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FLIGHT EVALUATION OF THE TERMINAL GUIDANCE SYSTEM

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INTRODUCTION

The operation of aircraft in a terminal area has been studied recently with the objective of identifying and finding solutions to the problems associated with heavy traffic maneuvering in limited airspace. Presently, aircraft arriving in a terminal area are vectored along a straight, shallow flight path to a landing. These approach paths are frequently over congested metropolitan areas and result in noise pollution and increased hazards both to people in the aircraft and on the ground. The approaches are long and require considerable time and use of fuel as well as necessitate an inefficient mix of low and high speed traffic. In some cases, terrain prevents straight-in approaches with shallow glideslopes. Therefore, the need has long existed for an alternative to the shallow-glide, straight-in approach.

The recent introduction of STOL aircraft into service creates new and magnifies old operational problems. These aircraft which are capable of providing increased commercial transport between large cities will be required to operate in limited, nonallocated airspace penetrated by tall buildings where noise pollution is particularly objectionable. A large number of terminal operations is required of the STOL aircraft for it to be economically viable, and speed incompatibility with CTOL aircraft causes delays and congestion.

The recommended use of curved steep approaches to solve or alleviate these problems has been made in many of the studies conducted.

Steep, curved approaches permit the routing of traffic around or, at relatively high altitudes, over critically populated areas and tall objects and reduce noise pollutions. A more efficient mix of slow and high speed traffic (see Figure 1) can be obtained with improved airspace utilization in the terminal area. More direct routing is also possible using curved approaches resulting in both reduced fuel costs and travel time.

Guidance along a descending curved path can be achieved with the microwave landing system. A great deal of time and money has been spent on studies, plans-development, hardware production, and flight tests to identify operation problems and evaluate the system. The microwave landing system should be operation by the mid-1980's.

The Langley and Dryden Flight Research Centers of NASA have conducted flight tests and studies designed to obtain a better understanding of problems associated with curved approaches. In 1971, the Dryden Flight Research Center (DFRC) conducted a flight test to investigate the feasibility of flying IFR curved landing approaches. These tests utilized a twin-engine, general aviation aircraft with a ground-based radar, computer, and transmitter in an arrangement shown in Figure 2. The aircraft's position was measured by radar. The approach geometry was stored in the computer where a comparison between the aircraft's position and a set of preprogrammed coordinates corresponding to the curved approach corridor was made and position errors generated. Flight path errors were transmitted to the aircraft through a data uplink and displayed on an ILS indicator. These tests led to the development of a system contained onboard the aircraft called the

Terminal Guidance System (TGS) which also gives guidance along a descending flight path to landing, but uses only the ground based VOR/DME station. The TGS was patented by DFRC and fabricated by Progress Aerospace Enterprises, Inc. A grant was made to the Cal Poly Foundation at San Luis Obispo for the flight evaluation of TGS.

The objectives of the evaluation were to:

1. Compare ILS straight-in and TGS curved approaches.

2. Determine the effects of pattern geometry on system performance.

3. Determine the effects of wind and turbulence on system performance.

4. Determine the effects of pilot experience on system operation.

The purpose of this report is to present the results of the flight evaluations.

TEST EQUIPMENT

The TGS consists of an analog computer unit with a control head. The computer is connected to the altimeter, RMI, DME, and gyro compass. Since the aircraft electrical system provides 12 volts dc and the altimeter requires 28 volts dc, a 28 v dc power supply was required. A 28 to 15 volt dc to dc converter was needed to provide power for the analog amplifiers in the circuit of the computer. In addition, a small amount of 26v 400 HZ synchro power was needed for the synchro converter references of the Gyro Compass and RMI, and also for an internal function module.

The TGS and the associated support equipment was connected as shown in the block diagram given in Figure 3. The equipment was installed in the Cessna 182 aircraft shown in Figure 4. Figure 5 shows the placement of the computer on the floor of the aircraft behind the right front seat. Figures 6 and 7 show the placement of the control head on the instrument panel.

Terminal Guidance System

The Terminal Guidance System is a vehicle-borne navigation approach guidance computer which gives guidance along a curved descending flight path to a termination point over a VOR/DME Station. The aircraft arrives over the terminal point on a selected heading and altitude by flying along the surface of an inverted imaginary cone half-angle of $90^o - \theta_{des}$, where θ_{des} is the guideslope angle selected by the pilot. The system consists of a computer, control head, and the support avionics. The support avionic includes an altimeter, DME, gyrocompass, and RMI which provides aircraft positional data in three-dimensional space. The termination point heading, altitude, and a wind correction angle are selected on the control head and are also provided as inputs to the computer.

The computer provides an analog solution in the form of heading and glideslope error angles by solving the following equations:

1. $\theta_{eh} = 2\theta_{vor} - \theta_{gyro} - \theta_{rw} \pm \theta_{wc} \pm 360^o$.

   θ_{rw} = magnetic runway heading selected on control head.

   θ_{wc} = wing correction angle selected on control head.

   θ_{gyro} = magnetic heading of aircraft obtained from gyrocompass.

θ_{vor} = magnetic bearing of aircraft from station obtained from RMI.

θ_{eh} = heading error which is the difference between the aircraft heading and the tangent to the optimal flight path. See Figure 8.

2. $$\theta_{eg} = \theta_{des} - \text{arctangent} \frac{(h - h_t)}{d^2 - h^2} .$$

θ_{des} = glideslope angle selected on control head.

h = absolute altitude obtained from the altimeter.

h_t = desired altitude over the termination point selected on the control head.

d = slant range distance from the aircraft to VOR/DME Station obtained from DME.

θ_{eg} = glideslope error which is the difference between the selected and actual glideslope angles as shown in Figure 9.

Either these error signals or the signals plus their differential are displayed on an indicator similar to an ILC indicator. The option of including the differential term is provided to minimize pilot overshoot. If the pilot flies the aircraft so that the two needles are centered, the error angles will be equal to zero, and the aircraft will fly along the desired flight path arriving over the termination point on the selected heading and altitude. This system used in conjunction with an R/NAV system which permits the offsetting of the VOR/DME Station can be used to fly curved approaches to a landing on any airfield in the vicinity of a VOR/DME Station. For a more complete system description see Reference 6.

Support Avionics

The avionics necessary to the TGS includes an altimeter, RMI, DME and Gyro Compass. A list of the types of support avionics used follows:

1. Altimeter-Datametrics - Model 1300 Pressure Transducer: This altimeter provides 0 ± 5 VDC for 0-15 psi. For standard pressure at 0 ft. mean sea level, an output of 4.847 VDC will result. At an altitide of 5000 feet, an output of 3.916 VCD will result and a linear variation between these altitudes is assumed. A modification of the TGS circuitry was made to include a null system. This system will allow adjustments to account for prevailing barometric conditions and different airfield elevations.

2. DME - King Kn 65: The DME provides nominal voltages of 0.000 to 0.400 VDC for a distance of 0 to 10 nautical miles. Since the TGS was designed for use with a King Kn 60 which provides different nominal voltages, it was necessary to modify the TGS circuitry so the Kn 65 could be used.

3. Gyro Compass - Narco HSI-100S.

4. RMI - King KNR 660 VOR/LOC Receiver.

Data Recording System

Data was recorded on each run by the safety pilot using the Cooper rating system. For several approaches, a portable strip chart recorder was used to record the heading and glideslope error signals. The results obtained were not satisfactory, so a new data recording system which records four times a second was fabricated and installed for fifteen approaches using two different pilots. Figure 10 shows a schematic of the data recording system which essentially consists of an intel SDK-80 microcomputer, a multiplexer, and an audio tape recorder. The synchro outputs of the gyro compass and RMI are converter to D.C. voltages using a synchro to D.C. converter. These two voltages plus the D.C. voltage output of the altimeter and DME were recorded on tape. In addition, the voltage outputs of the computer, which are the heading and glideslope error signal, were recorded.

TEST DESCRIPTION

Curved approach patterns with 0^{o}, 90^{o}, and 180^{o} turns were flown as shown in Figure 11. A turn radius of one nautical mile was used for the 0^{o} and 90^{o} turn approaches. Nominal turn radii of 557 meters (1500 ft.), 414 meters (3000ft.) and 1833 meters (6000 ft.) were used for the 180^{o} turn approaches. For most of the approaches, a turn of 180^{o} was used since there was no significant difference in the approaches of different angles except length of time spent on the flight path. Approach entry was made using a combination of ground check points and the VOR/DME display. Glideslope angles of from 3^{o} to 9^{o} were used, and three pilots with instrument flying time from 200 to 600 hours flew graded approaches. Wind directions were directly opposite and 90^{o} cross wind to the termination heading with velocities varying from 0 - 20 knots. Turbulence varied from calm to moderate. Four different VOR/DME stations were used. Most flights were made under simulated instrument conditions wtih a safety pilot to record data and spot other aircraft. A data recorder that records on magnetic tape all inputs to and outputs from the TGS computer was used for fifteen approaches. All approaches were made at 90 mph indicated air speed and several flap settings were used to determine preferred aircraft configuration.

The glideslope error needle becomes extremely sensitive and difficult to follow when within 1/2 m. DME distance from the station.

To eliminate the need to track the glideslope when very near the station, minimum altitudes of 200 ft. for 3^{o} and 400 ft. for 6^{o} glideslopes were established. The altitude minimums allowed pilots to discontinue tracking the glideslope at approximately 1/2 n.m. from the station. This is less than the distance between the ILS glideslope signal generator and the point where it is no longer necessary to track the glideslope. Usually, the ILS glideslope signal generator is placed on the end of the runway opposite touchdown. The localizer needle was tracked without difficult until over the station.

See Figure 12 for recapitulation of approaches flown.

RESULTS AND DISCUSSION

The results of the TGS flight evaluation program are included in Figures 14 to 42. The Cooper rating system shown in Figure 13 was used by the pilot to rate each approach, and the safety pilot evaluated the ride quality. Fifteen approaches were made using the package that recorded on tape all inputs to and outputs from the computer. The tapes were inserted into a computer graphics system, and graphs were made of the actual flight path in space. A computer program was written to construct the zero-error, no-wind flight path, and the two paths were graphically superimposed for easy comparison. An overhead flight path projection was made as were graphs showing glideslope and heading errors as functions of DME distance. The DME signal to the TGS contained considerable noise as shown in Figures 22, 23, and 24. It was necessary to smooth this data using a least square curve fitting technique before the data could be used for the graphs. Several of the resulting graphs are shown in Figures 24 through 42.

Comparison of Straight-In ILS and Curved Approaches

Figure 14 presents a comparison of pilot ratings for curved and straight ILS approaches with the turbulence level varying from light to moderate. The ILS approaches were flown by pilots at the DFRC and this data is published in Reference 6. All approaches recorded in Figure 14 were flown by the same pilot. A glideslope of 6^{o}, and a turn radius of 1833 meters, and a turn of 180^{o} was used for the curved approaches since they were not significantly more difficult to perform than the 3^{o} glideslope approaches for this particular pilot. Figures 27, 30, 33, 36, and 38 show flight data that reveal how accurately the glideslope and heading guidance can be tracked for several different turn radii and glideslopes.

The conclusion drawn from this data is that curved approaches of the type flown are no more difficult to fly than straight ILS approaches.

Effect of Pattern Geometry

Approaches were flown to determine the effect of varying turn radius, glideslope, and turn angle. Figure 15 compares the pilot ratings for approaches using 180^{o} turns, 6^{o} glideslope, varying turbulence level, and turn radii of 457, 914, and 1853 meters respectively. These approaches were all flown by one pilot who had 500 hours of instrument flying time and was the most experiences with the TGS. Although several approaches were flown using a turn radius of 457 meters of 1/4 n.m., approaches that start within 1/2 n.m. of the station are impractical since the published accuracy of the DME equipment used is $\pm$ 1/2 n.m.

Figures 25 through 33 are graphs constructed from flight data which show a 3^{0} glideslope, a 180^{0} turn, a light-to-moderate turbulence, a tailwind at entry of 10-20 knots, and turn diameters of 5345, 7743, and 12570 feet respectively. Inspection of the graphs of glideslope and heading error along with Cooper rating indicate that a turn radius of approximately 1/2 n.m. with a glideslope of 3^{0} can be flown satisfactorily.

Figures 34 through 39 are computer-constructed graphs which show a glideslope of 6^{0}, a 180^{0} turn, a light turbulence, a tailwind at entry of 10 knots and turn diameters of 6621 and 10667 feet. The glideslope and heading error graphs with the Cooper rating indicate that turn radius of approximately 1/2 n.m. with 6^{0} glideslope can be accurately flown.

The conclusion drawn from Figure 15 of pilot ratings and the computer-constructed graphs is that the TGS can be used for guidance to fly 180^{0} turns, curved-descending approaches of a 6^{0} glideslope and an approximately 1/2 n.m. turn radius.

The data of Figure 16 is for approaches for a 180^{0} turn, a 914 meter turn radius, a light-to-moderate turbulence, and a varying glideslope. This data indicate increased ratings with increased glideslopes. Glideslopes of 7^{0} can be flown by a pilot with sufficient TGS experience. The pilot commented that the glideslope needle is increasingly difficult to track for increasing glideslope angles.

Figure 17 compares pilot ratings for curved approaches using a 6^{0} glideslope, a 1853 meter turn radius, varying turbulence, and turns of 0^{0}, 90^{0}, and 180^{0}. The conclusion drawn from this data is that the turn angle is not a significant parameter for curved approaches. Straight-in and 180^{0} turn-angle approaches require approximately the same pilot workload.

Effect of Pilot Experience

Figures 18, 19, and 20 show the effect of pilot experience on ratings given for various curved approaches. These three figures show data for a 180^{0} angle, varying turbulence levels, and pilot experience of 200 hours, 500 hours, and 600 hours instrument flying time, and 1200 hours, 3000 hours, and 3500 hours total flying time.

Figure 18 shows data for a 3^{0} glideslope and turn radius of 1853 meters; Figure 19 shows data for a 6^{0} glideslope, and turn radius of 1853 meters; and Figure 20 shows data for a 6^{0} glideslope and turn radius of 914 meters respectively.

Figures 40 through 42 are computer-constructed graphs which show a 180^{0} turn, a 6986 feet turn diameter, a 6^{0} glideslope, moderate turbulence and a 10 knots tailwind at entry which are typical of several similar approaches flown by the pilot with 200 hour instrument time and who flew curved approaches. This approach was not completed because the pilot was having difficulty tracking the glideslope and heading signals. The pilot gave this approach a Cooper rating of 5 (unacceptable for normal operation).

The data supports these conclusions:

1. Pilot-experience was not a factor for glideslopes up to 3^{0} and a turn radius of 1853 meters for the pilots who flew the approaches.

2. Pilot-experience is a factor for a 6^{0} glideslope and approximately 914 meter turn radius. The pilot with the lowest instrument and total flying time gave the highest pilot ratings and had difficulty flying the approaches.

Pilot Comments Concerning TGS

Several pilot comments on and opinions of the TGS were given. One pilot commented that he thought better situation information was needed; another pilot felt that enough situation data was available, but the instruments displaying the data was not optimally arranged for easy use. Figure 6 shows the arrangement of the instrument panel. An integrated display which indicates the aircraft heading, altitude, DME distance to the VOR station, and the localizer, and glideslope errors would be an improvement. Pilots commented that initially a banked referenced condition necessary to hold a curved flight path presented some difficulty since they were accustomed to a wings-level reference condition for ILS approaches. Several approaches were flown before adjustments were made.

Because of the geometry of a curved, descending approach, the descent rate necessary to remain on the glideslope varies throughout the approach. Low descent rates are necessary initially, but higher descent rates are required for the portion of the flight path nearest the termination point. For a ground speed of 90 mph and a glideslope of 3^{0}, the rate of descent varies from 0 to 415 fpm. A constant adjustment of power is necessary to hold airspeed. Pilots commented that while this condition was not difficult to deal with, it was bothersome and increased pilot workload. Pilot comments support the conclusion that the presence of turbulence increases the workload required for curved approaches.

The safety pilot evaluating each approach for ride qualities commented that the curved approaches with glideslopes up to 6^{o} were comfortable. His opinion was that because of high rates of descent, steeper glideslopes would be somewhat uncomfortable for the passenger.

Effect of Wind and Turbulence

The system was not designed to maintain a given track in the presence of wind. But it was designed to bring the aircraft to a terminal point with the appropriate flight conditions to proceed in a straight path to the runway, which it does. However, useful information concerning the system capabilities can be gained by evaluating the effects of wind and turbulence on the performance of the system.

To determine the effects of winds, curved approaches were flown using 180^{o} turns in calm-to- m oderate turbulence conditions, varying glideslopes, and turn radii. It was observed that the bank angles needed to hold a given turn radius increased in the down-wind portion of the turn, and decreased in the upwind portion. The change in bank angle is required to compensate for the group speed change caused by winds. Steeper bank angles are required whenever the group speed is greatest. This effect was measured and reported in Reference 6. While the variation of bank angle will compensate for a variation of ground speed due to winds, it does not compensate for wind drift. Figures 26, 29, 32, 35, and 38 show the effect of wind drift caused by a direct tailwind at flight path entry. When viewed from above, the no-wind zero-heading error TGS generated flight path is a circle that passes through the approach entry point and is tangent to the runway heading at the terminal point. As indicated, the actual flight path is downwind of the "no-wind" flight path. These figures were computer-constructed from recorded flight data. The TGS does not correct to a given flight path over the ground or for drift caused by direct tail or head winds.

The TGS provides a wind correction control which slightly offsets the desired runway heading to correct for cross-wind. To use this capability, the pilot must calculate and select the desired wind correction angle. The wind correction switch is set to the direction of the wind across the runway, i.e.; for a wind moving from the left across the runway while facing the direction of the landing, the switch is set to L (left) position and the correction angle is selected. The runway heading is decreased by the amount selected. Figure 21 shows the flight paths that would result for a no-wind and no-correction, no-wind with cross-wind correction, and a cross-wind with cross-wind correction conditions. The wind correction control setting results in increased separation of the actual flight path from the no-wind and no-wind correction path for a 90° turn and reduced separation for the 180° turn flight path.

Several 180° turn approaches were flown with and without wind correction angles and 90° left cross winds of 15 knots. The aircraft drifted to the right of the flight path near the termination point and arrived over the termination point on a heading less than the runway heading by about 10°. The wind correction of left 19° caused the aircraft to cross the termination point on a heading approximately 20° less than the runway heading. It can be concluded from the wind effects tests and analysis that the TGS will not correct to a given path over the ground. Wind drift causes considerable deviation from a given ground path. For 180^{0} turns with a cross wind, the wind correction control reduces deviation for 180^{0} turns, but increased it for 90^{0} turns. For aircraft required to maneuver in limited airspace or along a given flight path in order to avoid ground objects, the inability of the TGS to correct to a given path over the ground and adequately compensate for wind drift could limit its use.

CONCLUDING REMARKS

The purpose of this study was to evaluate the terminal guidance system. The TGS is avionic equipment which gives guidance along a curved descending flight path to a landing. A Cessna 182 was used as the test aircraft and the TGS was installed and connected to the altimeter, DME, RMI and Gyro Compass. Approaches were flown by three different pilots. The conclusions drawn from these tests are:

1. When the aircraft arrives at the termination point, it is "set up" on final approach for a landing.

2. The TGS provides guidance for curved descending approaches with glideslopes of 6^{0} which required, for experienced pilots, workloads that are approximately the same as for an ILS.

3. The glideslope is difficult to track within 1/2 n.m. of the VOR/DME Station.

4. The system will permit, for experienced pilots, satisfactory approaches with a turn radius as low as 1/2 n.m. and a glideslope of 6^{0}.

5. Turn angles have little relation to pilot workload for curved approaches.

6. Pilot experience is a factor for curved approaches. Pilots with low instrument time have difficulty flying steep approaches with small turn radius.

7. Turbulence increases the pilot workload for curved approaches.

8. The TGS does not correct to a given flight path over the ground nor does it adequately compensate for wind drift.

The TGS will provide accurate guidance for curved descending approaches which can be followed by pilots with reasonable low instrument time. However, the inability to correct to a ground path and for wind drift will limit its use in airspace where deviation from a given flight path is critical.

