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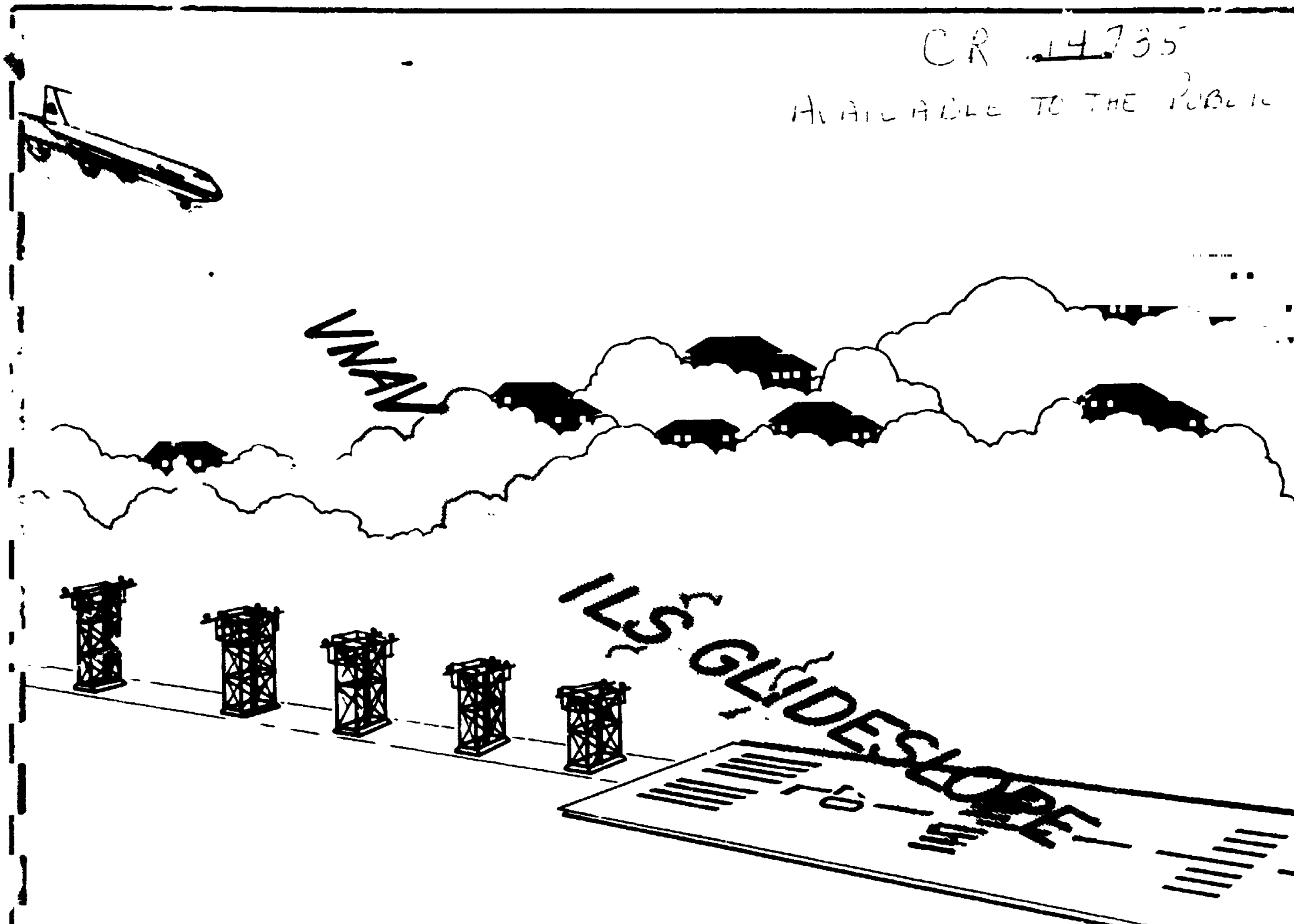

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FLIGHT EVALUATION
OF TWO-SEGMENT APPROACHES
FOR JET TRANSPORT NOISE ABATEMENT

By Robert A. Rogers, Captain Bernard Wohl,
and C. M. Gale

June 1973

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AMERICAN AIRLINES, INC.
Tulsa, Oklahoma

for

AMES RESEARCH CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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FLIGHT EVALUATION OF TWO-SEGMENT APPROACHES FOR JET TRANSPORT NOISE ABATEMENT

Robert A. Rogers, Captain Bernard Wohl, and C. Mike Gale

American Airlines, Incorporated

SUMMARY

A 75 flight-hour operational evaluation was conducted with a representative four-engine fan-jet transport in a representative airport environment. The flight instrument systems were modified to automatically provide pilots with smooth and continuous pitch steering command information during two-segment approaches.

A total of 26 guest pilots and two project pilots from most of the major airlines, FAA Flight Standards, ALPA, APA, and the NASA flew 234 two-segment approaches and 34 normal ILS approaches to evaluate the operational feasibility of the two-segment approach concept and procedure.

A large majority of the guest pilots reacted favorably to the avionics equipment and flight procedures developed by the project pilots. The evaluation configuration allowed the pilots: to fly a smooth pitch over transition from 3000 feet level flight to a 6° 3D-RNAV-generated upper segment glide slope without overshoot; and to fly a smooth pitch-up transition from a 6°glide slope to a 2.5° ILS-generated lower segment glide slope without dropping below the glide slope. The initiation altitude for transitioning to the 2.5 glide slope was set for 481 feet for the evaluation profile.

Calm, daytime, VFR weather conditions prevailed throughout the evaluation flights. The pilots unanimously agreed that a 481-foot transition initiation altitude does not induce adverse flight maneuvers and can be flown safely under VFR weather conditions.

The pilots differed in their opinions about the most desirable transition altitude for adverse weather and minimum ceiling IFR conditions.

Assuming a desire to retain present Category I and Category II weather minimums for two-segment approaches, a majority of the pilots preferred a transition altitude approximately 500 feet above the minimum weather ceiling.

There was general agreement that <u>all</u> approaches in scheduled airline service should be conducted in the same consistent manner, regardless of ceiling, visibility, wind shear, etc., to maximize flight safety. This was felt to be a necessary prerequisite for

adoption of two-segment approaches at any airport. This policy ensures that during the minimum number of times when Categories I or II weather conditions prevail, flight crews will have the experience and competence to perform these most-demanding approaches in a safe manner.

Considering adverse weather, minimum ceiling and flight crew experience criteria, a transition initiation altitude of approximately 800 feet AFL would have broadest acceptance for initiating two-segment approach procedures in scheduled service.

Independent of the transition altitude and weather minimum policies which might eventually be adopted, the pilots were in unanimous agreement that fully-coupled, lateral and vertical, autopilot capability was a prerequisite to serious consideration of two-segment approaches. They felt an autothrottle would be desirable, but not a necessity, short of a Category III autoland situation.

Measured noise reductions for the evaluation two-segment profile, when compared to a normal ILS approach with the same aircraft, are as follows:

Ground Noise Station[1]	Normal ILS	Two-Segment	Noise Reduction
1.0 nm	122.0 EPNdB	115.5 EPNdB	6.5 EPNdB
1.5	116.5	107.5	9.0
2.0	113.5	102.5	11.0
3.0	109.0	96.0	13.0
4.0	106.0	91.5	14.5
5.0	104.5	89.0	15.5
6.0	103.0	87.0	16.0

[1]On final approach centerline from runway threshold.

A more complete description of noise reductions is found in reference 6.

The 3D-RNAV data indicates that the two-segment system performed satisfactorily. It was basically a manual system since commands on the flight director were followed by tne pilot. The fully coupled ILS approaches (the conventional semi-automatic landing system) had less vertical deviation from the desired profile during most of an approach. However, during the last segment (on the glideslope), the manually flown two-segment approaches showed accuracy as good as or better than those made using the semi-automatic system.

The profile defined by the system gave an upper glidepath of approximately 6½ degrees. This was ½ degree greater than inserted into the area navigation system. The glidepath error is apparently due to an erroneous along-track, distance-to-waypoint signal resulting in the ADD computing an incorrect altitude profile. If the along-track distance-to-waypoint were correct, the vertical profile generated would have been correct.

Transition from the upper 6½ degree segment to the lower segment (2½ degree glideslope) was satisfactory. During transition the aircraft passed 13 feet underneath the ILS beam in the worst case. The geometric intercept of the two glideslopes was approximately 300 feet. Actual transition to the lower segment was initiated at about 481 feet. Pilotage errors were minimal for all types of approaches. The Stockton localizer was used for the purpose of guiding the aircraft to the runway. However, RNAV crosstrack error data was recorded.

INTRODUCTION

Background

Jet transport engine noise has become an ever-increasing concern to airport community residents, the airline industry, and related government agencies. Several complementary development efforts are underway to identify acceptable noise abatement solutions.

One noise abatement solution is centered around the engineering development of nacelle-mounted, acousitc treatment retrofit kits. This is a costly solution. It is also questionable that an economical technique can be developed and implemented for all aircraft types in a reasonable time period.

An alternate solution is centered around the development of operationally acceptable noise abatement flight procedures. Potential solutions under this heading offer several advantages over acoustic retrofit solutions. In general, flight procedure revisions are not only less costly; but, they also offer the potential of being implemented on a wide-scale basis in a relatively short time period.

The implementation of noise abatement flight procedures during take-off has already produced meaningful noise reductions. Development of noise abatement flight procedures for the final approach has been hampered by the need for a practical vertical reference path, the inadequacy of conventional cockpit guidance and display, and apprehension about the impact of higher-than-normal glide slopes on flight safety.

Previous Final Approach Noise Abatement Research

Several government-sponsored flight research programs have already been conducted to determine the merits of different types of final approach noise abatement flight procedures. The two-segment approach seemed to present the least number of operational difficulties, and to yield the most significant noise reductions.

NASA-Langley conducted simulated IFR flight tests at Wallops Island, Virginia, with six airplanes ranging in type from a Twin-engine turbojet executive transport to a four-engine turbofan commercial transport (Ref. 1, dated October 1969). Single-segment profiles from 3° to 7°, and two-segment profiles with upper segment angles of 5° to 9° were flown. All of the upper segments of the two-segment profiles were flown to a 760-foot altitude intercept of a 3° glide slope. The glide slope reference paths for all of these approach profiles were provided by a precision radar through an ILS data link.

From an operational viewpoint, the two-segment glide slope was preferred over the single-segment glide slope because of the lower vertical velocities near the ground. The NASA-Langley research pilots also considered 6° to be the maximum upper segment glide slope for adequate speed and flight path control.

NASA-Ames conducted a second series of approach noise abatement flight tests at Oakland Airport, California, with the Boeing 367-80 (707/KC-135 prototype) (Ref. 2, dated May 1970). The primary objective of this evaluation was to determine the airplane systems that would enable a pilot to fly noise abatement approaches with the precision required for weather minimums without an increase in pilot workload. Single-segment profiles from 2.65° - 6.0° were flown. Two-segment profiles with an upper segment of 6° were flown. The upper segments of the two-segment profiles were flown to 250-foot intercepts of a 2.65° ILS glide slope. Single-segment and two-segment decelerating approaches were also flown at glide slopes from 2.65° to 5°.

In the NASA-Ames tests, the conventional ILS at Oakland was used for the lower segment 2.65° glide slope; and, a radar landing approach system was used to generate the 6° upper segment glide slope.

The need to descend on a higher-than-normal glide slope during the upper segment of a two-segment approach creates several additional pilot tasks as compared to a normal approach procedure. The resulting changes in aircraft attitude and configuration cause the aircraft to behave somewhat differently. Aside from the technical feasibility of two-segment approach procedures, there is the overriding question of the typical airline pilot's ability to perform two-segment approaches without compromising flight safety in the scheduled service environment.

A common conclusion of these earlier studies was that new and/or improved flight instruments were needed for vertical guidance during the transition maneuvers. In order to minimize pilot workload, other possible cockpit provisions were identified, such as autothrottle, autotrim, and altitude hold.

Referring to the previously-mentioned NASA and FAA noise abatement research programs, several additional operational problems were identified. Some of these problems dealt with the cockpit guidance required by the pilot to transition from and to the upp segment flight path. Glide-slope tracking difficulties, leading to below-glide-slope deviations, were experienced in the upper-segment-to-lower-segment transition maneuver.

Difficulty was also experienced in acquiring the upper segment at intercept without overshooting.

The operational problem of how to provide a two segment glide slope was not addressed during the two NASA flight programs. A feasible alternative had been identified separately during a series of FAA research programs, and involved the use of conventional DME and barometric altimeter signals (Ref. 3, dated June 1967). Part of this FAA effort included the development of an on-board analog computer (known as a selective glide slope computer, SEGS) to perform the necessary vertical reference path calculations (Ref. 4, dated April 1970).

The previous NASA and FAA flight research programs dealt with several flight safety matters to some extent. Adequate engine thrust response to maintain the desired glide slope during the pitch-up transition from the upper segment to the normal ILS segment was one of the early concerns (Ref. 1). This concern is magnified by the higher-than-normal sink rates which are encountered on the upper segment. In either event, there should be no tendency for the pilot to undershoot the lower ILS glide slope segment.

Another flight safety item is an allowance in the cockpit procedure for all airline pilot types (age, experience, motivation, skill, etc.), in terms of their ability to perform the required maneuvers in a precise and repeatable manner.

Therefore, NASA-Ames established a requirement for another program that airline pilots, from as many airlines as possible, should fly and evaluate a two-segment approach procedure. It was felt that technical feasibility of the two-segment approach concept had progressed to a point where it was time to more fully assess airline pilot reaction. It was known that eventual acceptance of a two-segment approach technique would depend, to a great extent, on the collective judgment of the airline pilot community.

Test Objectives

The overall program objective was to define and implement an operational two-segment approach system. The more specific objectives of this flight evaluation were derived from the earlier noise abatement research efforts on the two-segment approach concept.

Primary Objectives
Determine the operational feasibility of:
1. Two-Segment Airline Pilot Procedures
2. Two-Segment Avionics Equipment

These primary objectives were to be accomplished by having a broad sample of airline pilots fly two-segment approaches with a representative four-engine jet transport in a representative airport environment. Their collective opinion of operational feasibility could then be used as a measure of potentital acceptability to the pilot community.

The major avionics equipment objective was the adaptation of standard airline electronic equipment for two-segment approaches with a minimum of modification. For the most part, the burden of this requirement centered around the development of an automatic scheme for providing the pilot with smooth and continuous pitch steering command information throughout the two-segment profile. The desired end result was the identification of a minimum cost control/display system modification that could be implemented by major airlines in a reasonably short time period.

Secondary Objectives
Engineering analysis of:
3. 3D-RNAV Equipment Accuracy
4. Ground Level Noise Reductions

These secondary objectives were to be accomplished by measuring: actual aircraft position throughout the two-segment approach with radar equipment positioned on the destination airport; cockpit navigation and guidance signals with an airborne data recorder; and, noise levels for normal and two-segment approaches with data recorders positioned under the final approach path. This data could then be used to establish the ability of 3D-RNAV equipment to generate the upper segment of a two-segment approach path, and to confirm noise benefits of the two-segment approach concept.

These research and development objectives represent another step toward the definition of an operationally acceptable technique. It was not expected that all operational requirements would be resolved during this program. Depending on the outcome of this feasibility evaluation, it was expected that further evaluations would be required before the two-segment approach can be seriously considered for scheduled airline service.

During the same time period, 3D-RNAV equipment was being developed by avionics manufacturers which generate vertical reference paths in somewhat the same way as the FAA-developed SEGS. A major difference involves the additional use of conventional VOR signals in the 3D-RNAV equipment to calculate both vertical and lateral light paths. Because of this feature, 3D-RNAV equipment does not require the transmitting VORTAC station to be located near the desired 3D-RNAV waypoint. Conversely, the exclusively DME-oriented SEGS requires the transmitting DME to be located at or very near the desired glide slope waypoint.

Therefore, 3D-RNAV concepts represent a potentially more flexible and practical means of generating an upper segment reference path in an airline operating environment. Evaluation of the 3D-RNAV concept represents an evolutionary extension of earlier NASA and FAA studies of veritcal reference path techniques.

Based on this earlier research, the following operational equipment requirements were posed as a minimum by NASA Ames for this program. Continuous pitch command data was to be provided to the pilot all the way from capture of the upper segment to Category I weather minimums. This guidance was to be provided on conventional flight director cockpit displays. No pilot switching or tuning should be required after commencement of the two-segment approach.

An arm and capture arrangement (similar to Flight Director capture of the standard ILS beam) was required to generate the curvilinear vertical command information the pilot needs to (1) transition from straight and level flight to the upper segment glide slope, and (2) transition from the upper segment to the normal ILS glide slope segment.

The area navigation system would be used to establish vertical guidance for the straight-line portion of the upper segment. The standard ILS glide slope signal would be automatically monitored by the flight director computer during the latter portion of the upper segment; and, when this signal reached a prescribed level, the vertical guidance command and situation displays would be automatically switched from the RNAV signal to the ILS glide slope signal. From this point to touchdown, all vertical guidance command and raw data displays would be driven by the standard ILS glide slope signal in a conventional manner.

Lateral command and situation data was to be provided in a conventional manner by the ILS localizer, and displayed throughout the two-segment profile.

The following section of this report discusses the conclusions reached for this noise abatement project. Remaining sections of the report discuss the test equipment, test procedures, and detailed results. The appendices provide more detailed descriptions of the flight director, the 3D-RNAV system, the data recording system, the tracking radar, the 3D-RNAV error models, and position error statistics.

CONCLUSIONS

Program Conclusions

This program proved that it is operationally and technically feasible to perform two-segment landings with commercial turbojet aircraft. The landing procedure developed during the program is acceptable for airline use with possible exception of the glide-slope intercept altitude and adverse weather conditions. Further study of these items is needed.

The majority opinion of the guest pilots was favorable toward the two-segment approach technique. Most were not concerned by the higher than normal sink rate. Pilots reported lower flight deck ambient noise, better visibility of the airport area, more positive flight control response, and that the pitch-up transition used to capture the ILS was mild.

Flight observers, although not fully representative of the traveling public, were asked to complete a passenger questionnaire. The passengers indicated that the two-segment approaches were less bumpy and less noisy, but steeper and faster, and had more vibration than the normal ILS approach. Also, they were less concerned about the terrain when making two-segment approaches.

It was concluded that the avionics used during this evaluation program would not be acceptable for widespread airline use. Recommendation for an operational avionics system is provided in a following section. Furthermore, the relationship between flight director parameters and profiles restricts the two-segment approach scheme to a fixed profile with present-day flight directors. It may prove necessary, in the future, to devise a method for automatic adjustment of the parameters when any one of several desired profiles is selected by the pilot.

Noise reduction, which is not a conclusion of this program, was significant, nevertheless. Centerline noise reduction varied from 1[illegible] EPNdB at 6 nautical miles to 6.5 EPNdB at 1 nautical mile from the runway threshold.

Concluding Remarks

Summary of Two-Segment Approach Advantages

. Noise abatement; considerable noise reduction (12 EPNdB at 2.2 nautical miles from landing threshold)

. Quieter onboard the aircraft; less onboard noise for the pilot and passenger.

. Above most smoke and smog in terminal area.

. Above a lot of local airport traffic

.

. Less exposure to terminal area terrain

. Much better view of airport, runway environment, and terminal area traffic

. Better capability to maintain a comfortable temperature for a longer period of time.

. Some fuel savings

. Reduced exposure to high engine temperatures during approach

. In the event of an emergency during the approach, aircraft has more going for it; e.g., more energy, more altitude, etc.

. Some ATC benefits.

. A quieter environment for people on the ground who are not living directly under the final approach flight path.

. More positive control response for airspeed management, etc.

3D-RNAV Equipment

An interesting side note to the project was the positive reaction and enthusiasm displayed by the guest pilots for area navigation concepts in general. In addition to generating an upper segment glide slope for two-segment approaches, a 3D-RNAV system offers the following additional benefits.

. Crosstrack deviation distance (helpful in detouring known areas of bad weather)

. Provides glide path information for VOR approaches and back course ILS approaches.

. Can be used to monitor an ILS approach.

. Provides both lateral and vertical guidance to non-instrumented runways.

. Backup landing aid in the event of a glide slope or localizer transmitter failure.

. Point-to-point enroute navigation (reduction in fuel costs)

. Relieves the Air Traffic Controller of some of workload (by putting more navigation back into the cockpit).

. Provide more accurate enroute navigation (allowing a reorganization of the available airspace.

Recommendations

The RNAV concept and its method of navigation must be accepted as operationally feasible and practicable before two-segment approaches using this equipment can be proposed for airline use. The airline industry needs more exposure and education in the field of 3D area navigation. A nationwide tour of an aircraft configured along the lines of the 720 used for this project would be instrumental in bringing to all the airlines and their pilots the RNAV program and its capabilities and at the same time present the operational feasibility of two-segment approaches for jet transports. A program of this nature would also provide valuable data in the areas of:

- The effects of different operational airport environments
- The effects of strong crosswind conditions
- The effects of tailwind conditions
- Approaches conducted under actual flight instrument conditions
- Further evaluation of the effects of nighttime two-segment approaches

Recommended two-segment noise abatement equipment for an operational system:

Hardware	Function
Modified FD-108 (Dual)	Pitch command throughout, and pitch-over/pitch-up guidance
ARINC MK I Area Nav or Modified B/N VAC/ADD (Single)	Upper segment vertical reference path, and reduced enroute cockpit workload
Autopilot	Fully coupled, approach, vertical and lateral control throughout
Modified Progress Display (Dual)	Two-segment profile anticipation cues
Cockpit Layout	Dual for display redundancy
CADC or 4th Altimeter	For an altitude input to the RNAV system

Hardware	Function
Altitude Hold	Positive pitch command prior to upper segment capture
Nav Receivers	A sufficient number to permit acceptable auto switching from RNAV to ILS receivers
Baro Altitude Signal	To rearm the flight director for ILS G/S capture (instead of a radio altimeter signal)
DME/VOR Receivers	Tighter calibration tolerances to minimize vertical signal oscillations

TEST EQUIPMENT

Aircraft

A representative four engine jet transport was required to provide the evaluation pilots with an operational cockpit environment. An AA Boeing 720-023B was chosen for this purpose. This aircraft is typical of the numerous 707 type, and other, four engine jet aircraft in commercial service at the present time. Except as noted below, none of the cockpit instrumentation, aircraft systems, or mechanical features were altered for this evaluation program. A photograph of the evaluation aircraft, N7545A, is shown in figure 1. It is a 109 passenger version of the standard Boeing 720 model. Maximum takeoff gross weight is 221,000 pounds, and maximum landing gross weight is 175,000 pounds.

The aircraft was fueled daily at Moffett Field, California. The aircraft normally weighed 175,000 pounds at the beginning of the sixth approach and 160,000 pounds at the end of the twelfth approach. This results in a 2000 - pound weight reduction for each approach.

The aircraft was flown during the evaluation under the standard FAA experimental certificate shown in figure 2 in order to expedite installation approval of the modified two segment avionics equipment. A copy of the FAA operating approval letter is shown in figure 3. In spite of this expediency the required avionics were installed in accordance with normal airline practice to insure compliance with evaluation program objectives. (See Avionics Section below.)

The only other exception to a normal airline configuration was the passenger cabin seating arrangement of only 34 seats. The first two rows of first class seats on the left side were removed for installation of the airborne data recording equipment. (See Airborne Data Measurement Section below.) The coach section was left vacant except for a second section divider and two rows of seats in the aft end. This was done to provide a diverse choice of seating for the flight observers. (See Passenger Evaluation Section below.) A schematic of the evaluation aircraft interior including seat numbers is shown in figure 4.

A removable 804 square centimeter radar corner reflector was mounted on the underside of the fuselage and forward of the nose landing gear during the flying in California. This was done to improve precision of the tracking radar data. It was designed for a maximum airspeed of 300 knots. A restriction placard to this effect was mounted on the pilot's flight instrument panel.

All normally required aircraft maintenance was performed by AA mechanics throughout the flight evaluation. Except for the modified avionics equipment the aircraft was maintained and operated as if the aircraft were flying in scheduled service.

Engines

Typical Pratt & Whitney Aircraft JT3D-1/3B fan jet engines were mounted on the evaluation aircraft. The 3B model engines for the AA 720s are downtrimmed to 17,000 pounds gross thrust. AA engine serial numbers with the 12th stage bleed air modification were deliberately chosen. In addition, engines with approximately 150 flight hours and 600 cycles remaining before overhaul were deliberately chosen. These deliberate choices were made in an effort to realize the worst case effects of maximum engine power extraction, and old engine power response during the upper-to-lower segment transition maneuver in the two-segment profile.

Airborne Navigation and Guidance

Flight Deck Modifications

The captain's normal B720-023B instrument panel was modified to accommodate the instruments required to implement the single system installation. The modified panel is shown in figure 5. Panel rework included replacing a Collins FD-105 with the Collins FD-108 indicators (ADI & CDI) described in appendix A.

At panel center, directly below the CDI, a three position Navigation Mode Selector Switch was installed with the following positions/legend:

POS 1 - NORMAL

POS 2 - RNAV

POS 3 - RNAV/ILS

A special Approach Progress Display Indicator was installed in the upper right-hand corner of the panel to provide annunciation in all three navigation modes, and anticipation cues for the attitude changes required to follow a two-segment profile. The Approach Progress Display is illustrated in figure 6.

Further modification of the instrument panel wiring for the two RNAV modes allowed presentation of RNAV-generated: distance to waypoint in the DME window of the CDI; magnetic "bearing to waypoint" in place of "bearing to VOR" on the No. 1 RMI needle; and vertical track deviation on the ADI raw data scales. Pitch command for the RNAV glide slope was displayed on the ADI pitch command bars. ILS roll command was displayed on the ADI roll command bars.

ILS localizer crosstrack deviation was displayed on the ADI and CDI raw data scales, and ILS glide slope vertical deviation was displayed on the CDI raw data scale throughout the two-segment RNAV/ILS mode.

The Turn and Bank Indicator at the lower left on the panel was replaced with a Lear-Siegler baro-corrected altimeter that provided dual-synchro altitude input to the vertical guidance portion of the 3D-RNAV system.

A Butler-National Symbolic Pictorial Indicator (SPI) was located in the lower right-hand section of the panel. The SPI crosspointers display RNAV-generated crosstrack deviation from the desired track and alongtrack distance to the RNAV waypoint. Magnetic heading of the desired aircraft track is set into the window at the top. Actual aircraft heading is indicated by the rotating aircraft symbol in the center of the SPI. This instrument also includes a annunciator of the crosspointer scale selected on the RNAV control panel, and a validity flag for the RNAV information displayed.

Available space in the center console allowed rearrangement for installation of the Butler-National Vector Analog Computer (VAC) control panel and Butler-National Ascent-Descent Director (ADD) control panel in an area easily accessible to the pilot for 3D-RNAV system control. The VAC/ADD control panels are described further in appendix B.

Because the evaluation required only one system for the left seat occupant, the First Officer's panel was retained in the standard Collins FD-105 configuration. The only deviation from the standard 720 configuration was installation of a second DME.

Additional circuit breakers were installed in the appropriate cockpit power panels to provide for ac and dc requirements of the following s stems:

1) Collins FD-108 Flight Guidance System

2) Butler-National 3D Area Navigation System

3) Lear-Siegler Baro-Corrected Altimeter

4) Battelle Airborne Data Recorder System

RNAV to Flight Director Interface

Below beam flight director capture of the upper segment RNAV glide slope is initiated by a discrete 28V dc signal from the ADD portion of the RNAV system. The ADD had an adjustable feature for setting the RNAV glide slope altitude deviation where this discrete signal would occur. Bench test adjustments were possible over an altitude deviation range of 60 to 600 feet through a 20-turn potentiometer in the ADD computer.

Approach Progress Display

A standard indicator light assembly (utilized by American Airlines as the approach progress display indicator on the CAT II Boeing 727-023 fleet) was modified to indicate the unusual sequence of the two-segment approach. This adaptation was facilitated by the structure of the assembly which is four dual lamp (AMBER or GREEN) sections in a vertical row with individual legend caps for each section. Legend caps were rearranged and engraved to present an appropriate progress sequence and nomenclature. The display and legend with remarks pertinent to the approach status are illustrated in figure 6.

Electronic Compartment Requirements

Major avionics equipment units include the following:

Flight Director System	3D-RNAV System
FD-108 Steering Computer	Vector Analog Computer (VAC)
FD-108 Instrument Amplifier	Ascent/Descent Director Computer (ADD)
	VAC Switching Unit

These units are described further in appendix A and appendix B.

The installed FD-108 Instrument Amplifier, Vector Analog Computer, and VAC Switching Unit were unmodified standard vendor configurations. The Collins FD-108 Steering Computer and the Butler-National Ascent-Descent Director Computer required modifications at the vendors' facilities. These modifications are discussed in detail below.

These units were mounted on a shelf fabricated by American Airlines and installed in an area immediately forward of the rose wheel well. This location afforded convenient access through the nose compartment hatch. An area was also required for the extensive interface and switching requirements of the program. This area was limited in space, and miniature terminal blocks were required to accommodate the numerous termination. Mode selection signal switching and the segment information switching was accomplished by relays mounted in the same area. Equipment location on the shelf is illustrated in figure 7.

The vertical track deviation information of the RNAV system required several scale and sensitivity adjustments during the project pilot portion of the flight program. The final scale sensitivities are shown in figure 50 and were flown by all the guest pilots.

A second DME Interrogator was also installed in the existing provisions on the right hand radio rack in the electronics equipment compartment. The antenna for this system was located on an existing mount provision at the top of the cockpit. The second DME system is not required for thi application, but is valuable in providing a cross-check on the validity of the Captain's RNAV-generated distance to waypoint information.

Flight Director Variables

As previously noted, American Airlines engaged Collins Radio to assist in development of the flight director modifications for two-segment approaches. During initial sessions with Collins, it was established that very little was known about the flight dynamics of large aircraft during two-segment approaches. Therefore, all adjustable parameters in the pitch steering computer were to be easily changed by external means. The intent was to allow optimization of the value of pitch-down bias in the pitch command signal at interception of the RNAV glideslope, and the deviation level for initiating pitch-up capture of the ILS glide slope. This optimization started during the flight simulator work at American's Greater Southwest (GSW) facility, and was completed after the first week at Stockton flying.

One Collins FD-108 steering computer was modified to allow external resistance changes through two decade resistor boxes. The decade boxes allowed changes over the parameter ranges shown in figure 51. The resistance decades were installed in the aft floor of the cockpit and wired to the pitch steering computer, allowing airborne adjustment between approaches. This configuration was retained throughout the program due to the flexibility available for profiles other than the baseline.

Adequate adjustment for a variety of profiles was accomplished with the decade boxes. The baseline profile (6^{o} to 400 ft) required a 10^{o} pitch-down bias at upper segment intercept and a 150 μa deviation for initiation of the meter changes; the same 6^{o} upper segment intercept of the ILS glide slope at 800 feet required a reduction in deviation to approximately 75 μa. Upper segment glide slope angle variations required changes in the pitch-down bias in direct proportion to the descent angle selection. The deviations to initiate capture of ILS glide slope from above the beam centerline may be roughly stated as inversely proportional to the intercept altitude.

Vendor Equipment Modifications

Collins Radio Company, assisted by the AA Avionics Engineering staff, developed a modification to the standard AA FD-108 Steering Computer, P/N 522-3121-195, that would accomplish the peculiar requirements of this program.

