REPORT NUMBER
(CR-137594)

UNITED AIR LINES

Report of

ENGINEERING SIMULATION DEVELOPMENT AND EVALUATION

of the

TWO-SEGMENT NOISE ABATEMENT APPROACH

Conducted in the

B-727-222 FLIGHT SIMULATOR

PREPARED UNDER CONTRACT NAS 2-7208

of 14 November 1972

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Ames Research Center

Moffett Field, California

30 January 1974

(NASA-CR-137594) ENGINEERING SIMULATION DEVELOPMENT AND EVALUATION OF THE TWO-SEGMENT NOISE ABATEMENT APPROACH CONDUCTED IN THE B-727-222 FLIGHT SIMULATOR (United Air Lines, Inc.) 182 p
N75-18195
Unclas
G3/03 13515

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FOREWORD

This report is prepared in compliance with Article I, Task IIg of National Aeronautics and Space Administration Contract NAS 2-7208 of 14 November 1972. By mutual verbal agreement between the cognizant NASA/ARC and UAL technical principals, the requirements of Task IIg 6 are more appropriately the subject of a separate report covering the Guest Pilot Evaluation in both the simulator and aircraft. These results have been submitted as a separate report.

ENGINEERING SIMULATION EVALUATION

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ENGINEERING SIMULATION EVALUATION

INTRODUCTION

Previous studies and evaluations have explored numerous aspects of profile modification as a means of reducing ground level noise from jet aircraft in the landing approach. As a result, the technical feasibility and noise abatement potential of a two-segment approach have been well established.

The evaluation in the B-727-200 is a logical extension of the previous efforts. The broad objective is to determine whether approach profile modification can be safely adapted to the operational environment of routine air carrier service in a manner acceptable to the air carrier community and which is also effective in reducing ground level noise. It was felt that this objective required an investigation into anything which had an effect on the pilot/aircraft combination or on the profile geometry.

The flight simulator was the logical place to accomplish the initial profile and procedures development tasks. The United Air Lines B-727-222 flight simulator was modified to incorporate the special cockpit hardware which would be in the prototype airplane installation. The two-segment system operational and aircraft interface logic was accurately emulated in software. Programs were developed to permit data to be recorded in real time on the line printer, a 14-channel oscillograph and an X-Y Plotter.

This report describes the two-segment profile and procedures which were developed in the Engineering Simulation Evaluation. Emphasis in this phase was upon operational concepts and constraints. The findings influenced the ultimate system design and aircraft interface. The appendices describe the two-segment system operational logic and the flight simulator capabilities in detail.

SUMMARY

The Engineering Simulation Evaluation was conducted from 10 October - 30 November 1972. It required approximately 160 hours of simulator flying time and involved 42 periods ranging from 1.5 to 6 hours in length. Comprehensive test matrices which became progressively more complex resulted in the establishment of a tentatively optimum profile. This phase of the evaluation also established the practical limits within which the profile parameters and certain crew procedures would be varied in the flight evaluation in the airplane in order to verify or modify the simulation profile as necessary.

Prior to commencing work in the simulator, detailed analyses of normal system operation and pilot/system interface and of the primary and secondary effects of system failures were conducted. The simulator had been accurately programmed to emulate the two-segment system logic and the aircraft interface. Thorough testing of all normal and abnormal conditions resulted in a high degree of confidence that the same results would be seen in the prototype airplane installation.

The basic procedures were first developed under simulated average conditions of operating weights, center of gravity and environmental factors. They were then tested under a wide range of precisely varied environmental and operating conditions to determine whether these variances would affect the two-segment approach differently from the standard ILS procedure under the same conditions.

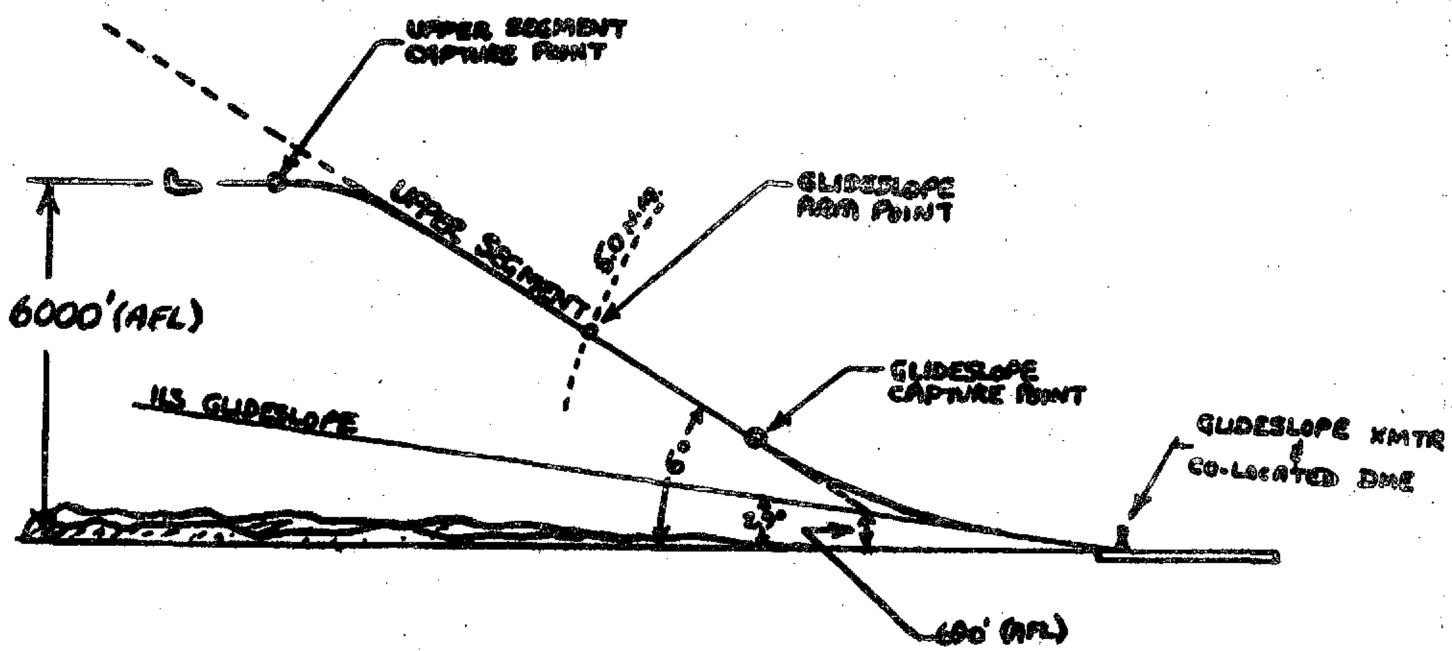
The optimum profile and practical variation limits developed in the simulator were:

Parameter	Optimum	Variation Limits
Upper Segment Angle	6°	$5.2^{\circ} - 6.5^{\circ}$
Lower Intersect Altitude '(AFL)	690' (2.9° G/S)	500-1000'(AFL)
Upper Segment Transition Time	17 Seconds	15-25 Seconds
Glideslope Transition Time	24 Seconds	18-30 Seconds
Upper Segment Intercept Altitudes	-	3000'(AFL)-12000'(MSL)*

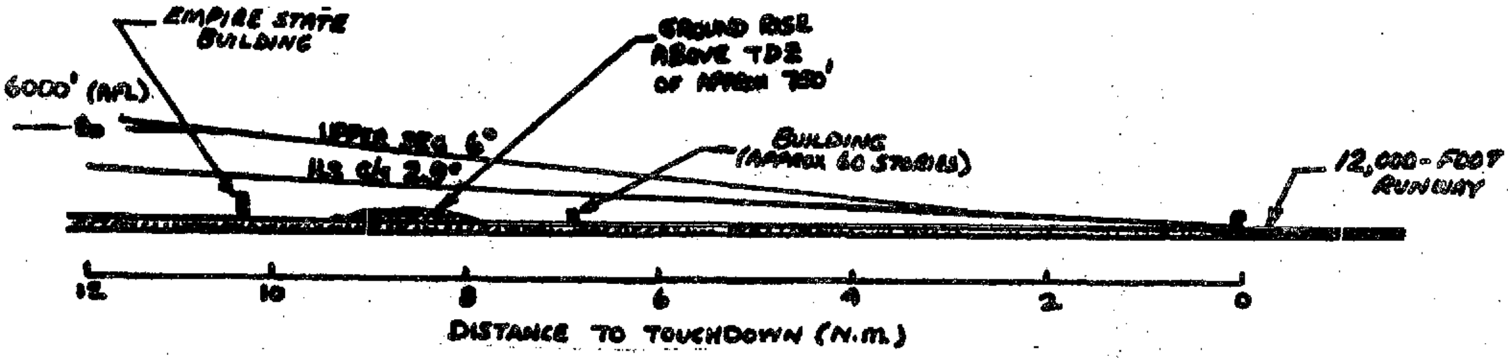
*NOTE: The 12000'(MSL) limit was dictated by the limits of the baro correction pot installed in the prototype airplane installation. It is not considered a valid operational limitation with an industry-acceptable altimetry interface.

The procedure is adaptable to a reasonably wide range of airspeed and configuration scheduling in the initial portions of the approach. For safety, repeatability and pilot workload reasons, it is necessarily less flexible from glideslope capture point onward for the same reasons that the standard ILS becomes more structured after glideslope capture. The principal operational constraints which limited initial approach flexibility are that the pilot should enter the transition to upper segment at an altitude and airspeed which permits stabilization on upper segment at upper segment target airspeed prior to reaching glideslope capture point, and that this portion of the approach does not require significantly greater or different crew workload or piloting techniques from the standard ILS transition and stabilization. The evaluation resulted in an optimum condition for a 3000'(AFL) entry from level flight, 160 KIAS, flaps 5° with an upper segment stabilized condition of Vref +15, gear down, flaps 30° by 300-500' below initial entry altitude. Entry at 3000'(AFL) should not exceed 190 KIAS in a no-wind condition. Entry below 3000'(AFL) did not permit adequate time for stabilization on the upper segment. The higher the entry altitude, the more flexible the entry conditions become, recognizing that pilot workload between entry and upper segment stabilization are directly related to the length of the upper segment. This is the same situation that the pilot faces today in an ILS transition made under a wide variation of entry airspeed, flap and landing gear configuration.

The simulation evaluation showed that the flight simulator is an indispensable part of a development program of this nature and magnitude. Not only does it permit the safe and deliberate consideration of all facets of the problem, but it is also the only way in which conditions can be exactly set or varied by any desired amount. It also significantly shortens the overall program time and significantly reduces the flying time required in the evaluation airplane.



2-SEGMENT PROFILE
(ANGLES EXAGGERATED - DIST. NOT TO SCALE)



2-SEGMENT PROFILE
(APPROXIMATELY TO SCALE)

FIGURE - 1

TWO-SEGMENT PROFILE AND COMMONLY USED TERMS

This and other reports and documents relating to the B-727 Two-Segment Noise Abatement Program use profile diagrams as a means of graphically illustrating certain ideas or concepts. These diagrams exaggerate the profile angles and will use different vertical vs horizontal distance scales in order to obtain clarity and to permit diagram labeling. These scaling and angular exaggerations tend to create the impression that the two-segment approach is much steeper than it actually is. Figure 1 shows the profile which has been developed and evaluated in the program. It is shown approximately to correct distance and angular scale below the exaggerated profile.

Frequent use will be made of a number of terms which have explicit meanings that are not necessarily self-evident. Where used, the terms appearing below will have the meanings shown unless otherwise noted in individual cases. Where additional basic information would be useful in understanding how the term relates to the system or procedure, that information also appears as part of the definition.

TERM	DEFINITION/RELATED INFORMATION
TWO-SEGMENT APPROACH	A guided landing approach profile consisting of an upper segment (6° for 727) and a lower segment which is the ILS glideslope for the runway to which the approach is being made (see Figure 1). The Captain's navigational system is configured for the approach when: (1) He places the two-segment selector switch in the "ARM" position and (2) The ILS for the approach runway is tuned and valid and (3) His DME is ON and valid and (4) All validity inputs required by the two-segment system are present. To obtain two-segment approach guidance he must have his flight director and/or autopilot in the respective auto approach mode(s).

TWO-SEGMENT SYSTEM

The two-segment system consists of:

(1) Collins special purpose units:
 (a) Two-Segment Computer
 (b) Switching Unit
 (c) Two-Segment Selector Switch ("ARM-OFF")
 (d) Airport Elevation Set Panel

(2) Aircraft components which provide computational/validity inputs to the two-segment computer:
 (a) Altimeter system capable of furnishing baro-corrected pressure altitude input to two-segment computer (computation/validity).
 (b) DME (computation/validity).
 (c) VHF NAV G/S Receiver (glideslope computation/validity for glideslope segment).

(3) Ground Equipment
 (a) DME co-located at glideslope transmitter.
 (b) Glideslope transmitter (essential for glideslope segment computation).

NOTE: The Flight Director, Autopilot and HSI and the ILS localizer are not parts of the system under this definition. Any and/or all are necessary in executing a two-segment approach; however it is important to recognize that the above airplane units are the users of the two-segment system output and are not vital to the system's performing its computational functions. The Flight Director and Autopilot receive and use the system output only when they are in their respective auto approach mode(s). The HSI vertical deviation display is coupled to the system output whenever the two-segment system is armed and valid, irrespective of the position of the Flight Director and/or Autopilot Mode Selectors.

ARMED AND VALID

The system is "armed and valid" when:

(1) The two-segment selector switch is in the "ARM" position and

(2) All two-segment switching unit relay logic checks are satisfactory and

(3) All aircraft component validity inputs above are present. Glideslope valid is not required for upper segment. The system cannot check inputs for reasonableness.

NOTE: Assuming required electrical power is available, the two-segment selector switch is solenoid-held in the "ARM" position when it is placed there by the pilot. It does not require satisfactory validity checks (2) and (3) above to remain in "ARM". It electrically trips out of the "ARM" position only if "GO-AROUND" is selected or if the parent 28VDC radio bus power fails. It can be manually tripped off by the pilot.

" ________ " CAPTURE

This term has the same connotation in the two-segment approach as LOC or glideslope capture in the standard ILS approach. The two-segment profile differs from the ILS in that it involves two distinct captures:

Upper Segment Capture - The point when approaching upper segment from below at which the transition maneuver from initial approach flight path to upper segment commences. This is signalled to the pilot by the change of the upper segment annunciator(s) from AMBER to GREEN. The flight director and/or autopilot will command the appropriate nose down maneuver.

Glideslope Capture - This is essentially identical to ILS glideslope capture from above. The "GLIDESLOPE" annunciator(s) change from AMBER to GREEN and the flight director and/or autopilot command the appropriate nose up maneuver to shallow the flight path from 6° (upper segment) to ILS glideslope angle.

Glideslope capture is further signalled to the pilot by the HSI vertical deviation display moving from centered (if A/C is centered on upper segment at this point) to some position approximately $1\frac{1}{2}$ dots below the centered position (aircraft above the glideslope) to indicate that the vertical deviation reference has switched from upper segment to glideslope. The bar will immediately begin movement back toward center as the airplane descends toward glideslope center.

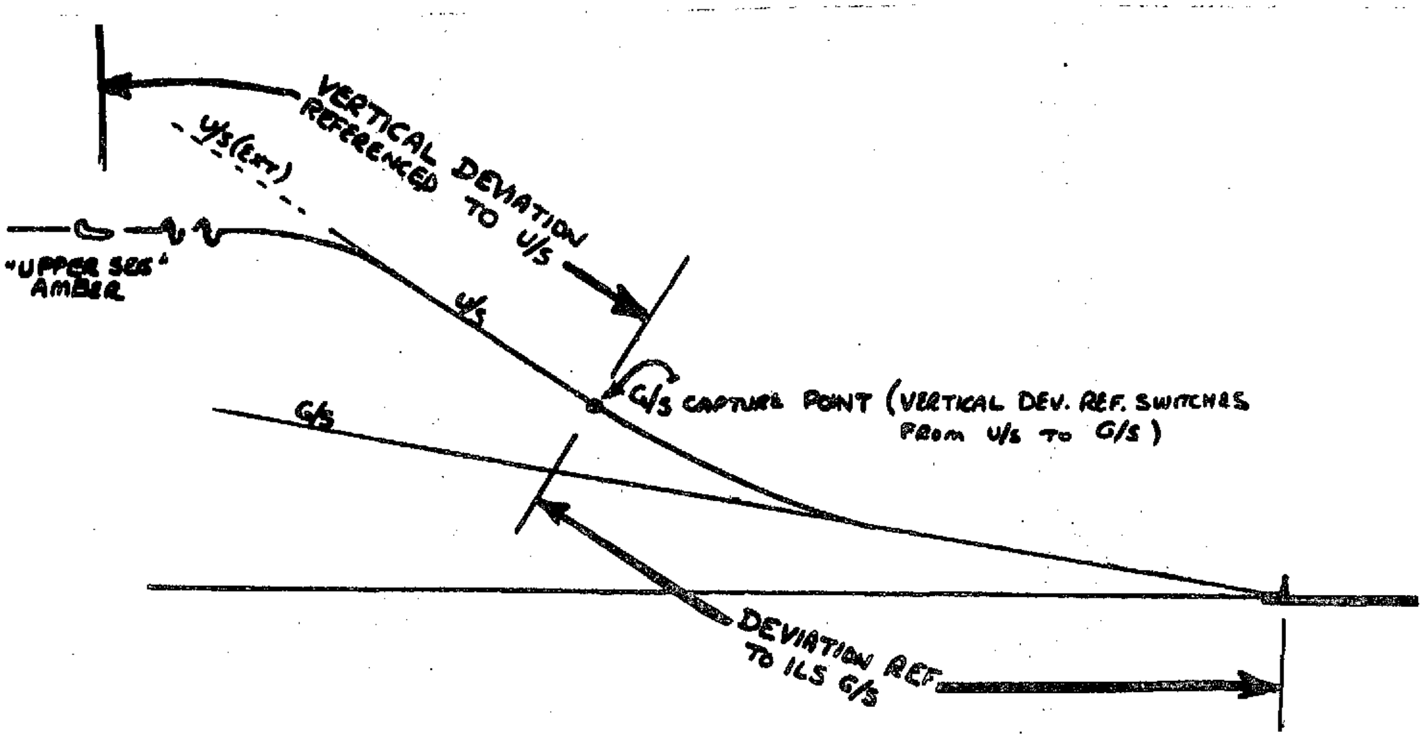
<u>VERTICAL DEVIATION REFERENCE</u> In the course of the two-segment approach, there are two vertical deviation references (see Figure below):

(1) Vertical deviation is referenced to upper segment from "UPPER SEGMENT" AMBER to Glideslope Capture Point. ("Glideslope GREEN")

(2) Vertical deviation is referenced to the ILS glideslope from glideslope capture point ("Glideslope" GREEN) for the remainder of the approach.

NOTE: Upper segment deviation is linear at 250'/dot.

Glideslope deviation is angular and exactly the same as standard ILS.



"ZERO DEVIATION" and "ON GLIDESLOPE"

The airplane is at zero deviation when it is on upper segment center and on glideslope when it is on ILS glideslope center.

"MIS-SET"

The term "mis-set" means that the signal value which the two-segment computer is receiving for its computational base is in error. A mis-set can be either the result of electro-mechanical error or it can result from the crew's mis-setting the airport elevation set panel and/or the baro correction on the altimeter. In either case, the system cannot check a signal value for reasonableness. The presence of any signal will be accepted by the computer and used at that value in computation.

PROFILE AND PROCEDURES DEVELOPMENT

Prior to commencing the work in the simulator, a thorough analysis of the system normal operational logic and system/pilot/aircraft interface was made. In addition, a comprehensive study of the effects of two-segment and related aircraft systems failures was conducted.

The first part of the simulator work was designed to investigate each individual variable while holding the others at some fixed value to determine:

(1) The effects of changing a given variable.

(2) The reasonable maximum and minimum value of the variable by observing that variations outside of this range introduced an unacceptable condition as to safety, repeatability, pilot workload or negligible reductions in ground level noise.

Having determined these effects and variation limits, the Project Pilot Team progressively combined the interrelated variables in order to narrow and eventually to optimize their values with respect to each other.

All of the systems failures were induced and carefully analyzed to determine that the principal effects were as expected and that they did not give rise to any other secondary effects which might not have been considered in the pre-simulator studies.

The final task was to combine all of the variables at their optimized values to derive the optimum profile and procedure. The profile with

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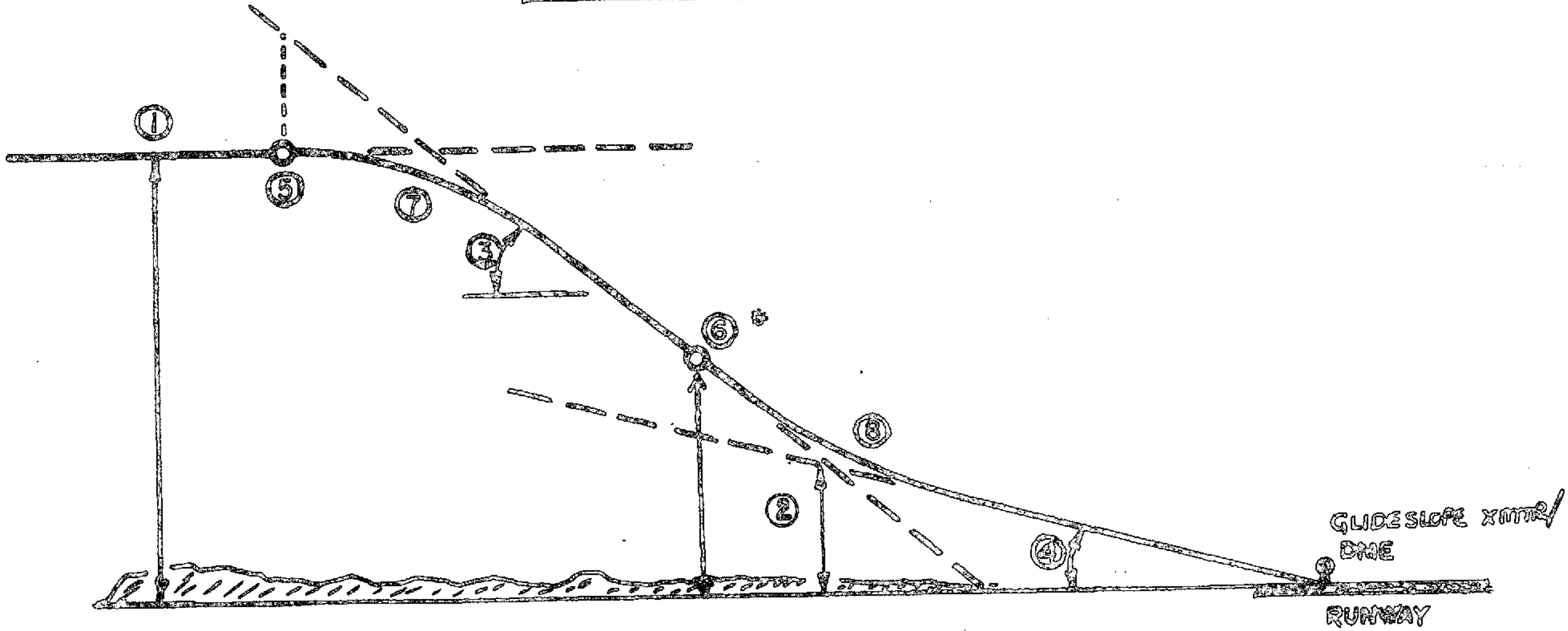
NOISE ABATEMENT APPROACH PROFILE
SIMULATION VARIABLES



1. UPPER SEGMENT INTERCEPT ALTITUDE
2. LOWER INTERSECT ALTITUDE
3. UPPER SEGMENT ANGLE
4. GLIDE SLOPE ANGLE
5. UPPER CAPTURE POINT
6. LOWER CAPTURE POINT
7. UPPER TRANSITION
8. LOWER TRANSITION

FIGURE 2 – TWO-SEGMENT PROFILE VARIABLES

the established variation limits of each variable were carried forward for verification or modification in the evaluation airplane.

Figure 2 illustrates the elements of the two-segment approach profile which were investigated in the Engineering Simulation Evaluation.

The 727 Program was conceived and structured to be a logical extension of the evaluation conducted in 1971 in the AA B720-023B. The 720 profile was therefore selected as a starting point for the profile variables investigations in the B-727-222 flight simulator.

Figure 3 shows the profile developed in the AA evaluation with the two-segment approach developed in the UAL 727-200 Program superimposed.

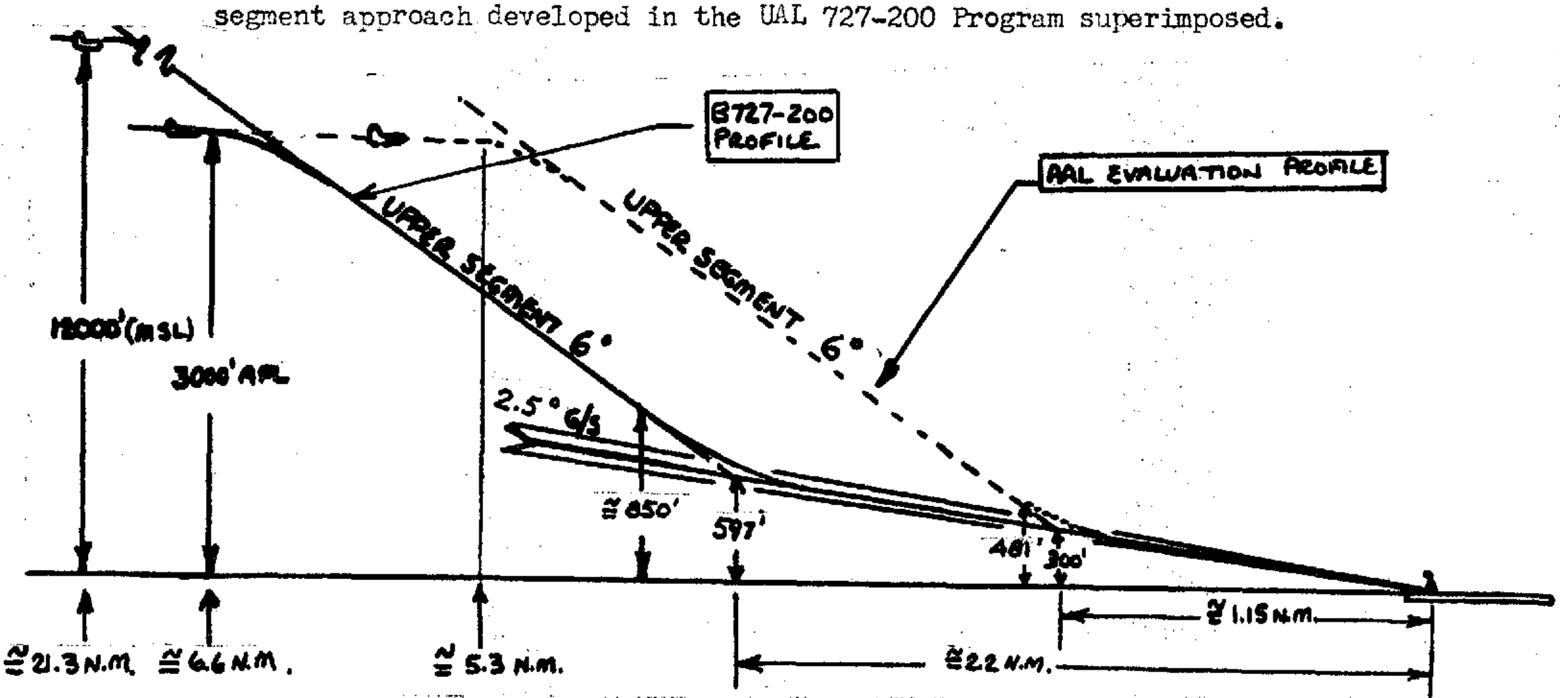


FIGURE 3 – COMPARISON BETWEEN AA 720-023B AND UAL 727-222 FLIGHT SIMULATOR 2-SEGMENT PROFILES.

It can be seen that there are substantial differences between the two profiles. This report discusses the development methods and rationale used in the 727 Simulation Evaluation. Where the 727 profile ultimately differs from the AA profile, the reasons for the differences will be explained.

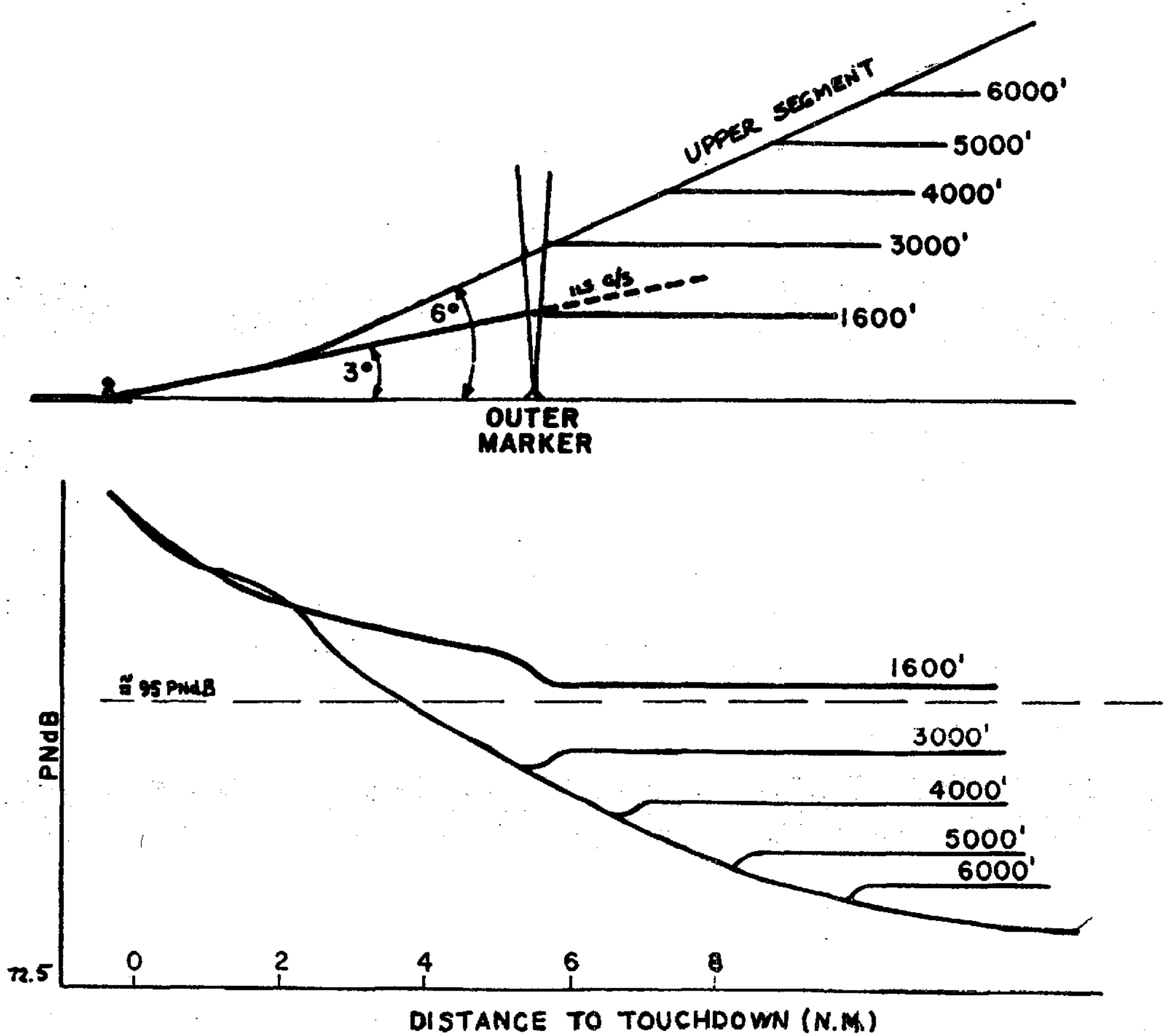


FIGURE 4 - UPPER SEGMENT INTERCEPT ALTITUDE AND GROUND LEVEL NOISE RELATIONSHIPS

Upper Segment Intercept Altitude/Airspeed

These variables were investigated for several important operational reasons:

(1) The physical principle of sound attenuation, as a function of distance from the noise energy source, suggested that there was a minimum upper segment intercept altitude below which no substantial ground level noise reductions would be realized. The Simulation Evaluation determined that this minimum both for sound abatement and operational reasons, should be 3000'(AFL). Figure 4 shows the approximate relationships between intercept altitudes and the corresponding PNdb noise level directly beneath the aircraft at any given point in the approach.

(2) A stabilized speed and configuration for entering glideslope transition was considered operationally necessary from a safety and crew workload standpoint. A matrix was flown to determine maximum upper segment intercept speeds for a given intercept altitude which permitted the pilot to configure and stabilize on upper segment prior to glideslope capture point. The maximum intercept airspeed at 3000'(AFL) which did not unduly increase crew workload on the upper segment for a Vref +15, flaps 30°, glideslope transition entry was found to be 190 KIAS. Optimum entry conditions for the B727 at 3000' was determined to be 160 KIAS; flaps 5°. Progressively higher entry speeds up to 250 KIAS, clean at 6000', were found to be manageable for deceleration to Vref +15 and flaps 30° at or above glideslope transition entry.

(3) Flexibility in the ATC environment was seen as a necessity. It was felt that a hard altitude entry such as the 3000'(AFL) used in the AA evaluation would unduly structure and limit the utility of this procedure. The Collins equipment, therefore, included the Airport Elevation Set Panel to give an altitude entry flexibility.

(4) A side effect of the two-segment procedure which is a function of entry altitude, is the potential for fuel savings in the approach since the fuel flow on upper segment is about one-half that required for the on-glideslope portion of a stabilized ILS. For the 727 intercepting upper segment at 3000', this saving would accrue from approximately 6.6 miles to about 2 miles from touchdown assuming that the 727 making a standard ILS approach had descended from 3000' to about 1500' at approximately the same fuel flow as is required for upper segment tracking. Entry altitudes higher than 3000' would increase the total savings.

While the simulator program was not written to cope with upper segment intercept and capture with the aircraft in a moderate descent or ascent, the prototype equipment and installation were modified to permit this. As with a variable level intercept altitude, it was felt that the capability for entry at moderate descent or ascent rates would increase the flexibility of the procedure in the ATC environment.

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Lower Segment Intersect Altitude

The investigation into this variable revealed that it is very influential from the noise abatement standpoint. It also directly or indirectly affects a number of the important operational and repeatability factors which would be involved in the use of the two-segment approach in regular line service, particularly in instrument weather.

Figure 5 illustrates a number of important considerations involved in varying the height above the field at which the upper segment intersects the ILS glideslope. It can be seen that the lower this altitude, the lower will be the ground level noise at any given point in the approach. In the two data traces shown, a variation of 340' yields a noise differential in the magnitude of about 6 PNdb throughout most of the upper segment portion of the two approaches. This is the result of two basic facts:

(1) The lower intersect altitude (420') moves the upper segment toward the touchdown point approximately 1 N.M. As a result, the airplane is consistently higher above the ground from upper segment capture to on-glideslope than for the higher intersect altitude.

(2) The power addition required to stabilize on-glideslope is the same in both approaches; however, the lower intersect altitude (420') places the airplane on glideslope approximately 1.5 miles closer to touchdown than the higher intersect point (760').

Taken to the theoretical extreme, it can be seen that if the upper segment intersected the glideslope at touchdown, some noise abatement yield could be realized throughout the entire approach. The operational and safety constraints, however, precluded using what is effectively a single-segment 6° approach to touchdown.

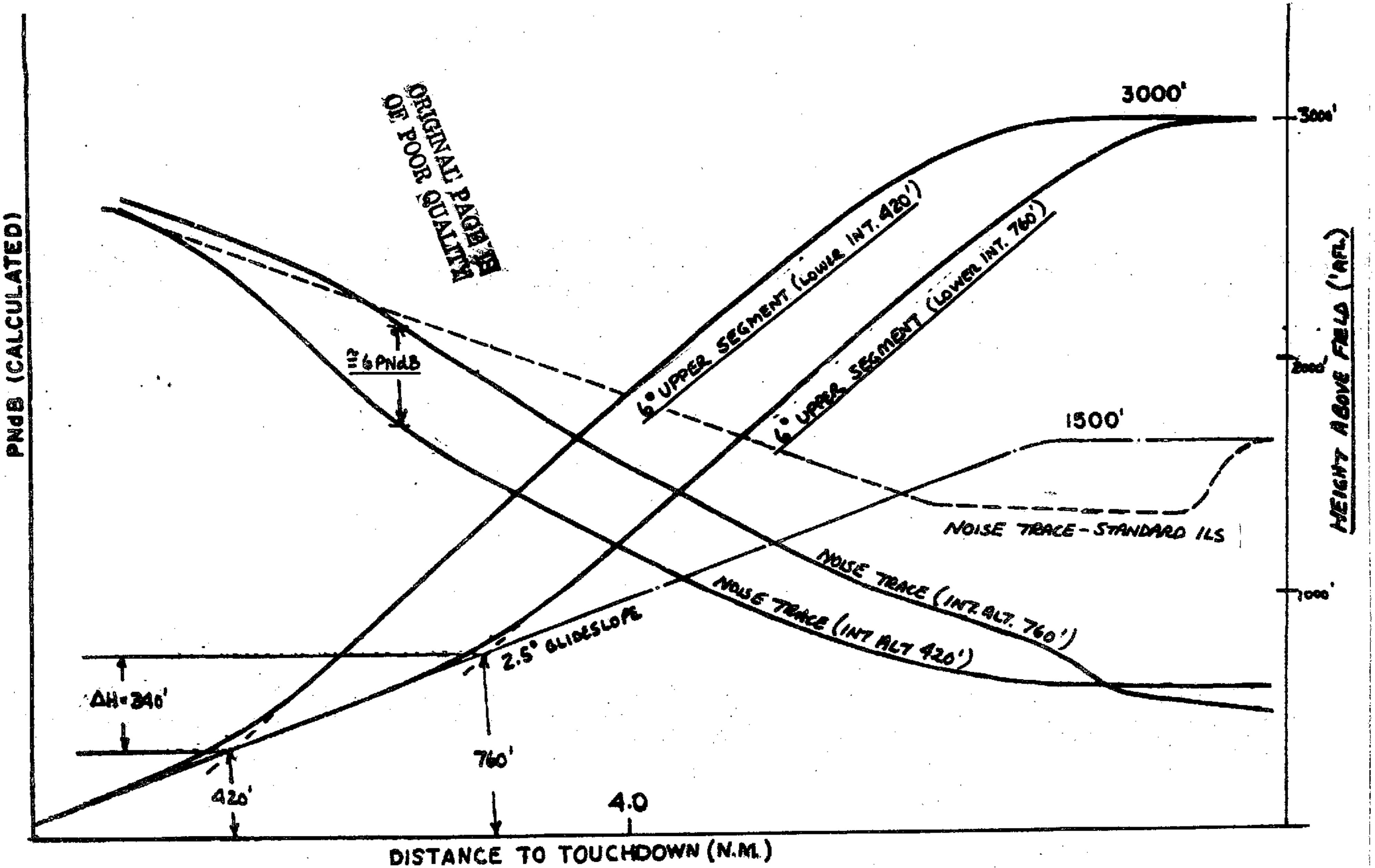


FIGURE 5 - EFFECT OF LOWER INTERSECT ALTITUDE

Operational considerations which made it necessary to investigate some intersect altitude other than that developed in the AA evaluation are:

(1) Some minimum time is required for stabilization on the glideslope before reaching the decision height or other designated ceiling/ visibility minima.

(2) The development for eventual use of the two-segment approach down to Category II minima.

