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UNITED AIRLINES

Report of the

# ENGINEERING SIMULATION EVALUATION

of the

# TWO-SEGMENT NOISE ABATEMENT APPROACH

in the

# DOUGLAS DC-8-61

15 April 1974

Prepared for the

National Aeronautics and Space Administration

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# INTRODUCTION

The principal objective of the DC-8 Two-Segment Noise Abatement Approach Program is identical to that of the B727-200 program conducted in 1972-73. In both programs, this objective is the development and operational evaluation of a noise abatement two-segment approach which is safe and operationally acceptable for routine use in air carrier service.

The primary differences between the two programs stem from:

(1) The aerodynamic and drag programming differences between the B727-200 and the DC-8-61, and

(2) The different avionics equipment used to generate two-segment approach guidance. The 727 utilized a special purpose two-segment computer which requires a DME collocated with the ILS glideslope transmitter. The DC-8 uses an ARINC Mark II Area Navigation (RNAV) system modified to provide two-segment approach guidance. The RNAV provides approach guidance to both ILS and non-instrumented runways.

The DC-8 program is structured into the following phases:

(1) Definition of operational requirements and constraints, system-pilot interface, failure modes and unreliable guidance protection and approach progress annunciation.

(2) Engineering simulation evaluation.

(3) Engineering flight evaluation and guest pilot evaluation.

(4) In-service evaluation.

This report describes the profile and procedures development work accomplished in the Engineering Simulation Evaluation phase of this program. Detailed results of the B727 simulation evaluation appear in NASA Report CR-137594 of 30 January 1974.

## SUMMARY

The DC-8 simulation evaluation was planned to utilize experience gained in the 727 program to the maximum extent possible. Because the effects of certain factors on the two-segment approach had been thoroughly evaluated in the 727 program, the DC-8 program was designed primarily to verify or modify the previous results to accommodate the differences between the DC-8-61 and the B727-200 airplanes.

The profile and procedures development work was accomplished at the UA Flight Training Center in Denver utilizing a DC-8-61 flight simulator. The simulation evaluation was conducted between 7 June - 20 September 1973. Approximately 300 different combinations of approach variables were evaluated. For each combination evaluated, approximately 5 approaches were flown to insure that the results were accurate and valid. This phase required about 135 simulator flying hours.

The profile developed in the simulator consists of a 5.5° upper segment which intersects the ILS glideslope (or 3° computer-generated lower segment for RNAV/RNAV) at 575' Above Field Level (AFL). The UPPER waypoint (Figure 1) is nominally 3500-4500' AFL at 7-8 n.m from touchdown. The UPPER waypoint is defined in software as a fixed geographic point with a specific programmed altitude. The RNAV transition to Upper Segment can occur only around this point. By contrast, the 727 system could capture Upper Segment at any altitude.

Because of the aerodynamic cleanliness and drag programming constraints of the DC-8-61, it was found that approach entry conditions of airspeed and configuration are more critical than in the B727. The optimum entry and approach procedures were tentatively established as shown in Figure 1:

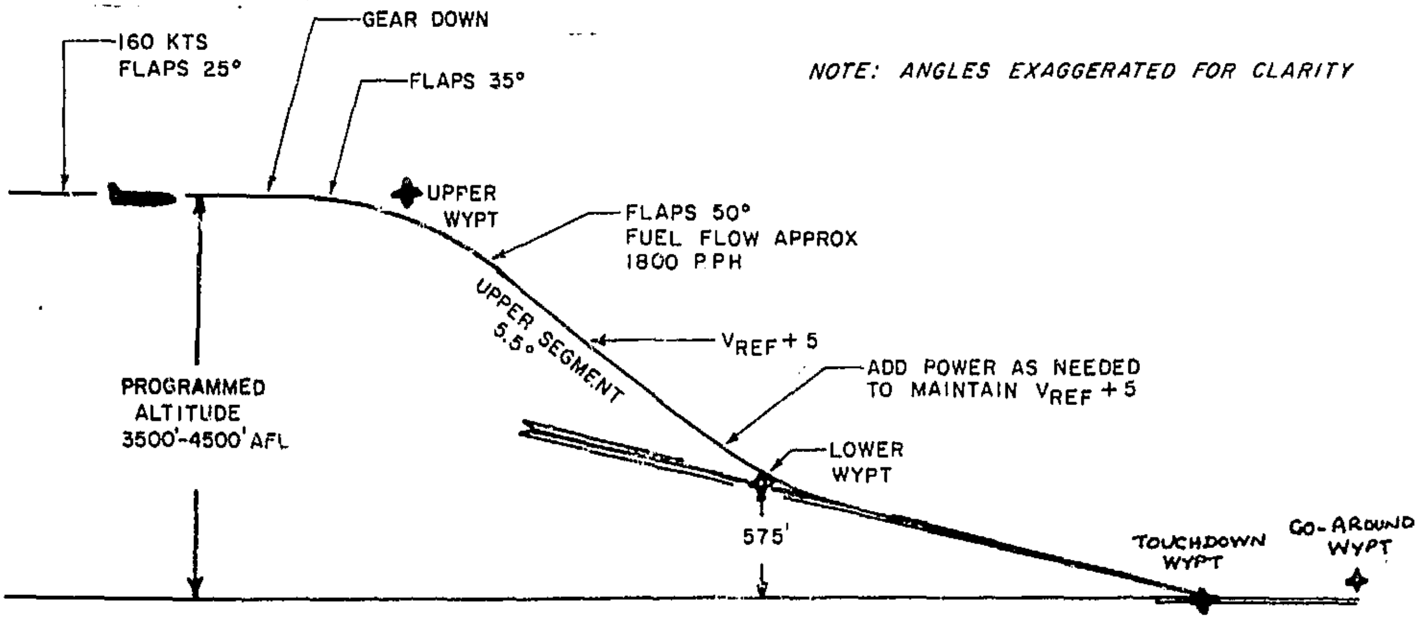



FIGURE 1.— SIMULATION EVALUATION PROFILE / PROCEDURES

Figure 2 compares the 727-200 vertical profile evaluated in line service and the DC-8-61 profile developed in the DC-8 simulator. It can be seen that the two profiles are very close to each other for most of the approach. As drawn in figure 2, the 727 is shown at an initial approach altitude of 3000' AFL and the DC-8 is shown at about 3500' AFL.