A summary of the modification package for the steering computer is as follows:

(1) Revise "G/S Capture" function to allow approach from above ILS glide slope beam center. Include a prevision for decade box adjustment of pitch-up capture initiation at any deviation above the ILS G/S centerline between 50 and 200 microamperes.

(2) Provide for utilization of the Ascent-Descent Director (ADD) vertical deviation output (ac voltage) as an altitude error signal to the Altitude Hold section of the FD-108 steering computer.

(3) Implement a method for presentation of command guidance information during the curved transition from level flight to the upper-segment glide shown. Include a provision for decade box adjustments of pitch over command authority between 1^{o} and 12^{o}.

The Butler-National Ascent-Descent Director, P/N 001021-101, required the following modifications:

(1) Convert the A/P-FD vertical deviation output to alternating current signal in same form as an altitude error signal from the air data system.

(2) Modify the altitude warning circuit to present a 28V dc discrete signal prior to intersection with the upper segment RNAV glide slope. Trip point for this signal to be adjustable during bench calibration between 60 and 600 feet vertical distance from the upper segment RNAV glide slope.

(3) During the flight test phase at Tulsa, an additional modification to the system was necessary to prevent fluctuations in the vertical track deviation output--reflected in both the vertical raw data and pitch steering command presentation on the ADI during upper segment glide slope tracking. Exhaustive testing finally isolated the source of fluctuation to the aircraft structure ground potential variations (i.e. noisy ground) coupled through grounded reference amplifiers in the vertical track deviation computer section. The reference for the amplifiers was changed from ground potential to a regulated 10V dc bus effectively eliminating the perceptible vertical track deviation fluctuation.

Flight Instrument Switching

Signal interfaces for this installation produced an unusual information switching situation. A simplified single line diagram of the signal interfaces and switching logic is shown in figure 8.

Navigation mode is manually selected by the pilot in the cockpit by means of the Navigation Mode Selector (a three-position rotary switch). With reference to figure 8, the alternate positions of the mode selector switch are as follows:

NORMAL Mode: All relays de-energized. All raw data and instrument sources routed through normal-closed contacts of relays as in standard aircraft configuration. No. 1 NAV receiver and DME information are primary signals available to autopilot (A/P), flight director, and cockpit displays.

RNAV Mode: Relays K2 and K1 (K4 de-energized) are actuated; all information displayed and routed to A/P and Steering Computer are outputs of the RNAV VAC and ADD units.

RNAV/ILS Mode: Relays K3 and K1 (K4 not grounded) are energized. Localizer crosstrack deviation information is distributed from the VOR/LOC output of the No. 2 NAV receiver, and vertical track deviation from the ADD is utilized for upper segment presentations and computations, except G/S deviation from No. 2 NAV receiver is maintained on the CDI vertical deviation raw data needle. This feature allows continuous monitoring of aircraft displacement from ILS G/S centerline throughout the two-segment maneuver.

At the position that G/S deviation (above beam) has decreased to the appropriate level to initiate G/S CAPTURE computations for the ILS G/S track portion of the approach relay K4 is grounded by the Steering Computer logic. K1 is de-energized to return all cockpit display and guidance information to the No. 2 NAV receiver.

The No. 1 NAV receiver must be tuned to a VOR station and furnishing VOR/DME to RNAV until the upper segment has been completed. No. 2 NAV receiver furnishes LOC and G/S information throughout the two-segment approach.

Operation During Two-Segment Approach

The three discrete phases of the two-segment profile, and the corresponding Approach Progress Display Indication sequence are illustrated in figure 9. Phase (1), ENROUTE 3D-RNAV, represents selection of the "pure" RNAV mode prior to start of the approach. See figure 10 for signal interfaces during Phase (1). During the final portion of Phase (1), cockpit preparation includes tuning NAV #1 receiver to the final approach VORTAC and establishing an upper segment RNAV glide slope waypoint (VOR bearing and DME distance selection on the VAC Control Panel) on the runway centerline. In addition, NAV #2 receiver is tuned to the local ILS frequency.

The ADD is programmed for the desired descent angle by selection of angle set on the ADD Control Panel. At approximately 10 nautical miles from waypoint (distance to waypoint is being displayed in DME window of the CDI), the pilot rotates the NAV Mode Selector from the RNAV position to the RNAV/ILS position to initiate Phase (2) of the two-segment approach.

Phase (2), 3D-RNAV/LOC MIX, allows all lateral control and guidance to be presented from the No. 2 NAV LOC deviation. See figure 11 for signal interfaces during Phase (2). The ADI roll steering command will track the localizer and/or the autopilot may be engaged in the VOR/LOC mode. LOC raw data deviation will be displayed on the ADI and CDI. Simultaneously the vertical raw data has been divided between ILS G/S raw data on the CDI and RNAV vertical track deviation on the ADI.

The pitch steering signal is maintained at zero until the following events occur: When the aircraft reaches a prescribed vertical distance between the aircraft and the upper segment RNAV glide slope centerline a 28V dc discrete signal from the

ADD is applied to the steering computer. This signal activates the pitch command bars, the Altitude Hold mode on the Flight Director, and inserts a 15-second wash-out pitch-down bias concurrently. This method allows an asymptotic capture of the upper segment centerline.

The aircraft then proceeds down the RNAV-generated upper segment glide slope in pure altitude hold operation. The error signals are produced by deviation from the upper segment glide slope as computed in the ADD. During the latter portion of Phase (2), the 1000-foot trip of the radio altimeter provides the discrete signal to rearm the Flight Director for ILS G/S capture from above. This interface was confirmed to be unsatisfactory at 1500 feet due to inadvertent captures of spurious glide slope transmitter lobes.

The transition between Phase (2) and Phase (3), NORMAL ILS G/S - LOC, is initiated when the Steering Comp senses the decay of ILS glide slope deviation to a presc "Fly-down" level. See figure 12 for signal interfaces ng Phase (3). This phase is not a standard presentation. it is different only in the sense that G/S and LOC information are being furnished to the captain's instruments and flight controls from the No. 2 NAV receiver.

At initiation of Phase (3), the Altitude Hold mode on the Flight Director is disabled and the Glide Slope "capture from above" information is furnished to the Steering Command bars. This "capture from above" scheme utilizes a method similar to the upper segment capture. A pitch-up bias with 15-second wash-out is inserted with pitch attitude and glide-slope deviation to allow asymptotic departure from the upper segment RNAV glide slope and gradual descent to the ILS glide-slope. The circuitry was designed to prevent abrupt steering commands and does not allow the trajectory to fall below the ILS glide-slope centerline.

<u>Autopilot System</u>

The auto-flight control system aboard N7545 was a standard Bendix PB20-D series system. Interface between the A/P and RNAV systems was limited to the enroute RNAV mode only and restricted to a lateral crosstrack deviation input. This input allowed the autopilot to follow the desired track between waypoints, processing crosstrack deviation in the same manner as a VOR deviation signal during cruise conditions.

No pitch deviation information was furnished to the autopilot from the RNAV system during this program. This is not to say that a pitch control system could not be devised th t would capture and track RNAV vertical track deviation, but provision of this capability was beyond the scope of this program. Inasmuch as the concept for transition from level flight to 6° glide sclopes, and 6° to 3° glide slopes was satisfactorily developed for a flight director pitch steering signal, it follows that equivalent results can be achieved for autopilot pitch steering signals.

When the RNAV Mode Selector is placed in the RNAV/ILS position, a special interface allows the autopilot to capture and track the localizer information of the No. 2 navigation receiver.

Data Acquisition

Airborne

Navigation and Guidance Signals

Battelle-Columbus Laboratories provided an electronic signal conditioner/amplifier unit which permitted the following cockpit display signals to be recorded on a NASA-provided Sangamo analog tape recorder.

Recorder Channel		Cockpit Display
(1)	Synchronized Time Code	-
(2)	Cockpit Flight Recorder Voice	-
(3)	Received VOR Bearing	RMDI
(4)	Received DME Distance	Capt's DME
(6)	Barometric Altitude (Input to Vertical RNAV)	LSI Altimeter
(7)	RNAV Distance to Waypoint	SPI
(8)	RNAV Bearing to Waypoint	RMDI
(9)	RNAV Vertical Deviation (RNAV glide slope raw data)	ADI
(10)	RNAV Lateral Deviation (raw data)	SPI
(11)	ILS Vertical Deviation (ILS glide slope raw data)	CDI (and ADI)
(12)	ILS Laterial Deviation (ILS localizer raw data)	ADI and CDI

(13) Pitch Command (RNAV G/S and ILS G/S) ADI

(14) Roll Command (ILS localizer) ADI

A detailed description of the Battelle signal conditioner equipment is included in appendix C. A photograph of the installed equipment is shown in figure 25.

Flight Deck Photorecorder

A Giannini Scientific Corporation 35mm camera was hard-mounted in the flight deck aisle immediately behind the Flight Engineer's seat. Plus X #4231 film was used in combination with a 40 mm Makro Kilar f/2.8 lens. Photographs were taken once a second. The field of view is illustrated in figure 13.

Ground

A portable Bell-Aerospace EEM Radar System was positioned adjacent to the Stockton ILS Glide Slope Transmitter and used to obtain three-dimensional aircraft position data and two-dimensional data plots of the vertical flight path. (See appendix D for equipment details.) The three dimensional analog data were recorded on magnetic tape. A typical radar plot is shown in figure 14.

It was found that use of along track slant range distance on the two dimensional data plots would introduce an error of less than 0.5 EPNdB in final approach noise data. This insignificant error results from considerations of the small difference between horizontal distance at the time of PNLT max and slant range distance at the time of PNLT max.

Acoustic Equipment

A total of nine different sites were used during the three weeks of noise measurement. No more than six sites were used at any one time. The nine site locations are illustrated in figure 26. The primary sites, 1 through 6, were located on the extended runway centerline, directly below the final approach path to runway 29 to Stockton. Distances to threshold ranged from 5550 feet to 36,420 feet. The secondary sites, 7, 8, and 9 were sideline locations used during the last two days of the third week. All sites were located using geological survey maps. The terrain was typically flat farm land.

Acoustic data was acquired using six battery operated, remote controlled, portable acquisition systems. A block diagram of the systems used is shown in figure 15. Each system utilizes a two channel analog tape recorder. One channel records acoustic data; the other channel records an IRIG B time signal. The time is broadcast over an FM radio link at 162.275 mHz. The time signal is a 1 kHz modulated carrier. The received time signal serves two functions. First it provides a common recorded time base for all six systems and secondly, the 1 kHz carrier operates a tape motion controller built by Hydrospace.

Roving field technicians check system operation, tape supply and administer a single frequency tone calibration once an hour. Each system was calibrated electrically once a week. A typical system frequency response is shown in figure 16. The high frequency preemphasis is removed during processing but provides a better signal for analog recording. It compensates for high frequency sound attenuation due to the atmosphere.

Microphone windscreens were used at all times. This insures against acoustic distortion for wind speeds up to 18 knots (21 mph).

Meteorological Equipment

Hourly weather data was collected at three different locations during the time the test aircraft was in the Stockton vicinity. Temperature (^{o}F), Humidity (%), Wind speed (mph), and Wind Direction (Relative to True North) were recorded at the central noise measurement van approximately 2 ½ nm to threshold. Temperature was recorded at 33 feet above the ground using an asperated wind vane. A Cambridge System Hygrometer unit was used to obtain dewpoint temperature. This was located at 20 feet above the ground. Wind speed and direction were recorded at 33 feet above the ground.

Two additional sites were used to verify nominal temperature and wind speed conditions in the measurement area. These parameters were measured at only five (5) feet above the ground.

Time Synchronization

A synchronized time signal was needed to correlate recorded ground radar data with ground noise data, airborne 3D-RNAV data, and airborne engine instrument data. This common time code signal was generated by a Datatron time code generator which was synchronized each day with WWV. The time signal contained hour, minute, and second information. The time code generator was located in the central noise measurement van near Site 3. The signal was transmitted IRIG B, modulated at 1000 Hz over 162.275 mHz, with a General Electric 30 watt FM transmitter. This signal was received at the six (6) noise measurement stations, the ground radar van, and the aircraft on Peterson HL-100 FM receiver.

The radar operator gave a "mark" at the first time pulse on his plots. The Hyrospace noise van operator recorded the time of this pulse. The accuracy is within 0.5 seconds. The radar plot then produced one pulse every 15 seconds during the flight. This "mark" and the subsequent pulses allowed Hydrospace to correlate the aircraft track to a common time base.

The received aircraft signal was synchronized with a passenger-cabin mounted Datatron time code translator. This synchronized signal was then recorded with the other airborne data.

Communication Links

The communication network at Stockton Airport is illustrated in figure 17. The prime communication link between the aircraft and the ground data personnel was a two way frequency of 123.3 mHz between the AA Flight Engineer and the ground radar operator. In addition, the Hydrospace noise measurement personnel monitored 123.3 mHz and the tower frequency of 120.3 mHz. A two way citizen band was used for communication between the radar operator and the noise measurement personnel. The FM timing RF link was also used on occasion by the noise measurement personnel to talk with the radar operator and the airborne data equipment operator.

Airport And Local Navigation Facilities

The Stockton Municipal Airport, Stockton, California, was chosen as the test site for the guest pilot evaluations. A layout of the Stockton Airport environment is shown in figure 18. The two-segment approach chart approved by the FAA for this evaluation is shown in figure 19. Normal IFR minimums were retained in spite of the 6^{o}/400 ft two-segment profile flown. This airport is in normal use as a commercial terminal and is representative of a standard ILS/VORTAC environment. It is maintained as a Category II training facility. The flat rural terrain around the airport also provided suitable noise measurement site locations under the final approach flight path to Runway 29R.

The particular significance of this airport environment is the orientation of the Stockton VORTAC relative to the ILS-equipped runway. The 3D-RNAV system needed to generate the upper segment glide slope utilizes conventional VOR/DME signals. The upper segment flight path of a two-segment approach at Stockton passes within 1 nautical mile at a point approximately half way down the upper segment. An unsuccessful attempt was made to use the Linden VORTAC which is 15.5 nm from the middle marker. The cause of this problem was not determined during the program.

TEST PROCEDURES

Pilot Evaluation

The operational portion of the test program consisted of four sequencial phases. Each phase formed the groundwork for succeeding phases. The sequence concluded with the selection of one two-segment profile and one two-segment cockpit procedure which the invited guest pilots were required to fly during their evaluations.

Profile Selection

Profile selection started with American Airlines project pilot test flying at the American Airlines Maintenance & Engineering Center in Tulsa, Oklahoma. This flying was intended primarily for calibration and checkout of the newly installed avionics modifications. However, this flying also provided the opportunity to investigate many two-segment profiles with the Tulsa VORTAC. Various combinations of the following profile variables were flown during 23 hours of Tulsa flight testing:

(1) Altitude intercept of upper RNAV segment: 2000 ft, 2500 ft, 3000 ft.

(2) Upper segment angle: 5^{o}, 6^{o}.

(3) Altitude intercept of lower ILS segment: 400 ft, 600 ft, 700 ft, 800 ft.

The AA project pilot flew a total of 48 two-segment approaches in Tulsa. During this time, flight director and RNAV equipment variables were also adjusted in an effort to establish an optimum interface between the avionics equipment, profile variables, and pilot workload.

The first week of flying at Stockton, California was performed by the NASA project pilot. A lesser number of profiles were flown during this period and included the following:

Profile	VORTAC
3000 ft/6^{o}/400 ft/2.5^{o}	Stockton and Linden
2500 ft/6^{o}/400 ft/2.5^{o}	Stockton
3000 ft/6^{o}/700 ft/2.5^{o}	Stockton
3000 ft/6^{o}/800 ft/2.5^{o}	Stockton
3000 ft/5^{o}/400 ft/2.5^{o}	Stockton

The NASA project pilot flew a total of 35 two-segment approaches during this period. While this flight experience was being accumulated, final adjustments were made in the avionics equipment variables which interact with profile variables and pilot workload.

Procedure Development

Procedure development started with the AA project pilot flying a 707 simulator at AA's Flight Academy in Fort Worth, Texas. Time did not permit installation of a modified Collins FD-108 steering computer in the 707 simulator. However, approximately 25 hours were spent in AA's standard 707 simulator to investigate general aircraft performance, and its impact on cockpit procedures for the two-segment profiles noted above. This initial simulator time was flown using raw data for guidance to an ILS-generated upper segment.

When the modified Collins FD-108 steering computer became available, it was installed in a 727 simulator. This permitted further investigation of pilot procedures in terms of command guidance to an artificially-created RNAV upper segment. The AA project pilot spent another 25 hours with this configuration and repeated most of the two-segment profiles flown in the 707 simulator.

The next step in the investigation of pilot procedures was undertaken in Tulsa during the initial 23 hours of flight testing. The earlier simulator work was applied and further refinements were made in the pilot procedures to account for actual flight conditions. These procedures were then used by the NASA project pilot during the first ten hours of flight testing at Stockton, California.

At the conclusion of this Stockton flying, the AA and NASA project pilots made a final selection of the one two-segment profile and pilot procedure they judged to be the most feasible from an airline operational viewpoint. This included a final determination of values for the interacting avionics equipment variables. The intent was to have each subsequent guest pilot fly and evaluate this particular profile and procedure.

Guest Pilot Selection and Training

Invitation letters were sent to senior flight management personnel in most of the 707-equipped U.S. airlines. The invitation list also included the major airline pilot associations, the FAA, and NASA research pilots other than the designated NASA project pilot. Each airline and agency was requested to designate one or more pilots as subjects for the flight evaluation. A total list of guest pilots, including airline or agency, are listed in figure 20 and figure 21.

The initial guest pilot prerequisite was that he be currently qualified in a 707-type aircraft. A currently qualified 707 pilot would be less affected by unfamiliarity with the basic aircraft. He would therefore be more relaxed and be able to more readily observe and evaluate the unusual aspects of a two-segment approach technique. However, this criteria was later relaxed. As the guest pilot evaluation progressed, several pilots who had little or no 707 experience were allowed to fly as subjects.

A typical routine for most of the guest pilots started the day before they flew. A formal two-hour briefing was conducted at Moffett Field by the AA project pilot. The briefing included the general background and purposes of the evaluation, avionics system operation, cockpit layout, two-segment approach pilot procedures, and 3D-RNAV route procedures between Moffett Field and Stockton Airport. This verbal briefing was accompanied by handout material for further study.

The aircraft departed from Moffett Field early the next morning with the guest pilot flying in the left-hand seat and the AA project pilot flying as copilot in command. Early morning flights were typically scheduled for noise data measurement purposes. The aircraft fuel loading at Moffett was such that the aircraft would be at a maximum gross landing weight of 175,000 pounds at the end of the five two-segment approaches at Stockton. This was also done for the convenience of noise data measurements.

The typical guest pilot flight plan called for him to fly from Moffett to Stockton over an RNAV airway, specially developed and approved by the FAA for this program. Upon arrival at Stockton, the typical guest pilot proceeded to fly five of the pre-established two-segment approaches to gain familiarity with the flight procedures.

During the first two practice approaches, the autopilot was coupled to the localizer. The guest pilot used his right hand to control the manual autopilot pitch wheel while the AA project pilot controlled the throttles from the copilot's seat. The third practice approach was completely manual with the subject pilot controlling attitude and power himself. The fourth practice approach was a manual "hooded" approach. The fifth, and last, practice approach was used by the guest pilot to investigate command guidance response to intentional deviations from the desired flight path. A pull-out was executed just prior to touchdown during these practice approaches to conserve evaluation flight time.

Guest Pilot Evaluation

Having thus completed his practice approaches, the guest pilot proceeded to fly five two-segment approaches for data record purposes. Five approaches were required to give the guest pilot a realistic exposure after his practice runs, and to satisfy noise measurement sampling criteria. These five approaches were flown in the same way as the first two approaches in the practice sequence.

A pull-out was also executed just prior to touchdown during most of these approaches. However, the guest pilot was typically allowed to execute at least one touch-and-go, or one full landing. After the complete sequence of two-segment approaches, the guest pilot was typically required to finish with two normal ILS approaches. This permitted an immediate comparison of reactions between the two-segment approach and the normal approach. This also yielded normal approach noise data which could be compared to the immediately preceding two-segment noise data.

A pilot debriefing was held at Moffett Field immediately following each flight. The guest pilot was asked to critique his reactions to the flight. Particular emphasis was placed on his reactions to the two-segment approach profile and procedure as flown. He was also asked to comment on the potential need for modifications and refinements to this pre-established technique. A standard questionnaire was given to each guest pilot at the end of his briefing. He was asked to return it at his own convenience. A copy of the Pilot Questionnaire is shown in figure 22.

The above-stated training/evaluation sequence was developed as the routine for guest pilots who were designated as primary subjects. The evaluation approaches flown by the twelve primary guest pilots are shown in the right-hand column of figure 20. Fourteen additional guest pilots were also able to fly to a lesser extent during the evaluation. These secondary pilot subjects are shown in figure 21. These secondary pilots were not necessarily present at the preflight breifings, but they often had the opportunity to observe a primary guest pilot from the cockpit jump seat before taking their turn in the left-hand pilot's seat. All of them were present during the debriefings. They were also asked to comment on the two-segment approach procedure and complete a pilot questionnaire.

<u>Passenger Evaluation</u>

Flight observers from the aviation industry were invited on the evaluation flights from time to time. They were allowed to observe guest pilot procedures from the cockpit to a limited extent. However, they spent most of their time in the conventional passenger seats provided in the cabin. This circumstance created an unintended opportunity to assess cabin passenger reaction to the two-segment approach technique. Although this was not among the NASA-defined test objectives, AA considered this to be a significant operational concern.

The Marketing Department at American Airlines worked with the American Project Team to develop a passenger questionnaire which could be used to identify areas of concern to the typical passenger. A copy of the passenger questionnaire is shown in figure 23. Only one questionnaire was developed, but it was designed for two-segment and normal approaches.

The typical sampling procedure required each observer to fill out three separate questionnaires. They were asked to fill out the first two questionnaires immediately following any two of the sixth through the tenth approaches in the two-segment flight sequence. It was not appropriate to obtain observer opinion during the first five practice two-segment approaches. The sixth through tenth two-segment approaches were more representative of what a typical passenger would experience in scheduled airline service.

Referring to figure 4, the observer was asked to sit in one of the forward first-class seats for one of the two-segment questionnaires, and to sit in one of the aft coach seats for his other two-segment questionnaire. This was done to permit an analysis of differences in response between cabin seat location.

The observers were asked to fill out the remaining questionnaire immediately following one of the two normal ILS approaches at the end of the guest pilot routine. These were typically flown after completion of the ten two-segment approaches. The observer was asked to sit in either the first-class section or the coach section at his discretion. A photograph of the aft coach seats is shown in figure 24.

Data Measurement/Processing Procedures

3D-RNAV Position Measurements/Processing

Major characteristics of the vertical and lateral position error models are illustrated in figures 27 and 28. A glossary of terms is shown in figures 29 and 30.

Some of the practical constraints which influenced design of the mathematical models included:

(1) The cockpit display signals which could be recorded by the airborne data recorder.

(2) Characteristics of the high precision tracking radar

measurements of actual aircraft position.

(3) Parameter and indicator sensitivities.

A computer program for the models was written in FORTRAN IV language by Battelle. Data required for the models are listed in figure 31.

The on-board and ground radar analog tapes were converted to a digital format by Battelle before input to the CDC 6400 computer. For two-segment approaches, the data were analyzed at 0.2 nautical mile intervals from touchdown out to 6.4 nautical miles from touchdown. Normal ILS approach data were analyzed at 0.4 nautical mile intervals from touchdown out of 5.4 nautical miles from touchdown. In each case, the radar value of actual alongtrack distance to touchdown was used to identify the required cross-section in the airborne recorded data.

The scale factors used to convert the airborne and ground radar FM tape values to engineering units are given in figures 32 and 33. In order to reduce recorder-induced inaccuracies, the radar data was divided into several bands for each of the radar variables (slant range, lateral deviation, and elevation). For each of the radar variables, one channel recorded the active band for that variable while the remaining channels for that variable are saturated.

The error model was then used to transform the recorded parameters into the position error parameters of interest. Three coordinate systems and five position vectors were used in the analysis as shown in figure 34. The two basic coordinate systems were (1) East-North-altitude (E-N-Z), and (2) alongtrack, crosstrack, and altitude (X-Y-Z) referenced to a runway magnetic heading of 291°. Thus, positive X was equal to magnetic bearing 111°, positive Y was equal to bearing 21° and altitude completed the righthand X-Y-Z system. The third reference system converted the E-N-Z system to a VORTAC bearing from magnetic North (clockwise positive), distance from VORTAC, and altitude (VOR-DME-Z).

The position error vectors are as follows:

$\overrightarrow{RNWY}$ = position of the runway touchdown point with respect to the VORTAC station

$\overrightarrow{VORTAC}$ = position of the aircraft with respect to the VORTAC station

$\overrightarrow{WYPT}$ = position of the RNAV waypoint with respect to the VORTAC station

$\overrightarrow{RNAV}$ = position of the aircraft with respect to the waypoint

$\overrightarrow{ACT}$ = position of the aircraft with respect to the runway touchdown point

Details of the mathematical equations and computations used to compute the vertical and lateral position error model parameters are shown in appendix E. Sample listings of the major position error parameters are shown in figures 35, 36, and 37. The definitions of each columnar listing are shown in figures 27 and 30.

A statistical analysis was performed on each position error parameter at each 0.2 nautical mile interval along the final approach path. The data sample for each position error parameter and each interval were analyzed in the same manner. A sample printout of the statistics and histograms is shown in figure 38 and 39. The basic statistics used to summarize the position error data are the mean, standard deviation (1σ), and confidence interval. These were computed using Bettelle's standard DESTAT (DEScriptive STATistics) computer program. Several additional statistics are also available from this program. All available statistics are defined in appendix F.

Acoustics Measurements/Processing

The acoustics data were processed at the Hydrospace San Diego facility. The processing equipment and the computer program used conform to the requirements of FAR part 36. The acoustics data were adjusted for system frequency response, effect of windscreen, grazing incidence, effects of temperature and humidity, and the effects of background.

A diagram of the Hydrospace EPNL processing technique is shown in figure 40. Analog tapes are processed using one-third octave filters to produce a digital tape of the raw one-third octave data every 0.5 second. Run number and calibration information is also included. This provides the necessary memory for long duration flyovers and stores the flyover in convenient form for subsequent processing.

The raw spectrums are immediately read back into the computer and converted to true sound pressure levels utilizing the calibration information. This is then converted to raw EPNL. After entry of aircraft range, the computer reads the appropriate atmospheric corrections from digital magnetic tape and calculates corrected EPNL. This EPNL is corrected to a standard day and includes other corrections for background, windscreen, grazing incidence and gain setting.

The EPNL and other support data are output to a third digital tape as an even further condensed form of the original analog tape. In addition, EPNL and support data are output to a hard copy. The above sequence is accomplished for each approach.

RESULTS AND DISCUSSION

Operational Procedures

Profile Geometry

A number of different two-segment profiles were flown by the American Airlines project pilot and the NASA-Ames project pilot prior to start of the guest pilot evaluation phase. After the first week of flying the evaluation aircraft in VFR weather conditions at Stockton, the profile shown in figure 41 was selected as being the most acceptable for the remainder of the evaluation. It consisted of a 6^{o} upper segment from level flight at 3000 feet altitude to interception of the ILS glide slope at 550 feet altitude. The figure 41 profile was chosen by the two project pilots after flying a total of 80 daytime, VFR approaches.

In addition to this experience, three two-segment approaches were flown at night. The two-segment approach appears to be higher and steeper at night than it does in daylight, due to the contrast of lights against the blackness of night. However, this was only evident at the start of the approach (3000 feet and capturing the 6^{o} RNAV glide slope). As the aircraft stabilized on the upper segment, the approach appeared as in daytime. These nighttime approaches were smooth and the project pilots felt that nighttime VFR approaches would not be a problem.

Some three-engine approaches (with No. 1 engine at idle thrust) were also made with no adverse control effects. With an engine loss on the upper segment (6^{o} glide slope), the situation seemed more comfortable than when operating on three engines during a normal ILS approach. The pilot has more altitude during most of the approach, and less power is required on the remaining engines to maintain aircraft position on the glide slope.

A typical radar trace of actual aircraft position during a two-segment approach to runway 29R at Stockton is shown in figure 14. The upper dotted line represents the 6^{o} upper segment glide slope. The lower dotted line represents the 2.5^{o} ILS glide slope at Stockton. The blips along the radar trace are time marks, spaced 15 seconds apart.

A curved pitch-over transition to the upper segment is initiated at an approximate range of 36,000 feet (6.0nm) from touchdown. The aircraft follows a nominal 6^{o} RNAV glide slope to a point approximately 550 feet AFL and 1.8 nautical miles to touchdown. It takes approxiamtely 100 seconds to cover this portion of the profile with a nominal wind of 8 knots from 320^{o}.

The curved pitch-up transition is initiated at approximately 550 feet altitude and 10,800 feet (1.8 nm) from touchdown, and is completed at approximately 350 feet of altitude and 8,000 feet (1.3 nm) from touchdown. The pilot then proceeds along the normal ILS glide slope to touchdown. It takes approximately 45 seconds to complete the second portion of the profile with a nominal wind of 8 knots from 320°.

This two-segment profile did not have any disadvantages when compared to the other candidate two-segment profiles. A 550 feet ILS glide slope intercept altitude provided approximately 45 seconds for a pilot to stabilize on the lower ILS segment before touchdown. This was considered to be a safe tradeoff between the minimum time required for safe approaches and the desire to maximize the reduction of ground level noise.

Pilot Procedures

A photograph of the guest pilot instrument panel is shown in figure 44. DME distance to the RNAV-generated upper segment waypoint was used as the pilot cue to configure the aircraft for landing prior to centering on the upper segment. This information was displayed in the conventional DME window of the CDI. This distance information was supplemented by the two-segment approach progress display lights. These unique displays, in combination with conventional ADI/ CDI displays of two-segment lateral and vertical, command and raw data, represent the primary instruments needed to execute the following two-segment approach procedures.

Prior to beginning a two-segment approach, the AA project pilot sets in the VOR/DME coordinates for the upper segment RNAV waypoint on the center pedestal-mounted VAC control panel. Vertical RNAV coordinates for the upper segment are set into the adjacent ADD control panel. A photograph of the RNAV control panels is shown in figure 45.

At a convenient point, before reaching 10 nautical miles from the RNAV waypoint, the pilot tunes the Nol 1 receiver to the appropriate VORTAC frequency; tunes the No. 2 receiver to the appropriate ILS frequency; and, resets the navigation mode select switch to the two-segment (RNAV-LOC) position. The flight director is now armed to automatically capture the localizer and the 6° RNAV glide slope.

The pilot proceeds to capture the localizer at an altitude of 3000 feet (AFL), 10 nautical miles out and establishes an airspeed of V_{ref} + 50 knots, with approximately 3400 lbs/hr fuel flow per engine. At this point in the profile, the V/L annunciator light is green, indicating localizer capture and the RNAV G/S light is amber, indicating the F/D computer is armed to capture the RNAV G/S which is positioned ahead of the aircraft at this point in the approach.

At eight miles (as shown by the DME indicator), the flaps are lowered to 20° and airspeed is reduced to V_{ref} + 30 knots;

seven miles out the flaps are lowered to 30° and airspeed is reduced to V_{ref} + 20 knots. At approximately 5½ miles out, and with the upper segment glide slope still approximately 5000 feet ahead, the vertical deviation bar in the ADI starts to move down. The F/D computer goes from arm to capture at approximately 3000 feet horizontal distance from the upper segment glide slope centerline, and the pitch command bars in the ADI start to indicate a shallow fly-down signal to the 6° RNAV glide slope.