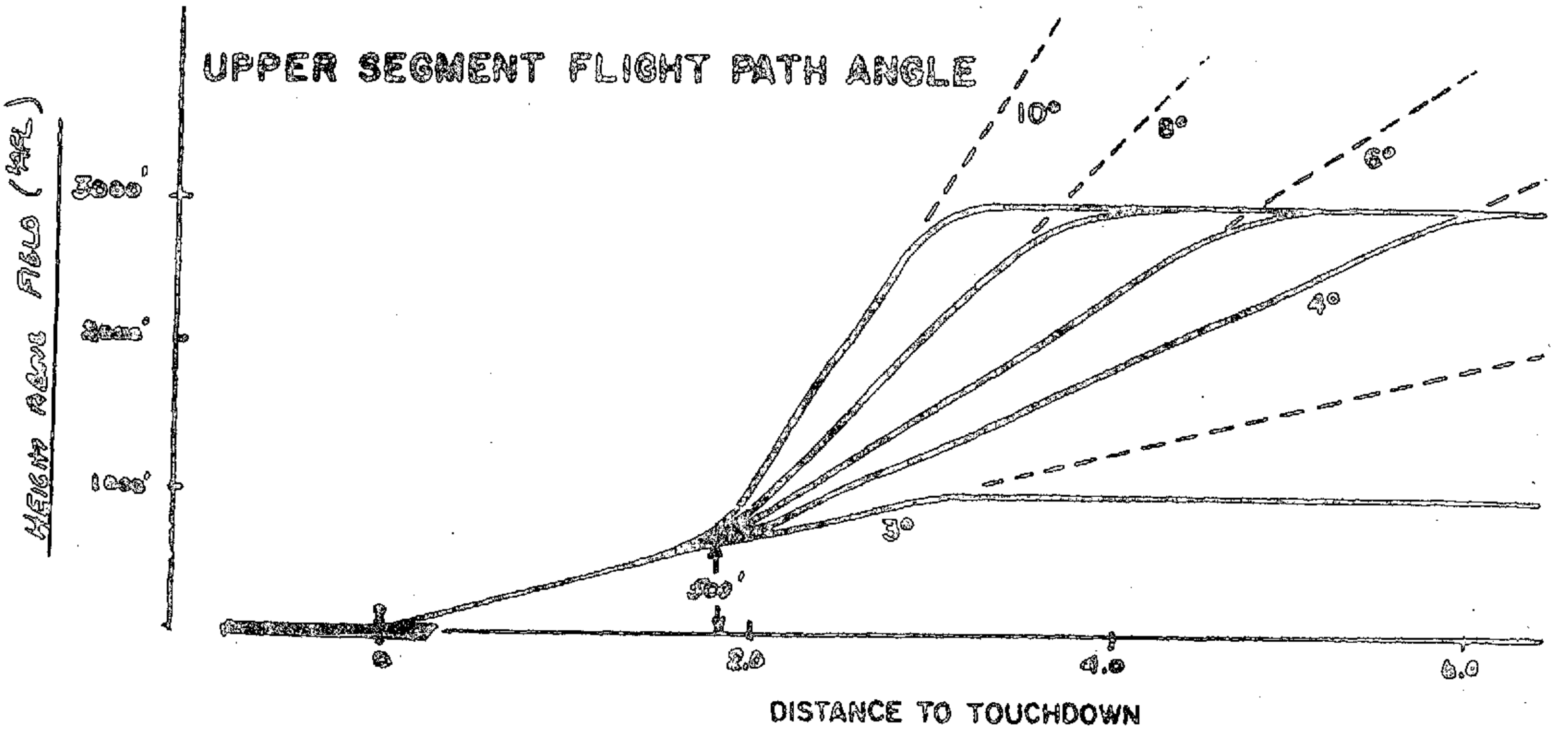
A matrix was flown which progressively raised the intersect altitude from 280' to 830' in nine steps of about 60' per step. The two approaches shown in Figure 5 were a part of that matrix. The lower altitude (430') resulted in a time from on glideslope center to touchdown of 37 seconds (no wind; Vref +10). The concensus in the Project Pilot Group was that this is too short a time for safe (or pilot-acceptable) stabilization. The higher intersect altitude (760') resulted in a 69-second interval from zero glideslope deviation to touchdown. The Project Pilot Group concurred that this was slightly more time than was required for a comfortable and safe stabilization. Having flown the entire matrix, the Project Group optimized the intersect altitude of 690' for a 2.9° glideslope which resulted in approximately 60 seconds of stabilized flight on the lower segment, and stabilization on glideslope at or above 500'(AFL). This value was selected since it appeared to best satisfy the safety, pilot acceptability and glideslope stabilization criteria at the slight expense to noise abatement (which was always secondary to safety in all of the determinations made in the profile and procedures development phase).

Upper Segment Angle

The upper segment angle is critical from the operational standpoint in that relatively small variations introduce factors bearing directly on pilot workload which are out of proportion to the resultant noise improvement. While there are significant sound reduction differences between the lowest and highest angles tested, the operational requirement for immediate thrust response at any point on the profile established a practical Upper Segment limit of 6.5°. The practical noise abatement lower angle limit was determined to be 5.2°.

The total matrix which was flown in investigating upper segment angle variation effects included angles from 2.5° to 10°. It was known beforehand that the angles in the 2.5° - 4.0° range could not be expected to yield any significant ground level noise reductions. They were included in order to investigate both a constant angle to threshold flight profile and as upper segments.

It was logical to assume that the steeper the angle became, the greater the noise abatement. This was assumed to be true because at any given point from touchdown, the airplane is higher above the ground than it would be at a lower angle, and because the engine power requirements to maintain a given speed became less as the angle increases. The angles in the 8°-10° range were investigated to determine the airspeed, power, configuration and vertical speed problems inherent in such angles. As was suspected, angles above 7° were not operationally feasible. At 10°, for instance, the speed stabilized at Vref +30 to +50



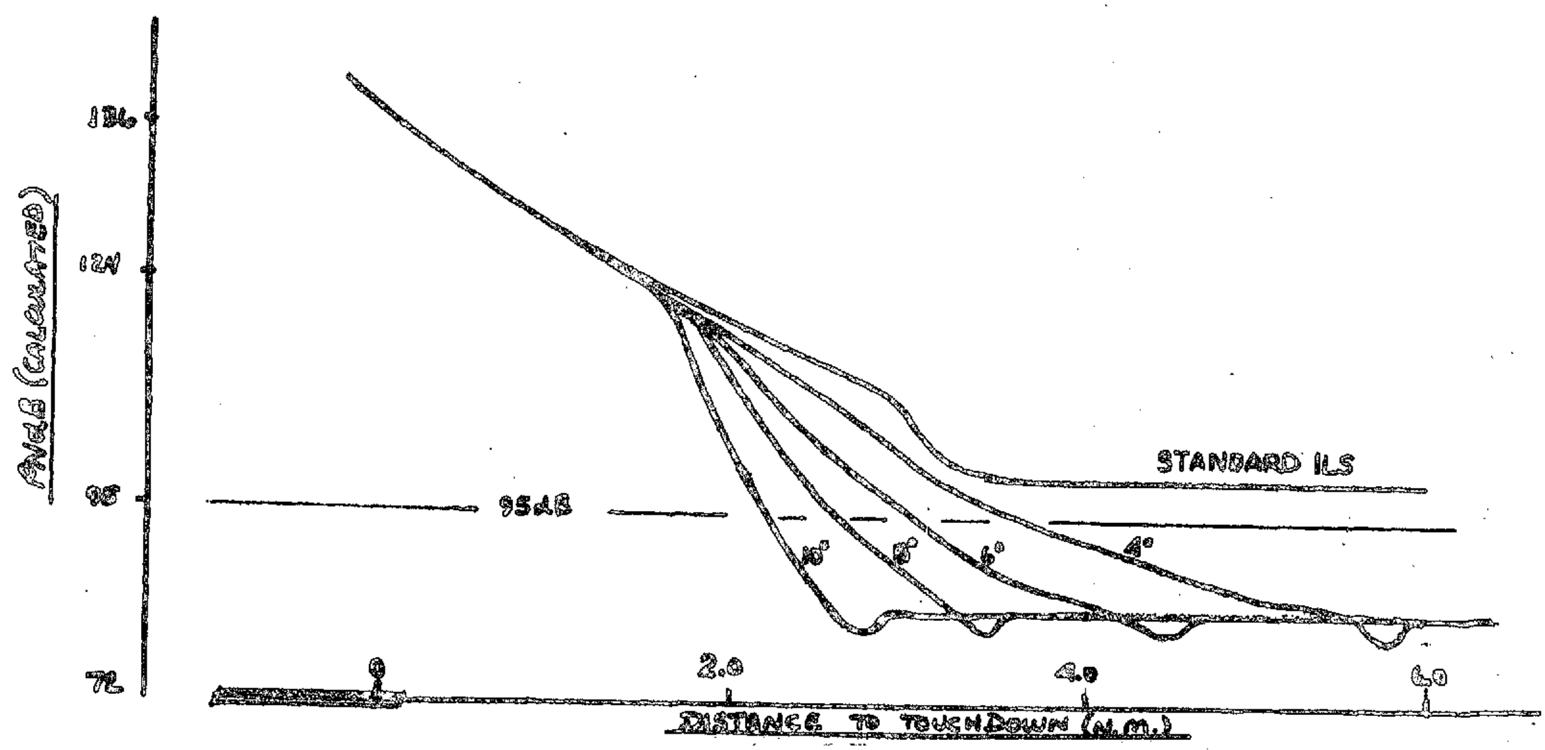


FIGURE 6 - EFFECT OF UPPER SEGMENT ANGLE ON GROUND LEVEL NOISE

knots, depending on gross weight with gear down, flaps 40° and thrott at idle. The only way that the speed could be brought down to an acceptable value was to extend the speed brakes with the flaps extended, which is not an acceptable or authorized configuration for the B-727 series aircraft.

An angle of 7° was manageable; however, this demanded pilot attention to configuration and power scheduling which was too critical to justify the relatively small noise abatement yield over the slightly lower angles.

Figure 6 illustrates the profile and noise plots for the 3°-10° upper segment angle range as recorded on the X-Y Plotter. Lower intersect altitude was set at 500' for these tests. In interpreting this plot and all other X-Y plots which appear in this report, it should be noted that:

(1) The X-axis was scaled to 1":½ N.M.

(2) The Y-axis for the flight path angle plots was scaled to 1":400'.

The X- and Y-axis scaling differences result in the flight path angle exaggerations in all such plots.

(3) The X-axis scaling for the noise plots remained 1":½ N.M; the PNdb (Y-axis) was scaled 1":6.4db.

A detailed description of the noise prediction program used in the simulation evaluation appears in Appendix II.

In examining Figure 6, one sees the obvious effects upon noise of variations in upper segment angle which are contained in the general statements above. As the angle steepens, the distance from touchdown that the 95 PNdb level is experienced directly beneath the airplane moves toward touchdown by a rather significant amount. The facts which are not obvious are the increasingly less acceptable operational factors inherent in steepening the angle.

Figures 7 and 8 are X-Y noise and profile plots of a portion of the investigation into the upper segment angle variation effects upon ground level noise. They point up the fact that in the 5°-6.5° upper segment angle range, the distance to touchdown difference at which a given PNdb level is experienced is about 0.5 N.M., whereas a variation from 4.5° to 5.5° moves this point approximately 0.9 N.M. It is also obvious that the higher the angles, the closer the 95db point is to touchdown. Despite the smaller movement between 5° and 6.5° than at the lower angles, it became apparent that the 5°-6.5° upper segment angle range represented the best area for trade-off between noise abatement and operational factors in view of the principal overall objective of developing a safe and operationally acceptable approach procedure.

The investigation resulted in establishing the practical upper segment angle range for the B-727 between 5.2° and 6.5°. The lower limit (5.2°) was selected because the noise abatement yield became too small at lower angles to justify the use of a two-segment profile. The high limit (6.5°) was set because the operational difficulties attendant with the angles higher than this offset the noise abatement yields which accrue from these angles. The upper segment angle was tentatively set at 6° as the optimum angle which represented maximum noise abatement yield while still permitting the airspeed, power, configuration and vertical speed factors to remain easily manageable.

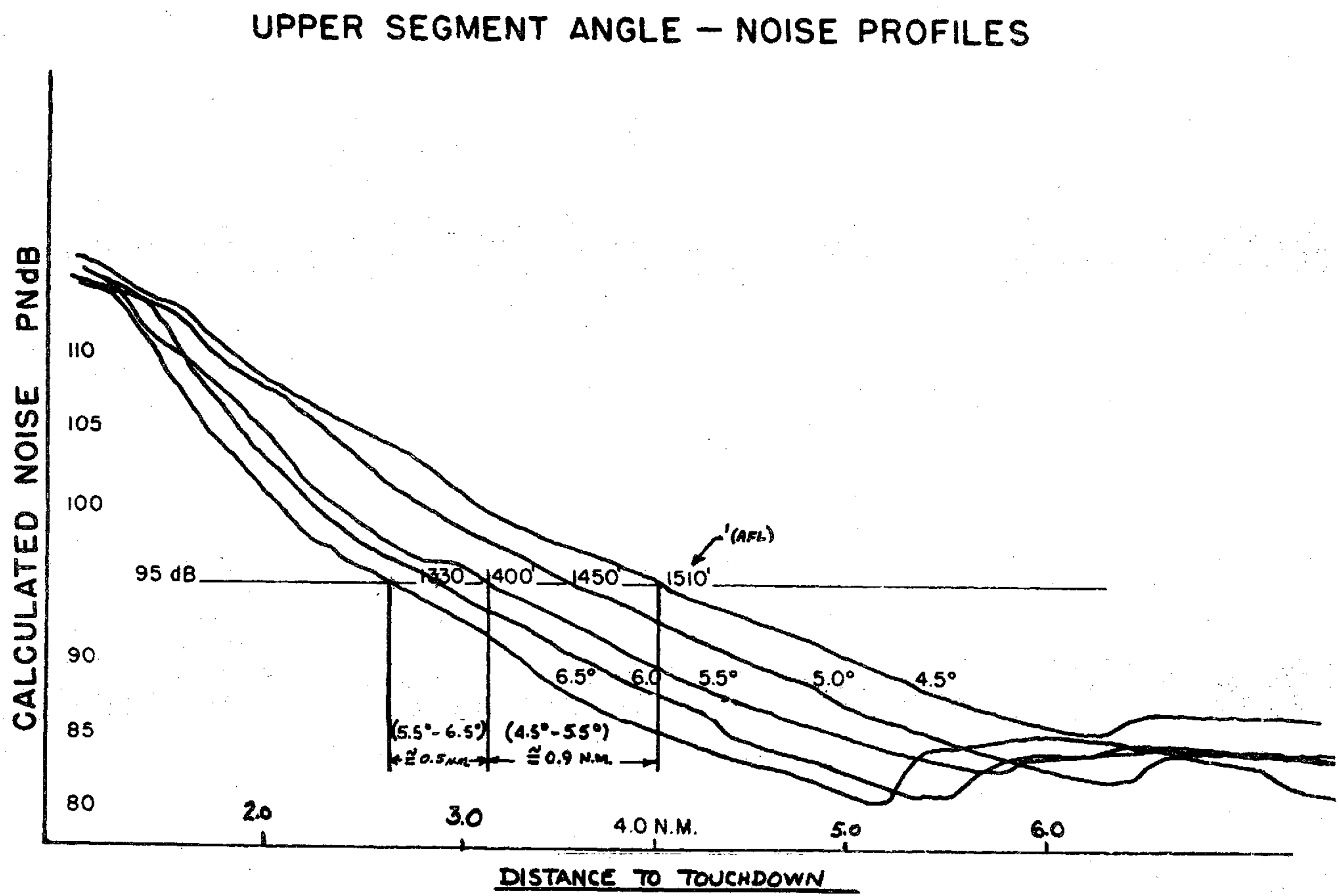

UPPER SEGMENT ANGLE — NOISE PROFILES
CALCULATED NOISE PNdB
110
105
100
95 dB
90
85
80
1330'
1400'
1450'
1510'
1 (AFL)
6.5°
6.0
5.5°
5.0°
4.5°
(5.5°-6.5°)
(4.5°-5.5°)
≅0.5 N.M.
≅0.9 N.M.
2.0
3.0
4.0 N.M.
5.0
6.0
DISTANCE TO TOUCHDOWN

FIGURE 7

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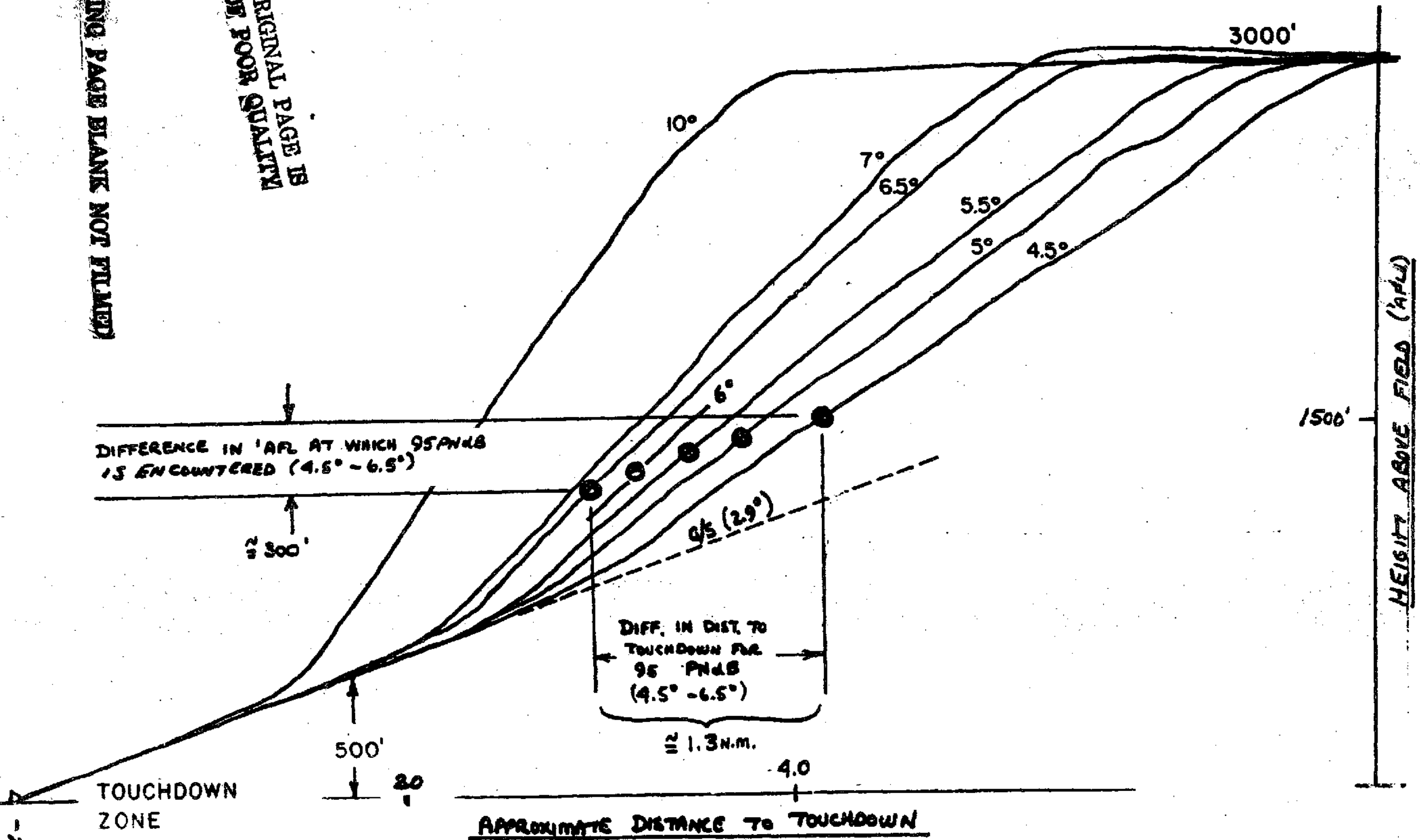

3000'
10°
7°
6.5°
6°
5.5°
5°
4.5°
1500'
HEIGHT ABOVE FIELD ('AFL)
DIFFERENCE IN 'AFL AT WHICH 95PNdB IS ENCOUNTERED (4.5° - 6.5°)
≅ 300'
G/S (2.9°)
DIFF. IN DIST. TO TOUCHDOWN FOR 95 PNdB (4.5° - 6.5°)
≅ 1.3 N.M.
500'
TOUCHDOWN ZONE
2.0
4.0
APPROXIMATE DISTANCE TO TOUCHDOWN

FIGURE 8

Upper Segment Capture Point

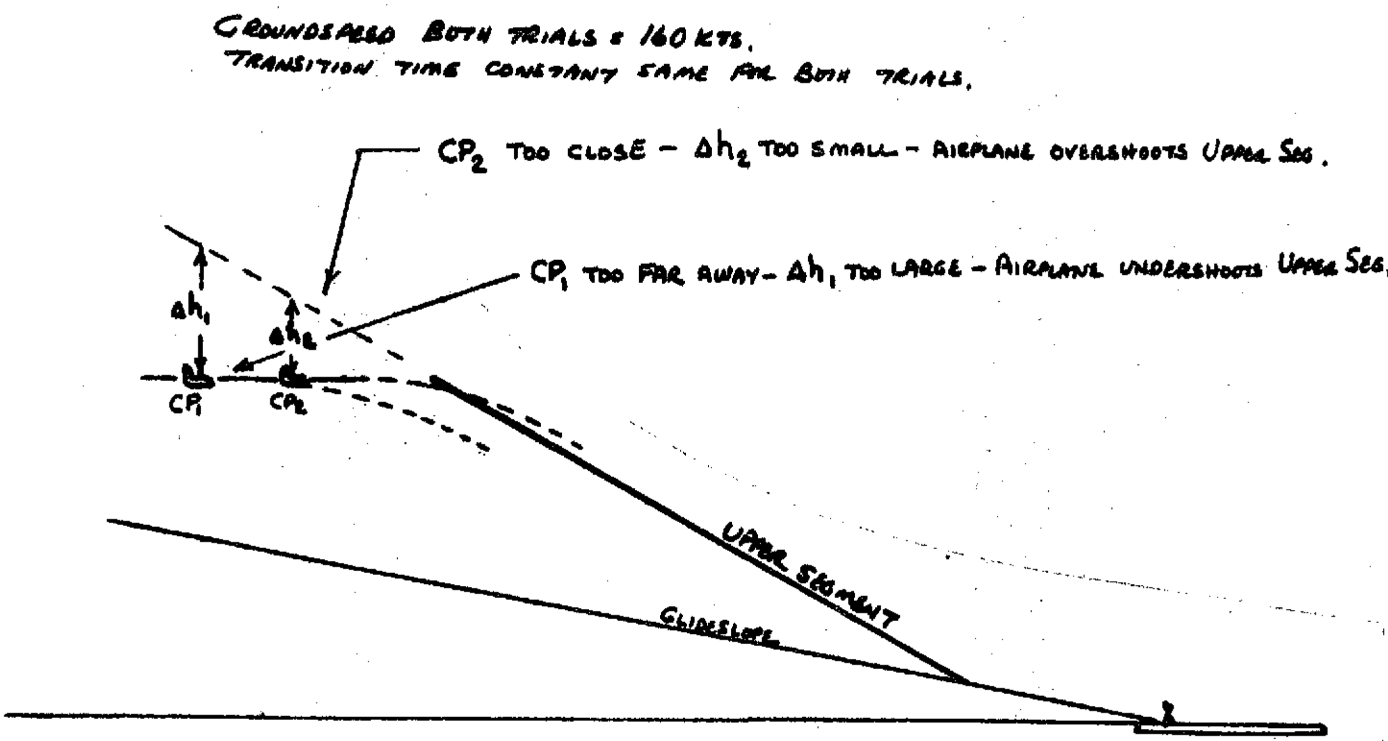
Unlike some of the other profile geometry which can be fixed at some value and hard-wired into the two-segment computer (e.g., upper segment angle of 6°), the upper segment capture point is calculated as a function of the instantaneous rate at which the aircraft is approaching the computed upper segment. This rate is interpreted in the computer in terms of the rate at which the vertical distance between upper segment (extended) and the aircraft (approaching from beneath) is changing. Using this rate information, the computer calculates the point at which the pitch-over command must be initiated in order to transition the aircraft on to upper segment without overshoot. The faster the aircraft is approaching upper segment, the earlier the pitch-over command is initiated since, as will be shown in the next section, the time for accomplishing the maneuver is a constant.

The development task of establishing the upper segment capture point involved two constraints:

(1) Variations in ground speed (IAS + wind component) will vary the horizontal distance from the upper segment center that the pitch-over command will be initiated since the transition time is a constant. In attempting to optimize the Delta h (see diagram below) at which this occurs, it was necessary to fix the ground speed in order to derive a value appropriate to that ground speed. If this value is established, the two-segment computer is designed to cope with variations from this "benchmark" value. The Project Team selected 160 KIAS, no wind, 3000' level as the principal test condition.

(2) Transition time constants from 15 to 25 seconds were selected in the interdependent investigation into upper transition.

Holding the transition time constant at one of the above values, and groundspeed constant at 160 KIAS, Delta h was varied. At the expiration of the selected transition time, the aircraft deviation from upper segment center was measured. If the trial value of Delta h had resulted in an undershoot, Delta h was decreased; if overshoot, it was increased.



UPPER SEGMENT CAPTURE POINT AS FUNCTION OF Δh AND GROUNDSPEED

Subsequent trials using values of Delta h between Delta h_1 and Delta h_2 and transition times between 10-30 seconds resulted in empirically determining the proper value of Delta h of 400' and transition time of 17 seconds for upper transition at 160 KTS groundspeed.

Upper Transition

The upper transition is that portion of the two-segment approach profile from upper segment capture point to some point on (or near) upper segment center. The transition places the aircraft on upper segment center provided:

(1) The point at which the transition maneuver begins is correctly computed for the instantaneous speed of approach to upper segment, and

(2) The DME component of this speed remains substantially constant throughout the transition maneuver, and

(3) The pitch maneuver is precisely commanded and executed, and

(4) The transition time (a computer constant) has been correctly established.

An operational constraint was placed upon this maneuver. This was that the aircraft should transition to upper segment with virtually no overshoot. During the transition, the autopilot and/or flight director predicate their commands to their respective pitch channels on certain memorized closure rate outputs from the two-segment computer. The transition time constant establishes the time it takes to wash these commands out. If the combination of capture point and transition time do not place the airplane on (or very near) upper segment, an unacceptable correction command could result. It is for this reason that particularly any appreciable overshoot of upper segment in the transition would result immediately after transition in a command to increase the nose down attitude to correct back to upper segment. This would logically result in higher vertical speeds, increased speed/power problems and potentially unacceptable g-force sensations in the passenger cabin.

Three approaches to the upper transition problem were theoretically possible:

(1) Commence the pitch maneuver at some fixed point before reaching upper segment and vary the pitch rate.

(2) Vary both the point at which the maneuver commences and the pitch rate.

(3) Fix the time that the transition maneuver will take and compute the point based on speed of approach to upper segment at which the maneuver should commence in order that at the end of this fixed transition time, the aircraft is positioned on upper segment.

For operational and technical reasons, neither of the first two options was acceptable.

The computer was therefore designed around the logic implicit in option (3) above. Using the inputs described in the discussion of upper segment capture point, the computer can consistently calculate this point over a reasonable range of speeds.

It was the objective of the investigation into this variable to establish an optimum transition time which was expressed in the computer hardware in very simple conceptual terms as a time constant that was "triggered" at the computed upper segment capture point and "expired" some fixed number of seconds thereafter.

As with the other investigations, a set value was assigned to all interdependent or interrelated variables, and transition rates were developed by varying the time it took to alter the flight path angle a fixed number of degrees (in this case from level to 6° down).

The primary operational criterion which governed (and ultimately limited) this particular parameter was the ease and consistency with which the pilot could follow the flight director pitch command, keeping in mind the desirability of making this transition as close as possible to the familiar standard ILS transition.

In a matrix of trials in which the upper segment capture points were varied from $\Delta h = 300'$ to $\Delta h = 600'$ and transition times for 15 seconds to 25 seconds, an optimum transition time of 17 seconds was derived.

Lower Transition

Conceptually, the same problems exist at lower transition as for the upper transition except that a pitch-up maneuver is required and it is usually (though not necessarily) of a smaller magnitude than the upper segment capture maneuver.

The same options for approaching the problem existed for this transition as were discussed earlier in upper transition. For the same basic reasons, lower transition time is a constant with the computed glide-slope capture point varying as a function of rate of approach to the ILS glideslope.

From an operational standpoint, this is probably the most critical of the profile variables. Not only do the operational constraints which applied to upper transition also apply to the lower, but the factors of safety and more stringent accuracy and repeatability necessarily overrode noise abatement considerations in this portion of the approach profile.

The safety protection features of the equipment are discussed in Appendix I of this report. The provision of three essentially independent fail capture protectors serves to emphasize the degree to which the ends of safety as regards protection from failures at this point in the profile were considered.

The lower transition was viewed as the psychologically most critical part of the entire approach. The airplane is descending at lower power and at a higher rate than the pilot is accustomed to seeing in a standard ILS approach. While the upper segment descent rate may well be less in many cases than are dictated by some of the "keep em higher longer" VFR procedures in use today, the fact remained that the two-segment procedure was being developed for routine use in inclement weather (eventually to CAT II minima).

From the safety and pilot acceptance standpoint, the instrument guidance the pilot receives and the impact upon his workload at this critical point in the approach were the most important considerations in the lower transition development. The specific criteria which were applied were that the transition from upper segment to ILS glideslope must be accomplished by an operationally acceptable height above the ground and at a distance from touchdown (or before DH) which would permit the pilot to feel comfortably stabilized before the land-go-around decision had to be made. A delicate balance had to be struck between a pitch rate that was too subtle to signal to the pilot that the transition had commenced and one which might be so rapid as to increase the possibility of flying through the glideslope and/or which might result in unacceptably fast speed decay and pitch trim workloads in the transition.

The interrelationships between lower transition time and glideslope capture point are analogous to the upper segment capture/upper transition time relationship. For this reason, lower capture and lower transition times were investigated and optimized in a set of trials in which both were varied within the matrix.

Very short transition times (10 seconds) were tried. While the aircraft could very readily make the transition in this short a time, it was too rapid a pitch rate to be comfortable for the pilot. This variable was carefully investigated in about 2-second steps up to 30 seconds. It was optimized for aircraft evaluation at 24 seconds.

Glideslope Capture Point

As with development of a Δh - transition time combination for upper segment transition, a similar matrix was flown to develop this lower combination. Using transition times between 10 and 30 seconds, the range of capture point values tested in this matrix was from 900'(AFL) to 1400'(AFL).

With the lower intersect altitude of 690'(AFL) for a 2.9° glideslope, the nominal glideslope capture point for a Vref +15, flaps 30°, no wind approach is 1050'(AFL), transition time 24 seconds.

The lower intersect altitude, lower transition rate and glideslope capture point differences between the 727-200 evaluation and the AA 720-023B evaluation account for the major differences in the two profiles.

Flap-Airspeed Scheduling/Crew Procedures Development

The development of a safe, operationally acceptable two-segment profile and crew procedure were the basic criteria applied in the profile development and optimization process.

The principal considerations relating directly to operational acceptability were:

(1) Crew duties to fly the two-segment approach must be as similar as possible to the duties of flying the standard ILS approach.

(2) Guidance and performance instrumentation displays should be interpreted by the pilot in the same way as when they are being used for other instrument approach guidance and progress monitoring.

(3) Two-segment system failures and unreliable guidance warnings should be furnished to the pilot in the same manner as in conventional system/guidance failures of the same nature, including signal monitoring and retraction techniques. This also included provision for the safe and easy reversion to such other navigational and guidance equipment as was unaffected by the two-segment system failure.

(4) The two-segment approach should not significantly increase pilot workload or require inordinate attention to some particular item(s) to the exclusion of other equally important cockpit activity.

(5) The minimum acceptable level of engine power at any point on the profile must provide an immediate thrust response to throttle movement.

(1) <u>CREW DUTIES TO FLY THE TWO-SEGMENT APPROACH MUST BE AS SIMILAR AS POSSIBLE TO THE DUTIES OF FLYING THE STANDARD ILS APPROACH.</u>

These were analyzed before the simulator work began and were verified in the early part of the evaluation. Only two additional steps are required to configure for the two-segment approach which are not required in the ILS configuration:

(a) Place the Two-segment Selector Switch to "ARM" - this can be considered as more of a pilot decision than a procedural step. This makes the two-segment system outputs available to the Flight Director and/or Autopilot in their auto modes only. The HSI Glideslope Bar is switched to upper segment deviation reference.

(b) Set the published TDZ elevation in the Airport Elevation Set Panel. This input to the two-segment computer is necessary in order to position the upper segment in the correct spatial relationship to the approach runway. It is classified as a procedural step because of the requirement to actually set the numbers in the panel. The pilot routinely checks this figure when making a CAT II approach. A discussion of the effects of mis-setting this panel is contained in Appendix I.

In addition to the two steps above, the pilot must verify that the DME switch is in the ON position. This can be considered a procedural step only because the equipment requires an input from the DME unit co-located at the ILS Glideslope Transmitter site. This is an action the pilot would normally complete if he were making an ILS approach to any runway equipped with a DME Transmitter.

(2) GUIDANCE AND INSTRUMENTATION DISPLAYS SHOULD BE INTERPRETED BY THE PILOT IN THE SAME WAY AS WHEN THEY ARE BEING USED FOR OTHER INSTRUMENT APPROACH GUIDANCE AND PROGRESS MONITORING. SINCE THE SYSTEM PROCESSES PITCH GUIDANCE INFORMATION, PROVISION FOR DISPLAYING PURE ILS GLIDESLOPE DEVIATION THROUGHOUT THE APPROACH IS ESSENTIAL TO SAFETY.

These were extensively examined and coordinated among the program principals in the earliest days of the program. Inputs from other carriers and the industry were also requested and considered. Several important equipment design and system logic changes resulted from this effort. All of these changes were made for the principal purpose of improving the pilot-system interface or to insure that the pilot could interpret his instrumentation and displays in the same basic way he currently interprets them when flying a standard ILS approach. An important part of the simulator functional testing was the verification of the following operationally important instrumentation and annunciation modifications for the two-segment system:

(a) The Approach Progress Display was modified to include "UPPER SEGMENT" Annunciators between the "VOR/LOC" and "GLIDESLOPE" Annunciators. These incorporated the standard AMBER (armed)-GREEN (capture) logic. They were placed above the Glideslope Annunciators to preserve the continuous progression concept in the Progress Display.

(b) The ADI Glideslope and Localizer Displays were kept independent of the two-segment system, and were not switched. They always display aircraft deviation with respect to the ILS and provide the pilot with a continuous familiar reference floor that he must not go below.

(c) The HSI Glideslope Bar displays vertical displacement from the reference segment (upper then glideslope) whenever the system is armed and valid. From glideslope capture point ("Glideslope" GREEN) onward, the vertical deviation displays on the HSI and ADI should be identical.

The potentially confusing factor of the pilots' seeing different HSI and ADI vertical deviation displays in the upper segment portion of the approach was carefully weighed against the need to provide the pilot with a continuous reference to the ILS glideslope. The latter was considered operationally essential.

It was also considered necessary to provide the pilot with a pre-capture configuration cue similar to that which he sees approaching the glideslope on a standard ILS. Upper segment deviation was set at 250'/dot. This meant that the glideslope bar starts the familiar downward movement from the upper stop just before upper capture which occurs at about 400' below upper segment in a level entry at 160 KTS. At substantially higher entry speeds, this cue is slightly later: however, to increase the deviation/dot to preclude this would have resulted in lessening the upper segment tracking accuracy.

(3) <u>TWO-SEGMENT SYSTEM FAILURES AND UNRELIABLE GUIDANCE WARNINGS SHOULD BE FURNISHED TO THE PILOT IN THE SAME MANNER AS IN CONVENTIONAL FAILURES OF THE SAME NATURE, INCLUDING SIGNAL MONITORING AND RETRACTION TECHNIQUES. THIS ALSO INCLUDED PROVIDING FOR THE SAFE AND EASY REVERSION TO THE NAVIGATIONAL AND GUIDANCE EQUIPMENT WHICH WAS UNAFFECTED BY THE FAILURE.</u>

All standard aircraft system failures retained the same flags or other warning as before. In those cases in which the two-segment system was not receiving a validity input from some aircraft component, it displayed the appropriate flag.

The system itself was designed so that it would not arm unless all validity signals were present. When the system is being used for guidance, it biases the Flight Director Command Bars from view and/or trips off the Autopilot if any validity signal is lost or if an attempt to use the system under improper conditions is made. A detailed discussion of these conditions and of the failure protection in the system is contained in Appendix I.

Reversion to any other Flight Director or Autopilot mode requires only the selection of the new mode. Operation in the new mode is immediately restored to standard. The system logic is designed to prevent one system from being under two-segment system guidance control while the other is under basic airplane system guidance control. Selection of any reversionary Flight Director mode, therefore, will trip the Autopilot off. Selection of a reversionary autopilot mode will bias the Command Bars from view. To re-engage the two-segment system after a reversionary mode selection on either the Flight Director or Autopilot, the pilot must manually re-cycle the Two-segment Selector Switch to "OFF" then back to "ARM". He must then re-select the desired auto mode(s). Unless all system validity conditions are satisfied at this point, the Command Bars will immediately bias from view and the Autopilot will trip off.

(4) <u>THE TWO-SEGMENT APPROACH SHOULD NOT SIGNIFICANTLY INCREASE PILOT WORKLOAD OR REQUIRE UN-FAMILIAR FLIGHT TECHNIQUES AS COMPARED TO THE STANDARD ILS</u>.

These factors strongly influenced the Project Team's investigation and optimization of the two-segment profile parameters. A good example is that upper segment angles above 6.5° yielded better noise reductions than lower angles, but were not operationally acceptable because of the workload and flight techniques problems posed by the requirement of flap-airspeed configurations required to meet the thrust response requirement.

After the basic profile parameters had been investigated and their practical variation limits established, a comprehensive matrix involving flap configuration and airspeed combinations was flown:

(a) To develop and optimize the flap and airspeed schedule combinations which minimized pilot workload and which also were effective noise reducers.

(b) To determine any limitations in the use of an otherwise operationally-acceptable two-segment profile and procedure.

The following flap/airspeed combinations represent only a small portion of the total matrix. They are discussed here only to illustrate how one or more of the workload/technique factors influenced its overall acceptability:

Flaps/Airspeed Combination	Comments
Flaps 40° from commencement of approach to landing. Airspeed Vref +30 on upper with bleed to Vref at landing.	(1) Required no power adjustment from establishment of Vref +30 to touch-down. (2) Provides 70% N_1 required for full anti-ice. (3) Trimming required throughout airspeed bleed (30 KTS). (4) Negligible noise reduction. Not a recommended procedure due to lack of noise abatement, pilot trimming workload and effect of environmental variables on proper speed throughout the speed bleed.
Flaps 40° from commencement of approach to landing. Vref +10 to +20 on upper with speed bleed to Vref on glide-slope.	(1) Requires power adjustment/trimming after speed bleed. (2) Does not provide 70% N_1 for full anti-ice. (3) Improved noise reduction over 40°/Vref +30. A basically acceptable procedure. Not recommended because requires higher power than 30° approach without offering compensating advantages.
Flaps 30° on upper to flaps 40° on glideslope.	Not acceptable because it requires simultaneous power, airspeed, pitch and trim management.
Flaps 0°-25° on upper to 30°-40° on glideslope.	No acceptable combination for same reasons as 30°-40° above.
Flaps 30°, Vref +20 on upper to flaps 30°, Vref +5 on glideslope.	(1) Slightly noisier than above. (2) Trim and power adjustment required in transition speed bleed (15 KTS). Acceptable but not optimum.
Flaps 30°, Vref +10 to +15 on upper to flaps 30°; Vref +5 on glideslope.	(1) Quiet approach. (2) Minimum trim and power adjustments required in transition. Recommended as optimum approach flap/air-speed combination.

(5) <u>THE MINIMUM ACCEPTABLE LEVEL OF ENGINE POWER AT ANY POINT ON THE PROFILE MUST PROVIDE AN IMMEDIATE THRUST RESPONSE TO THROTTLE MOVEMENT</u>.

This requirement was considered essential to safety. It was particularly influential in limiting upper segment angle and establishing the maximum permissible upper segment tailwind.

It was determined that the thrust response below approximately 1500#/hr fuel flow did not satisfy this requirement.

The optimum profile and optimum flap/airspeed combination satisfied this requirement while providing appreciable ground level noise reductions.

Anti-Ice

The effects on anti-ice capabilities were investigated in the simulator. It appears that a 6° two-segment approach which yields any significant ground level noise reduction is not compatible with maintaining full anti-ice capabilities at the typical 727 landing gross weights.

This point is illustrated by the results of one of the key trials. Upper segment angle was established at 5°. The approach was flown at flaps 40°, upper segment speed Vref +15, gross weight 108,000#. This did not provide the 70% N_1 required for full anti-ice. Gross weight under the above conditions had to be increased to 140,000# before 70% N_1 power was required.

