0875	"CP131 - all runs"
NF0419/NF0571/NF0671	"CPS01 - all runs"

Sharon S. Paulson
SSP:smp

APPENDIX D

SAMPLE RECORD FROM TRANSMITTAL TAPE SHOWING FORMAT

```
W     1    55555555555555555534 55555555555555553434 01241720235506142455 22463644345515052207 05552225165534440215 55555555555555555555
                              1                        1 1  A T O P S   F L T    R - 3 9 1    M E R G  F   R U N    1 9 8 M
W     7    55555555555555555555 55555555555555555555 55555555555555555555 55555555555555555555 55555555555555555555 55555555555555555555

FILE    1  RECORD       2  WAS READ IN ASCII/BCD MODE AND CONTAINS     12 WORDS
                           THE UNUSED BIT COUNT IS  0

W     1    55555555555555555555 24111505555555555555 26201723550522221722 22010414550522221722 26052224550405265555 14012455040526555555
                                  T I M E                V P O S   E R R O R  R A D L   E R R O R  V E R T   D E V        L A T   D E V
W     7    03075531555555555555 03075532555555555555 04112324552417550717 14162305555555555555 26162305555555555555 04052355201711162456
            C G   Y                C G   Z              D I S T   T O   G O  L N S F                 V N S E                D E S   P O I N T

FILE    1  RECORD       3  WAS READ IN ASCII/BCD MODE AND CONTAINS     12 WORDS
                           THE UNUSED BIT COUNT IS  0

W     1    55555555555555555555 23050323555555555555 06050524555555555555 06050524555555555555 06050524555555555555 06050524555555555555
                                  S E C S              F E E T              F E E T              F E E T              F E E T
W     7    06050524555555555555 06050524555555555555 15052405222355555555 06050524555555555555 06050524555555555555 15052405222355555555
            F E E T                F E E T              M E T E R S          F E E T              F E E T              M E T E R S

FILE    1  RECORD       4  WAS READ IN ASCII/BCD MODE AND CONTAINS     12 WORDS
                           THE UNUSED BIT COUNT IS  0

W     1    55555557423534433536 33054533405555555734 36344442373505453335 55555557413540353736 35054533375555465740 40333333333305453336
              . 7 2 1 8 2 3   0 E + 0 5        . 1   3 1 9 7 4 2 E + 0 2          . 6 2 5 2 4 3   2 E + 0 4      - . 5   5 0 0 0 0 0 E + 0 2
W     7    55555557344135413333 33054533375555465736 35444136374105453340 55555557364143434244 40054533375555555735 40343643403305453340
              . 1 6 2 6 0 0   0 E + 0 4      - . 3   2 9 6 3 4 6 E + 0 5          . 3 6 8 8 7 9   5 E + 0 4      . 2   5 1 3 8 5 0 E + 0 0

FILE    1  RECORD       5  WAS READ IN ASCII/BCD MODE AND CONTAINS     12 WORDS
                           THE UNUSED BIT COUNT IS  0

W     1    55555557374135413736 35054533375555555740 41363444423705453336 55555557354034373343 33054533405555555555 55555555555555555555
              . 4 6 2 6 4 3   2 E + 0 4        . 5   6 3 1 9 7 4 E + 0 3          . 2 5 1 4 0 8   0 E + 0 5
W     7    55555555555555555555 55555555555555555555 55555555555555555555 55555555555555555555 55555555555555555555 55555555555555555555

FILE    1  RECORD       6  WAS READ IN ASCII/BCD MODE AND CONTAINS     12 WORDS
                           THE UNUSED BIT COUNT IS  0

W     1    55555557423534433634 33054533405555555735 36373634413505453335 55555557413436354340 43054533375555465740 40333333333305453336
              . 7 2 1 8 3 1   0 E + 0 5        . 2   3 4 3 1 6 2 E + 0 2          . 6 1 3 2 8 5   8 E + 0 4      - . 5   5 0 0 0 0 0 E + 0 2
W     7    55555557344136373333 33054533375555465736 35424244343605453340 55555557364144434436 34054533375555555735 40334344354105453340
              . 1 6 3 4 0 0   0 E + 0 4      - . 3   2 7 7 9 1 3 E + 0 5          . 3 6 9 8 9 3   1 E + 0 4      . 2   5 0 8 9 2 6 E + 0 0
```

APPENDIX E

TRANSMITTAL DATA TAPE LIST

The following documents describe the content and format of the tapes, containing the 50-meter interval statistics, delivered to the FAA Office of Aviation Standards.

MEMORANDUM

DATE: 06 May 1985
MEMO NO.: DRD-85-33

TO: Jim Branstetter, FAA

FROM: S. Paulson, SDC

SUBJECT: Tape Format for STEP 50 meter interval tapes - DH to land, DH to go around, DH to low approach.