The landing gear is lowered at initial movement of the raw data vertical deviation needle from the full fly-up position. Shortly thereafter, flaps are lowered to 40°, then to the full 50° position. While descending on the 6° glide slope, the V/L and RNAV G/S lights on the approach progress display are both green. While on the 6° G/S, and airspeed of V_{ref} + 20 knots is maintained with a fuel flow of approximately 1500 lbs/hr and 1900 lbs/hr, depending on existing wind speed and direction. A fuel flow of 1500 lbs/hr is enough to keep the engine spools spinning (i.e., 52% N_1 and 75% N_2).

At 1000 feet above the ground (in this case, based on a signal from the radio altimeter), the F/D computer automatically rearms for capture of the ILS glide slope. This is indicated by the G/S light on the approach progress display going from OFF to AMBER. At approximately 550 feet, the F/D captures the upper edge of the ILS glide slope beam. This is indicated by the G/S light going from AMBER to GREEN and the pitch command bars on the ADI start to show a shallow fly-up signal to the 2.5° ILS glide slope. The RNAV G/S light goes out at the same time.

While using command guidance to pitch up the aircraft, the pilot initially lets the airspeed bleed off from V_{ref} + 20 to V_{ref} + 10 knots. He then begins to apply power gradually from the upper segment level of 1500 lbs/hr engine fuel flow to a normal approach level approximately 3000 lbs/hr engine flow in order to maintain position on the lower ILS glide slope segment. The approach from this point to touchdown is then completed in a normal conventional manner.

Avionics Equipment

The avionics systems flown during this evaluation are representative of present "state-of-the-art" equipment that has "off-the-shelf" availability. The modifications required to adapt several of the system components are minimal and are neither expenseive nor time consuming.

The equipment configuration represents a reasonable compromise between R & D objectives and the rigorousness of design requirements for an airline-operational system. Because the flight evaluation was to be accomplished in VFR conditions, little effort was expended on "fail-safe" concepts. The installed single-system performed admirably throughout the program, and only one premature failure, probably due to human error, occurred on a steering computer at the outset of the flight test program in California.

Displays

The adequacy of command and raw data display on the ADI and CDI of the FD-108 flight director is attested to by the consistency of the approaches performed by the primary guest pilots after a two-hour orientation briefing and five practice approaches. This consistency can be attributed to maintaining airline standard scales and sensitivities on all flight instrument displays whenever possible.

One circumstance developed during the project that was not resolved. Slight fluctuations occurred in the pitch steering command during capture and track of the NAV glide slope. Close observation revealed that these very low frequency disturbances were reflections of a minute variation in the vertical deviation signal from the RNAV system.

This variation is believed to be a product of slight instabilities of the DME distance information furnished to the RNAV system that results in varying the position of the selected waypoint and therefore the upper segment slope. It can be shown that slight disturbances in the waypoint position will produce oscillations in vertical deviation that increase as the slope angle increases.

Any further effort to expand or improve the RNAV concept for approaches based on distance/bearing parameters should make extra provisions to establish a stable, accurate waypoint datum. More precise airborne VOR and DME receivers appear to be the critical supporting equipment for the RNAV system.

Concern for VOR/DME equipment accuracy should not be restricted to the airborne components. Variations in the VOR/DME data transmitted from the Stockton VORTAC necessitated slight corrections of original FAA-provided waypoint coordinates. Corrections on the VAC control panel were required several times to reposition the two-segment waypoint to achieve a 400-foot altitude intercept of the Stockton ILS glide slope.

RNAV to Flight Director Interface

The capture point for the 6° upper segment was evaluated with capture varying from 200 feet to 600 feet below the 6° segment. A value of 300 feet was finally selected as giving the pilot sufficient time to anticipate centering on 6° RNAV glide slope.

Radio Altimeter to Flight Director Interface

Use of the 1000-foot trip of the radio altimeter as an interlock for arming the ILS glide slpe mode of the steering computer was very effective in eliminating capture of false ILS lobes. However, a situation involving extremes in terrain up to the runway threshold could produce either failure to arm, intermittent arm interlock, or premature arm, depending on topography. An improvement for coping with this situation could involve a barometric-trip mechanism referenced to runway elevation.

Approach Progress Display

The advantages of a progress display are the presentations of flight director status and anticipation cues throughout the approach. Another imporant consideration for this progress display scheme is the passive "failure warning" action when the ARM to ENGAGE (AMBER to GREEN) transition does not correspond with the raw data deviation information. The ENGAGE (GREEN) indication in each display section is a discrete output of the steering computer that verifies input signal processing by the appropriate operational circuits within the computer.

Therefore, if the ARM/ENGAGE transition does not occur at the preset raw data deviation values, the pilot is informed that either a procedural error has been committed or the steering computer logic has malfunctioned. In either case this "fail-safe" feature permits the pilot to correct the situation or abort the approach, as required.

Autopilot

No pitch deviation information was furnished to the autopilot from the RNAV system during this program. This is not to say that a pitch control system could not be devised that would capture and track RNAV vertical track deviation, but provision of this capability was beyond the scope of this program. Inasmuch as the concept for transition from level flight to 6^{o} to 3^{o} glide slopes was satisfactorily developed for a flight director pitch steering signal, it follows that equivalent results can be achieved for autopilot pitch steering signals.

Pilot Opinion

Profile Geometry

Traditionally, airline pilots have been trained, refreshed and monitored to insure that they fly their jet transports in accordance with prescribed operational policies and procedures. A requirement that has been stressed and highlighted with the advent of the jet civil transports was for the pilot to get into the landing configuration as soon as practicable, preferably around 1000 feet above the ground, and from that point on attempt to keep the aircraft and engine power stablized and a constant sink rate less than 1000 feet/minute. This technique is safe and has proven to have considerable merit over the past decade.

The two-segment approach, therefore, is a departure from the established method of landing. In general, the guest pilots confirmed acceptability of the chosen profile for the VFR weather conditions actually encountered at Stockton during the evaluation. A total of 21 guest pilot questionnaires were submitted. Responses to the three profile-related questions in the pilot questionnaire are tabulated in figure 42. Representative responses are quoted in the right-hand column.

The guest pilots agreed almost unanimously that the two-segment profile flown during this evaluation does not induce adverse flight maneuvers and can be flown safely. Level flight capture of the upper segment RNAV glide slope can be performed smoothly and comfortably with no tendency to overshoot. Flight path command guidance offers the pilot confidence and assurance that the proper aircraft attitude can be established and maintained. Pitch-over is mild and requires no abrupt elevator or stabilizer movement. Pitch-up capture of the lower segment ILS glide slope is also smooth and requires no abrupt flight control changes.

Procedure

The previously described two-segment approach procedure was used consistently by the 26 guest pilots throughout the daytime, VFR two-segment evaluation flights listed in figures 20 and 21. The pilots reacted almost unanimously in favor of this procedure for a 6^{o} upper segment, 550 feet altitude intercept profile. Results from the 21 pilot questionnaires for the procedure-related questions are tabulated in figure 46. Pilot questionnaire responses reflecting general attitudes toward the need for noise abatement efforts are shown in figure 47.

There was a general feeling that there is no tendency to undershoot the lower ILS glide slope because the sink rate is protected by an airspeed cushion, and engine RPM on the upper segment glide slope is sufficient to insure adequate engine responses (i.e., spools are still spinning). Power application at capture of the ILS glide slope does not exceed the level required during a normal ILS approach.

Equipment

In all fairness to the guest pilots, it should be noted that the cockpit instrumentation and avionics systems developed for this project did not totally represent a true airline cockpit environment. Some of the questions in the pilot questionnaire required prior background and exposure to certain of the avionics systems installed in the test aircraft. However, the guest pilot responses were typically thorough and displayed a lot of imagination.

The guest pilots were in agreement that the two-segment display information provided in the evaluation aircraft is adequate for VFR conditions. The pitch steering information displayed on the ADI is continuous throughout the approach; and, if followed, provides a smooth transition to the 6^o and 2.5^o glide slopes. The DME distance to runway waypoint, progress display lights, and raw data information provided valuable anticipation cues.

However, each guest pilot had differing opinions about the cockpit instrumentation and systems required to safely execute two-segment approaches in adverse IFR weather conditions. Most of the pilots did not feel there was a need for autothrottle if a fully-coupled autopilot was implemented. They felt an autothrottle would be desirable, but not a necessity.

All of the pilots felt that when conducting two-segment approaches in IFR conditions, there was an obvious need for complete signal and display redundancy between the right- and left-hand flight instruments.

Most of the pilots liked having raw data for the ILS glide slope displayed continuously on the CDI throughout the approach. This provided a redundant source of assurance that they could see the ILS G/S when approaching the lower intercept point. They knew they could revert to this reference if automatic switching of the ADI command and raw data from RNAV to ILS glide slope signals did not occur. There was also a general feeling of the need for a feature whereby the aircraft would be automatically leveled off at approximately 400 feet altitude, or an appropriate warning if the automatic switching from RNAV to ILS glide slope did not occur.

Most of the pilots expressed a desire that both the vertical and lateral modes be coupled to the autopilot throughout the two-segment approach. This was stated as an essential requirement for VFR and IFR conditions. A few pilots also thought it would be desirable to have an altitude hold command signal on the ADI prior to capture of the upper segment. This feature was not included in the equipment provided in the present program. Two of the pilots indicated that they had to pay an excessive amount of attention to the displays during a two-segment approach as compared to a normal ILS approach.

Weather Minimums

Guest pilot opinion about the impact of weather minimums on two-segment concepts was diverse and ranged over the entire spectrum of potential operational policies. All of the guest pilots were in agreement that the profile, procedures, and equipment actually flown at Stockton were fundamentally adequate for the fair weather, VFR conditions encountered. The differences of opinion and reservations begin to occur when this first-hand experience is extrapolated to IFR weather conditions.

Responses to the two weather-related questions in the pilot questionnaire are shown in figure 48. Six of the guest pilots did not get the opportunity to fly under the hood. Nevertheless, they also estimated weather minimum criteria.

There was no majority opinion on the value for a minimum ceiling, but 11 of the 21 pilot responses indicated a preference for continued use of present Category I/Category II minimums. A related issue involves the buffer (altitude difference between ILS intercept altitude and minimum ceiling) which the guest pilots felt they would be comfortable with during an IFR two-segment approach. A special tabulation of the responses to questions (4) and (5) in the pilot questionnaire is shown in figure 49.

This tabulation indicates that a strong majority of 17 pilots, who had preference for minima other than Category I and Category II, preferred the ILS intercept altitudes above the minimum ceiling, the buffer averaged 350 feet over a range from 100 feet to 900 feet. Alternatively four pilots wanted to be visual at the ILS transition altitude. The stated altitude margin below the prevailing ceiling averaged 400 feet over a range from 100 feet to 600 feet.

These results are not conclusive; but, there is a general pattern which indicates the desire for an approximate 400-foot altitude buffer between the ILS intercept altitude and the IFR ceiling minimum which is chosen for the two-segment approach. It is also clear that two-segment approach minimums will have to be defined and developed in the same manner as single-segment ILS/VOR/ADF approach minima.

Pilot Training

The experience level of the guest pilots progressed through a whole spectrum, from NASA research pilots to airline line pilots, airline management pilots, and ALPA/APA representatives. This also included several retired airline captains acting in the capacity of aviation consultants. Previous flight experience for the guest pilots listed in figures 20 and 21 averaged approximately 13,000 hours and ranged between 4,000 and 26,000 hours. Some of these pilots had never flown a 707-type aircraft, and some had never flown a Collins FD-108 flight director. Most were not acquainted with area-navigation concepts or procedures.

Any ILS-trained pilot would have no difficulty flying this approach, provided he has been properly trained in the two-segment approach procedures developed for this project. The lack of 707 or RNAV experience did not appear to affect flyability of the two-segment approach. However, those pilots who had no previous Collins FD-108 flight director experience took somewhat longer to get comfortable with the pitch command V-bars in the ADI display.

The guest pilots stated they arrived at Moffett Field with an initial apprehensive, skeptical attitude toward the desirability, acceptability, and feasibility of two-segment approach techniques. Their reaction by the end of their evaluation flight was nearly a complete reversal to opinions ranging from cautious optimism to mild enthusiasm. Their confidence in acceptance of the concept appeared to progress in direct proportion to the number of approaches flown.

This suggests the possibility that flight training for the typical line pilot would not have to be very extensive. Although the two project pilots were the only ones who had the advantage of simulator time prior to actually flying, lack of simulator training did not seem to hamper the guest pilots. The concentrated two-hour preflight briefing could be expanded somewhat, but this preflight exposure seemed to prove adequate.

The five approach flight training sequence for the guest pilots also appeared to be sufficient. Typically, a guest pilot seemed to have the procedure in hand by the third practice approach. The second set of five approaches served as a confidence builder, and would be a suitable number in any flight training program.

Passenger Opinion

Most of the flight observers during this program were invited on the basis of their professional interest and need to know. They were not pre-selected as being necessarily representative of the traveling public. However, their presence and willingness to fill out passenger questionnaires represented a convenient opportunity to assess the potential of a passenger's reaction to the two-segment approach procedure.

Sample Characteristics

The seat distribution of flight observer responses is shown in figure 52. The responses in the two-segment sample are well dispersed throughout the cabin. This is somewhat less true for the normal approach sample which was approximately 50% smaller than the two-segment sample.

Respondent characteristics in the sample are tabulated in figure 53 and figure 54. The largest portion of the two-segment sample was obtained for the sixth and seventh approaches in the two-segment sequence. The largest portion of the normal approach sample was obtained after the observer had already experienced ten two-segment approaches (question B and figure 23).

Observer occupation was diverse with concentrations in Airline, Airport Planning, Aviation, and NASA (question E). The sample was predominatly male (question F).

The observers in the sample were very experienced commercial airline travelers. For example, in the two-segment sample, 6.7% flew on business flights six or more times in the past 12 months; 34% in the two-segment sample also flew for personal/pleasure reasons at least two to five times in the past 12 months (question C).

Pilot experience in the sample was rather heavy. Only 37% of the two-segment sample did not have pilot experience (question D).

Normal versus Two-Segment Approaches

In accordance with standard statistical practice, 95% statistical confidence limit tests were applied to each evaluation parameter. If a difference in average response for a given parameter met the 95% confidence test, then the response for that parameter was judged to be statistically significant.

The significant differences between a two-segment approacn and a normal approach are shown in figure 55. In an "overall" sense, the two-segment was rated slightly better than the normal. This rating reflects the net result of the four significant passenger parameters shown in figure 55, namely:

Smooth - Bumpy
Quiet - Noisy
Gradual - Steep
Slow - Fast

The two-segment was rated as relatively less bumpy and less noisy, but steeper and faster. Of particular interest is the large spread between the latter two parameters and the first two parameters in favor of the normal approach; and yet, the overall rating was in favor of the two-segment. This indicates that the respondents weighted bumpiness and noise more heavily than steepness and speed in their overall rating.

<u>First-Class versus Coach Section</u>

The significant differences between first-class and coach seat responses during the upper segment of the two segment approach are shown in figure 56. In the "overall" sense, first-class was rated slightly better than coach. This rating reflects the net result of the three significant passenger parameters shown in figure 56, namely:

Smooth - Bumpy
Quiet - Noisy
No Vibration - Vibration

Each of these parameters was rated as relatively more severe while seated in coach, with vibration being significantly more noticeable in coach.

The dramatic difference in vibration between first-class and coach is further highlighted, when the two-segment vibration results are compared to the normal approach vibration results in figure 57. Two-segment vibration was rated overall as being slightly more severe than during a normal approach. This was also true whether the respondent was seated in first-class or coach, with vibration being significantly more noticeable in coach, regardless of whether it was a two-segment or normal approach.

<u>Weather and Terrain</u>

All of the approaches in this passenger sample were flown in relatively calm, daytime, VFR weather to an airport surrounded by flat, rural terrain. In an attempt to compensate for this, the respondents were also asked to speculate on their reactions to other, more adverse flight conditions (question 4).

A majority of the respondents said terrain features would have no effect on their reaction to either the normal or two-segment procedure. However, a sizable minority of the respondents said they would be relatively more concerned about normal approaches over industrial, residential, and mountainous areas, than they would be about two-segment approaches over the same areas. Sample results are shown in figure 58.

A majority of the respondents also said adverse weather would have no effect on their reaction. Again, however, a sizable minority said they would be relatively more concerned about normal approaches in cloudy/foggy weather and at night than they would be about two-segment approaches in the same conditions. Sample results are shown in figure 59.

Almost equal, but sizable, minority concern was also expressed about the effects of turbulent/rough air. Considering all the terrain and weather factors included on the questionnaire, turbulent/rough air represents the most significant concern, as shown in figure 59.

Acoustics Measurements

The desired approach profile for this test was a 6-degree glide slope with upper intercept at 3000 feet and a 550 feet intercept of the Stockton glide slope of 2.5 degrees. The Stockton ILS glide slope (2.5°) was chosen as the noise measurement reference profile. The maximum noise reductions achieved in this test program were from 6.5 to 16.0 EPNdB at points from 1 to 6 nautical miles from runway threshold along an extension of the runway centerline. See figure 61. The average measured noise levels at each noise measurement site under the approach path are statistically within ± 1.5 EPNdB of the true acoustic level at the site for both the reference and desired profile data. The two-segment approach typically had a standard deviation of approximately 2.5 EPNdB. This is a measure of the actual data scatter.

Two-segment approaches achieve noise reduction from two sources: 1) an increased distance above the ground and 2) a reduction in noise level as a function of slant range due to reduced power settings. Power changes are especially evident at the lower transition where the two-segment has a lower noise level at the same altitude as the ILS approach.

Inclusion of two-segment approaches into present noise exposure forecast (NEF) computations yield answers that are not consistent with actual measurements. Care must be taken in the use of the present NEF computation to provide for the power change at the lower transition and for sideline corrections. The upper transition affects the existing NEF prediction techniques less drastically.

Incremental noise levels along the approach ground track are significantly affected by pilot-operating technique, especially power changes. Further reductions of 1 to 2 EPNdB may be achieved at critical points on the approach ground track by control of aircraft attitude, speed, and power changes.

The meteorological data recorded near noise measurement site 3 is shown in figure 60. This data was used during noise data processing to correct raw EPNL measurements to a standard acoustic day.

Wind speed exceeded the FAR Part 36 Limit of 10 knots (11.5 mph) on several occasions. However, the recorded EPNL values were corrected by using microphone windscreen correction values. A review of actual aircraft position radar plots confirmed the consistency with which the guest pilots flew the desired two-segment profile throughout the prevailing wind speeds and direction. Therefore, no noise data was eliminated due to inconsistencies in aircraft flight path. Although three-dimensional digital tracking data is more accurate, the available two-dimensional track date introduced a maximum error in the acoustic results of less than $\pm$0.25 EPNdB for this test. This number is based on atmospheric absorption differences between the true slant range at the time of maximum tone-corrected perceived noise level ($PNLT_{max}$) and vertical distance at the time of $PNLT_{max}$. For this reason, EPNL was plotted as a function of slant range from the two-dimensional track date with a minimum introduction of error.

3D-RNAV Data

Figures 64 through 82 illustrate the 3D-RNAV data results. The data plotted use recorded radar position as a basis for comparison. Therefore, errors in the tracking radar and antenna boresighting are included in the results. Also, errors in the ground and airborne instrumentation are included in the data and not identifiable.

Most figures show maximum, minimum, and mean of the data analyzed. For isolated cases the standard deviation is shown. It is believed, however, that the extreme values of maximum and minimum are of the widest interest.

Data near touchdown (0.2. n.m.) is often not included in the figures, since the procedure of pulling up for going around influenced the data taken near the runway.

On several figures an approach window 0.6 n.m. to runway touchdown is illustrated. This window is near the middle marker. Data closer to touchdown is affected by the pullup approaches. Therefore, a window far enough from the runway was chosen so it would not be influenced by pullups. It offers a means of comparing vertical height for various conditions of pilotage, since the plotted data is not readible because of scaling.

The material to follow is organized into general results and specific results. A list is shown below:

OVERALL RESULTS	FIGURES
Altimeter Error	64
System Crosstrack Error	65
System Alongtrack Error	66
SPECIFIC RESULTS	
Profile Definition	67, 68, 69, 70, 71
Aircraft Vertical Trajectories	72, 73, 74, 75, 76
Aircraft Lateral Trajectories	77
Nature of Deviation	78, 79, 80, 81
Programmed Excursions	82

Altimeter error is shown in Figure 64. Although the mean error was less than 30 feet, errors as large as 150 feet were recorded. This resulted from several reasons. One was instrumentation error. Electro-mechanical analog-to-digital converters were used for data processing. Also field pressure altitude was corrected the first approach of the morning. Often it was not reset for subsequent approaches.

The RNAV error was defined relative to the waypoint as inserted into the RNAV computer referenced to the VOR/DME station. The RNAV computer settings were empirically obtained such that a 300-foot intercept would be obtained at the ideal crossover of the 2-½^{o} and 6^{o} glideslopes (at 300 feet altitude).

The first waypoint was based on the geometric location of the ideal waypoint referenced to the Stockton VOR/DME station (3.4 n.m. at 306.4^{o}). The resultant vertical profile was too high at the transition to the 2-½^{o} glideslope. The waypoint apparent to the VAC was 0.2 nm closer to touchdown than desired. The waypoint coordinates were moved 0.2 nm closer to touchdown (resulting in a 300-foot ideal transition to the 2-½^{o} glideslope) by altering the waypoint coordinates to 3.6 nm at 306.4^{o}. The resultant vertical profile was approximately as desired, but the RNAV cross-track error was now approximately 0.2 nm for the second waypoint setting. A third waypoint was, therefore, set to 3.5 nm at 303.4^{o} for the last portion of the Stockton flight program to remove the 0.2 nm cross-track error. Only the approaches flown using the second VAC waypoint are analyzed in this report.

The Stockton Airport localizer was used for lateral approach guidance. Therefore, system crosstrack error, defined in Figure 30, was computed but it was not used for guidance. Figure 65 illustrates this error. It is the combined system ability (i.e., altimeter, VOR, DME, and RNAV equipment) to determine lateral position during the upper segment portion of the approach. The mean error is less than 0.3 nautical miles and errors as large as 0.4 n.m. were recorded.

Alongtrack error, defined in Figure 30, was also computed. Figure 66 illustrates this error. The mean error was as large as 0.35 nm and errors as large as 0.55 nm were recorded. The mean error was negative resulting from the indicated distance being less than the actual distance to waypoint. If the error is referenced to the ideal geometric waypoint (or, equivalently, if the apparent 0.2 nm alongtrack bias error is removed), the resultant RNAV alongtrack error is initially 0.2 nm, then approximately zero between 3.0 and 4.0 nm to touchdown, and then about -0.1 nm. The net effect of this error on the ADD computations is described in following paragraphs.

There are several ways of considering vertical profile errors. One way of looking at this error is deviation of the computed profile from the straightline $6^{\circ}/2\frac{1}{2}^{\circ}$. In this case equipment plays a major role. The VOR, DME, RNAV system and accuracy of the data recording are all involved.

Figures 67 through 70 illustrate the system computed glideslope where the system may be combinations of the altimeter, VOR, DME, and RNAV equipment. These Figures should not be confused with the aircraft trajectories. These particular system glideslopes are defined as actual commanded altitude, which is the sum of actual vertical position and the system commanded position (RNAV deviation or glideslope deviation as appropriate).

For each of Figures 67 to 70, the following condition is observed along the 6° -glidepath segment. At a given altitude, the difference between the desired distance to touchdown and the actual distance to touchdown is initially +0.2 nm, and is approximately zero between 3.0 to 4.0 nm to touchdown, and then becomes roughly -0.1 nm. This error is identical to the RNAV alongtrack error with the known +0.2 -nm bias removed. As a result, it would appear that the ADD computer was generating the proper vertical commands based upon the along-track distance to touchdown signals it computed from.

As illustrated, the profiles defined by the system are fairly uniform. The commanded altitude should be independent of the method used for following vertical commands.

Figure 71 illustrates the ILS commanded glideslope. This was computed by adding the recorded values of actual altitude and glideslope deviation. The glideslope is well defined as indicated by the small deviation from the mean. The computed glideslope was nearer to 2.4 degrees than the published value of 2½ degrees. The 1/10 degree difference is attributed primarily to error in the data acquisition and reduction system.

Figures 72 through 76 show the actual aircraft glidepath. The approaches are grouped as Visual Flight Rules (VFR), Hooded, combined VFR and Hooded, Pitch Thumbwheel Control and normal 2-½° ILS coupled (both lateral and vertical). Note that the actual aircraft glidepaths closely follow the system glideslopes indicating that pilotage errors were small. The vertical dimension of an approach window 0.6 nautical miles from touchdown gives a quick assessment of guidance accuracy. It has the following vertical dimensions:

	No. of Approaches	Min Altitude	Mean Altitude	Max. Altitude
VFR	(4)	148 ft.	155 ft.	160 ft.
Hooded	(6)	139 ft.	149 ft.	159 ft.
VFR & Hooded	(10)	139 ft.	151 ft.	160 ft.
Using A/P Pitch Thumbwheel	(21)	122 ft.	144 ft.	164 ft.
Fully coupled to ILS	(10)	114 ft.	136 ft.	156 ft.

As shown above, the window height is only 50 feet. (164 versus 114).

Figure 72, 73 and 74 show similar results. The aircraft follows the commanded glidepath with good precision. The deviations from the nominal 6° glideslope are due primarily to error in the commanded glideslope and not the pilots ability to follow the commanded glidepath. Transition to the ILS glideslope shows a slightly greater tendency for the aircraft to fly below the desired glideslope during hooded approaches. However, vertical path stabilization on the glideslope has occurred by 0.75 nautical miles to touchdown.

Figure 75 shows a greater variation in aircraft vertical position when the autopilot control is used to obey vertical steering commands.

Figure 76 shows the relatively small variation in aircraft vertical position when the aircraft makes normal 2½ degree fully-coupled approaches using the ILS throughout. However, at the 0.6 n.m. approach window, the fully-coupled approaches had vertical extremes greater than those flown manually.

Figure 77 shows the mean aircraft lateral position. The Stockton Localizer was used for all approaches. The two-segment approaches were comparible in accuracy to the ILS approaches.

Figure 78, 79, 80, and 81 show deviations from the computed glidepaths. These are recorded deviations converted to feet. All figures show that control of the aircraft was progressively improved as the touchdown point was approached.

Figure 79 shows that the VFR approaches were slightly better than the hooded approaches (Figure 78). Larger deviations resulted during autopilot pitch thumbwheel controlled approaches (Figure 80). Smallest vertical deviations resulted from normal ILS approaches as shown in Figure 81.

Figure 82 is the result of five approaches labeled "excursions". These were planned excursions from the desired flight path flown by the project pilots to evaluate system performance - in particular, the ability to recapture the two-segment profile. Note that the 2½ degree glideslope was captured and followed successfully for all five approaches.

As illustrated in Figure 82, the approach window of 0.6 nautical miles to touchdown was 134 feet to 160 feet in altitude. This compares favorably to results for the normal two-segment approaches.

Fuel Savings

A slight fuel savings results from the reduced engine thrust settings which are used on a two-segment approach for landing. Fuel savings per aircraft per year is computed from the following facts and test observations:

(1) 720-023B aircraft fitted with JT3D-1/3B fan jet engines.

(2) Four engines operating during each approach.

(3) Reduced fuel flow rate from 3000 pound/hour/engine to 1500 pound/hour/engine for 1½ minutes during each two-segment approach.

(4) Fuel costs 1.76 cents per pound.

(5) 1,550 average landings per 720 aircraft per year.

Fuel savings, then, is approximately $4,100 per year for an aircraft which exclusively makes two-segment approaches for each landing. This is a representative savings for four-engine jet aircraft operated in a route structure similar to that of American Airlines.

APPENDIX A

FLIGHT DIRECTOR DESCRIPTION 1/

Collins FD-108

The FD-108 Integrated Flight System specifications are listed in figure A-1.

Course Indicator

The basic course display, shown in figure A-2, consists of a servo-driven azimuth card which is read in relation to the miniature aircraft in the center of the Course Indicator. The course display is completely pictorial, showing a symbolic plan view of aircraft position and heading with respect to the compass and to the selected heading and course.

The azimuth card repeats the gyrostabilized magnetic compass information, and aircraft heading is indicated by the lubber line at the top of the Course Indicator. The miniature aircraft is fixed to the center of the instrument glass face and represents the actual aircraft. It displays present position in relation to movable parts on the Course Indicator. Heading and course can be selected by rotating the HDG and COURSE controls. Selected heading is displayed by the heading marker (a triangular symbol located in front of the azimuth card numbers). Selected course is displayed by the position of the course arrow and by the digital COURSE readout in the upper left corner of the Course Indicator. A distance display located in the MILES window in the upper right corner of the Course Indicator presents DME information. Meter movements in the Course Indicator display present VOR, localizer, and glide slope deviation information.

The Course Indicator is mounted on the flight instrument panel and can be removed as a single unit for servicing. The Course Indicator is protected by a removable aluminum alloy case. All electrical connections are made through two connectors at the rear of the case.

Flight Director Indicator

The basic attitude display, shown in figure A-3, consists of a flat attitude tape which is servo driven in both pitch and roll. The attitude tape is read against the fixed miniature aircraft in the center of the Flight Director Indicator face. Roll and pitch attitudes are displayed by the relative positions of the fixed miniature aircraft and a horizon bar on the attitude tape. Roll attitude is also displayed by a bank indicator and bank scale located near the top of the Flight Director Indicator.

1/ Reference Collins Maintenance Manual 34-24-OF, Dec. 15, 1964, pp 3-6.

Steering commands are displayed by the V-bar command indicator which consists of two tapered bars that form a shallow inverted V and flank the miniature aircraft. The tapered bars move in unison and are servo driven in both pitch and roll to indicate the changes required to obtain a desired flight path. The steering commands are generated in the Steering Computer and depend upon the mode of operation.

The PITCH TRIM control is located on the front lower-left corner of the Flight Director Indicator. It may be adjusted to change the position of the horizon bar in relation to the fixed miniature aircraft and to establish a different pitch attitude reference. The mode selector switch located on the front lower-right corner provides for selection of OFF, HDG, V/L or GS modes of operation.

Meter movements located at the side and at the bottom of the Flight Director Indicator provide glide slope and VOR/localizer deviation presentations. An inclinometer located at the bottom of the Flight Director Indicator provides slip or skid indications.

Basic construction, mounting characteristics, and electrical connections, in the Flight Director Indicator are similar to the Course Indicator.

Instrument Amplifier

The Instrument Amplifier processes and amplifies the signals that drive the display and command indicators of the FD-108 Integrated Flight System. Functionally the Instrument Amplifier consists of a command channel, a display channel, and a monitor channel.

Steering signals are applied to the command channel from the Steering Computer. The V-bar command signal output drives the V-bar circuitry in the Flight Director Indicator. Display signals are applied to the display channel, the output of which drives the azimuth card display in the Course Indicator and the attitude display in the Flight Director Indicator.

The monitor channel evaluates monitor input signals and produces signals for operation of warning flags and shutters in the Course Indicator and the Flight Director Indicator.

The Instrument Amplifier can be removed as a single unit for servicing. All electrical connections are made through two connectors at the rear.

Steering Computer

The Steering Computer provides pitch and roll steering signals for the FD-108 Integrated Flight System. The Steering Computer consists of a pitch channel, a roll channel, and a monitor channel.