ENGINEERING SIMULATION EVALUATION CONCLUSIONS

General

(1) In an evaluation of this nature and magnitude, a flight simulator evaluation phase is an indispensible prelude to flying a prototype installation in the aircraft. The simulator is the only vehicle in which factors which can vary (or be varied) can be established at known values, changed by known precise amounts, repeated as often as necessary and accurate effects of these factors upon other interdependent factors determined.

(2) The flight simulator will significantly shorten the overall program time and reduce flying time required in the airplane.

(3) The simulator permits the safe and deliberate analysis of failure and mis-management effects including confirmation that no unexpected or potentially hazardous side effects will result from these failures.

Specific Operational or Technical

(1) The 6° upper segment represents the best operational trade-off between safety, crew workload and noise abatement for the 727 type aircraft.

(2) The principal differences between the AA 720 and the 727 profiles stem from applying certain operational criteria in the 727 development which were considered essential to the routine use of the two-segment procedure in instrument weather. They have produced a higher glideslope intersect point, higher glideslope capture point and slower transition pitch rates in the 727 profile.

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(3) The two-segment procedure as developed for the 727 does not appear compatible with conditions requiring the use of full anti-ice.

(4) Use of the procedure where tailwinds greater than 20 KTS exist on the upper segment is not permissible because such conditions require engine power settings below the immediate thrust response level.

(5) Other environmental conditions do not appear to limit the use of the procedure in any way that they would not similarly limit the standard ILS procedure.

(6) The procedure yields ground level noise reductions outward from about 2.5 miles from touchdown.

APPENDIX I

to

UNITED AIR LINES

Report of

ENGINEERING SIMULATION DEVELOPMENT AND EVALUATION

of the

TWO-SEGMENT NOISE ABATEMENT APPROACH

THE TWO-SEGMENT APPROACH AND TWO-SEGMENT SYSTEM

30 January 1974

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ENGINEERING SIMULATION EVALUATION - APPENDIX I

TABLE OF CONTENTS

INTRODUCTION

This appendix contains a basic operational description of how the two-segment system generates the two-segment profile and how it interfaces with the airplane navigational and guidance systems.

The means by which the system performs its computational functions is contained in the Collins Radio Company System Technical Documentation.

Additional Terms and Definitions

In addition to the terms defined in the Simulation Report, a number of other terms which will be frequently used in this appendix are defined or explained to assist the reader in understanding their operational function in the two-segment system.

TERM	DEFINITION/RELATED INFORMATION
"________" AMBER "________" GREEN	These are convenient "shorthand" terms which are derived from the color which the specific Approach Progress Annunciator will properly have at the point on the two-segment profile which is under discussion. The more important connotation, when used because of their shorthand value in this appendix, is: (1) That a certain state or set of conditions exists at specific points along the profile and (2) The change from AMBER to GREEN indicates a proper and normal progression of system logic and (3) The airplane flight path is conforming to the profile within prescribed tolerances. The system has been designed so that the pilot can interpret the Approach Progress Display in exactly the same way as he interprets it when using it for a standard ILS.

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TERM	DEFINITION/RELATED INFORMATION
h'(AFL)	This is the instantaneous value of the computed height of the airplane above the published touchdown zone elevation (TDZ) of the approach runway.

It is important to recognize that the two-segment system computes the value of this term by using the following basic input relationship:

$$h'(AFL) = PA' - TDZ'$$

where PA = Airplane instantaneous baro-corrected pressure altitude (MSL)

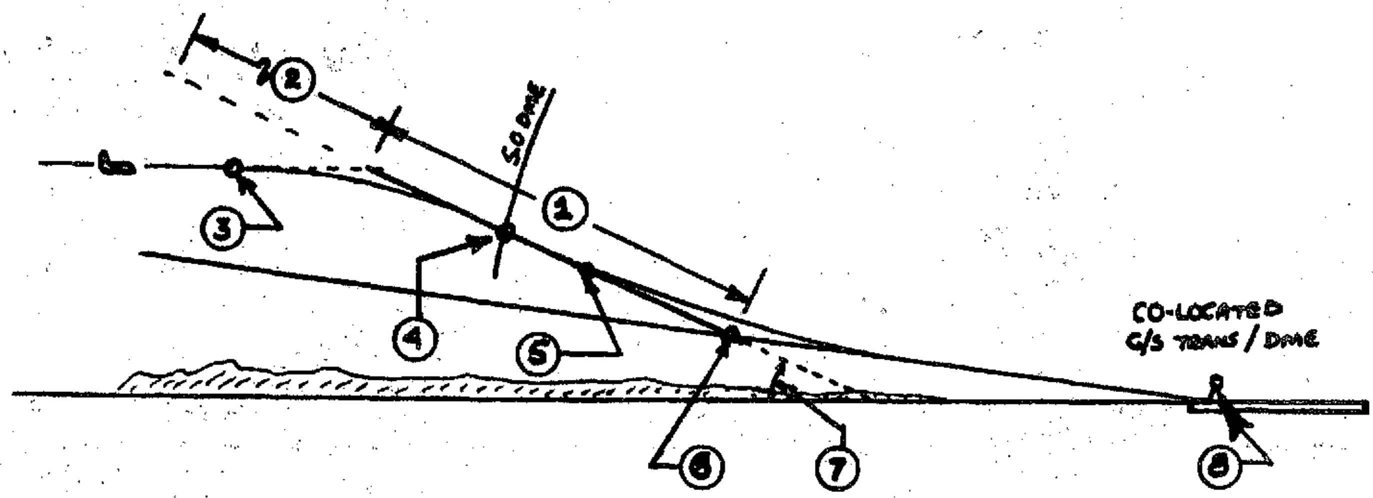
TDZ = Published touchdown zone elevation appearing on the Airport Elevation Set Panel.

The effects of errors in PA and/or TDZ are discussed at length in this appendix.

DME

This is the airplane's instantaneous line-of-sight distance from the DME Transmitter which must be co-located at the ILS Glideslope Transmitter site. A valid DME input signal is required for system operation.

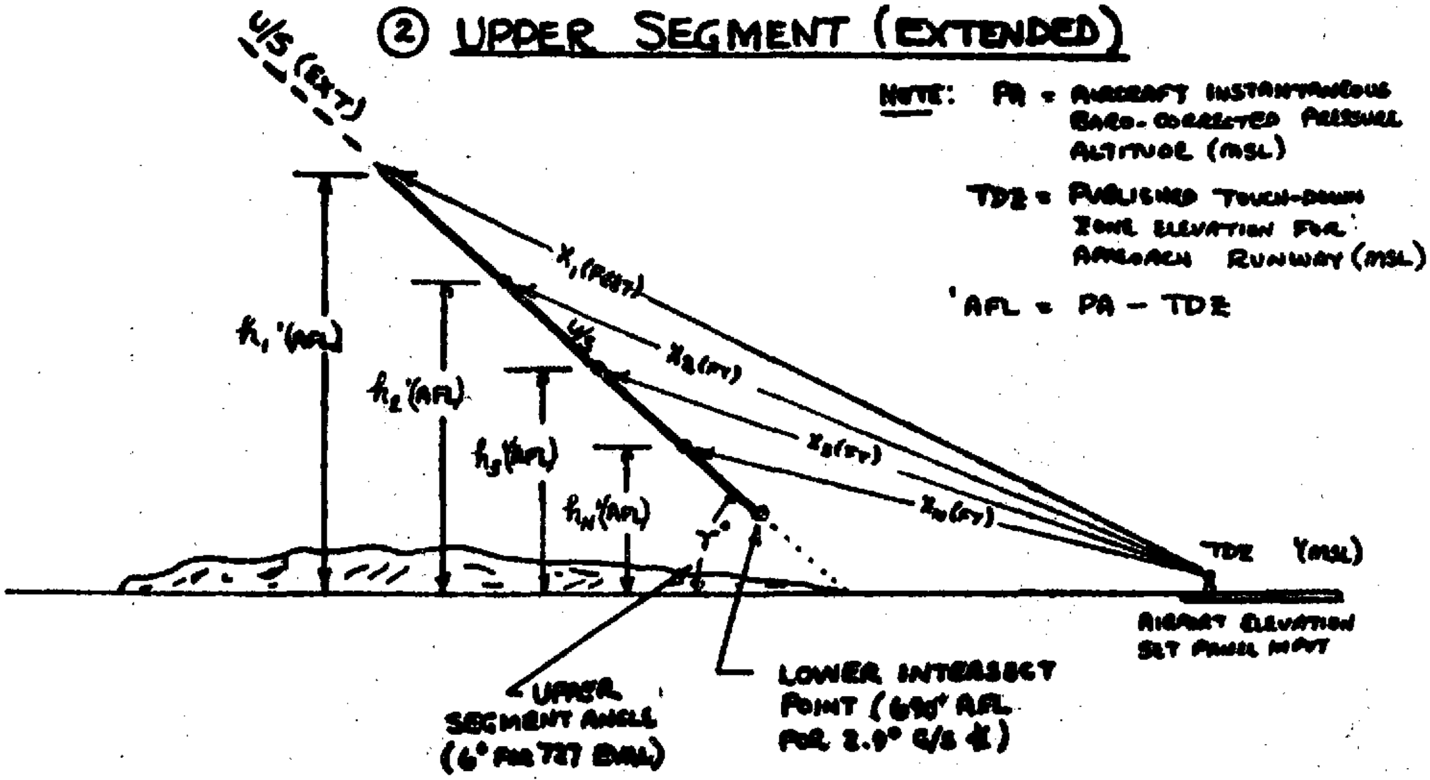
TWO-SEGMENT PROFILE TERMS AND DEFINITIONS



1 - UPPER SEGMENT
2 - UPPER SEGMENT (EXTENDED)
3 - UPPER SEGMENT CAPTURE POINT
4 - GLIDESLOPE ARM POINT
5 - GLIDESLOPE CAPTURE POINT
6 - LOWER INTERSECT POINT
7 - UPPER SEGMENT ANGLE
8 - AIRPORT ELEVATION

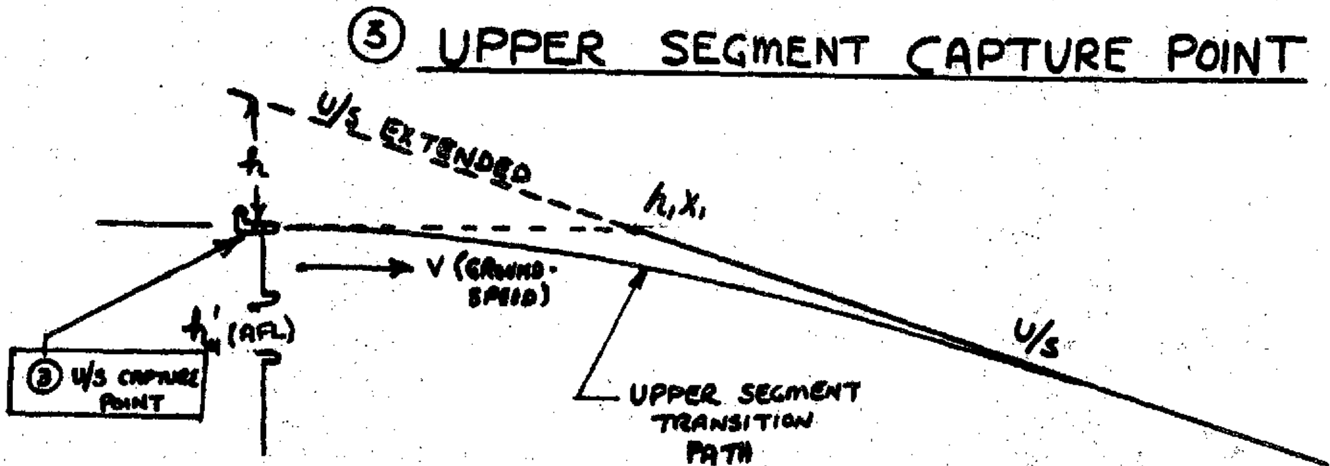
The eight key elements illustrated above define the approach profile and/or system logic check or AMBER-to-GREEN switchover points. Each is briefly discussed in the following pages in order that their basic operational function may be better understood in the more detailed descriptions contained later in this appendix.

① UPPER SEGMENT
② UPPER SEGMENT (EXTENDED)



The upper segment is an infinite series of h'(AFL) and X'(DME) points. Each point on the upper segment has an exact and unique h'(AFL)/X'DME relationship for any given upper segment angle and lower intersect point. The computer receives instantaneous baro-corrected pressure altitude and DME from the airplane systems. It compares the airplane's h'/X' with the h'/X' corresponding to the on-upper segment value. It interprets any differences between the two h/X relationships to determine the airplane's instantaneous deviation from upper segment.

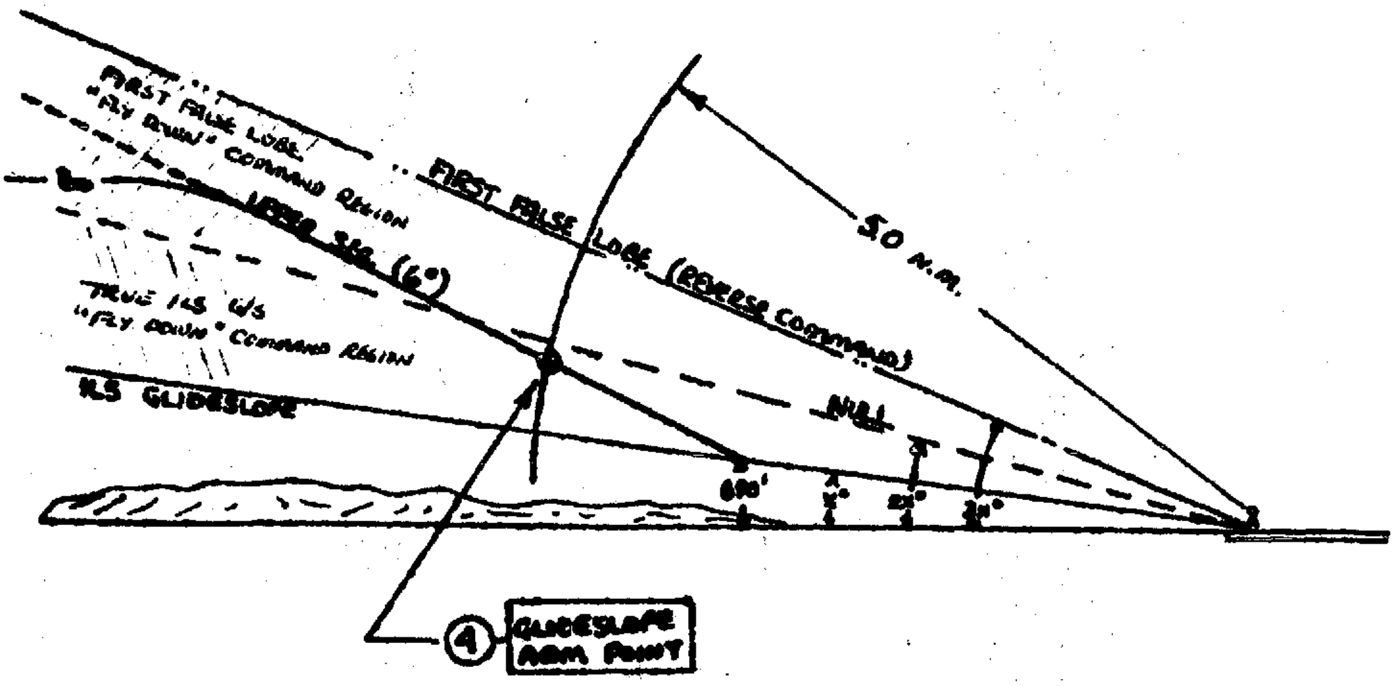
The upper segment (extended) is determined in the same way as the upper segment. It is the rate at which the airplane's vertical distance from upper segment (extended) is changing that determines upper segment capture point.



The upper segment capture point is that point in the two-segment approach at which the pitch-over maneuver should commence in order to intercept the upper segment without overshooting. The two-segment computer calculates this point based on the rate at which the vertical deviation from upper segment (extended) (dh/dt) is changing. This rate is, in turn, a function of the ground speed at which the aircraft is approaching the upper segment. It is important to recognize that this is a ground speed (based on the rate of change of DME) and thereby compensates for variations in both the airspeed and the wind components.

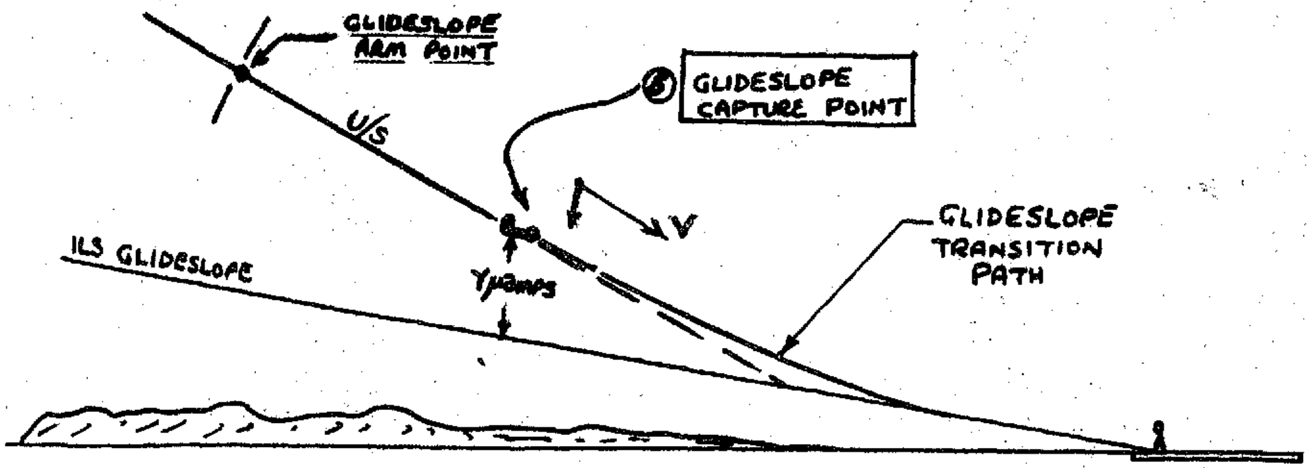
If the two-segment system is armed and valid and the Flight Director and/or Autopilot are in their respective auto approach modes, the pitch commands to transition to upper segment will occur at this point.

4 GLIDESLOPE ARM POINT



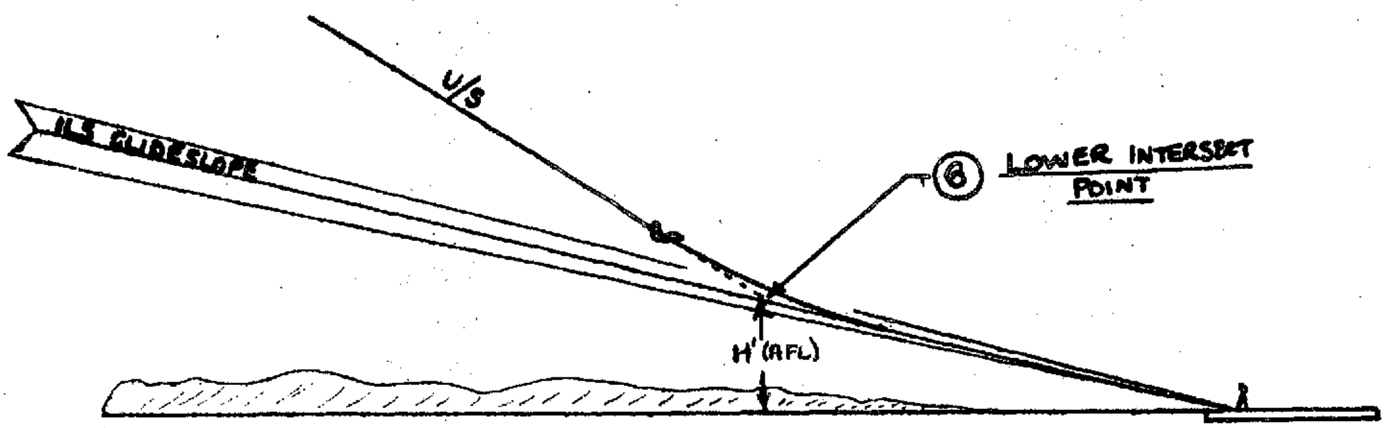
This point was established to insure that the Flight Director and/or Autopilot are not armed to capture glideslope until the aircraft (descending on upper segment) has crossed the null boundary between the first false lobe (a reverse sensing lobe) into the true ILS beam pattern (proper sensing). For a 2.5° glideslope, this point was set at 5.0 N.M. (DME). This is the point on the upper segment at which the Glideslope Annunciator(s) illuminate AMBER provided that the system is in upper segment GREEN.

⑤ GLIDESLOPE CAPTURE POINT



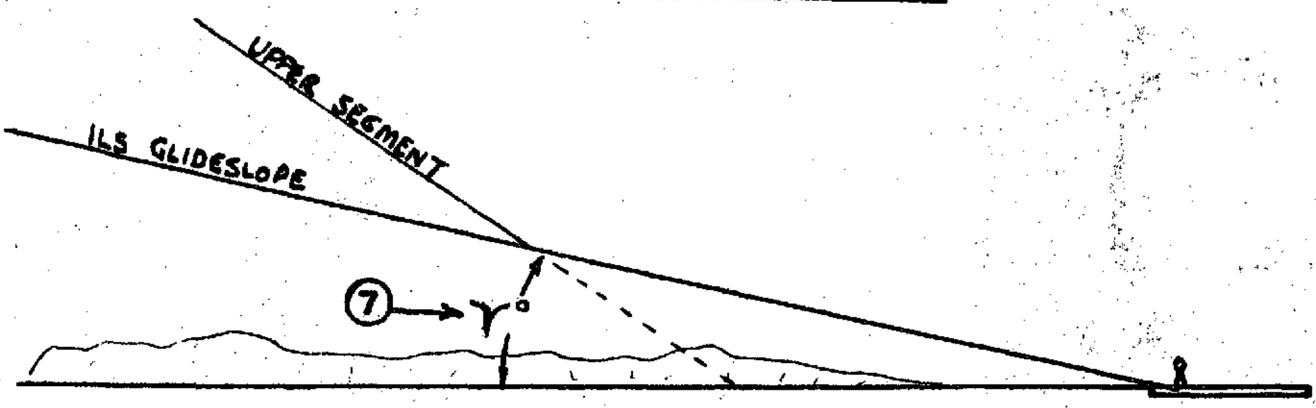
The glideslope capture point is that point in the two-segment approach at which the pitch-up maneuver should commence in order to transition from upper segment to the ILS glideslope without overshooting (going below) glideslope center. The two-segment computer calculates this point as a function of the displacement from glideslope center and the rate at which the aircraft is approaching center (-dy/dt). The calculation using this rate therefore compensates for variable rates of descent resulting from airspeed and/or wind component differences. As with the upper segment capture maneuver, if the flight director and/or autopilot are in their respective auto approach modes <u>and</u> upper segment has been captured (upper segment GREEN), the pitch maneuver would be initiated at this point. At this point, the vertical deviation display on the HSI shifts from displaying deviation from upper segment to deviation from ILS glideslope for the remainder of the approach. The "Glideslope" Annunciators switch from AMBER to GREEN.

⑥ LOWER INTERSECT POINT



The lower intersect point is that point on the two-segment profile at which the upper segment intersects the ILS glideslope center. This is a significant profile point because of the effect it has upon the altitude at which the aircraft is stabilized on ILS glideslope, and the effect small variations in this point have upon the ground level noise footprint area. This point has been set at 690' (AFL) for a 2.9° glideslope. This results in a no-wind glideslope capture point of approximately 1050'(AFL).

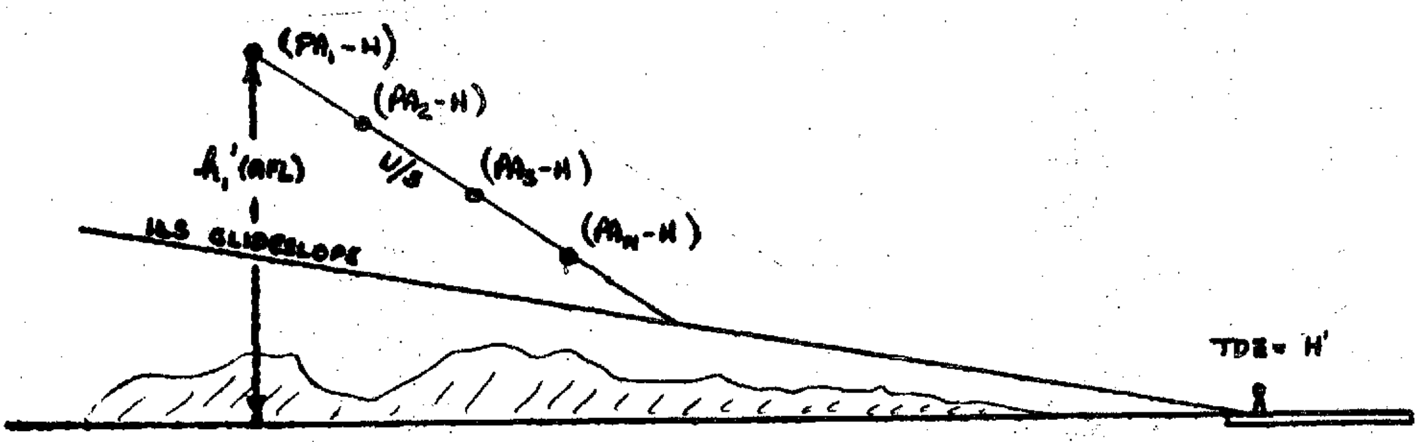
⑦ UPPER SEGMENT ANGLE



The upper segment angle is espressed in degrees above horizontal.

For the 727 type aircraft, this was established at 6°.

⑧ AIRPORT ELEVATION



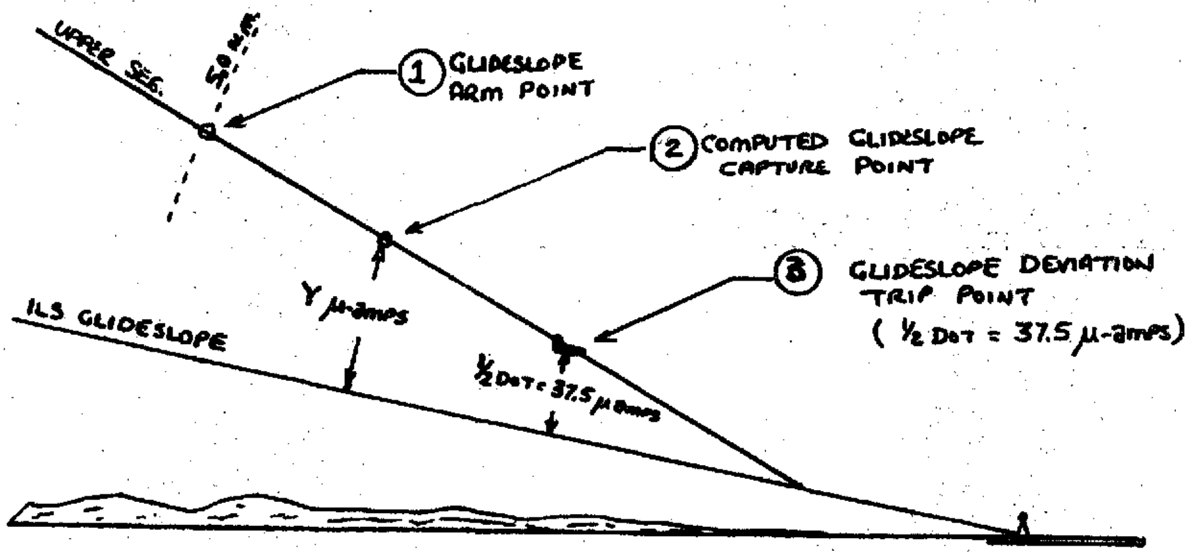
NOTE: ① BARO-CORRECTED PA − TDZ = 'AFL
② "AIRPORT ELEVATION" = TDZ (TO NEAREST 10') (MSL)

The computer requires airport elevation ('MSL) in order to establish the correct position of the upper segment in relation to the approach runway. This is supplied (to the nearest 10') when the crew sets the published touchdown zone elevation in the Airport Elevation Set Panel. The effects of an error in this input are discussed in detail later in this appendix.

FAIL GLIDESLOPE CAPTURE PROTECTORS ("SAFETY PROTECTORS")

The equipment design provides three essentially independent features for removing the flight director and autopilot guidance in the event the system fails to capture the ILS glideslope at the glideslope capture point. Each is described briefly below. A more detailed discussion follows in a later section of this part:

I. GLIDESLOPE DEVIATION PROTECTOR



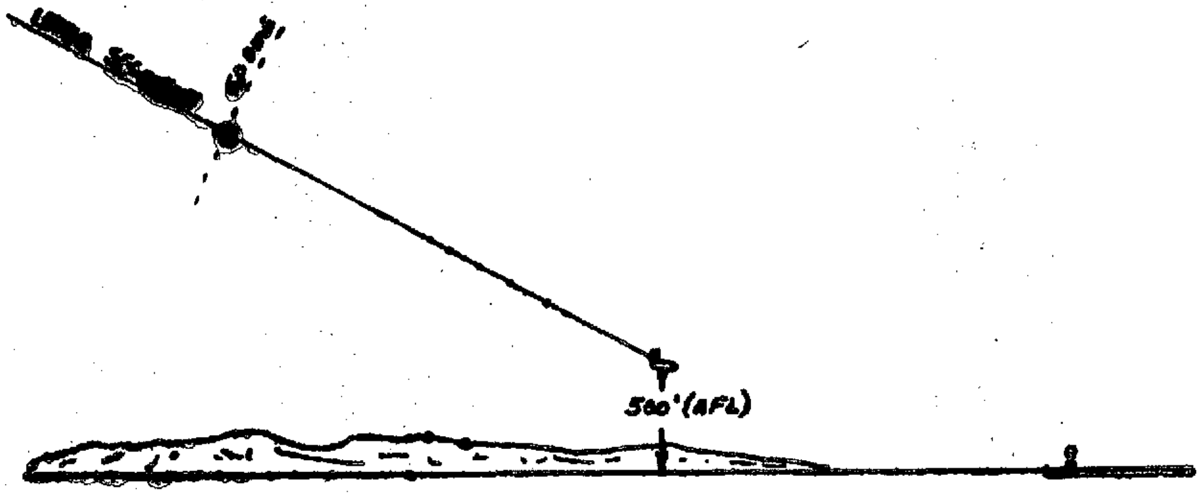
Situation: Aircraft is descending on upper segment. Glideslope is present and valid.

① Aircraft has passed through the false lobe and null regions. At 5.0 N.M. DME, aircraft will be in beam pattern of true ILS glideslope for all glideslopes of 2.5° or greater. The two-segment system arms for glideslope capture (Approach Progress "Glideslope" Annunciator(s) illuminate amber).

② At computed glideslope capture point, transition to glideslope should be commanded for flight director and/or autopilot (if in auto approach mode(s)). This point is nominally 1050' (AFL).

③ Aircraft has passed through ② without commencing glideslope transition maneuver. At ½ dot (37.5 micro-amps) above glideslope center, autopilot will trip off and flight director command bars will bias from view. Approach Progress Display Annunciator(s) will extinguish.

II. HEIGHT ABOVE FIELD TRIP

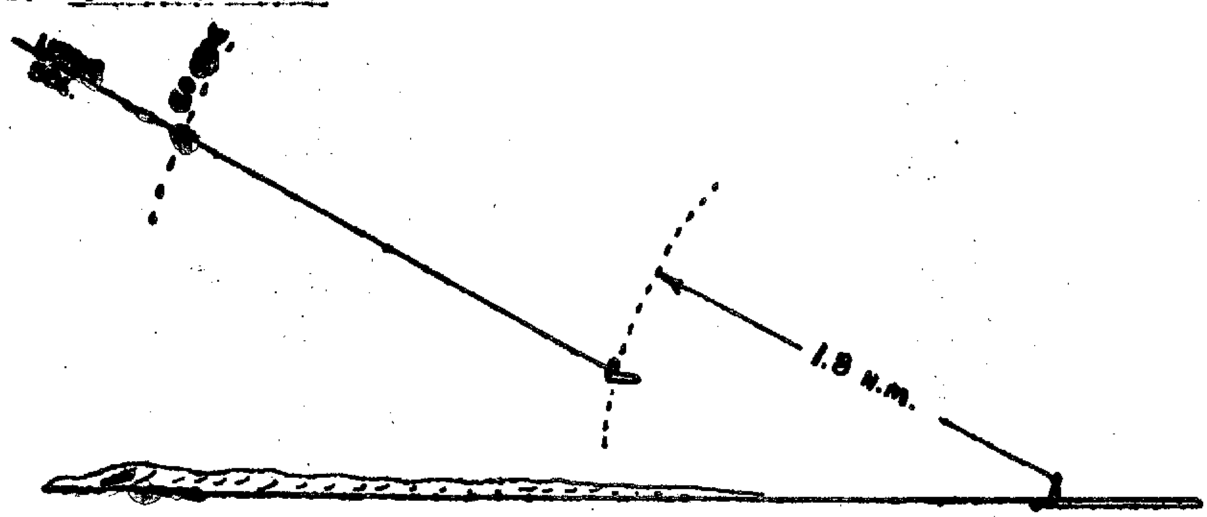


Situation: Aircraft is descending on upper segment. ILS glideslope has failed, or glideslope deviation protector (I above) has not activated for some unknown reason.

When aircraft descends to 500' above the selected airport elevation, Autopilot will trip off and Flight Director Command Bars will bias from view.

NOTE: The effects upon this protector of an erroneous airport elevation (or baro-correction) input are discussed in detail later.

III. MINIMUM DME TRIP



Situation: (Same as II above).

When aircraft approaches within 1.8 N.M. DME without glideslope capture, autopilot trips off and flight director command bars bias from view.

NOTE: With correct airport elevation and baro-set inputs to the computer, the height above field and the minimum DME trips are at approximately the same point in space. The effects of erroneous inputs upon the relationship in space of these two trips is discussed in detail later.

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TWO-SEGMENT SYSTEM COMPONENTS AND INTERFACE

Collins Special Purpose Components

Aircraft Components of System

Ground Equipment Components of System

Aircraft Interface

COLLINS SPECIAL PURPOSE COMPONENTS

The Collins components of the two-segment system consist of the following units:

Two-Segment Computer
Switching Unit
Airport Elevation Set Panel
Two-Segment Selector Switch ("ARM-OFF")

The operational functions of these units is discussed below. The technical description will be included in the equipment manufacturer's documentation and reports.

1. The Two-Segment Computer - This is the heart of the two-segment system. Given the upper segment angle and lower intersect altitude, it calculates the upper segment as a function of altitude above field and DME distance to touchdown. This becomes the positional reference from which vertical deviations and vertical tracking commands are ultimately derived. Having established the upper segment in a specific spatial relationship to the co-located DME, the computer constantly compares the aircraft instantaneous position with the computed upper segment in order to:

   (a) Determine the point appropriate to the aircraft groundspeed at which the pitch-over maneuver should be initiated to intercept the upper segment. It similarly determines the proper point at which the glideslope capture maneuver should commence.

   (b) Supply the flight director and autopilot systems with deviation information upon which they will act (in their respective auto modes only) to correct back to or continue tracking upper segment or ILS glideslope as appropriate.

   (c) Monitor the aircraft position in relation to the upper segment in order to inhibit certain events or to continue the orderly prescribed sequence of events in the normal two-segment approach. An example of an inhibited event would be the preventing of upper segment capture if the computer determines that the aircraft is above the upper segment at the time the pilot selects the auto approach mode on the autopilot. An example of normal event sequence control would be inhibiting the flight director and/or autopilot from arming for glideslope capture until the aircraft is on upper segment and has passed the glideslope arm point (5.0 N.M. <u>and</u> "UPPER SEGMENT" GREEN).

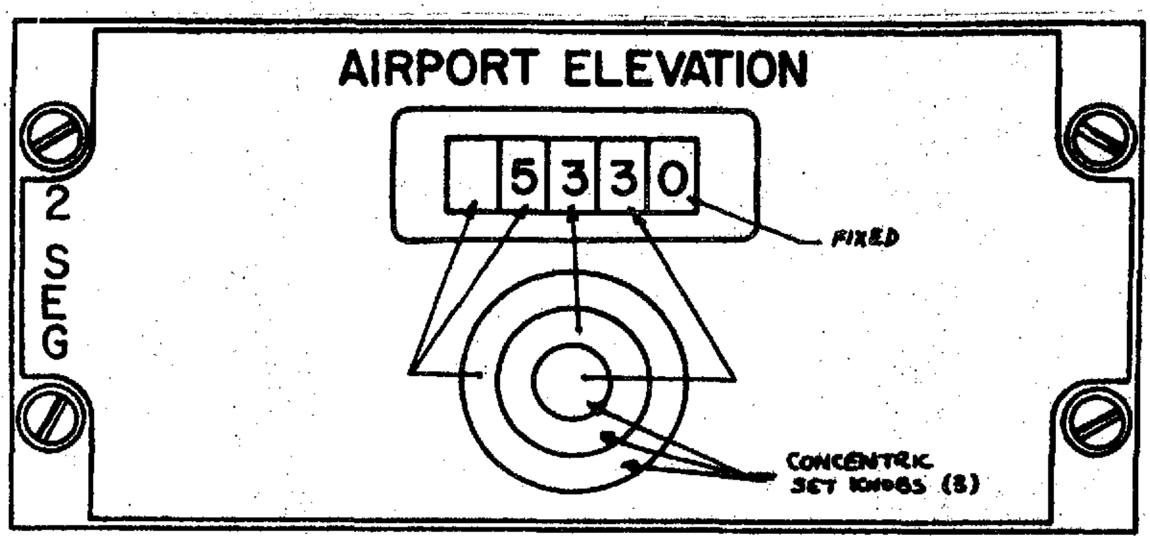
The computer continually performs certain self-tests and, through the switching unit, receives essential aircraft component validity signals as a prerequisite to initial arming and validation and as a condition for continuing normal operation throughout the approach. Failing any of these, it displays the appropriate failure flag(s) and, if the flight director and/or autopilot are utilizing the computer output for guidance, it will cause the flight director command bars to be biased from view and/or the autopilot to be disengaged. It monitors upper segment and glideslope capture and will remove the vertical guidance (bars from view and/or autopilot disconnect) under the fail capture conditions just described.

2. <u>The Switching Unit</u> - The switching unit logic was emulated in software in the simulator. The prototype unit consists primarily of logic-

controlled relays. Whenever the unit is powered (selector in "ARM"), the computer receives the essential aircraft computational and validity inputs through the unit, and the computed deviation outputs are supplied back to the flight director and autopilot pitch channels for translation into appropriate pitch commands. The approach progress signals pass through this unit to control these annunciations in the two-segment mode. The computed vertical deviation from the reference segment is passed through this unit from the computer to the HSI vertical deviation display.

The switching unit is powered only when the two-segment selector switch is in the "ARM" position. When it is not powered, no signal processing out to the autopilot, flight director or instruments and displays is done by the two-segment computer. It is as though the two-segment computer were not installed in the airplane. The unit is designed so that if the two-segment system is turned off or fails, all relays relax to restore normal aircraft system capabilities.

3. Airport Elevation Set Panel - The Airport Elevation Set Panel is shown below (approximately actual size). In the evaluation aircraft installation (single two-segment system), this panel was placed in the Captain's forward pedestal panel displacing the #1 ADF control head (#1 ADF removed). In a retrofit situation, if dual two-segment systems were required, this unit would probably have to be re-located to some point accessible to both the Captain and First Officer and would be modified internally to provide independent airport elevation inputs into each system.