INTERSPERSED CURVED AND STRAIGHT-IN APPROACHES

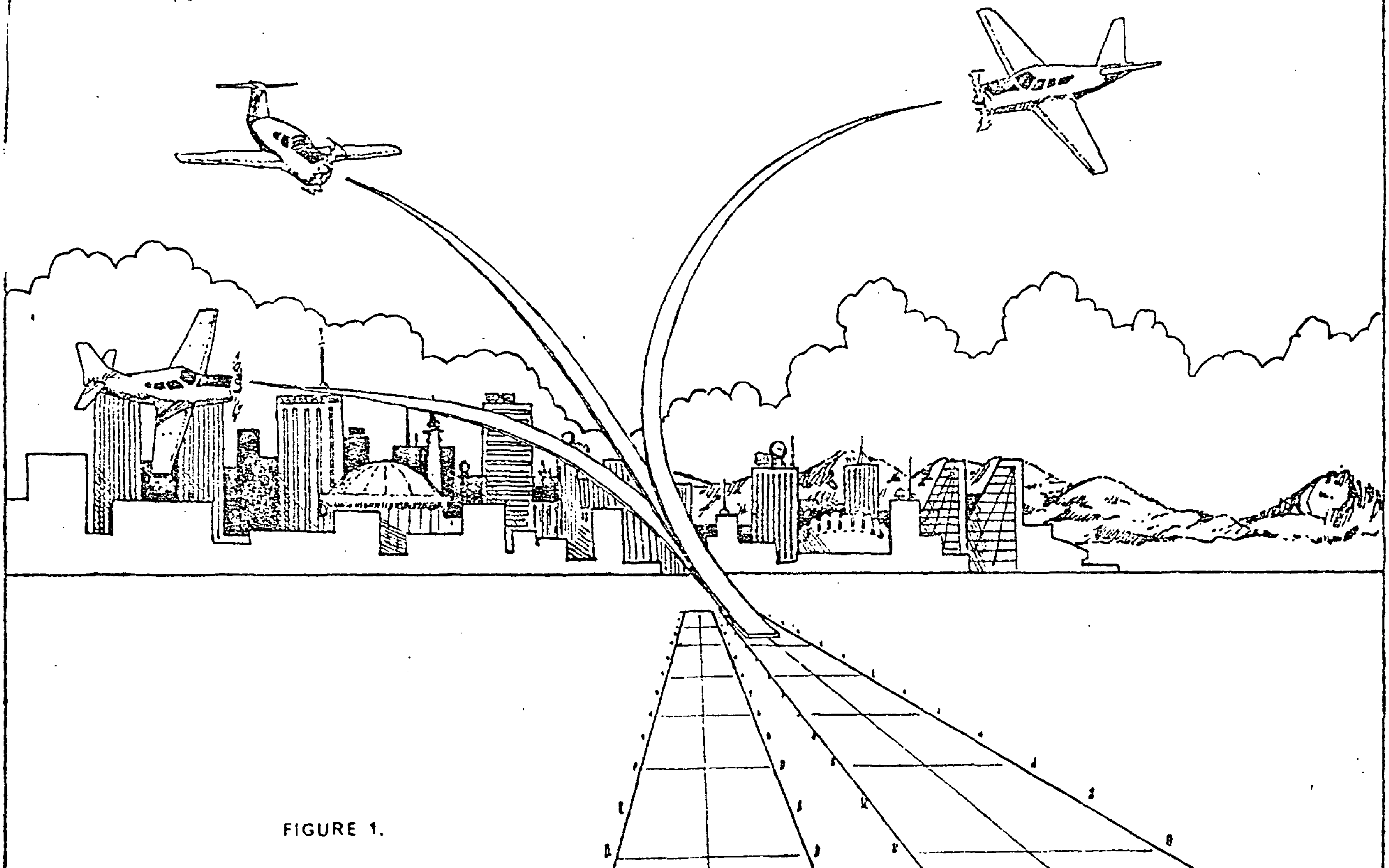


FIGURE 1.

CURVED APPROACH MECHANIZATION SCHEME
FOR DFRC FLIGHT TESTS

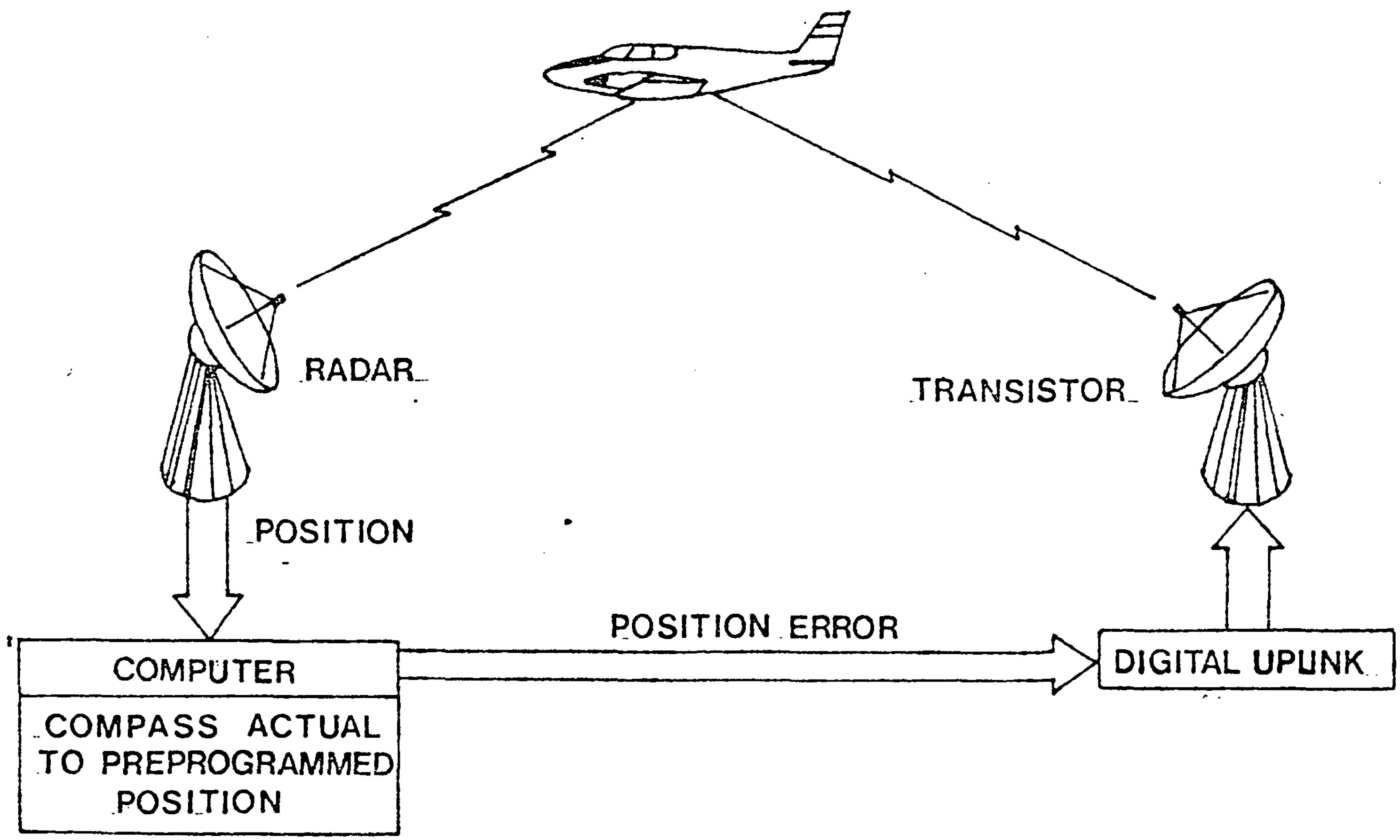


FIGURE 2.

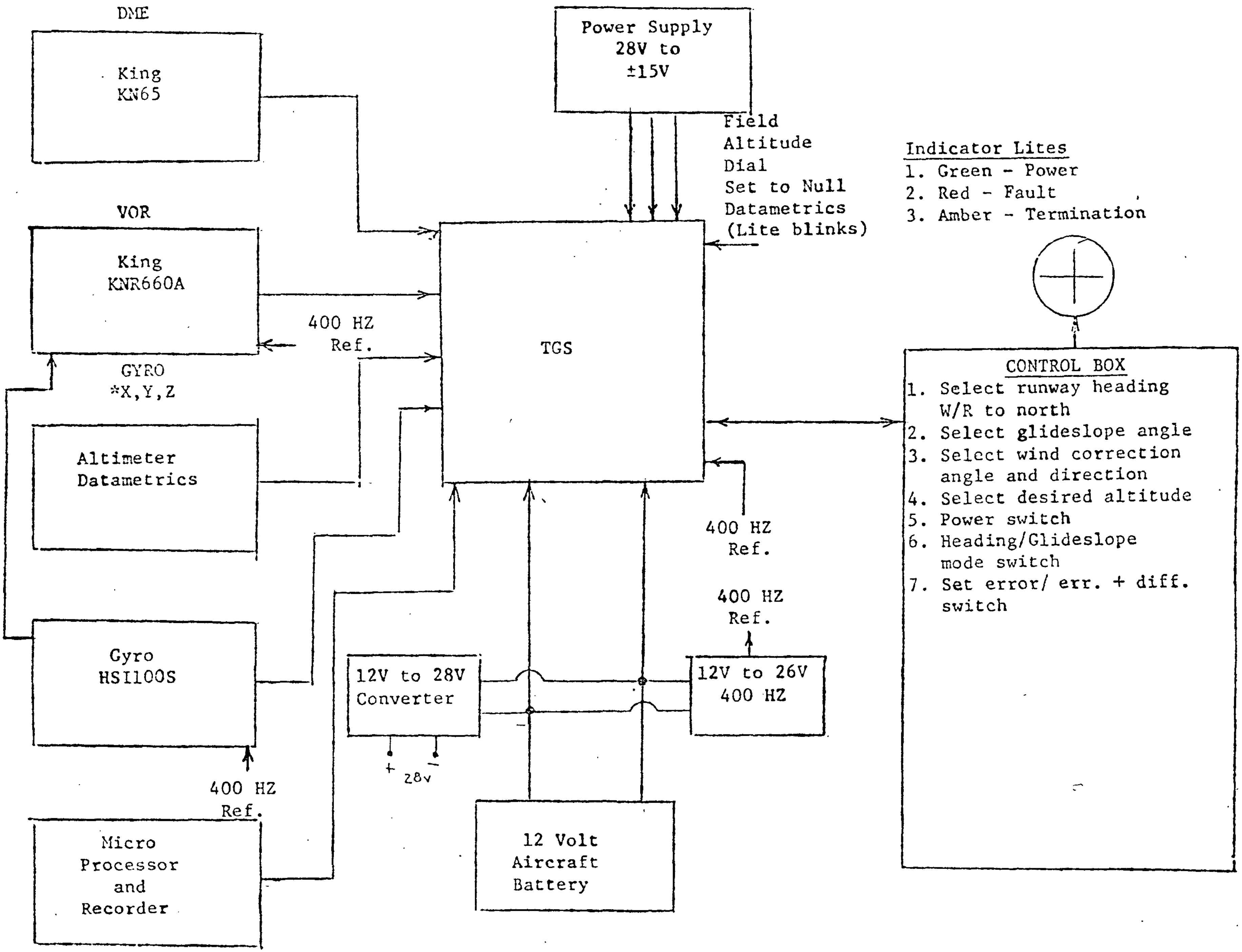

DME
King
KN65
VOR
King
KNR660A
400 HZ
Ref.
GYRO
*X,Y,Z
Altimeter
Datametrics
Gyro
HSI100S
400 HZ
Ref.
Micro
Processor
and
Recorder
Power Supply
28V to
±15V
Field
Altitude
Dial
Set to Null
Datametrics
(Lite blinks)
TGS
400 HZ
Ref.
400 HZ
Ref.
12V to 28V
Converter
+ 28v −
12V to 26V
400 HZ
12 Volt
Aircraft
Battery
Indicator Lites
1. Green - Power
2. Red - Fault
3. Amber - Termination
CONTROL BOX
1. Select runway heading
W/R to north
2. Select glideslope angle
3. Select wind correction
angle and direction
4. Select desired altitude
5. Power switch
6. Heading/Glideslope
mode switch
7. Set error/ err. + diff.
switch

FIGURE 3.

Test Aircraft (Cessna 182)

FIGURE 4.

TGS Computer

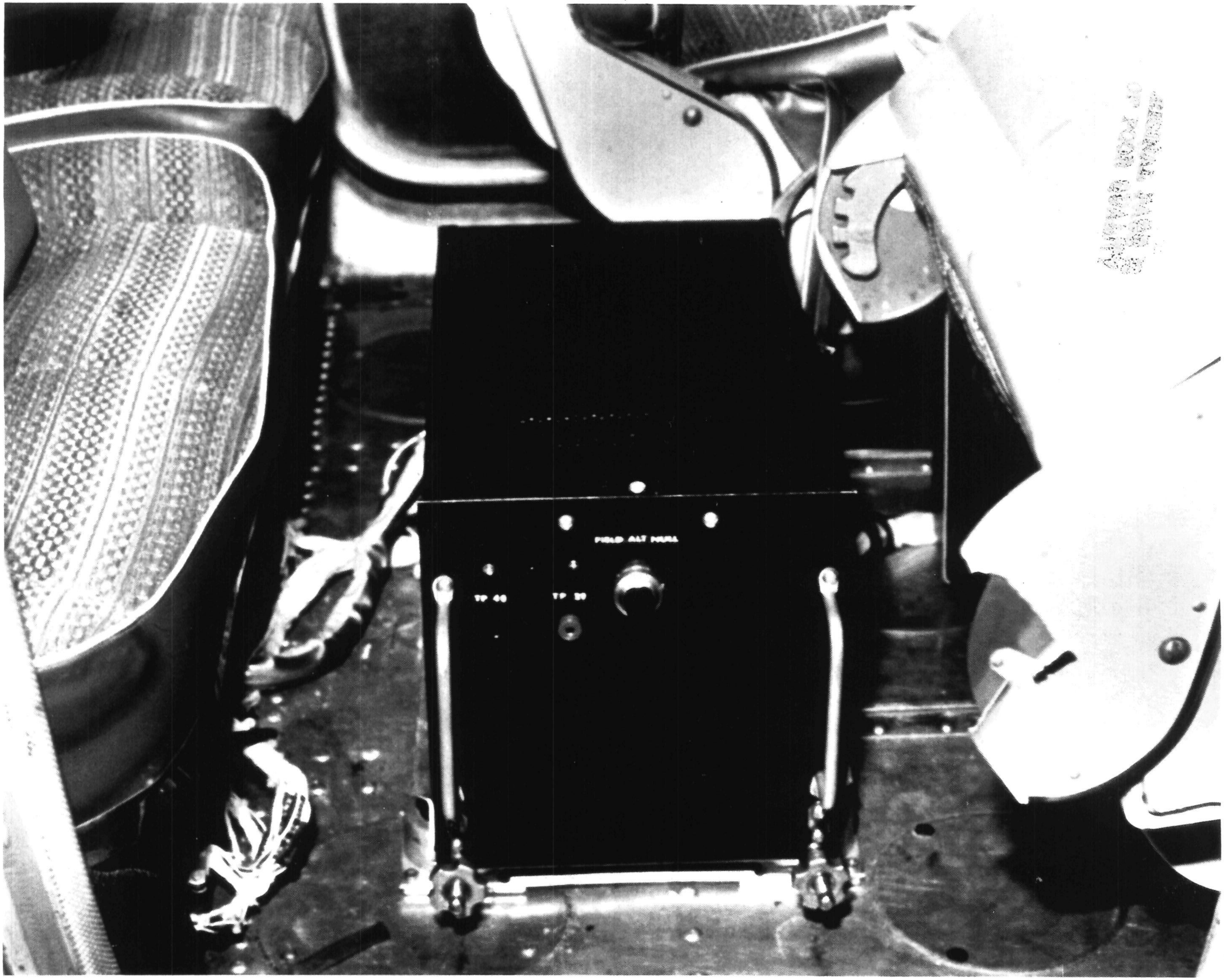


FIGURE 5.

Placement of TGS Control Head on Instrument Panel

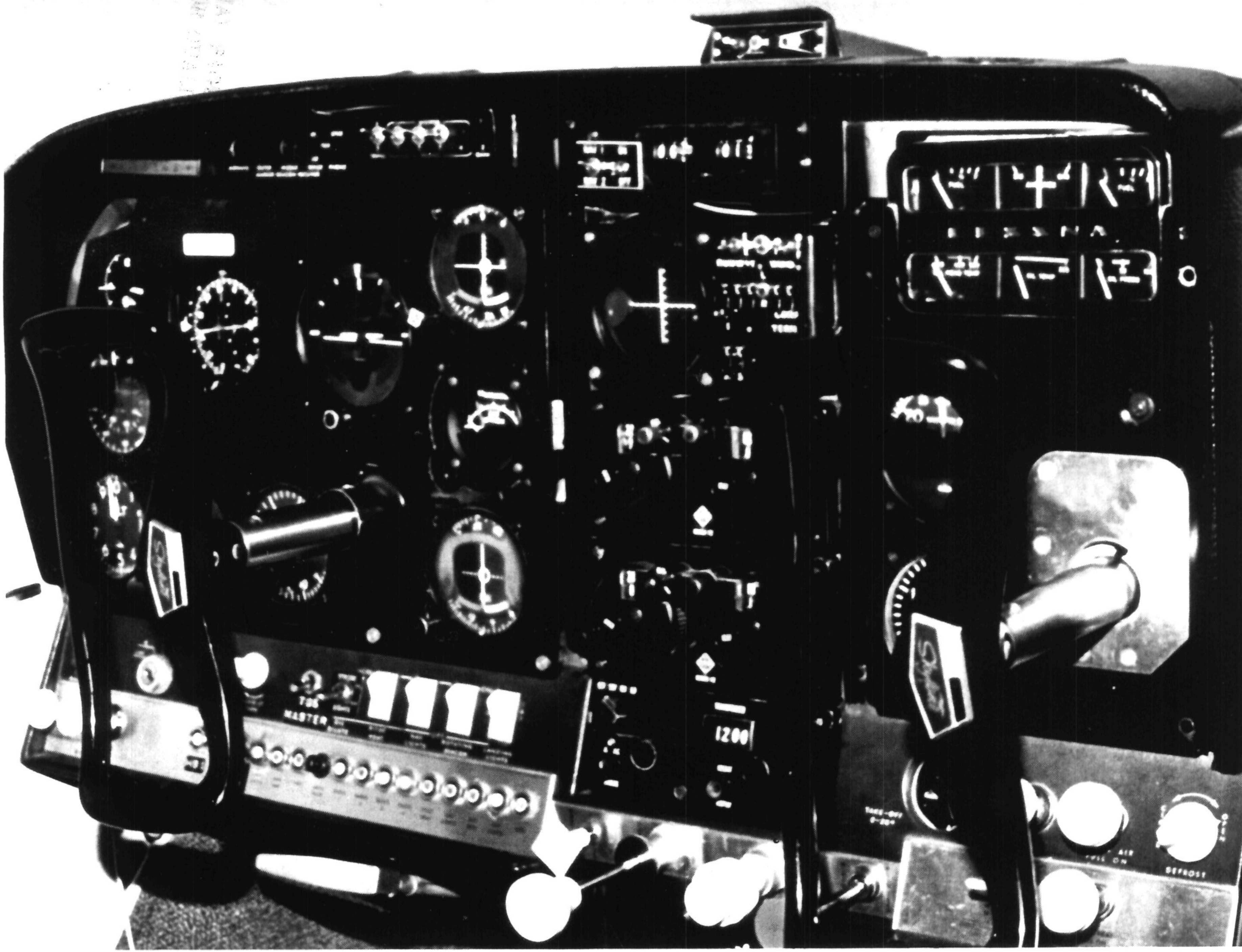


FIGURE 6.