VOR or localizer deviation, heading deviation, and roll information signals are applied to the roll channel of the Steering Computer. The signals are processed, and the resultant roll steering output signal is used to position the V-bar indicator in the Flight Director Indicator for a roll steering command. Glide slope deviation and pitch information signals are applied to the roll channel of the Steering Computer. The signals are processed, and the resultant roll steering output signal is used to position the V-bar indicator in the Flight Director Indicator for a roll steering command. Glide slope deviation and pitch information signals are applied to the pitch channel of the Steering Computer. These signals are processed, and the resultant pitch steering signal is used to position the V-bar indicator in the Flight Director Indicator for a pitch steering command.

The monitor channel evaluates monitor input signals from each of the input sources and produces a computer warning flag signal which is applied to the Instrument Amplifier. The computer warning flag signal is used to indicate a malfunction.

The Steering Computer can be removed as a single unit for servicing. All electrical connections are made through one dual connector at the rear of the case.

CHARACTERISTIC	SPECIFICATION
TSO status	Conforms to FAA TSO C52a.
Power requirements	115 volts, 400 cps: 70 va. +28 volts d-c: 150 ma.
Equipment size	
Flight Director Indicator	4-inch-diameter face.
Course Indicator	4-inch-diameter face.
Steering Computer	1/4 ATR short.
Instrument Amplifier	1/4 ATR short.
System weight	25.6 pounds maximum.
Operating temperature range	-22° to $+122^{\circ}$F (-30° to $+50^{\circ}$C).
Storage temperature range	-85° to $+158^{\circ}$F (-65° to $+70^{\circ}$C).
Humidity range	0 to 95% relative humidity at $+158^{\circ}$F ($+70^{\circ}$C).
Maximum altitude	-1000 to +40,000 feet.

Reference: Collins Maintenance Manual 34-24-OF, Dec. 15, 1964, pp 3-6.

Figure A-1 - System specification for the Collins FD-108 flight director.

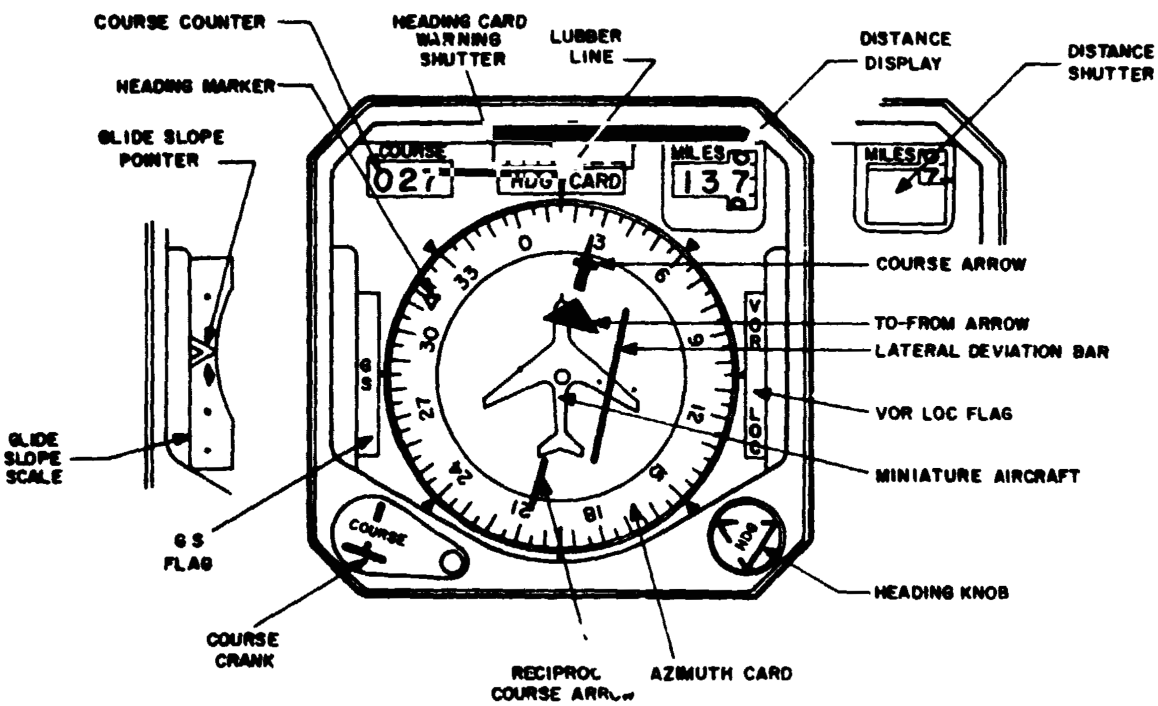


Figure A-2 - Course deviation indicator (Collins 331A-6D CDI).

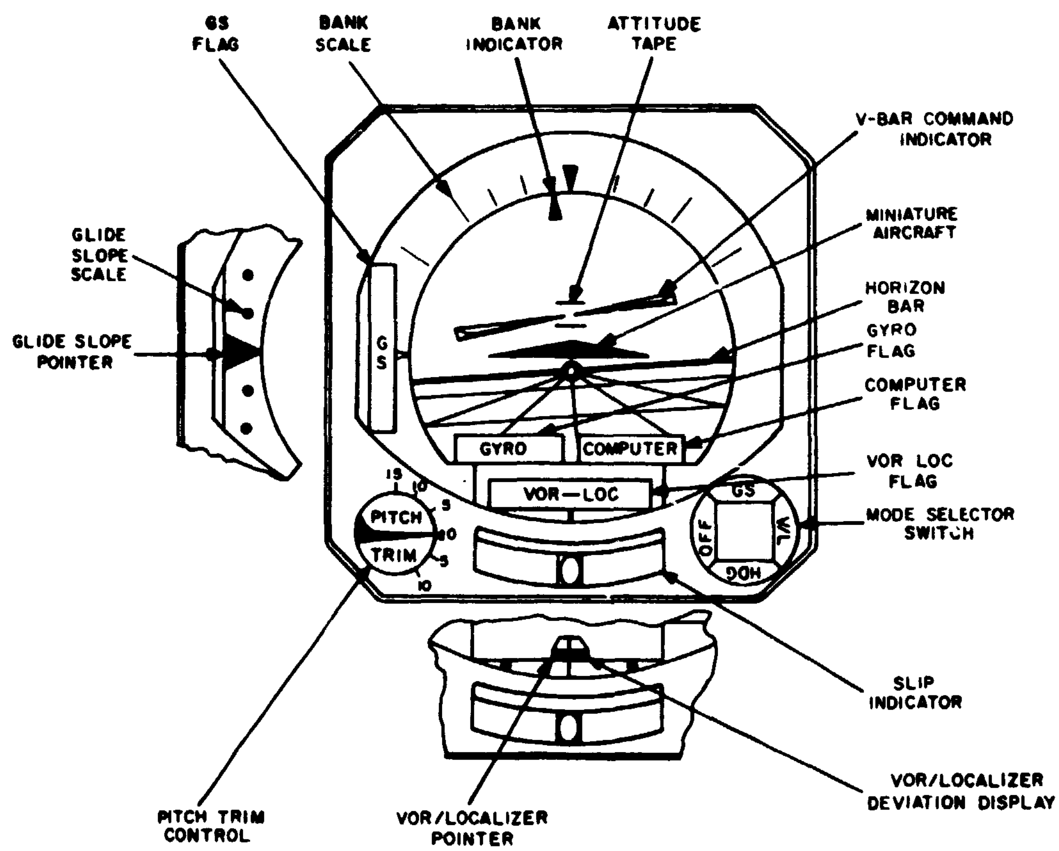


Figure A-3 - Standard altitude director indicator (Collins 329B-7G ADI).

APPENDIX B

3D-RNAV DESCRIPTION

Butler-National System

Lateral Navigation

Vector Analog Computer

The Butler-National Vector Analog Computer (VAC) is an airborne analog device which automatically computes horizontal (2D) navigation information for the pilot. Conventional VOR bearing and slant range corrected DME distance signals are used to perform navigation triangulation computations in the lateral plane. The VAC enables a pilot to transfer actual VOR/DME stations along VOR radials to any phantom location of his choice. (figure B-1) The location of this "phantom VOR/DME station" is known as a waypoint.

This is accomplished by use of a center-pedestal-mounted VAC waypoint selector control in the cockpit. (figure B-2) The coordinates for each waypoint are defined in terms of VOR radial and DME distance to the pertinent VOR/DME station. Two sets of waypoint coordinates can be set into the control unit at any one time. A toggle switch in the center of the control unit permits manual selection of either established waypoint. Waypoint coordinate values can be inserted before or during flight, and can be changed manually at any time during flight. Resultant navigation information can be displayed to the pilot in one or both of two ways simultaneously.

Symbolic Pictorial Display

The Butler-National VAC system includes a cockpit display known as a Symbolic Pictorial Indicator (SPI). (figure B-2) The SPI is activated when the VAC system is on and the pilot has tuned in the VOR/DME station frequency associated with the waypoint coordinates selected on the VAC control unit. The pilot then sets in desired track heading to the established waypoint with a knob on the SPI. This value is displayed at the top of the SPI. With these waypoint coordinates established, the SPI displays situation data for: actual distance to the waypoint along the desired track, on the horizontal needle; actual crosstrack (perpendicular distance) off the desired track, on the vertical needle; and actual aircraft heading relative to the desired track heading, by the airplane symbol in the center of the SPI. The intersection of the two needles represents the desired waypoint. The airplane symbol (which rotates through 360°) always depicts the aircraft's actual to/from position and actual heading relative to the desired waypoint.

The scale factors for the five tick marks on the vertical and horizontal axes of the SPI are set in by the pilot with the control knob on the bottom-center of the waypoint control unit. He has two selections to make. As shown in figure B-2, the normal position (NORM) activates the 1, 2, or 10 nautical miles per tick mark scales. The pilot then sets in 1,2, or 10 on the VAC control panel, depending on the sensitivity he desires. The selected sensitivity value is displayed in the "scale" window on the SPI. Therefore, the full scale crosstrack and distance to waypoint sensitivities of the SPI in the NORM mode are 5, 10, or 50 nautical miles, when the desired waypoint is in view on the SPI. These sensitivities are generally used by the pilot during enroute navigation.

The approach position (APP) on the VAC waypoint control unit activates the 0.25 nautical mile per tick mark scale. Therefore, the full scale crosstrack and distance to waypoint sensitivity in the APP mode is 1.25 nautical miles when the desired waypoint is in view on the SPI. These sensitivities are used by the pilot during final approach to perform more precise navigation maneuvers. The illustrated sensitivities can be altered in the shop prior to installation to permit other pilot-selectable sensitivity range combinations.

Conventional Command/Situation Display

While 2D-RNAV situation information can be displayed to the pilot on the SPI, it can also be displayed, either separately or simultaneously, on conventional airline cockpit instruments. AA's experience on the MDC 188 (STOL) navigation evaluation program (ref. 5) indicated that RNAV situation and command information should be displayed to the pilot in his normal "T" scan field of view to minimize cockpit workload.

While in the RNAV mode, "Command" navigation data is displayed on the Flight Director Indicator (Attitude Direction Indicator, ADI) and horizontal situation data is displayed on the Course Deviation Indicator (CDI) and Radio Magnetic Direction Indicator (RMDI). This approach is illustrated in figure B-3 with a typical set of conventional airline indicators.

A switching unit is required to transfer the computed VAC signals to the Flight Director roll computer, ADI, CDI, RMDI, and DME indicators.

Distance Proportional Filtering

One unique technical feature of the VAC computer deserves special mention. Butler-National Corporation has patented a technique called "distance proportional filtering". This technique improves the resolution of received VOR bearing signals. The filtering technique is mechanized so the maximum rate of change of the received VOR bearing signal is limited to a value which is proportional to the maximum practical ground speed of the aircraft.

Distance proportional filtering may be expressed in equation form as follows:

$$\frac{d\phi}{dt} = \frac{K}{D} \qquad (1)$$

Where $\frac{d\phi}{dt}$ = maximum allowable rate of change of VOR bearing, (deg/sec)

D = distance from the VOR station, (nm)
K = constant selected in accordance with maximum aircraft speed

From equation (1), the value for the maximum allowable rate of change increases as (D) decreases; this results in a proportional error at values of (D) equal to less than approximately 0.5 nautical miles.

To illustrate this filtering technique, consider figure B-4. Waveform "A" represents a hypothetical VOR radial scallop which is non-symmetrical in amplitude. Waveform "B" represents the output of a resistance-capacitance (RC) filter to which Waveform "A" is applied. If Waveform "B" was recorded in a flight test, it could easily be assumed that the actual radial scallop consisted of two basic frequencies; a low frequency called a "blend", and a higher frequency called a "scallop". Because the RC network is a low pass filter, the low frequency component is attenuated to a lesser degree than the higher frequency.

Waveform "C" represents the output of a distance proportional filter when Waveform "A" is applied to its input. No course bend occurs because the filter is insensitive to amplitude.

Vertical Guidance

Ascent-Descent Director

The Butler-National Ascent Descent Director (ADD) is an airborne analog computer designed for vertical guidance. It uses slant range corrected distance to RNAV waypoint signals from the VAC and Baro-corrected altitude signals to perform the necessary glide slope computations.

The ADD is an airborne computer which establishes a cone of descent (or ascent) glide slopes, originating at the 3D-RNAV waypoint. The particular glide slope line on the conical surface is determined by the desired magnetic heading value set into the TRACK SET window of the SPI. (figure B-5)

The glide slope cone is established by pilot entry of four vertical coordinate values in a center-pedestal-mounted ADD control unit (figure B-6).

(a) The altitude of the pertinent VOR/DME station (STA ELEV).

(b) The desired point over the ground where the desired altitude is to be reached, relative to the 2D waypoint set into the VAC (DIST OFFSET).

(c) The desired altitude waypoint to which the aircraft is to descend, or ascend (DESIRED ALT).

(d) The desired angle at which the aircraft is to intercept the desired altitude waypoint (ANG SET).

Flight paths up to a 9.9° ascent or descent slope can be established in this way. One set of vertical waypoint coordinates can be set into the ADD at any one time.

The resulting vertical navigation signals from the ADD can be displayed in a conventional manner on the ADI and CDI as command and situation information relative to the desired flight path. A mode annunciator light tells the pilot whether he is seeing VAC/ADD information on his primary flight instruments.

3D-RNAV Signal Sources

VOR Receiver - The existing ARINC 547 (Collins 51RV1) VOR/ILS receiver interfaces with the VAC computer without modification. VOR bearing input to the VAC computer is provided by the manual section OBI resolver and left/right deviation.

DME Interrogator - Distance input to the ADD computer is provided by the optional potentiometer output of an ARINC 521D (Collins 860E-2) DME Interrogator. This signal is slant range - corrected in the VAC before being used to calculate distance to waypoint.

Dual Synchro Altimeter - The VAC/ADD system requires baro-corrected altitude input to provide computations for slant range correction, and vertical guidance. This input is provided by dual synchro outputs from one of the pilot's altimeters.

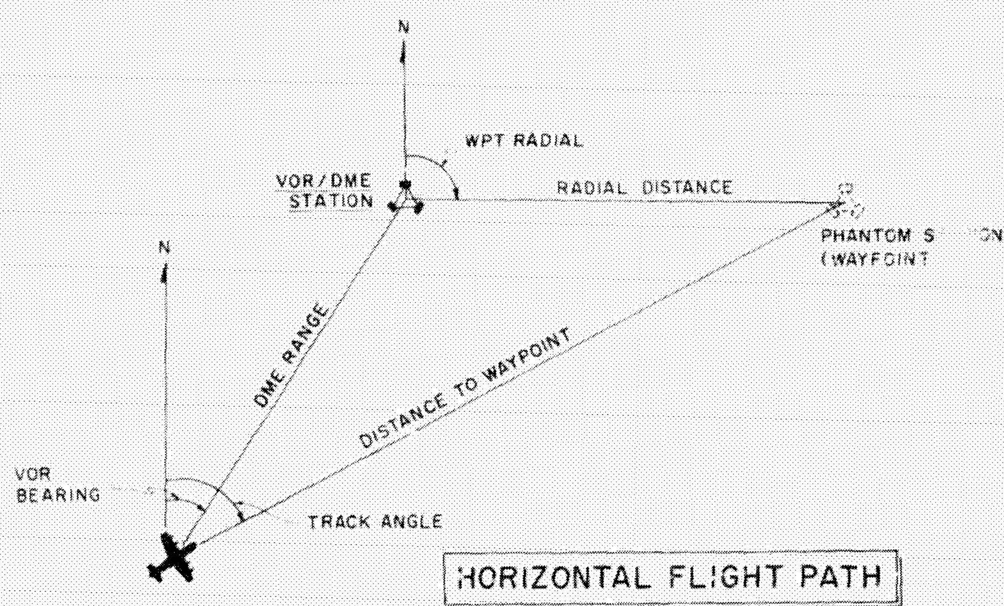


Figure B-1 - Area navigation waypoint.

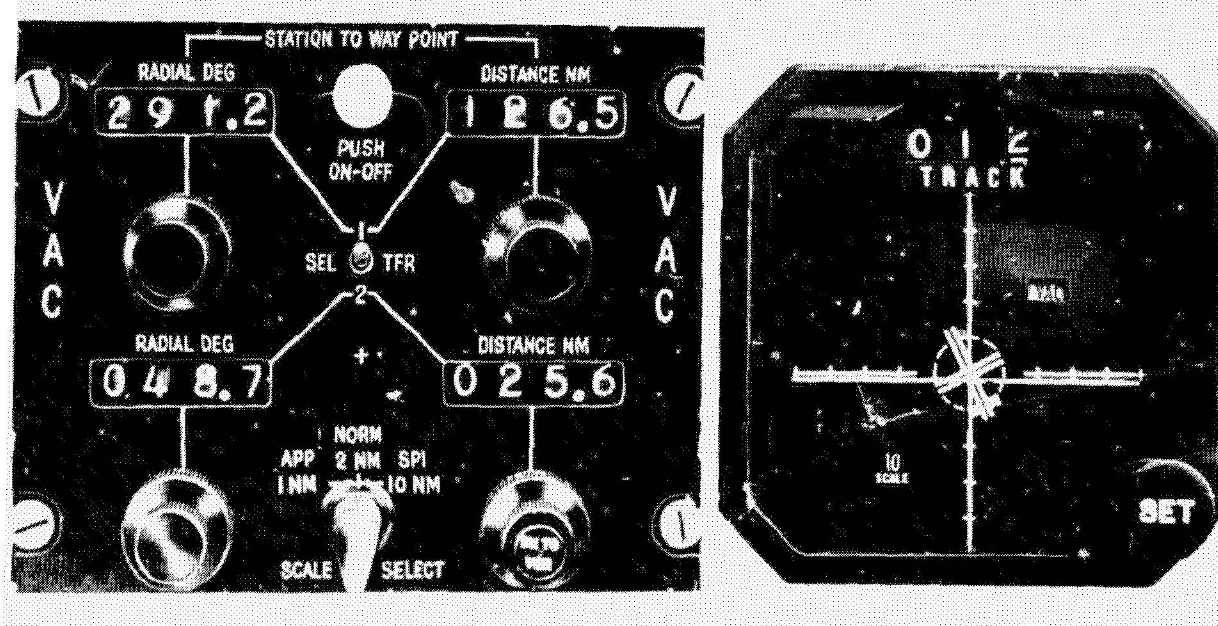


Figure B-2 - Butler-National VAC system.

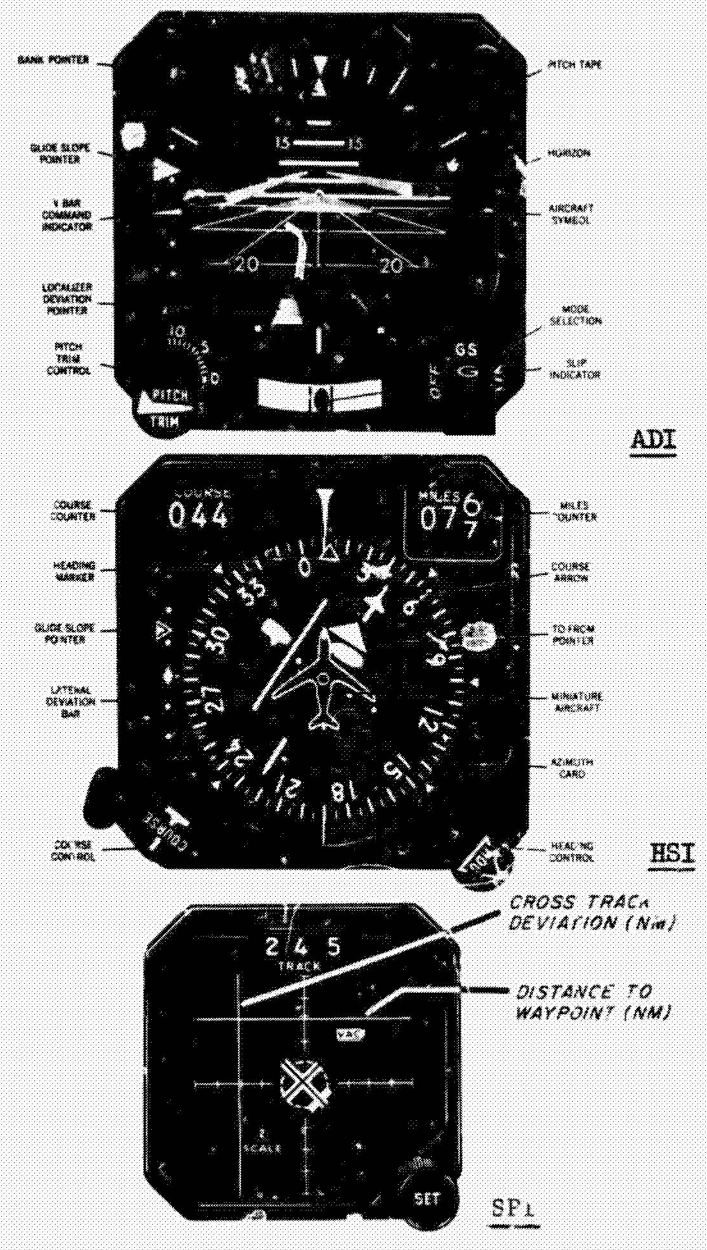


Figure B-3 - Conventional cockpit displays for area navigation.

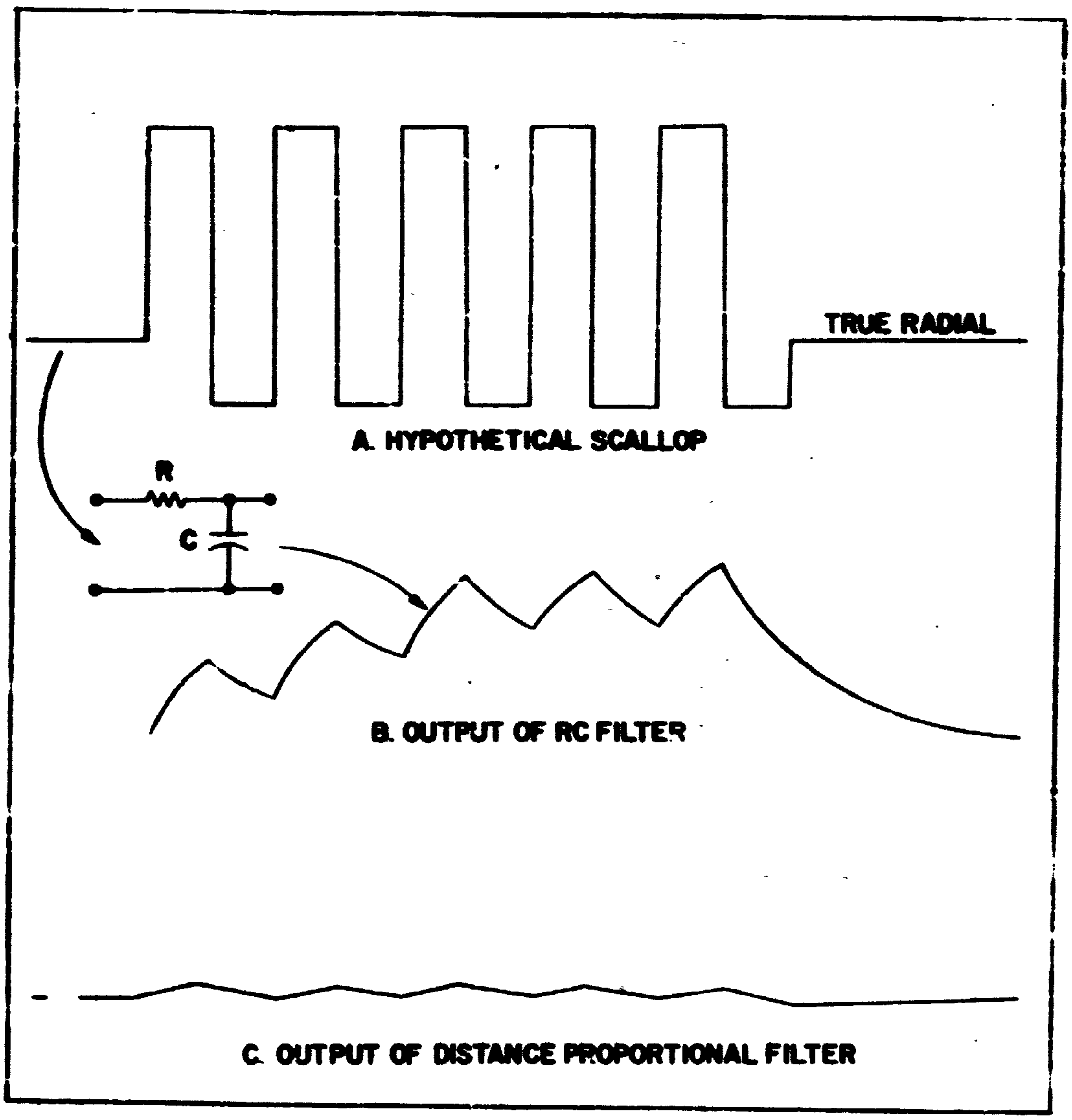


Figure B-4 - Illustrative waveforms for on-board VOR processing.

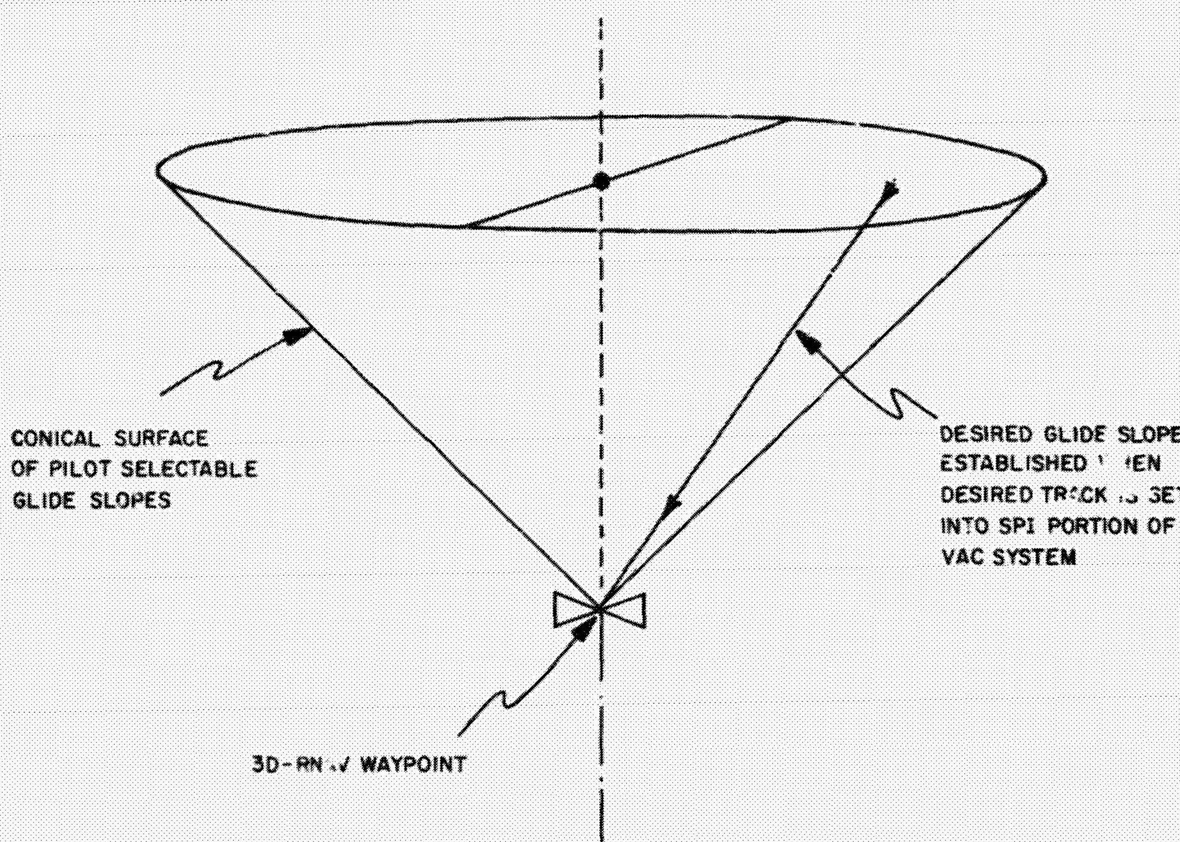
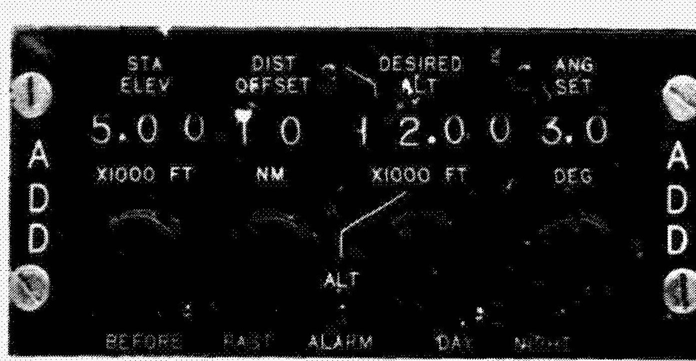
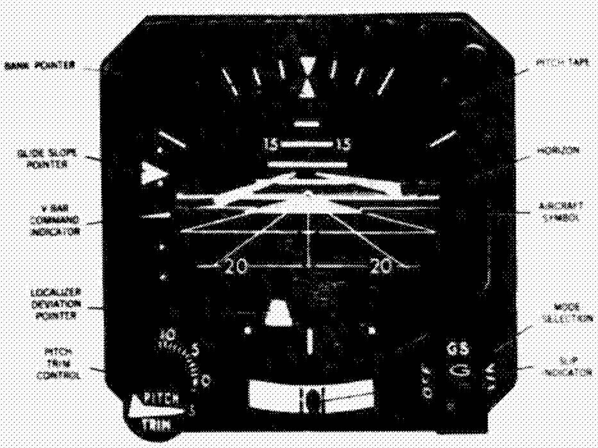


Figure B-5 - 3D-RNAV waypoint for a vertical glide slope.