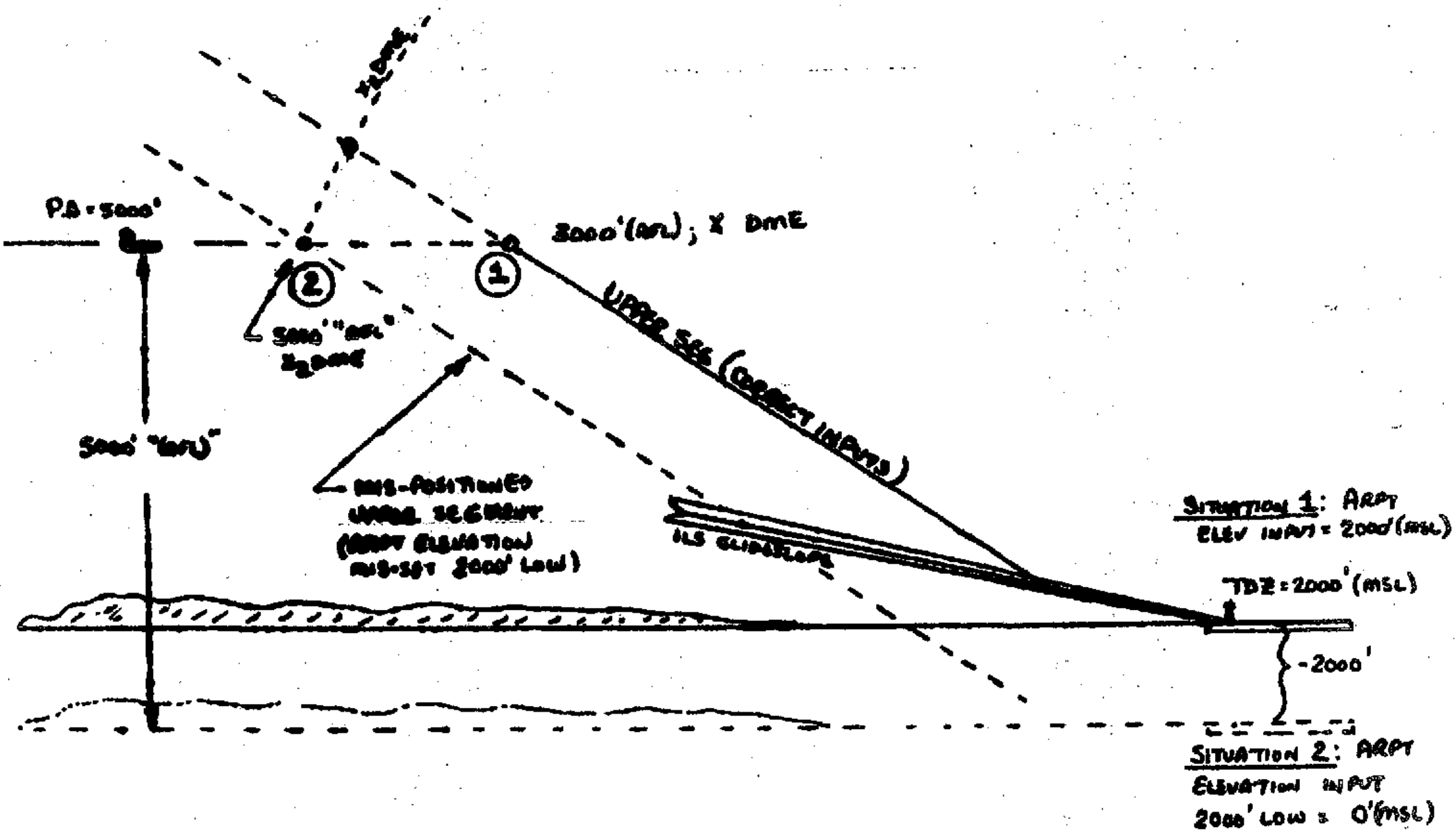


AIRPORT ELEVATION SET PANEL

The arrows show which digits each of the three concentric knobs sets. The units digit does not move. Published touchdown zone elevation to the nearest 10' is set in the windows prior to commencing the approach. In the example shown above, the 5330' would be for an approach to 26L at DEN, published elevation of 5331' MSL.

The earlier discussion of "upper segment" showed that the two-segment computer defines the upper segment as an infinite series of height above field ('AFL)/DME points. The computer subtracts airport elevation (TDZ) from baro-corrected aircraft pressure altitude in order to determine 'AFL which is essential to positioning the upper segment in the proper spatial relationship to the co-located DME. Because it is the input from the Airport Elevation Set Panel which tells the computer what the TDZ elevation is, the mis-setting of this input has a vital effect not only on the spatial position of the computed upper segment, but it also creates an operational anomaly which required equipment modifications described in detail later.

The figure below illustrates the effect which the mis-setting of the Airport Elevation input to the computer has upon the position of the upper segment with respect to the real-world runway:



Situation 1: Aircraft is proceeding inbound at 5000' baro corrected pressure altitude for a two-segment approach to a runway with published TDZ of 2000' (MSL). The airport elevation

input is set correctly (2000'). The upper segment is correctly positioned in space with respect to the runway. As the aircraft approaches position (1), normal capture would occur and a normal approach would be completed.

<u>Situation 2</u>: Aircraft is proceeding inbound as in Situation 1 above. Airport Elevation <u>input</u> to the computer is in error by 2000' (low). The effect of this mis-set error is that the computer is being "told" that TDZ is 0'(MSL) instead of 2000' (MSL). The computer therefore "sees" the airplane approaching at 5000' (AFL) (5000' pressure alt - 0'(MSL) instead of 3000' (AFL), which is the actual real-world situation). When the airplane reaches the DME corresponding to 5000' AFL (position (2) above), if the two-segment system is armed and valid and the flight director and/or autopilot are in their auto approach modes, the system will capture and track the mis-positioned upper segment.

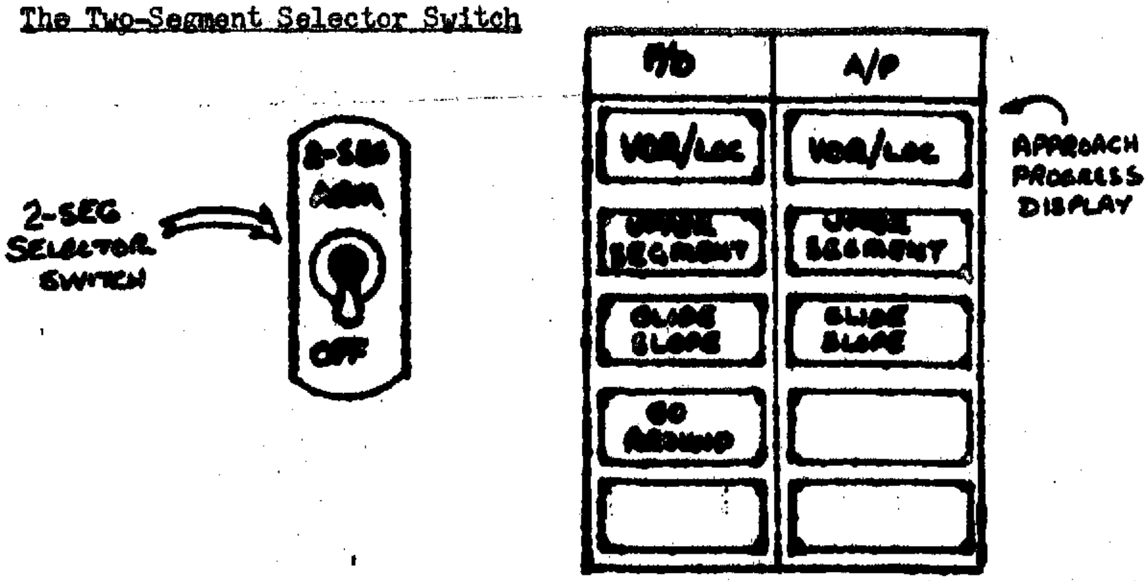
NOTE: This error has two potential sources:

(1) Electro-mechanical malfunction in the Airport Elevation Set Panel.

(2) Crew has entered incorrect TDZ in panel.

Computer will accept any signal value. It cannot check this input for reasonableness.

4. <u>The Two-Segment Selector Switch</u>



This switch was added to the Captain's instrument panel immediately to the left of the Approach Progress Display. More specifically, it was to be at the same level as the "upper segment" annunciator which was added to the APD.

When placed in the "ARM" position, this switch energizes the switching unit and thus makes the two-segment computer outputs available to the autopilot and/or flight director when each is placed in its auto approach mode. It is important to understand the distinction that the outputs are only made available for use by the A/P and F/D. Until and unless the auto mode is selected, these units operate normally in any of their other modes.

When placed in the "ARM" position by the pilot, it is solenoid-held in "ARM". It will remain in "ARM" unless physically moved to the "OFF position by the pilot or unless the pilot selects "GO-AROUND" after the glideslope capture maneuver has been initiated by the system ("GLIDESLOPE" GREEN).

As presently designed, the switch is held in "ARM" even though the conditions might exist which cause the autopilot to trip and the flight director command bars to bias from view. This is necessary to supply certain warning flag power which would not be available through the normal systems. I would drop to "OFF" if solenoid power were lost.

The selector switch, remaining as it does in the "ARM" position, the autopilot and/or flight director can be reverted to any other mode than automatic (except manual G/S on autopilot) by the movement of the mode selector to the desired mode. However, to re-engage the auto modes, the pilot must first move the selector switch to the "OFF" position and back to "ARM" and then re-cycle the mode selectors back to auto. In this case, if all validity and logic requirements are not satisfied, the F/D command bars will bias from view and the autopilot will trip off.

AIRCRAFT COMPONENTS OF THE SYSTEM

Only those aircraft components which contribute a computational or validity input to the two-segment computer are technically part of the system as such. The HSI, flight director, autopilot and Approach Progress Display are users of the system output and their presence or absence as users does not affect the computational capability of the system.

With this in mind, very few of the basic aircraft components are part of the two-segment system (as defined). Aside from power derived from various aircraft electrical buses and some added circuit breakers, only the following aircraft components are parts of the system:

(1) Altimeter/CADC - Baro-corrected pressure altitude is an essential input to the computer for determining aircraft instantaneous 'AFL (baro-corrected pressure altitude minus TDZ ('MSL). Principally because of the program time constraints, the installation evaluated in this program involved the use of a special electric altimeter which was capable of converting baro-corrected pressure altitude to a d-c signal. This signal was then fed to the Airport Elevation Set Panel which subtracted out the TDZ elevation and passed the resultant to the computer as a 'AFL d-c signal. This was a third altimeter which had to be set prior to commencing the approach if the upper segment were to be properly positioned with respect to the runway. Such a solution to the problem would not be acceptable in an industry retrofit situation. In United Air Line's judgment, the Collins computer should be modified to accept existing ARINC fine-coarse synchro inputs from the CADC rather than forcing the industry to backfit its altimetry to provide the kind of input utilized in the prototype installation. Aside from the very considerable costs involved, the proneness to failure or to unreliable output of the D-C potentiometer would make its use in a certified system less advisable, especially in view of the effect upon the upper segment position if the input signal is in substantial error.

(2) DME - The two-segment system cannot perform a computational function without a DME input to the computer. It contributes the

DME half of the 'AFL/DME upper segment combination and the attendant deviation computations for intercepting and tracking upper segment. It is further essential that this DME be co-located with the ILS glideslope transmitter. The effect of DME error upon upper segment position and related factors is shown in DME (ground) in the next section

Certain discrete DME values are involved in normal system sequencing and fail capture protection. Localizer gain programming is also a function of a discrete DME value:

(a) 5.0 DME - Glideslope Arm and Localizer gain programming.

(b) 1.8 DME - Minimum DME Protector trip.

(c) Glideslope Capture (onward) - Glideslope gain programming based on DME instead of time.

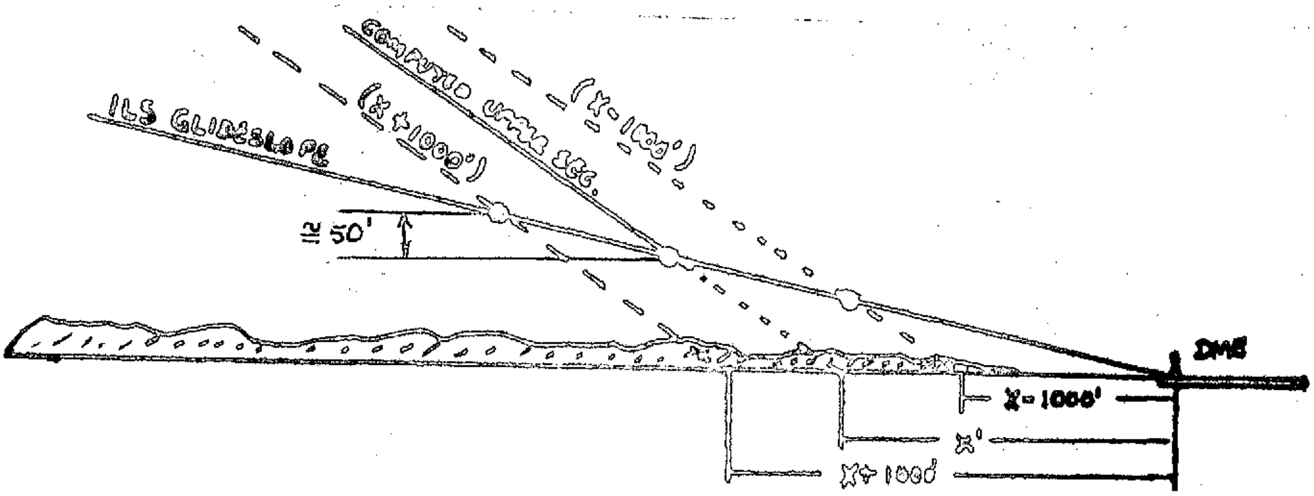
(3) <u>VHF NAV Receiver</u> - The system requires glideslope valid for glideslope transition. The receiver input (G/S section) is essential for glideslope tracking.

NOTE: The system will capture and track an upper segment without a glideslope present. If, however, the aircraft descends on upper segment and glideslope valid input is not present at glideslope arm point ("Glideslope"AMBER), the system will trip the A/P and F/D.

GROUND EQUIPMENT COMPONENTS OF THE SYSTEM

In order to execute a two-segment approach, the system must have a DME co-located at the glideslope transmitter site and a glideslope to complete the approach. The lack of an operative localizer does not affect the operation of the system in any way. The system does no roll channel processing or modification except to trigger localizer gain programming at 5.0 DME instead of at the 1500' RADALT trip.

(1) The geometry of a given approach is affected by DME error since a principal determinant of the computed upper segment is DME distance from touchdown. The effect of DME error is illustrated in the figure below:



EFFECT OF DME ERROR UPON POSITION OF COMPUTED UPPER SEGMENT

Not only does a 1000' error as shown above move the lower intersect point (intersection of computed upper segment and glideslope) toward or away from the touchdown point by 1000', but it also raises or lowers that intersection by about 50'/1000' of error. It was seen in the report that a change of about 100' in the height of this intersection makes a difference in ground level noise of about 2 PNdb during the upper segment portion of the two-segment approach. The X' shown above for the 6°/3° profile is about 8,000'.

(2) ILS Glideslope - The two-segment approach cannot be completed without an ILS glideslope. The fail glideslope capture protectors discussed earlier showed that failure to transition from the upper segment to the ILS glideslope will trip the system and remove autopilot and flight director guidance. The upper segment can be computed and flown down to "Glideslope" AMBER without a glideslope present and without the requirement that the localizer be captured.

(3) Localizer - This is not a pre-requisite to upper segment tracking. It is, however, an operational prerequisite to completing the ILS portion of the approach.

AIRCRAFT INTERFACE

No attempt will be made to describe the technical details of the two-segment/aircraft interface. The general operational philosophy which influenced the equipment and interface design is:

(1) When the two-segment equipment is not being used by the pilot for the purpose of making a two-segment approach (two-segment selector switch "OFF"), all of the normal flight control, instrument and navigational systems operate in exactly the same manner as they would if the two-segment equipment were not installed.

(2) When the two-segment system is in use, it serves only as a processor and supplier of vertical deviation information for normal use by the flight director and autopilot pitch channels in the same manner that these systems utilize ILS glideslope deviation information when these systems are in their respective auto modes. It modifies no normal system logic or functions except that in the

two-segment mode, it DME gain programs the ILS glideslope input and inhibits localizer gain programming until the glideslope capture point. Neither of the gain programming provisions (G/S or LOC) in the aircraft equipment is altered when the two-segment system is not in use.

(3) Reversion to the normal aircraft navigational and guidance systems is accomplished as previously described in reversionary mode selection or by the movement of the two-segment switch to the "OFF" position (manually or by selection of "GO-AROUND" after "G/S" GREEN).

(4) Lack of any system validity or logic required for proper guidance will preclude arming the system, or if any validity is lost or system logic is not proper while the system is in use, it will disengage the autopilot and/or bias the command bars from view. It cannot be re-engaged without specific overt actions on the part of the pilot.

(5) The system makes use of all existing warning systems. There are no additional warning lights or audibles involved.

OPERATIONAL DESCRIPTION OF THE TWO-SEGMENT SYSTEM

General

Upper Segment

Upper Segment Capture Point

Glideslope Arm Point

Glideslope Capture Point

Lower Intersect Point

Fail Capture Protection

Flight Path Deviation and Tracking Commands

GENERAL OPERATIONAL DESCRIPTION OF THE TWO-SEGMENT SYSTEM

This section will expand upon the design and logic concepts of the various elements in the two-segment profile discussed earlier. It will not go into the technical design of the Collins hardware. It will provide a further understanding of the operational concepts which influenced the methods used in the profile and procedures development tasks described in the main report.

CAPT ______________________ DATE 11/6/72

ID # ______________________ ATTN ______________

PROJECT PILOT Snyder - Monteith

SIM [X] ACFT [ ] B727 [X] DC-8 [ ] APPROACH # ________

NBR. HOURS _____ DAY [ ] NIGHT [ ] DUSK [ ]

AIRPORT/RUNWAY ______________________ WX ______________

COMMENTS:

1. Testing was conducted on the upper segment intercept alt, U/S angle and speed schedules. The alt range was from 1500' to 8000'. The angle varied from 4° to 8°. The upper capture point was maintained at a setting of 400. The lwr capture point was at 330 for angles of 6° and greater, and varied btwn 250 and 200 for the 4° and 5° angles.
2. Configuration scheduling was to fly inbound to the upper capture point with 0° flaps, gear up and 200 KTS. At capture, thrust was reduced to idle and flap extension begun, continuing to 30° as rapidly as leading edge devices permitted. Only one approach was flown at 40° (for a noise comparison trace), the balance being 30° Vref+15 on the upper segment and 30° Vref+5 on G/S.
3. U/S intercept altitudes below 3000' do not offer an adequate reduction in noise levels from current procedures. Intercept altitudes above 3000' pose no problems by themselves, and will be further explored to achieve maximum noise reduction and remain compatible with ATC procedures.
4. U/S angles above 6° do not appear practical due to large thrust, pitch, and trim changes required during transition to G/S.
5. The tested configuration scheduling does not demonstrate itself to be operationally sound. Idle thrust, although yielding maximum noise reduction for a given angle, presents problems in spool up time and proper lead. On the 8° U/S angle with a 8000' intercept alt, using the tested configuration scheduling, the throttles were in idle from capture to 650'.
6. It appears that the proper U/S angle, for all considerations tested to date, lies between 5° and 6°. Secondly, when using an U/S intersect alt of 3000' to 4000', the 0° flap intercept

CAPT ______________________ DATE 11/6/72

ID # - ______________________ ATTN ______________

PROJECT PILOT ______________________

SIM [ ] ACFT [ ] B727 [ ] DC-8 [ ] APPROACH # ________

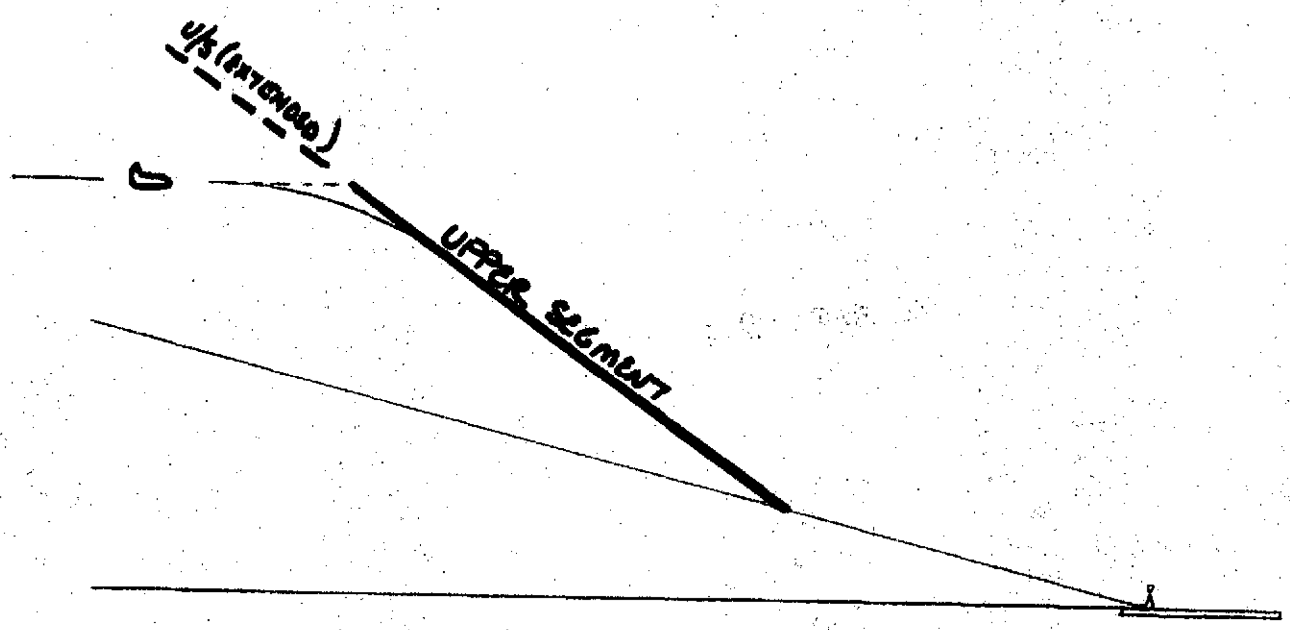
NBR. HOURS _____ DAY [ ] NIGHT [ ] DUSK [ ]

AIRPORT/RUNWAY ______________________ WX ______________

COMMENTS:

is impractical in that the thrust is minimal to low alt with greatly tapering airspeed, even during the G/S transition, as was the case in the higher angle U/Ss.

THE UPPER SEGMENT



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THE UPPER SEGMENT

The upper segment is a computed path in space, based on an infinite series of 'AFL/'DME combinations. In Figure 1 below, the 'AFL-DME combination is unique to that particular upper segment point. If the system is armed and valid, as the aircraft is at h_2, if the DME is other than x_2, the computer calculates a deviation from upper segment and displays this deviation on the HSI and makes it available to the flight director and/or autopilot (in auto modes). Similarly, if the aircraft when passing x_2 is not at h_2, a deviation display and appropriate corrective output to the flight director and/or autopilot will occur.

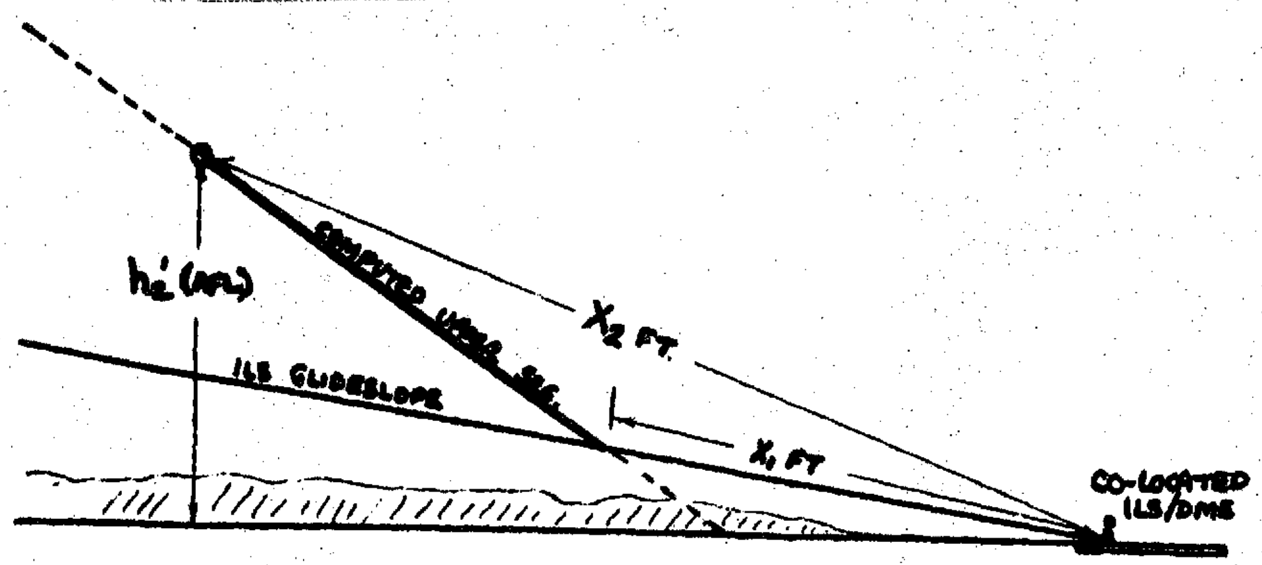

FIGURE 1 - UPPER SEGMENT DEFINITION

Several facts regarding upper segment definition become obvious from Figure 1:

(1) If X_2 varies while X_1 and h_2 remain constant, the upper segment angle will vary.

(2) If X_1 and X_2 vary equally (and h_2 remains constant), the upper segment angle remains fixed but the segment moves toward or away from the touchdown zone.

(3) If h_2 varies and X_2 and X_1 remain constant, the computed upper segment angle will vary.

(4) In any of the above cases, the height above TDZ elevation at which the calculated upper segment intersects the ILS glideslope ("lower intersect altitude") will vary.

NOTE: It should be understood that the values of X_2 and h_2 shown above are instantaneous incremental values which correspond to only one of an infinite number of X-h values by which the two-segment computer defines the upper segment.

The special altimeter baro-corrected d-c input furnished the aircraft altitude in feet (MSL) to the Airport Elevation Set Panel which subtracts out TDZ elevation (MSL) to the nearest 10' and inputs 'AFL into the computer. The effects upon the actual position of the upper segment (in relation to the real-world runway) as a result of an erroneous signal input to the computer as the result of errors in either TDZ or altimeter baro-correction are shown in the following illustration:

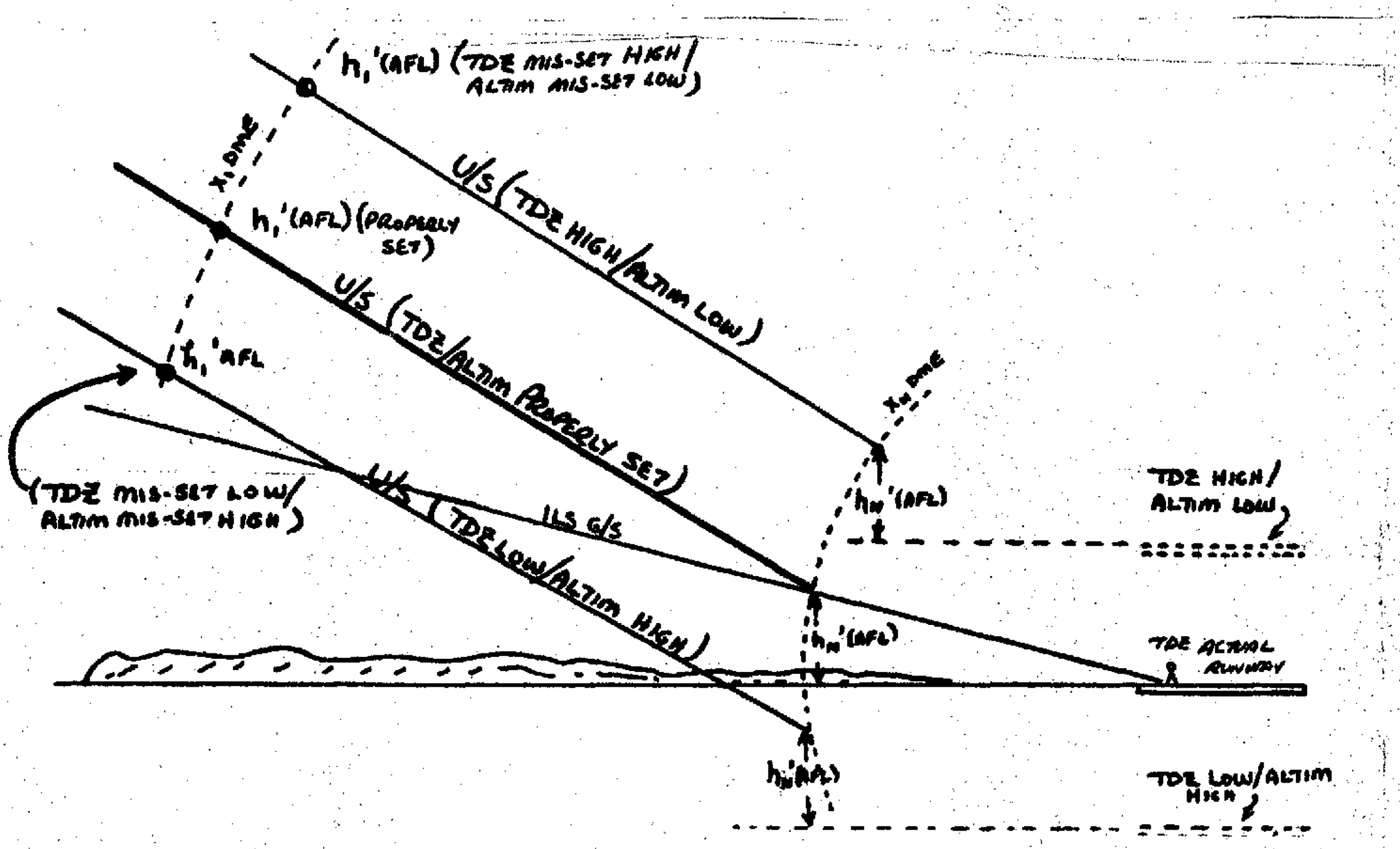

FIGURE 2 - EFFECT OF ERRONEOUS TDZ ELEVATION OR ERRONEOUS ALTIMETER CORRECTION INPUT UPON ACTUAL POSITION OF COMPUTED UPPER SEGMENT.

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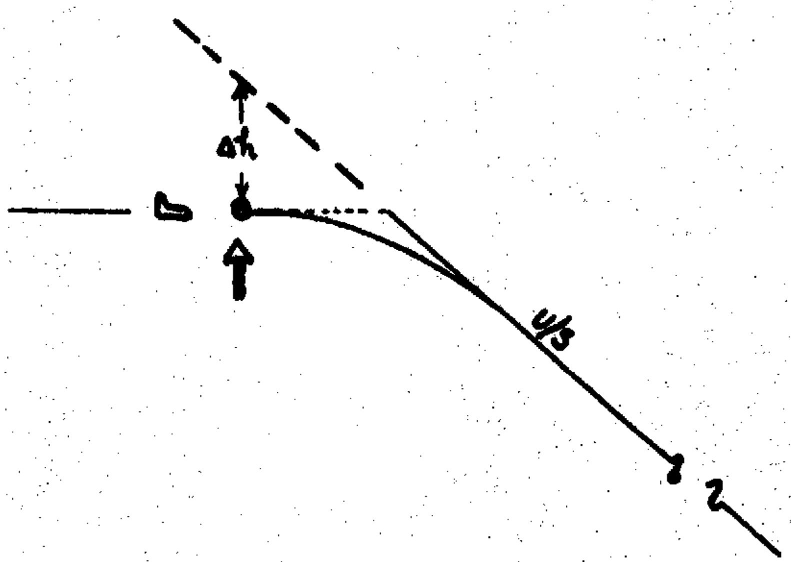
UPPER SEGMENT CAPTURE POINT



UPPER SEGMENT CAPTURE POINT

This is the point before the aircraft reaches the computed upper segment (from beneath) at which the pitch-over command must be initiated in order to transition the aircraft from its initial approach flight path on to the upper segment. The two-segment computer accomplishes the transition maneuver in a fixed number of seconds regardless of the speed at which the aircraft is approaching the upper segment.

Some important operational considerations are related to this profile parameter:

(1) To be operationally viable, the two-segment system must be capable of transitioning the aircraft on to upper segment at any speed within operationally reasonable airspeed (groundspeed) limits. In the real-world ATC environment, the controller may require the pilot to maintain any of a number of airspeeds to (and perhaps after) the upper segment capture point, depending on the existing traffic situation in the arrival area.

(2) The transition must not induce any appreciable physiological sensation in the passenger cabin, particularly as regards g-force sensations.

(3) The transition must be initiated at the precise point appropriate to the existing conditions so that there is no overshoot of the upper segment.

(4) Failure of the two-segment system to initiate the transition at this point (or failure on the part of the pilot to configure the autopilot in the auto approach mode prior to this point) prevents the autopilot from capturing upper segment except by re-cycling the mode selector and descending below upper segment for capture from below. The flight director will furnish late capture commands up to the point at which the aircraft flies through upper segment.

The method by which the two-segment computer determines upper segment capture point is beyond the technical scope of this report. The general methodology is, however, important in understanding the simulator programming rationale and in appreciating the importance of this point in the development of an operationally acceptable transition to upper segment.

This point on the profile is not a fixed point. Since transition time is a constant, the point at which the pitch-over command must be initiated is necessarily a variable which is a function of the rate at which the aircraft is approaching the upper segment.

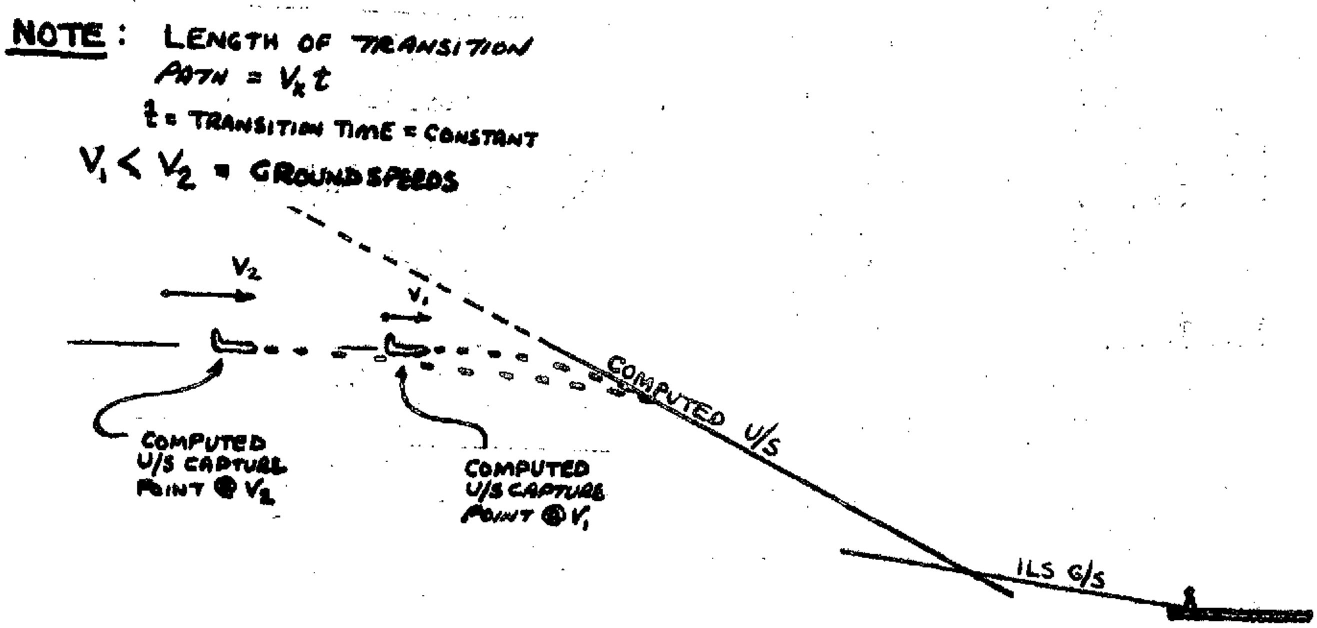


FIGURE 1 - UPPER SEGMENT CAPTURE POINT AS A FUNCTION OF RATE OF APPROACH TO UPPER SEGMENT.

It can be seen that for a constant transition time, the point at which the transition maneuver must commence varies as a function of the rate at which the aircraft is closing on the upper segment. The V_1 and V_2 shown in Figure 1 are groundspeeds since the computer must correct for the wind as well as the airspeed component.

Since the pitch guidance commands for tracking or correcting to upper segment are derived from a comparison of the instantaneous vertical position of the aircraft with respect to the computed upper segment, the computer uses the rate at which this vertical deviation is changing to compute an upper segment capture point which is proper for that instantaneous vertical closure rate.

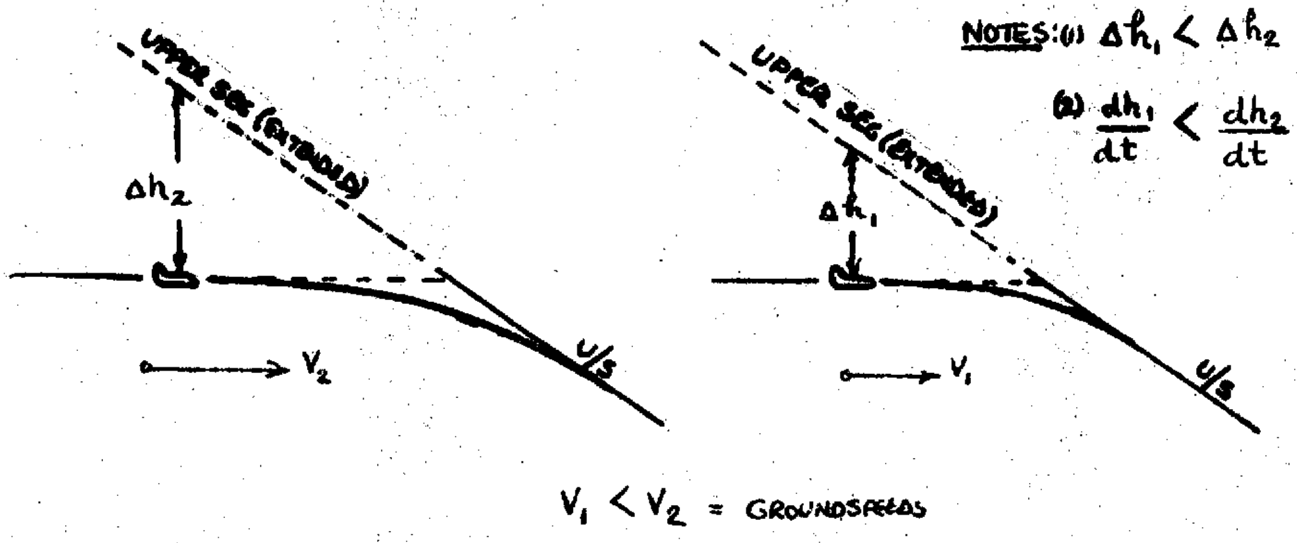
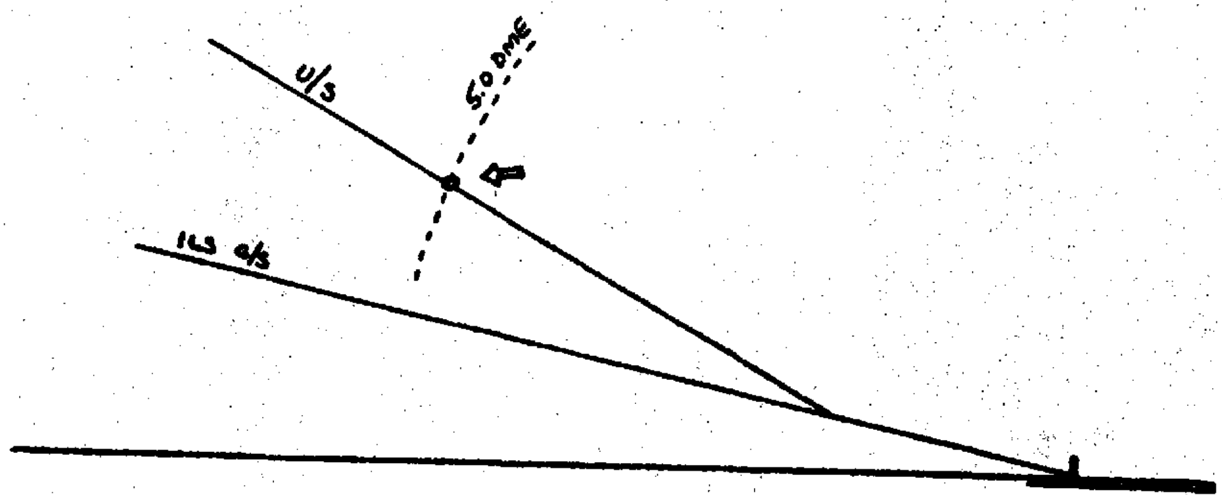


FIGURE 2 - UPPER SEGMENT CAPTURE POINT - COMPUTATION BASIS

From Figure 2, it can be seen that if the aircraft is approaching upper segment in the first case at V_2 and the second case at V_1 (where $V_2 > V_1$), the rate at which Δh_2 (dh_2/dt) is changing is higher than the rate at which Δh_1 (dh_1/dt) is changing. Since the time to complete both maneuvers is the same, it is logical that the pitch-over command must be initiated at some greater value of Δh for V_2 than for the Δh which is appropriate to the slower V_1.