TGS Control Head

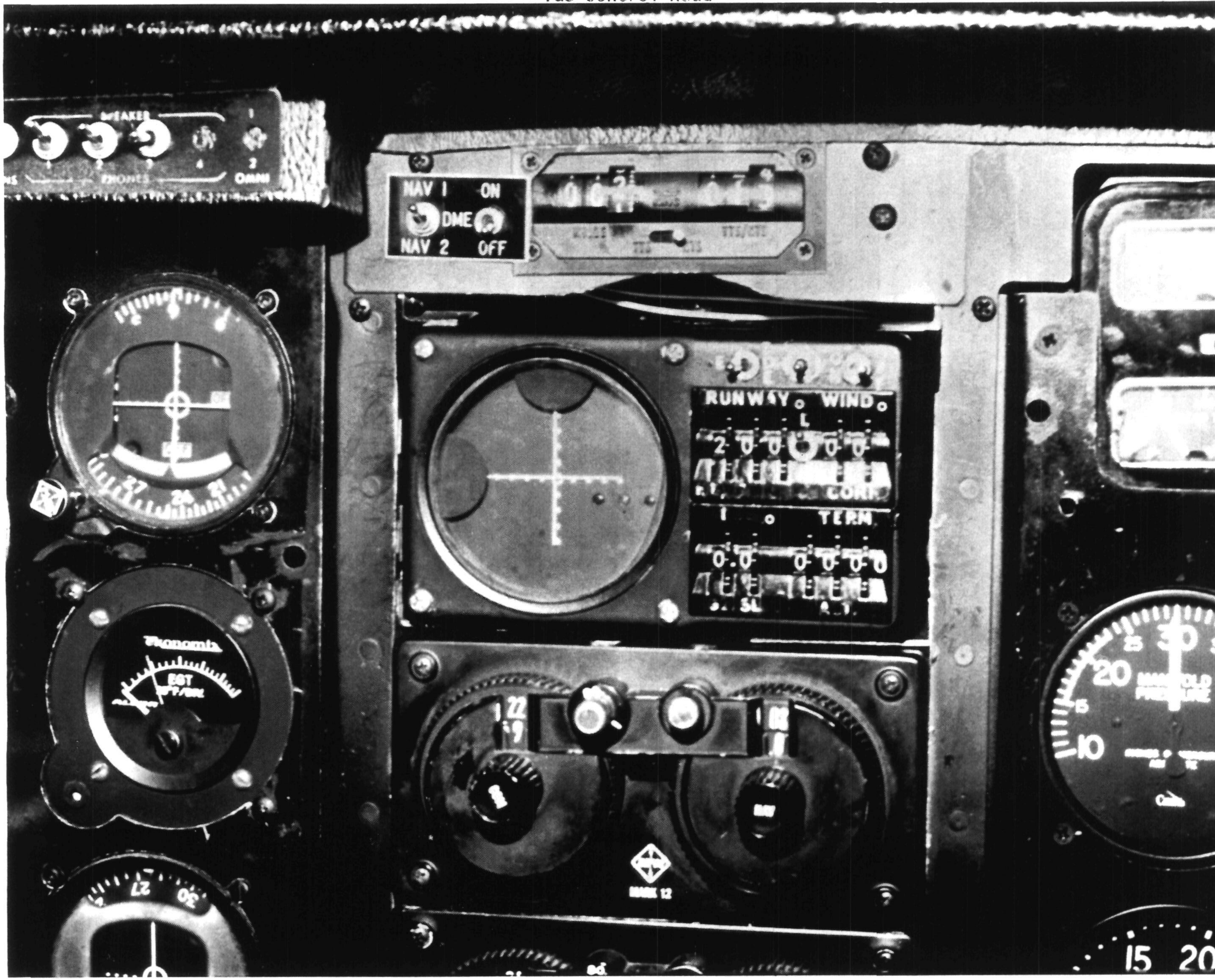
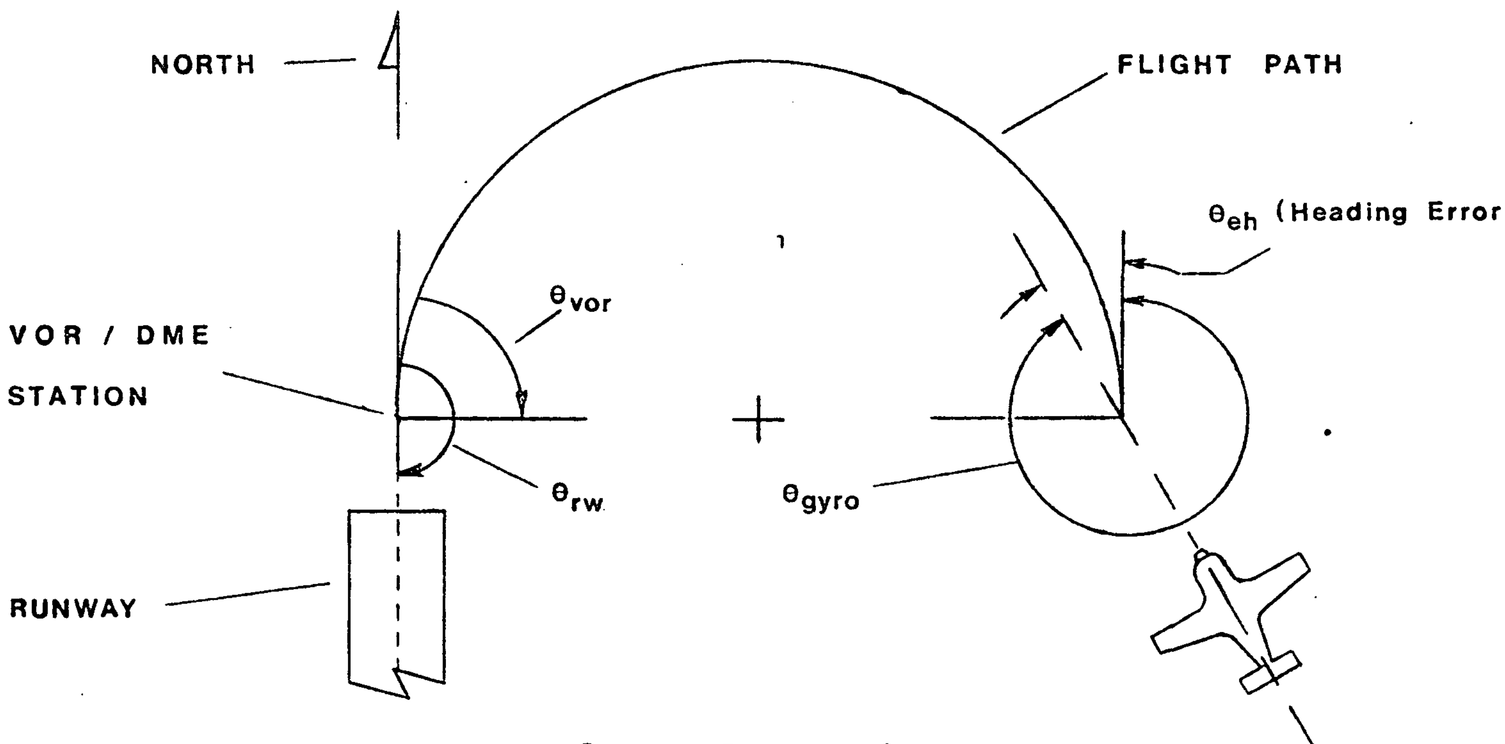


FIGURE 7.

HEADING ERROR EQUATION



$$\Theta_{eh} = 2\,\Theta_{vor} - \Theta_{gyro} - \Theta_{rw} \pm \Theta_{wc} \pm 360^{\circ}$$

θ_{eh} • Angle Between A/C Heading And Tangent To Flight Path

θ_{vor} • Bearing Of A/C From Station

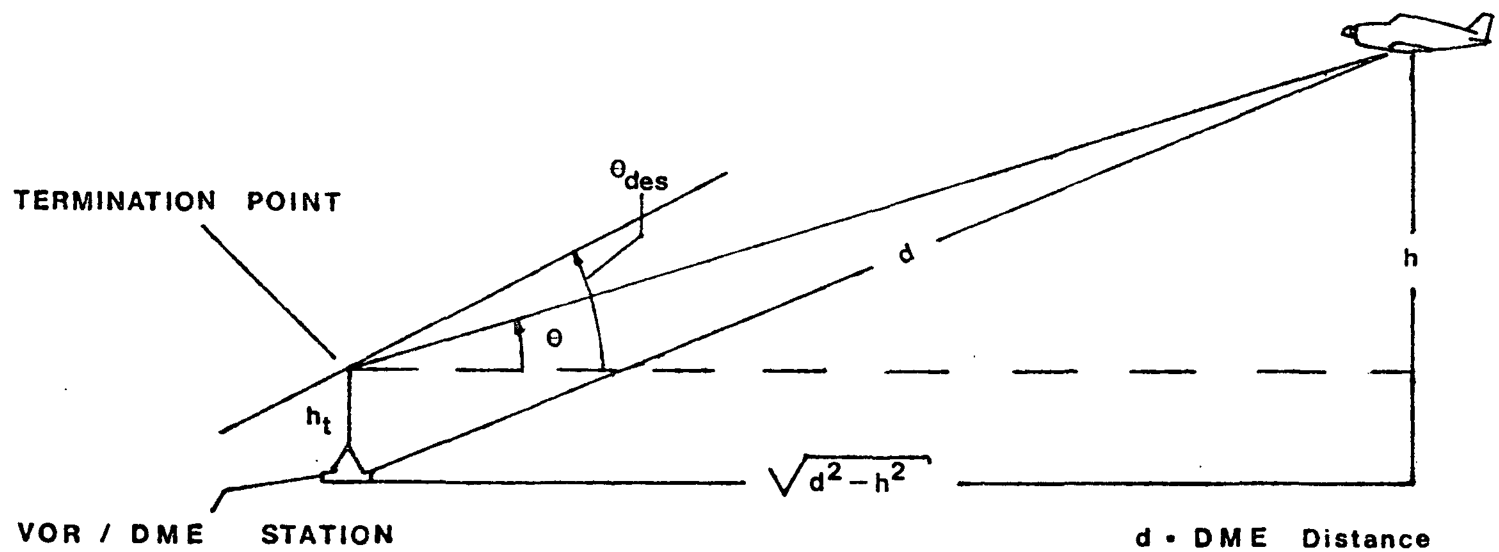
θ_{gyro} • A/C Heading

θ_{rw} • Runway Heading

θ_{wc} • Wind Correction

FIGURE 8.

GLIDESLOPE EQUATION



$$\theta_{eg} = \theta_{des} - \theta$$

$$\theta_{eg} = \theta_{des} - \mathrm{TAN}^{-1}\left(\frac{h - h_t}{\sqrt{d^2-h^2}}\right)$$

d • DME Distance

h • Altitude

h_t • Termination Point Height

θ • Glideslope

θ_{des} • Desired Glideslope

θ_{eg} • Glideslope Error

FIGURE 9.

IN-FLIGHT RECORDING SYSTEM

USNA 1980

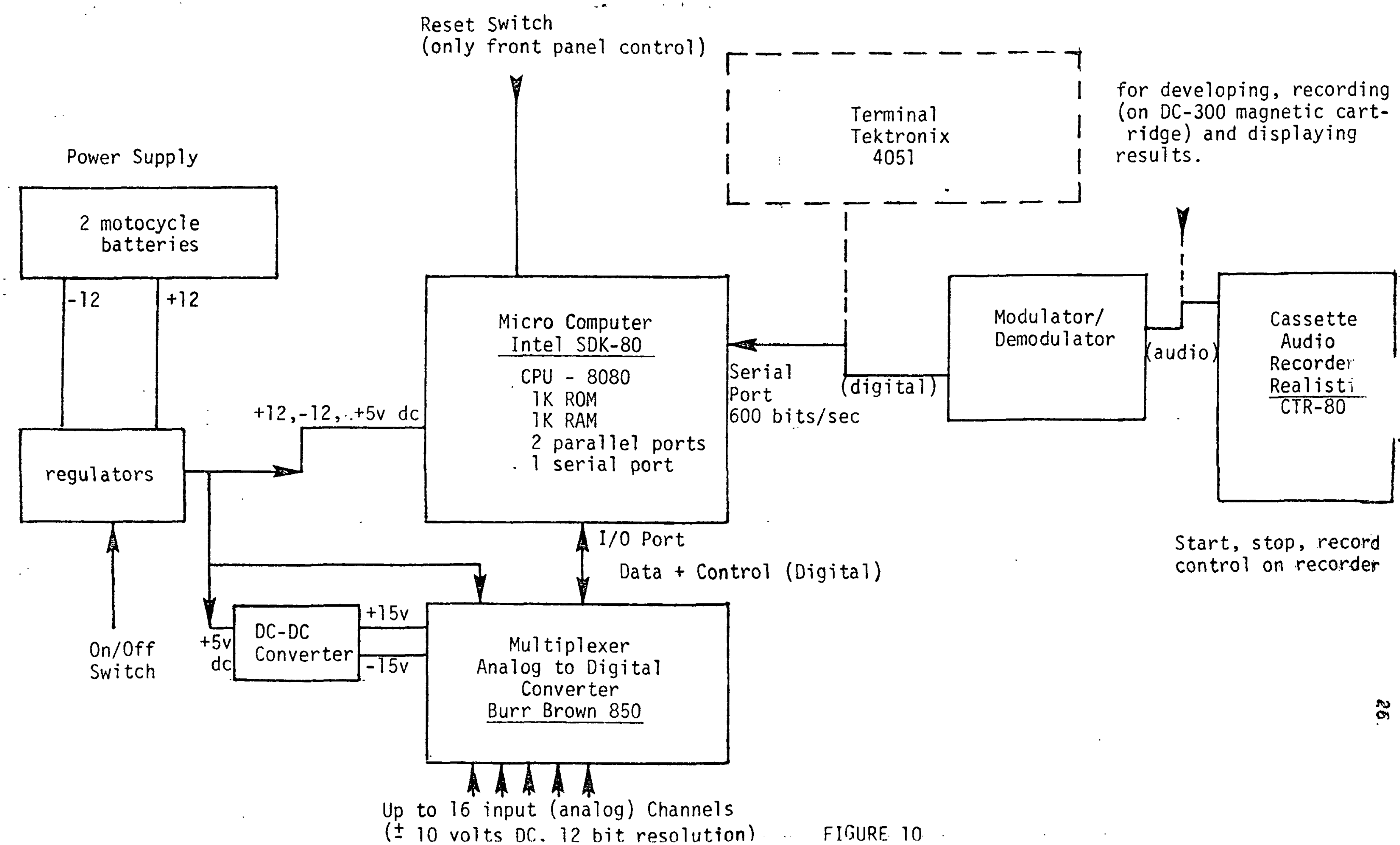


FIGURE 10

FLIGHT PATHS FOR VARIOUS TURN ANGLES

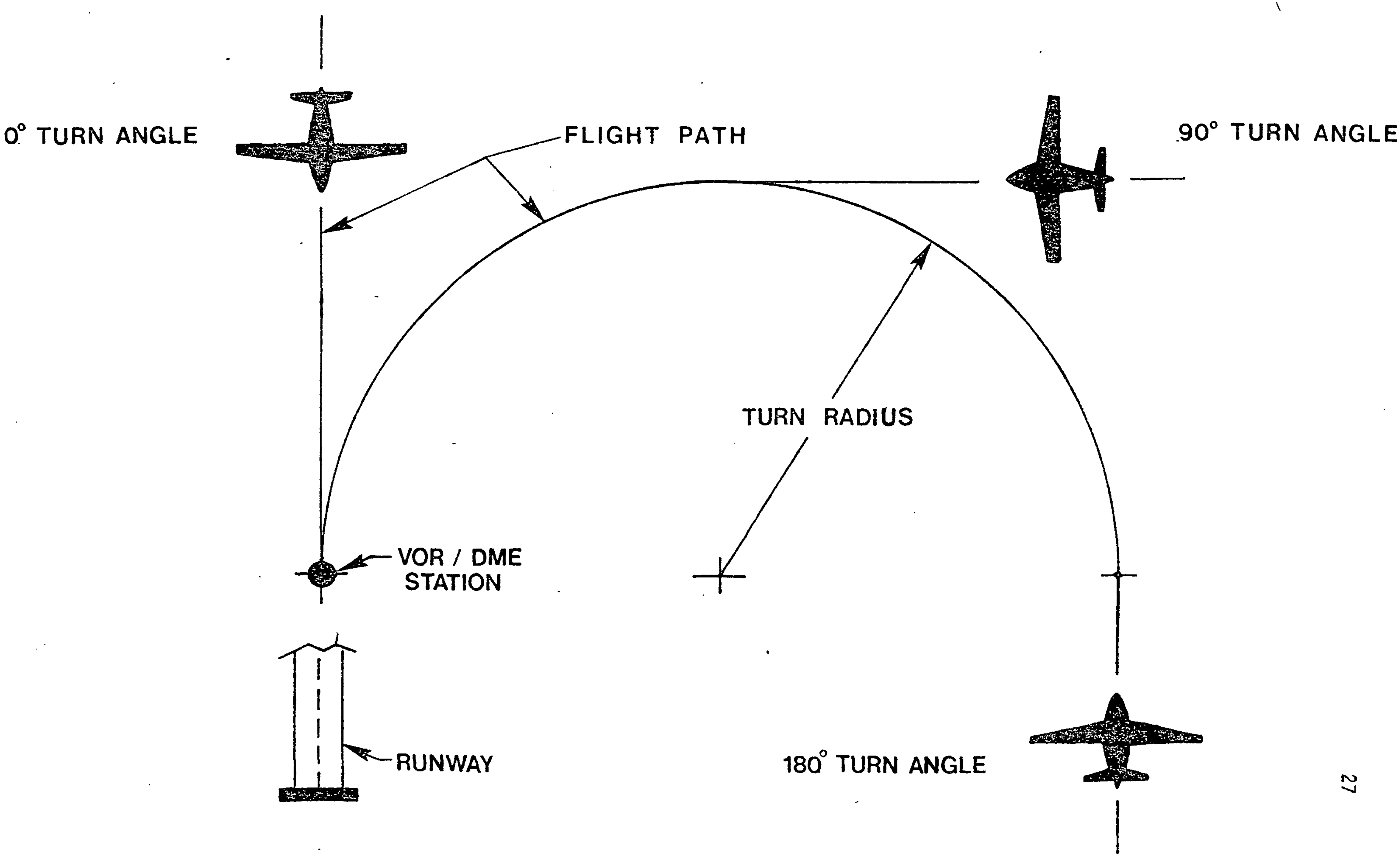


FIGURE 11.

SUMMARY OF APPROACHES FLOWN

GLIDE SLOPE	3^o	4^o	5^o	6^o	7^o	8^o	9^o
0^o ANGLE	6	3	1	6		3	4
90^o ANGLE	13			8	4	5	
180^o ANGLE 1853 M RADIUS	43			23			
180^o ANGLE 914 M RADIUS	20			25	8	13	10
180^o ANGLE 457 M RADIUS				5			
180^o ANGLE 1853M RADIUS 90^o CROSS WIND	15			15			
TOTAL	230						

Pilots	Schlein	Sandlin	Hewett
Inst. Time	200 hrs	500 hrs	600 hrs
# Approaches	23	137	35

FIGURE 12

COOPER RATINGS

OPERATING CONDITIONS	ADJECTIVE RATING	NUMERICAL RATING	DESCRIPTION	PRIMARY MISSION ACCOMPLISHED	CAN BE LANDED
NORMAL OPERATION	SATISFACTORY	1	EXCELLENT, INCLUDES OPTIMUM	YES	YES
		2	GOOD, PLEASANT TO FLY	YES	YES
		3	SATISFACTORY, BUT WITH SOME MILDLY UNPLEASANT CHARACTERISTICS	YES	YES
EMERGENCY OPERATION	UNSATISFACTORY	4	ACCEPTABLE, BUT WITH UNPLEASANT CHARACTERISTICS	YES	YES
		5	UNACCEPTABLE FOR NORMAL OPERATION	DOUBTFUL	YES
		6	ACCEPTABLE FOR EMERGENCY CONDITION ONLY[1]	DOUBTFUL	YES
NO OPERATION	UNACCEPTABLE	7	UNACCEPTABLE EVEN FOR EMERGENCY CONDITION[1]	NO	DOUBT-FUL
		8	UNACCEPTABLE - DANGEROUS	NO	NO
		9	UNACCEPTABLE-UNCONTROLLABLE	NO	NO
	CATASTROPHIC	10	MOTIONS POSSIBLY VIOLENT ENOUGH TO PREVENT PILOT ESCAPE	NO	NO

[1] FAILURE OF A STABILITY AUGMENTER

FIGURE 13

PILOT RATINGS FOR CONVENTIONAL ILS AND CURVED APPROACH TASKS

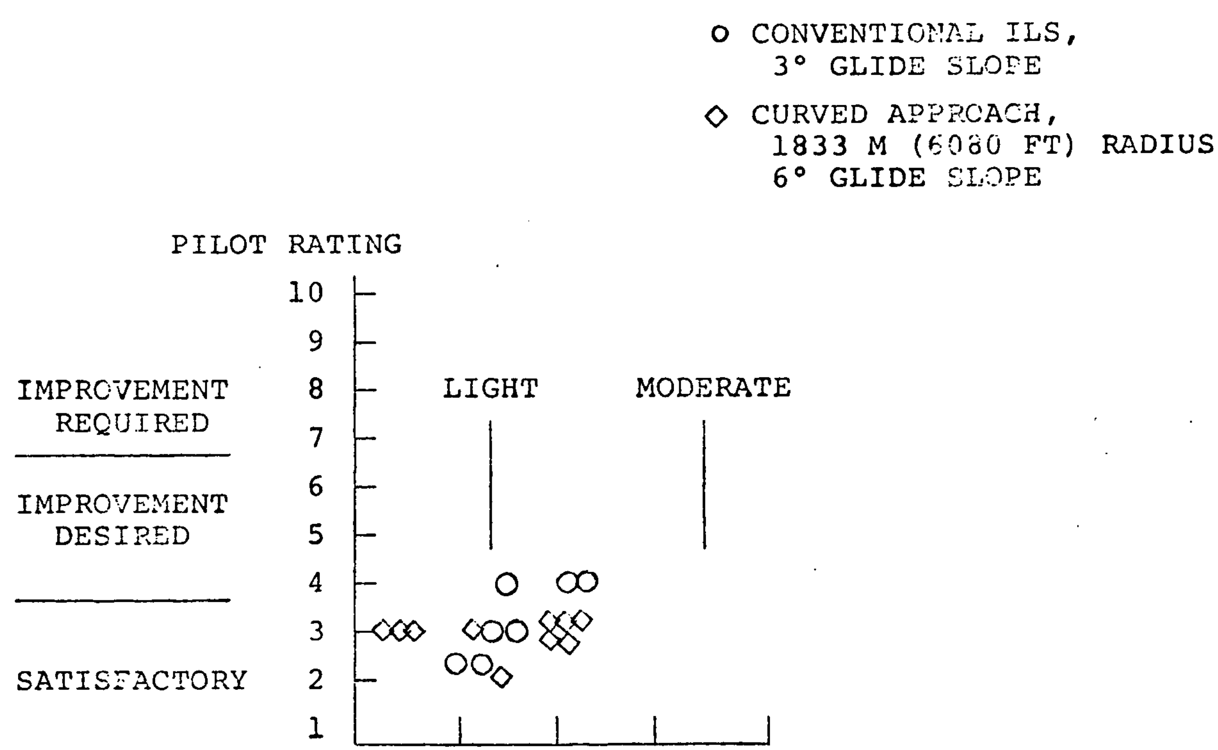


FIGURE 14

EFFECT OF PATTERN GEOMETRY DURING CURVED APPROACHES

(TURN RADIUS)