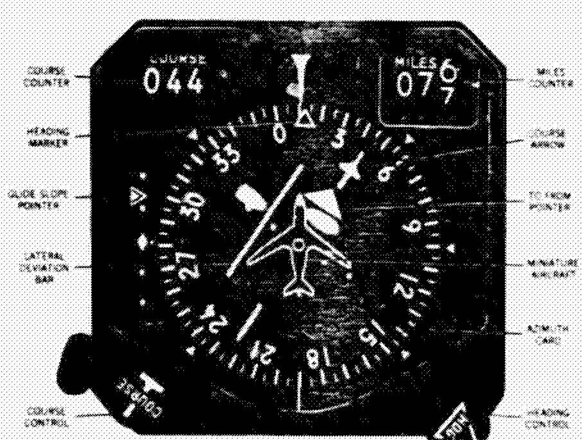


ADD Waypoint
Selector
Control

Figure B-6 - Butler-National cockpit-mounted ascent-descent director.



ADI



HSI

Figure B-7 - Conventional cockpit displays for vertical guidance.

APPENDIX C

AIRBORNE DATA RECORDER EQUIPMENT

Navigation and Guidance Signals

Bettelle-Columbus Laboratories (Columbus, Ohio) designed and operated the required airborne data acquisition system as a subcontractor to American Airlines. The system consisted of two major units: an electronic signal conditioner/amplifier unit, built by Battelle; and a Sangamo 3560 series portable FM magnetic tape recorder/reproducer, on loan from NASA. Both units were mounted in the passenger cabin. The signal conditioner/amplifier unit operated the 28V dc supply and the 110V 400 Hz ac supply. The recorder operated from a 110V, 60 Hz ac supply generated by a dc-to-ac converter supplied by American Airlines. The signal conditioner/amplifier unit also supplied $\pm$ 10V dc power to the 2000 ohm potentiometer generating the DME range signal.

All data channels were capable of recording dc signals. Since nominal upper frequency content of the signals was about 1 Hz, channel band width was not a problem. Thirteen data channels and the tape edge voice channel were used in the flight test. A listing of recorded parameters and major signal characteristics are shown in figure 32 and figure 33.

Functional Unit Design

Design of the data collection equipment can be explained by referring to figure C-1, the block diagram of the airborne data acquisition equipment. All signals and power are connected to the equipment through a terminal strip inside an enclosure. The funcational units are discussed below.

DC-DC Converter

Aircraft 28V dc power is coupled to the -to-dc converter which is located on a power supply panel alo ith the reference voltage generator and the calibration signal generator. The dc-to-dc converter contained two dc-to-dc converters regulated to 0.1% whose outputs were isolated from their inputs. The negative output of one converter and the positive output of the other converter were grounded to produce an isolated $\pm$ 15V dc with a common ground. This voltage was used to power the reference voltage generator, the calibration signal generator, the high impedance input amplifiers, the differential amplifiers, and the signal conditioning amplifiers.

Reference Voltage Generator

The reference voltage generator contained two Zener diodes as voltage references and four series regulated power supplies providing calibrated voltages of + 10, + 1, -1, and - 10 volts from the ± 15V dc supplied by the dc-to-dc converter. These voltages were used to supply the recorder calibration signals of + 1, 0, and -1V dc to the recorder coupler unit; + 10, +1, -1, and - 10V dc to the calibration signal generator; ± 10V dc to the 2000 ohm potentiometer on the output shaft of the DME equipment; and ± 10V dc to the 20,000 ohm output potentiometers of the synchro-to-dc converters.

Calibration Signal Generator

The generator contains a linear, 10-turn wire wound potentiometer with 10-turn dial capable of being switched to any of the four reference voltage generator outputs. The slider of this potentiometer is connected to an operational-type power amplifier so that a well-regulated voltage of +10, + 1, - 1, or -10 volts (or any fraction thereof, depending upon the dial setting), can be generated at the output of the calibration voltage generator. The calibration voltage is connected to the mode switches on each of the signal conditioning amplifiers, and the high input impedence amplifiers. This arrangment enables a preset voltage of either polarity to be delivered to any of these locations.

Synchro-to-DC Converter

The synchro-to-dc converter is an electromechanical servomechanism for converting a three-wire synchro transmitter signal into a dc signal corresponding to the shaft position of the synchro transmitter. Basic elements of the converter are a high impedance control transformer, an ac power amplifier, a phase-sensitive motor and a precision wire-wound potentiometer. The control transformer stator is coupled directly to the synchro input signal. Its output, the rotor signal, is coupled to the power amplifier which drives the motor. Motor and amplifier power are derived from 110V, 400 Hz ac input power supplied to the converter. The control transformer, motor, and potentiometer shafts are coupled together through a gear train.

Converter operation is explained briefly as follows. Any difference between the control transformer shaft position and the synchro transmitter shaft position implicit in the synchro signal causes the control transformer to generate an error signal whose amplitude and phase are related to the magnitude and direction of the difference in shaft positions. This error signal is amplified and applied to the motor along with the reference 115V 400 Hz ac. The motor drives the control transformer shaft to correspond to the input shaft position to reduce the error signal at zero. The shaft drives the output potentiometer whose resistance is proportional to shaft position.

High Input Impedance Amplifiers

High input impedance (>10^7 ohms) and low output impedance was used to isolate the input signal from the output. The amplifier can be connected to three input signals through a rotary switch. These are GROUND for zeroing the amplifier, SIGNAL for passing the desired signal, and CAL for calibrating and checking the amplifier or adjusting subsequent stages.

Differential Amplifiers

These amplifiers are located in groups of five on three separate amplifier panels. These same panels provide space for differential amplifiers as need. The amplifiers are equipped with a 100,000 ohm 10-turn continuous gain adjustment potentiometer providing a gain range from 0 to 5. They also have a step gain adjustment which changes the gain in steps of 4 over a gain range from 0 to 20.

The amplifiers utilize a suppression circuit employing a 20,000 ohm suppression resistor and 1000 ohm 10-turn suppression adjustment potentiometer. The suppression circuit can be connected to any of the four reference voltages of + 10, + 1, - 1, - 10V dc. The input impedance of the amplifier is 20,000 ohms. The amplifier input can be connected by rotary switch to GROUND for zeroing the amplifier when the suppression is turned off, i.e., suppression resistor to ground; SIGNAL when the input signal is to be processed; and CAL for calibrating and checking the amplifier.

Recorder Coupler

The recorder coupler is a set of ganged rotary switches, one for each signal channel, in series between the outputs of the signal conditioning amplifiers and the recorder. The function of the recorder coupler is to enable the equipment operator to conveniently couple calibration signals of +1, 0, and - 1V dc into the recorder input. This is done by turning the rotary switch to the desired signal source. In normal operation, the switches are set to the SIGNAL position and the recorder inputs connected directly to the amplifier outputs.

Recorder Microphone

The recorder microphone is an accessory to the tape recorder that allows the equipment operator to record oral information about the data being recorded on the magnetic tape along with the data. This feature does not interfere with the recording of data on the data channels and is a second voice channel separate from the cockpit voice data being recorded on one of the data channels.

Interconnecting Cabling

The interconnecting signal cabling is shown in figure C-2. All signals were carried in shielded cables. All single-ended signals were carried in shielded coaxial cables between units. Coaxial cable connectors were located on the front panel of most equipment to permit convenient connection to the signal at the input to the unit for voltage measurement or other purposes.

Signal Flow

Five types of signals were connected to the input of the data collection equipment. The first was a dc signal referenced to ground; the second is a dc floating output requiring a load to ground of 20,000 ohms or more, with a signal level on the order of 200 millivolts and a differential impedance of about 200 ohms; the third is a set of three-wire synchro signals; and the fourth was a dc signal generated by the slider of a 2000-ohm potentiometer connected to -10V dc and ground and the fifth is an audio signal requiring isolation from system ground. Each type of signal was processed differently. The processing is explained below.

Single-Ended Signals (Channels 1, 10, 13, and 14)

The first type, called single-ended signals, is represented by Group F in figure C-2. These signals are coupled directly to the signal conditioning amplifiers with one amplifier for each signal channel. Amplifier gain and suppression are set to provide voltages in the range of $\pm$ 1.4V dc at the output of the amplifier for corresponding voltages over the full scale span of the input signal. The outputs of these amplifiers are then coupled to the recorder through the recorder coupler.

Differential Signals (Channels 7, 9, 11, and 12)

The four channels with differential input signals, shown as Group E in figure C-2 are coupled into the differential amplifiers. These amplifiers convert the differential signals into single-ended signals for further processing by the signal conditioning amplifiers. The differential amplifiers have sufficient common mode and differential input impedance (about 30,000 and 160,000 ohms respectively) to not load the circuits to be measured. The signal conditioning amplifiers gain and suppression are set as described previously for single-ended signals.

Synchro-Derived Signals (Channels 3, 6, and 8)

This type of signal is shown as Group D in figure C-2. These signals are connected to the synchro-to-dc converts, one signal set to a converter. The synchro converter positions its control transformer shaft to correspond to the synchro shaft position implicit in the input signal. The control transformer shaft drives the slider of a potentiometer which is connected to -10V dc and ground. The slide voltage indicates shaft position which in turn corresponds to synchro shaft position. One turn of the synchro shaft generates a 10-volt swing of the slider voltage. The slider voltage is connected to a high impedance input amplifier. The amplifier, whose input impedance is greater than 10 megohm does not significantly load the synchro-to-dc converter 20,000-ohm output potentiometer. This output signal corresponds to the converter output within 99.95 percent. The output of the high input impedance amplifier is then connected to a signal conditioning amplifier. The signal conditioning amplifier gain and suppression are set and the resultant signal coupled to the recorder as described previously.

Potentiometer Derived Signals (Channel 4)

This signal is shown as Group B in figure C-2. It is similar in nature to the output of the synchro-to-dc converter and is processed in the same manner. It is coupled to a high input impedance amplifier and in turn to a signal conditioning amplifier and the tape recorder through the recorder coupler. Adjustment of the amplifier is as described previously.

Audio Signal (Channel 2)

This signal is shown as AUDIO in the block diagram. It is coupled to the signal conditioning amplifier through an isolation transformer. Amplifier gain was adjusted with the air of an oscilloscope to obtain $\pm$ 1.4 volts peak to peak at the upper limit of expected input audio signal magnitude.

Recorder Signals

All signals to the recorder are coupled to it through the recorder coupler except the tape edge voice channel. As previously discussed the recorder coupler is used to conveniently introduce calibration signals into all of the recorder channels.

Daily Operating Procedure

The daily operating procedure was as follows:

(1) In the preflight period the equipment was turned on and allowed to warm up,

(2) A reel of tape was carefully installed in the unit so the tape position indicator reading would record approximately the same tape position and length of tape each day.

(3) Just before takeoff the aircraft was switched to internal power.

(4) The zero setting of the amplifiers was initially checked several times a day; after it was found that zero drift was negligible and noncumulative, the setting was checked once a day.

(5) After the aircraft reached cruise altitude, the recorder was placed in the record mode and the standard + 1, -1V and ground signals were coupled to all channels inputs. In addition, the date, day number, time, and tape number were recorded on the tape edge voice channel. The recorder was then put in a standby mode.

(6) The tape recorder was switched to the record mode at the start of each approach and run until the approach was completed (about 3½ minutes).

(7) During the approach, the approach number and verbal comments about significant developments in the approach, if any, were recorded through the tape edge voice channel by the equipment operator.

(8) At the completion of the approach, the tape recorder was switched to the standby mode.

(9) Steps 6 through 7 were repeated for each approach during the flight.

(10) At the end of a flight the tape was rewound and removed from the recorder.

(11) Each tape was played back on the ground on a laboratory tape playback unit and the channel outputs recorded on a strip chart recorder.

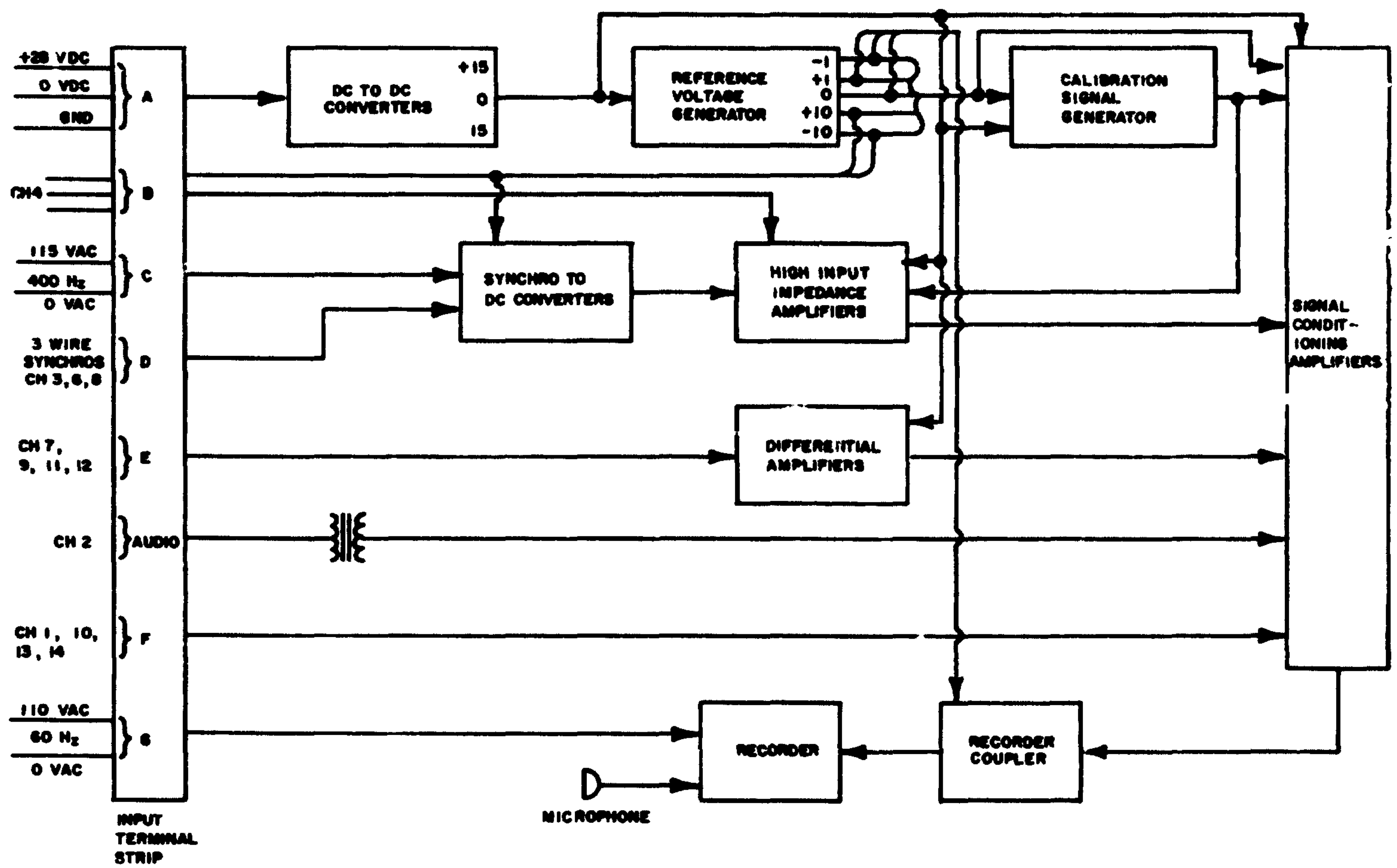


Figure C-1 - Airborne data acquisition equipment block diagram.

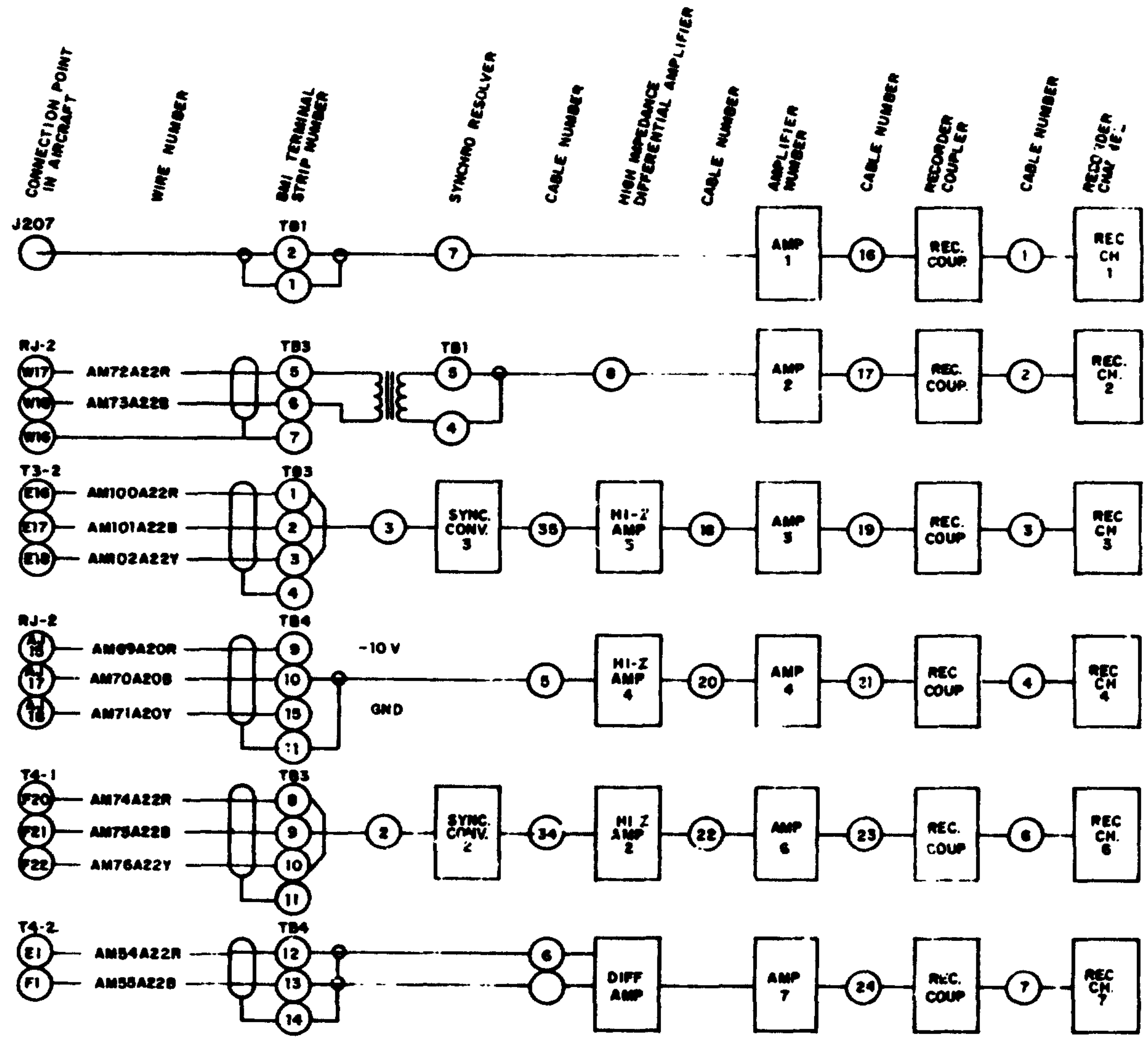
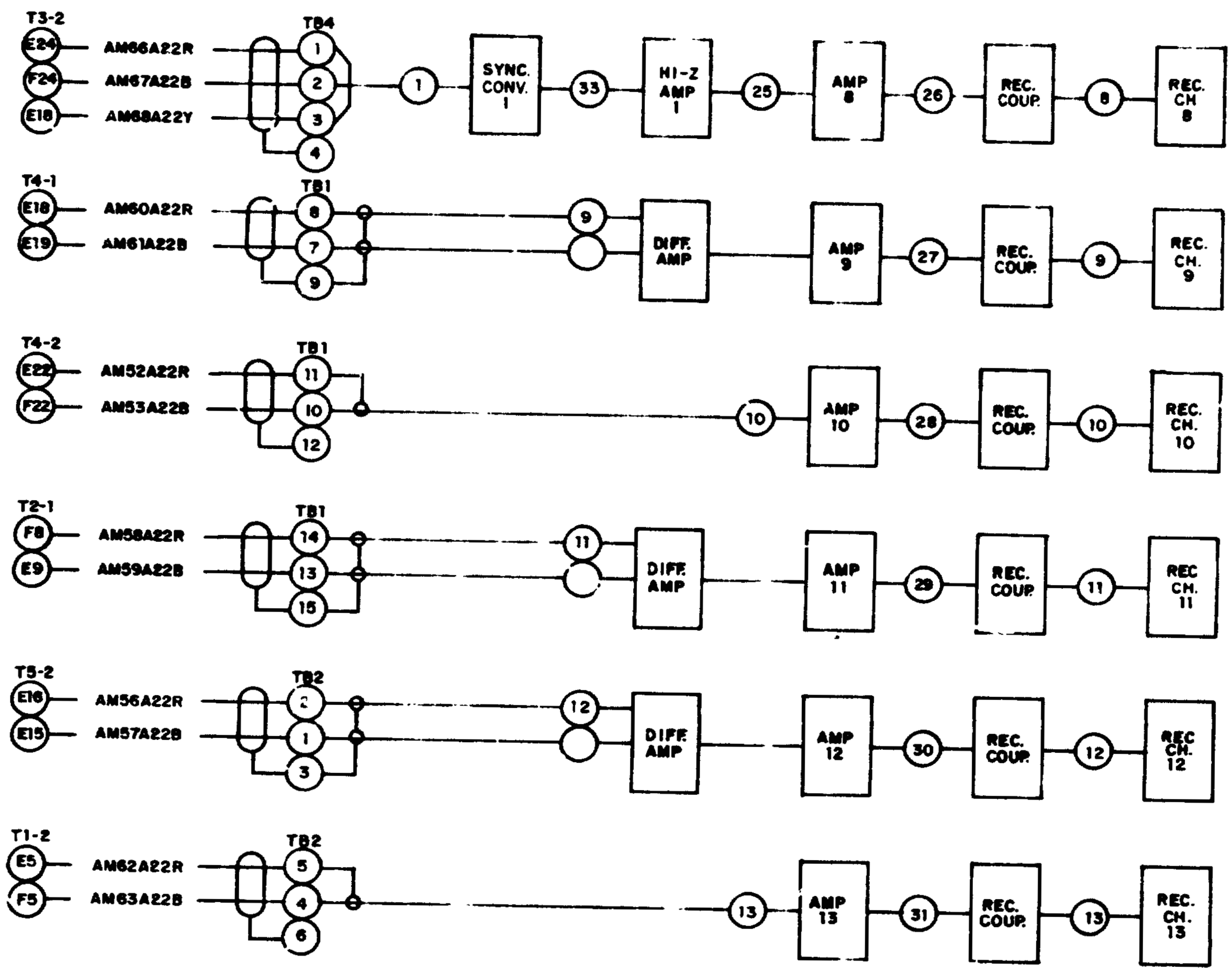


Figure C-2 - Interconnecting signal cabling.



Figu   - Interconnecting signal cabling (cont'd.).

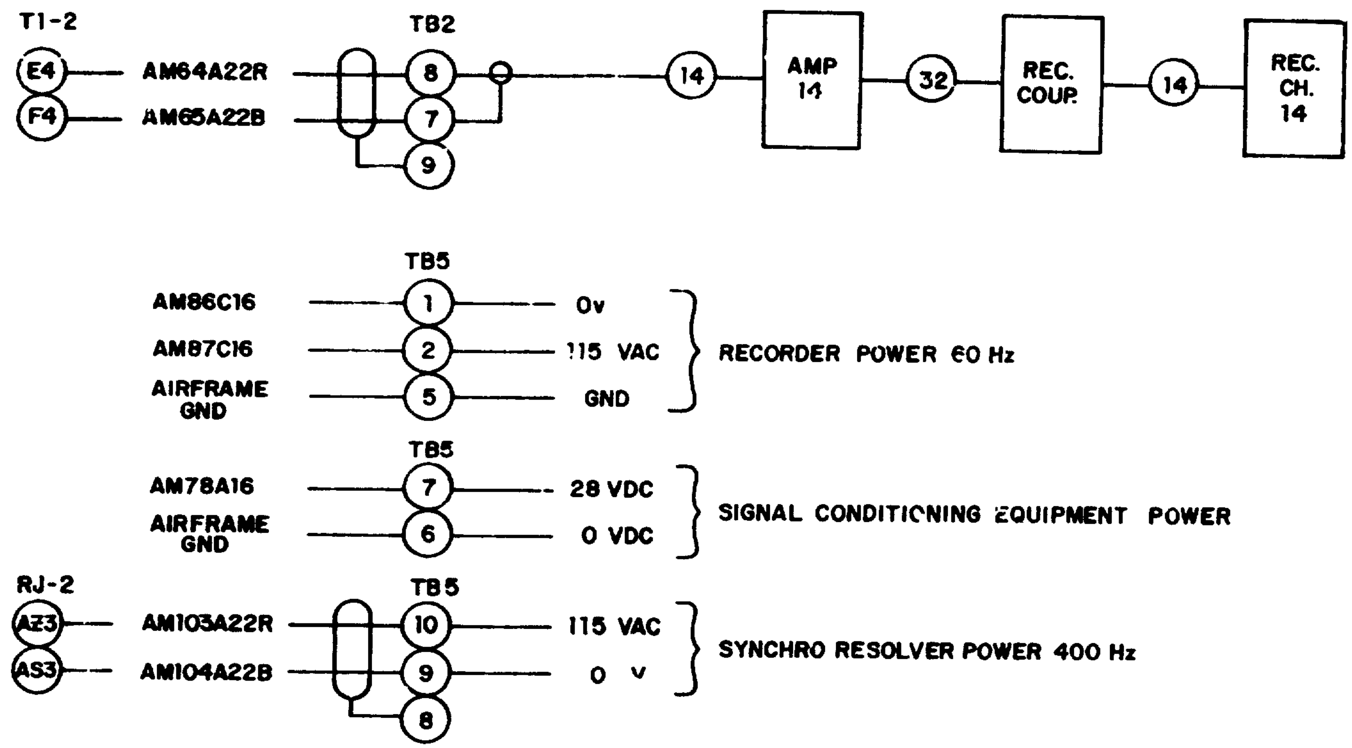


Figure C-2 - Interconnecting signal cabling (cont'd.).

APPENDIX D

TRACKING RADAR EQUIPMENT

CHARACTERISTICS

The Bell Aerospace EEM tracking radar system is housed in a portable van. The basic system components include VHF and UHF transmitters, ILS equipment, two analog computers, the operator's console, the radar antenna and pedestal (which is positioned next to the van during use), and a diesel generator. Set up time, including alignment, usually requires two days.

Operating Principles

The Bell Aerospace EEM Tracking Radar consists of a reflector with a radiator, spin motor, and a reference generator. The circular waveguide is offset to produce a conical scan pattern. The modulated return signal (100 Hz) is detected and used as an error signal to keep the axis of the conical antenna pattern centered on the aircraft during tracking mode.

The receiving section of the radar converts returning echo pulses to an intermediate frequency and detects the video information. The range tracking system receives the video target pulses from the receiving system and is automatically tracked for ranges up to 50,000 feet (8 nm).

Basically the range tracking system measures the time elapsed between the transmitted pulse and a selected echo pulse. The range tracking system converts this to a dc voltage proportional to slant range distance (R_S) of the aircraft.

Radar Transmitter

1.	Frequency Band	Ka
2.	Frequency Range	33.0 to 33.4 gHz
3.	Type of Transmission	Pulse
4.	Pulse Repetition Rate	2000 $\pm$ 100 pulses per second
5.	Pulse Width	0.2 microseconds
6.	Peak Power Output	50 kilowatts
7.	Average Power	20 watts

Radar Receiver

1.	Reception	Superhetrodyne
2.	Frequency Range	33.0 to 33.4 gHz
3.	Receiver Gain	100 db
4.	Oscillator Frequency	60 mHz below transmitter
5.	IF Frequency	60 mHz

R oar Antenna

1.	Antenna Type	Parabolic reflector with front offset nutating feed.
2.	Scan	Conical
3.	Antenna Gain	48.7 db
4.	Polarization	Circular or Linear
5.	Init al Positioning	Manual or Automatic
6.	Limits of Travel	70^o azimuth, -5^o, $+30^o$ elevation
7.	Limits of Automatic Search Pattern	20^o azimuth, 1^o elevation from initial reference position
8.	Beam width without nutation	0.57^o
9.	Beam width with nutation	0.85^o

Tracking Coordinates

Azimuth and elevation information is obtained from precision sinecosine potentiometers geared to both the aximuth and elevation gimbals of the antenna. Slant range distance (R_s) from the range tracking portion of the radar is applied to the inputs of the potentiometers and the following three dimensional X, Y, Z coordinates are obtained at the outputs for subsequent recording:

R_s corrected tc [illegible]erline	(X)	$R_s \cos \psi$
Lateral displacement	(Y)	$R_s \sin \psi$
Altitude	(Z)	$R_s \sin \theta$

Where θ is elevation gimbal angle and ψ is azimuth gimble angle.

NOTE: The radar does not compute θ or ψ directly, nor does compute ground range ($R_s \cos \psi$) $\cos \theta$.

Tracking Accuracy

1	Range Tracking	15 ft or 1% of slant range whichever is greater
2.	Static Angular Error	0.01^o
3.	Dynamic Angular Error a. Angular Tracking Rate of 50^o/sec	0.? milliradian (rms) (azimuth and elevation)

General Capabilities

The EEM Radar is capable of tracking any large aircraft, i.e., DC-8, Convair 990, etc. up to 8 nautical miles range without a corner reflector installed on the aircraft. However, a small 804 square centimeters corner reflector was added to N7545A to insure good ra ge tracking and noise free data. The corner reflector provided an enhanced return for point tracking and thereby eliminated the tendency of the radar to skin track the airplane.

An Esterline Angus XZ plotter is normally used for real time plotting of aircraft altitude versus slant range distance. The radar is also equipped at present with an Ampex CP-100 analog magnetic tape recorder (NASA-owned) which is used to record X, Y, Z, coordinate position data.

The radar can be used in both open- and closed-loop operations. In the open-loop mode, the radar passively records aircraft positions, but no feedback is given to the pilot. In the closed-loop mode the EEM, using two analog computers, can compare a preprogrammed flight path, (linear as well as nonlinear) with actual aircraft position in real time and generate error signals which are transmitted over an ILS data link (331.1 mHz for glide slope, 111.9 mHz for localizer) to the aircraft. Both flight path and ILS sensitivity can be programmed to any specifications.

Voice communication with the aircraft is achieved through use of two independent VHF transceivers which can be tuned to all common VHF frequencies.

APPENDIX E

3D-RNAV POSITION ERROR MODELS

Actual Position

ACTX, ACTY, and ACTZ, the actual position of the aircraft with respect to the runway touchdown point was computed from the radar measurements RADARX, RADARY, and RADARZ as follows:

$$\theta_1 \quad \arcsin\,(RADARZ/RADARX)$$

$$ACTX = RADARX \bullet \cos\,(\theta_1)$$

$$ACTY = RADARY$$

$$ACTZ = RADARZ$$

Because of a +12 arc minute misalignment of the X-axis radar measurement prior to August 26, 1971, the altitude measurements for those days were low by 12 arc minutes. Hence, for those days the RADARZ measurement was first corrected as follows before the above computations were made:

$$\theta_2 = \arcsin\,(RADARZ/RADARX)$$

$$RADARZ = RADARX \sin\,(\theta_2 + 12 \text{ arc minutes})$$

Desired Position

Figure E-1 depicts the desired two-segment approach profile. (The desired component of Y is 0.) Given ACTX, the desired Z was expressed as follows:

$$DESZ = ACTX \tan 2.5^o,\ 0 \leq ACTX \leq 9161.7 \text{ feet}$$

$$DESZ = (ACTX - 5344.8) \tan 6^o,\ 9161.7 \leq ACTX \leq 33{,}680.7$$

$$DESZ = 3000 \text{ ft., } ACTX > 33{,}680.7$$

ACTX and ACTY were used to compute the alongtrack (RNAVX) and crosstrack (RNAVY) components of the RNAV coordinate system centered at the waypoint.

$$RNAVY = ACTX - 5355.8$$

$$RNAVY = ACTY$$

Vertical Error Model

The vertical error model involved computing the RNAV vertical errors during RNAV guidance (for a distance to touchdown greater than 1.6 nm) and the glideslope error during ILS guidance. The vertical error model is shown in figure 27.