The two-segment system is designed to compute the upper segment capture point for any reasonable value of dh/dt. One development task (discussed in the main report was to establish a value of Δh which resulted in a proper transition to upper segment for a fixed value of V. It was seen that the Project Team developed a narrow band of transition times which were then used in conjunction with a fixed airspeed (groundspeed) to derive the h value corresponding to those conditions. The simulator software (and associated hardware) were provided so that h could be varied by the Project Team between the limits of 100' and 600' in 100-foot increments.

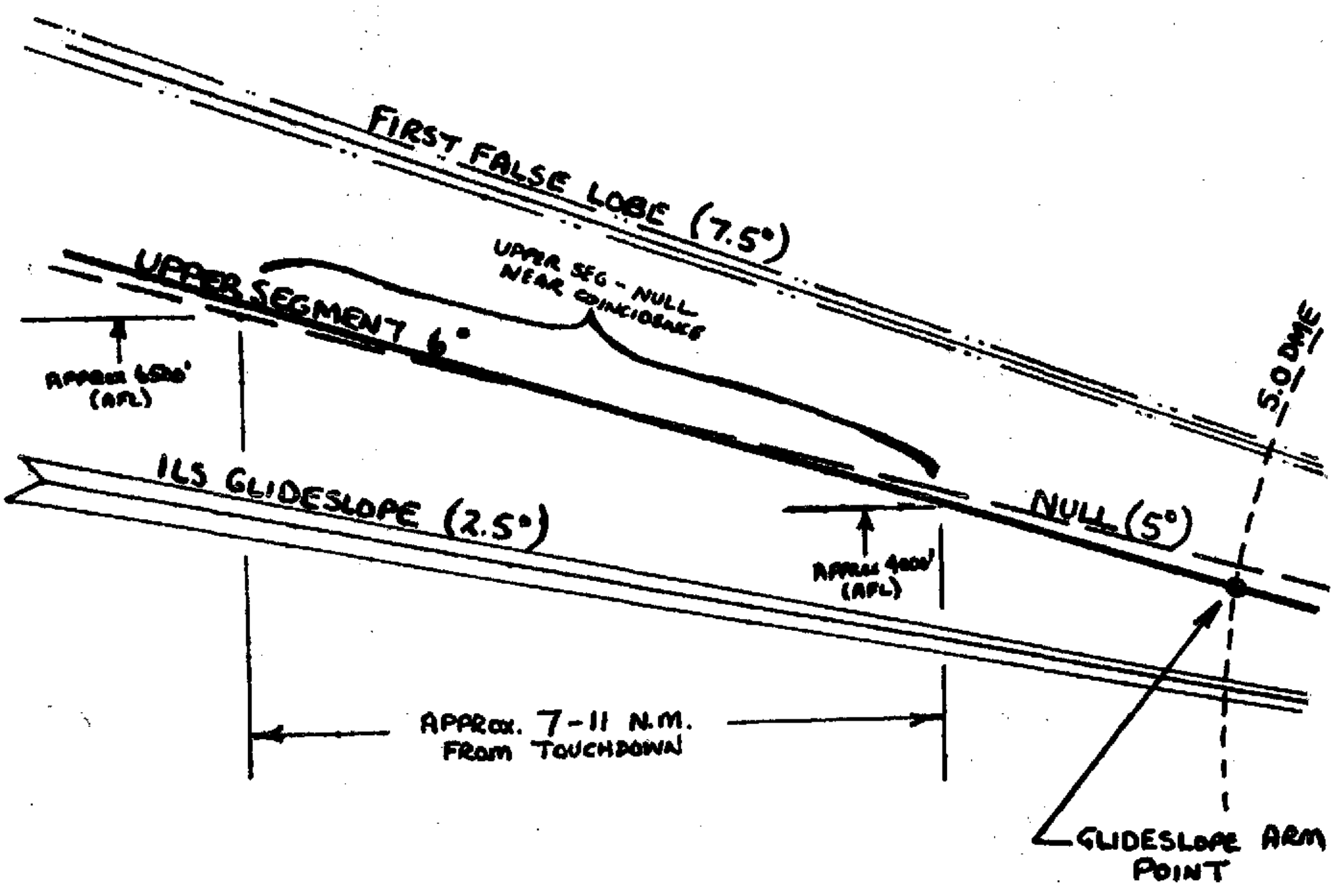
GLIDESLOPE ARM POINT



GLIDESLOPE ARM POINT

The earlier discussion of glideslope arm point describes the basic reasons for establishing it. The earlier illustration is, however, misleading in that it implies a much greater divergence between the null and the 6° upper segment than actually exists.

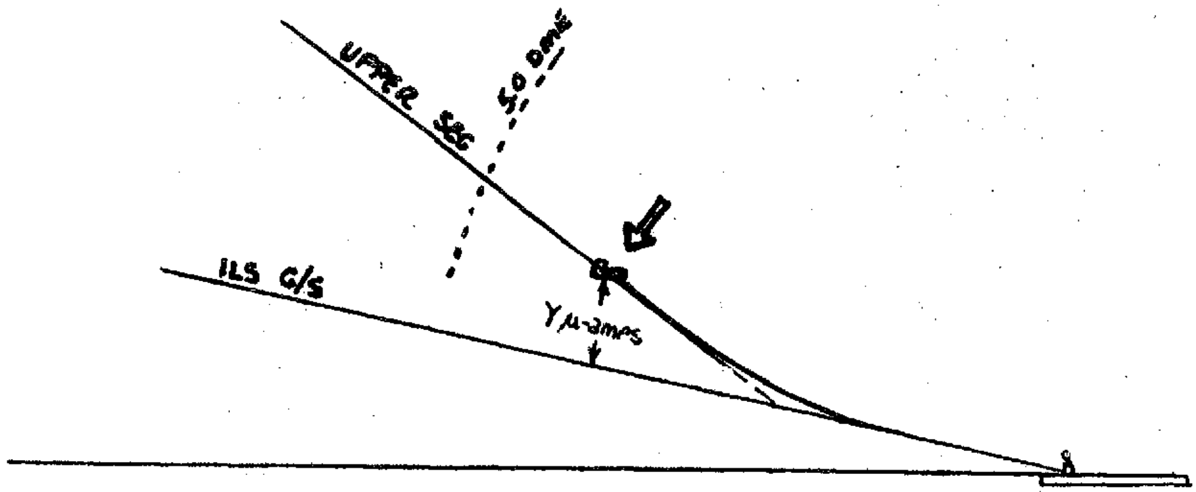
The illustration below still exaggerates the divergence relationships; however, it will better illustrate and explain the problem associated with the presence of this null in the vicinity of a certain portion of the upper segment in the 2.5° glideslope/5° null/7.5° first lobe situation (upon which the illustration is based).



The null is theoretically a zero signal boundary. In practice there is usually some signal noise; however, it is at a low enough level that the two-segment computer interprets the boundary and its immediate environs as a zero deviation signal (on course). If the system armed for capture in this near-coincidence regime, capture could be instantaneous and on the 5° null. The aircraft might continue to track this null. What is more likely, however, is that it might start some unexpected (and perhaps violent) correction, either to the true ILS glideslope or respond to the reverse sensing of the first false lobe.

The illustration opposite shows that at 5.0 N.M. DME the 6° upper segment has crossed the null boundary into the true ILS glideslope beam pattern. Since actual capture ("Glideslope" GREEN) occurs considerably later on upper segment, it was considered safe to arm the Flight Director and/or Autopilot for capture at this point in order to indicate to the pilot that a valid glideslope was present and to arm the fail glideslope protector well outside of the 37.5 micro-amps trip regime.

GLIDESLOPE CAPTURE POINT



GLIDESLOPE CAPTURE POINT

This is the point at which the pitch-up maneuver must be initiated in order to transition the aircraft flight path smoothly from upper segment to ILS glideslope. This is not a fixed point. Like upper segment capture point, there is one and only one point which is exactly appropriate to the instantaneous rate at which the aircraft is approaching ILS glideslope from above. Since this rate can be expected to vary from approach to approach, this point will also vary.

There are important operational and safety considerations associated with the accurate determination of this point:

(1) The two-segment system must be capable of determining this point over a reasonable range of conditions. This range is logically much narrower than that which might be encountered in the approach speeds to upper segment capture; however, the accuracy with which this point is determined is more critical than any other point in the earlier portions of the approach.

(2) The physiological constraints applicable to upper segment transition also apply to the glideslope transition.

(3) The system must compute the precise point at which the transition is initiated for the instantaneous conditions in order that the

aircraft is on glideslope center at 500' (AGL) with no permissible overshoot (below glideslope). (A UAL-established operational requirement for the evaluation).

(4) The protective features to guard against failure to commence transition at this point were discussed earlier. The further discussion of these features will point up the additional safety constraints and precision requirements associated with this point.

The method by which the two-segment system determines the exact point for any given set of conditions is beyond the technical scope of this report. An explanation of the basic concepts will, however, be useful in understanding the fail-capture protection features. It will also help to explain the simulator programming rationale as well as the methods used in the development tasks related to the glideslope transition portion of the profile.

As previously explained in the discussion of false lobe capture protection, the system is not armed for glideslope capture until the aircraft is inside of the 5.0 N.M. DME range. In Figure 1 below, the aircraft has passed the glideslope arm point and is descending on upper segment toward glideslope capture point in both cases shown:

C-2

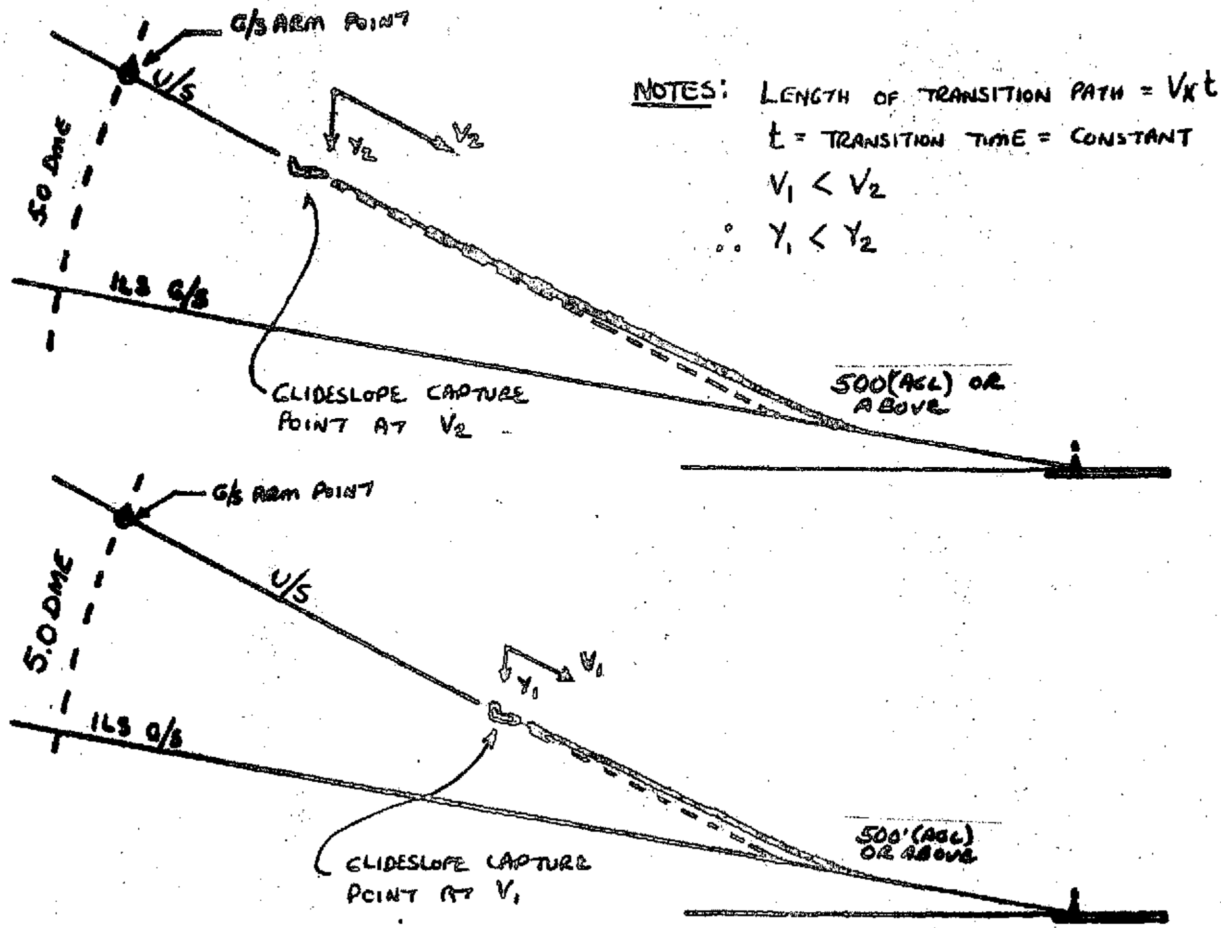


FIGURE 1 - GLIDESLOPE CAPTURE POINT - AS FUNCTION OF APPROACH SPEED.

In the two cases above, it can be seen that with a constant transition time and with both transitions terminating at the 500' (AGL) point on the glideslope, if V_2 is greater than V_1, the transition must commence earlier for the higher speed V_2 than for V_1 since the physical length of the V_2 transition path ($V2t$) is greater than the V_1 path (V_1t).

Since the upper segment is not a radiated beam, it was necessary to compute upper segment capture point by comparing the instantaneous position of the aircraft with the computed upper segment and initiating the pitch-over maneuver at some Δh below the upper segment which is appropriate to the rate at which Δh is changing (dh/dt).

The ILS glideslope is, however, a radiated beam. For the sake of added accuracy, as well as for using the auto approach guidance already built into the autopilot and flight director systems, it was logical that the glideslope capture point be determined by the rate at which the aircraft is approaching glideslope center.

In figure 2 below, V_2 and V_1 represent linear velocities along the upper segment. V_2 is greater than V_1. The rate of change of $-dy_2/dt$ is therefore higher than for V_1 $(-dy_1/dt)$. Since transition time is a constant, and since both transitions terminate at 500' (AFL) OR ABOVE on the ILS glideslope, the transition initiation point for V_2 must be higher above glideslope beam center than for the V_1 capture point:

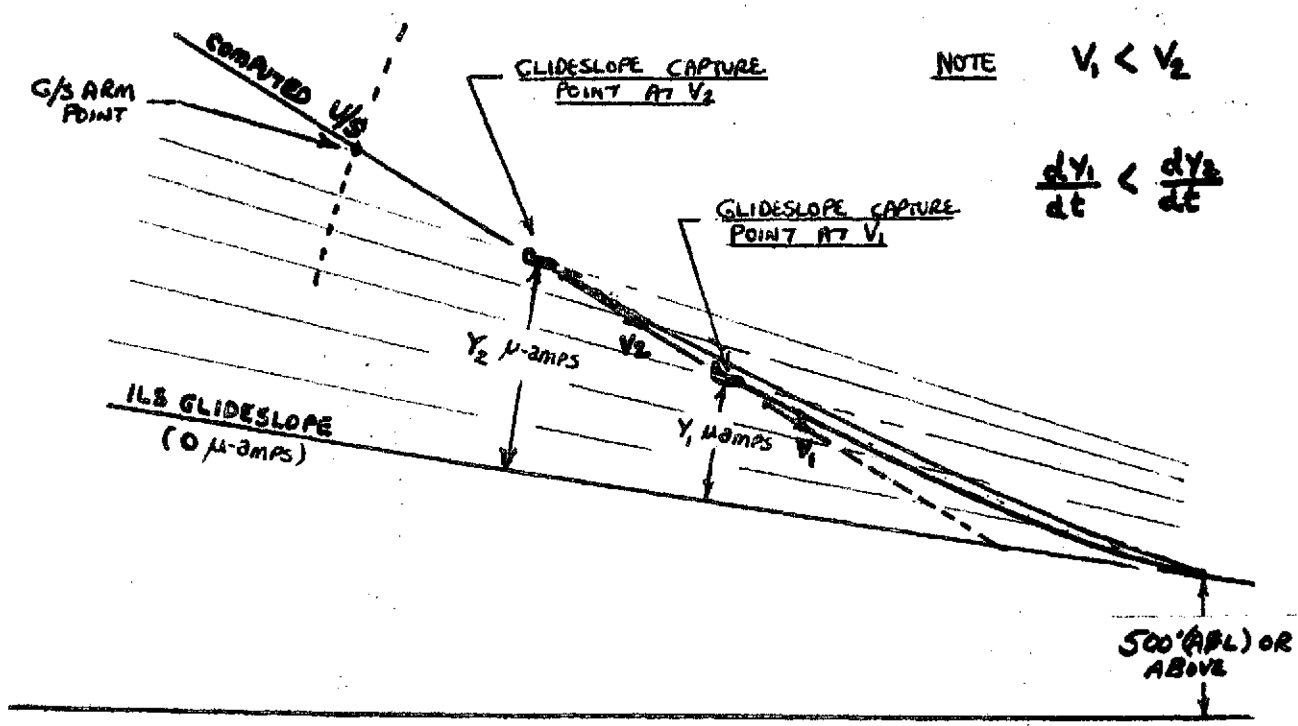


FIGURE 2 - GLIDESLOPE CAPTURE POINT AS A FUNCTION OF HEIGHT ABOVE G/S CENTER AND CLOSURE RATE

The simulator program provided a means by which the Project Team could vary glideslope capture point by setting different values in feet above glideslope center.

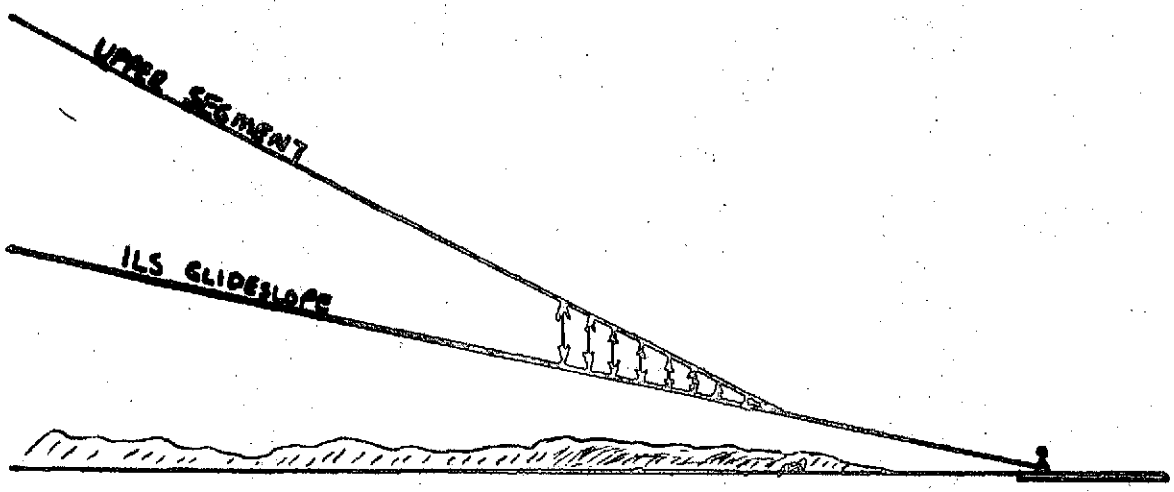
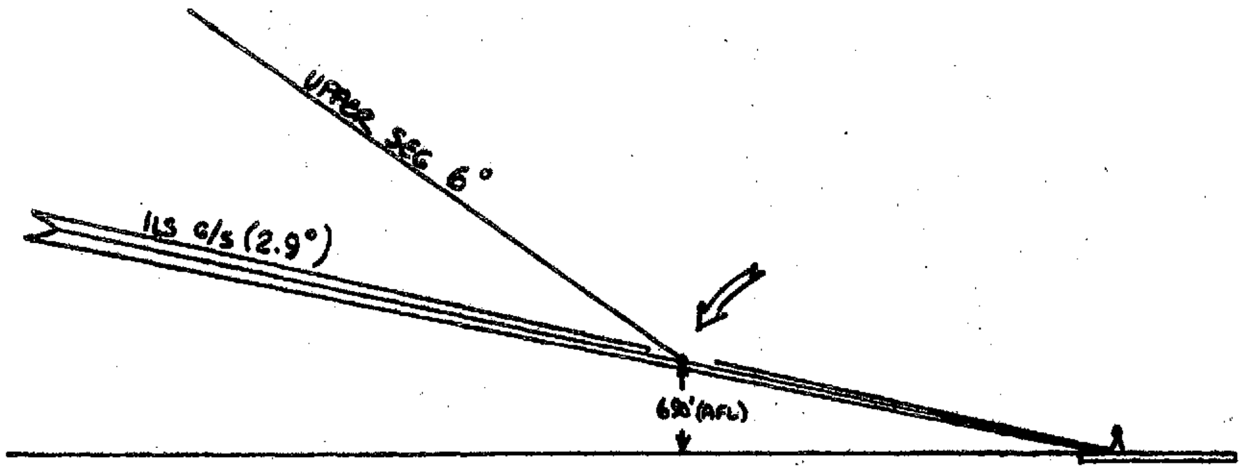


FIGURE 3 - SIMULATOR PROGRAM PROVISION FOR VARYING GLIDESLOPE CAPTURE POINT.

It can be seen in Figure 3 that the method used in the simulator for setting this point is technically different from the actual method by which the two-segment computer sets this point for a given linear velocity along upper segment. The development task of optimizing this lower transition, however, could be just as well and much more readily accomplished in simulation by the use of a settable height above glideslope center.

LOWER INTERSECT POINT



LOWER INTERSECT POINT

This is the point at which the computed upper segment intersects the ILS glideslope. Determination of its optimum value was very important because of the interdependence between this point and glideslope capture point and on-glideslope point.

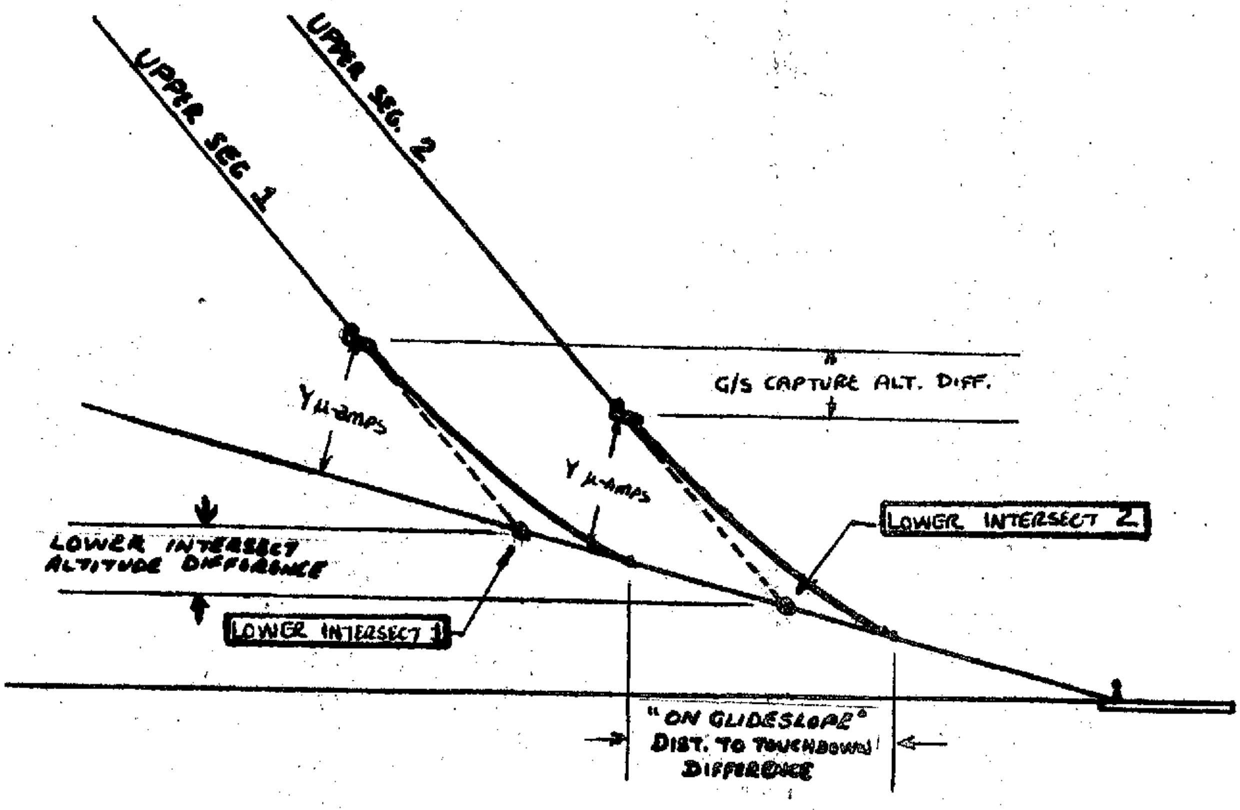


FIGURE 1 - EFFECT OF LOWER INTERSECT ALTITUDE UPON GLIDESLOPE CAPTURE POINT ALTITUDE AND ON-GLIDESLOPE DISTANCE TO TOUCHDOWN.

It is apparent from Figure 1 that variations in lower intersect altitude directly affect the altitude of the glideslope capture point and the distance from touchdown at which the aircraft is on glideslope (linear velocity on upper segment, upper segment angle and transition time identical in both cases shown).

In the discussion of glideslope capture point, the UAL operational criterion that the on-glideslope point should be 500' (AFL) or above logically dictates that this point must be at some height above touchdown zone elevation greater than 500'. The development method used for optimizing this point is discussed in the main report.

The significance of this point upon ground level noise is considerable. The effects are discussed in detail in the main body of this report.

FAIL CAPTURE PROTECTION
(Equipment Failure/System Mis-management)

General

Upper Segment Capture

Glideslope Capture

(A) Glideslope Deviation

(B) Minimum Height Above TDZ

(C) Minimum DME

(D) Fail Capture Protector Modifications

Fail Capture Protection - General

Several important protective features have been designed into the two-segment system. A failure will manifest itself to the crew in an explicit and overt manner. The conventional system component failure flags which appear on the instrument displays continue in use in the two-segment system. In addition, if the flight director and/or autopilot are providing flight guidance, and if a system component vital to that guidance fails or if any validity parameter vital to the two-segment system logic is not correct, the autopilot and/or flight director guidance is immediately removed and the approach progress annunciations are extinguished to alert the pilot to take alternative action appropriate to the conditions that exist at that time.

For technical design reasons relating to electrical power dependencies for validity failure inputs, the two-segment arm switch remains in the "2-SEG ARM" position (solenoid-held) in the event of a system failure. The flight director and/or autopilot do not therefore automatically revert to the conventional operating logic. Reversion is accomplished by manually selecting the desired reversionary mode or by moving the "2-SEG" switch to the "OFF" position.
If the pilot selects "GO-AROUND" after glideslope capture point, the "2-SEG" switch drops out of the "ARM" position automatically.

A "GO-AROUND" selection prior to this point will trip the autopilot, but will not drop the switch out of "ARM".

Fail Upper Segment Capture

It has been stated earlier that one of the operational criteria in the system design is that the transition to upper segment must be accomplished with no overshoot. This constraint was included to prevent a situation in which the aircraft has passed upper segment capture point, and then the system is armed (or becomes armed) for capture. Having passed the capture point appropriate to the instantaneous conditions, an overshoot would be inevitable if a transition were commenced at that time. At the end of the transition time, the system would then command a larger nose down attitude in order to correct back down on to upper segment. A steeper nose down position than that necessary to track upper segment was considered operationally unacceptable at least in the present state of development of the equipment and in light of the general pilot community apprehension about the approximately 1500'/min. rates of descent and lower engine power settings involved in normal upper segment tracking.

The fail upper capture protection therefore involves the following:

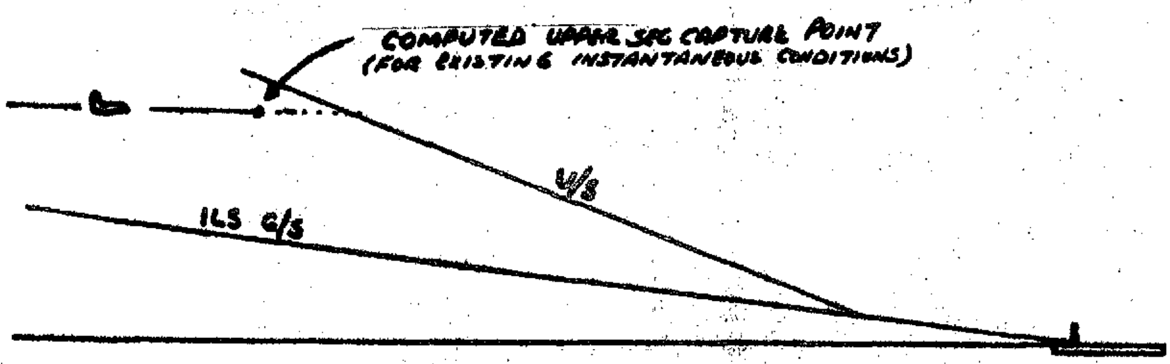
(a) The absence of any essential input from the aircraft navaids and/or flight guidance systems, or the failure of any validity check which the two-segment system makes will prevent the arming of the system for upper segment capture. In such a case, the "2-SEG" switch will not hold in the "ARM" position and the "UPPER SEGMENT" approach progress annunciator(s) will not illuminate amber. If the problem stems from an inoperative navaid, the appropriate flag(s) will be displayed on the instrument(s).

(b) Failure on the part of the pilot to configure the system properly prior to reaching the computed upper segment capture point will preclude the autopilot from attempting upper segment capture. If the flight director is properly configured at some point after capture point but before passing through upper segment, flight director commands for a late capture will be given.

(c) As presently designed, if the system has been properly configured and if, for any reason, the system fails to initiate the capture maneuver properly, the upper segment annunciator(s) remain amber; and the aircraft would remain on its current flight path until the pilot took alternative action.

(d) Because of the complexity of differentiation logic between having flown through the upper segment without capture and the situation in which all the necessary inputs and validity checks are proper but the aircraft position is above upper segment at the time the two-segment configuration is completed, the system would perform as stated in (c) above in this case. As presently designed, the pilot could not capture upper segment until and unless he maneuvers the aircraft from the point above upper segment to some point beneath it and re-cycles the "2-seg" switch and appropriate mode selector(s). The figures below illustrate the fail upper segment capture situations described above:

CASE 1: ABSENCE OF ESSENTIAL NAVAID INPUT OR FAILURE OF VALIDITY CHECK:

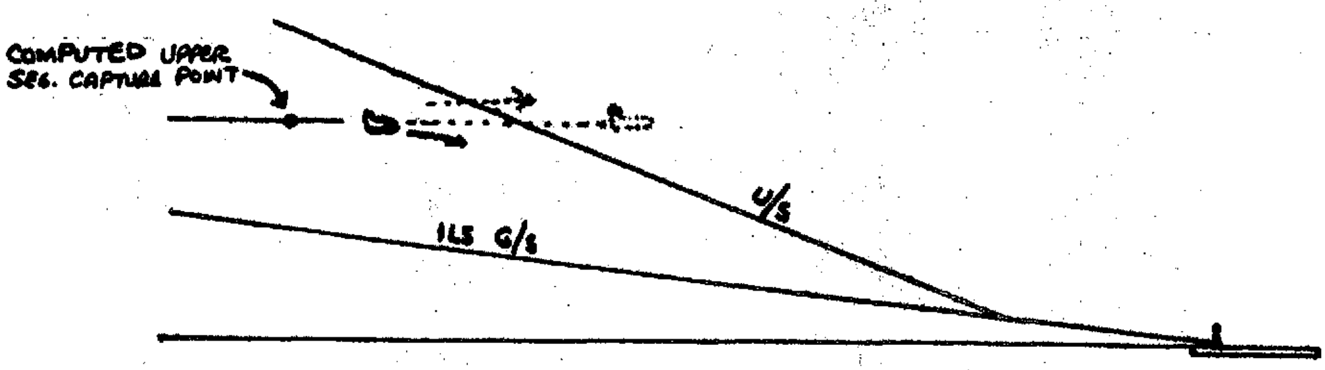


1. Two-segment switch in "ARM". NAV receiver tuned to ILS. Glideslope receiver section inoperative.

2. F/D and A/P selected to auto approach mode.

3. "Upper Segment" annunciator(s) illuminate amber. Aircraft continues inbound. Captures upper segment, descends to glideslope arm point. System trips off at 5.0 DME due to lack of glideslope validity input.

CASE 2: SYSTEM CONFIGURATION COMPLETED AFTER PASSING UPPER SEGMENT CAPTURE POINT:

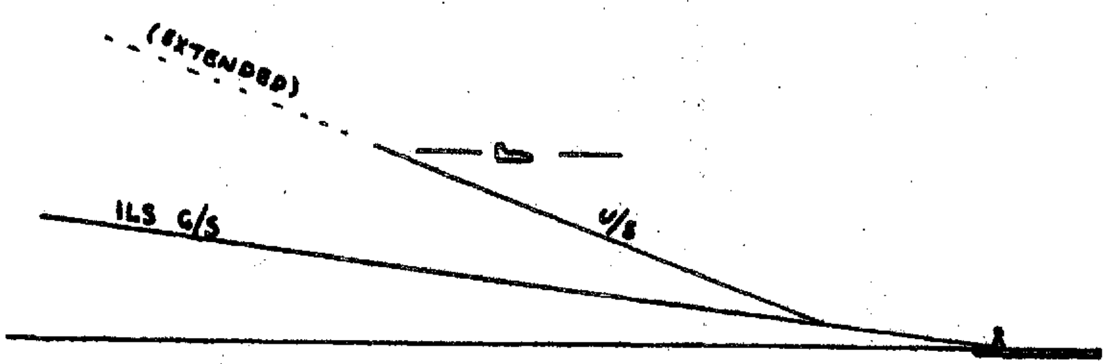


1. All system validity checks and navaid inputs proper. Two-segment switch in "ARM"; flight director in "AUTO", Autopilot "OFF".

2. Flight director "Upper Segment" annunciator green. Command bars are commanding pitch-over. Autopilot "Upper Segment" annunciator not illuminated.

3. Autopilot mode selector placed to "AUTO G/S". If placed in "AUTO G/S" after passing "Upper Segment" GREEN, it would not attempt capture but would maintain current flight path.

CASE 3: <u>TWO-SEGMENT SYSTEM CONFIGURED WITH AIRCRAFT ABOVE UPPER SEGMENT</u>.



1. All system validity checks and navaid inputs proper. Aircraft has passed (or is physically above) upper segment. Pilot configures for two-segment approach (ILS tuned, 2-SEG switch to "ARM"; F/D and/or autopilot to respective auto mode.)

2. System properly configured; F/D and A/P "UPPER SEGMENT" annunciators amber.

3. System will remain in this state until the aircraft is below upper segment (extended). Thereafter, if the aircraft passes through the 'AFL/DME combination, which is proper for upper segment capture point under those conditions, the system would capture upper segment.

A potentially important anomaly exists with the present system design. The system does not require localizer capture as a pre-requisite to upper segment capture. If the system is armed as described in this case, the system behaviours for upper segment capture are illustrated in Figures 1 and 2 below:

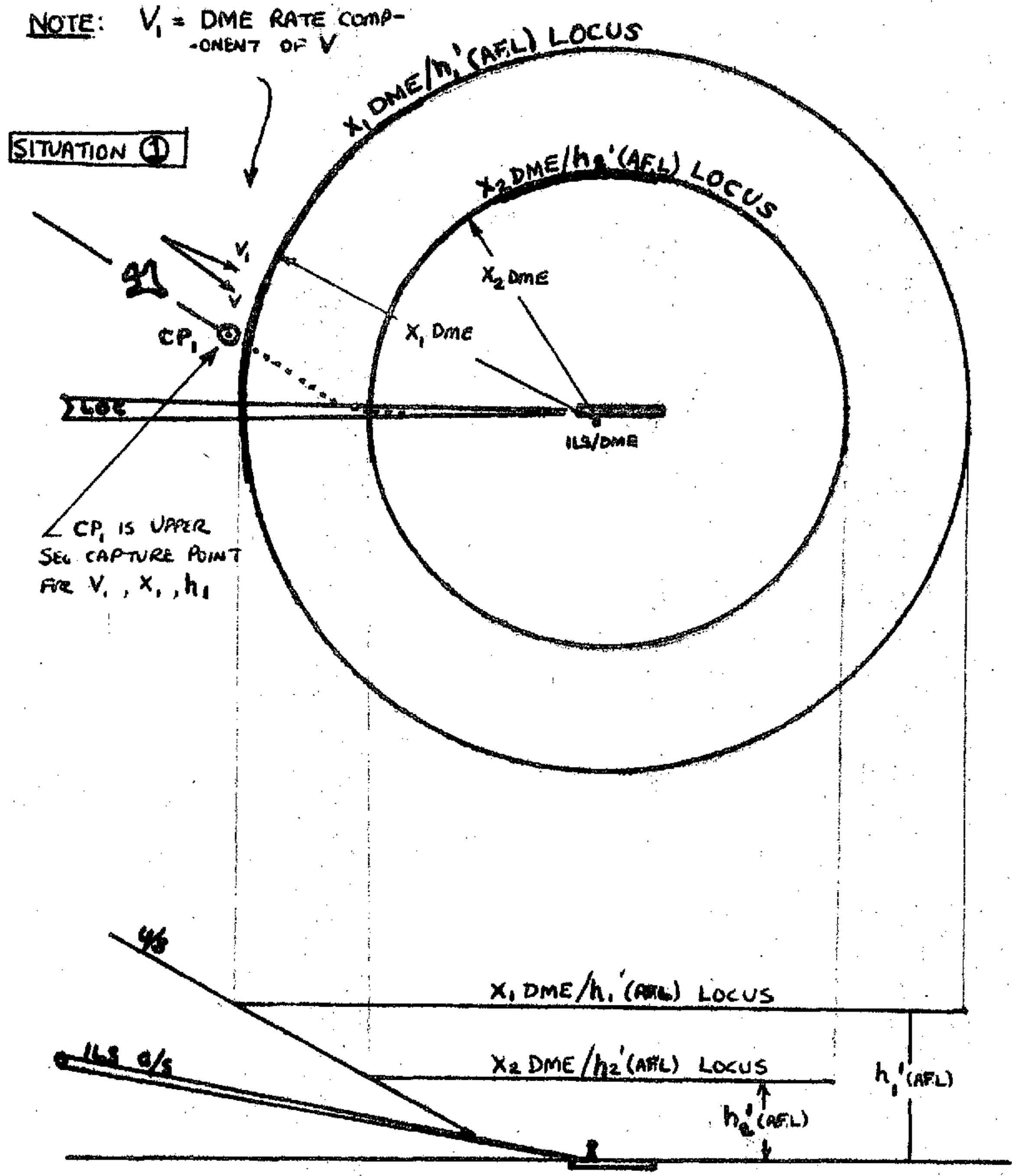


FIGURE 1 - UPPER SEGMENT CAPTURE AS FUNCTION OF HEIGHT ABOVE FIELD ('AFL) AND DME

Situation ① Aircraft is proceeding for localizer intercept. Two-segment system armed and valid, F/D and A/P in auto approach modes.

All inputs valid. Pilot is maintaining an altitude of h_1' (AFL). With the two-segment system armed and valid, when the aircraft reaches CP_1, the "UPPER SEGMENT" annunciators would go GREEN and the F/D and A/P would command a pitch-over maneuver to track the upper segment on the path shown. Localizer capture would be completed at some point in upper segment descent.

Figure 2 illustrates a similiar phenomenon which is admittedly quite hypothetical but is described here to illustrate the principles involved in upper segment computation and vertical guidance independent of localizer capture.

In the case illustrated, the aircraft is transiting the area at h_2' (AFL) proceeding to the initial approach fix shown. The pilot configures for a two-segment approach. All required inputs are valid. The F/D and A/P are placed into their respective auto approach modes.