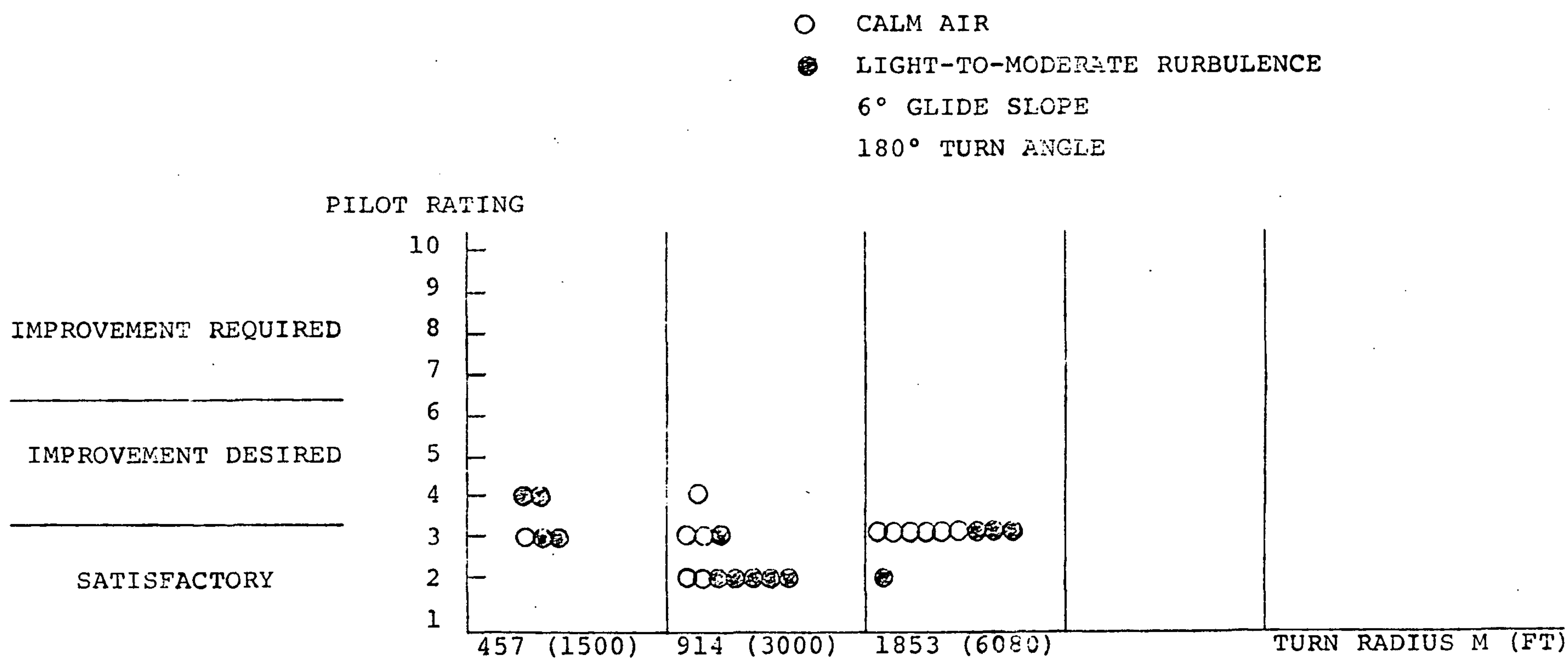


FIGURE 15

EFFECT OF PATTERN GEOMETRY DURING CURVED APPROACHES

(GLIDE SLOPE)

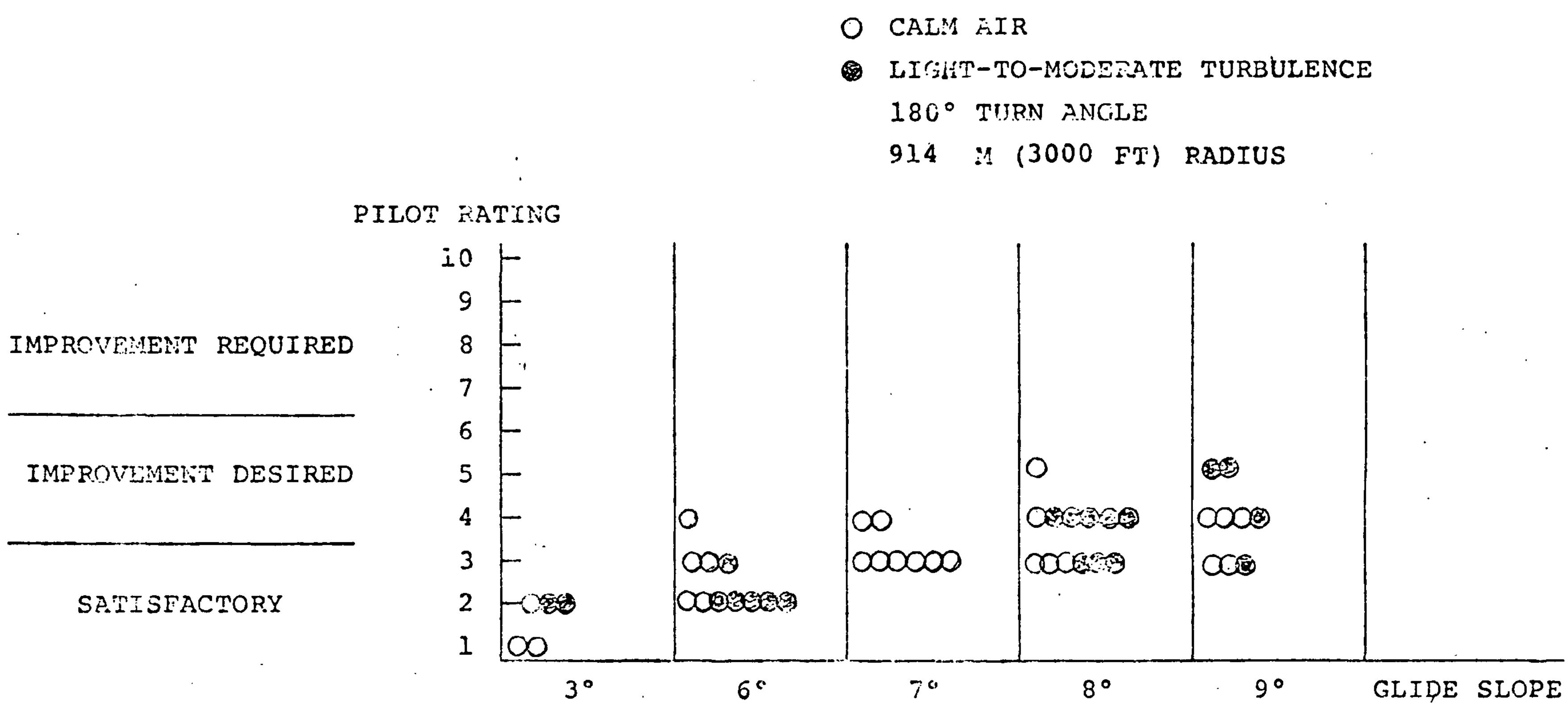


FIGURE 16

EFFECT OF PATTERN GEOMETRY DURING CURVED APPROACHES

(TURN ANGLE)