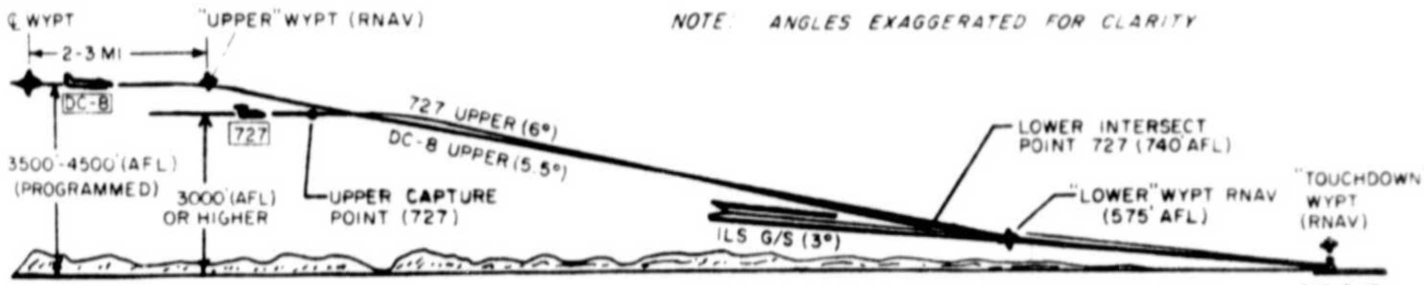



FIGURE _ - COMPARISON OF B-727 AND DC-8-61 TWO-SEGMENT PROFILES

Although the position in space of both of these profiles is approximately the same, there are important operational differences:

(1) Entry speed and initial configuration are more important in the DC-8-61 because of its aerodynamic cleanliness and drag programming constraints.

(2) The altitude required for the DC-8 upper and lower transitions is less than the 727 transitions principally due to the pitching moment from the underslung DC-8 engines as compared to the 727 engines which produce no pitching moment with a change in thrust.

(3) The 727 approach was a reduced flaps (30°) procedure with a 10-knot airspeed bleed in the lower transition. The DC-8 approach is a full flaps (50°) procedure with constant airspeed (V ref +5) established as soon as possible after upper segment transition (see figure 1).

The 727 two-segment was capable of approaches only to ILS runways equipped with a DME collocated with the glideslope transmitter. The RNAV system permits two-segment RNAV/ILS approaches to conventionally-equipped ILS runways. It also permits non-precision RNAV/RNAV approaches to non-instrumented runways by utilizing NAVAIDS in the terminal area to determine lateral position. Using this position information and altitude inputs, it generates the appropriate profile guidance.

Protectors for failure to capture ILS glideslope, or for going below glideslope prior to capture have been provided. If the aircraft goes below ILS glideslope at any point before LOWER SEGMENT amber, or if the glideslope has not been captured by 500' AFL or 1.7 n.m. from touchdown, the autopilot will be disconnected and the Flight Director command bars will be biased from view.

Two operational constraints in the RNAV/RNAV approach procedure are:

(1) Glideslope flag is to be displayed on the Attitude Director Indicator (ADI) as a positive reminder to the pilot that he is not descending to intercept a precision glideslope. This is accomplished by the pilot's tuning his ILS receiver to an ILS frequency which is out of reception range.

(2) During the lower transition, as the LOWER waypoint (Figure 1) is passed, the autopilot disconnects and the flight director command bars are biased from view. The Horizontal Situation Indicator (HSI) continues to display deviation from the computer-generated 3° Lower Segment and the lateral indicator displays deviation from the course to the Go-Around waypoint which was established for this evaluation at the center of the far end of the approach runway (Figure 1).

Upper segment tailwind components in excess of 15 kts will result in unacceptably high rates of descent and power below the immediate thrust response level. Conditions requiring full anti-ice capabilities will probably preclude use of the two-segment procedure due to engine power settings too low to provide this full capability.

## DEVELOPMENT AND EVALUATION METHODS

Project Team Organization

Flight Simulator

Procedures Development

## PROJECT TEAM ORGANIZATION

Captain Gordon Brown, UA DC-8 Fleet Manager and Manager of Flight Operations (DC-8) - Captain Brown established the major operational criteria and constraints within which the project pilots would develop the two-segment procedures for the DC-8-61. He made the key decisions relating to the system-pilot interface and to guidance displays and annunciations.

John A. "Mo" Morrison - Lead Project Pilot for both the DC-8 and the B-727 programs. He directed the efforts of the project pilots and project flight engineers throughout the development and evaluation phases of the program.

| | |
|---|---|
| Project Pilots - (UA Flight Instructors) | W. B. (Bill) Brown<br>H. K. (Hal) Snyder |
| Project Flight Engineers - (UA Flight Operations Instructors) | A. R. (Art) Causer<br>K. O. (KO) Dauderman<br>J. E. (Jim) Harrison |

Generally, at least two of the three members of the Project Pilot group and one Project Flight Engineer conducted each simulator session. The objectives for the session were established in a pre-simulator briefing. The principal reference document was the Engineering Simulation Evaluation Test Plan of 11 April 1973. The plan was laid out in a manner which called for the logical progression through the various test matrices. The results and data from the previous session were reviewed and discussed. If all of the work planned in the previous session had been satisfactorily accomplished, the next set of trials appearing in the plan formed the objective of the session.

## FLIGHT SIMULATOR

The FAA-certified DC-8-61 Flight Simulator located at UA's Flight Training Center in Denver was used for the Engineering Simulation Evaluation.

Prior to the profile and procedures development work, the simulator cockpit was modified to include either the same instruments as would be used in the airplane evaluation, or instruments and indicators which were functionally the same and would provide the necessary information to the pilot.

The principal cockpit hardware modifications or additions included:

(1) A modified HSI with a servo-driven course bug which slewed to the course to next waypoint upon passing a programmed waypoint. This instrument had a dual DME display with one display for conventional DME and the other for distance to waypoint. Technical problems precluded activating these displays in the simulator. To provide this information, a dual ARINC 521 DME indicator was installed in the upper left corner of the Captain's instrument panel.

(2) A modified ADI which contained a raw glideslope deviation indicator on the left side of the instrument.