As presently designed, when the aircraft reaches CP_2, the "UPPER SEGMENT" annunciators would go GREEN and the F/D and A/P would descend the aircraft from CP_2 to CPA and then climb the aircraft out on a symmetrical pattern from CPA as shown. It should be remembered that this discounts the fact that the crew would not permit the aircraft to follow this path since their knowledge of the navigational position would tell them that an inadvertent capture and descent had occurred at CP_2.

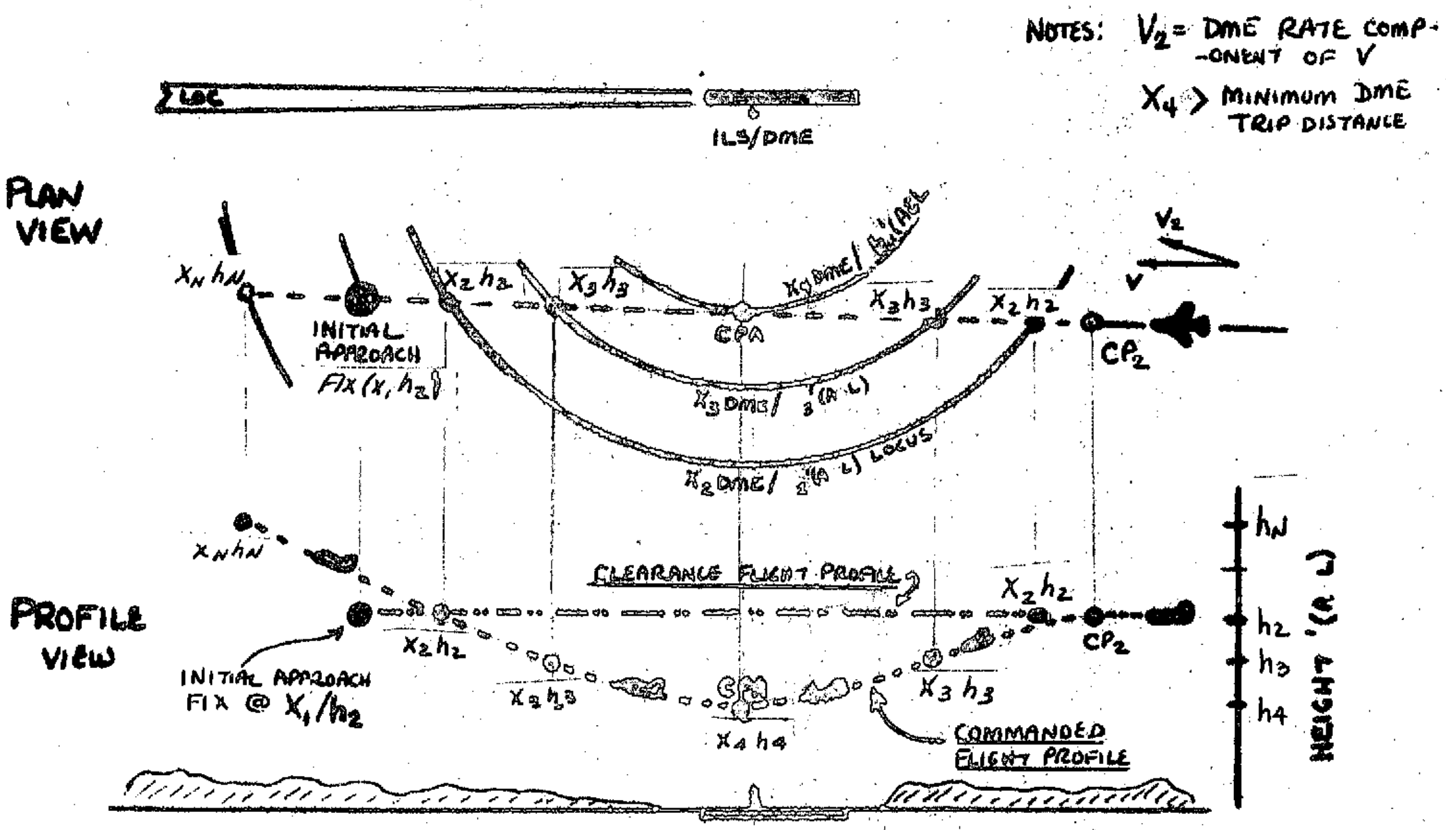


FIGURE 2 - <u>UPPER SEGMENT PROFILE - AREA TRANSIT CASE (Two-segment system armed and valid - F/D and A/P in auto modes)</u>

3. <u>Fail Glideslope Capture Protection</u> - The safety and pilot acceptance implications of failure to initiate transition from upper segment to ILS glideslope resulted in three essentially independent fail glideslope capture protectors:

(A) <u>Glideslope Deviation Protection</u> - The glideslope arm point and glideslope capture point logic have been discussed earlier in this report. Assuming that there is no mis-positioning of the upper segment due to erroneous inputs or system mismanagement, the glideslope deviation protector is the first of the three that should be activated in the event the transition maneuver has not commenced at glideslope capture point. This protector is illustrated in Figure 3 below;

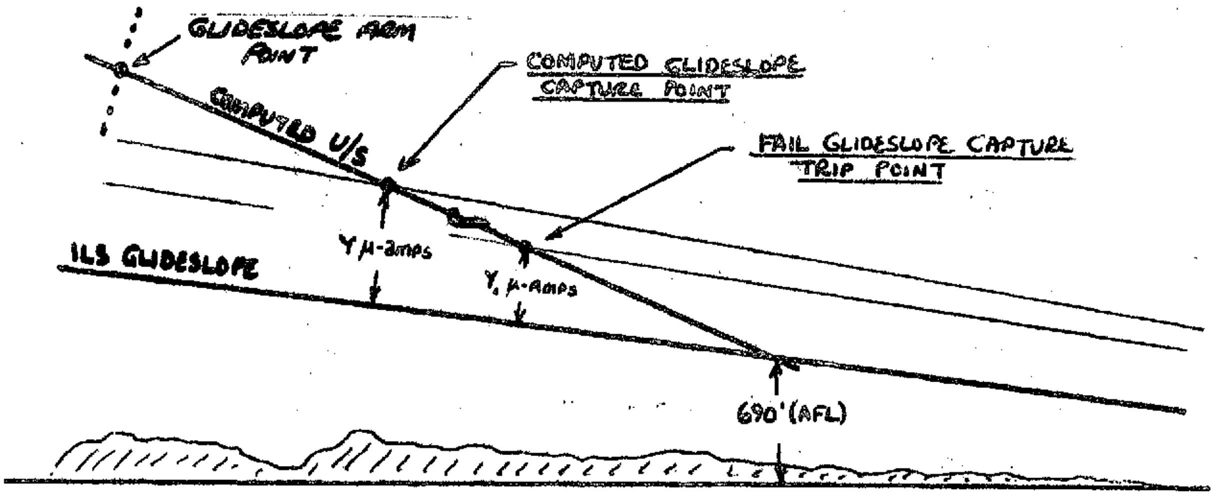


FIGURE 3 - GLIDESLOPE DEVIATION PROTECTOR - FAIL GLIDESLOPE CAPTURE

As shown earlier, the glideslope capture point is determined by the computer at some value above glideslope center (Y Micro-amps). If the aircraft passes this point without commencing the glideslope transition maneuver ("Glideslope" GREEN), the system is designed to trip the autopilot and bias the command bars from view at Y_1 Micro-amps = $\frac{1}{2}$ dot = 37.5 Micro-amps.

(B) Height Above Field Trip - If for any reason the glideslope deviation trip protector described above fails to function, a second independent protective device has been designed into the equipment. It will trip the autopilot and bias the command bars from view if the aircraft has not commenced the glideslope transition maneuver by the time the aircraft has descended to 500' above the field elevation which is set in the airport elevation set panel:

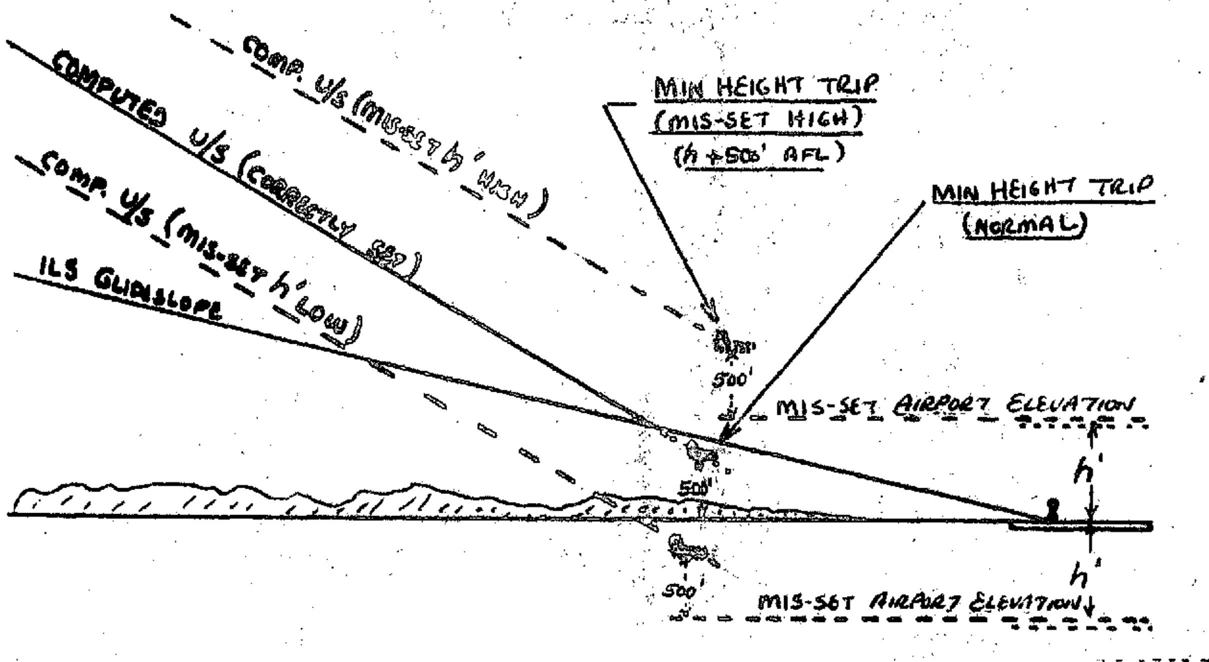


FIGURE 4 - HEIGHT ABOVE FIELD TRIP (INCLUDING AIRPORT ELEVATION MIS-SET HIGH AND LOW)

It can be seen from Figure 4 above that this protector is keyed to a fixed number of feet above whatever field elevation is set in the airport elevation set panel. In the elevation mis-set high case shown, the system would trip unless the glideslope capture maneuver had already commenced before reaching h + 500'.

The mis-set low case has the effect of moving the height trip below the normal trip altitude by the number of feet that the airport elevation is mis-set low. In the extreme case shown (mis-set h' low) it is readily apparent that this is not a viable protector in the case illustrated above.

(C) Minimum DME Trip

The third independent fail capture corner protector is keyed to a fixed DME distance. If the two protectors described above had failed, the system would trip the autopilot and bias the command bars from view when the aircraft reached this minimum DME distance from touchdown. As presently designed, the minimum DME is set to be very close to the distance corresponding to 500' AFL for a 2.9° ILS glideslope (1.8 NM).

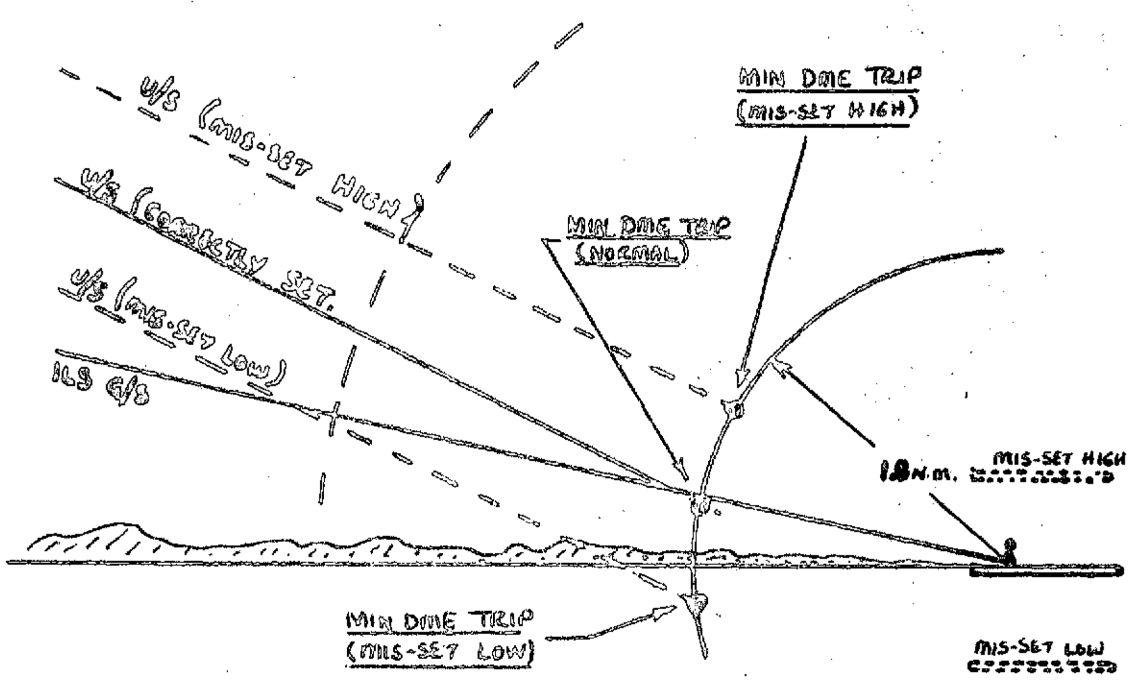


FIGURE 5 - MINIMUM DME TRIP - INCLUDING EFFECT OF MIS-SETTING AIRPORT ELEVATION HIGH OR LOW.

It can be seen from Figure 5 that the normal DME trip would occur at approximately the same point in the profile as the height above field trip.

It should be noted in the mis-set low case shown that the mis-setting of airport elevation to some value less than the baro-corrected elevation of the field to which the actual approach is being made has the effect of mis-positioning the computed upper segment in space. In the extreme case shown, it can be seen that this protector (as well as the height above field protector) would not protect against failure of the glideslope deviation protector discussed in (1) above. For this reason, the prototype design was modified in the manner described in the following section.

Mis-setting the airport elevation higher than the baro-corrected field elevation mis-positions the computed upper segment as shown above. It can be seen in this case that if the aircraft were tracking this upper segment, the system would be tripped at minimum DME or at height above field (mis-set high) at some point before the aircraft reached the glideslope deviation limits (37.5 Micro-amps) set to activate the deviation trip.

In examining this figure, it should be kept in mind that the angles, distances, etc., are greatly exaggerated for clarity and that the mis-set cases are representative of airport elevation mis-sets of the magnitude of ± 3000'.

It must also be kept in mind that the term mis-set does not necessarily imply that the crew has mis-set (or failed to re-set) airport elevation prior to commencing an approach. This phenomenon would occur in a case where the crew had set the airport elevation panel properly but the value of the input signal to the two-segment computer was in error by some amount due to a mechanical or electrical fault in the system.

Fail Glideslope Capture Protection Modification

Analysis of test results with the prototype installation led to the discovery that the three safety protectors described above would not cope with all potential airport elevation (and/or altimeter mis-set) cases.

In review, the glideslope arm point was incorporated to protect against arming the flight director and/or autopilot for glideslope capture until the aircraft (descending on upper segment) has passed the null boundary and is in the true ILS glideslope beam pattern. As originally designed, this was accomplished by preventing the system from "looking for" the ILS glideslope until passing this point. This feature served the purpose for which it was intended. Because the system did not "look for" an ILS glideslope in the first false lobe regime (which is always well outside of 5.0 N.M. DME), the autopilot and/or flight director, which would normally attempt capture (in auto modes) were not armed at this point, and the aircraft therefore passed through this false lobe area without the autopilot and/or flight director attempting false lobe capture.

The fact that the system was conditioned not to test for the presence of a glideslope outside of the 5.0 N.M. DME meant, however, that there were cases in which an erroneous airport elevation or baro-correction input to the computer would mis-position the upper segment with respect to the real-world runway and DME such that in an extreme case, none of the three fail glideslope capture protectors would perform its function properly. Figure 6 below illustrates a serious airport elevation (low)/ altimeter correction (high) case and the effect upon these protectors:

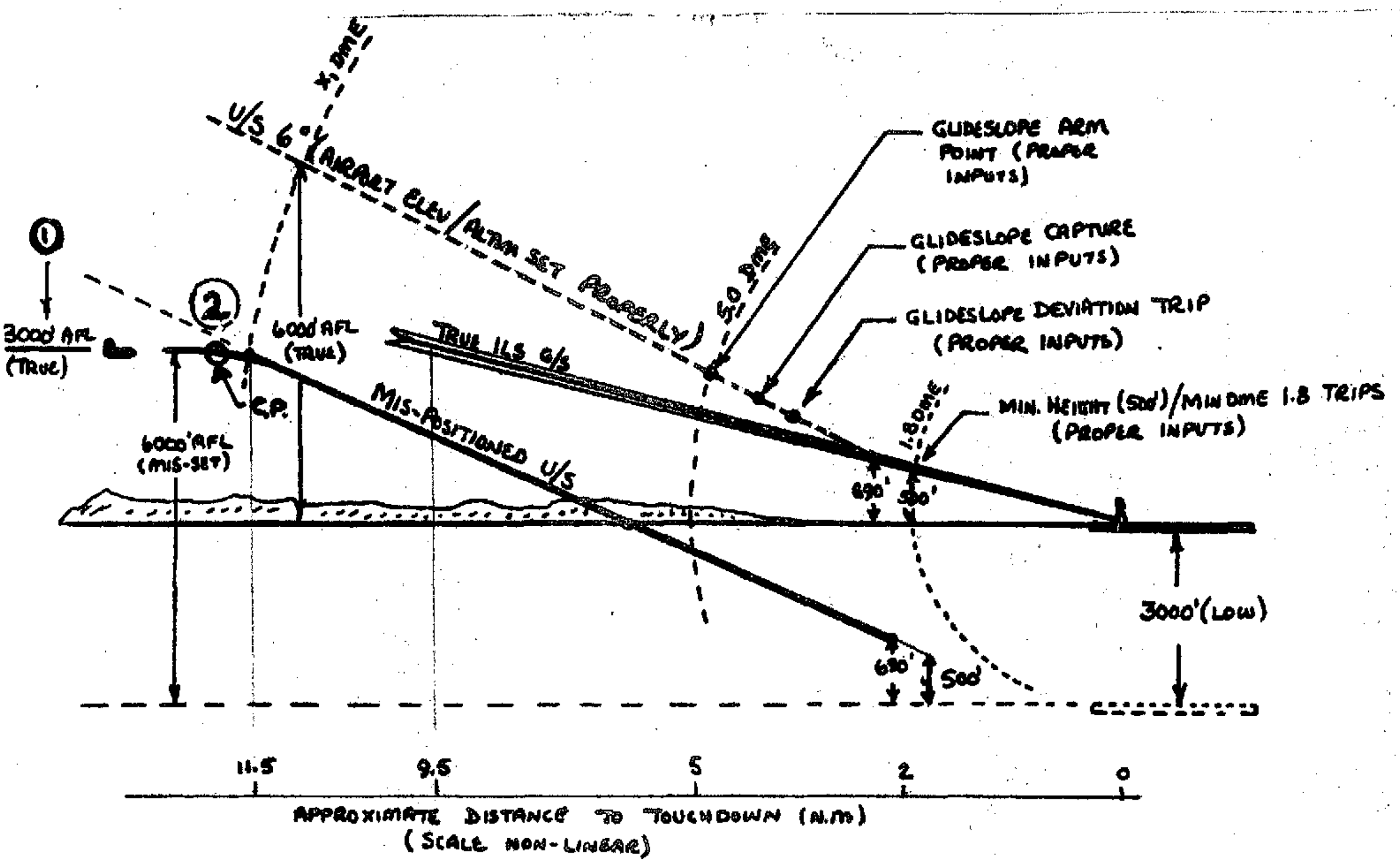


FIGURE 6 - EFFECT UPON FAIL GLIDESLOPE CAPTURE PROTECTORS OF AIRPORT ELEVATION MIS-SET LOW (ALTIMETER BARO-CORRECTION MIS-SET HIGH

Situation: (a) At position 1, aircraft is approaching a field at 3000'(AFL). Pilot is intending to make a two-segment approach. At this point, the pilot arms the two-segment system and selects the auto modes on the flight director and autopilot. System is valid. "UPPER SEGMENT" AMBER.

(b) He has set his altimeter to the reported field barometric and has set the published TDZ elevation for the runway on the airport elevation set panel.

(c) The airport elevation panel signal value output to the computer is 3000' in error due to an electrical fault in its circuitry. The pilot is not aware of this, and the computer cannot check it for reasonableness. So long as a signal of some value is present, it will accept this signal as correct, and interpret it accordingly. In the case shown above, the airport elevation panel is "telling" the computer that TDZ elevation is 3000' lower (MSL) than it actually is.

(d) Using this input, it applies TDZ (as received from the panel) to the aircraft baro-corrected pressure altitude. As a result, it "sees" the aircraft approaching at 6000' (AFL) (3000'AFL actual + 3000' error). It calculates the upper terminus of the upper segment as 6000'AFL; X_1 DME. It can be seen, however, that the calculated upper segment is seriously mis-positioned with respect to the real-world runway.

(e) At position 2, the aircraft will pitch-over and capture and track what appears to the computer to be a proper upper segment.

In the situation described above, Figure 6 shows that none of the three fail glideslope capture protectors will perform their protective functions as the result of the mis-setting of airport elevation:

(1) Glideslope Deviation Trip - As orginally designed, the equipment was prevented from "looking for" a glideslope until the aircraft reached 5.0 DME. In the case shown above, the upper segment (mis-positioned) passes through the true earth's surface at about 7 miles from touchdown. The entire flight path from upper segment capture onward, is totally below ILS glideslope and outside of the glideslope arm point (5 N.M. DME).

(2) Height Above Field Trip - This trip is calculated as 500'AFL based on what the computer has been "told" is TDZ elevation. In the case shown, this trip point is about 2500' below actual ground level.

(3) Minimum DME Trip - It is obvious from Figure 6 that if the aircraft tracks the upper segment (mis-positioned), this protector is of no value.

The need for false lobe protection still existed, but it was also necessary to protect against the obviously unacceptable situation described above.

An equipment modification was therefore incorporated. This modification in effect allows the system to "look at" the glideslope to determine where the aircraft is with respect to the ILS glideslope (extended) at any time the system is armed and valid, but still inhibits arming for glideslope capture until 5.0 N.M. DME (if on upper segment).

The basic logic statement upon which the modification is based is that there is no situation in which the aircraft can properly be on upper segment and below glideslope at the same time.

The equipment modification includes a ten-second timer which arms to run when the system is armed and valid. Once armed, it starts to run at any time the aircraft is below glideslope. If the aircraft is below glideslope for a period of ten consecutive seconds prior to upper segment capture and the aircraft does not thereafter go above glideslope prior to upper segment capture, the autopilot disconnects and flight director biases from view at upper segment capture. Refer back to Figure 6. Assume the armed and valid leg prior to reaching position 2 exceeds ten seconds. Since the aircraft did not go above glideslope at any time between running the clock down (between 1 and 2), the system will trip the autopilot and/or flight director at upper segment capture (Position 2).

The remaining logic cases in which the aircraft was below glideslope for ten or more seconds but passed above glideslope prior to upper segment capture are illustrated below:

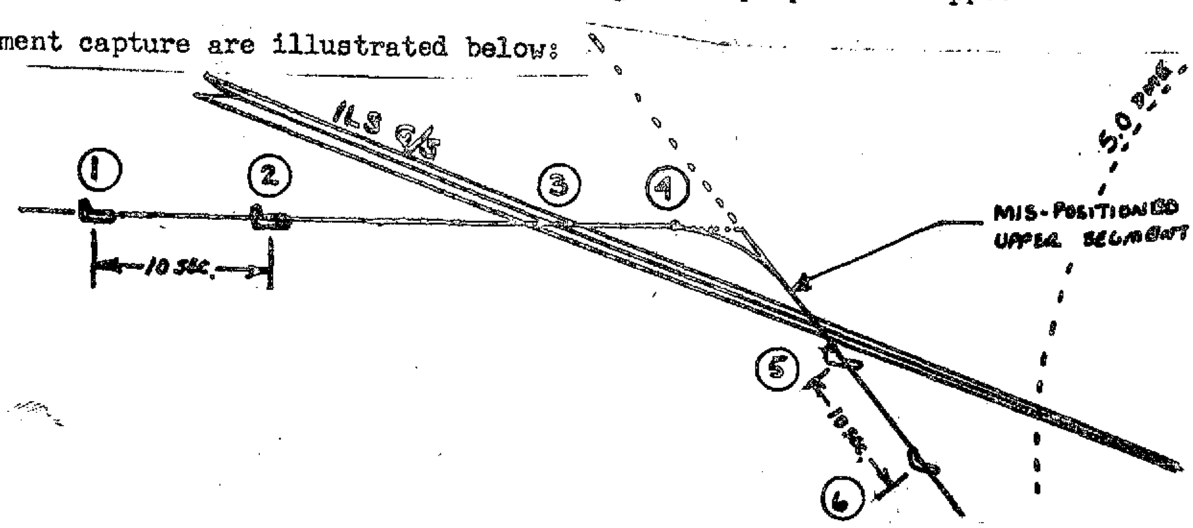


FIGURE 7 - BELOW-TO-ABOVE GLIDESLOPE PRIOR TO UPPER SEGMENT CAPTURE CASES

Position (1) - System armed and valid. Autopilot and flight directors in auto approach modes. Ten-second clock starts running down because computer determines that aircraft is below ILS glideslope.

Position (2) - Clock has run down. Trip is armed.

Position (3) - Prior to upper segment capture, computer determines that aircraft is now above ILS glideslope. Clock is reset. Trip is dis-armed.

Position (4) - Capture of mis-positioned upper segment. Aircraft descends on upper segment.

Position (5) - Computer determines aircraft is below ILS glideslope. Clock starts run-down.

Position (6) - After ten seconds (approximately 250' descent), autopilot trips and flight director command bars bias from view.

This modification appeared to solve both the false lobe and the below glideslope problems. In the On-Line Evaluation, however, it was discovered that this modification had given rise to another problem which was not intrinsically dangerous; however, it was operationally unacceptable. This problem has been termed the "Nuisance Disconnect".

At this writing an additional modification involving the use of a RADALT controlled trip is being evaluated.

INTENTIONALLY BLANK

FLIGHT PATH DEVIATIONS

AND

TRACKING COMMANDS

Upper Segment

Glideslope

Localizer

Upper Segment Deviation/Tracking - It is essential that the upper segment be captured and tracked with a high degree of accuracy. The system accomplished this by comparing the aircraft instantaneous height above field and instantaneous distance from the co-located DME transmitter with the instantaneous computed 'AFL-FDME coordinates by which the upper segment is defined.

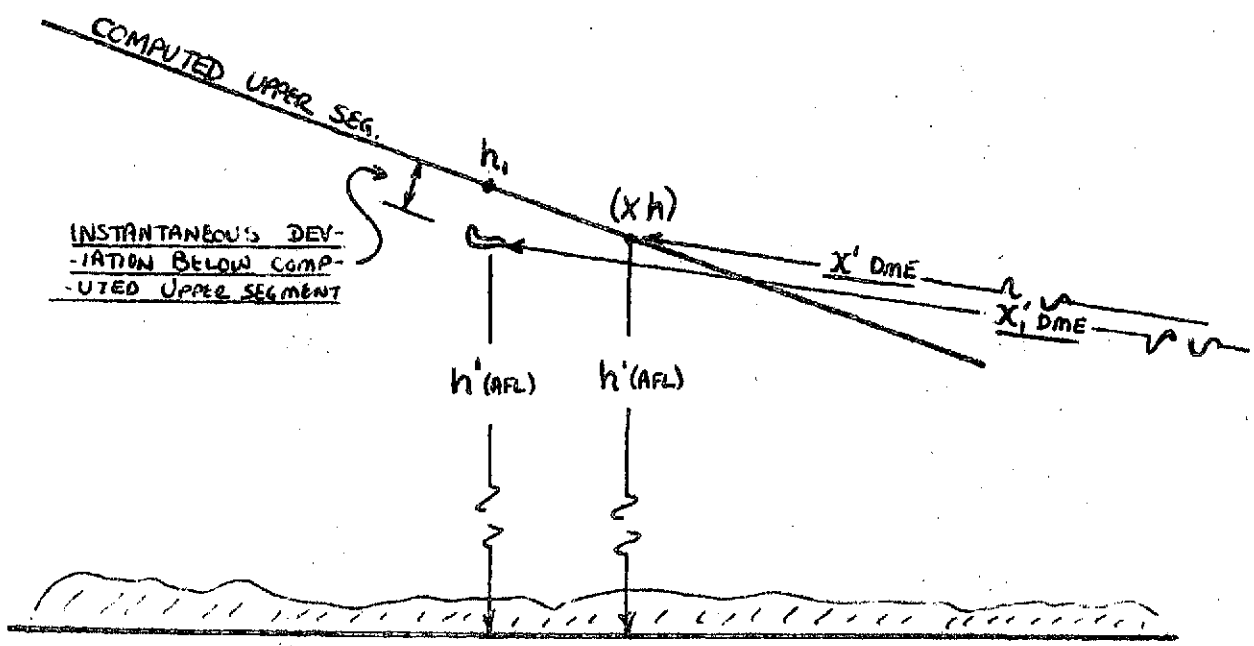


FIGURE 1 - UPPER SEGMENT DEVIATION - DME vs AFL

In the case shown in Figure 1 above, the aircraft is descending on a two-segment approach. As the altitude reaches h'(AFL), if the aircraft were on upper segment, it would be at X DME. It is however at X_1 DME ($X_1 > X$) when passing h'(AFL). It can be seen that the aircraft must therefore be below upper segment. The computer resolves the $(X_1-X)/(h_1-h)$ disparity and translates the resultant into a deviation (in feet) from upper segment. This deviation is gain programmed into the vertical deviation indicator in the HSI on a linear scaling of 250'/dot.

In their respective auto approach modes (required for two-segment tracking), the autopilot and/or flight director pitch channels would issue the nose-up command appropriate to this deviation in order to correct the aircraft back to upper segment. The computer furnishes the autopilot and flight director with deviation information. These systems take the corrective action in the same manner as they do when furnished similar deviation from ILS glideslope information.

It is also important to note that the vertical deviation indicator (horizontal bar) in the HSI is displaying deviation from upper segment from the time the system is armed and valid until the aircraft descends on upper segment to glideslope capture point at which point it switches over to display deviation from ILS glideslope for the remainder of the approach.

At "Upper Segment" AMBER, the HSI horizontal bar will move to full scale to the top of the instrument. With vertical deviation scaled at 250'/dot, the bar will start to move toward center when the aircraft is about 500' below upper segment (extended). This furnishes the pilot substantially the same visual configuration cue which he has available when approaching glideslope in the standard ILS procedure.

Glideslope Deviation/Tracking - It was felt that the vertical deviation indicator on the HSI was an essential performance indicator for intercepting and tracking upper segment. For this reason, it displays upper segment deviation down to the glideslope capture point. At this point, it ceases to be referenced to upper segment and displays raw ILS glideslope deviation in exactly the same manner as in the standard ILS.

Because of the fact that this approach involves descent on an upper segment to ILS glideslope, it was considered necessary to display raw glideslope deviation to the pilot throughout the approach. This information is displayed on the glideslope deviation indicator on the left side of the ADI. After glideslope capture point, this indication and the HSI vertical deviation indicators should be substantially identical. Until that point, the raw glideslope indicator in the ADI should show the ILS glideslope below the aircraft and the HSI vertical deviation display of upper segment centered (or displaying vertical deviation from upper segment center, if any). When the HSI deviation reference switches from U/S to ILS G/S, as the transition to G/S is made, both indicators should be in agreement thereafter.

(3) Localizer (Lateral) Deviation - The two-segment system does not involve localizer or the autopilot/flight director roll channels in any way except that it was found necessary to delay initiation of localizer gain programming until passing the glideslope arm point. The two-segment system takes advantage of DME rather than time base gain programming in the pitch channel in the ILS glideslope phase. A reversion to normal (two-segment off and re-cycle autopilot to auto G/S) at this point might encounter a momentary gain disparity in the autopilot pitch channel.

The technical concepts and methodology described in this part of the report generally reflect the state of development of the special purpose two-segment approach system and procedures evaluated in the UAL 727-222 through approximately 10 October 1973. The modification which was incorporated to cope with the nuisance disengagement problem has not been described herein. It was evaluated in line service for approximately the last two weeks in October.

APPENDIX II

to

UNITED AIR LINES

Report of

ENGINEERING SIMULATION DEVELOPMENT AND EVALUATION

of the

TWO-SEGMENT NOISE ABATEMENT APPROACH

THE FLIGHT SIMULATOR AND SIMULATION DATA SYSTEMS

30 January 1974

ENGINEERING SIMULATION EVALUATION - APPENDIX II

TABLE OF CONTENTS

INTRODUCTION - APPENDIX II

The Flight Simulator phase was an indispensible part of the overall program. It permitted the detailed investigation of many factors under precisely controlled conditions and with known degrees of variation. By determining the reasonable maximum and minimum limits of the profile and procedures variables and their effect upon each other and upon ground level noise, it was possible to develop a small family of profiles of approximately equal operational and noise abatement merit. This permitted the Project Team to concentrate their evaluation efforts in the prototype aircraft upon confirming and/or modifying the simulator results and upon optimizing the profile and procedures which would be evaluated by the Guest Pilot group and by the UAL Line Pilots in the six-month On-Line Evaluation.

This appendix will not present in-depth data analysis. It will present only typical samples of the data which was recorded in the Engineering Simulation Evaluation. The peripheral devices used with the simulator precluded recording data on tape or other form which would permit computer processing or statistical analysis by any means other than manual reduction and overlay grids. The Project Pilot team used this data in this way to analyze the results from each session during the profile and procedures development phase.

THE FLIGHT SIMULATOR

A. Its Function in the Overall Evaluation

B. Hardware - Basic Simulator

C. Hardware - Two-Segment Computer

D. Software

- Aircraft Systems
- Two-Segment Computer

E. Sound Prediction

- General
- PNdb vs Distance to Touchdown and
  Altitude vs Distance to Touchdown
- 90 PNdb Contour ("Footprint")

F. Other Data Systems

- 14-Channel Oscillograph
- Line Printer
- Project Pilot Comment Summaries and Approach Data Cards
- Evaluation Pilot Questionnaires (Off-Line)
- Sound-Video Tape

A. The Flight Simulator - Its Function in The Overall Evaluation

The Collins two-segment computer system characteristics and aircraft interface were programmed into the flight simulator immediately after definition by NASA/Collins/and UAL. This permitted the Project Pilot Team to proceed with the development and analysis tasks at the same time Collins was developing, fabricating and testing the prototype hardware which was to be installed in the evaluation aircraft. Not only did this significantly reduce the overall program time, but made possible certain investigations into profile and procedures development which would not have been possible in the actual aircraft installation. The principal functions which the flight simulator has served are listed below in general terms. Each of these is discussed in detail in Part III of this report.

1. Profile and Procedures Development

(a) Profile Geometry Variables

(1) Investigation into effects of varying a profile parameter.

(2) Establish a practical maximum and minimum value of each parameter.

(3) Optimize the value of a variable in combination with other related profile variables.

(4) Determination of the effect of a variable and combination of related variables upon ground level noise.

(b) Environmental Effects

(a) Investigation into effects of wind, wind shear, turbulence, visibility, ceiling, time of day (as it affects visual cues), structural and/or engine icing.

(b) Determination of the manner in which the above factors affect the two-segment profile/procedures differently from the ILS profile.

(c) Determination of the degree to which any of these factors limit the use of the two-segment approach procedure more than it would limit the ILS procedure under the same conditions.

(c) Airspeed/Configuration Scheduling

(1) Investigation into maximum and minimum practical airspeeds for intercepting, tracking and transitioning on two-segment profile.

(2) Investigation into configuration scheduling which is compatible with airspeeds, established configuration schedules and crew workload.

(3) Determination of the effects of these variables (singly and in combination) upon ground level noise.

2. Profile and Procedures Optimization - Having accomplished the tasks in (1) above:

(a) Combine the profile variables within the established limits into a family of profiles.

(b) From the possible combinations, derive the few profiles which optimize safety, repeatability and over-all crew workload.

(c) Determine the relative noise abatement merits of the profiles selected in (b) above.

3. Equipment Failure and System Mis-Management Effects Analysis

(a) Accurately and completely simulate the two-segment system and its interface with the basic aircraft systems.

(b) Make an extensive pre-evaluation analysis of normal two-segment system behaviour and test in the simulator.

(c) Make a similar pre-evaluation analysis of the effects of failures in basic aircraft systems and of failures and mis-management of the two-segment system. For purposes of this analysis, the system was considered "mis-managed" if certain actions were not taken to place the system into operation or actions were taken out of sequence or at an improper time during some phase of the approach procedure.

(d) Evaluate the effects of mis-setting airport elevation and altimeter baro-corrections.

The simulator proved to be a valuable development tool for the above purposes. In a few instances the observed behaviour was at variance with that which had been expected. The further analysis led to some minor logic discrepancies in the two-segment equipment design. These were corrected in the prototype hardware and thus saved time and effort in the engineering flight evaluation phase.

B. SIMULATOR HARDWARE - The flight simulator used in this evaluation is described below.

1. General

The simulator cockpit conforms to UAL B-727-222 N7647U (Boeing QA 428 modified to UAL specifications). Cockpit configuration and systems operation are identical in all significant respects to the 28 B-727-222 aircraft in the UAL fleet. Performance characteristics are based on the Pratt and Whitney JT8D-7 engine. The fuselage unit contains an instructor's console from which environmental conditions can be set and varied and from which malfunctions in all aircraft systems can be inserted. Considerable additional detail on these capabilities is given in the Environmental Conditions section and in the malfunction descriptions associated with each of the components/systems discussed below. In addition to the specific malfunctions described, failures of electrical bus(es) and/or circuit breaker(s) associated with the operation of a piece of equipment or a system will manifest themselves in the same manner as in the aircraft. Where there are operational interdependencies (as between NAV receivers and flight director), insertion of a malfunction specific to the parent component will produce the proper side effects in the operationally dependent component(s) or system(s).

2. Autopilot and Navigation

Full operational simulation of the equipment listed below is provided. Specific malfunction(s) associated with each are described, bearing in mind that some will result in secondary effects in other components when the primary component failure is inserted:

a. Autopilot - Sperry SP50-LWM-SPC system. All operating modes are simulated. The Sperry 2585802-8 controller is installed. (Also see Approach Progress Display below.)

MALFUNCTIONS:

(1) Upper Yaw Damper Fail
(2) Lower Yaw Damper Fail
(3) Runaway Stabilizer Trim Nose Up
(4) Runaway Stabilizer Trim Nose Down
(5) Jammed Stabilizer
(6) Autopilot Aileron Engage Fail
(7) Autopilot Elevator Engage Fail
(8) No. 1 Vertical Gyro Fail
(9) No. 2 Vertical Gyro Fail

b. Flight Director: Dual Collins FD-109A Integrated Flight Director System. The system hardware including roll and pitch computers and instrument amplifiers are actual aircraft hardware except that the skid ball in the ADI is servo driven. An aircraft ADI is interchangeable if necessary except that the skid ball would be inoperative. All software inputs (except skid ball) are made to the flight director computers and instrument amplifiers. All operating modes are simulated. Mode selectors are Collins Part No. 722-5378-001.

FLIGHT DIRECTOR MALFUNCTIONS:

(1) No. 1 Steer Computer Fail
(2) No. 2 Steer Computer Fail
(3) Altitude Hold Fail
(4) Captain's Course Indicator Fail
(5) First Officer's Course Indicator Fail
(6) Captain Localizer Pointer (Rising Runway) Fail
(7) First Officer Localizer Pointer (Rising Runway) Fail

c. Approach Progress Display: Dual Boeing Spec 10-61330-4 displays installed. Displays had two unused annunciators on flight director side and three unused annunciators on autopilot side. As previously described, the Captain's annunciator was modified to include an "Upper Segment" annunciator between "VOR/LOC" and "Glide Slope".

d. Standby Attitude Indicator: Fully operational system is simulated. All aircraft electrical power dependencies are included. In event of simulated complete aircraft electrical failure, SAI reverts to its own self-contained battery power source (simulated).

e. Mach/Airspeed: Dual indicators with servo driven movement (Astek B024381911) per Boeing Spec. 10-60922-11. Airspeed and Mach number as well as overspeed warning and flight director airspeed hold are included.