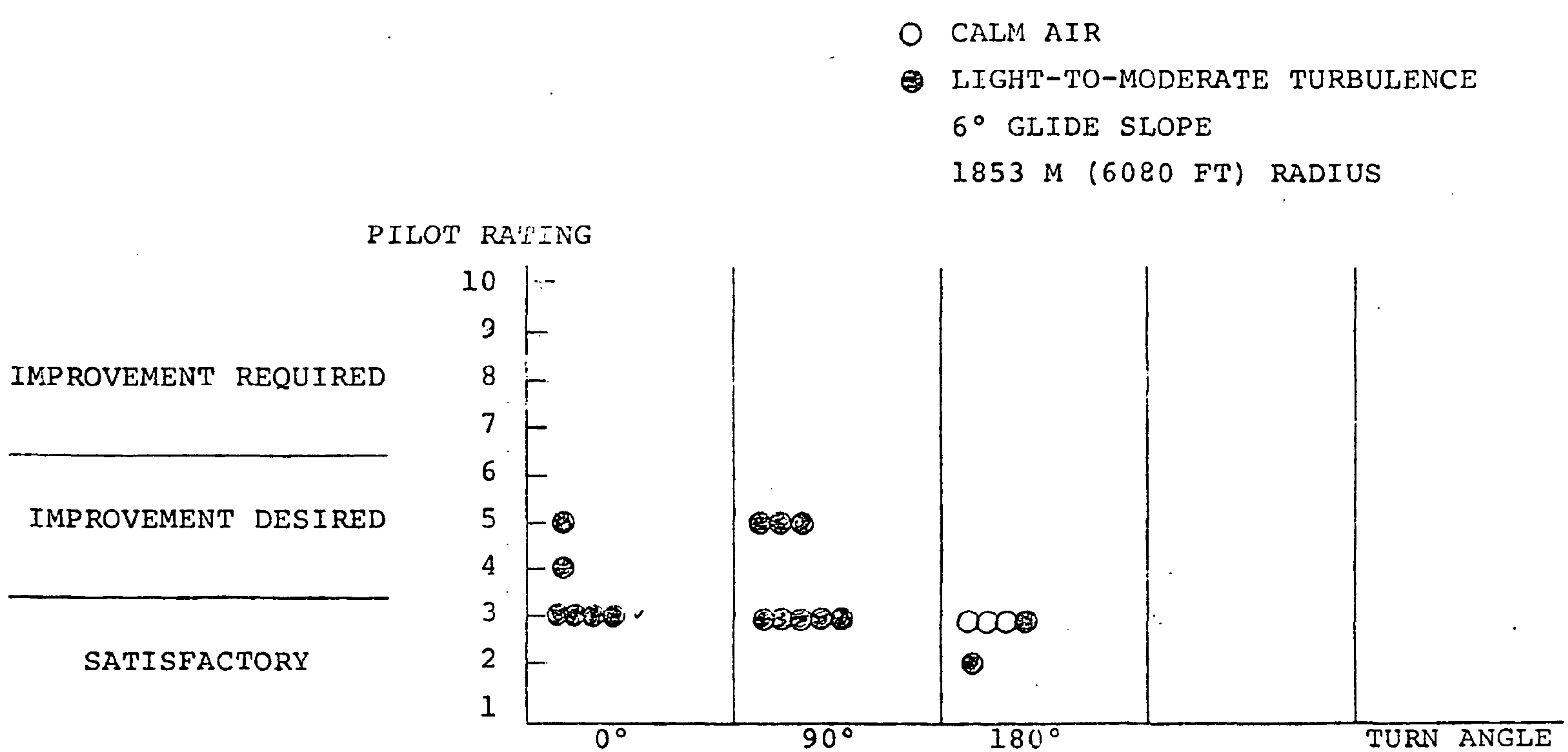


FIGURE 17

EFFECT OF PILOT EXPERIENCE DURING CURVED APPROACHES

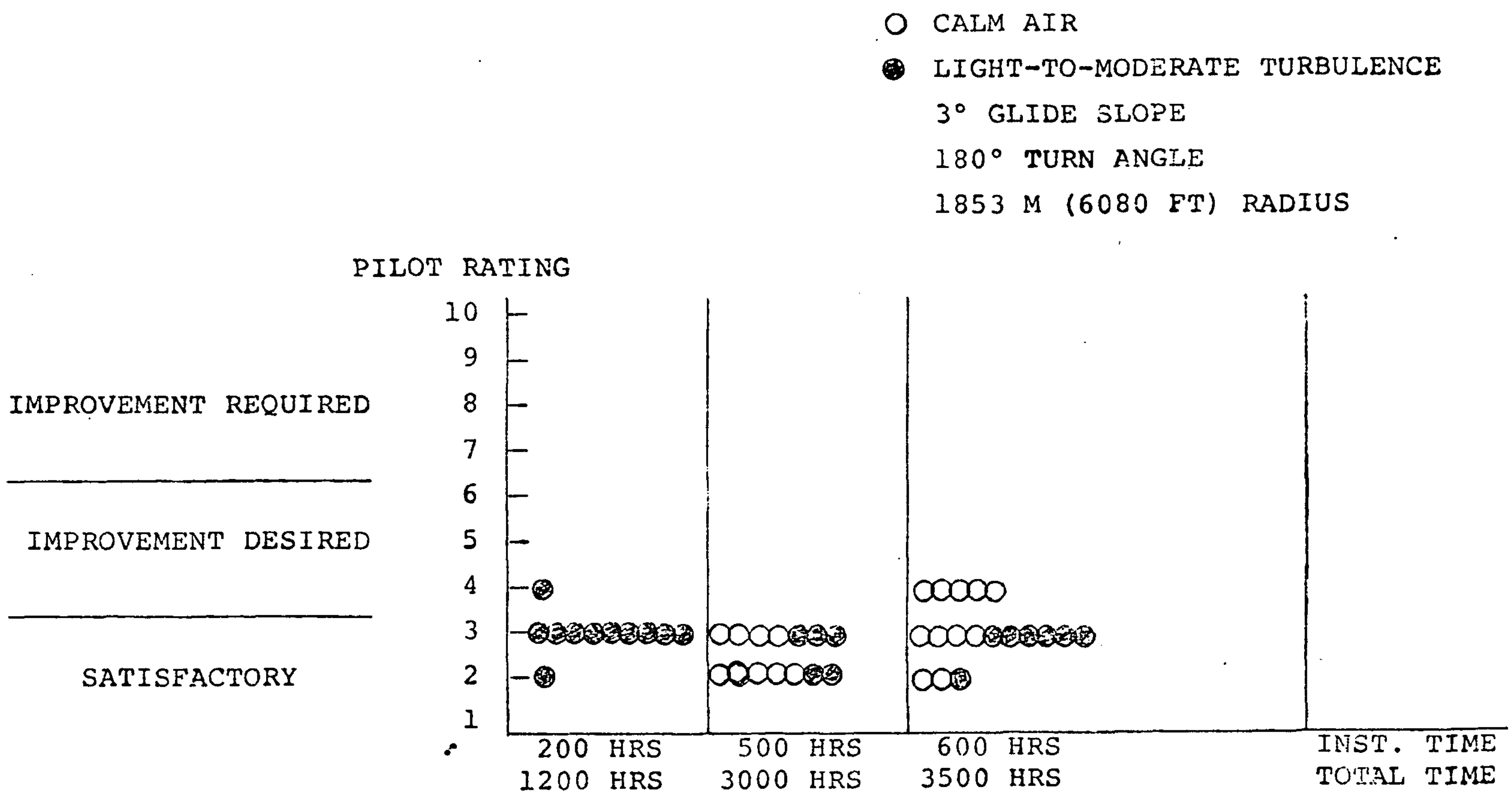


FIGURE 18

EFFECT OF PILOT EXPERIENCE DURING CURVED APPROACHES

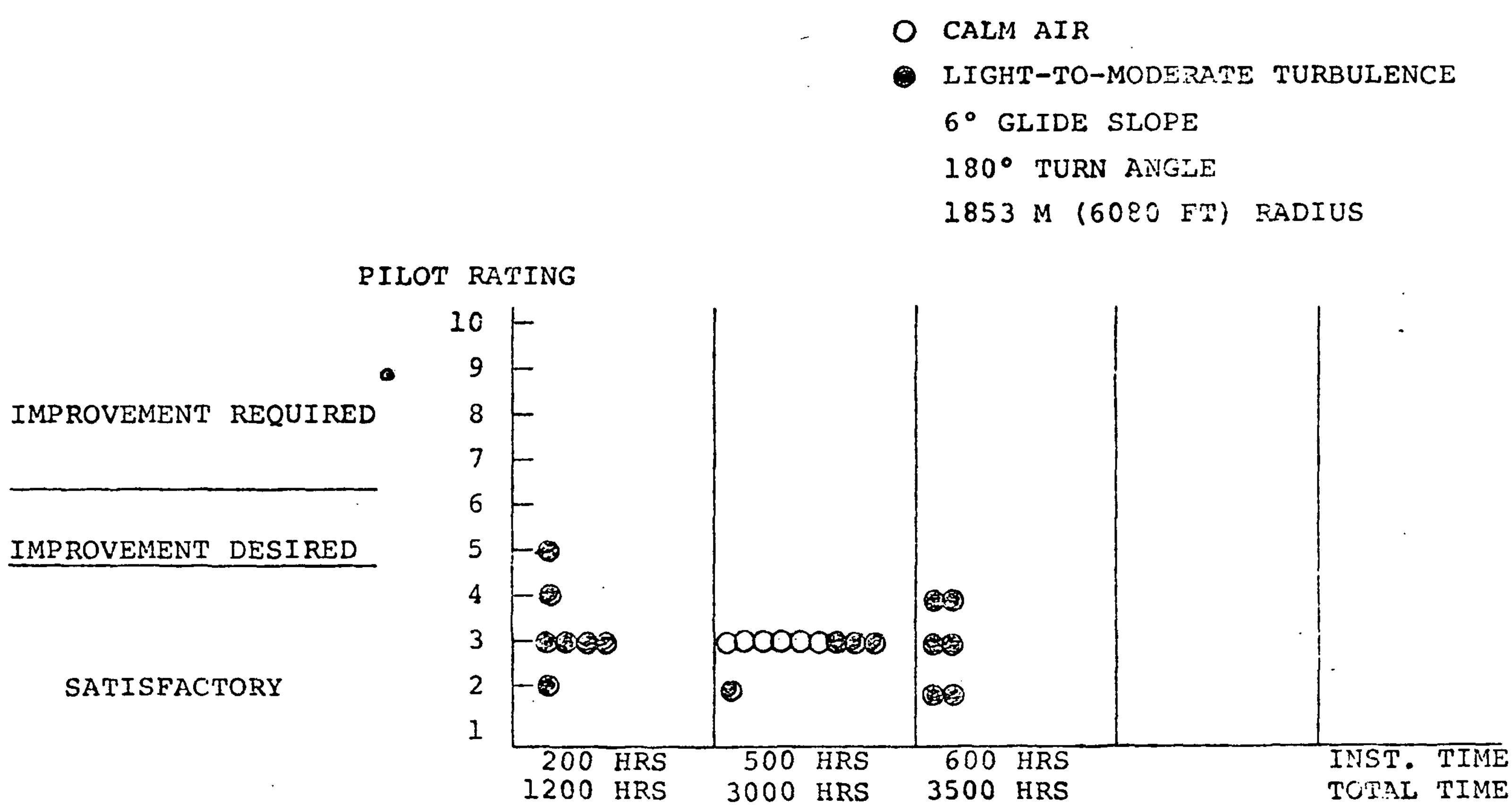


FIGURE 19

EFFECT OF PILOT EXPERIENCE DURING CURVED APPROACHES

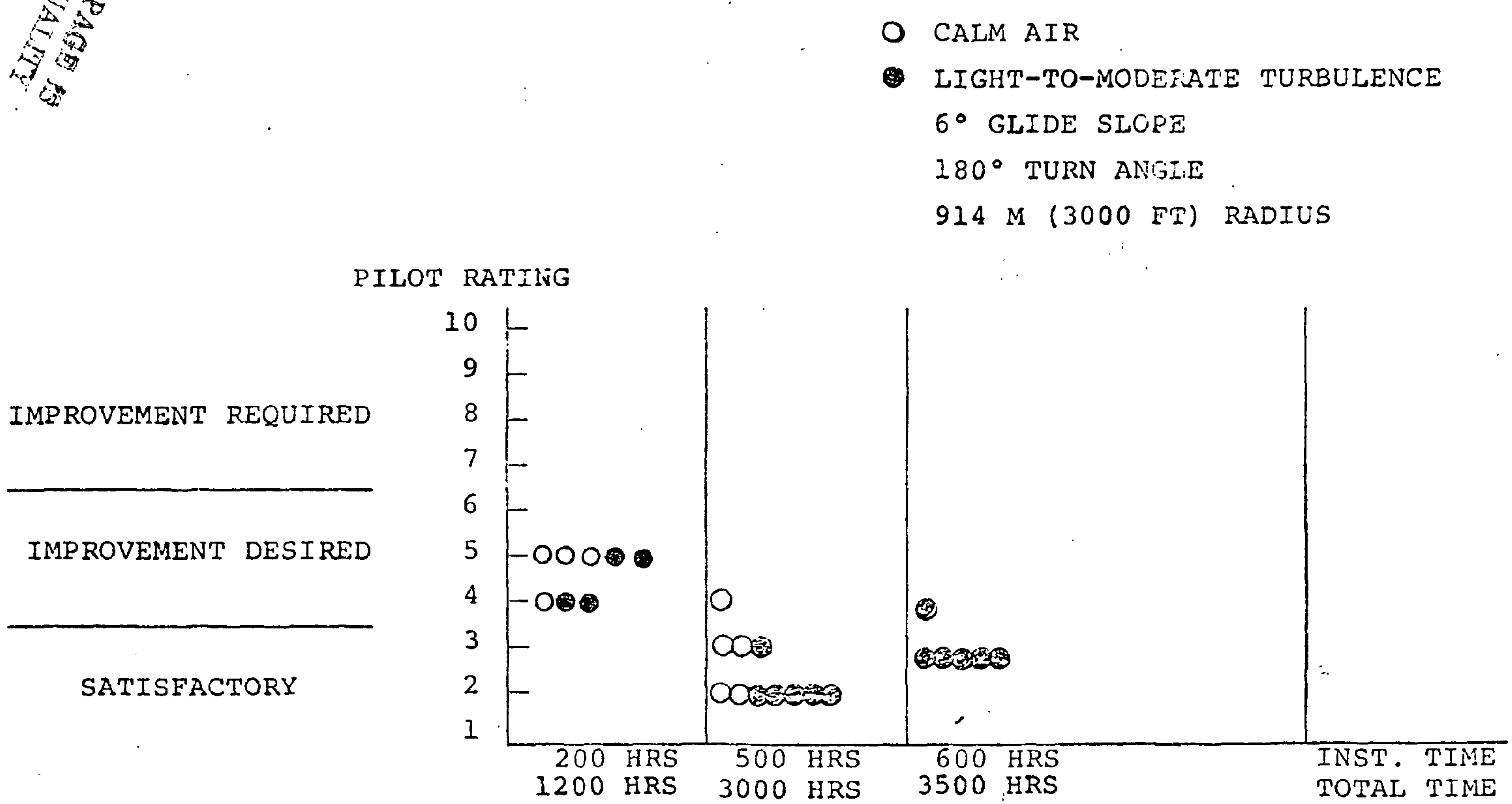


FIGURE 20

CROSS WIND EFFECTS

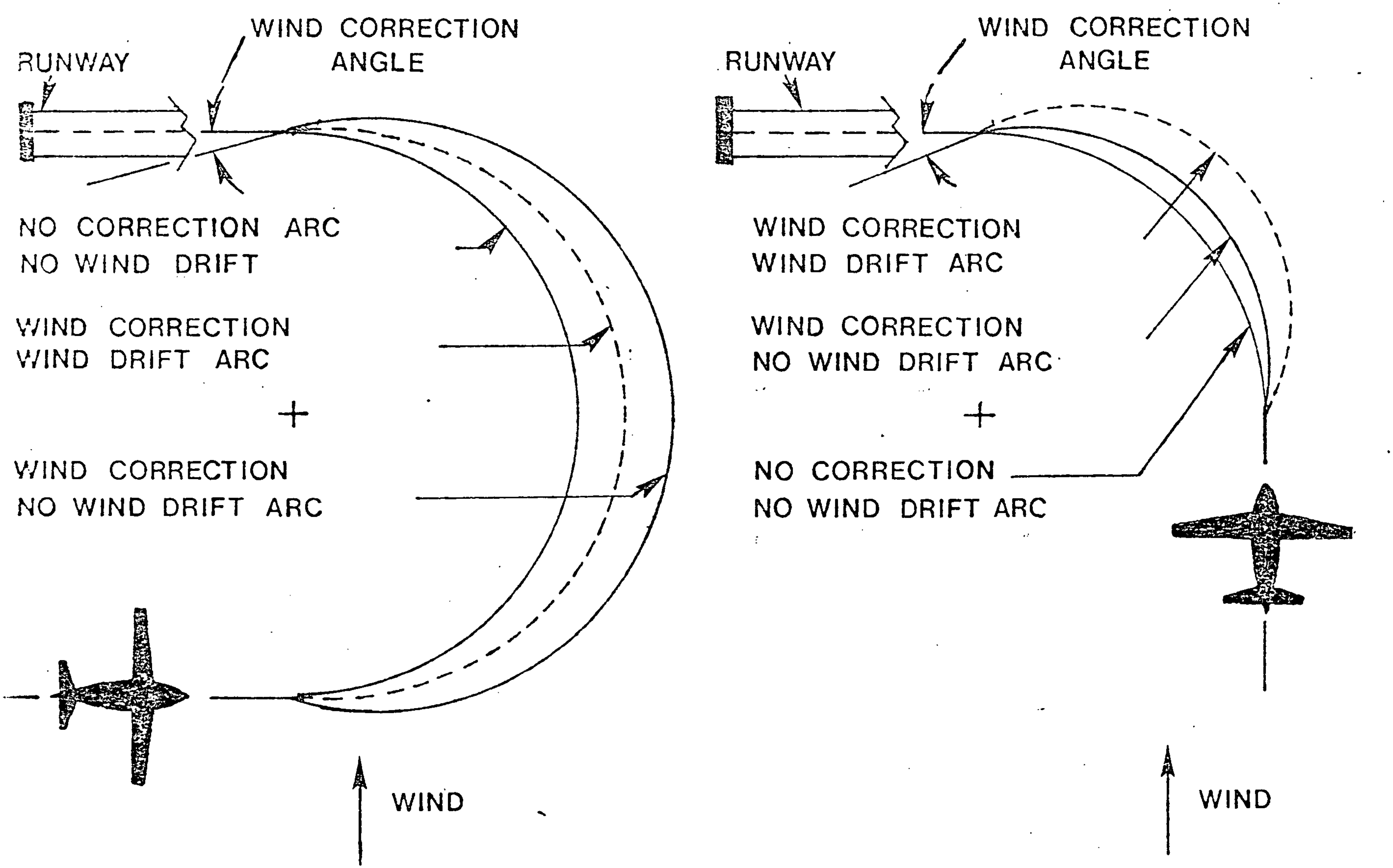


FIGURE 21.

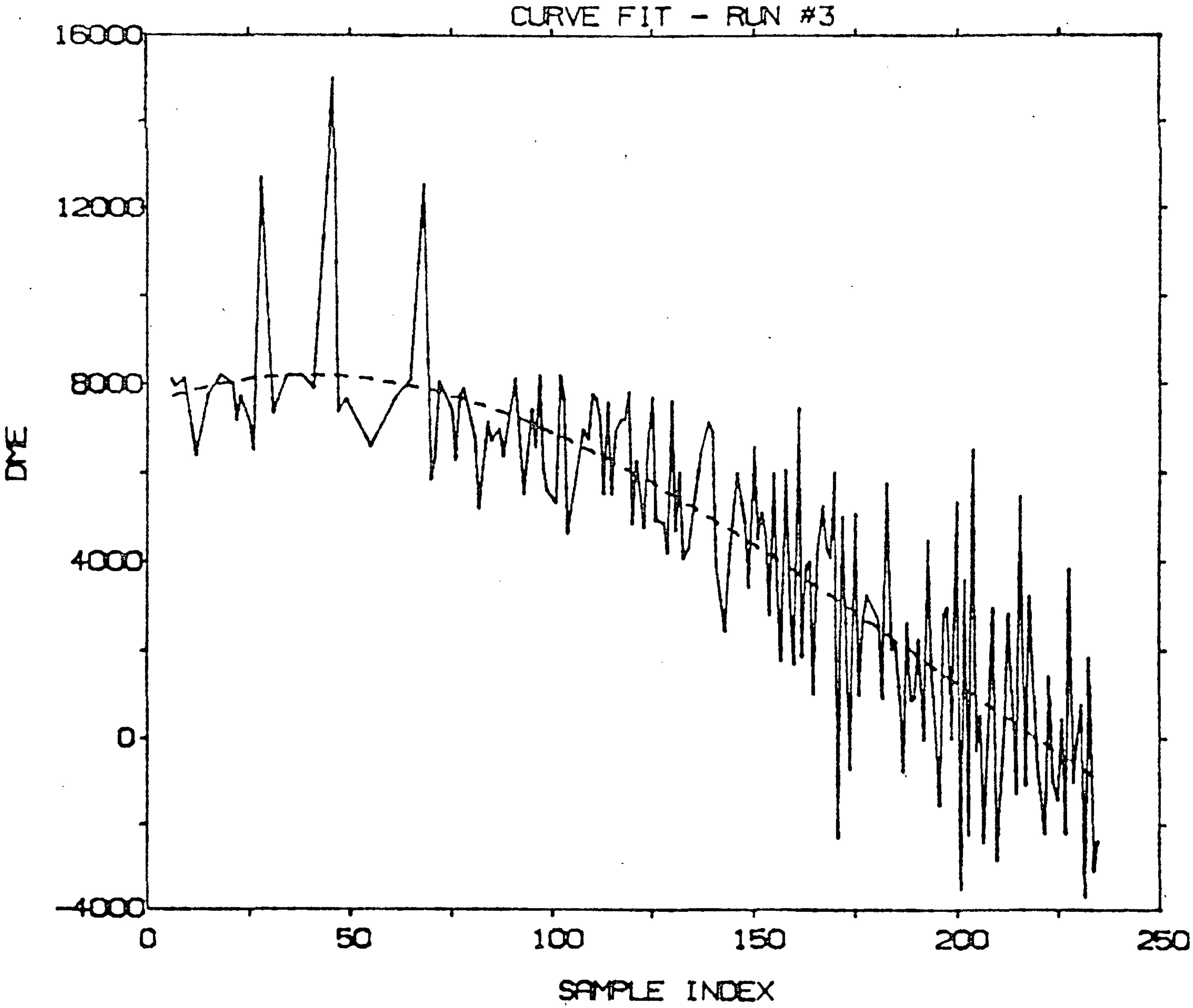

CURVE FIT - RUN #3
16000
12000
8000
4000
0
-4000
DME
0
50
100
150
200
250
SAMPLE INDEX

FIGURE 22

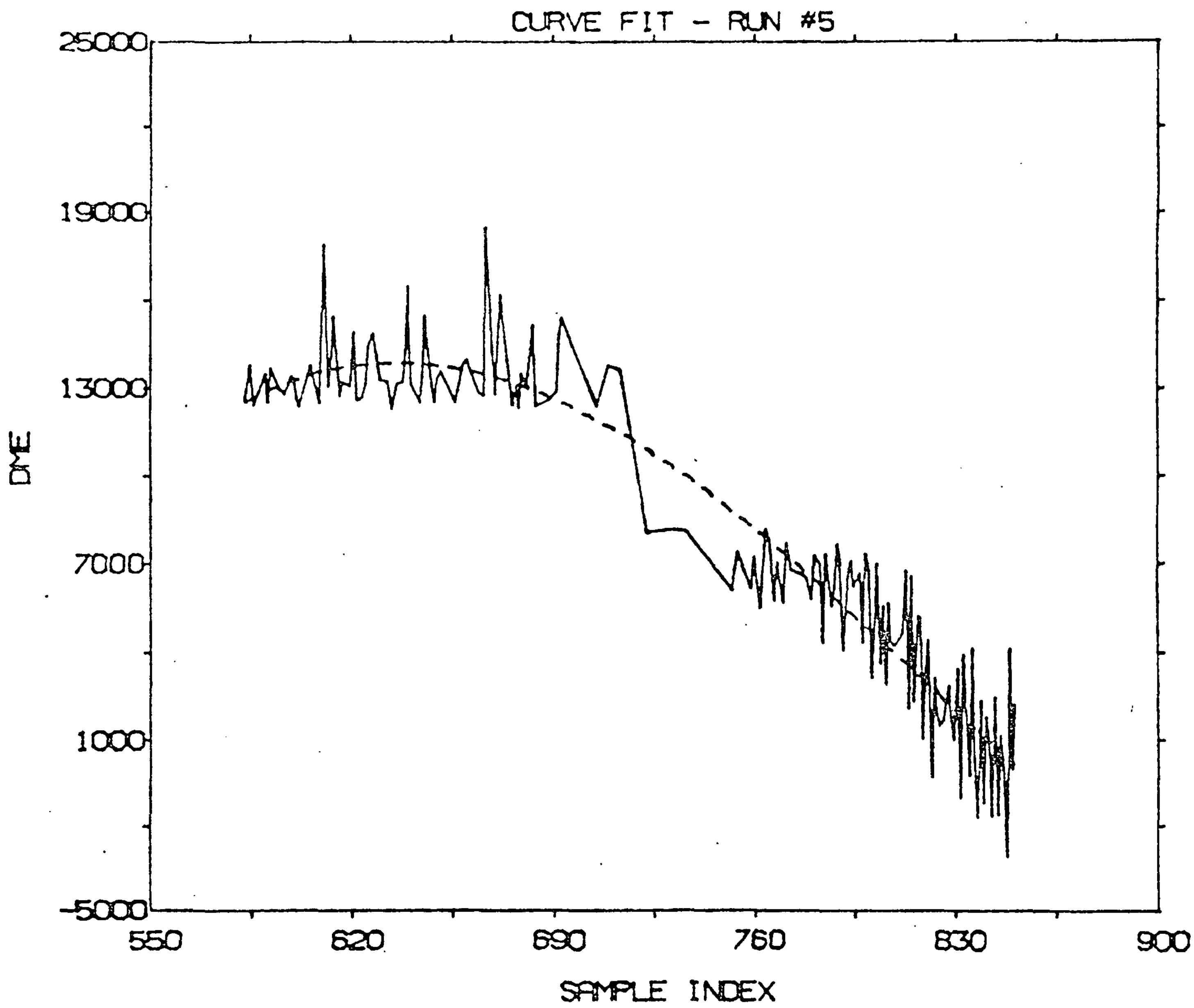

CURVE FIT - RUN #5
25000
19000
13000
7000
1000
-5000
DME
550
620
690
760
830
900
SAMPLE INDEX

FIGURE 23

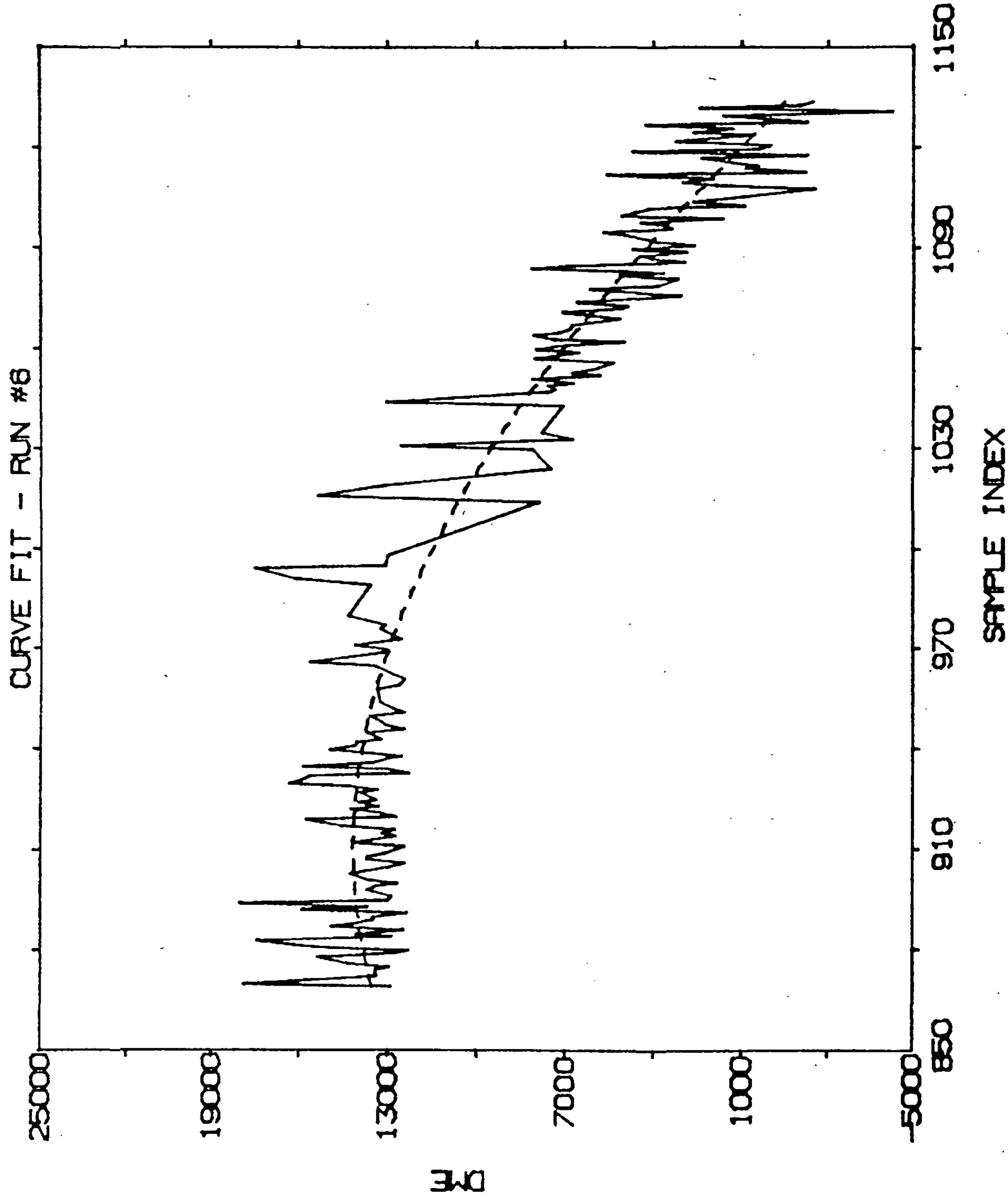
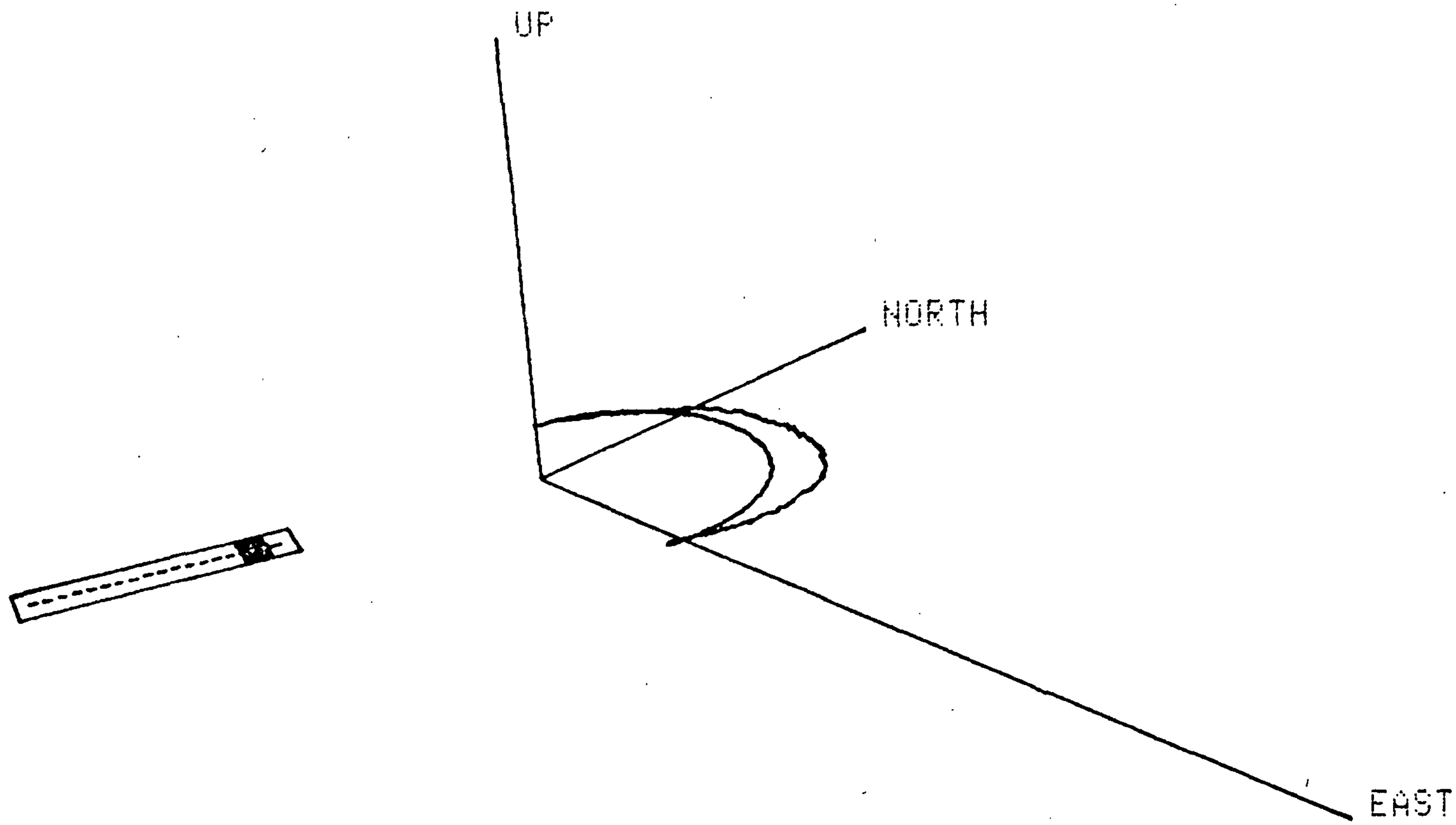

CURVE FIT - RUN #6
DME
25000
19000
13000
7000
1000
-5000
850
910
970
1030
1090
1150
SAMPLE INDEX

FIGURE 24

Computer Constructed Curve - Run #9 in Three-Dimensional Space

PILOT : SANDLIN

APRIL 1980



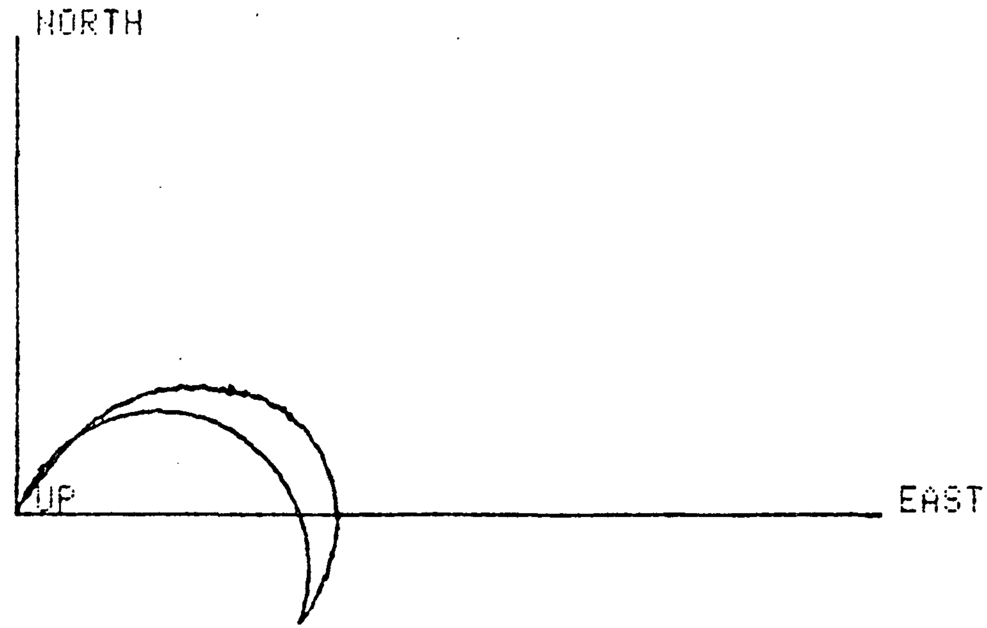
RUN NUMBER : 9
TURBULENCE : LIGHT
GRADE : 2
INITIAL DME : 5395 FT.

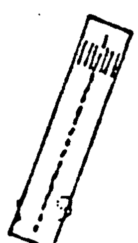
RUNWAY HEADING : 200
TERMINAL ALTITUDE : 897 FT.
GLIDE SLOPE : 3 DEGREES
INITIAL ALTITUDE : 1200 FT.