1. The transmittal tapes were generated on a Control Data Corporation 750 computer using a NOS 1.4 operating system.

2. The following tape format and record manager options were used to write the tapes.

   (a) 9-track, 1/2-inch magnetic tape

   (b) Density, 6250 CPI

   (c) Odd parity, ASCII

   (d) 80-character records

   (e) Unlabelled

   (f) Unblocked - one line image record per block

   (g) 0.60-Inch inter-record gap

   (h) One EOF between each file; two EOF's at end of data

SSP

SSP:smp

Attachment

LIST OF 50 METER INTERVAL TAPES

TAPE NAME	CONTENTS
181DHL	CP181 - 50 meter intervals DH to land
181DHG	CP181 - 50 meter intervals DH to go around
50DHLD	CP182 - 50 meter intervals DH to land
50DHLA	CP182 - 50 meter intervals DH to low approach
50DHGA	CP182 - 50 meter intervals DH to go around
83DHLD	CP183 - 50 meter intervals DH to land
83DHLA	CP183 - 50 meter intervals DH to low approach
83DHGA	CP183 - 50 meter intervals DH to go around
91DHLD	CP901 - 50 meter intervals DH to land
91DHLA	CP901 - 50 meter intervals DH to low approach
91DHGA	CP901 - 50 meter intervals DH to go around
92DHLD	CP902 - 50 meter intervals DH to land
92DHLA	CP902 - 50 meter intervals DH to low approach
92DHGA	CP902 - 50 meter intervals DH to go around
31DHLA	CP131 - 50 meter intervals DH to low approach
31DHLD	CP131 - 50 meter intervals DH to land
31DHGA	CP131 - 50 meter intervals DH to go around
S1DHLA	CPS01 - 50 meter intervals DH to low approach
S1DHLD	CPS01 - 50 meter intervals DH to land
S1DHGA	CPS01 - 50 meter intervals DH to go around

DATE: 3 March 1986

MEMORANDUM

MEMO NO.: DRD-86-13

TO: Jim Branstetter, FAA

FROM: S. S. Paulson, R. S. Thompson, SDC

SUBJECT: Tape Format for STEP 50 meter interval tapes - STEEP ANGLE - to DH, DH to Land, DH to 1000.

1. The transmittal tape was generated on a Control Data Corporation 750 computer using a NOS 2.3 Operating System.

2. The following tape format and record manager options were used to write the tapes.

   (a) 9-track, 1/2 inch magnetic tape

   (b) Density - 1600 CPI

   (c) Odd parity - ASCII

   (d) 80-character records

   (e) Unlabelled

   (f) Unblocked - one line image record per block

   (g) 0.60-Inch inter-record gap

   (h) One EOF between each file; two EOF's at end of data

SSP:smp

Attachment

LIST OF 50 METER INTERVAL TAPES
STEP - STEEP ANGLE FLIGHTS

TAPE NAME	CONTENTS
DH4050 DH405A DH405B	-Profile 4.0 -to DH -Runs 7WA-4WA, 13PM-16PM, 17RW, 1RB-4RB, 9DS-12DS, 25BM-28BM, 5RW-7RW, 12LM-15LM, 6JR-9JR.
DH3850 DH385A DH385B	-Profile 3.8 to DH -Runs 5WA-8WA, 21PM-24PM, 5RB-8RB, 13DS-16DS, 29BM-32BM, 8RW-11RW, 16LM-18LM, 10JR-14JR.
DH3550 DH355A DH355B	-Profile 3.5 to DH -Runs 9WA-12WA, 17RB-20RB, 33BM-36BM, 15LM-22LM, 23RW-30RW, 31JR-34JR.
DH1K40	-Profile 4.0 DH to 1000 -Runs 1WA, 3WA, 13PM, 15PM, 1RB, 3RB, 9DS, 11DS, 25BM-27BM, 6RW, 14LM, 6JR, 9JR.
DH1K38	-Profile 3.8 DH to 1000 -Runs 5WA, 7WA, 21PM, 23PM, 5RB, 7RB, 13DS, 15DS, 29BM-31BM, 8RW, 11RW, 17LM, 10JR, 12JR, 14JR.
DH1K35	-Profile 3.5 DH to 1000 -Runs 9WA, 11WA, 17RB, 19RB, 33BM, 35BM, 15LM-16LM, 18LM, 20LM, 23RW, 25RW, 29RW, 30RW, 32JR, 33JR.
DHLA40	-Profile 4.0 DH to LAND -Runs 2WA, 4WA, 14PM, 16PM, 17PM, 2RB, 4RB, 10DS, 12DS, 28BM, 5RW, 7RW, 12LM, 13LM, 15LM, 7JR, 8JR.
DHLA38	-Profile 3.8 DH to LAND -Runs 6WA, 8WA, 22PM, 24PM, 6RB, 8RB, 14DS, 16DS, 32BM, 9RW, 10RW, 16LM, 18LM, 11JR, 13JR.
DHLA35	-Profile 3.5 DH to LAND -Runs 10WA, 12WA, 18RB, 20RB, 34BM, 36BM, 17LM, 19LM, 21LM, 23LM, 24RW, 26RW-28RW, 31JR, 34JR.

NASA
National Aeronautics and Space Administration

Report Documentation Page

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15. Supplementary Notes

J. R. Branstetter - FAA Langley Engineering Field Office, Hampton, Virginia.
W. F. White - NASA Langley Research Center, Hampton, Virginia.

16. Abstract

A series of flight tests were conducted jointly by the FAA and NASA to collect data for jet transport aircraft flying curved-path and steep-angle approaches using MLS guidance.

During the test, 432 approaches comprising seven different curved-paths and four glidepath angles varying from 3° to 4° were flown in NASA Langley's Boeing 737 (TSRV) aircraft using an MLS ground station at the NASA Wallops Flight Facility. Subject pilots from Piedmont Airlines flew the approaches using conventional cockpit instrumentation (flight director and HSI). The data collected will be used by FAA procedures specialists to develop standards and criteria for designing MLS terminal approach procedures (TERPS).

The use of flight simulation techniques greatly aided the preliminary stages of approach development work and saved a significant amount of costly flight time.

This report is intended to complement a data report to be issued by the FAA Office of Aviation Standards which will contain all detailed data analysis and statistics.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
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