The glideslope deviation in dots (ONB11) was first converted to glideslope deviation in feet (IND GLS). The following formula was used:

$$\text{Indicated deviation in dots (ONB11)} = 164 \; \frac{\text{(Indicated deviation in feet)}}{\text{(Horizontal projection of distance along glideslope)}}$$

The glideslope is located at the runway touchdown point. Hence, using the above formula,

IND GLS = ACTX*ON311/164

Since the Stockton glideslope is set at 2.5^{o}, the actual glide slope deviation (GLS) was computed as follows:

GLS = ACTZ - ACTX*tan (2.5^{o}),

from which the glideslope error was computed as:

GLSE = IND GLS - GLS.

The RNAV vertical errors were computed as follows: For ACTX greater than 9,161.7 feet, the indicated RNAV distance to waypoint recorded on Channel 7, was used to compute the desired altitude as a function of indicated distance to waypoint (IND DIST WYPT), i.e.

DES ALT INDX = 3000 feet if IND DIST WYPT is greater than or equal to 28,324.9 feet, and

DES ALT INDX = IND DIST WYPT*tan (6^{o}) if IND DIST WYPT is less than 28,324.9 feet.

The desired altitude was computed as a function of the distance to the waypoint in a similar fashion:

DES ALT ACTX = 3000 feet if RNAV ATK is greater than or equal to 28,324.9 feet.

DES ALT ACTX = RNAV ATK*tan (6^{o}) if RNAV ATK is less than 28,324.9 feet.

The RNAV commanded altitude (RNAV COM ALT) was defined as the sum of indicated altitude (IND ALT) recorded on Cahnnel 6 and the

RNAV vertical path deviation (ALT DEV) recorded on Channel 9, that is,

RNAV COM ALT = IND ALT + ALT DEV.

The actual commanded altitude (ACT COM ALT) is the sum of the actual altitude (ACTZ) and the RNAV vertical path deviation:

ACT COM ALT = ACTZ + ALT DEV.

The actual altitude error (ACT ALT ERR) can be expressed as the difference between the desired altitude at the present position and the actual altitude, that is,

ACT ALT ERR = DES ALT ACTX - ACTZ.

The altitude error attributable to the distance error (DIST ALT ERR) was defined as:

DIST ALT ERR = DES ALT INDX - DES ALT ACTX.

The altitude error due to the RNAV system (RNAV ALT ERR) was defined as:

RNAV ALT ERR = RNAV COM ALT - DES ALT INDX.

The net altitude error (NET ALT ERR) was defined as:

NET ALT ERR = RNAV COM ALT - DES ALT ACTX.

The altimeter error (ALTIM ERR) was defined as the difference between the indicated altitude (IND ALT) and the actual altitude, i.e.,

ALTIM ERR = IND ALT - ACTZ.

<u>Horizontal Error Model</u>

The horizontal error model computed the RNAV and VORTAC indicated horizontal position errors and decomposed these errors into their along-track and cross-track components and their VOR and DME components. (figure 28)

The RNAV indicated position, decomposed into X and Y components (RNAVIX, RNAVIY), was computed using the RNAV horizontal deviation, Channel 10 (ONB10), and the distance to waypoint Channel 7 (ONB7), as follows:

RNAVIY = ONB10

RNAVIX = ONB7

The RNAV cross track error (RNAV XTKE), RNAV along track error (RNAV ATKE) and RNAV horizontal error (RNAV HORE) were then determined as follows:

$$\text{RNAV ATKE} = \text{RNAVIX} - \text{RNAVX}$$
$$\text{RNAV XTKE} = \text{RNAVIY} - \text{RNAVY}$$
$$\text{RNAV HORE} = [(\text{RNAV ATKE})^2 + \text{RNAV XTKE})^2]^{1/2}$$

The RNAV indicated position referenced to the VORTAC station was then computed. The RNAV position referenced to the VORTAC station (RNAV VOR) is determined as follows:

$$\overrightarrow{\text{RNAV VOR}} = \overrightarrow{\text{WYPT}} + \overrightarrow{\text{RNAV}}.$$

The indicated and actual RNAV positions referenced to the VORTAC station were computed by converting the RNAV from X-Y coordinates to E-N coordinates and then to bearing-distance coordinates. The RNAV VOR error (RNAV VORE) and RNAV DME error (RNAV DMEE) was computed as:

$$\text{RNAV VORE} = \text{RNAV IVOR} - \text{RNAV VOR, and}$$
$$\text{RNAV DMEE} = \text{RNAV IDME} - \text{RNAV DME}.$$

A similar error analysis was performed on the VORTAC indicated position. The VORTAC indicated DME was recorded on the onboard channel 4 (ONB4). The VORTAC indicated DME (VORTAC IDME) was corrected for slant range errors as follows:

$$\text{VORTAC IDME} = \text{ONB4*cos (arcsin (ACTZ/ONB4))}$$

The VORTAC indicated bearing was computed from the onboard Channel 3 (ONB3) and the computed heading of the aircraft as described in the following paragraphs.

ONB3 was the recorded bearing of the VORTAC station referenced to the aircraft heading. From the aircraft's present position (ACTX, ACTY) and past position (ACTXP, ACTYP), the heading of the aircraft with respect to the runway (θ_4), was approximated as follows:

$$\theta_4 = - \arctan \frac{(\text{ACTYP} - \text{ACTY})}{(\text{ACTXP} - \text{ACTX})}$$

The sum of ONB3 and θ_4 was the bearing to the VORTAC station from the aircraft with respect to runway bearing 291° (-69°). Subtracting 69° from θ_4 changed the reference bearing to a reference bearing of 360° (magnetic North). This bearing is 180° out of phase with the bearing of the aircraft from the VORTAC station referenced to magnetic North. Hence the VORTAC indicated bearing (VORTAC IVOR) was computed as follows:

$$\text{VORTAC IVOR} = \text{ONB3} + \theta_4 - 69^\circ + 180^\circ$$

The remainder of the VORTAC error analysis follows the analysis performed on the RNAV indicated position measurements.

The indicated localizer deviation (dots deflection) was recorded on the onboard measurement channel 12 (ONB12). It was converted to indicated localizer deviation in feet (IND LOC) as follows.

The Stockton ILS has a 4^o localizer. For a 4^o localizer, the following formula applies:

$$\text{Indicated deviation in dots (ONB12)} = 57.3 \frac{(\text{Indicated deviation in feet})}{(\text{Centerline projection of distance along localizer})}$$

The Stockton localizer is located 8750 feet behind the runway touchdown point. Hence, using the above formula

$$\text{IND LOC} = (\text{ACTX} + 8750)\ \text{ONB12}/57.3.$$

The localizer error, LOCE, is then

$$\text{LOCE} = \text{IND LOC} - \text{ACTY}$$

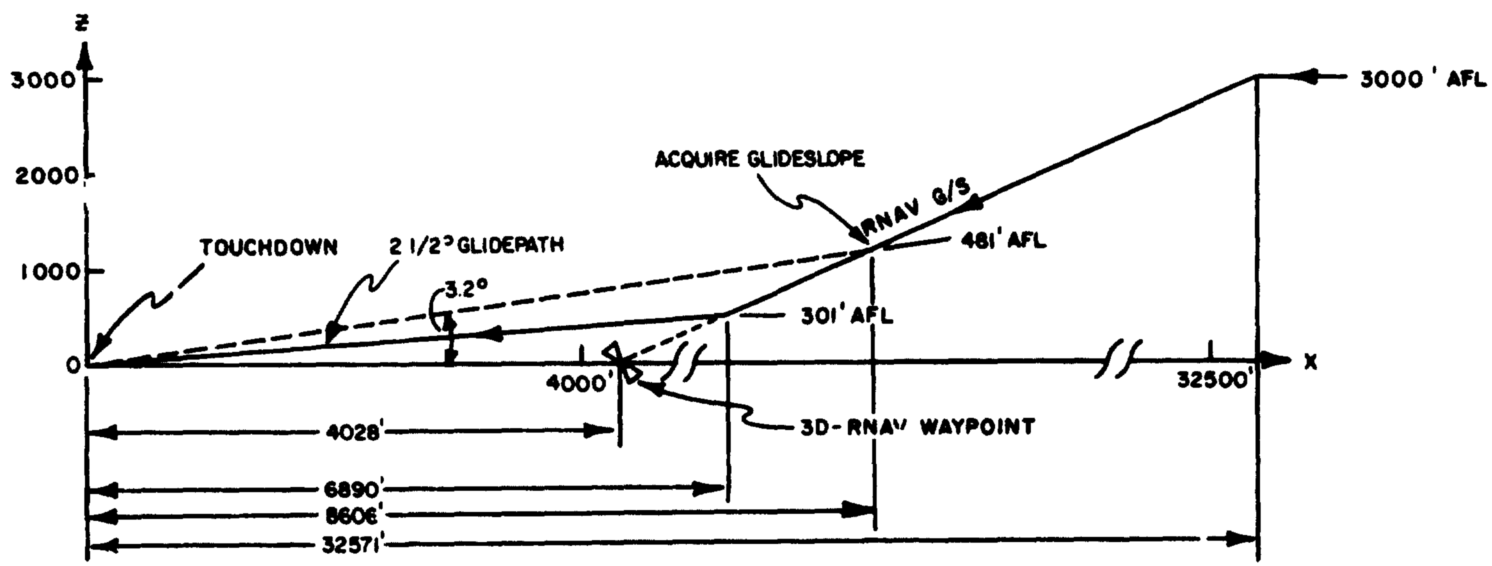


Figure E-1 - Desired two-segment approach profile.

APPENDIX F

POSITION ERROR STATISTICS

A total listing of all available sample statistics is shown in figure F-1. Actual statistics for each error parameter at each 0.2 nautical mile interval along the final approach path are shown in figures 35, 36, and 37.

MINIMUM	Smallest in algebraic value of $x_1, \ldots, x_n$
MAXIMUM	Largest in algebraic value of $x_1, \ldots, x_n$
RANGE	Maximum minus minimum
SAMPLE SIZE	Number of observations, or n
SUM	$\sum_{i=1}^{n} x_i$
MEAN	$\sum_{i=1}^{n} x_i / n$; denoted by $\bar{x}$
MEAN DEVIATION	$\sum_{i=1}^{n} \lvert x_i - \bar{x} \rvert / n$
SUM OF SQUARES	$\sum_{i=1}^{n} x_i^2$; denoted by S_x^2
VARIANCE	$(S_x^2 - n\,\bar{x}^2)/(n-1)$; denoted by s_x^2
STANDARD DEVIATION	$\sqrt{s_x^2}$; denoted by s_x
STANDARD ERROR OF THE MEAN	$s_x/\sqrt{n}$
COEFFICIENT OF VARIATION	$s_x/\bar{x}$
SKEWNESS	$\Sigma(x_i - \bar{x})^3/(S_x^2)^{3/2}$

Figure F-1 - Formulas for statistical measures of DESTAT.

KURTOSIS	$\sum (x_i - \bar{x})^4 / S_x^4$
NUMBER OF RUNS UP AND DOWN	Number of times that $(x_{i+1} - x_i)$ and $(x_i - x_{i-1})$ have different algebraic signs; denoted by RUNS
EXPECTED NUMBER OF RUNS	$(2n-1)/3$; denoted by ENR
STANDARD DEVIATION OF NUMBER OF RUNS	$[(16n-29)/90]^{1/2}$; denoted by SDR
TEST FOR RUNS	$\lvert \mathrm{RUNS} - \mathrm{ENR} \rvert / \mathrm{SDR}$
SERIAL CORRELATION COEFFICIENT	$\dfrac{\sum_{i=1}^{n-1}\left(x_i - \frac{1}{n-1}\sum_{i=1}^{n-1} x_i\right)\left(x_{i+1} - \frac{1}{n-1}\sum_{i=1}^{n-1} x_{i+1}\right)}{\left[\sum_{i=1}^{n-1}\left(x_i - \frac{1}{n-1}\sum_{i=1}^{n-1} x_i\right)^2 \sum_{i=1}^{n-1}\left(x_{i+1} - \frac{1}{n-1}\sum_{i=1}^{n-1} x_{i+1}\right)^2\right]^{1/2}}$, denoted by r_1
RANKS OF THE RAW DATA	$r_1, \ldots, r_n$ where r_i is the algebraic rank of x_i; $r_i = j$ if x_i is the j^{th} smallest among $x_1, \ldots, x_n$
RANK CORRELATION COEFFICIENT	$1 - 6\sum_{i=1}^{n} (i - r_i)^2 / n(n^2-1)$; denoted by r_s where r_i is the algebraic rank of x_i among $x_1, \ldots, x_n$.
t-TEST OF RANK CORRELATION	$(n-2) r_s^2 / (1 - r_s^2)^{1/2}$; denoted by t and follows the "t" distribution with n-2 degrees of freedom.

Figure F-1 - Formulas for statistical measures of DESTAT (Cont'd).

MEAN CONFIDENCE LB (Lower Bound)	$\bar{X} - \frac{t_{\alpha/2}}{\sqrt{n-1}} s_x$; $1-\alpha = Pr(-t_{\alpha/2} < t < t_{\alpha/2})$, α = confidence, t = t-statistic with n-1 degrees of freedom
MEAN CONFIDENCE UB (Upper Bound)	$\bar{X} + \frac{t_{\alpha/2}}{\sqrt{n-1}} s_x$
VARIANCE CONFIDENCE LB (Lower Bound)	$\frac{(n-1)\, s_x^2}{\chi^2_{\alpha_2}}$; $\alpha_2 = Pr(\chi^2_{\alpha_2} < \chi)$, χ^2 chi-square statistic with n-1 degrees of freedom
VARIANCE CONFIDENCE UB (Upper Bound)	$\frac{(n-1)\, s_x^2}{\chi^2_{\alpha_1}}$; $\alpha_1 = Pr(\chi < \chi^2_{\alpha_1})$

Figure F-1 - Formulas for statistical measures of DESTAT (Cont'd).

SYMBOLS AND ABBREVIATIONS

AA	-	American Airlines, Inc.
ac	-	alternating current
ADD	-	ascent-descent director
ADF	-	automatic direction finding equipment
ADI	-	attitude director indicator
AFL	-	above field level
ALPA	-	Airline Pilots Association
APA	-	Allied Pilots Association
A/P	-	autopilot
APP	-	VAC approach position
ATC	-	air traffic control
CDI	-	course deviation indicator
dc	-	direct current
DH	-	decision height
DME	-	distance measuring equipment
EEM	-	engineering evaluation model radar (SPIN-10 prototype)
EPNdB	-	effective perceived noise in decibels
FAA	-	Federal Aviation Administration
FD	-	flight director
FM	-	frequency modulated
FMV	-	frequency modulated voltage
ft	-	foot
G/S	-	glide slope

Hz - hertzian; prefixes K(Hz x 10^3), m(Hz x 10^6), g(Hz x 10^{12})

IFR - instrument flight rules

ILS - instrument landing system

IRIG - inter-range instrumentation group

KVA - thousand volt-amperes

lb - pound

LOC - localizer

LSI - Lear Siegler, Inc.

MDC - McDonnell Douglas Corporation

ma - miliamperes

m^2 - square meters

mph - miles per hour

NASA - National Aeronautics and Space Administration

NAV - navigation

nm - nautical mile

$PNLT_{max}$ - maximum tone corrected perceived noise level

Rs - slant range distance

RC - resistance/capacitance network

RF - radio frequency

rho - area navigation terminology for distance data input. (DME distance in this case.)

R & D - research and development

RMDI - radio magnetic direction indicator (same as RMI)

RMI - radio magnetic indicator

RNAV - area navigation

rpm - revolutions per minute

SPI - symbolic pictorial indicator

theta - area navigation terminology for angular data input. (VOR radial in this case.)

V - volt

VAC - vector analog computer

VFR - visual flight rules

VHF - very high frequency

VOR - VHF omni-directional range

VORTAC or VOR/TAC - co-located VOR and TACAN stations

WWV - call letters for National Bureau of Standards time transmissions

3D-RNAV - three dimensional area navigation system

μa - microampere

Other symbols are defined in figures 29 and 30.

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8. Battelle Columbus Laboratories: Position Error Statistics and Histograms NASA-AA Two-Segment Approaches Using Second VAC Waypoint. December 10, 1971.

9. Battelle Columbus Laboratories: Position Error Statistics and Histograms NASA-AA Two-Segment Approaches Using Third VAC Waypoint. December 10, 1971.

10. Battelle Columbus Laboratories: Position Error Statistics and Histograms NASA-AA ILS Approaches. December 10, 1971.

11. Battelle Columbus Laboratories: Approach Model Data NASA-AA Two-Segment/ILS Approaches. December 10, 1971.

Figure 1 - Boeing 720-023B (N7545A) evaluation aircraft.

Form Approved
Budget Bureau No. 04-R0058

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
APPLICATION FOR AIRWORTHINESS CERTIFICATE

INSTRUCTIONS — Print or type. Do not write in shaded areas; these are for FAA use only. Submit original only to an authorized FAA Representative. If additional space is required, use an attachment. For special flight permits complete Sections II and VI or VII as applicable.

I. AIRCRAFT DESCRIPTION

1 REGISTRATION MARK	2 AIRCRAFT BUILDER'S NAME (Make)	3 AIRCRAFT MODEL DESIGNATION	4 YR MFG	FAA CODING
N7545A	Boeing	720-023B	1961	
5 AIRCRAFT SERIAL NO	6 ENGINE BUILDER'S NAME (Make)	7 ENGINE MODEL DESIGNATION		
18031	Pratt & Whitney	JT3D-1/3B		
8 NUMBER OF ENGINES	9 PROPELLER BUILDER'S NAME (Make)	10 PROPELLER MODEL DESIGNATION		11. AIRCRAFT IS
4	N/A	N/A		NEW / USED X / IMPORT

II. CERTIFICATION REQUESTED

APPLICATION IS HEREBY MADE FOR: (Check applicable items)

A 1 STANDARD AIRWORTHINESS CERT (Indicate category): NORMAL / UTILITY / ACROBATIC / TRANSPORT / GLIDER / BALLOON

B X SPECIAL AIRWORTHINESS CERTIFICATE (Check appropriate items)

- 2 LIMITED
- 5 PROVISIONAL (Indicate class): 1 CLASS I; 2 CLASS II
- 3 RESTRICTED (Indicate operation(s) to be conducted): 1 AGRICULTURE & PEST CONTROL; 2 AERIAL SURVEYING; 3 AERIAL ADVERTISING; 4 FOREST (Wild life conservation); 5 PATROLLING; 6 WEATHER CONTROL; 0 OTHER (Specify)
- 4 X EXPERIMENTAL (Indicate operation(s) to be conducted): 1 X RESEARCH AND DEVELOPMENT; 2 AMATEUR BUILT; 3 EXHIBITION; 4 RACING; 5 CREW TRAINING; 6 MKT. SURVEY; 0 TO SHOW COMPLIANCE WITH FAR
- 8 SPECIAL FLIGHT PERMIT (Indicate operation to be conducted, then complete Section VI or VII as applicable on reverse side): 1 FERRY FLIGHT FOR REPAIRS, ALTERATIONS, MAINTENANCE OR STORAGE; 2 EVACUATE FROM AREA OF IMPENDING DANGER; 3 OPERATION IN EXCESS OF MAX. CERTIFICATED TAKE OFF WEIGHT; 4 DELIVERING OR EXPORT; 5 PRODUCTION FLIGHT TESTING

C 6 MULTIPLE AIRWORTHINESS CERTIFICATE (Check appropriate Restricted Operation and Standard or Limited as applicable above)

III. OWNER'S CERTIFICATION

A REGISTERED OWNER (As shown on Certificate of Aircraft Registration) — IF DEALER, CHECK HERE →

NAME	ADDRESS
American Airlines, Inc.	633 3rd Avenue, New York, N.Y. 10017

B AIRCRAFT CERTIFICATION BASIS (Check applicable blocks and complete items as indicated)

X	AIRCRAFT SPECIFICATION OR TYPE CERTIFICATION DATA SHEET (Give No. and Revision No.) 4A28	X	AIRWORTHINESS DIRECTIVES (Check if all applicable AD's complied with and give latest AD No.) 71-9-2
	AIRCRAFT LISTING (Give page No(s).)		SUPPLEMENTAL TYPE CERTIFICATE (List number of each STC incorporated)

C AIRCRAFT OPERATION AND MAINTENANCE RECORDS

X CHECK IF RECORDS IN COMPLIANCE WITH FAR 91.173	TOTAL AIRFRAME HOURS — Enter for used aircraft only: 28,289	3	EXPERIMENTAL ONLY — Enter hours flown since last certificate issued or renewed: 0

D. CERTIFICATION — I hereby certify that I am the owner (or his agent) of the aircraft described above, that the aircraft is registered with the Federal Aviation Administration in accordance with Section 501 of the Federal Aviation Act of 1958, and applicable Federal Aviation Regulations, and that the aircraft has been inspected and is airworthy and eligible for the airworthiness certificate requested.

DATE OF APPLICATION	NAME AND TITLE (Print or type)	SIGNATURE
7/9/71	P. C. Johnson, Mgr.-FAA & ATA Programs	[illegible]

IV. INSPECTION AGENCY VERIFICATION

A THE AIRCRAFT DESCRIBED ABOVE HAS BEEN INSPECTED AND FOUND AIRWORTHY BY (Complete this section only if FAR 21.183(d) applies)

2 FAR PART 121 OR 127 CERTIFICATE HOLDER (Give Certificate No.)	3 CERTIFICATED MECHANIC (Give Certificate No.)	6 CERTIFICATED REPAIR STATION (Give Certificate No.)	
5 AIRCRAFT MANUFACTURER (Give Name of Firm)			
DATE	TITLE	SIGNATURE	

V. FAA REPRESENTATIVE CERTIFICATION

I have inspected the aircraft described in Item I or VII and find it meets the requirements for:

A STANDARD AIRWORTHINESS CERTIFICATE — B SPECIAL AIRWORTHINESS CERTIFICATE

4 C AMENDMENT OR MODIFICATION OF ITS CURRENT AIRWORTHINESS CERTIFICATE

DATE	DISTRICT OFFICE	4 DESIGNEE'S SIGNATURE AND NO	1 FAA INSPECTOR'S SIGNATURE

FAA Form 8130-6 (3-69) SUPERSEDES FAA FORM 305, AND FAA FORM 8100-3

Figure 2 - Application for an airworthiness certificate.

VI. PRODUCTION FLIGHT TESTING

A. MANUFACTURER

NAME	ADDRESS

B. PRODUCTION BASIS (*Check applicable item*)

- PRODUCTION CERTIFICATE (*Give production certificate number*)
- TYPE CERTIFICATE ONLY
- APPROVED PRODUCTION INSPECTION SYSTEM

C. GIVE QUANTITY OF CERTIFICATES REQUIRED FOR OPERATING NEEDS

DATE OF APPLICATION	NAME AND TITLE (*Print or type*)	SIGNATURE

VII. SPECIAL FLIGHT PERMIT PURPOSES OTHER THAN PRODUCTION FLIGHT TEST

A. DESCRIPTION OF AIRCRAFT

REGISTERED OWNER	ADDRESS
BUILDER (*Make*)	MODEL
SERIAL NUMBER	REGISTRATION MARK

B. DESCRIPTION OF FLIGHT

FROM	TO	
VIA	DEPARTURE DATE	DURATION

C. CREW REQUIRED TO OPERATE THE AIRCRAFT AND ITS EQUIPMENT

- PILOT
- CO-PILOT
- NAVIGATOR
- OTHER (*Specify*)

D. THE AIRCRAFT DOES NOT MEET THE APPLICABLE AIRWORTHINESS REQUIREMENTS AS FOLLOWS

E. THE FOLLOWING RESTRICTIONS ARE CONSIDERED NECESSARY FOR SAFE OPERATION (*Use attachment if necessary*)

Airspeed is restricted to 300 KIAS when radar corner reflector is installed.

F. CERTIFICATION—I hereby certify that I am the registered owner (or his agent) of the aircraft described above, that the aircraft is registered with the Federal Aviation Administration in accordance with Section 501 of the Federal Aviation Act of 1958, and applicable Federal Aviation Regulations, and that the aircraft has been inspected and is airworthy for the flight described

DATE	NAME AND TITLE (*Print or type*)	SIGNATURE
7/9/71	F.C. Johnson, Mgr.-FAA & ATA Programs	[illegible]

VIII. AIRWORTHINESS DOCUMENTATION (FAA use only)

A Operating Limitations and Markings in Compliance with FAR 91.31 as Applicable	G Statement of Conformity, FAA Form 317 (*Attach when required*)
B Current Operating Limitations Attached	H Foreign Airworthiness Certification for Import Aircraft (*Attach when required*)
C Data, Drawings, Photographs, etc. (*Attach when required*)	I Previous Airworthiness Certificate Issued in Accordance with FAR ______ CAR ______ (*Original attached*)
D Current Weight and Balance Information Available in Aircraft	
E Major Repair and Alteration, FAA 337 (*Attach when required*)	J. Current Airworthiness Certificate Issued in Accordance with FAR ______ (*Copy attached*)
F This Inspection Recorded in Aircraft Records	

GOVERNMENT PRINTING OFFICE 1969 OF—347-330

Figure 2 - Application for an airworthiness certificate (cont'd.).

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

20 July 1971

AIR CARRIER DISTRICT OFFICE
Greater Southwest Int'l Airport
Fort Worth, Texas 76125

Captain H. B. Benninghoff
Assistant Vice President - Flight
Training and Procedures
American Airlines' Flight Academy
Greater Southwest Int'l Airport
Fort Worth, Texas 76125

Dear Captain Benninghoff:

American Airlines is authorized to operate N7545, a Boeing 720 aircraft, which is in an experimental status, in VFR and IFR conditions day or night, in your NASA 3D RNAV noise abatement contract, subject to the following conditions:

1. No persons or property may be carried for compensation or hire.

2. Each person carried must be advised of the experimental nature of the aircraft.

3. The 3D RNAV equipment will only be utilized on those RNAV routes and approach procedures which have been specifically established for this program between and into the airports of Moffett Field NAS, Mountain View, California, and Stockton Metro, Stockton, California.

4. The control towers at the airports in Item 3 will be notified of the experimental nature of the aircraft and of the procedures being utilized.

5. Whenever the 3D RNAV equipment is being utilized, it will be monitored, utilizing normal VOR/DME and/or ILS navigation systems to ensure that the flight path of the aircraft is maintained in accordance with the routes, procedures, and altitudes prescribed in the charts provided for this program.

Sincerely,

C. ROWBOTTOM
Principal Operations Inspector, AAL

Figure 3 - FAA operating approval letter.

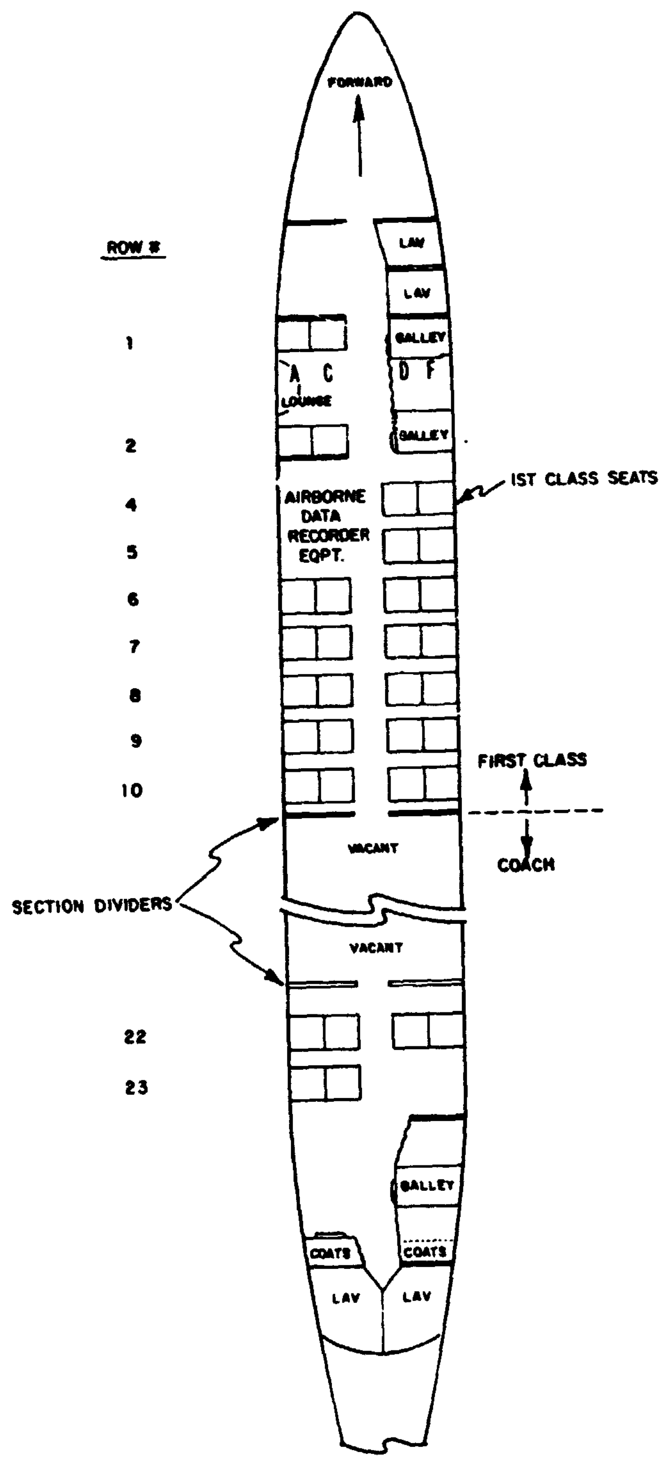


Figure 4 - Evaluation aircraft floor plan, B720-023B (N7545A).