FIGURE 25

Overhead Projection of Computer Constructed Curve - Run #9

PILOT : SANDLIN APRIL 1980





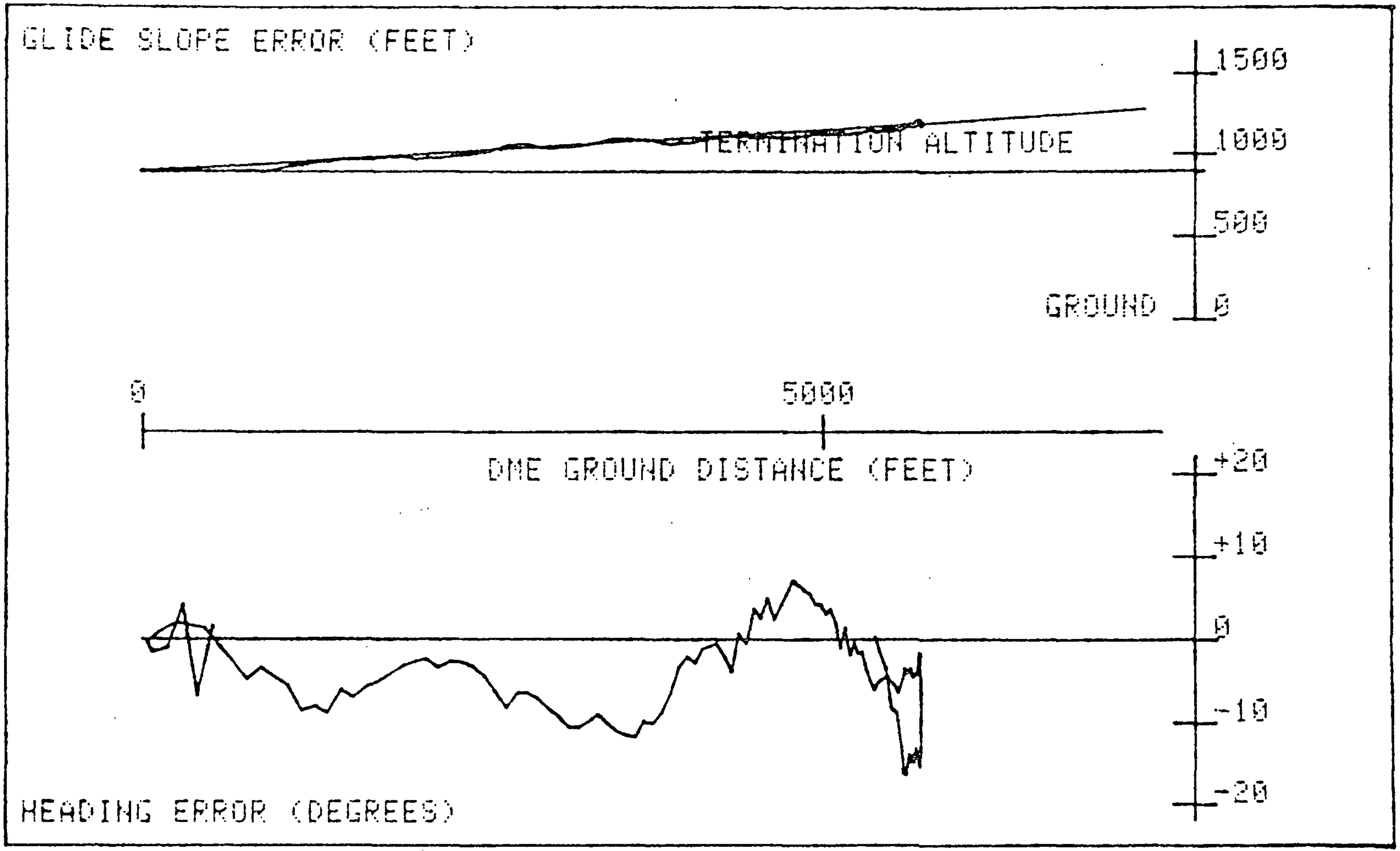
RUN NUMBER : 9
TURBULENCE : LIGHT
GRADE : 2
INITIAL DME : 5395 FT.

RUNWAY HEADING : 200
TERMINAL ALTITUDE : 897 FT.
GLIDE SLOPE : 3 DEGREES
INITIAL ALTITUDE : 1200 FT.

FIGURE 26

Glide Slope and Heading Errors for Computer Constructed Curve - Run #9

PILOT : SANDLIN APRIL 1980



RUN NUMBER : 9
TURBULENCE : LIGHT
GRADE : 2
INITIAL DME : 5395 FT.

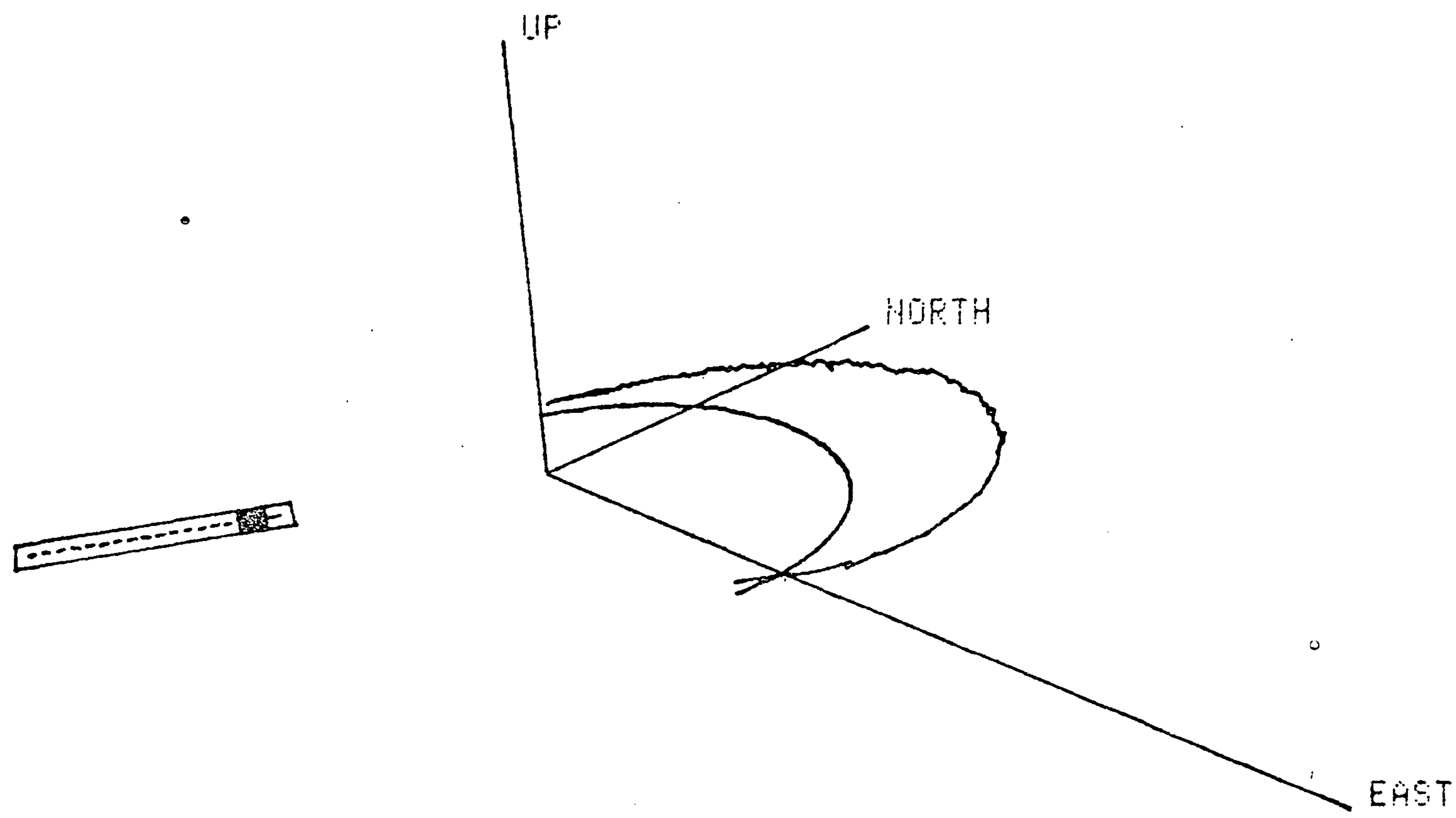
RUNWAY HEADING : 200
TERMINAL ALTITUDE : 897 FT.
GLIDE SLOPE : 3 DEGREES
INITIAL ALTITUDE : 1200 FT.

FIGURE 27

Computer Constructed Curve - Run #3 in Three Dimensional Space

PILOT : SANDLIN

APRIL 1980



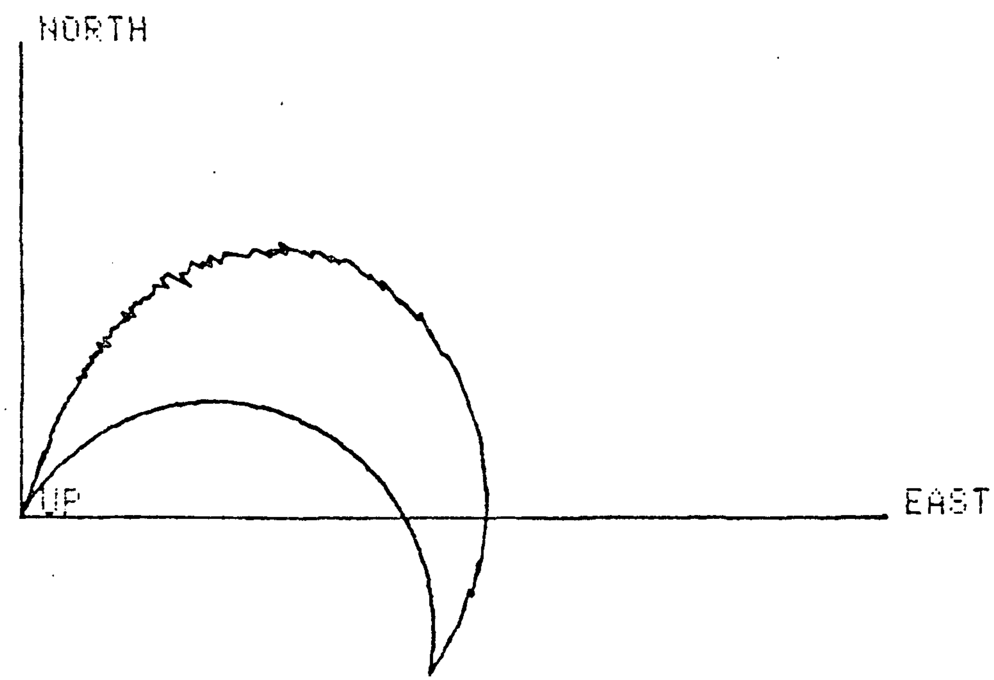
RUN NUMBER : 3
TURBULENCE : MODERATE
GRADE : 2
INITIAL DME : 7743 FT.

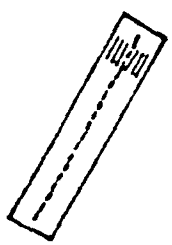
RUNWAY HEADING : 210
TERMINAL ALTITUDE : 995 FT.
GLIDE SLOPE : 3 DEGREES
INITIAL ALTITUDE : 1563 FT.

FIGURE 28

Overhead Projection of Computer Constructed Curve - Run #3

PILOT : SANDLIN | APRIL 1980





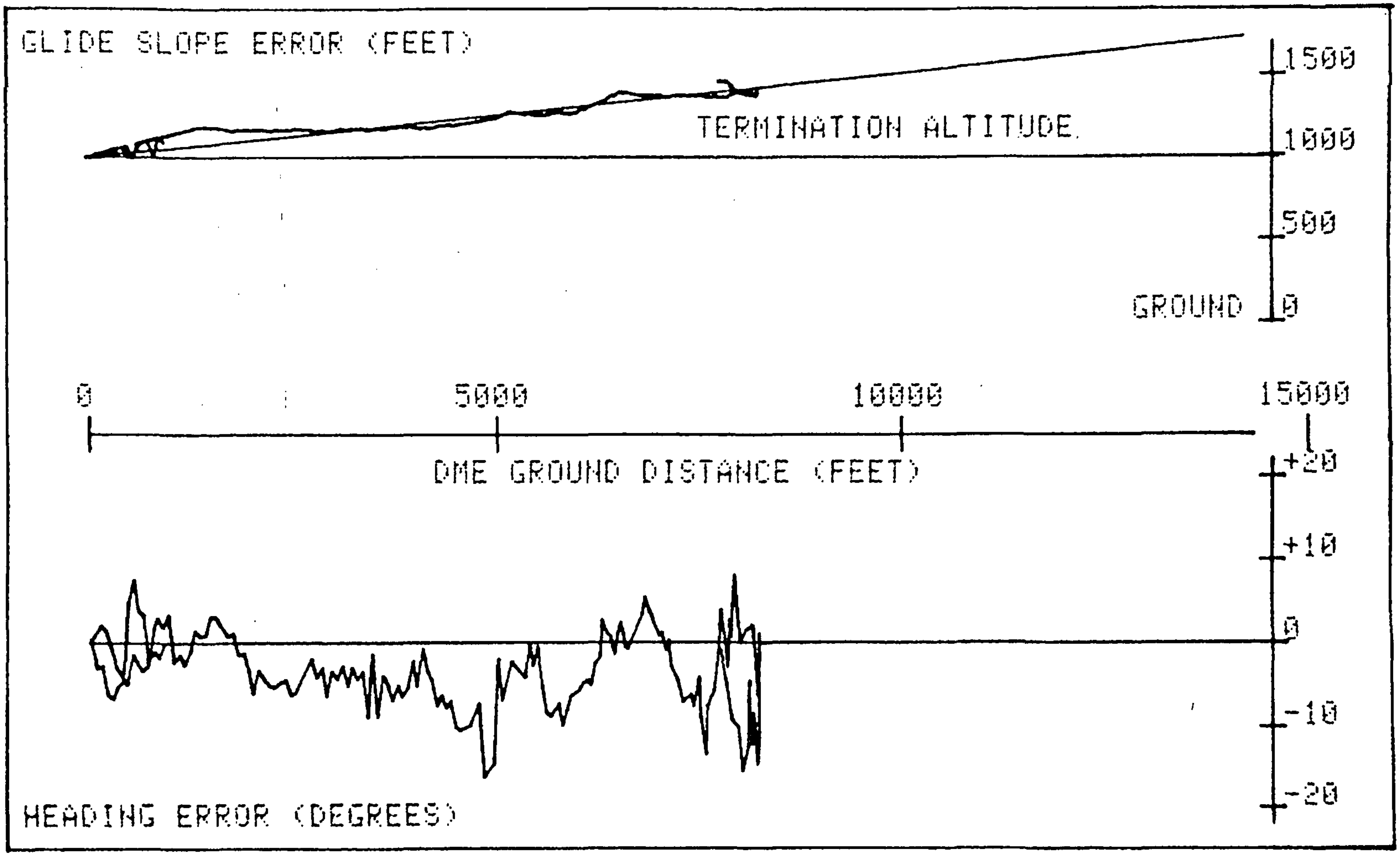
RUN NUMBER : 3
TURBULENCE : MODERATE
GRADE : 2
INITIAL DME : 7743 FT.

RUNWAY HEADING : 210
TERMINAL ALTITUDE : 995 FT.
GLIDE SLOPE : 3 DEGREES
INITIAL ALTITUDE : 1563 FT.

FIGURE 29

Glide Slope and Heading Errors for Computer Constructed Curve - Run #3

PILOT : SANDLIN APRIL 1980



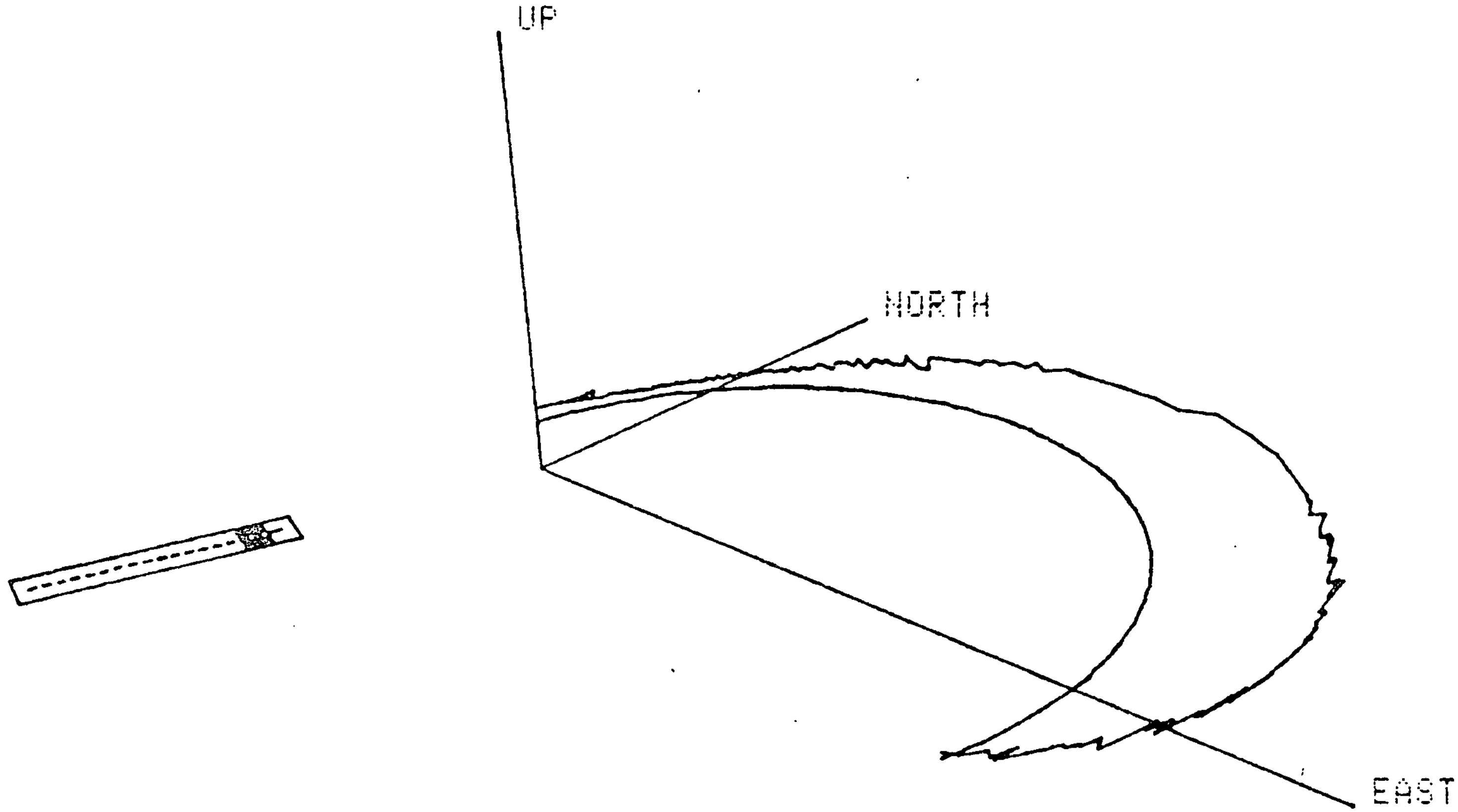
RUN NUMBER : 3
TURBULENCE : MODERATE
GRADE : 2
INITIAL DME : 7743 FT.

RUNWAY HEADING : 210
TERMINAL ALTITUDE : 995 FT.
GLIDE SLOPE : 3 DEGREES
INITIAL ALTITUDE : 1563 FT.