(3) A modified Flight Director Mode Selector which incorporated an "RNAV" position counter-clockwise from the "OFF" position.

(4) The "AUX NAV" position on the autopilot controller was activated.

(5) An autothrottle system and controls were installed and activated.

(6) A simulated RNAV Control Display Unit (CDU) was installed on the Captain's forward pedestal. This was a closed circuit television slide projector device which could not display any flight dynamics. It was programmed to cycle the display on the Flight Plan page to show the passage of waypoints only.

(7) An Approach Progress Display was added to the Captain's panel directly above the altimeter. It contained Flight Director and Autopilot annunciations of "RNAV" (to indicate to the pilot that he had selected the RNAV mode on his navigation equipment); "UPPER SEGMENT", "LOWER SEGMENT" and "GO AROUND" (F/D only). Standard AMBER (armed) GREEN (capture) logic was used in this display.

The Collins ANS-70A two-segment logic and interface were emulated in the simulator software. A special control box was developed which would permit any profile parameter to be set or varied. An RNAV/ILS or RNAV/RNAV selector switch provided the display and annunciation differences between the RNAV/ILS and the RNAV/RNAV approaches.

Two data recording devices used:

(1) A 14-channel oscillograph recorder. Excerpts from a typical approach record are shown in Figure 3.

(2) An X-Y Plotter. This plotter could generate a profile trace (altitude vs distance to touchdown) or ground level noise directly beneath the airplane (calculated PNdB vs distance to touchdown). This noise data was not intended to be correlated with actual measurements. It was used to assess the relative noise between two different approach profiles. A typical profile and noise trace are shown in Figure 4.

Extensive functional testing to verify the accuracy of the system and interface simulation was conducted between the period 15 March - 1 June 1973.

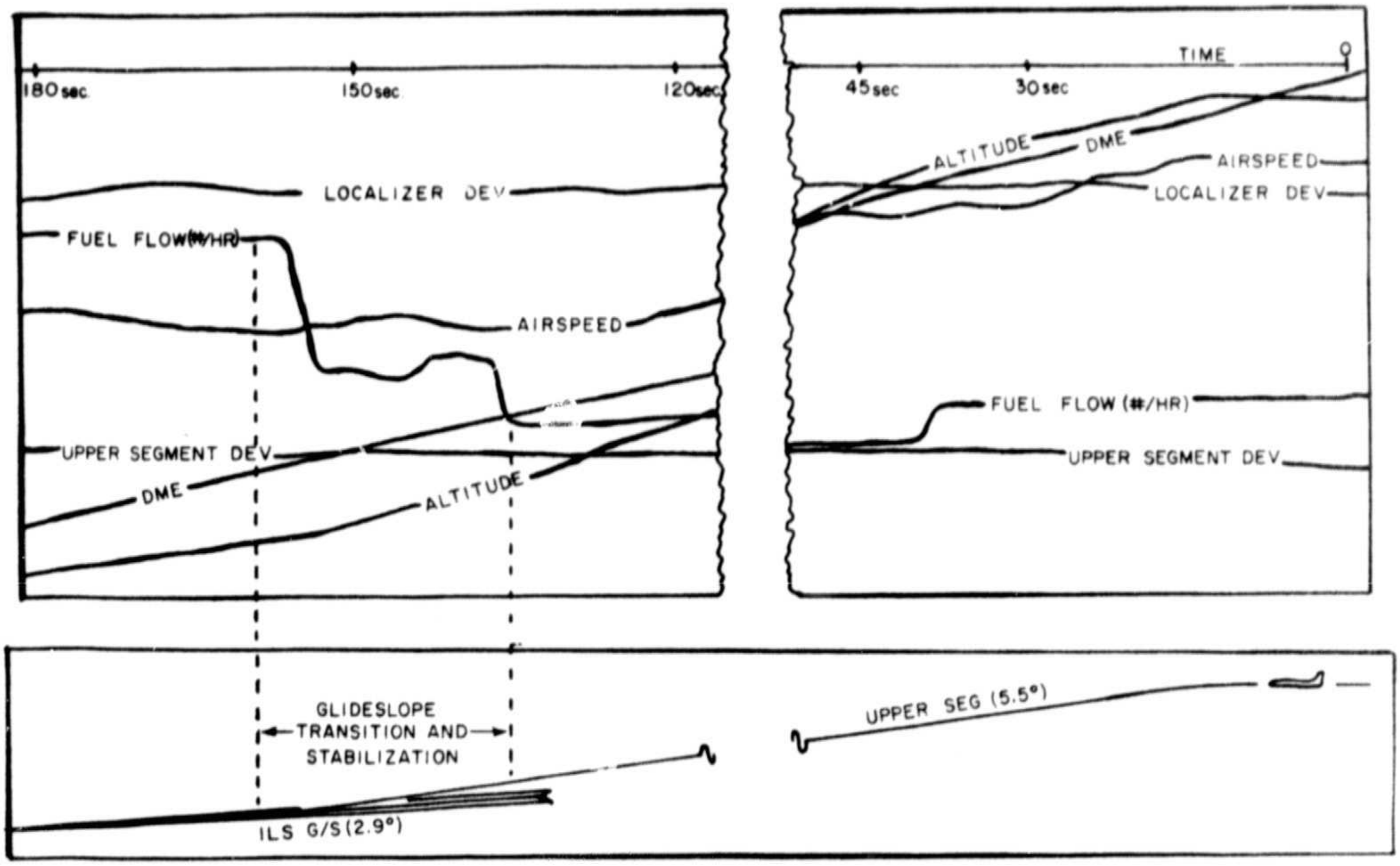



FIGURE 3.- TYPICAL OSCILLOGRAPH RECORDER TRACE
DC-8-61 Engineering Simulation Evaluation