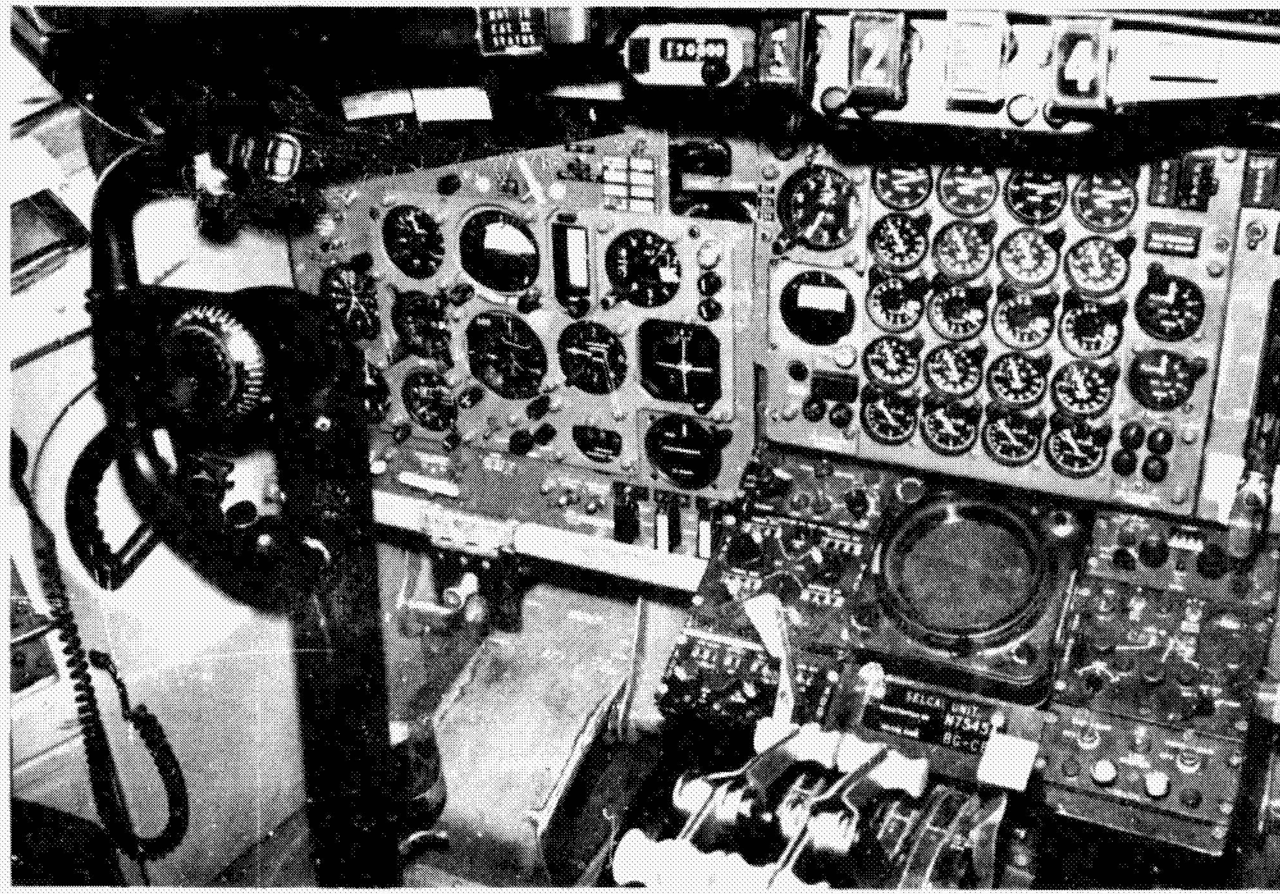


Figure 5 - Captain's and center instrument panels.

VOR/LOC	AMBER	- Strg. Cptr. ARMED for VOR/LOC capture.
	GREEN	- Strg. Cptr. ENGAGED in VOR/LOC capture/track mode.
RNAV*	AMBER	- (Not used).
	GREEN	- NAV Mode Selector in RNAV position.
RNAV/GS	AMBER	- NAV Mode Selector at RNAV/ILS; Strg. Cptr. ARMED for capture of upper segment.
	GREEN	- (RNAV/ILS selected) Strg. Cptr. ENGAGED in capture and track of upper segment.
GLIDE SLOPE	AMBER	- NAV Mode Selector at NORMAL; Strg. Cptr. ARMED for G/S capture/track from below beam.
	GREEN	- (NORMAL selected) Strg. Cptr. ENGAGED in G/S capture/track mode from below beam.
	AMBER	- (RNAV/ILS selected) at radio altitude 1000 feet; Strg. Cptr. ARMED to capture G/S from above beam centerline.
	GREEN	- (RNAV/ILS selected) Strg. Cptr. ENGAGED in G/S capture/track from above beam.

*NAV Mode Selector at RNAV position extinguishes all other progress display indications.

Figure 6 - Approach progress display modified for two-segment profiles.

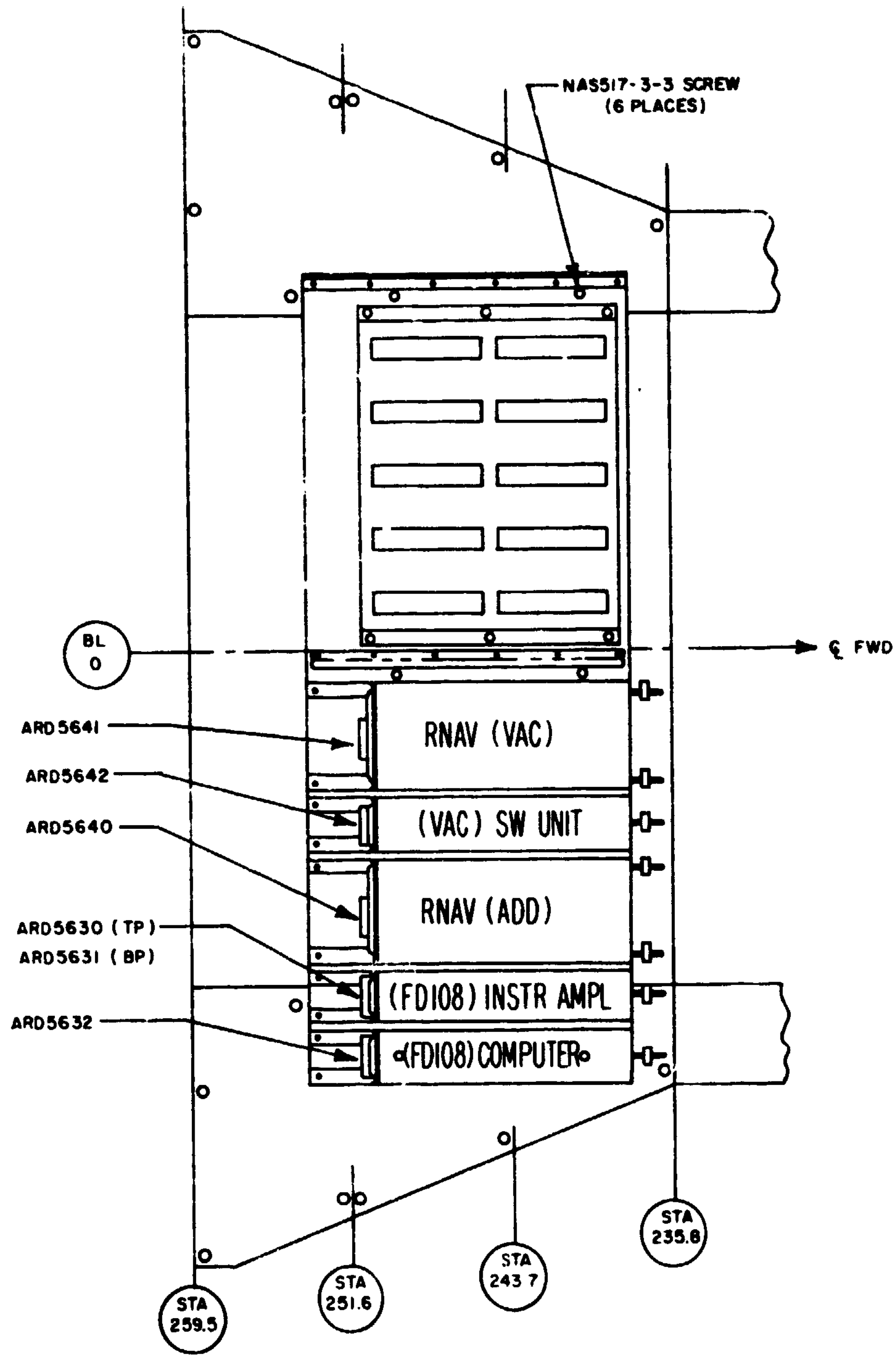


Figure 7 - Radio rack locations of two-segment avionics units.

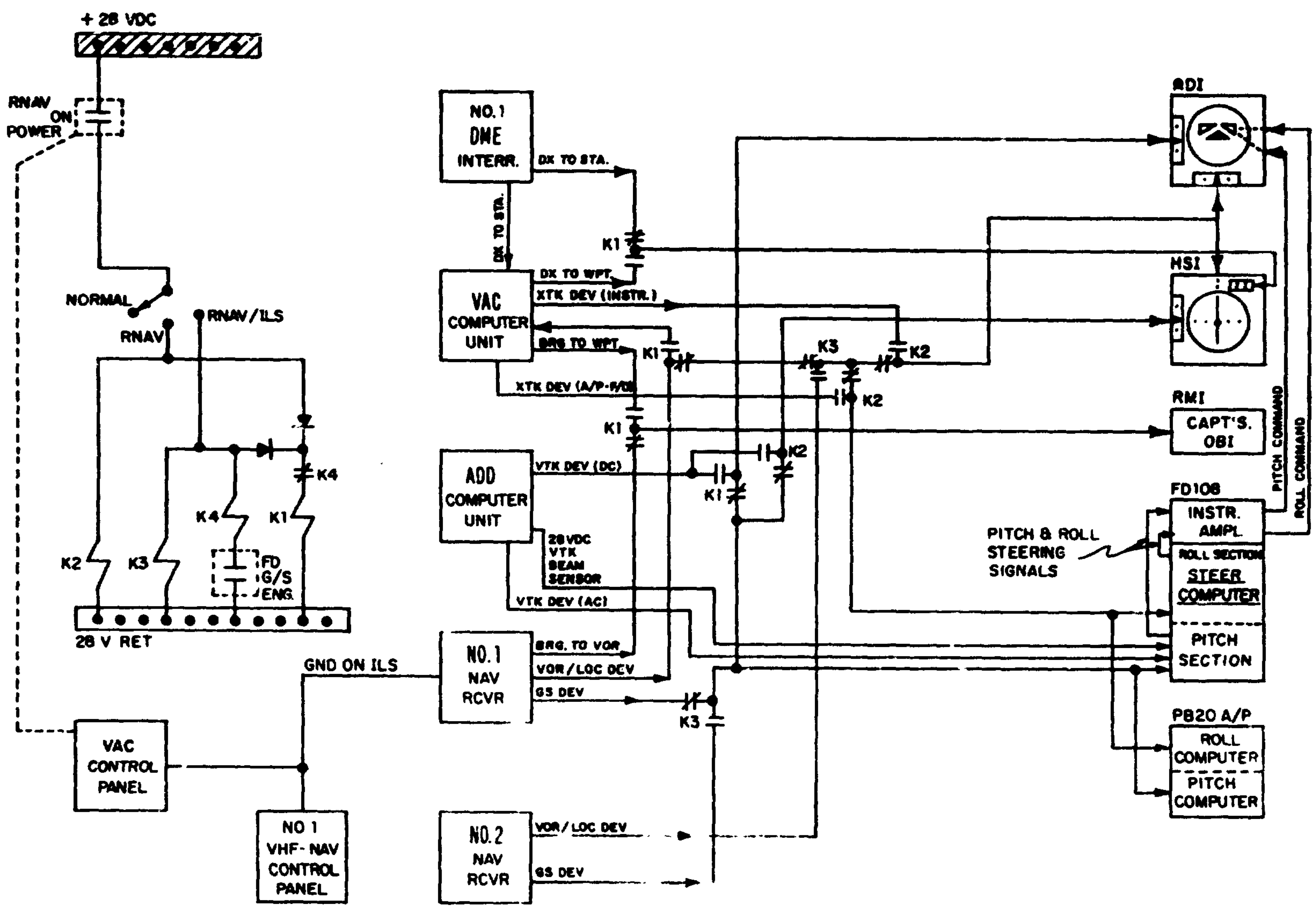


Figure 8 - Two-segment flight instrument switching.

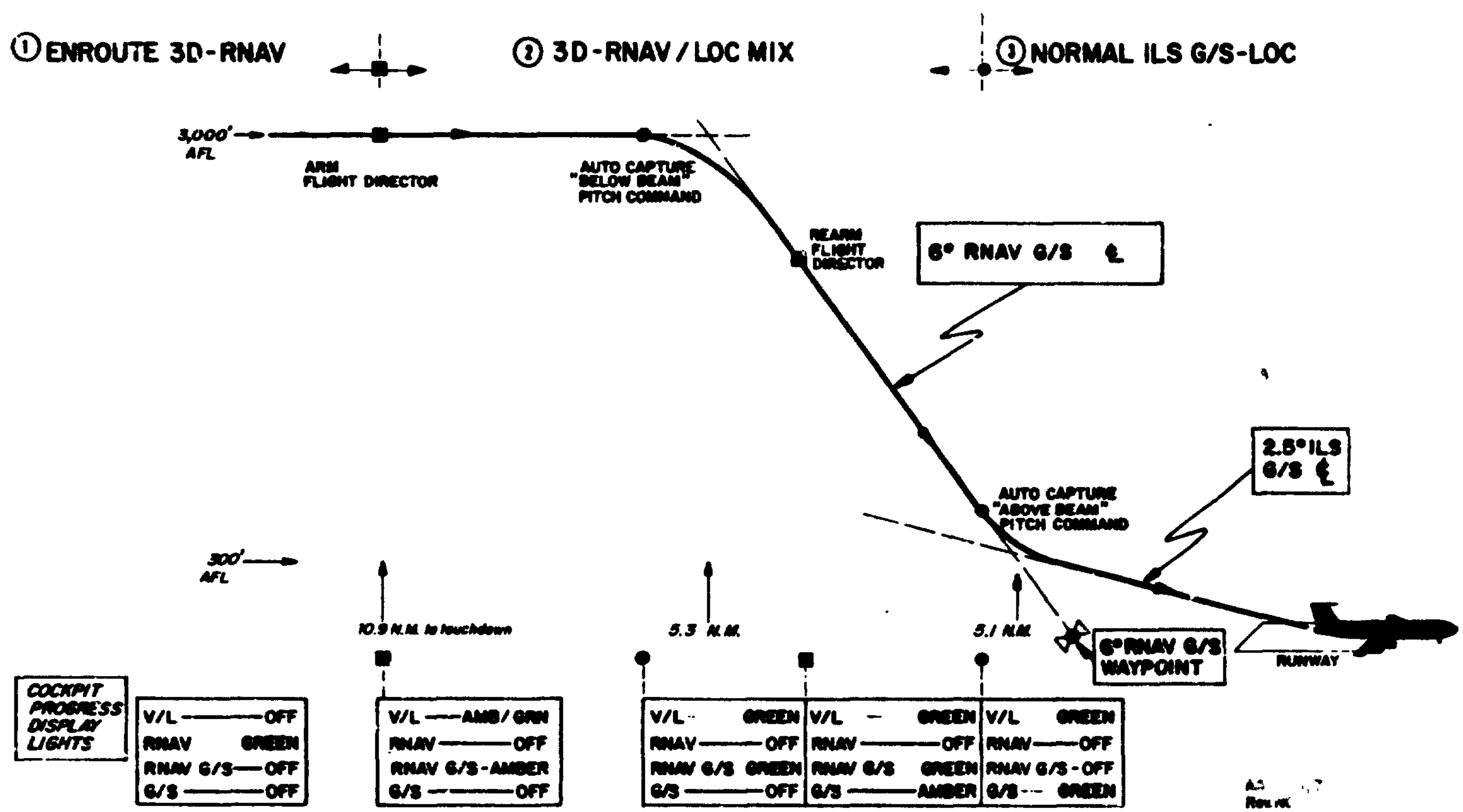
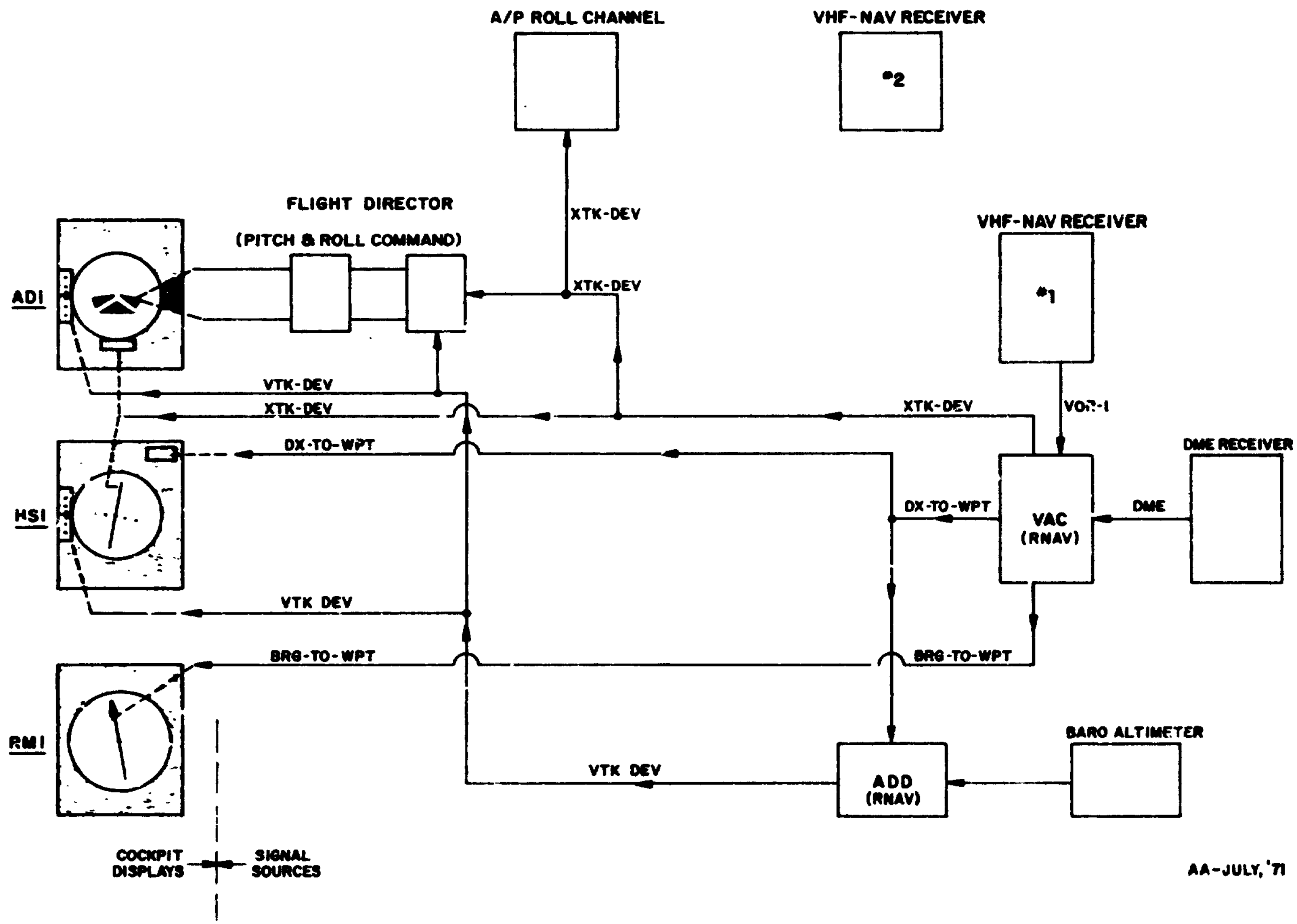


Figure 9 - Flight director mechanization (not to scale).



Figur - Enroute 3D-RNAV.

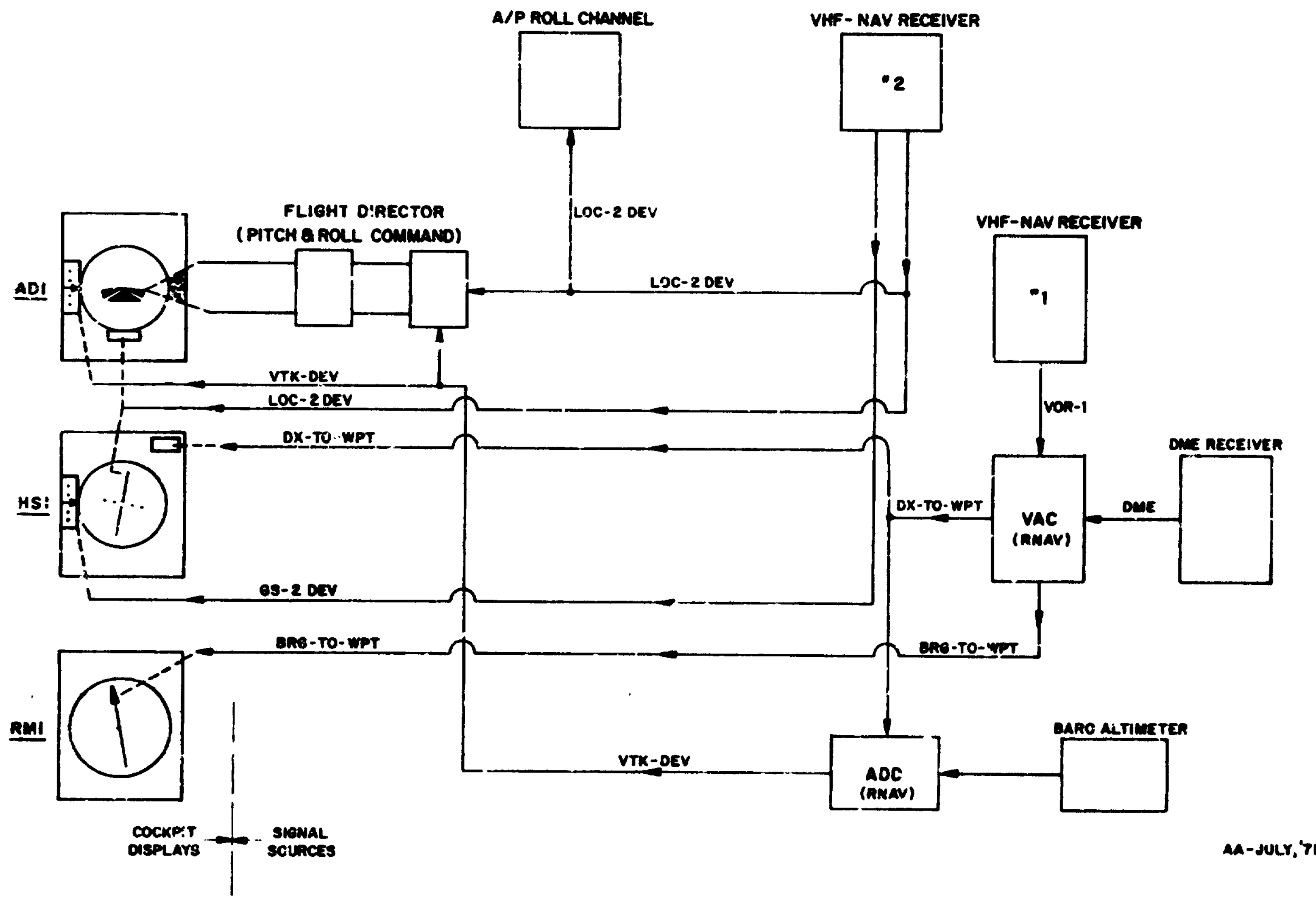


Figure 11 - 3D-RNAV/LOC mix 6° upper segment.

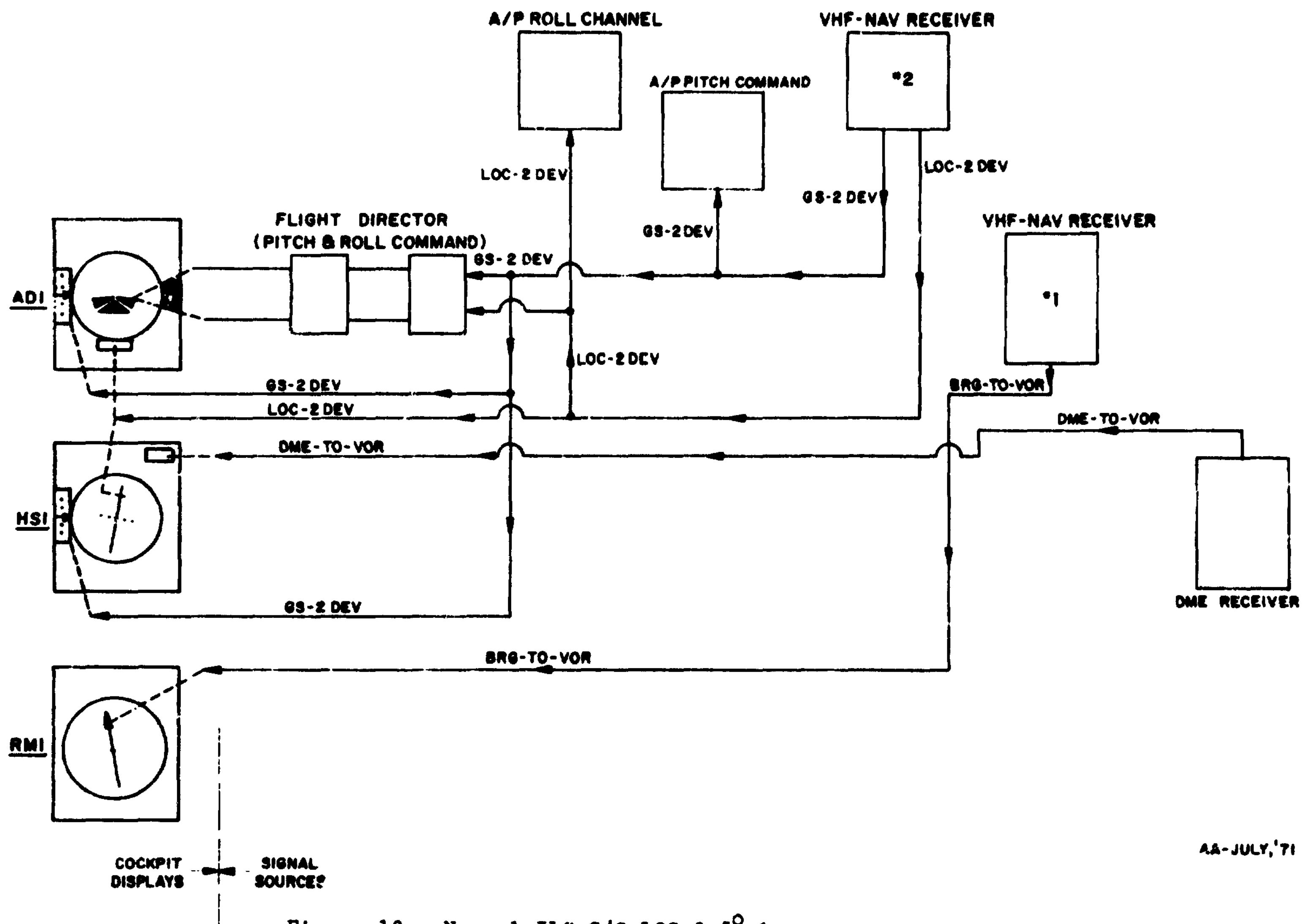


Figure 12 - Normal ILS G/S-LOC 2.5° lower segment.

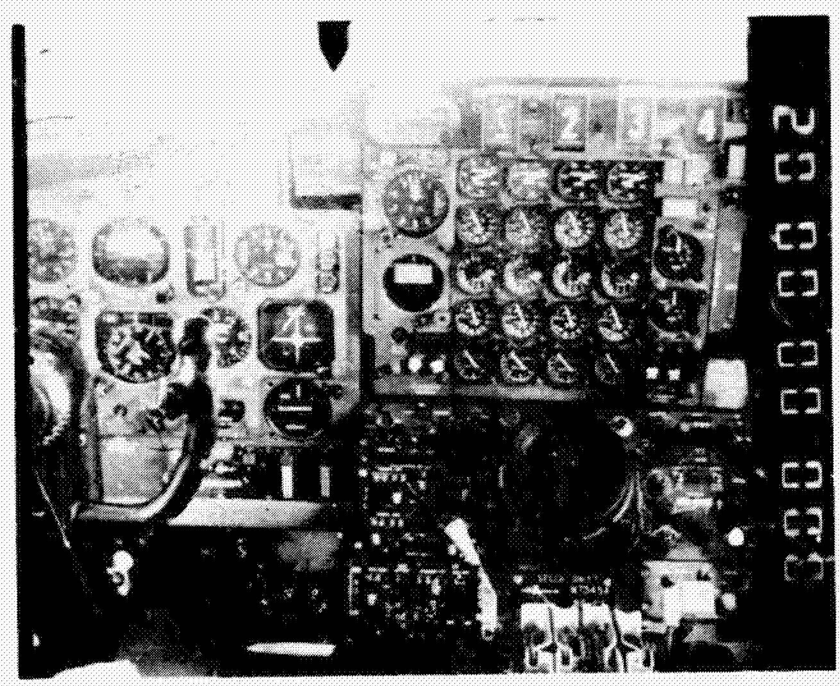


Figure 13 - Field of view of the cockpit photorecorder camera.

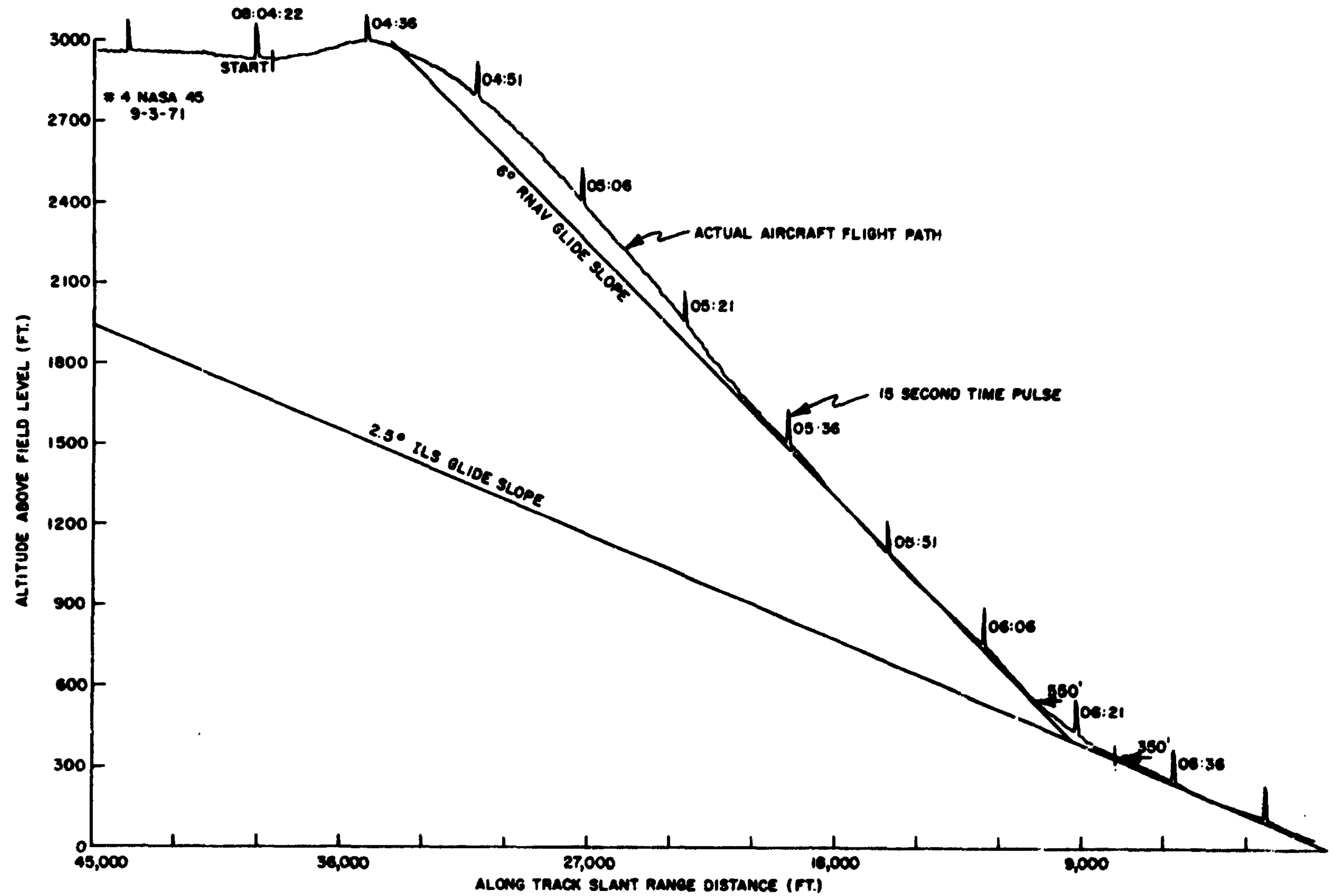


Figure 14 - Typical radar plot for Bell-Aerospace tracking system.