FIGURE 30

Computer Constructed Curve - Run #5 in Three-Dimensional Space

PILOT : SANDLIN APRIL 1980



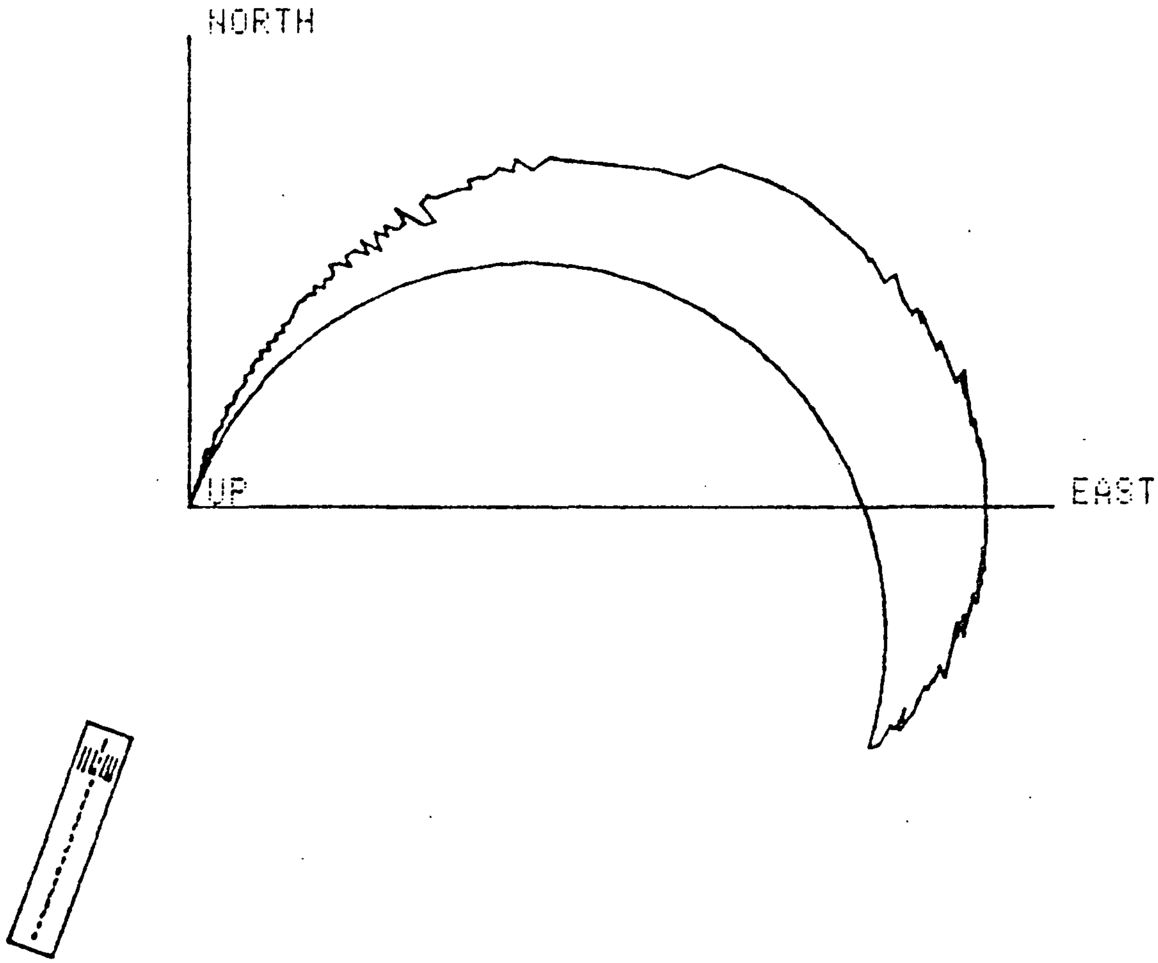
RUN NUMBER : 5
TURBULENCE : LIGHT
GRADE : 2
INITIAL DME : 12570 FT.

RUNWAY HEADING : 200
TERMINAL ALTITUDE : 794 FT.
GLIDE SLOPE : 3 DEGREES
INITIAL ALTITUDE : 1522 FT.

FIGURE 31

Overhead Projection of Computer Constructed Curve - Run #5

PILOT : SANDLIN APRIL 1980



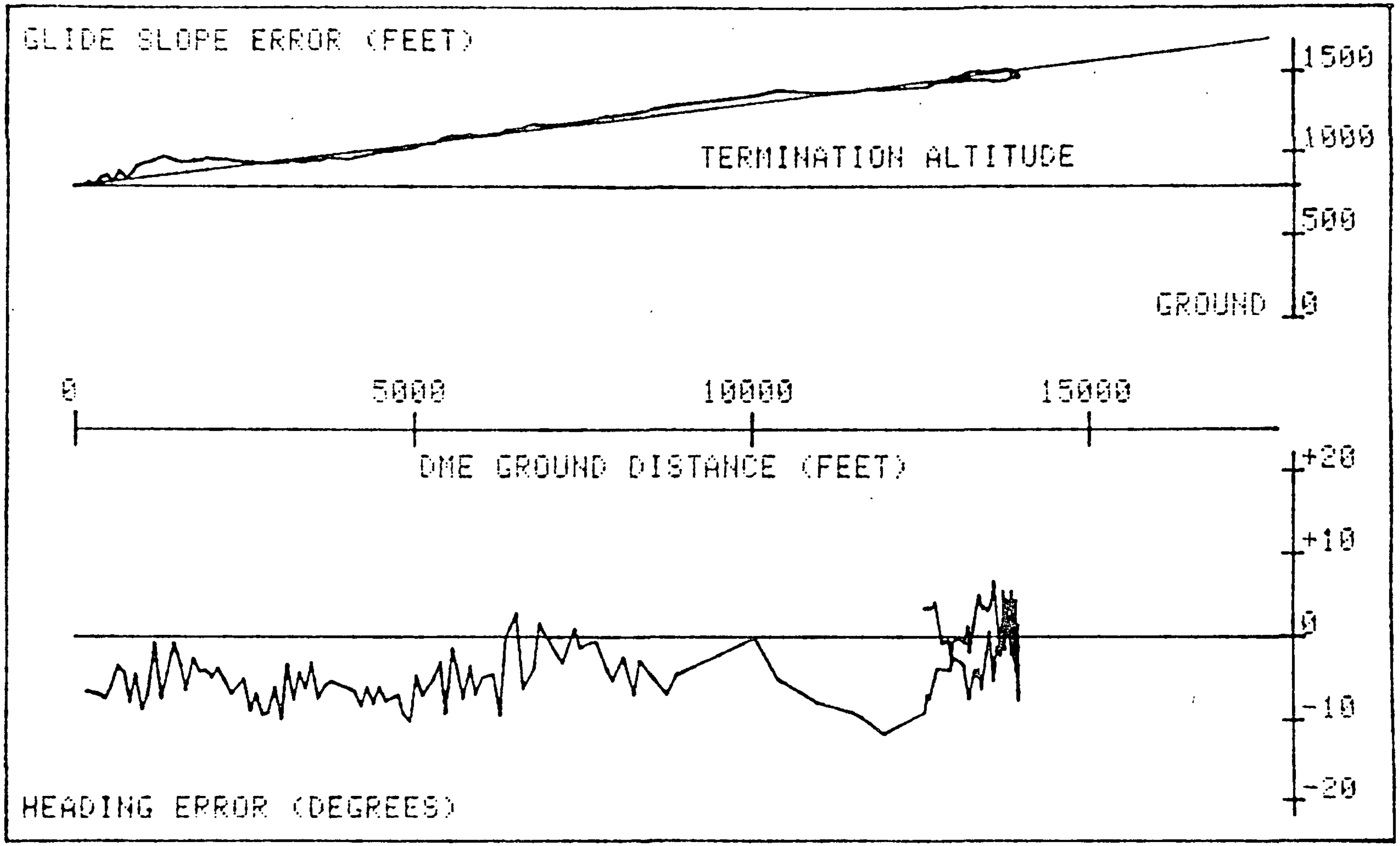
RUN NUMBER : 5
TURBULENCE : LIGHT
GRADE : 2
INITIAL DME : 12570 FT.

RUNWAY HEADING : 200
TERMINAL ALTITUDE : 794 FT.
GLIDE SLOPE : 3 DEGREES
INITIAL ALTITUDE : 1522 FT.

FIGURE 32

Glide Slope and Heading Errors for Computer Constructed Curve - Run #5

PILOT : SANDLIN APRIL 1980



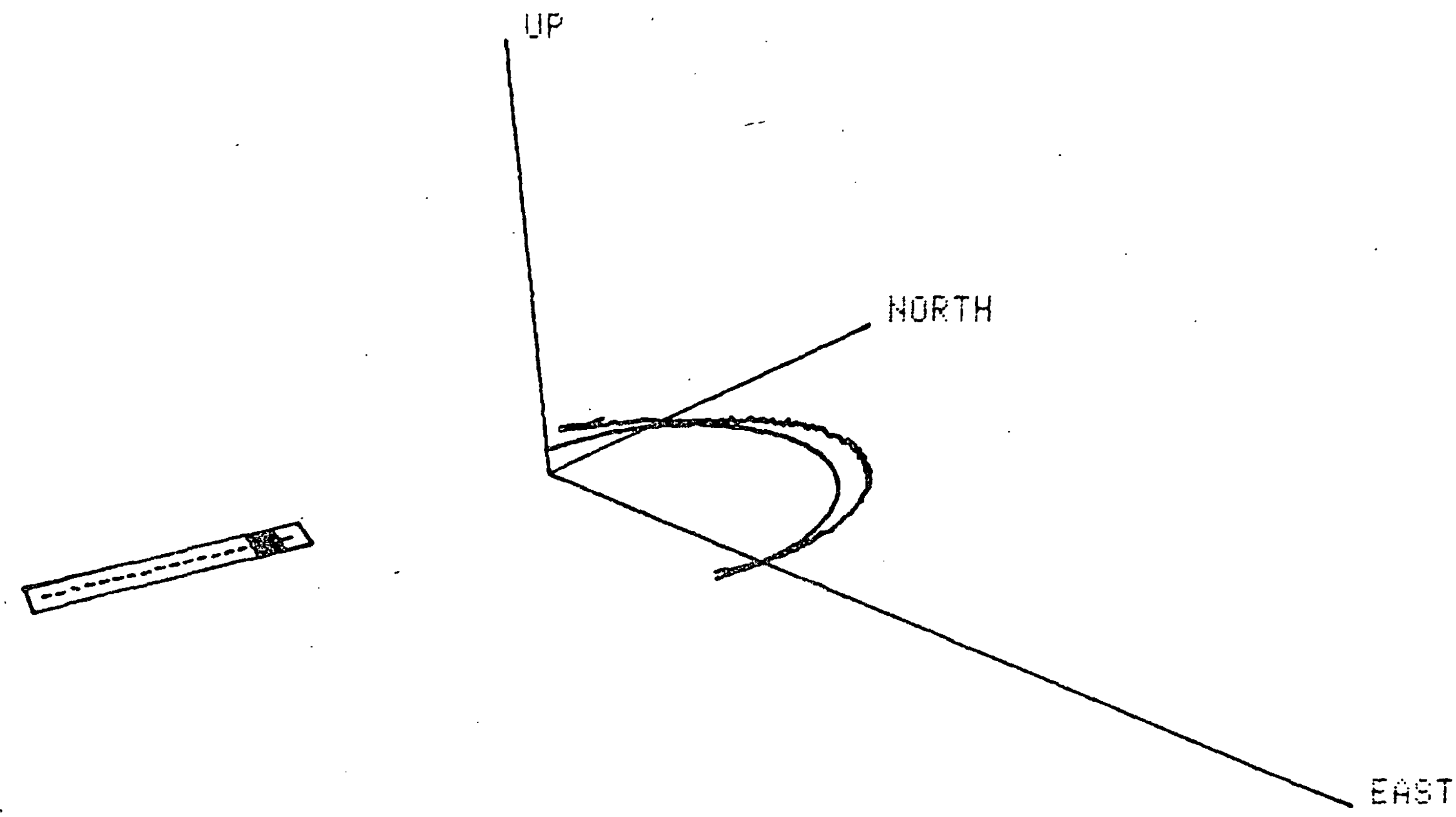
RUN NUMBER : 5
TURBULENCE : LIGHT
GRADE : 2
INITIAL DME : 12570 FT.

RUNWAY HEADING : 200
TERMINAL ALTITUDE : 794 FT.
GLIDE SLOPE : 3 DEGREES
INITIAL ALTITUDE : 1522 FT.

FIGURE 33

Computer Constructed Curve - Run #11 in Three-Dimensional Space

PILOT : SANDLIN APRIL 1980



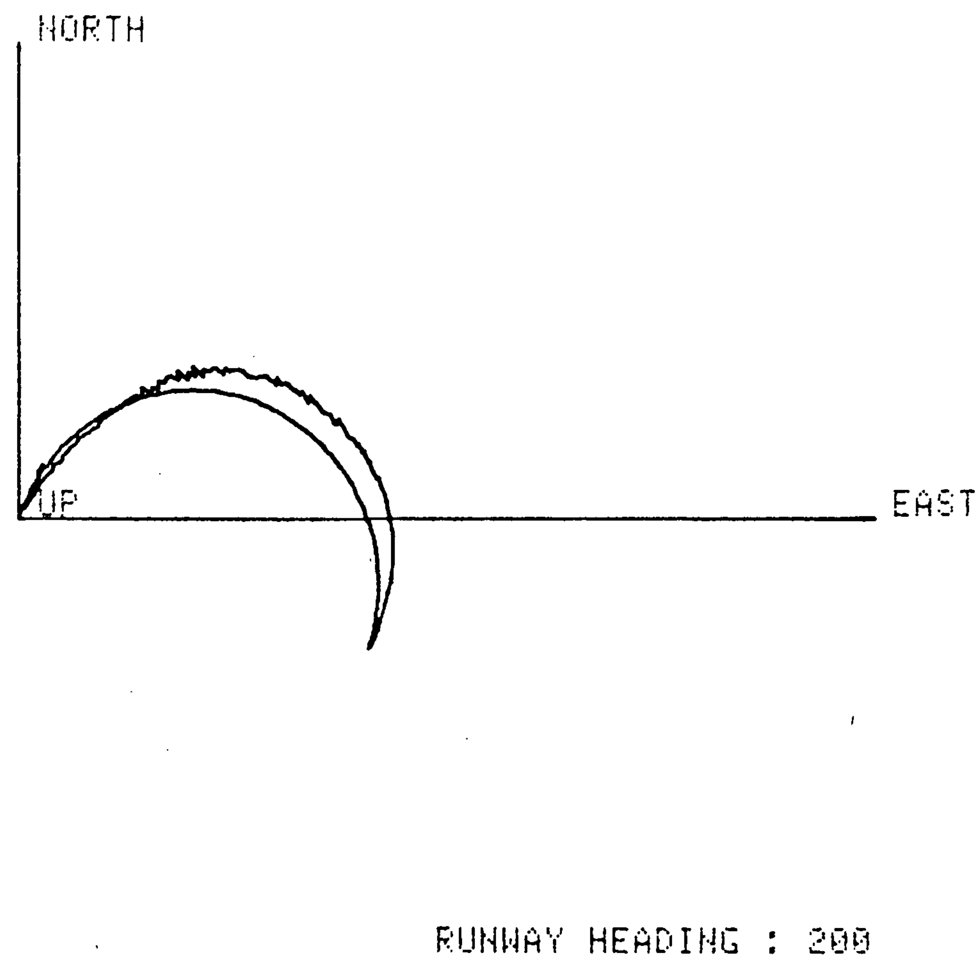
RUN NUMBER : 11
TURBULENCE : LIGHT
GRADE : 3
INITIAL DME : 6621 FT.

RUNWAY HEADING : 200
TERMINAL ALTITUDE : 397 FT.
GLIDE SLOPE : 6 DEGREES
INITIAL ALTITUDE : 1173 FT.

FIGURE 34

Overhead Projection of Computer Constructed Curve - Run #11

PILOT : SANDLIN APRIL 1980



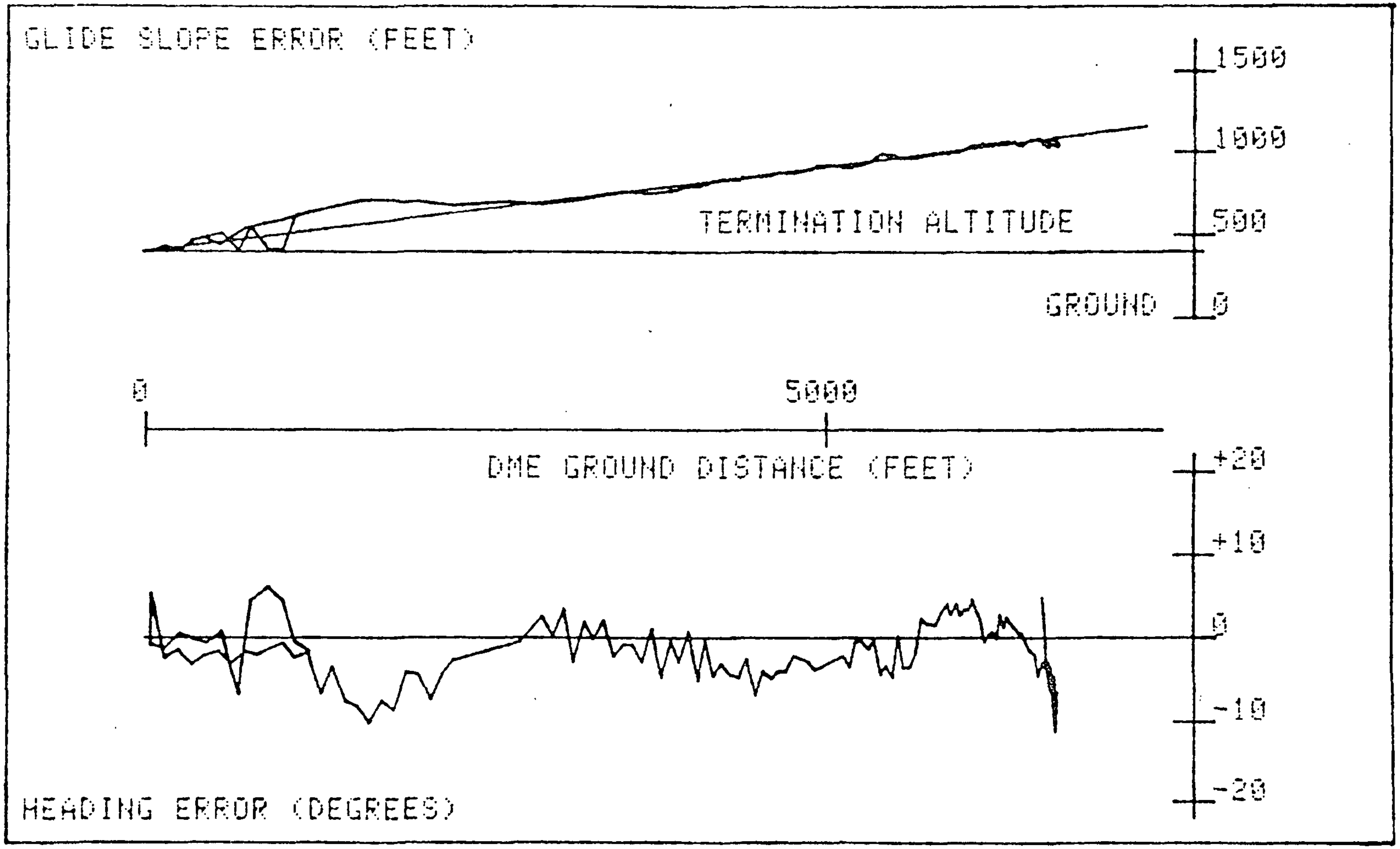
RUN NUMBER : 11
TURBULENCE : LIGHT
GRADE : 3
INITIAL DME : 6621 FT.

RUNWAY HEADING : 200
TERMINAL ALTITUDE : 397 FT.
GLIDE SLOPE : 6 DEGREES
INITIAL ALTITUDE : 1173 FT.

FIGURE 35

Glide Slope and Heading Errors for Computer Constructed Curve - Run #11

PILOT : SANDLIN APRIL 1980



RUN NUMBER : 11

TURBULENCE : LIGHT

GRADE : 3

INITIAL DME : 6621 FT.

RUNWAY HEADING : 200

TERMINAL ALTITUDE : 397 FT.

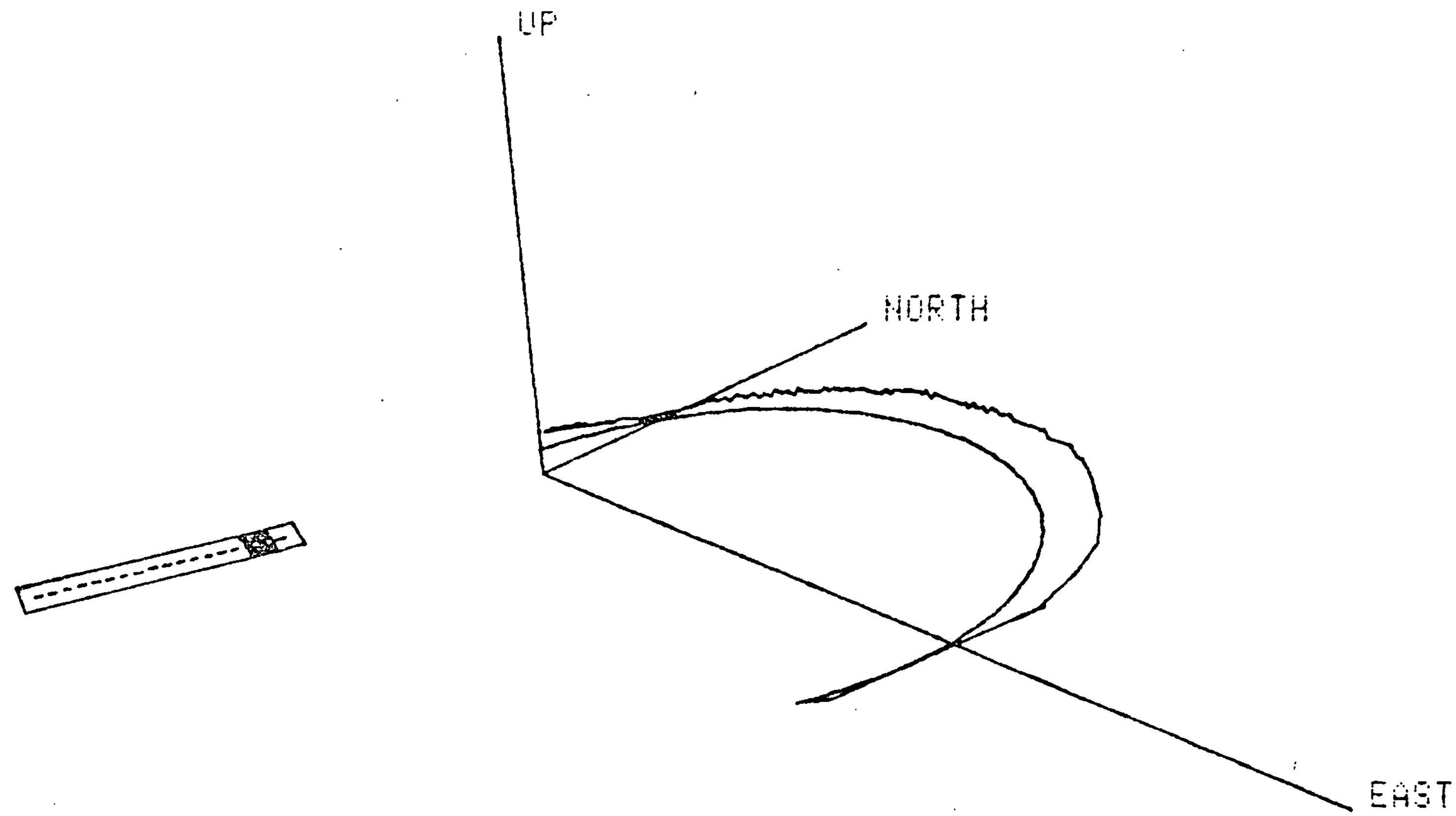
GLIDE SLOPE : 6 DEGREES

INITIAL ALTITUDE : 1173 FT.