Separate true airspeed digital readout provided (Litton Ind. 850714).

f. DME: Dual Bendix 7913-IN13A1 indicators. Program computational accuracy to approximately ± 0.015 feet.

g. Barometric Altimeter: Dual Kollsman servo-pneumatic (Kollsman B38689-10-005). Servo-pneumatic programmed for captain's altimeter only. Altitude computational accuracy approximately ± 0.015 ft.

BARO ALTIMETER MALFUNCTIONS

(1) Freeze Captain Altimeter (simulates mechanical movement freeze)
(2) Captain Static Line Leak
(3) Captain Static Line Plugged

h. Radio Altimeter: Dual Collins 522-4363-007. Full operational simulation including 2500' alert and selectable decision height.

i. Altitude Alert: Simulated barometric system with selections from -2000' to 53,000'. System provides visual and aural warnings when ± 750' and ± 300' from barometric altitude selected by crew. Selected altitude is ambient barometric pressure compensated by baro set control on altitude selector panel.

j. IVSI: Dual indicators. Servo driven movement. Scale range ± 6000'/minute. Reflects G-force and ground effect phenomena.

k. Heading-Course Deviation Indicator: Dual Sperry 1783993-485 indicators. (MHR-4)

HEADING-COURSE DEVIATION INDICATOR MALFUNCTIONS:

(1) Captain's Course Indicator Fail (also fails First Officer's RMI compass card)
(2) First Officer's Course Indicator Fail (also fails Captain's RMI compass card)
(3) No. 2 ILS Bearing Error (1° localizer error in #2 localizer)
(4) No. 1 VOR Bearing Error (5° bearing error in #1 VOR)

l. RMI: Dual Bendix 36158-1AF25A1 with VOR-ADF switching module (#1 and #2 needles) for each indicator.

RMI MALFUNCTIONS:

(1) Captain ADF Fail (Fails direction finding capability on captain's ADF receiver)

(2) First Officer ADF Fail (Fails DF capability on F/O ADF receiver.)

m. Standby Compass: Servo driven (simulated "whisky" compass)

n. VHF NAV Receivers: Actual receiver hardware is software simulated. Dual VHF NAV receiver tuners are Gables G1728.

VHF NAV RECEIVER MALFUNCTIONS: For flexibility, these receivers are treated in software as separate localizer and glideslope receiver sections. Because of the high degree of operational dependence of the flight director and autopilot (in appropriate modes), the following malfunctions have significant bearing upon the navigational displays and upon certain flight director and autopilot modes:

(1) Captain (No. 1) Localizer Receiver Fail
(2) First Officer (No. 2) Localizer Receiver Fail
(3) Captain (No. 1) Glideslope Receiver Fail
(4) First Officer (No. 2) Glideslope Receiver Fail

o. Low Frequency ADF Receivers: Dual Collins 522-2357-018. As with VHF NAV, receiver hardware (except tuner) is software simulated. The #1 ADF was removed and the Airport Elevation Set Panel was installed in the tuning head location on the Captain's forward pedestal.

ADF RECEIVER MALFUNCTIONS: (SEE RMI ABOVE)

NOTE: The above navigation receiver failures are aircraft equipment failures. In addition to these, the individual NAVAIDS can be selectively failed. In this connection, the VORTAC stations are programmed so that either the VOR or DME function can be failed separately from the other.

p. Marker Beacons: The 75 mc marker beacon receiver operation is simulated aural and visual signals as in aircraft. Instrument panel contains blue (outer), amber (middle) and white (airways) marker lights.

3. Environmental Conditions Controls

An environmental conditions panel on the instructor's console permits the setting and/or variation of the environmental conditions described below:

a. Altimeter Setting: Permits settings (to 2 decimal places) from 24-35 in. Hg.

b. Q.F.E.: Permits 12 in. Hg Variation.

c. Sea Level Temperature: Permits settings (in whole degrees) from -35° to $+65^{\circ}C$.

d. Outside Air Temperature: Is related to sea level temperature by lapse rate and altitude. Variation of either SLT or OAT will change the other by the same amount. Permits $100^{\circ}C$ variation of OAT.

e. Lapse Rate: Permits variations (to 2 decimal places) from $-6^{\circ}C/1000'$ to $+1^{\circ}C/1000'$.

f. Wind Program: The panel provides the means for setting airfield height wind direction (whole degrees) from 0° - 359° and velocity (whole knots) from 0-250 knots. A separate set of controls sets the non-friction (2000' AGL and above) wind through the same limits as above. These separate controls permit the operator to establish a virtually infinite number of wind shear conditions. The computer performs a linear integration between the 2000' and surface directions and velocities such that at any point from 2000' AGL to touchdown the wind acting upon the aircraft is the resultant of these two winds. (e.g., if the 2000' wind is set at $270^{\circ}/30$ knots and surface wind is $360^{\circ}/10$ knots, the wind acting on the aircraft when above 2000' AGL would be $270^{\circ}/30$ knots. As a descent below 2000' AGL is made, the wind direction would move from 270°

toward 360° at a linear rate of 4.5°/100' and velocity would decay from 30 knots to 10 knots at a linear rate of 1 knot/100'). The wind program is integrated into the flight director and autopilot programs so that the proper wind and wind shear compensations are called up in these program outputs and displays.

g. Rough Air/Turbulence: The motion system receives inputs from this control which is infinitely variable from no rough air (no fuselage excursions) to maximum which induces random excursions in all three axes corresponding to severe turbulence. Instruments which normally fluctuate in turbulence will fluctuate to a degree proportional to the severity of the turbulence selected.

h. Gross Weight: This control permits the setting of gross weight from 100,000 lbs. (zero fuel weight) to approximately 200,000 lbs. in combination with the total fuel set control below. A given gross weight can either be held constant or permitted to decrease by an amount (and at a rate) corresponding to fuel burn-out.

i. Center of Gravity: Permits the operator to set the airplane C.G. to any desired value from 10%-60% MAC. An instantaneous (and if applicable constantly updated) digital readout of the value of any of the above parameters is available on the panel. A continuously updated digital readout of the wind acting upon the simulator at any instant is also provided.

4. Condition Freeze Controls

The operator can freeze the following conditions in the state that existed at the instant the particular freeze is selected. For purposes of this evaluation, particularly in the initial and procedures development phases, these freezes proved to be quite valuable.

a. Flight Freeze: Freezes simulator in attitude, airspeed, altitude and geographic position existent at time of selection. Aircraft systems continue to function normally (power changes, hydraulics, electrical systems, etc.).

b. Position Freeze: Freezes simulator in geographic location at instant of selection.

c. Problem Freeze: Complete freeze of all computer outputs/inputs at the values which existed at instant of selection.

d. Level Flight: Removes any existing roll, pitch or yaw and holds simulator in level attitude.

e. Fuel Quantity Freeze: Freezes fuel tank quantities and fuel weight at values existent at time of selection. This was used in conjunction with gross weight above when it is desired to conduct operations at some fixed gross weight value.

5. Repositioning Controls

The simulator incorporates a number of controls for rapidly repositioning or slewing the simulator. These are:

a. Flight Reset: When activated, the simulator is instantaneously returned to the geographic point on the earth's surface from which a standing start takeoff was last commenced. The heading and altitude are slewed to the values that existed at that point.

b. Preset Initial Positions: The existing program contains 64 preset positions to which the simulator can be instantaneously slewed. Of these, 17 are positions related to points on the visual terrain model. The remaining 47 are airborne fixes in an arrival area at some selected point and at some preset altitude and heading. Any feeder or other fixes required for this evaluation were programmed as required.

c. Positioning to NAVAID: Similar to the initial position system above except that this system instantaneously slews the simulator to the geographic position of the NAVAID selected. There is no pre-programmed altitude or heading slew involved in this system.

d. Altitude Slew: Permits the rapid slew of the simulator altitude to any selected value from sea level to 50,000'.

e. Airspeed Slew: Permits the rapid slew of indicated airspeed to any selected value from 0 - Full Mach/ASI Scale.

6. Approach Progress and Position Monitoring

A Continuously updated digital readout of the following is available on the instructors console.

a. Distance/Bearing to Station Monitor: The current distance (nearest 0.1 N.M.) and bearing (nearest degree) of the simulator to any selected NAVAID is displayed.

b. Lat/Long: The current Lat/Long of the simulator (to the nearest 0.1') is continuously displayed.

c. Approach Deviation Monitor: Deviations above or below glideslope and right or left of localizer centerline (to the nearest foot) and distance to touchdown (to the nearest 0.1 N.M.) are displayed when any programmed ILS or GCA station is referenced.

7. Three-Axis Motion System

The simulator incorporates a hydraulically powered 3-axis system. The control loading system (stabilizer trim, elevator, aileron, nosewheel steering, etc., is also hydraulically powered and can be operated with or without the motion system on.

8. Visual System

The simulator incorporates a visual system with a color image projected on a large screen in front of the cockpit. The image is developed by an optical probe transiting a 2000:1 rigid terrain model which represents an area on the earth's surface of approximately 10 NM X 5 NM. The parallel runways are oriented along the 10-mile axis of the model and are situated approximately 6 miles in from the ILS front course edge of the model. The system is designed so that by selection of any given pre-programmed ILS or GCA reference station, the 10 X 5 mile model is made to represent that portion of the earth's surface surrounding the referenced ILS/GCA runway. All associated NAVAIDS in the arrival are properly oriented and situated with respect to this runway. For purposes of this evaluation, Stockton airport and all associated NAVAIDS required (including co-located glideslope DME) were programmed into the simulator.

A visual control panel is on the instructor's console. The controls of interest in this evaluation are as follows:

a. Projector Transit Control

This control moves the true picture from a position in front of the Captain's seat to the other side if the occupant of the First Officer's seat is flying the approach.

b. Visual Environment Controls

(1) Visibility in miles and quarters of a mile can be set from 0-9 3/4 miles. RVR can be set in 100-foot increments from 0-9900 feet.

(2) Ceiling is settable in 50-foot increments from 0-2000'. A physical limitation in the Z-axis hardware of the optical probe

precludes ceiling selections higher than 2000'. This meant that visual contact with the runway did not occur before reaching the point on the upper segment corresponding to 2000 feet above airport elevation (with maximum ceiling set in).

c. "Time of Day" Controls - Three selections are possible. These are "Day", "Dusk" and "Night". These result in three levels of general area illumination of the model and except for the differences which exist in the real world at those times of day, these selections do not affect the much more accurately controlled visibility described above.

d. Lighting - The front course lighting on the ILS runway (11,500') is CAT II lighting. The HIGH INTENSITY RUNWAY LIGHTS ~~HIRL~~, centerline and touchdown zone lights can be turned on or off or brightened or dimmed independently from the approach light system and sequenced flasher lights. The APPROACH LIGHTING SYSTEM ~~ALS~~ and SEQUENCED FLASHING LIGHTS ~~SFL~~ are also independently selectable and controllable.

C. Two-Segment System Hardware - The cockpit components of the two-segment system were installed in the simulator cockpit in the same locations that they were installed in the evaluation airplanes (off-line and on-line). The altimeter was not replaced by the drum-counter altimeter which was used in the airplane installations. This decision was made for two reasons:

(1) An altimeter was not available in the time frame of the simulation evaluation.

(2) The baro-correction input to the two-segment computer in the aircraft necessitated an altimeter installation which could furnish this input. It was available in the regular simulator software package without requiring a special altimeter set pick-off.

The two-segment switch was installed and controlled the two-segment system logic in the simulator program exactly as it does in the aircraft installation.

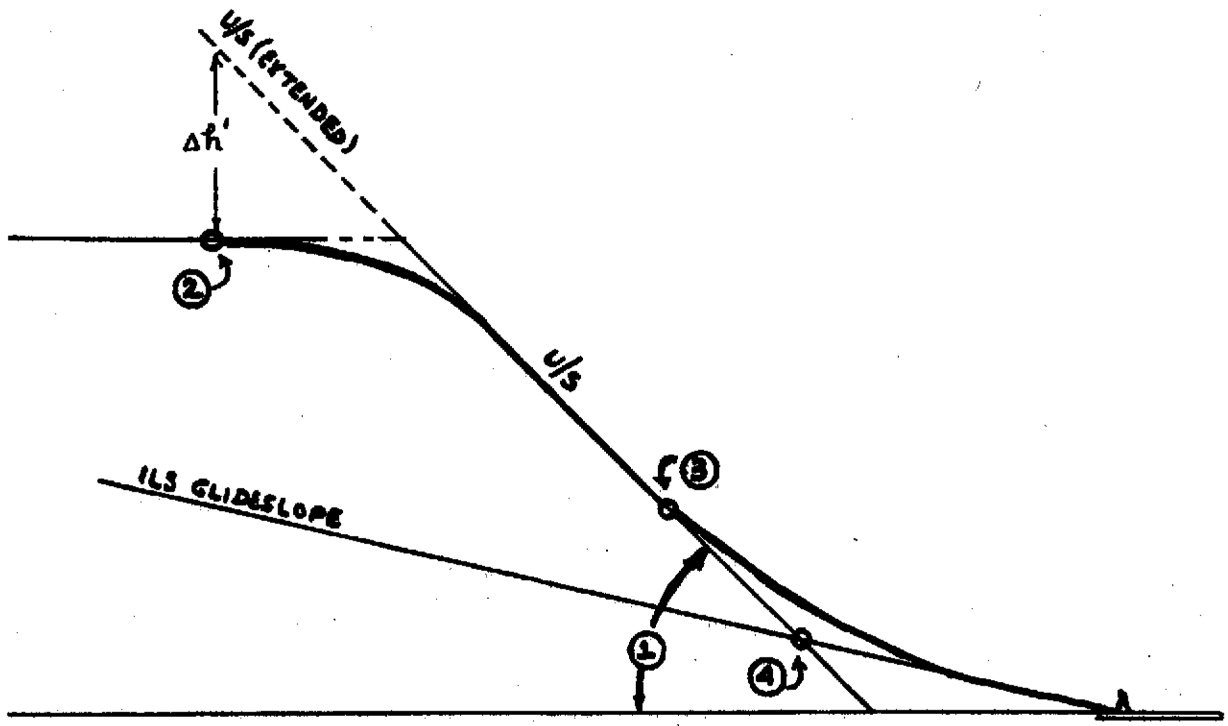
The Airport Elevation Set Panel was installed to provide a simulator program input which is functionally the same as the aircraft input.

The Approach Progress Display was modified as shown earlier in Part I of this report.

D. Simulator Software - The basic aircraft system software packages remained unchanged with the incorporation of the two-segment and data system programs. In this way, the simulator was available for routine training use at any time it was not required for this evaluation. Both the two-segment and data software programs remained resident in spare core at all times. The majority of the two-segment program was full-rate. This did not affect any of the other full-,half-,quarter-, or eighth-rate programs since the simulator was built with 20% spare time over and above all of the normal program time requirements.

The two-segment computer and switching unit were functionally and operationally simulated with software. All of the interface, validity inputs and computer outputs to the flight control and navigational instrument displays accurately reflected the actual system behaviour.

As will be explained in Part III, the profile variables investigations required the provisions for permitting the Project Pilot Team to set a number of the critical profile parameters at some accurate value in order to measure their effect upon the two-segment procedures and upon ground level noise. A program was thus written which accomplished this objective. Each was selectable on the instructor console with a discrete switch and infinitely variable potentiometer with direct value digital readout. The variables and their settable limits are shown in Figure 1.



1. Upper Segment Angle From 2.5° TO 10°

2. Upper Segment Capture Point (Expressed in Terms of Feet Below Upper Segment (Extended). 100 ' to 600 '

3. Lower Segment Capture Point (Feet AGL) 630 ' to 1100 '

4. Lower Intersect Point (Feet AGL) 400 ' to 800 '

FIGURE 1 - SETTABLE PROFILE PARAMETERS FOR 2-SEGMENT APPROACH.

UAL B727-222 FLIGHT SIMULATOR

PNdb PREDICTION PROGRAM

PNdb vs. Distance To Touchdown

and

Altitude vs. Distance To Touchdown

E. <u>Sound Prediction Programs</u> - The following general information is applicable to the sound prediction programs described in this section:

1. The simulator sound prediction programs were developed principally:

   (a) To quantify the effect upon ground level PNdb of each of the approach profile geometry variables as each is varied through a reasonable range (e.g., upper segment angle between 4° and 7°, etc.).

   (b) To quantify the effect of airspeed and configuration schedules (individually and in combination) upon ground level PNdb.

   (c) To quantify the ground level PNdb <u>differences</u> between two different approaches (e.g., ILS vs. some fixed geometry two-segment approach) and between different two-segment approach profiles (e.g., upper segment 6° vs. upper segment 5°, etc.).

   (d) To quantify the net ground area <u>differences</u> beneath the approximate 90 PNdb footprint between different approaches.

2. The simulator sound prediction programs were not developed to yield accurate <u>absolute</u> PNdb values for direct correlation with actual noise measurements. In this regard, the following must be considered in any attempt to correlate simulator data with actual aircraft data:

   (a) The PNdb vs. distance to touchdown program was predicated on Boeing data as shown in Figure 1. This is lateral engine noise for the JT8D-7 engine as installed in the B727-222.

   (b) The 90 PNdb footprint program utilized the same Boeing data as above.

   (c) Neither program applies certain real-world factors such as ground effect, temperature and relative humidity, etc. These factors and others which affect actual PNdb were considered unnecessary because the noise prediction programs were developed to quantify relative PNdb values as described in 1 above.

3. Simulator line printer data was analyzed to extract values of certain key parameters which are typical of the thrust and airspeed schedules used in the two-segment approach used in the On-Line Evaluation (6° upper; 2.9° glideslope; 690'AFL intersection of upper segment and glideslope). These correlate very closely with actual aircraft values under the same conditions. These are:

   Upper Segment Stabilized EPR - 1.15

   Upper Segment Stabilized Airspeed - 135 KIAS (.205 M.N.)

   Thrust for 1.15 EPR at .205 M.N. = 2400 #/engine (approx.)

   A representative sample of the X-Y plots from the Off-Line Evaluation pilots (simulator) have been analyzed against this data through the stabilized portion of the approach from about 2500'AFL to about 1000'AFL.

   The two separate sound prediction programs used in the simulation evaluation are described in detail in the following pages. It is important to realize that the plots which these programs generated were vital in the development and optimization investigations conducted in the simulation portion of the overall evaluation by accomplishing the objectives stated in (1) above.

PNdb vs. DISTANCE TO TOUCHDOWN

A. Program Objective: To calculate and to plot with an X-Y peripheral plotter, the approximate ground level PNdb directly beneath the airplane for any given distance from touchdown (within 7.5 NM). The plane proceeds along a known approach profile (i.e., height above ground is known within close limits throughout the profile for any given distance from touchdown).

The X-Y plotter was also capable of recording airplane altitude above field level versus distance from touchdown. For purposes of recording data, an altitude trace was plotted, and on the same sheet, the PNdb trace corresponding to that profile was also plotted against the same distance to touchdown scale (1": ½ mile).

B. Program Data Base: The lateral noise characteristics of the JT8D-7 and engine with untreated nacelle forms the principal data base for this program. This data is shown in Figure 1 in tabular form and Figure 2 in graph form.

Figure 3, shows the programmed engine thrust for engines 1 and 3, and engine 2, for a given EPR at various mach numbers. This is based on Boeing data furnished to the simulator manufacturer and checked and certified in the simulator by the FAA.

C. Program Methodology:

1. The PNdb table (Figure 1) was placed into the computer as a data base.
2. Thrust (on #1 engine only) as generated in the engine program from the #1 engine table in Figure 3, was used as the thrust

entering argument to the PNdb table.

3. Height above ground which is constantly computed in the basic simulator program was used as the other entering argument.

4. The computer interpolated the thrust-height above ground instanteous values to generate an interpolated PNdb value from the table.

5. This value was then output to the X-Y plotter in the Y-axis which was scaled 6.4 db/inch. Any value below 72.5 db or above 124.2 db (minimum and maximum PNdb table values) was limited to and plotted as a minimum (72.5) or maximum (124.2 db) value.

6. Distance to touchdown which is being constantly computed and updated, was simultaneously output on the X-axis, which was scaled 1" : $\frac{1}{2}$ nautical mile.

7. The resultant trace was thus the PNdb vs. distance to touchdown. In most cases, the 124.2 db limit was reached at about 1 NM from touchdown after which the trace leveled at that value. (See Figure 4.)

8. The altitude vs. distance to touchdown trace was generated by taking the constantly updated height above field as the Y-axis output scaled 1" : 400'. Distance to touchdown was on the X-axis as in (6) above.

A typical plot with descriptive labelling is shown in Figure 4.

REF: PUGET SOUND FLYOVER, 13 AUGUST 1967

JT8D-1/7 ENGINE

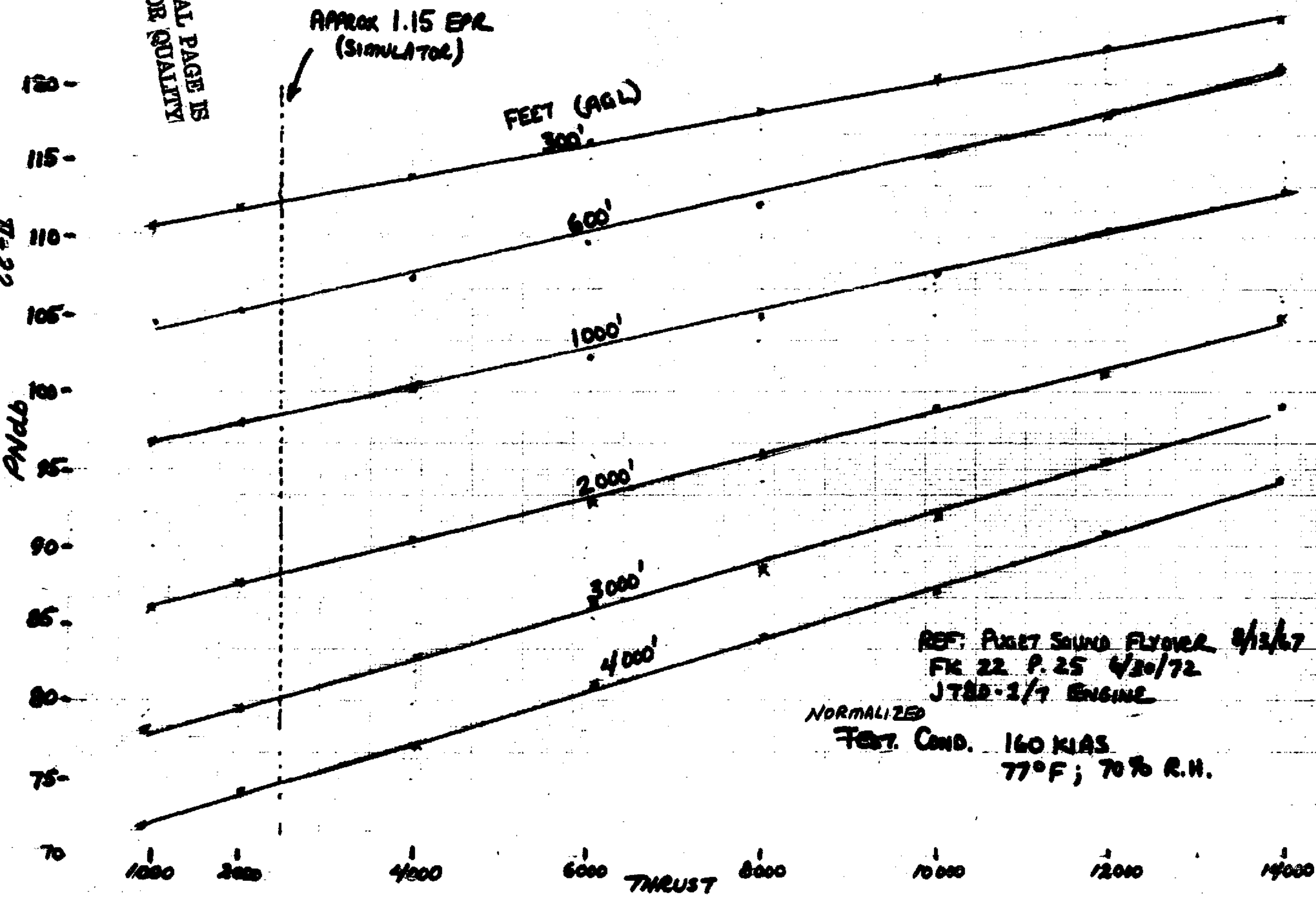
NORMALIZED ~~TEST~~ CONDITIONS: 160 KIAS
77° F ; 70% R.H.

PNdB

THRUST ⇨ (LBS) / FEET AGL ⇩	1000	2000	4000	6000	8000	10,000	12,000	14,000
300	110.7	111.8	113.9	116.0	118.1	120.1	122.2	124.2
600	104.4	105.5	107.7	109.8	112.0	114.2	116.2	118.3
1000	96.7	98.0	100.4	103.0	105.5	108.0	110.3	112.9
2000	86.0	87.4	90.3	93.2	96.0	98.9	101.7	104.5
3000	78.2	79.8	83.0	86.2	88.4	92.6	95.8	99.0
4000	72.5	74.2	77.5	81.0	84.2	87.6	90.9	94.2

FIGURE 1- PNdB AS FUNCTION OF THRUST VS HEIGHT ABOVE GROUND
(JT8D-7 ENGINE - UNTREATED NACELLE)

FIGURE 2 - PNdb AS FUNCTION OF THRUST VS HEIGHT ABOVE GROUND



FUNCTION	DATA OR EQUATION

THRUST -v- MN. FOR ENGINES * 1 and 3

THRUST DATA Scaled at B15

MN's	EPR 0.8	EPR 1.0	EPR 1.1	EPR 1.2	EPR 1.4	EPR 1.7
0	-2300	300	2075	3775	6725	10720
0.1	-2300	300	1850	3300	6100	9920
0.2	-2300	300	1750	3090	5660	9400
0.3	-2050	400	1700	2980	5550	9100
0.4	-1900	550	1760	3000	5450	8945
0.5	-1670	710	1900	3100	5500	9020
0.6	-1360	960	2140	3300	5700	9330
0.7	-1200	1248	2430	3620	6000	9805
0.8	-1050	1610	2860	4050	6510	10500
0.9	-770	2000	3300	4560	7170	11450

MN's	EPR 2.1	EPR 2.3	EPR 2.6
0	15300	17480	20850
0.1	14350	16550	19950
0.2	13790	16000	19500
0.3	13490	15800	19320
0.4	13440	15810	19400
0.5	13660	16175	20500
0.6	14200	16790	20900
0.7	14950	17800	22100
0.8	16000	19050	23650
0.9	17380	20600	25400

FUNCTION

THRUST -v- MN FOR ENGINE * 2

THRUST DATA SCALED AT B 15

MN's	EPR 0.8	EPR 1.0	EPR 1.1	EPR 1.2	EPR 1.4	EPR 1.7
0	-3700	350	2075	3720	6650	10550
0.1	-3700	300	1850	3300	6000	9770
0.2	-2500	325	1700	3010	5570	9240
0.3	-2250	390	1650	2910	5400	8925
0.4	-2000	450	1700	2940	5350	8820
0.5	-1650	660	1850	3040	5420	8850
0.6	-1350	950	2075	3260	5620	9150
0.7	-1150	1200	2350	3550	5910	9600
0.8	-700	1600	2770	3980	6450	10325
0.9	-500	2000	3250	4500	7100	11250

MN's	EPR 2.1	EPR 2.3	EPR 2.6
0	14950	17080	20400
0.1	14080	16180	19450
0.2	13500	15670	19000
0.3	13240	15420	19000
0.4	13175	15460	19000
0.5	13400	15820	19600
0.6	13860	16450	20550
0.7	14600	17400	21750
0.8	15650	18690	23500
0.9	17050	20250	25150

FIGURE 3 - THRUST vs EPR

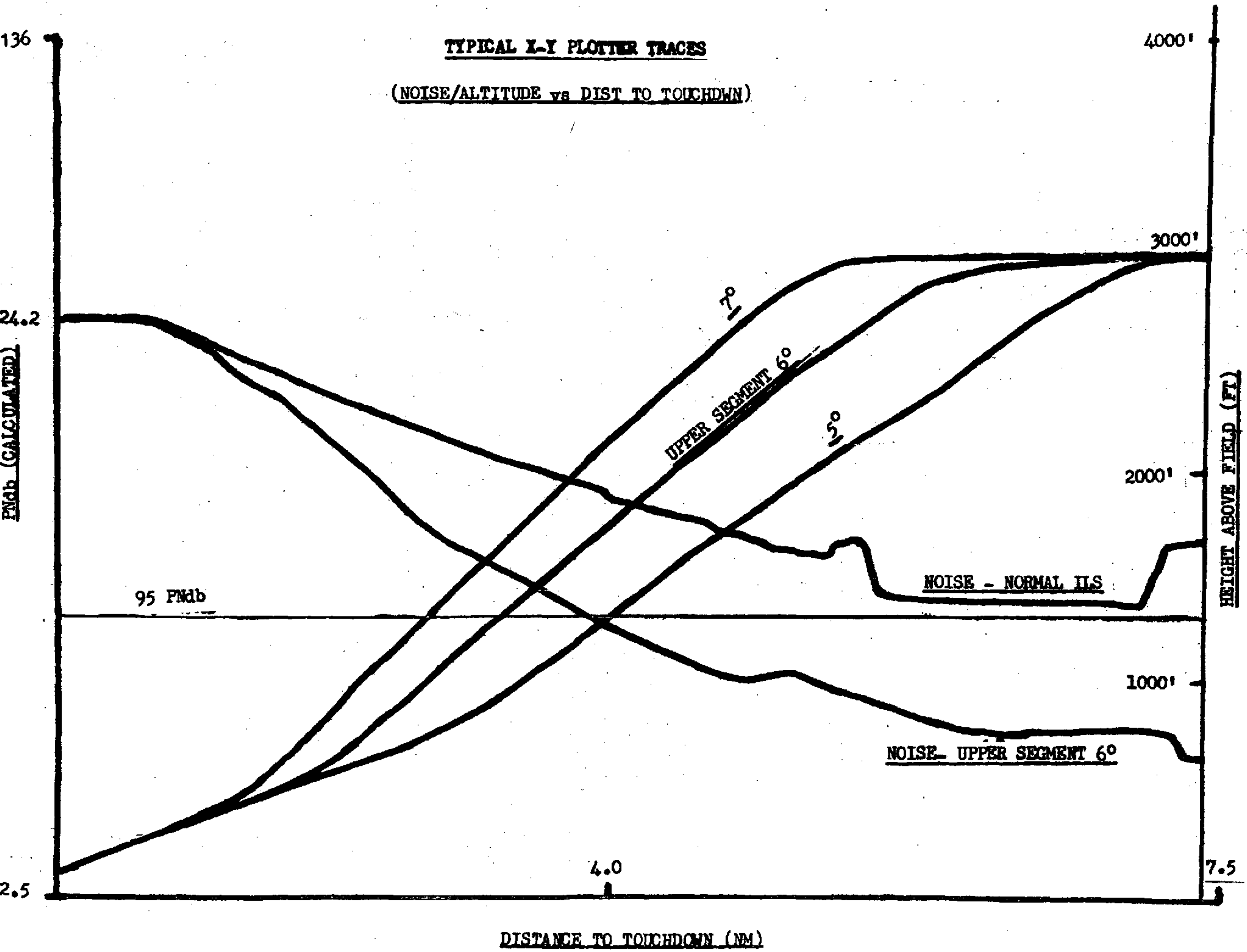

TYPICAL X-Y PLOTTER TRACES
(NOISE/ALTITUDE vs DIST TO TOUCHDOWN)
136
124.2
72.5
PNdb (CALCULATED)
95 PNdb
4000'
3000'
2000'
1000'
HEIGHT ABOVE FIELD (FT)
7°
UPPER SEGMENT 6°
5°
NOISE - NORMAL ILS
NOISE- UPPER SEGMENT 6°
4.0
7.5
DISTANCE TO TOUCHDOWN (NM)

FIGURE 4

UAL B727-222 FLIGHT SIMULATOR

NOISE PREDICTION PROGRAM

90 PNdb CONTOUR

90 PNdb CONTOUR

A. Program Objective - To calculate and record on an X-Y peripheral device, the approximate 90 PNdb footprint in terms of lateral distance in feet from ground level flight path centerline versus distance to touchdown in nautical miles. As with the PNdb vs. distance to touchdown program (Enclosure (1)), the more complex factors which affect actual ground level PNdb were not taken into account since this program was designed to serve as a relative indicator of footprint area for different approaches.

B. Program Data Base - Principal lateral noise data was derived from the table used in the other sound prediction program (Figure 1, Enclosure (1)).

C. Program Methodology

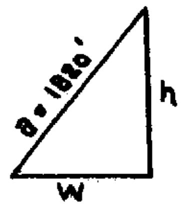
1. The radius of the 90 PNdb envelope is calculated by entering the table (Figure 1) with thrust and determining the "feet AGL" which corresponds to 90 PNdb. This result is the radius of the envelope.
2. This radius is then treated as the hypotenuse of a right triangle. Height above ground is the vertical leg.
3. The right triangle is then solved for the horizontal leg. The length of this leg represents the distance laterally from the ground level flight path centerline of the instantaneous 90 PNdb footprint.

An example to illustrate the above is shown in Figure 5. A typical set of traces showing the right half of relative footprint areas beneath four different approaches is shown in Figure 6.

EXAMPLE: THRUST = 2500# INCREASING TO 4000# AT ABOUT 600' (AFL)

TO DETERMINE RADIUS OF 90 PNdB ENVELOPE, ENTER TABLE (FIGURE 1 OF PREVIOUS PROGRAM DESCRIPTION) WITH 2500# THRUST AND INTERPOLATE FOR 90 PNdB TO FIND "FEET AGL" CORRESPONDING TO 2500#/ 90 PNdB. THIS RESULTS IN APPROX. 1820' = RADIUS OF 90 PNdB ENVELOPE.

WITH THRUST REMAINING AT 2500#, THE TRIANGLE SHOWN BELOW WAS SOLVED:



δ = 90 PNdB RADIUS = 1820' (2500#)
h = AIRCRAFT HEIGHT' (AFL)
W = LATERAL DISTANCE FROM ℄ OF 90 PNdB CONTOUR FOR GIVEN VALUE OF h.

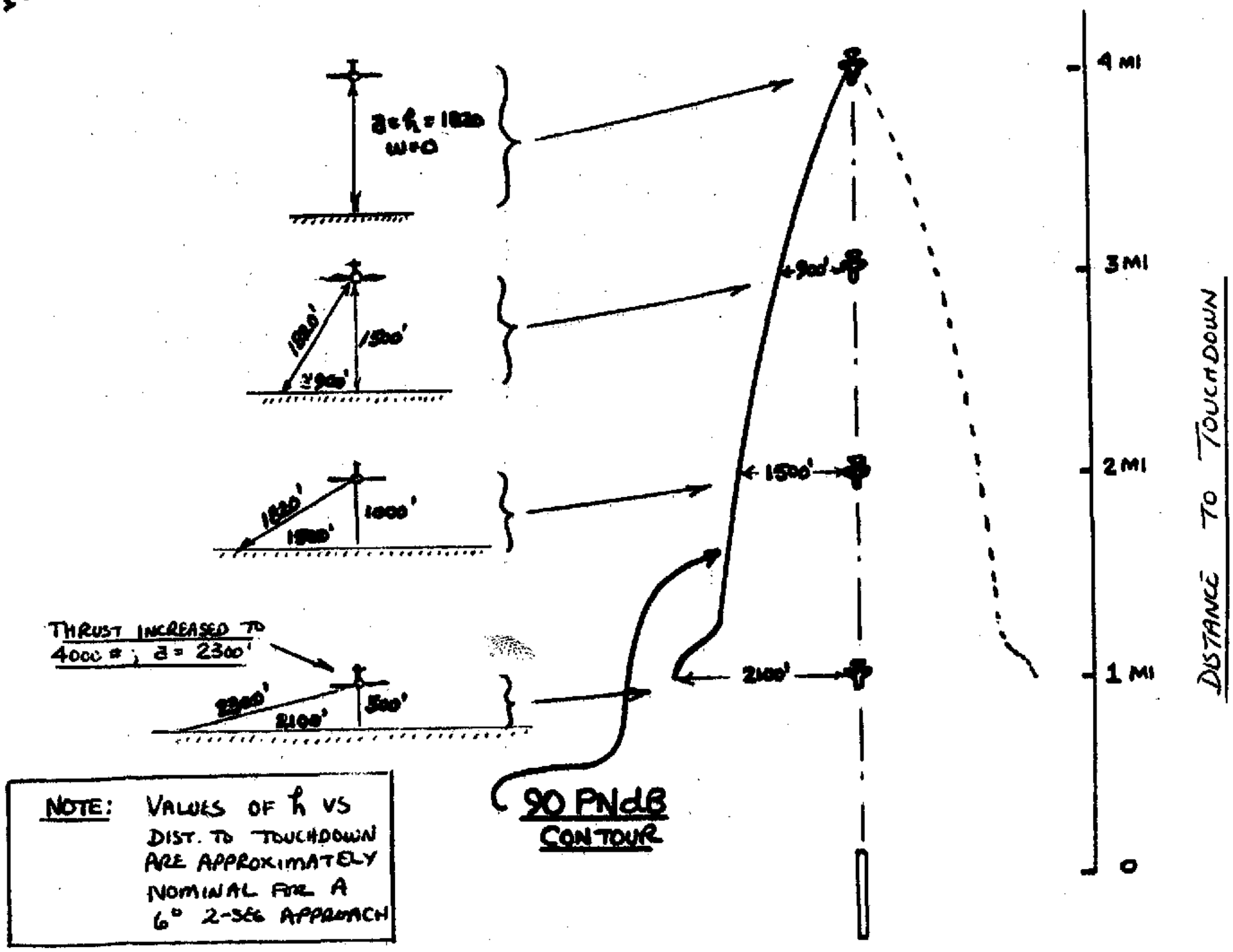


FIGURE 5 - 90 PNdB CONTOUR COMPUTATION

90 PNDB CONTOURS

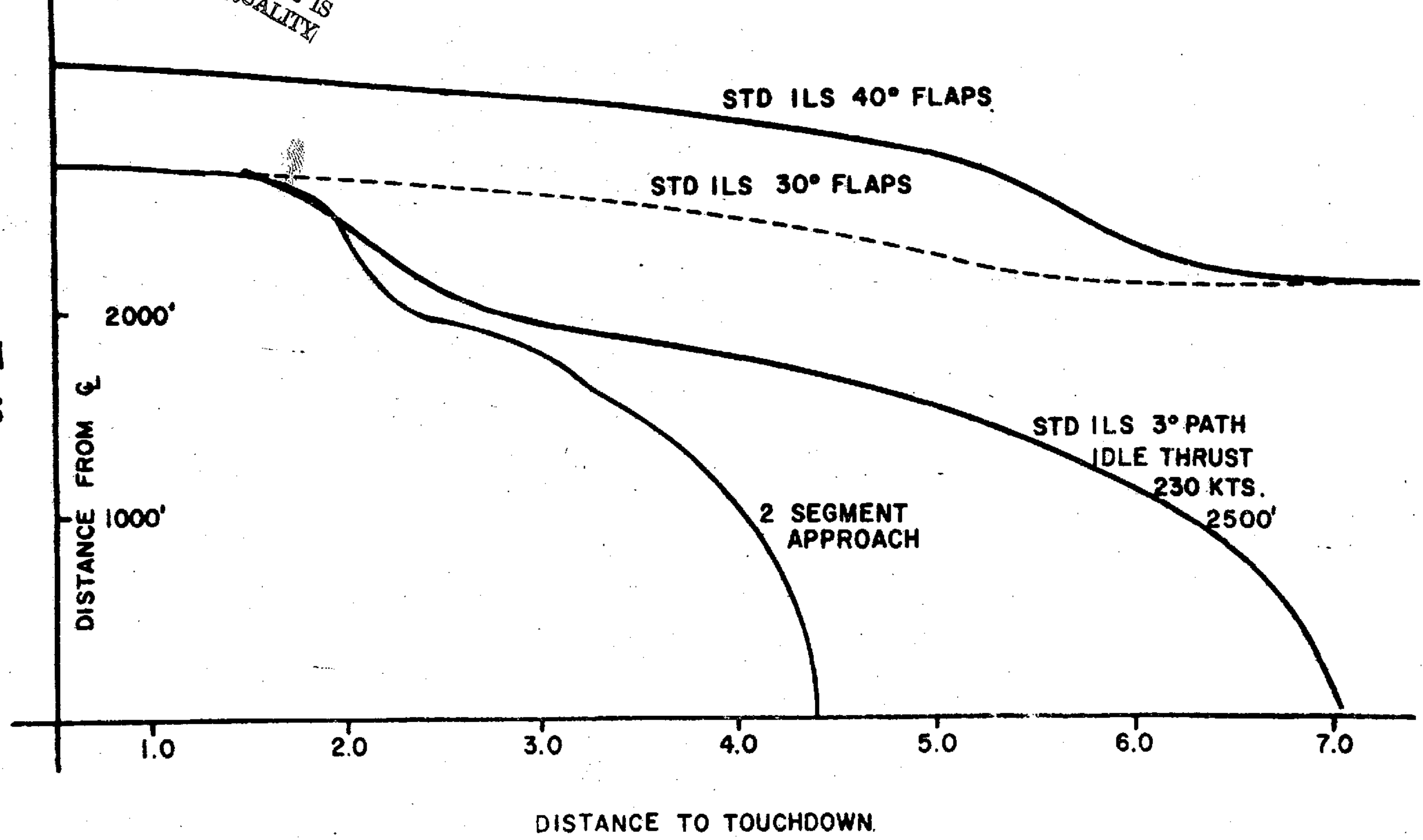


FIGURE 6

F. OTHER DATA SYSTEMS

F. Other Simulator Data Systems - Programs were written to derive and output data on two other peripheral devices in addition to the X-Y plots described in the sound prediction section preceding. These were the 14-channel oscillograph and the line printer programs. Details of each are provided later in this section.