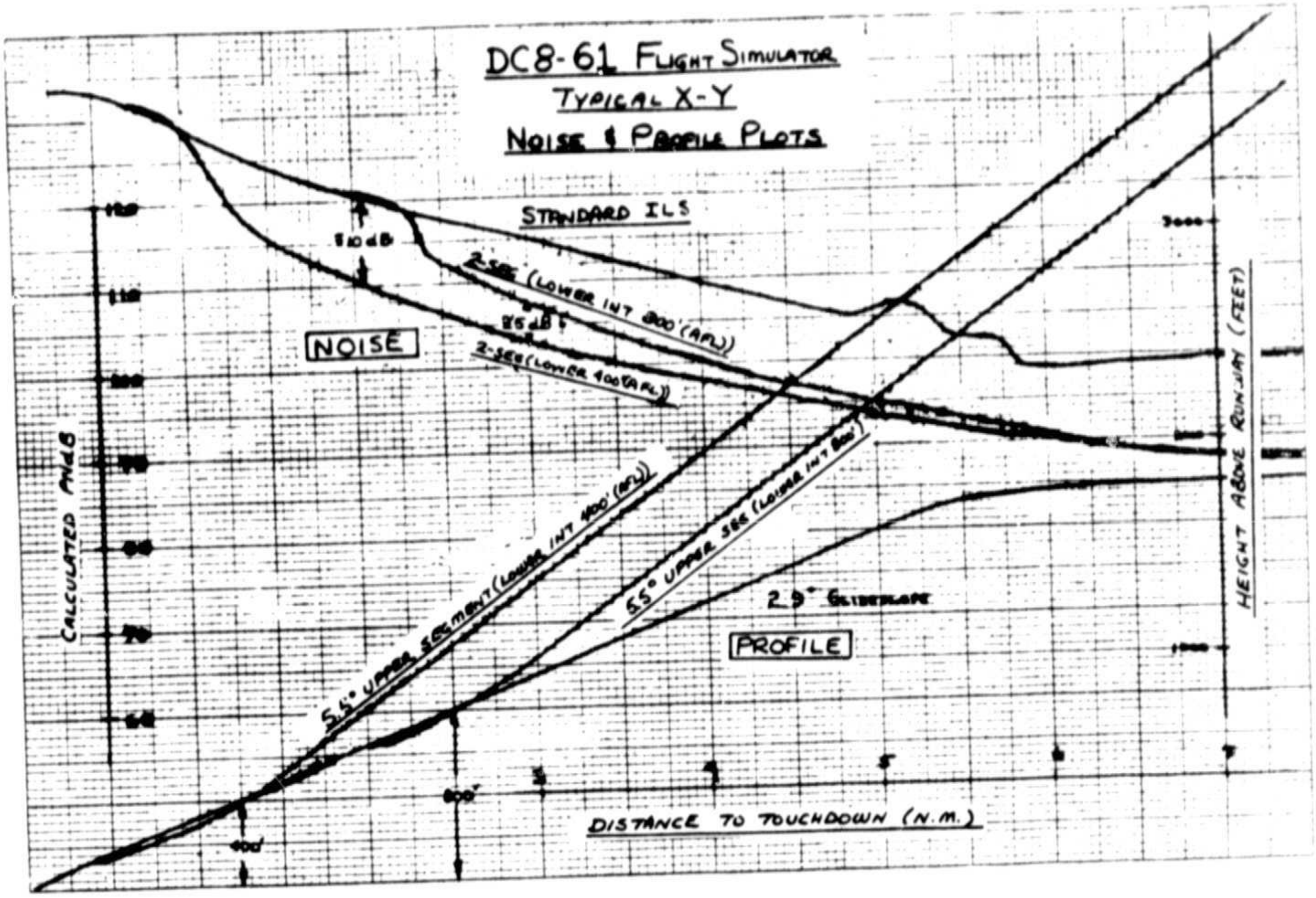



Figure 4- Typical X-Y Noise and Profile Plots
DC8-61 Engineering Simulation Evaluation

## DC-8 PROCEDURES DEVELOPMENT

The basic approach taken to develop the profile and procedures in the DC-8 program was that much that had been developed and proven in the B-727 program would require only appropriate modification to fit the differences between the two airplanes.

It was known that the principal areas in which the B-727 profile and procedures would require modification were those which were affected by the differences in the aerodynamic cleanliness and drag programming limitations of the DC-8-61. Another difference which it was felt would play an important role principally in the transitions was the pitching moment resulting from the DC-8 underslung engines as compared to the 727 engines which are much closer to the pitch axis.

The other differences were related to the use of an RNAV in the DC-8 as compared to the special-purpose system in the 727. This added two development and evaluation tasks in the DC-8 which had not been covered in the 727 program:

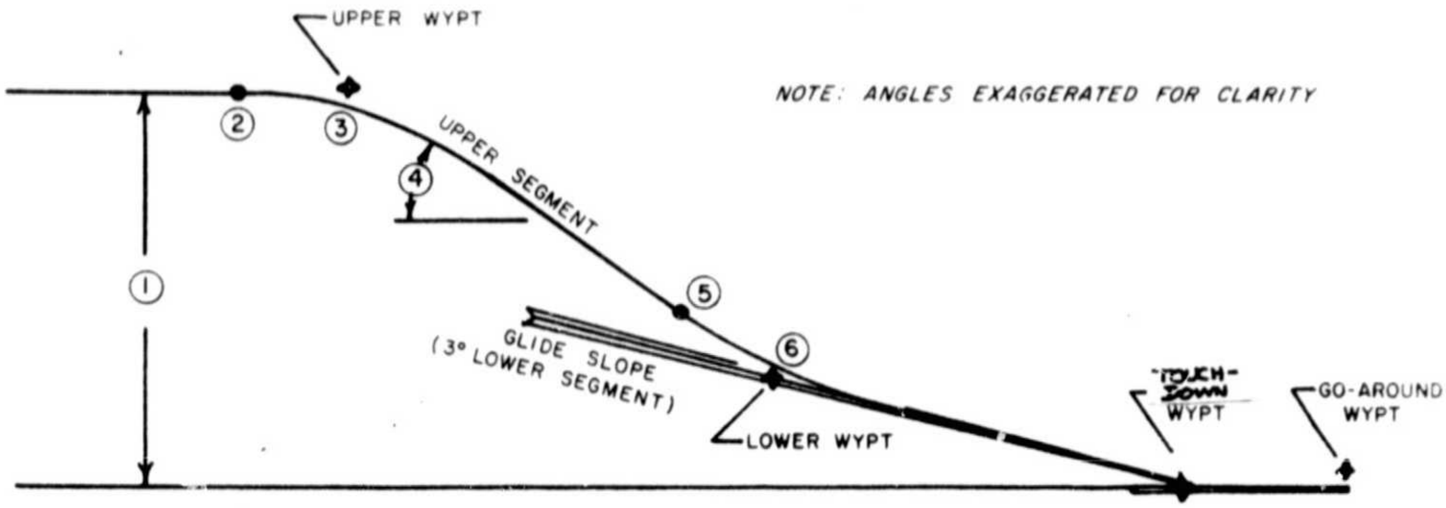
(1) Both lateral and vertical steering are provided in the RNAV system. The 727 system provided only two-segment vertical guidance.