FIGURE 36

Computer Constructed Curve - Run #8 in Three-Dimensional Space

PILOT : SANDLIN APRIL 1990



RUN NUMBER : 8
TURBULENCE : LIGHT
GRADE : 3
INITIAL DME : 10667 FT.

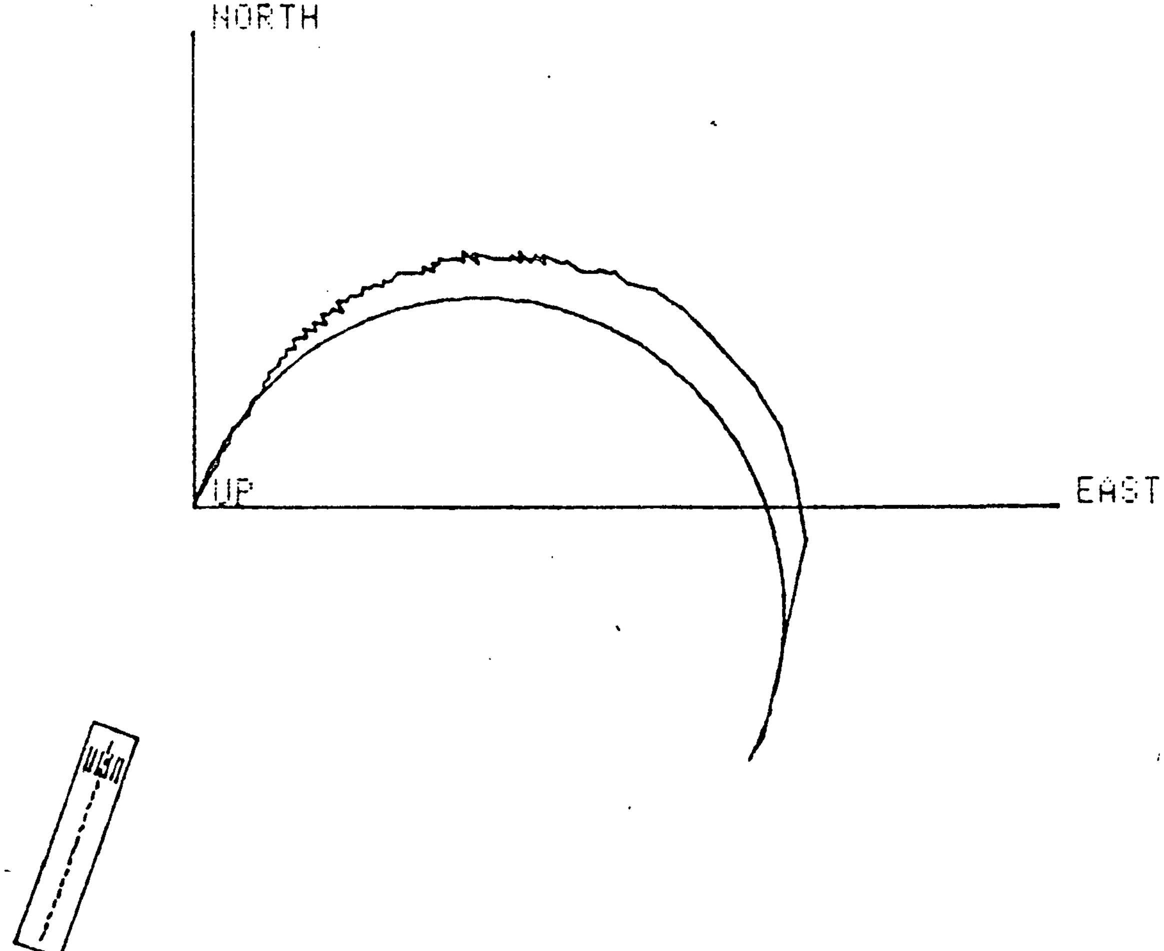
RUNWAY HEADING : 200
TERMINAL ALTITUDE : 397 FT.
GLIDE SLOPE : 6 DEGREES
INITIAL ALTITUDE : 1512 FT.

FIGURE 37

Overhead Projection of Computer Constructed Curve - Run #8

PILOT : SANDLIN

APRIL 1980



RUN NUMBER : 8

TURBULENCE : LIGHT

GRADE : 3

INITIAL DME : 10667 FT.

RUNWAY HEADING : 200

TERMINAL ALTITUDE : 397 FT.

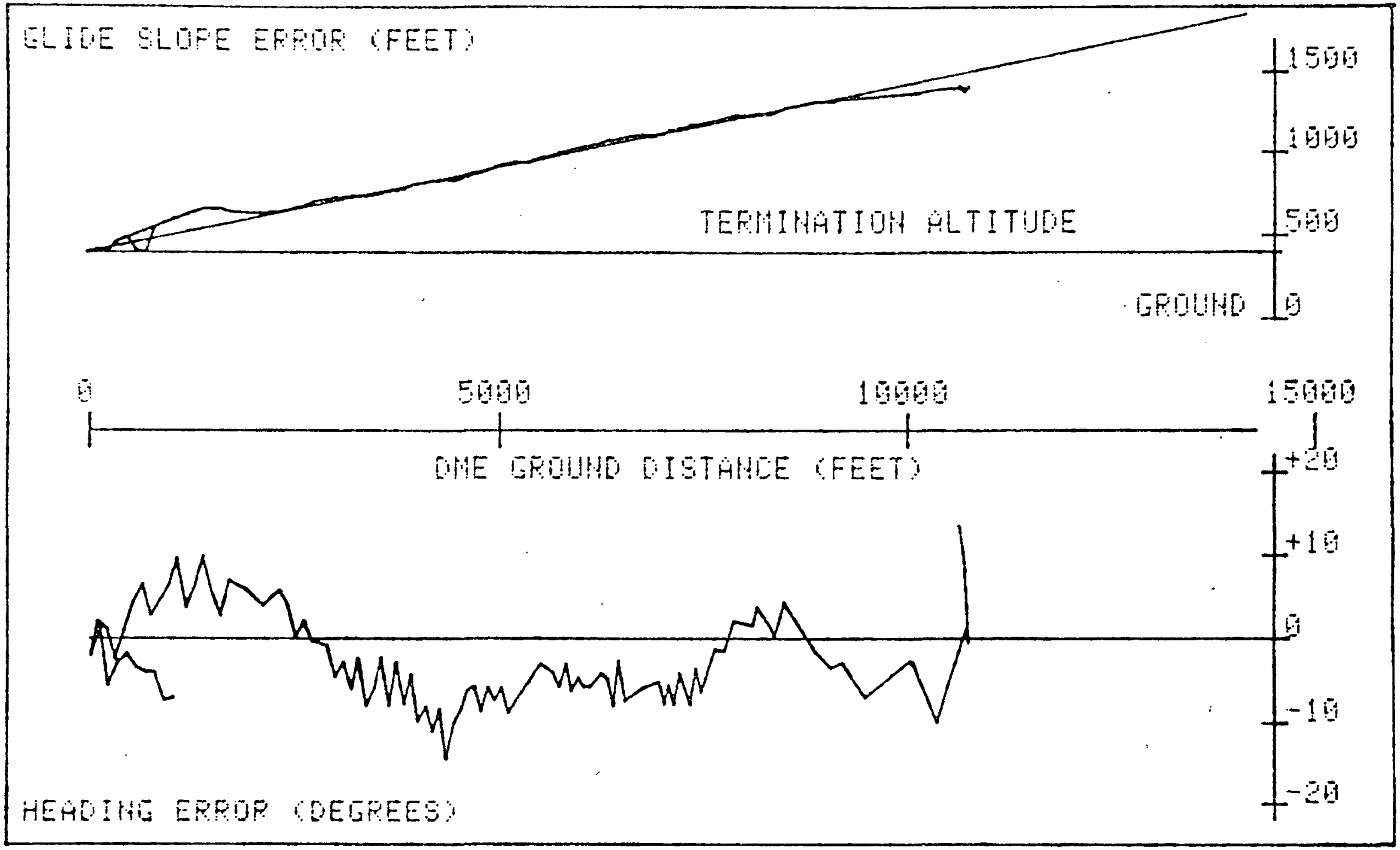
GLIDE SLOPE : 6 DEGREES

INITIAL ALTITUDE : 1512 FT.

FIGURE 38

Glide Slope and Heading Errors for Computer Constructed Curve - Run #8

PILOT : SANDLIN APRIL 1980



RUN NUMBER : 8

TURBULENCE : LIGHT

GRADE : 3

INITIAL DME : 10667 FT.

RUNWAY HEADING : 200

TERMINAL ALTITUDE : 397 FT.

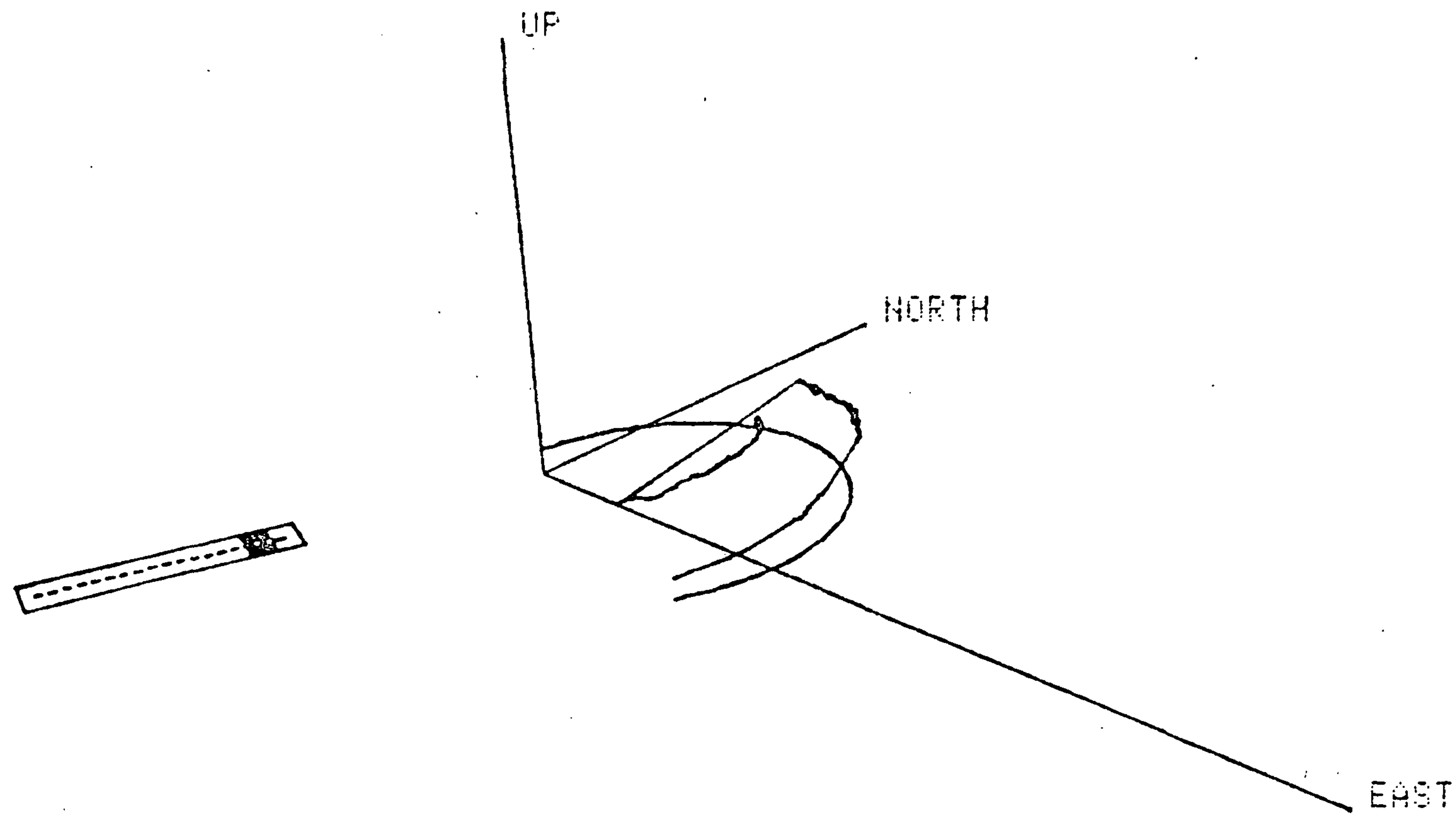
GLIDE SLOPE : 6 DEGREES

INITIAL ALTITUDE : 1512 FT.

FIGURE 39

Computer Constructed Curve - Run #15 in Three-Dimensional Space

PILOT : SCHLEIN | APRIL 1980



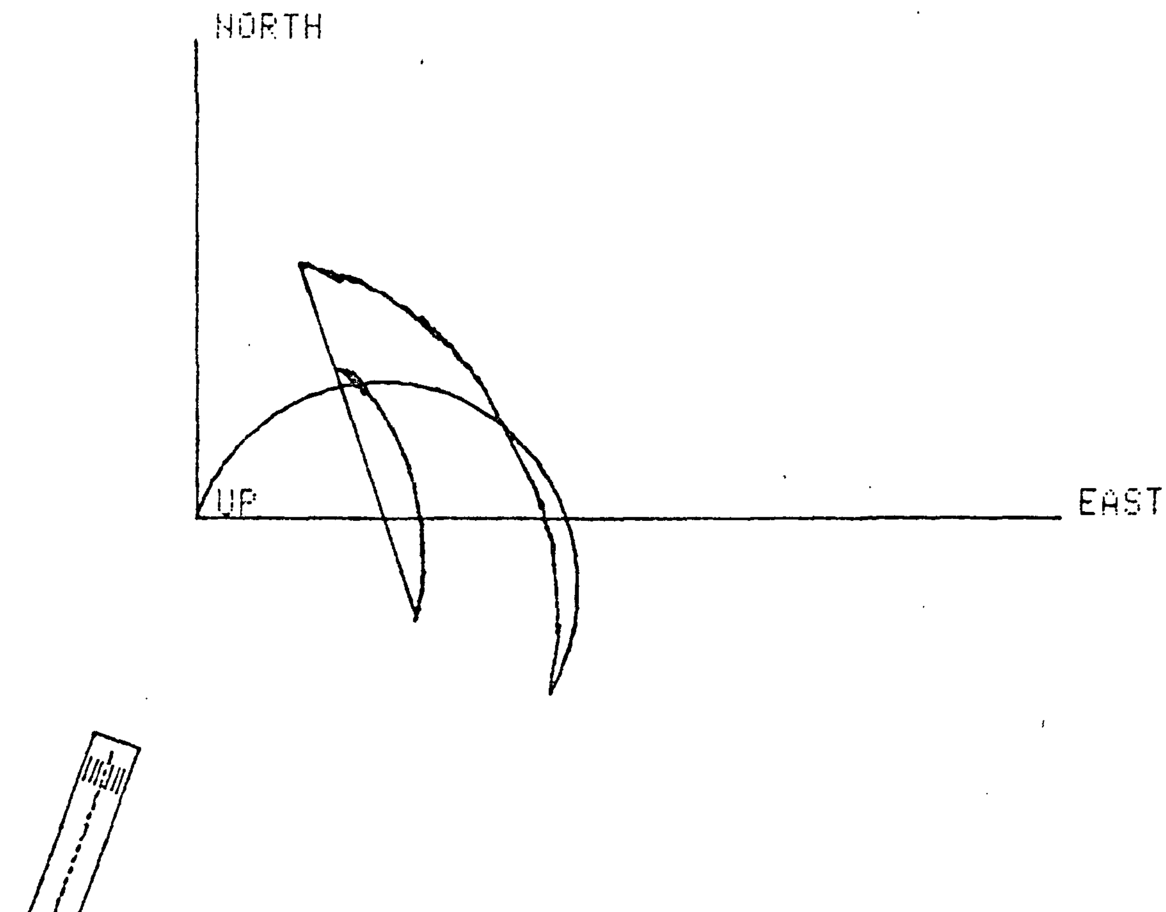
RUN NUMBER : 15
TURBULENCE : MODERATE
GRADE : 5
INITIAL DME : 6986 FT.

RUNWAY HEADING : 200
TERMINAL ALTITUDE : 397 FT.
GLIDE SLOPE : 6 DEGREES
INITIAL ALTITUDE : 1417 FT.

FIGURE 40

Overhead Projection of Computer Constructed Curve - Run #15

PILOT : SCHLEIN APRIL 1980



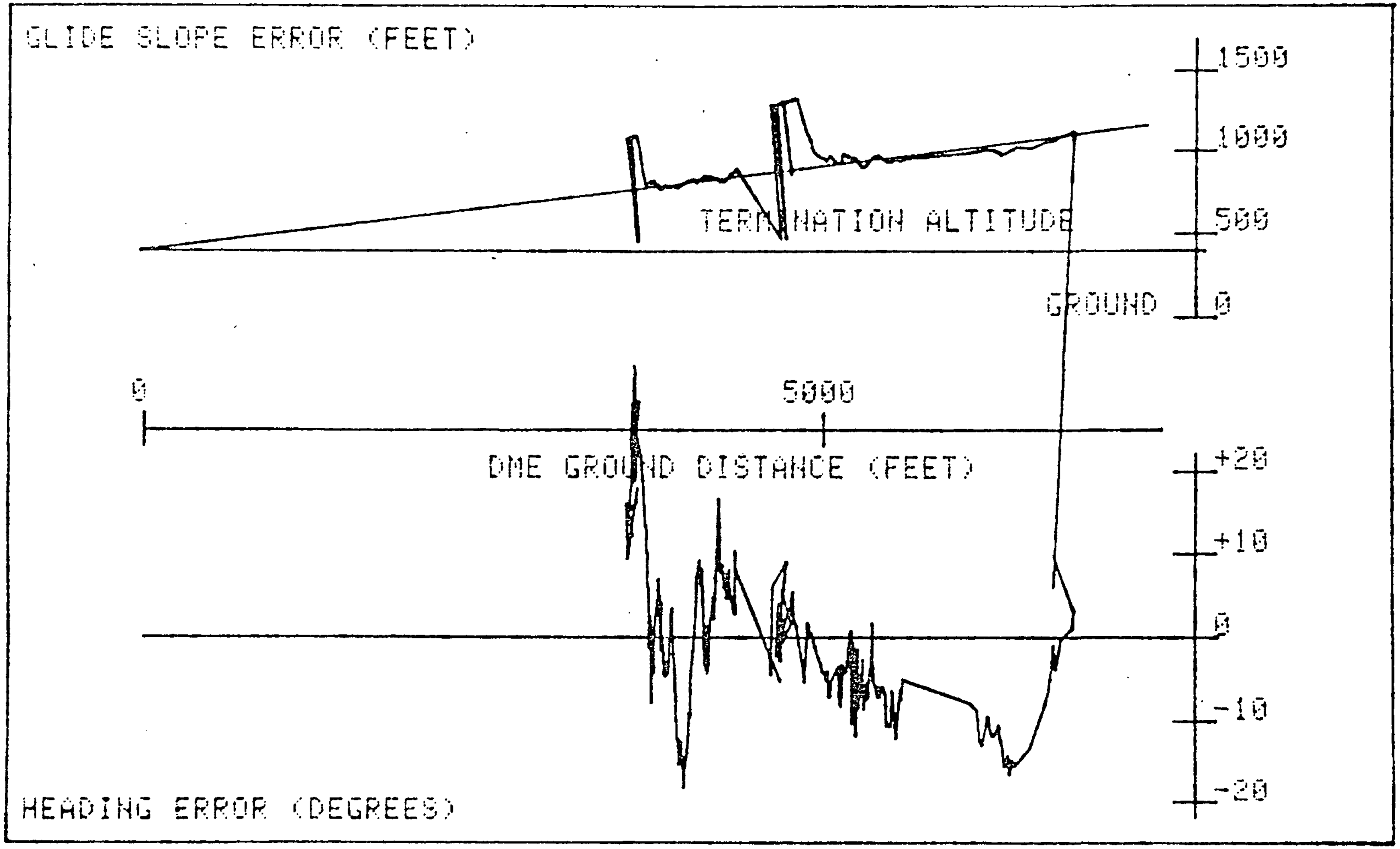
RUN NUMBER : 15
TURBULENCE : MODERATE
GRADE : 5
INITIAL DME : 6986 FT.

RUNWAY HEADING : 200
TERMINAL ALTITUDE : 397 FT.
GLIDE SLOPE : 6 DEGREES
INITIAL ALTITUDE : 1417 FT.

FIGURE 41

Glide Slope and Heading Errors for Computer Constructed Curve - Run #15

PILOT : SCHLEIN APRIL 1980



RUN NUMBER : 15

TURBULENCE : MODERATE

GRADE : 5

INITIAL DME : 6986 FT.

RUNWAY HEADING : 200

TERMINAL ALTITUDE : 397 FT.

GLIDE SLOPE : 6 DEGREES

INITIAL ALTITUDE : 1417 FT.

FIGURE 42

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