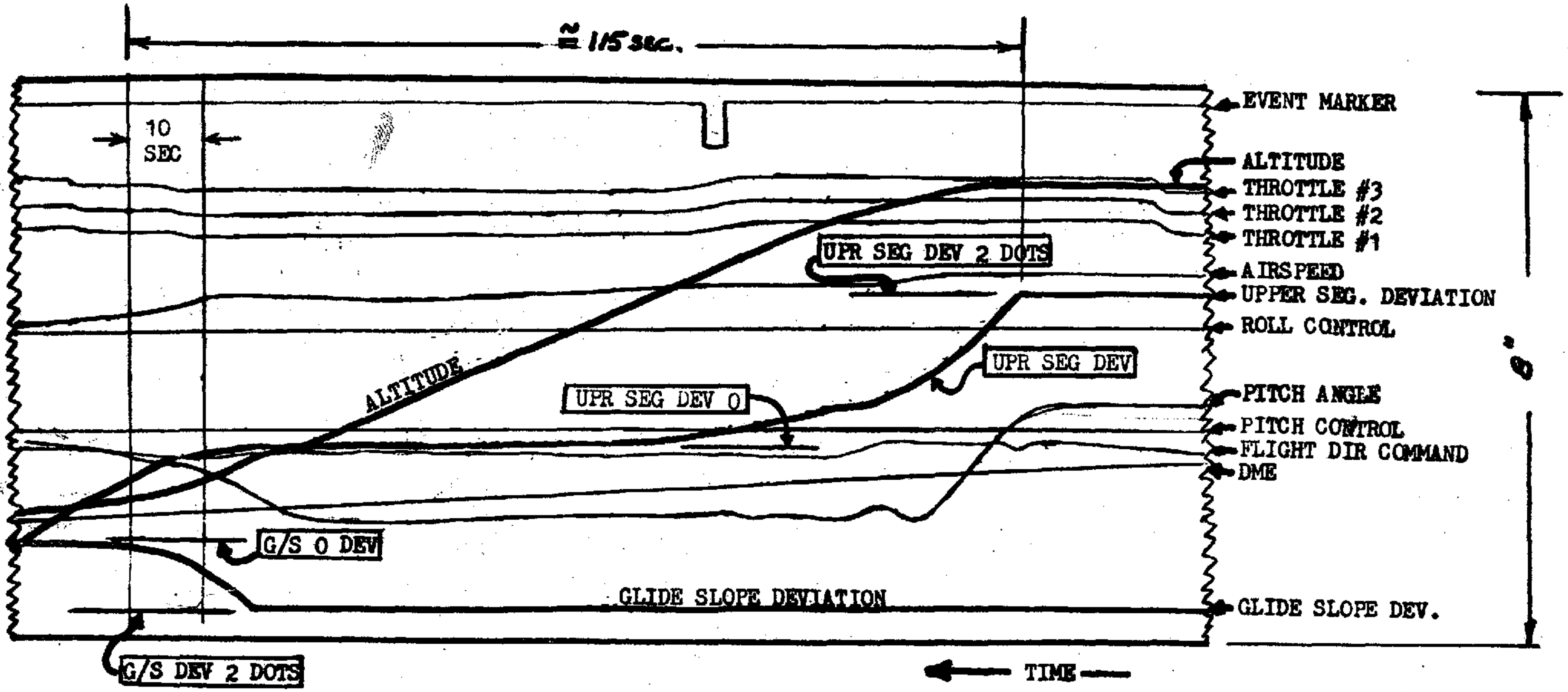
In addition to the above, the Project Pilots filled out rather detailed written summaries of each of the functional testing and simulation evaluation trials. Only typical examples of this data will be included in this report. A complete summary will be included in the final Project report.

For the Off-Line Pilot Evaluation phase, the guest pilots and their Project Pilot counterparts filled out questionnaires and written summaries of their simulator familiarization period prior to flying the Evaluation aircraft. A separate Off-Line Evaluation report will be submitted to cover this phase. This data will therefore not appear in this report.

Sound-video tape records were taken of each of the Off-Line Evaluation pilots' simulator period. Though this medium did not yield any particularly valuable data, it led to the extremely beneficial use of this medium during the On-Line STC Flights and will be extensively used in the subsequent DC-8/RNAV Program which is to follow the B-727/Two-Segment Program.

14-CHANNEL OSCILLOGRAPH PROGRAM

The 14-channel oscillograph proved to be an extremely effective recording and analysis tool in the development phase of the Program. The Project Pilot Team selected the parameters shown in Figure 1. The scaling and general use of these parameters and combinations of parameters for profile analysis, are described in this section.



NOTE: The above is a copy of an actual data trace showing a 2-segment approach 6° Upper Segment 2.5° Glide Slope. Initial approach altitude 3030' MSL.

FIGURE-1 - A TYPICAL 14-CHANNEL OSCILLOGRAPH DATA TRACE

Event - When the event button is depressed, a square wave spike of the amplitude shown is generated for the duration the button is depressed. The spike shown is approximately three seconds (see time scaling on upper left of Figure 1).

Altitude - For most of the matrix trials, the initial approach altitude was 3030'MSL (3000'AFL at Stockton). The level segment on the right hand side of Figure 1 represents 3000'(AFL), scaled as it was for all 3000' initial approach altitudes. Some matrix trials called for commencement altitudes up to 10,000' (AFL). In those cases, this parameter was appropriately re-scaled.

Throttles (#3-2-1) - Scaled in percent of lever travel. This is not intended to be a precise parameter. It was included to show the areas in the profile of throttle activity and a general indication of the magnitude of movement.

Airspeed - As shown in Figure 1, the valve is about 160 KIAS, with a slowing to about 145 KIAS.

Upper Segment Deviation - High resolution scaling was selected for this parameter in order to record the upper segment intercept regime accurately. In combination with other simultaneously recorded parameters it serves that purpose very well. Figure 2 below excerpts those parameters from Figure 1 and relates them to the aircraft position on the profile during that period:

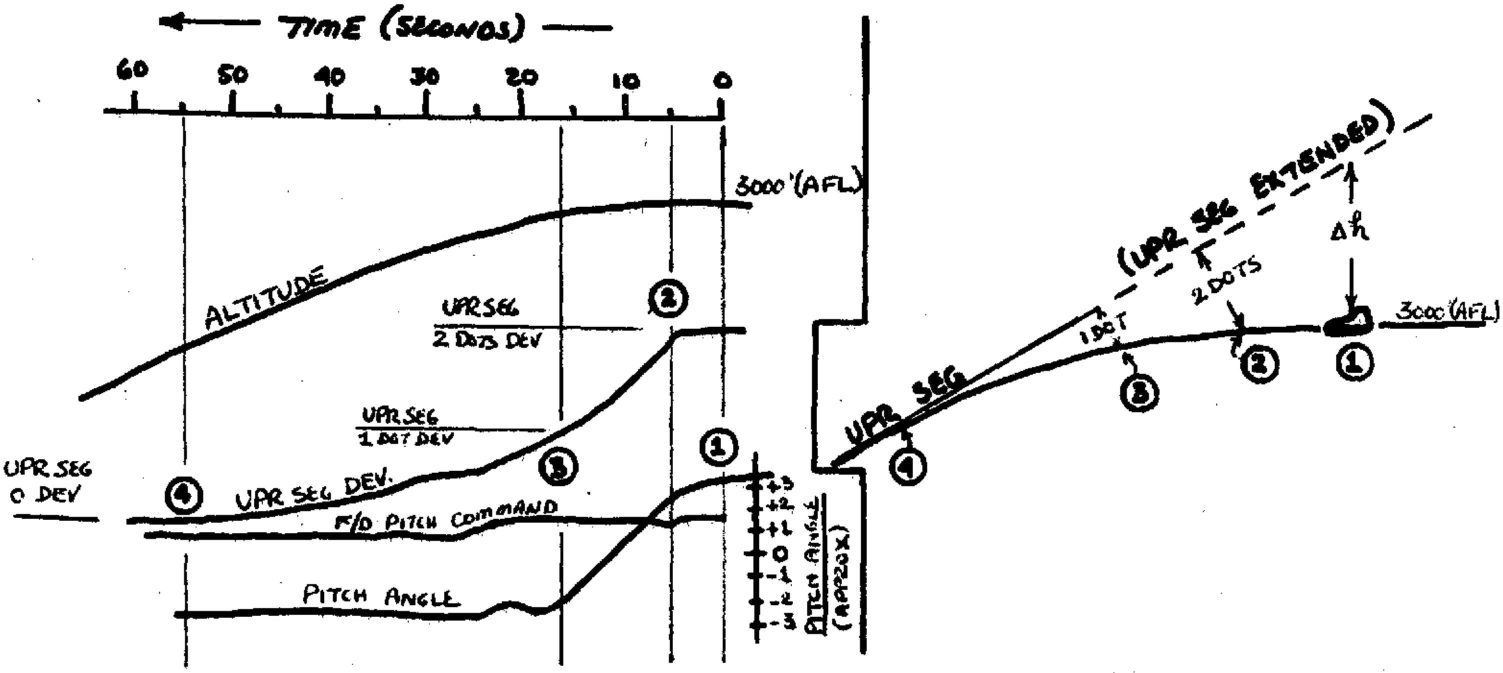


FIGURE 2 - UPPER TRANSITION OSCILLOGRAPH DATA RELATED TO AIRCRAFT POSITION IN PROFILE

At ① , the aircraft has reached the computed upper segment capture point (Δh appropriate to the speed of approach to upper segment). The pitch maneuver is commanded and the pilot changes the pitch angle to commence the descent.

At ②, the HSI vertical deviation indicator has reached 2 dots. The aircraft departs altitude.

At ③, the aircraft is in mid-transition having moved to within 1 dot of upper segment.

Between 3 and 4, the upper segment deviation appears to have started to level at approximately $\frac{1}{2}$ dot. The pitch angle changes to a slight pitch-up to correct the aircraft toward upper segment. Shortly thereafter, the flight director commands a resumption of the previous pitch angle.

At 4, the upper segment deviation is 0. The aircraft is on upper segment.

Roll Channel - This is the autopilot roll channel command. It is a straight line in Figure 1 which depicts a flight director approach. For a coupled approach, this would record the localizer tracking commands. The two-segment system does not process lateral information. It was therefore felt that the recording of flight director roll commands would not contribute valid information with respect to evaluating the two-segment equipment which is strictly confined to the vertical portion of the approach guidance.

Pitch Angle - This is a high resolution scaling factor. Pitch angle changes required very close analysis in the development and optimization of the intercept, transition and tracking regimes. The scale shown on Figure 2 above is approximate. It shows that prior to 1, a constant attitude of about $+3^{\circ}$ was required to maintain stabilized level flight. Between 1 and 3, it can be seen that the pitch attitude changed from about $+3^{\circ}$ to -3° in the approximate 17-second interval shown. Between 3 and 4, the pilot shallowed the angle momentarily which is reflected shortly thereafter by a leveling of upper segment deviation and a flight director pitch command for nose down.

Pitch Control - The pitch control parameter is the autopilot command in the pitch channel. As with the roll control above, it is a straight line in Figure 1 since the autopilot was off for this approach. In a coupled approach, it would record autopilot pitch commands for intercepting and tracking vertical approach profile.

Flight Director Command - Shows the direction and magnitude of the commands displayed on the flight director in flying the approach.

DME - This is a simple linear time-distance record. Figure 1 is not representative of the scaling used for most of the matrix trials. The resolution was approximately doubled over that shown.

Glideslope Deviation - As with upper segment deviation, this record was program limited between 2 dots and 0 deviation. The input polarity was reversed on this trace so that it goes from 2 dots to 0 in the direction opposite from the rest of the parameters. This was done principally to avoid clutter.

As with upper segment deviation, this parameter, when used in conjunction with certain other simultaneous records, permitted a through analysis of the lower transition regime. Figure 3 below illustrates the direct relationship between the oscillograph record and the aircraft position on the flight profile:

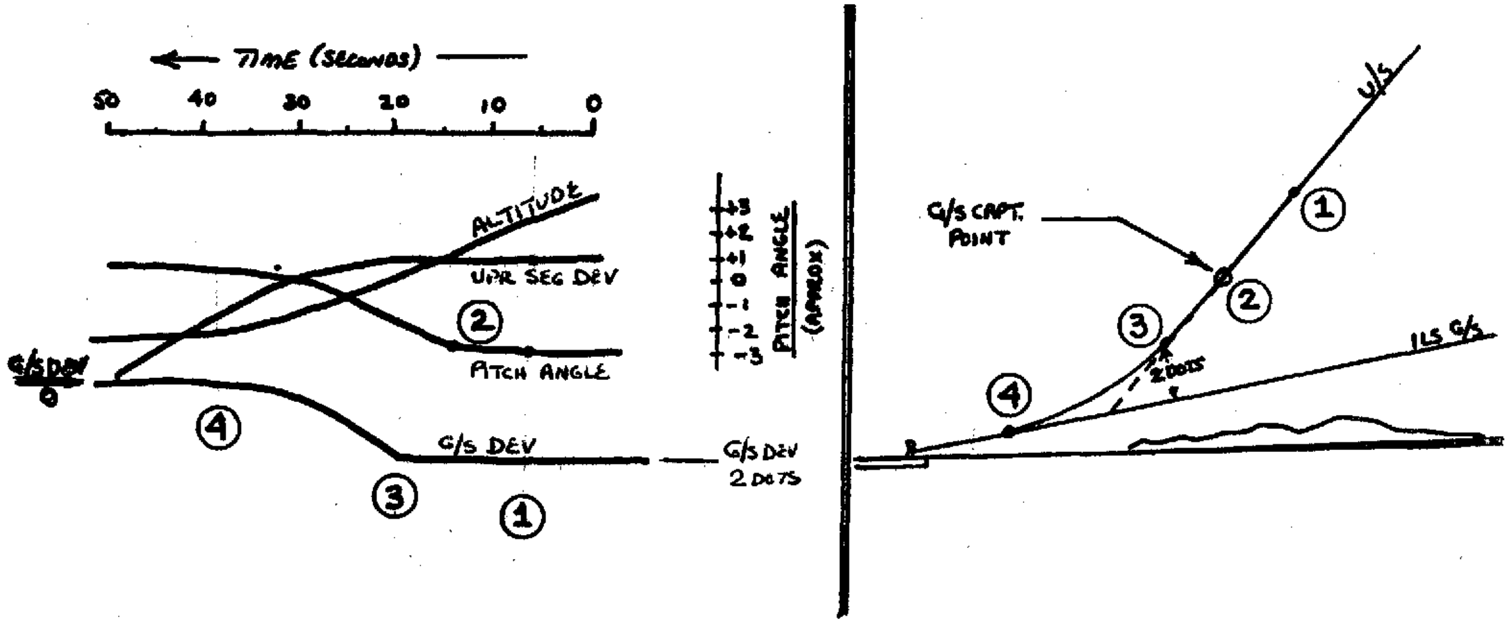


FIGURE 3 - GLIDESLOPE TRANSITION OSCILLOGRAPH DATA RELATED TO AIRCRAFT POSITION IN PROFILE

AT (1) - The aircraft is on upper segment (upper segment deviation 0, pitch angle constant approximately 3° nose down).

AT (2) - The flight director has commanded a pitch up to transition from upper segment to glideslope. Between 2 and 4 this angle changes from about -3° to $+1^{\circ}$.

AT (3) - Glideslope deviation starts to move from 2 dots toward 0. Upper segment deviation is changing and the altitude rate starts to decrease.

AT (4) - The aircraft is on glideslope. (G/S deviation 0).

LINE PRINTER PROGRAM

The Line Printer Program

The simulator line printer did not have a real-time print-out capability when the Program commenced. With considerable effort and assistance from the manufacturer service representative, the interface and I/O's were modified to permit the line printer to function as a real-time peripheral device. Figure 1 shows a representative flight director two-segment approach. The program was designed to accumulate the values of each parameter shown and to output them on the printer each second. The details of the use of this data for analysis will be included in more detail in the Off-Line Evaluation.(Guest Pilot) Report.

Referring to Figure 1, a few specific points in the approach are discussed here to assist the reader in interpreting the format:

Page 001

① (First Data Line) -

Position is 6.1 DME; 2937' AFL; "upper segment" is GREEN; "glideslope" is AMBER. (Note: At the time this record was made, glideslope arm point had not been established at 5.0 DME). Airspeed B4 KIAS, Flaps 24°, gear up. Pitch Control, pitch command show stabilized flight, power stable, #3 throttle at 20% (throttles 1 & 2 are matched within 5% less); on localizer; glideslope deviation 1 dot (or more) high. (NOTE: Since the program limits to ± 1 dot, the actual value, which is a great deal more than 1 dot at this point, is not shown. The resolution (± 1 dot in tenths of a dot was chosen to give precise deviation information on the glideslope segment).

Page 002 (Glideslope Capture Point)

2 Position is 2.6 DME; 918'(AFL); "glideslope" has switched from AMBER to GREEN; flaps 30°; speed 138 KIAS.

Note that 4 seconds later glideslope deviation becomes less than 1 dot high and moves to 0.1 dot high 14 seconds later. Body angle starts from down 2° towards up. Approximately 12 seconds after capture, body angle goes through level to up.

3 At 541' on glideslope (0.1 dot high), speed starts to decay 125 to 120 KTS. Pilot adds power to catch speed and to stabilize on glideslope.

Page 003

4 Power addition at 3 slightly excessive. Speed builds back up to 126 KIAS. Pilot reduces power, remains stabilized for remainder of approach until about 80' AFL; adds power to GO-AROUND (does not select "GO-AROUND").

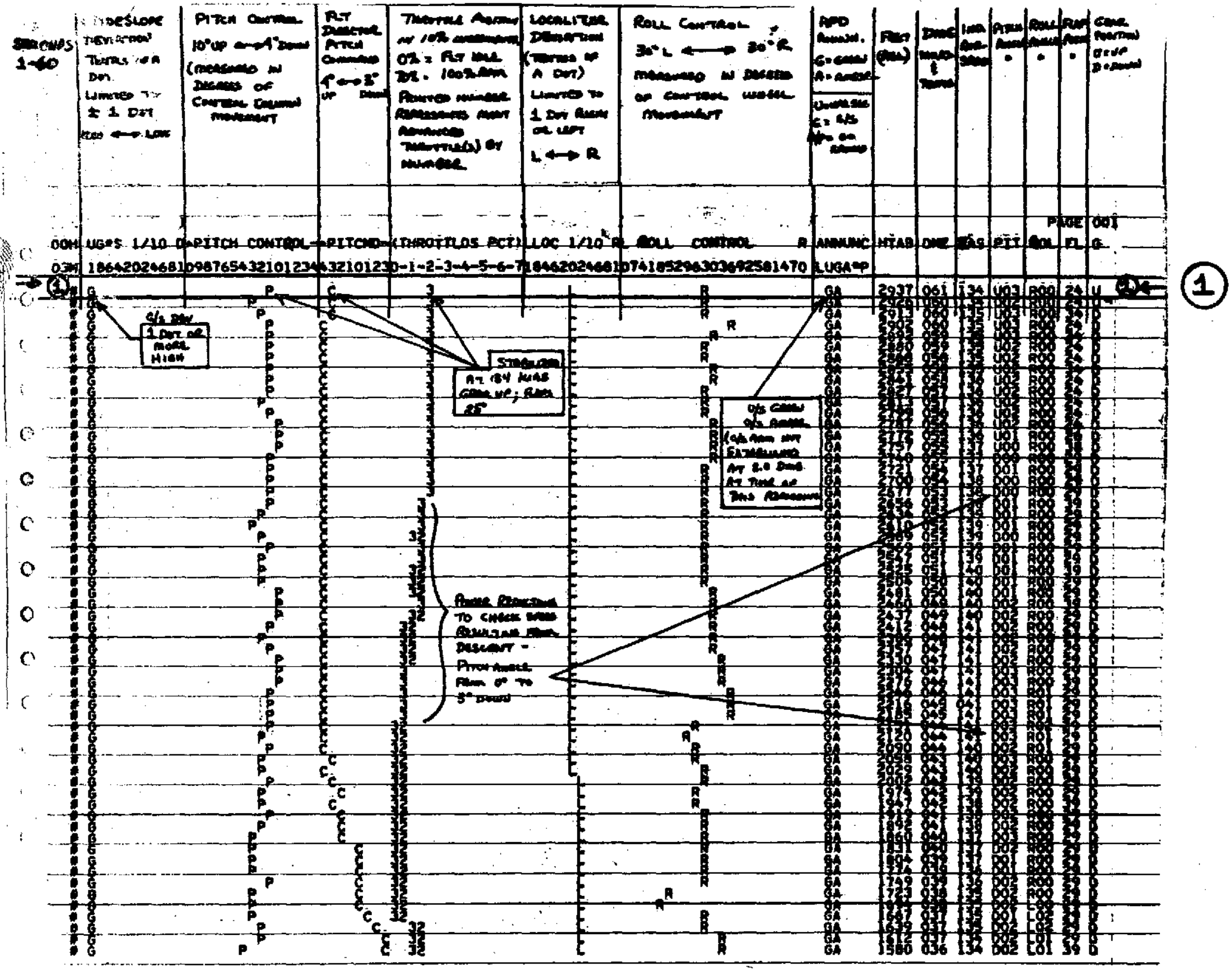
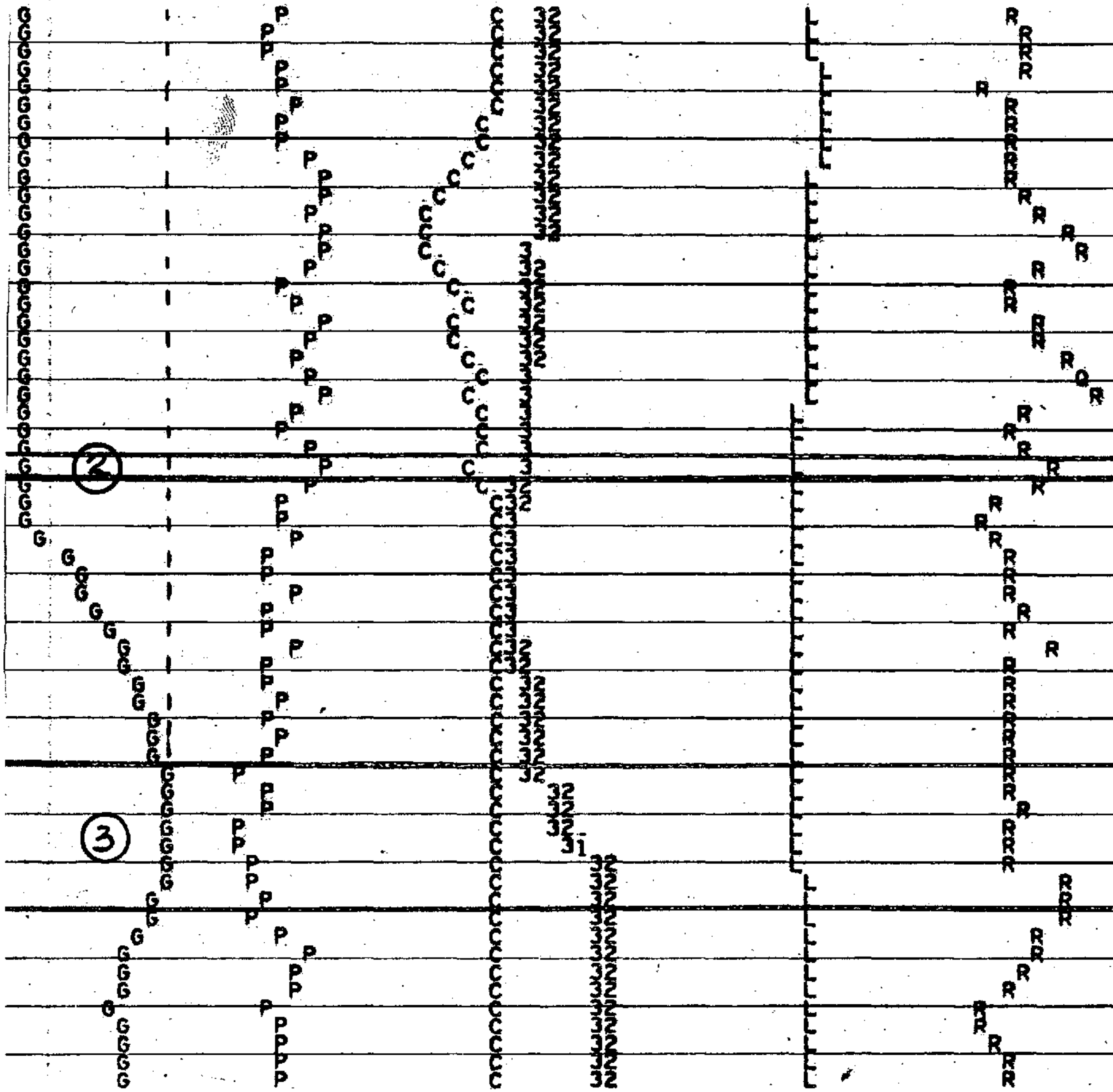


FIGURE 1 - TYPICAL SIMULATOR LINE PRINTER DATA (PAGE 001)
(FLIGHT DIRECTOR - 2-SEGMENT)

UG*S 1/10 D+PITCH CONTROL-+PITCMD-(THROTTLDS PCT)LLOC 1/10 RL ROLL CONTROL R ANNUNC HTAB DME HAS PIT ROL FL G

186420246810987654321012344321012340-1-2-3-4-5-6-7184620246810741852963036925814 70 LUGA/P



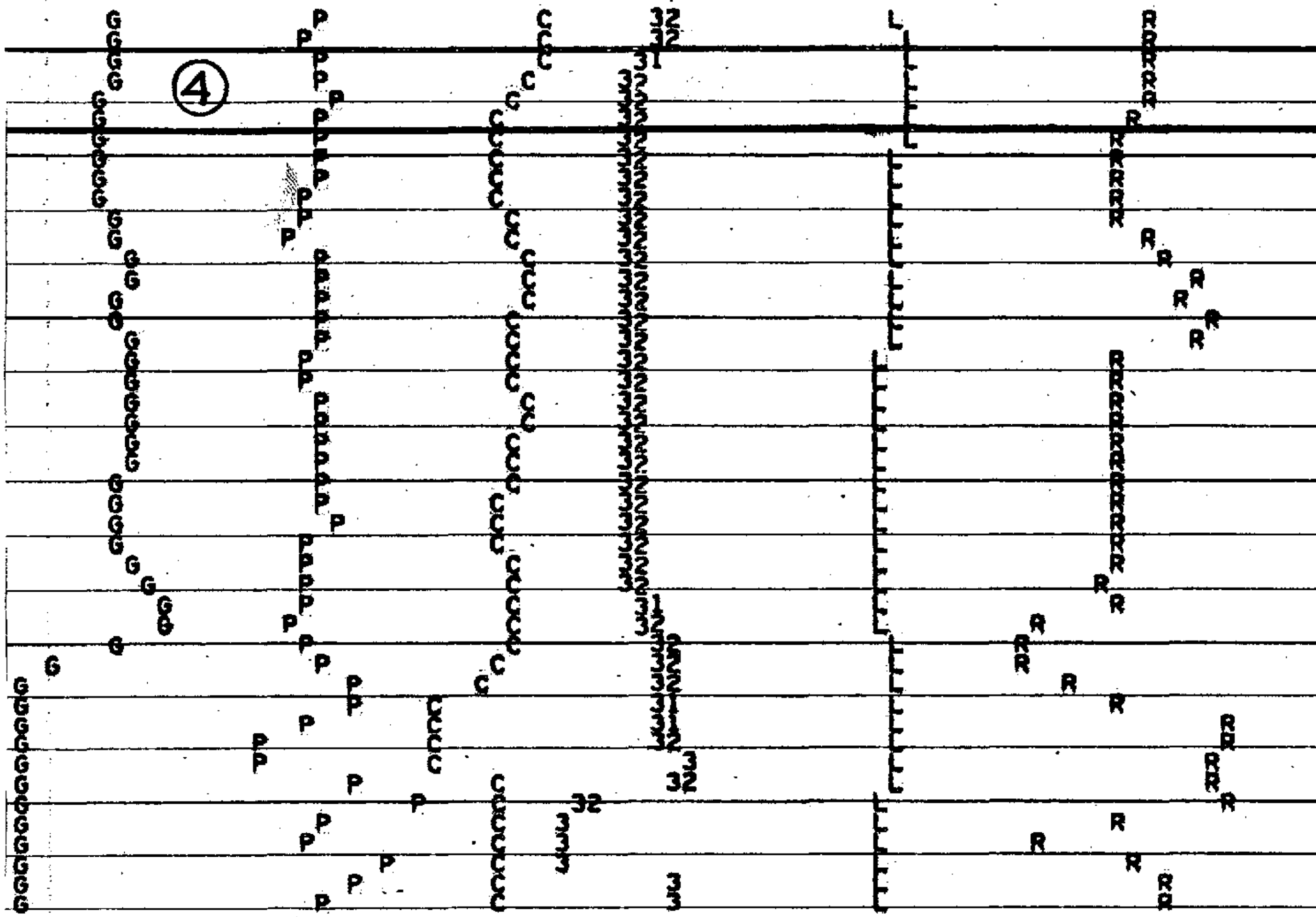
ANNUNC	HTAB	DME	HAS	PIT	ROL	FL	G
GA	1551	036	135	D01	L00	29	D
GA	1522	035	135	D01	L00	39	D
GA	1495	035	135	D01	L01	29	D
GA	1470	035	135	D00	L01	29	D
GA	1445	034	136	D00	L01	29	D
GA	1422	034	136	D00	L01	29	D
GA	1401	033	136	D00	L02	29	D
GA	1380	033	136	D00	L02	29	D
GA	1359	033	137	D00	L02	29	D
GA	1339	032	137	D00	L02	29	D
GA	1320	032	137	D01	L02	29	D
GA	1298	031	137	D02	L02	29	D
GA	1274	031	138	D02	L01	29	D
GA	1249	031	138	D02	L00	29	D
GA	1223	030	139	D03	R00	29	D
GA	1194	030	139	D03	R00	29	D
GA	1166	029	139	D01	R00	29	D
GA	1139	029	139	D02	L00	29	D
GA	1114	029	139	D03	L00	29	D
GA	1084	028	139	D02	L00	29	D
GA	1056	028	139	D02	R00	29	D
GA	1029	027	139	D02	R01	29	D
GA	0999	027	139	D02	R02	29	D
GA	0971	027	138	D02	R02	29	D
GA	0944	026	138	D01	R02	29	D
GG	0918	026	138	D02	R02	29	D
GG	0892	025	137	D03	R02	29	D
GG	0859	025	137	D03	R02	29	D
GG	0828	025	137	D02	R02	29	D
GG	0799	024	137	D02	R01	29	D
GG	0768	024	137	D01	R01	29	D
GG	0742	023	136	D01	R01	29	D
GG	0718	023	135	D00	R01	[illegible]	C
GG	0695	023	135	D00	R01	[illegible]	[illegible]
GG	0673	022	134	D00	R01	[illegible]	[illegible]
GG	0652	022	133	U00	R01	[illegible]	[illegible]
GG	0632	021	132	U00	R01	29	D
GG	0614	021	131	U01	R01	29	D
GG	0598	021	130	U02	R01	29	D
GG	0582	020	128	U02	R01	29	D
GG	0568	020	127	U02	R01	29	D
GG	0555	019	126	U02	R01	29	D
GG	0541	019	125	U03	R01	29	D
GG	0529	019	123	U04	R01	29	D
GG	0518	018	122	U04	R01	29	D
GG	0508	018	121	U04	R00	29	D
GG	0497	018	121	U05	L00	29	D
GG	0488	017	120	U06	L00	29	D
GG	0482	017	120	U07	L01	29	D
GG	0477	017	120	U06	L00	29	D
GG	0473	016	120	U06	L00	29	D
GG	0470	016	120	U06	L00	29	[illegible]
GG	0466	016	120	U06	R00	29	[illegible]
GG	0462	015	120	U04	R00	39	[illegible]
GG	0454	015	121	U03	L00	[illegible]	[illegible]
GG	0443	015	122	U03	L00	[illegible]	[illegible]
GG	0431	014	122	U04	L00	39	D
GG	0420	014	123	U04	L01	29	D
GG	0409	013	124	U04	L01	29	D
GG	0400	013	124	U04	L01	29	D

FIGURE 1 – PAGE 2 OF 3

FIGURE 1 – PAGE 2 OF 3 PAGES (PAGE 002)

UG*S 1/10 D+PITCH CONTQOL=+PITCMD=(THROTTLDS PCT)LLOC 1/10 RL QOLL CONTROL R ANNUNC HTAB DME HAS PIT QOL FL G

186420246810987654321012344321012З0-1-2-3-4-5-6-71846202468107418529630369258147Q LUGA/P



4

GG	0391	013	125	U04	L01	29	D
GG	0382	012	125	U04	L01	29	D
GG	0374	012	126	U04	L01	29	D
GG	0366	012	126	U04	L01	29	D
GG	0358	011	125	U03	L01	29	D
GG	0348	011	125	U02	L00	39	D
GG	0337	011	126	U02	L00	29	D
GG	0324	010	126	U02	L00	29	D
GG	0312	010	126	U02	L01	39	D
GG	0299	010	126	U02	L01	29	D
GG	0285	009	126	U02	L01	29	D
GG	0272	009	127	U03	L01	29	D
GG	0259	008	127	U03	L00	29	D
GG	0248	008	126	U03	L00	29	D
GG	0238	008	126	U03	R00	29	D
GG	0227	007	126	U03	R00	29	D
GG	0216	007	126	U03	R02	29	D
GG	0204	007	126	U03	R03	29	D
GG	0193	006	127	U03	R02	29	D
GG	0181	006	127	U03	R02	29	D
GG	0171	005	126	U03	R02	29	D
GG	0161	005	126	U03	R02	29	D
GG	0151	005	126	U03	R02	29	D
GG	0142	004	126	U03	R02	29	D
GG	0131	004	126	U03	R01	29	D
GG	0120	004	126	U02	R01	29	D
GG	0108	003	127	U02	R01	29	D
GG	0095	003	127	U02	R01	29	D
GG	0082	003	127	U03	R01	29	D
GG	0071	002	127	U03	R01	29	D
GG	0062	002	127	U04	R01	39	D
GG	0054	002	127	U04	L00	29	D
GG	0047	001	127	U05	L03	29	D
GG	0042	001	127	U04	L05	29	D
GG	0038	001	127	U03	L06	29	D
GG	0031	001	128	U02	L05	29	D
GG	0022	001	129	U02	L02	29	D
GG	0013	001	130	U05	L00	29	D
GG	0012	001	131	U05	R00	29	D
GG	0015	001	131	U03	R02	29	D
GG	0015	001	130	U00	R04	29	D
GG	0008	001	129	000	R02	29	D
GG	0009	002	128	U00	L02	29	D
GG	0009	002	127	000	R00	29	D
GG	0009	002	126	000	R00	26	D

FIGURE 1 - PAGE 3 OF 3 (PAGE 003)

FIGURE 1 (PAGE 3 OF 3)

PROJECT PILOT APPROACH DATA CARD

PROJECT PILOT COMMENT SUMMARIES

EVALUATION PILOT QUESTIONNAIRES (OFF-LINE)

SOUND-VIDEO TAPE

The Project Pilot Approach Data Card

A sample of the card used by the Project Pilots for each approach flown is shown on the following page. These were used to capture the data shown on the card and to record any comments the pilot had immediately after the approach was flown. This card was also used in the Engineering Flight Evaluation for the same purposes as in the simulator.

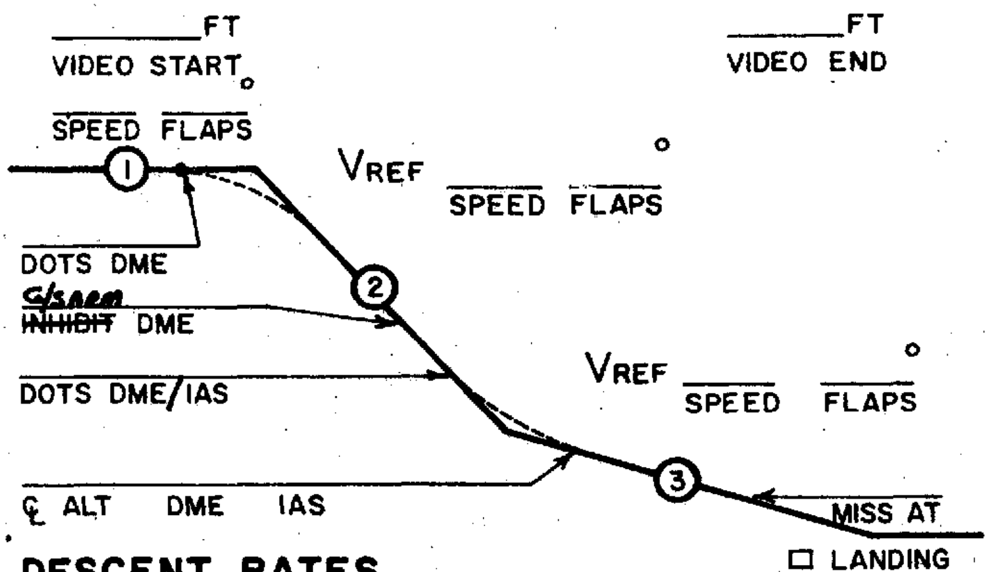
AVIONICS VERIFICATION | ______ APPROACH# ______ FDEP# ______ DATE

AIRPORT ________ RUNWAY ______ SURFACE WIND ___/___

STD ILS ☐ GROSS WT. ________ VREF ________

2-SEG ☐

COUPLED ☐ ______ BEGIN Z ______ SECONDS FROM ______ DME TO ______ DME



DESCENT RATES

1 ______________

2 ______________

3 ______________

COMMENTS: ____

PROJECT PILOT APPROACH DATA CARD

Project Pilot Comment Summary

After each simulator period, the Project Pilots summarized their comments on a summary sheet. An example of such a summary appears on the following page.

Evaluation Pilot Questionnaires

During the Guest Pilot phase, each Guest Pilot was asked to complete a questionnaire on specific items. The results of this phase are the subject of a separate report and will therefore not be further discussed here.

Sound-Video Tape

The true value of this medium was not fully recognized until well into the Engineering Flight Evaluation phase. Sound-video tapes were taken for each of the Guest Pilot simulator sessions; however, they did not yield any particularly valuable data at that point. It did, however, serve to point up its potential as an excellent development medium.
It was used in the 727 On-Line STC Flights and was accepted by the FAA as a record of certain system behaviours which did not thus have to be demonstrated on the STC Flight.

Extensive use will be made of this medium in the DC-8 Engineering Flight Evaluation.