(2) The RNAV has the capability to provide guidance to non-instrumented runways as well as ILS runways. This required the development of an approach procedure which does not include the interception and tracking of Localizer/Glideslope on the final segment of the approach.

## SIMULATION EVALUATION RESULTS

### PROFILE VARIABLES

Figure 5 shows the two-segment profile variables which were investigated in the simulation evaluation. The methods of investigation and the operational criteria that were applied in optimizing each variable are discussed in this section.




(1) INITIAL APPROACH ALTITUDE

(2) UPPER CAPTURE POINT

(3) UPPER TRANSITION

(4) UPPER SEGMENT ANGLE

(5) LOWER CAPTURE POINT

(6) LOWER TRANSITION

FIGURE 5. – SIMULATION PROFILE VARIABLES

### INITIAL APPROACH ALTITUDE

There are operational and technical considerations involved in the optimization of the initial approach altitude and in the deceleration segment which precedes upper segment capture.

The four waypoints shown in Figure 5 are all very specifically defined by position and altitude and they all have a rigid relationship to each other for any given approach. For reasons that will be discussed later, LOWER has been set at 575' AFL for all approaches. TOUCHDOWN and GO-AROUND are fixed in relationship to the runway. The position and altitude of UPPER therefore determine not only the upper segment angle, but also the length of the upper segment, the length of the approach pattern and the initial approach altitude. The only significant technical constraint that has been placed on the position of UPPER in the evaluation system is that it must be on final approach course centerline. The principal operational constraint is that the aircraft must pass UPPER within narrow lateral and vertical tolerances in order to continue the approach. UPPER altitude is therefore technically settable at any reasonable altitude. The operational criteria which were applied in defining UPPER (and therefore initial approach altitude) were:

(1) Upper segment length - The upper segment must be long enough to permit stabilization in landing configuration prior to commencing transition to lower segment or glideslope.

(2) Approach pattern length - For obvious reasons, the length of the pattern required to make an approach should be as short as safety and operational acceptability will permit.

(3) Pre-Approach ground level noise - Both the 727 and DC-8 tests show that if this maneuvering occurs at 3000' AGL or higher, ground level noise reductions approximating those shown in Figure 4 can be expected in the 5.5-6 mile from touchdown range as compared to the standard ILS or non-precision approaches that commence at about the same altitude as the ILS.

In the simulation tests it was determined that the initial approach altitude had to be 3500' AFL or higher to provide the upper segment length required to consistently stabilize in landing configuration on a 5.5 upper segment prior to commencing lower transition with an above-surface tailwind component of 15 knots. This 3500' minimum was further predicated on ideal entry conditions of flaps 15° or 25°, speed 160 knots (180 knots maximum). It was determined that if the initial approach altitude were 4000' the flexibility of the procedure in interfacing with the terminal ATC environment would be significantly increased. This extended the approach length; however, it was decided that the other advantages outweighed this slight increase. Initial approach altitude was therefore established at 4000 ± 500' AFL.

There appears to be a requirement for a pre-approach deceleration segment for the DC-8-61. Its aerodynamic cleanliness and drag programming constraints make it important that the entry conditions stated above are established prior to commencing upper segment descent. A matrix of trials was flown to establish the limits of maximum airspeed/minimum drag that the DC-8-61 could start a 5.5° descent and be stabilized at flaps 50°, speed V Ref + 5 prior to commencing lower transition. It was found that at an entry of 250 knots, the airplane could not be slowed to approach speed and configured for landing without using in-flight reversing regardless of the length of the 5.5° segment. The two tables below indicate very strongly that this deceleration segment should be level (or very nearly level) and that it needs to be 5 miles or more if deceleration from 250 kts. to acceptable entry speed is required. The operational impact of this factor will be assessed in the in-service evaluation phase of the program.

DC-8-61 LEVEL DECELERATION TIMES - VARYING GROSS WEIGHTS
(THROTTLES IDLE - CLEAN)

| GROSS WEIGHT (1000 LBS) | 250 KTS TO 200 KTS | 250 KTS TO 180 KTS | 250 KTS TO 160 KTS |
|---|---|---|---|
| 170 | 1'56" | 2'37" | 3'05" |
| 210 | 1'48" | 2'20" | 2'40" |
| 240 | 1'37" | 2'02" | 2'11" |

DC-8-61 DECELERATION TIMES WITH VARYING DESCENT RATE
(THROTTLES IDLE - CLEAN - GROSS WEIGHT 240,000 #)

| RATE OF DESCENT | 250 KTS TO 200 KTS | 250 KTS TO 180 KTS | 250 KTS TO 160 KTS |
|---|---|---|---|
| 1000'/min | Would not slow down | | |
| 800'/min | Stabilized at 240 KTS | | |
| 500'/min | 4'10" | 5'10" | 5'43" |

## UPPER CAPTURE POINT

The RNAV system in this evaluation determines the point at which Upper Segment capture commences as a function of the speed at which the airplane is approaching the UPPER waypoint. The system will not initiate the upper capture pitch maneuver unless the airplane is within narrow lateral or altitude deviation limits of the programmed position and altitude of the UPPER waypoint. This is significantly different from the B-727 special-purpose system which would capture Upper Segment at any 'AFL-DME combination that lay on the computed upper segment. The significance of the more rigid requirements in the RNAV system upon flexibility in the ATC terminal area environment will be assessed in the In-Service Evaluation phase of the program.

At this point in the two-segment approach profile the following operational annunciations and displays are provided:

Approach Progress Display - The basic amber (armed)/ green (capture) convention of the standard approach progress display was implemented in this system. The "UPPER SEGMENT" AMBER illuminates at 8 miles (via planned route) before UPPER. "UPPER SEGMENT" GREEN is illuminated at the commencement of the upper segment capture maneuver.

Vertical Deviation Bar on the HSI - At "UPPER SEGMENT" AMBER the vertical deviation bar on the HSI switches its reference from planned path to deviation from Upper Segment. As the airplane approaches upper capture, when deviation from upper segment becomes less than 2 dots (full scale) the deviation bar starts to move down toward center. This was incorporated in the system to give the pilot a configuration cue that is nearly identical to the cue he receives when approaching the glideslope in a standard ILS.

Initially the system used linear deviation in the pre-approach and upper segment tracking phases, shifting to angular for glideslope capture and tracking. It was in an attempt to optimize this linear deviation to a value that would provide an acceptable configuration cue, that the Project Pilot team concluded that linear deviation would not be operationally acceptable for this purpose. A deviation of about 400'/dot was needed to provide an acceptable configuration cue. This was too sensitive for pre-approach maneuvering and too insensitive to provide acceptable upper segment tracking accuracy. The team tried 250'/dot; however, it was found that this was too sensitive outside of about 5 n.m. and too insensitive for good lower transition tracking. To have retained the linear deviation feature would have required at least two distinct deviation changes in the course of the approach. The decision was therefore made to utilize angular deviation from UPPER AMBER onward. This resulted in near-ideal deviation gains at all of the points in the profile.

## UPPER TRANSITION

This is a high workload portion of the two-segment procedure. At 1 1/2-2 dots on the HSI vertical deviation indicator, the gear is extended. As soon as the gear is down and locked, the flaps are extended to 35°. The pitch attitude change from level to Upper Segment tracking attitude commences. To prevent the airspeed from increasing, the flaps are extended to 50° and the power is retarded and adjusted to establish $V_{ref}$ + 5, for the remainder of the approach.

The upper transition is the first point on the profile at which the pitching moment difference between the DC-8-61 and the 727 engine positions has operational significance. The power retardation required at this point tends to drop the nose. This makes it very easy for the pilot to follow the pitch commands without any significant change in control column forces.

Since the RNAV system utilizes the vertical leg-to-leg turn anticipation principle, the point at which the transition maneuver commences will vary as a function of the rate at which the airplane is approaching the UPPER waypoint. The development tasks relating to this profile variable therefore centered on optimizing the initial approach speed and configuration which would result in a manageable pilot workload in configuration scheduling and establishing stabilized speed and tracking on upper segment.

## UPPER SEGMENT ANGLE

This was one development area in which there was significant carry-over from the 727 evaluation. It was known that the aerodynamic cleanliness of the DC-8-61 would almost certainly assure that the upper segment angle could not be greater than the 6° angle used in the 727. A comprehensive matrix was developed and flown to optimize the upper segment angle. One item of note - in the DC-8, EPR is very difficult to adjust as accurately as was necessary to investigate this area correctly. Fuel flow (FF), on the other hand, is very sensitive and can be accurately set and adjusted. Fuel flow, therefore, was used throughout as the parameter for setting engine power.

| US/ANGLE | AVG FF (WINDS CALM) | AIRSPEED | AVG FF (15 KT TAILWIND) | AIRSPEED | COMMENTS |
|---|---|---|---|---|---|
| 5.0° | 2100 | Controllable | 1600 | Controllable | Easy to fly with normal technique |
| 5.2° | 2000 | " | 1500 | " | " |
| 5.5° | 1800 | " | 1350 | " | Easy to fly - must get into landing configuration as soon as on path |
| 5.7° | 1600 | " | 1200 | Difficult | Flyable - must get to landing configuration during upper transition |
| 6.0° | 1400 | Difficult | Idle 1000 | No Control | Minimum performance - must configure & close throttle during transition |
| 6.2° | 1250 | " | Idle 1000 | " | Idle thrust most of the time |
| 6.4° | Idle 1000 | No Control | Idle 1000 | No Control | Idle thrust & airspeed holds about 160 kts IAS. |

It can be seen from the above table that the 5.5° Upper Segment angle is the maximum angle which satisfies the operational acceptability constraints with a 15-knot upper segment tailwind component. Lower angles become progressively easier to fly; however the ground-level noise benefits of angles below 5° are too small to warrant use of the two-segment procedure for noise abatement. Figure 6 illustrates the approximate relative ground level noise (in calculated PNdB) for the angles shown.

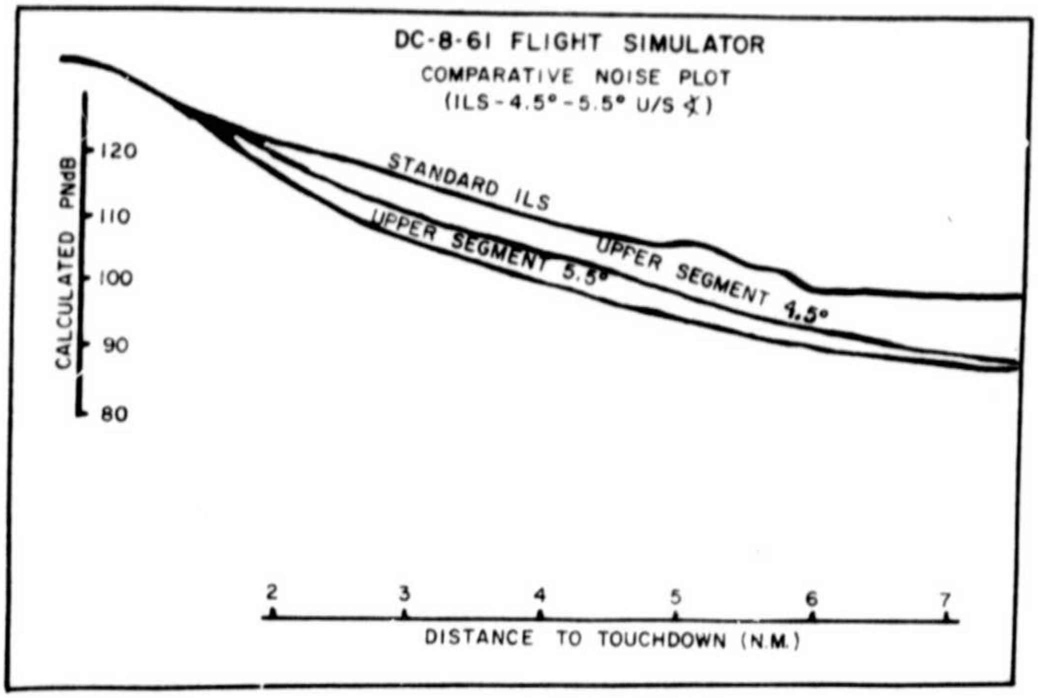



FIGURE 6.- GROUND LEVEL NOISE AS FUNCTION OF UPPER SEGMENT ANGLE

## LOWER WAYPOINT

In the RNAV system, LOWER waypoint is the lower terminus of the Upper Segment. Like the UPPER waypoint (which is the upper terminus of the Upper Segment), it is a fixed geographic point with a programmed (noneditable) altitude. It is on Glideslope (or 3° computed lower segment) center.

LOWER is an operationally critical point in the two-segment profile. It is also one of the two most influential factors in determining the noise abatement yield from any given profile.

Its operational significance stems primarily from the following:

(1) It is the point around which the RNAV system builds the lower transition and consequently determines, to a large degree, the altitude at which the lower capture maneuver commences.

(2) It is the principal determinant of the altitude at which the airplane is stabilized on glideslope. As in the 727 program, this altitude has been set at 500' AFL minimum.

Earlier, Figure 4 illustrated the significant effect which variations in LOWER have upon ground level noise. It was seen that the lower this point is, the greater the noise reductions.

The principal development task was therefore to optimize LOWER waypoint at the lowest height above touchdown that still satisfied the operational requirements for a safe and acceptable transition and stabilization on glideslope.

The decision to use one height for LOWER for all glideslope angles was to attain operational standardization in which the pilot could expect the lower transition to commence at about the same height AFL for all runways (given the same environmental conditions). It also has the effect of increasing the glideslope stabilization time on the lower angle glideslopes. The 727 evaluation indicated that this is desirable. Since LOWER is a programmed three dimensional waypoint, the RNAV system can accept the individuality of any waypoint. In the matrix which the Project Pilots flew, LOWER was varied from 200'-800' AFL. As a result of these trials, LOWER was established at 575' AFL. This was the lowest height (and therefore the most noise-beneficial) which consistently resulted in a smooth, easy transition and glideslope (lower segment) stabilization by 500' AFL.

Figure 7 illustrates the differences in the fixed upper segment position with lower intersect varying with glideslope angle and the RNAV fixed LOWER height with upper segment position varying with glideslope angle. The longitudinal displacement of upper segment between a 2.75° and 3.0° glideslope is about 1400', with the longer glideslope stabilization time being at the lower glideslope angles. The 727 system involved a longitudinal movement of the lower intersect point of about 1000' and an altitude difference of about 120' with the shorter stabilization time on the lower glideslope angles.

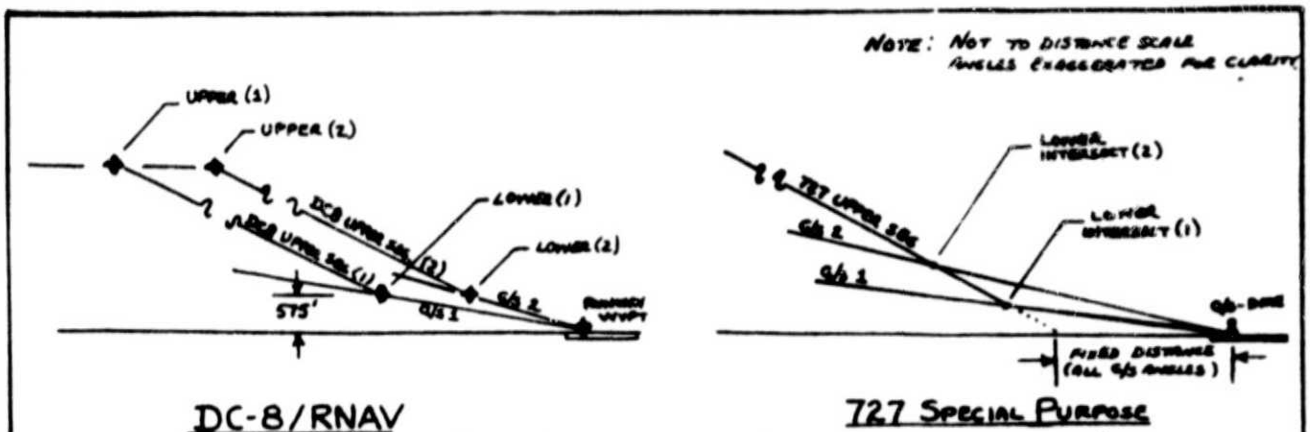



FIGURE 7- COMPARISON OF DC-8/RNAV AND 727 LOWER GEOMETRY
(FIXED LOWER WYPT HEIGHT VS FIXED UPPER SEGMENT)

GLIDESLOPE (LOWER SEGMENT) CAPTURE POINT

This is the point on the two-segment profile at which the transition from Upper Segment to ILS glideslope (or 3° Lower Segment for RNAV-RNAV) is initiated. The "LOWER SEGMENT" Approach Progress annunciator had illuminated AMBER at 5.0 n.m. from touchdown. The system had been inhibited from arming for lower capture until the 5-mile point due to the false glideslope lobe phenomena discussed in detail in the 727 Engineering Simulation Evaluation report. At the capture point, the annunciation is switched to GREEN, and the Flight Director and/or Autopilot pitch-up command starts the transition.

At this point, the vertical deviation bar in the HSI moves downward to display deviation from glideslope (or 3° Lower Segment on RNAV-RNAV). This is a momentary partial-scale excursion, and the bar immediately starts back toward center since the airplane is substantially less than 2 dots high at this point. For the remainder of the approach, this indication and the raw glideslope deviation indication on the ADI should be in agreement.

There are technical differences in the manner by which the RNAV system determines this point for RNAV-ILS and RNAV-RNAV. These differences do not have operational significance to the pilot and will therefore not be developed in this report. It suffices to say that the Lower Capture Point is determined by the rate at which the airplane is descending toward ILS glideslope center or the 3° computer-generated Lower Segment (in RNAV-RNAV). It nominally occurs at 700-850' AFL depending on Upper Segment rate of descent.

LOWER TRANSITION

There is a slight increase in pilot workload in this portion of the approach. If $V_{ref}$ + 5 has been established on Upper Segment prior to entry into the transition this increase is comparable to (or less than) that involved in intercepting the ILS glideslope from above. The transition requires only following the pitch command and the addition of power as it is needed to maintain speed. There is no lateral tracking requirement that would not also exist in the standard ILS. This is the second point at which the pitching moment from the underslung engines is beneficial in assisting the pilot to make the required pitch attitude change.

In the RNAV-ILS procedure, the transition and subsequent guidance are identical to intercepting the ILS glideslope from above except that it occurs closer in than glideslope interception from above would probably occur if the pilot were intending to make an ILS approach.

In the RNAV-RNAV procedure, two operationally significant alterations to the RNAV guidance presentation have been made:

(1) The glideslope flag is displayed in the ADI as an indication to the pilot that he is not descending to intercept a precision glideslope. In the evaluation system, it was decided that this would be accomp-

lished by the pilot's tuning his ILS receiver to an ILS frequency that was known to be out of reception range before commencing the RNAV-RNAV approach.

(2) As the airplane passes the LOWER waypoint, the autopilot is disconnected and the Flight Director command bars are biased out of view. The HSI continues to display lateral deviation from the course to go-around waypoint, vertical deviation from the computed 3° lower segment and distance to runway waypoint (touchdown point). (See Figure 5).

The principal operation criteria applied in the development of the lower transition (and the interdependent variables of LOWER waypoint altitude and lower capture point) were that the transition maneuver should require a pitch rate that is smooth and easy for the pilot to follow and that it must place the airplane on the ILS glide-slope (or 3° lower segment) center by 500' AFL.

## RNAV AND AIRPLANE COMPONENT FAILURE AND EFFECTS

The anticipated effects of the failure of any of the RNAV units or of any airplane component which provides an input to the RNAV or is a user of the RNAV system output were thoroughly analyzed before the simulation evaluation began. The RNAV system and interface were accurately emulated in software.

The Project Pilots then induced each of these failures to confirm that the effects were as expected and that none gave rise to any secondary effects which might have been overlooked in the pre-simulator analysis.

## AIRPLANE IRREGULARITIES AND EMERGENCIES

All of the airplane irregularities and emergencies which bear on the Captain's decision to select the type of approach which is appropriate for the situation were investigated in order to determine whether the two-segment approach would be intrinsically less appropriate than the standard ILS under the same conditions. The two types of problems which appear to fall into this category are those in which a malfunction prevents full flap extension or those in which the procedure calls for the selection of limited flaps.

## ENVIRONMENTAL AND AIRPLANE FACTORS

A number of environmental and airplane factors were investigated to determine whether they affected the two-segment procedure differently from the standard approach procedures.

The airplane factors which were investigated were gross weight, center of gravity and high altitude field performance. None of these appears to have any effect upon the two-segment procedure which they would not have in using any other type of procedure.

The environmental factors which were investigated were turbulence, wind she..., wind components (tail, head, cross) and icing. As suspected from the 727 investigation into these same factors, only the upper segment tailwind and icing conditions represent limitations on the use of the two-segment procedure which are different from using standard procedures under the same conditions.

## SIMILARITY TO STANDARD OPERATING PROCEDURES

In every phase of the development of two-segment approach crew procedures, a principal consideration by the Project Pilots was that a crew task should be accomplished in the same (or very similar) way that a comparable task is accomplished in the standard procedures. It was felt that there would be some additional workload resulting mainly from the requirement to make two vertical path transitions instead of one as in the standard ILS. It was also felt, however, that if this increase involved only working a bit harder at familiar tasks rather than requiring the mastery of new tasks, the procedure would be safer, and the pilot acceptance would be higher.

The main areas in which this principle was applied in crew procedures development were:

(1) Provision of a pre-approach deceleration segment which provides the opportunity to establish a speed and initial configuration which facilitates normal drag programming thereafter.

(2) Pre-UPPER configuration cues by use of the HSI vertical deviation bar and the addition of an Approach Progress Display. The HSI deviation bar movement is very similar to the presentation that the pilot sees when approaching the glideslope on a standard ILS.

(3) An upper segment of sufficient length that the pilot can establish his landing configuration and final approach airspeed before commencing the lower transition.

(4) Display of un-processed raw ILS glideslope information on his primary attitude and guidance instrument, coupled with the switching of the HSI vertical deviation bar to the same reference at the commencement of the lower transition.

(5) Approximately 2 miles of on-glideslope prior to landing. Transition requires only a small pitch attitude change (which is fully guided) and the addition of power as necessary to maintain final approach airspeed which has been previously established.

(6) Vertical and lateral Flight Director and/or autopilot guidance throughout the entire RNAV-ILS approach. Vertical and lateral guidance down to approximately 550' AFL on the non-precision RNAV-RNAV approach with continuing vertical and lateral deviation information available on the HSI.

(7) No impact on standard checklist procedures (normal or irregular).

It is obvious that the addition of an RNAV system to the airplane introduces new and unfamiliar duties in managing the system. It was a matter of importance in the operational definition of the system-pilot interface that the pilot should be able to interpret his primary instrumentation and his failure flags unreliable guidance annunciations in the same manner as he interprets them in the standard operating procedures.

## AUTOTHROTTLES

An autothrottle system was installed in the flight simulator for the purpose of evaluating whether they are operationally necessary or desirable in the two-segment procedure. The system appears to make substantially larger and more numerous power adjustments in the lower transition than the pilot makes in manually controlling his power. It appears that autothrottles will degrade the noise benefits without supplying significant pilot workload relief.

## ENGINEERING SIMULATION EVALUATION CONCLUSIONS

The maximum Upper Segment angle which is manageable in the DC-8-61 with a 15-knot Upper Segment Tailwind component is 5.5°.

Lower waypoint should be 575' AFL on glideslope (on 3° Lower Segment) center. This permits glideslope stabilization by 500' AFL.

Power required for Upper Segment tracking will probably not provide full anti-ice capability in the DC-8-61.

Pilot workload is not unacceptably high provided the airplane is slowed to 180 knots (max), flaps 25° prior to commencing Upper Segment capture.

Initial approach altitude should be 4000' ± 500' AFL to provide time to stabilize at $V_{ref} + 5$, flaps 50° on Upper Segment prior to commencement of lower transition.