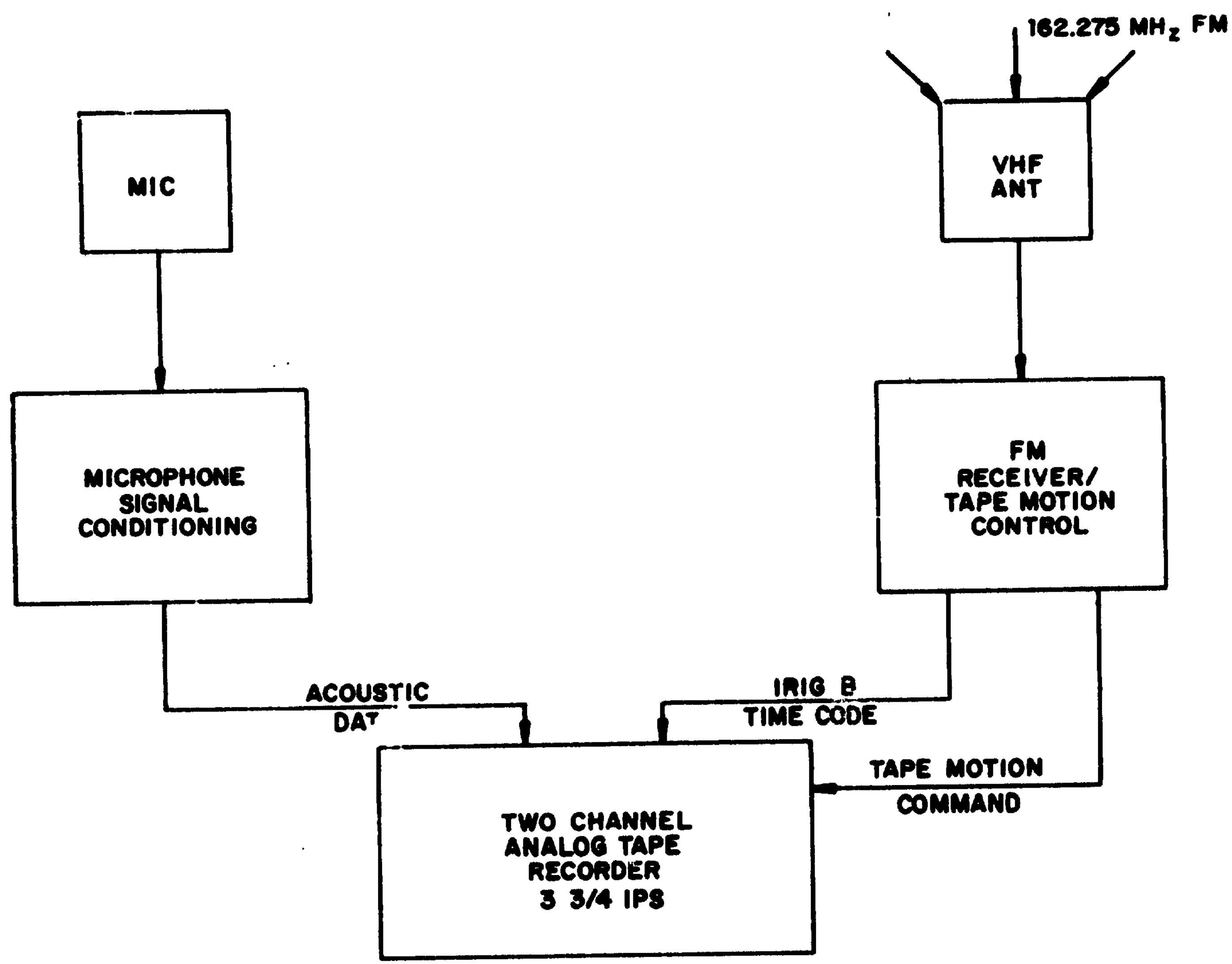


Figure 15 - Typical noise acquisition system, Hydrospace Research Corporation.

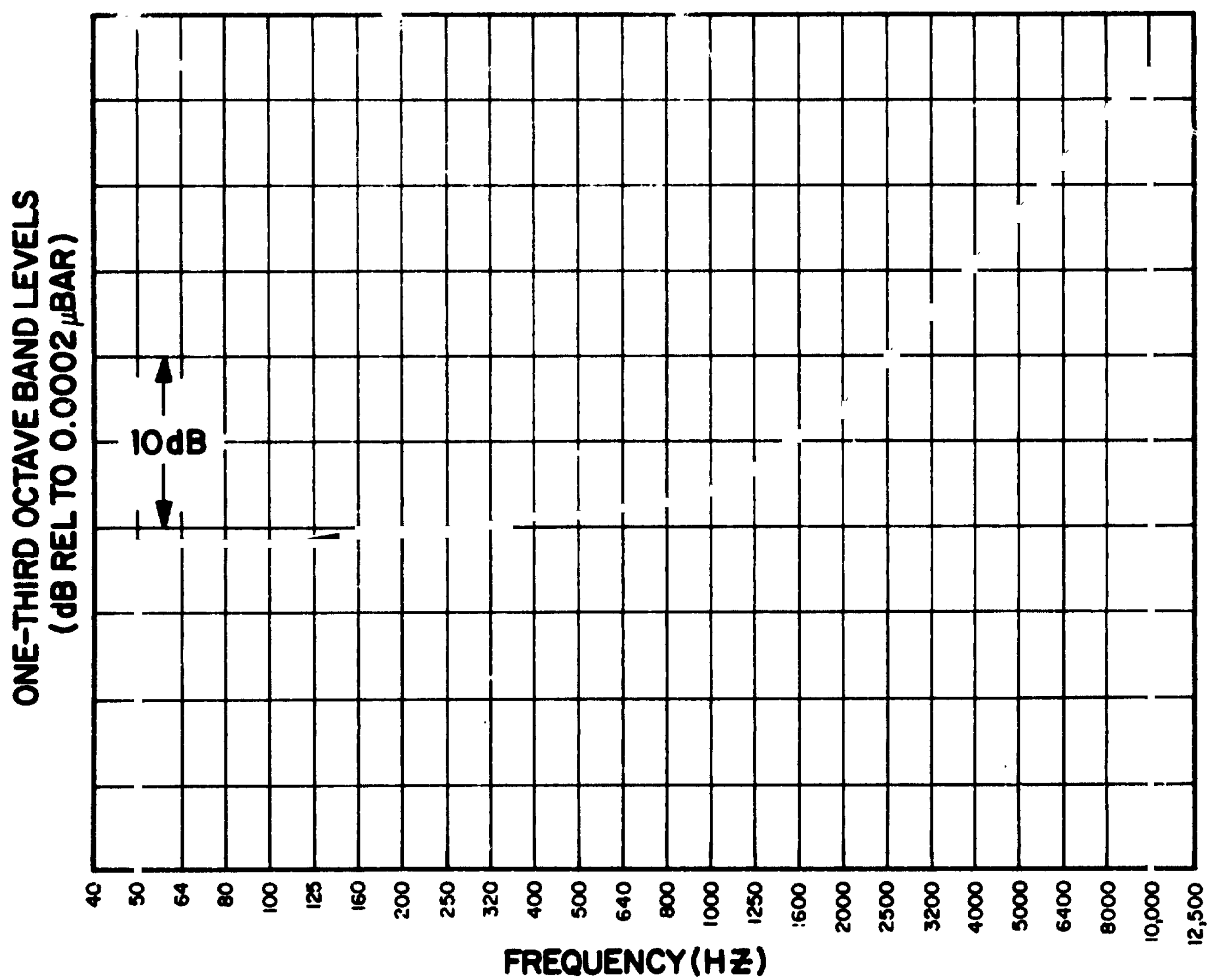


Figure 16 - Typical frequency response, Hydrospace noise measurements.

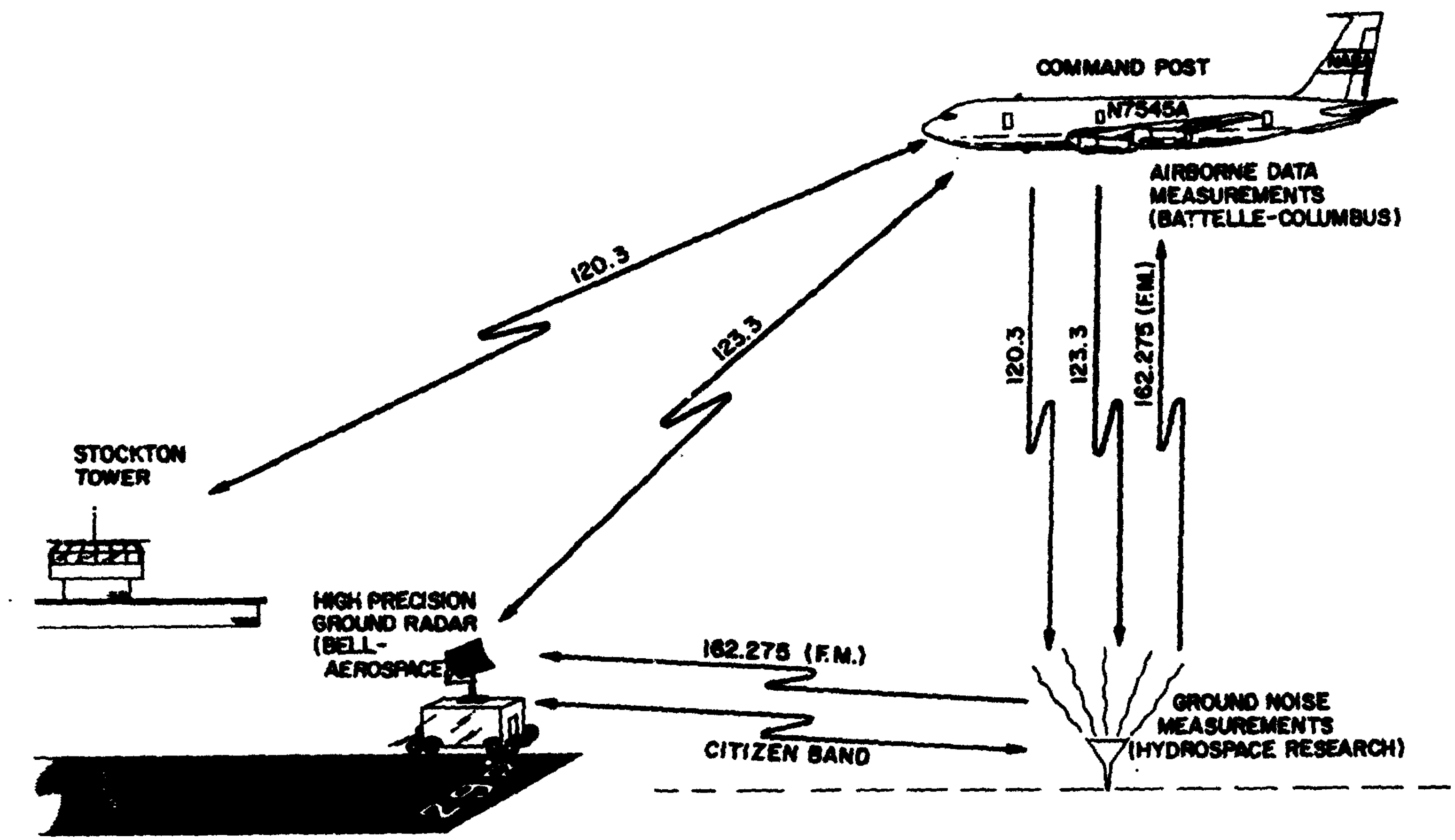
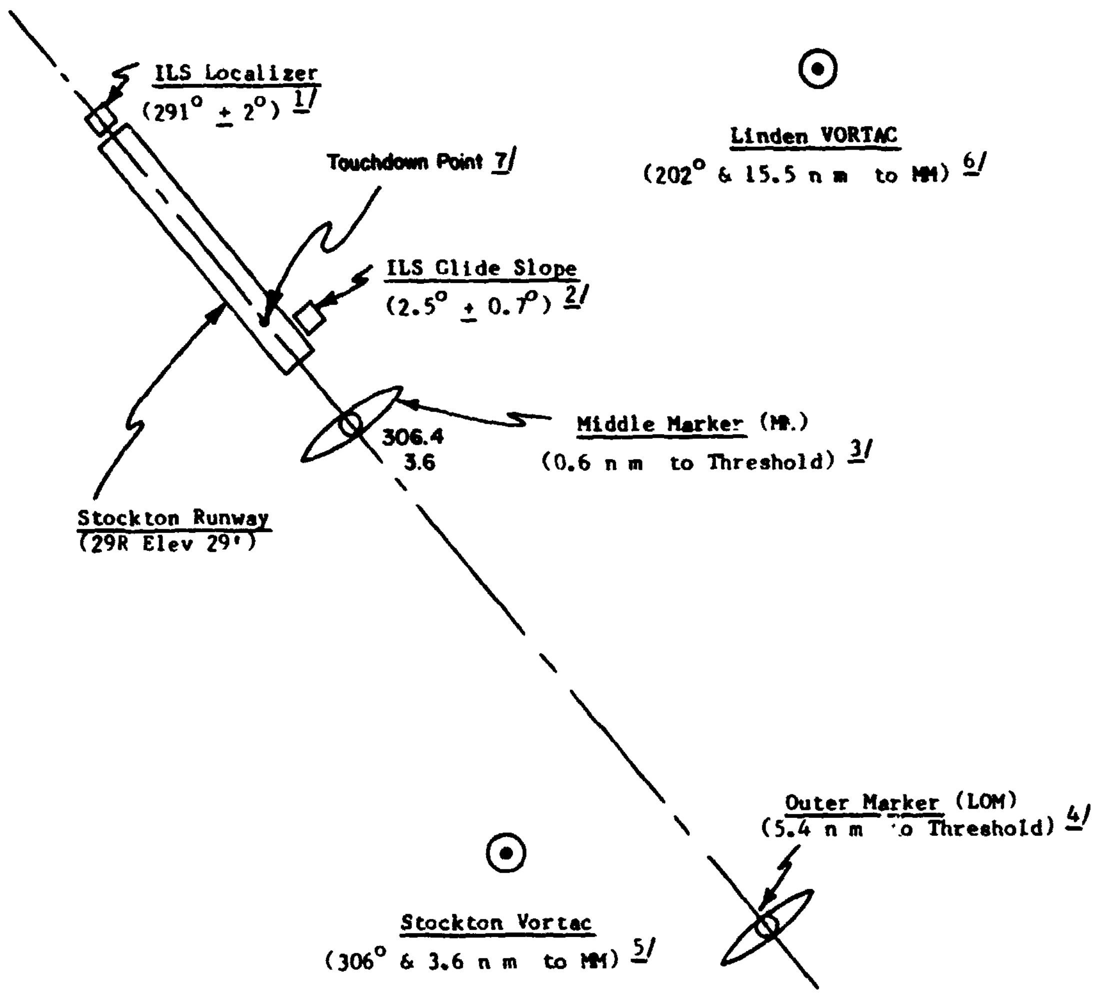


Figure 17 - Communications and command network, Stockton Airport, California.



FOOTNOTES:

1/ 10,050' after Threshold

2/ 1,250' after Threshold

3/ Elevation 32'/37° 52' 49" N - 121° 12' 46.5" W

4/ Elevation 52'/37° 49' 54" N - 121° 08' 03" W

5/ Eleva'ion 40', 1 n m off Runway Centerline/37° 50' 01" N - 121° 10' 13" W

6/ Elevation 257'/38° 04' 29" N - 121° 00' 10" W

7/ Elevation 29'/37° 53' 18.3" N - 121° 13' 36.6" W

Figure 18 - Navigation facilities, Stockton Airport, California (not to scale).

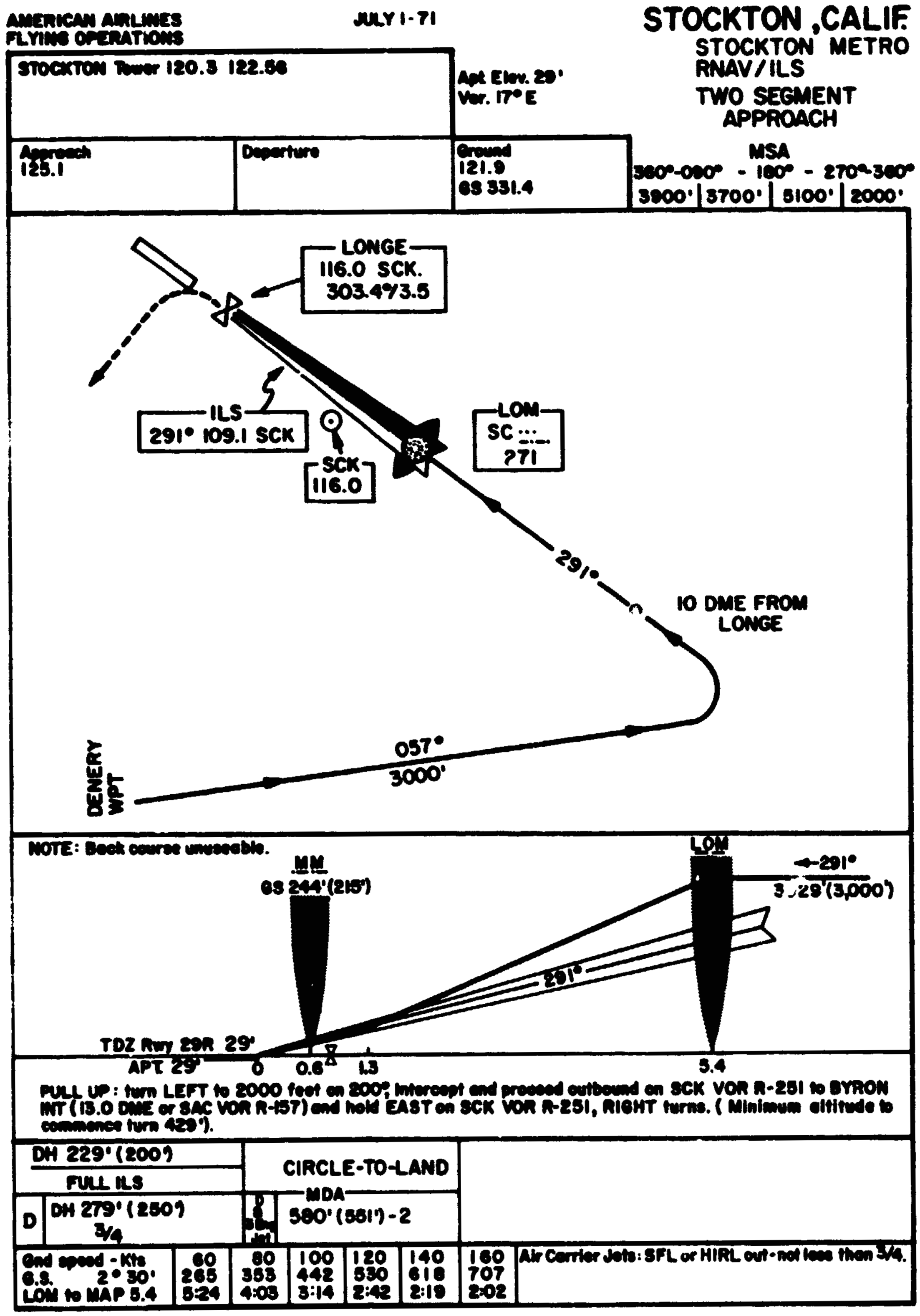


Figure 19 - Stockton metro RNAV/ILS two-segment approach.

Airline or Agency	Location	Title	Name	Stockton Approaches		
				Two-Segment		Normal
				Training	Evaluation	ILS
Project Pilots						
American	LaGuardia, N.Y.	Line Pilot	Capt. B. Wohl	(40 at Tulsa plus 50 hrs. in AA 707 & 727 Simulators)	6 plus Co-pilot for all other Pilots	6
NASA/ARC	Moffett Field, Cal.	Research Pilot	F. J. Drinkwater	(5 at Tulsa plus 4 hrs. in AA 707 & 727 Simulators)	35	2
Guest Pilots						
American	San Francisco, Cal.	Base Supt. of Flying	Capt. E.H.Ehmann	5	7	2
FAA S.W.Region	Fort Worth, Texas	Air Carrier Insp.	J. Dydek	5	5	2
Allied Pilots Assoc. (APA)	Arlington, Texas	Chairman-ATC Com. (Line Pilot-AA)	Capt. F.P.McCormick	5	5	1
Airline Pilots Assoc. (ALPA)	Washington, D. C.	Noise Abatement Committee Member (Training Captain - Pan American)	Capt. T.G.Foxworth	5	5	2
Continental	Los Angeles, Cal.	720 Flight Manager	Capt. C.L.Rogers	5	6	2
American	Fort Worth, Texas	Asst. V.P.-Flying Trng. & Prcdrs.	Capt. H. B. Benninghoff	5	5	2
Western	San Francisco, Cal.	Chief Pilot - 720	Capt. D.C.Thompson	5	7	2
United	San Francisco, Cal.	Line Pilot	Capt. E. A. Ernst	5	5	2
Western	Los Angeles, Cal.	Mgr.-Flt. Standards	Capt. A.H.Weidman	5	5	4
Pan American	Kennedy Airport, New York	Director-Flt.Opns. Tech Services	Capt. P. Roitsch	5	2	1
Northwest	Minneapolis, Minn.	V.P.-Operations	Capt. P. Soderlind	5	2	1
Trans World	San Francisco, Cal.	Gen.Mgr.-Flying	Capt. W.A. Dixon	5	2	1
		TOTAL PRIMARY EVALUATION APPROACHES		60	96	29

Figure 20 - Primary evaluation pilots for two-segment flight testing.

Airline or Agency	Location	Title	Name	Stockton Approaches		
				Two-Segment		Normal ILS
				Training	Evaluation	
NASA/ARC	Moffett Field, Cal.	Branch Chief-Flt.Ops.	G. E. Cooper	3	1	1
NASA/ARC	Moffett Field, Cal.	Research Pilot	G. H. Hardy	3	2	1
NASA/ARC	Edwards AFB	Research Pilot	F. Fulton	3	3	2
FAA Flt.Stds.	Washington, D. C.	Check Pilot	M. E. Russell	2	-	-
Eastern	Miami, Fla.	Line Pilot	Capt. H.D.Slayden	1	-	-
Eastern	Miami, Fla.	Line Pilot	Capt. A. Cleaver	1	-	-
American	Fort Worth, Texas	Director-Flying Engineering	Capt. A.M.Reeser	3	-	-
Consultant	Connecticut	Retired Captain-American	S. Saint	1	-	-
United	San Francisco, Cal.	Flt. Manager - 720	Capt. R. Roberts	1	-	-
United	San Francisco, Cal.	Manager-Flt. Opns.	Capt. P. Learned	1	-	-
R.Dixon Speas	Palo Alto, Cal.	Retired Captain-United	R. Van Tuyle	1	-	-
NASA/ARC	Moffett Field, Cal.	Research Pilot	R. Innis	3	1	-
NASA/ARC	Moffett Field, Cal.	Research Pilot	R. Gerdes	2	-	1
	TOTAL SECONDARY EVALUATION APPROACHES			26	7	5

Figure 21 - Secondary guest pilots for two-segment flight testing.

FLIGHT EVALUATION OF TWO-SEGMENT APPROACH PROCEDURES
FOR NOISE ABATEMENT

(NASA-Ames and American Airlines, Inc.)

FLIGHT DATE ________________ REPRESENTING ________________________

GUEST PILOT ________________ PREVIOUS FLIGHT TIME ________________

(1) DO YOU FEEL THERE IS A NEED TO REDUCE AIRCRAFT NOISE? YES____ NO ____
WHY?

(2) DO YOU FEEL NOISE ABATEMENT EFFORTS SHOULD BE DIRECTED TOWARD ENGINEERING CHANGES, OPERATIONAL PROCEDURES, AIR TRAFFIC CONTROL PROCEDURES OR ALL OF THESE?

ENGINEERING _________ OPERATIONAL _________ ATC ________________

ALL ____________ OTHER (specify) _________ WHY?

(3) WHAT ADDITIONAL FLIGHT INSTRUMENTATION OR AIRCRAFT SYSTEMS DO YOU FEEL ARE NEEDED TO FLY TWO-SEGMENT APPROACHES (other than what you saw today)?

NONE _____________ OTHER _____________ WHY?

(4) ALL THINGS CONSIDERED, WHAT ALTITUDE DO YOU FEEL IS MOST COMPATIBLE FOR TRANSITIONING TO THE ILS G/S?

ALTITUDE _________________ WHY?

(5) WHAT WEATHER MINIMUM DO YOU FEEL TWO-SEGMENT APPROACHES COULD BE FLOWN TO IN SCHEDULED AIRLINE SERVICE?

MINIMUMS _________________ WHY?

(6) ON THE UPPER BEAM SEGMENT, DID THE HIGHER THAN NORMAL SINK RATE CONCERN YOU? YES _________ NO _________ WHY?

(7) DO YOU THINK AN AIRSPEED LESS THAN REF + 20 COULD BE USED ON THE UPPER 3D-RNAV BEAM? YES _________ NO _________ WHY?

(8) WHAT DID YOU THINK OF THE UPPER 3D-RNAV BEAM (6°) CAPTURE?

(9) WHAT DID YOU THINK OF THE LOWER ILS G/S BEAM CAPTURE?

(10) WHAT TYPES OF AIRCRAFT MALFUNCTIONS DO YOU THINK WOULD PRECLUDE MAKING TWO-SEGMENT APPROACHES? WHY?

(11) AFTER FLYING TWO-SEGMENT APPROACHES, AND THEN FLYING NORMAL ILS APPROACHES; WHAT DIFFERENCES DID YOU NOTICE?

(12) DID FLYING THE TWO-SEGMENT APPROACH UNDER THE HOOD HAVE ANY EFFECT ON YOU? YES _________ NO _________ WHY?

(13) BECAUSE THIS IS AN OPERATIONALLY ORIENTED RESEARCH PROJECT, WE ARE OPEN TO ANY AND ALL COMMENTS. IF YOU HAVE ANYTHING FURTHER TO ADD TO THIS QUESTIONNAIRE, PLEASE USE EXTRA PAGES OR THE BACK SIDE OF THIS QUESTIONNAIRE.

THANK YOU FOR COMING TO MOFFETT AND FLYING WITH US. YOUR COMMENTS ON THIS QUESTIONNAIRE WILL BE VERY HELPFUL IN DETERMINING THE SUITABILITY OF TWO-SEGMENT APPROACHES.

CAPTAIN BERNARD WOHL
PROJECT PILOT
AMERICAN AIRLINES

Figure 22 - Pilot questionnaire.

American Airlines

Dear Observer:

May we please have your personal opinion of this approach. Your assistance will help us evaluate passenger reaction to approach techniques which may be used in scheduled airline service.

Since conditions may differ from one approach to another, your remarks on this form should apply only to the approach just completed.

Thank you for your cooperation.

Figure 23 - Passenger questionnaire.

PLEASE GIVE US YOUR OPINION OF THE FINAL APPROACH AND LANDING PHASE JUST COMPLETED:

1. Listed below are a series of boxes shown between opposing statements. A check in the box on the left indicates strong agreement with the statement on the left. A check in the box on the right indicates strong agreement with the statement on the right. The boxes toward the middle indicate a range of opinion in between.

Calm weather	☐	☐	☐	☐	☐	Turbulent weather
Smooth	☐	☐	☐	☐	☐	Bumpy
Relaxed feeling	☐	☐	☐	☐	☐	Tense, jittery feeling
No effect on ears	☐	☐	☐	☐	☐	Ears "popped"
No effect on stomach	☐	☐	☐	☐	☐	Stomach fe[illegible]sy

2. Overall, what is your opinion of the final approach and [illegible] phase just completed?

The best	☐	☐	☐	☐	☐	The worst

3. Aside from your overall opinion of this approach, you may have different opinions about various phases of the approach. The following questions concern two phases of the approach --- just after the landing gears were lowered, and the final approach started, --- and then just before the actual landing.

a. Please rate the phase <u>just after the landing gears were lowered</u>.

Quiet	☐	☐	☐	☐	☐	Noisy
No effect on body	☐	☐	☐	☐	☐	Felt stress on body
The descent seemed to be gradual	☐	☐	☐	☐	☐	The descent seemed to be steep
The approach seemed to be slow	☐	☐	☐	☐	☐	The approach seemed to be fast
Felt no vibration	☐	☐	☐	☐	☐	Felt vibration

b. Please rate the phase <u>just before the actual landing</u>.

Quiet	☐	☐	☐	☐	☐	Noisy
No effect on body	☐	☐	☐	☐	☐	Felt stress on body
The descent seemed to be gradual	☐	☐	☐	☐	☐	The descent seemed to be steep
The approach seemed to be slow	☐	☐	☐	☐	☐	The approach seemed to be fast
Felt no vibration	☐	☐	☐	☐	☐	Felt vibration

Figure 23 - Passenger questionnaire (cont'd.).

4. Do you feel your evaluation of this approach would have been differen[illegible] if the approach to the airport were: (Please check "Yes" or "No" for [illegible] condition and if "Yes," whether your opinion might have been "bet[illegible]" or "worse.")

	Would Opinion Be Different?		If "Yes," It Would Be	
	Yes	No	Better	Worse
Over water (a lake, b[illegible] ocean)......	☐	☐	☐	☐
Over an industrial ar[illegible]...............	☐	☐	☐	☐
Over a residential area..............	☐	☐	☐	☐
Over a mountainous area..............	☐	☐	☐	☐
In clear weather.....................	☐	☐	☐	☐
In cloudy, foggy weather.............	☐	☐	☐	☐
In the night.........................	☐	☐	☐	☐
In calmer weather....................	☐	☐	☐	☐
In more turbulent, rough weather.....	☐	☐	☐	☐

FOR CLASSIFICATION PURPOSES, PLEASE TELL US:

A. What is your seat: Row Number #____________ Seat Number #_________

B. Counting this approach, how many demonstration approaches have you experienced during your visit? ____________________

C. How many commercial airline trips have you made in the past 12 months for:

Business Reasons____________ Pleasure/Personal Reasons____________

D. Have you ever been a pilot? Yes ☐ No ☐

If "Yes," what is (was) your rating?

- Private........................ ☐
- Commerical..................... ☐
- Air Transport Rating........... ☐
- Military....................... ☐
- Other.......................... ☐

What are your total flying hours, as a pilot?________________Hours

E. What kind of work do you do? What is your position?

Industry________________ Position________________

F. Your Sex: Male ☐ Female ☐

Please use the space below for any additional comments you would like to make:

Figure 23 - Passenger questionnaire (cont'd.).

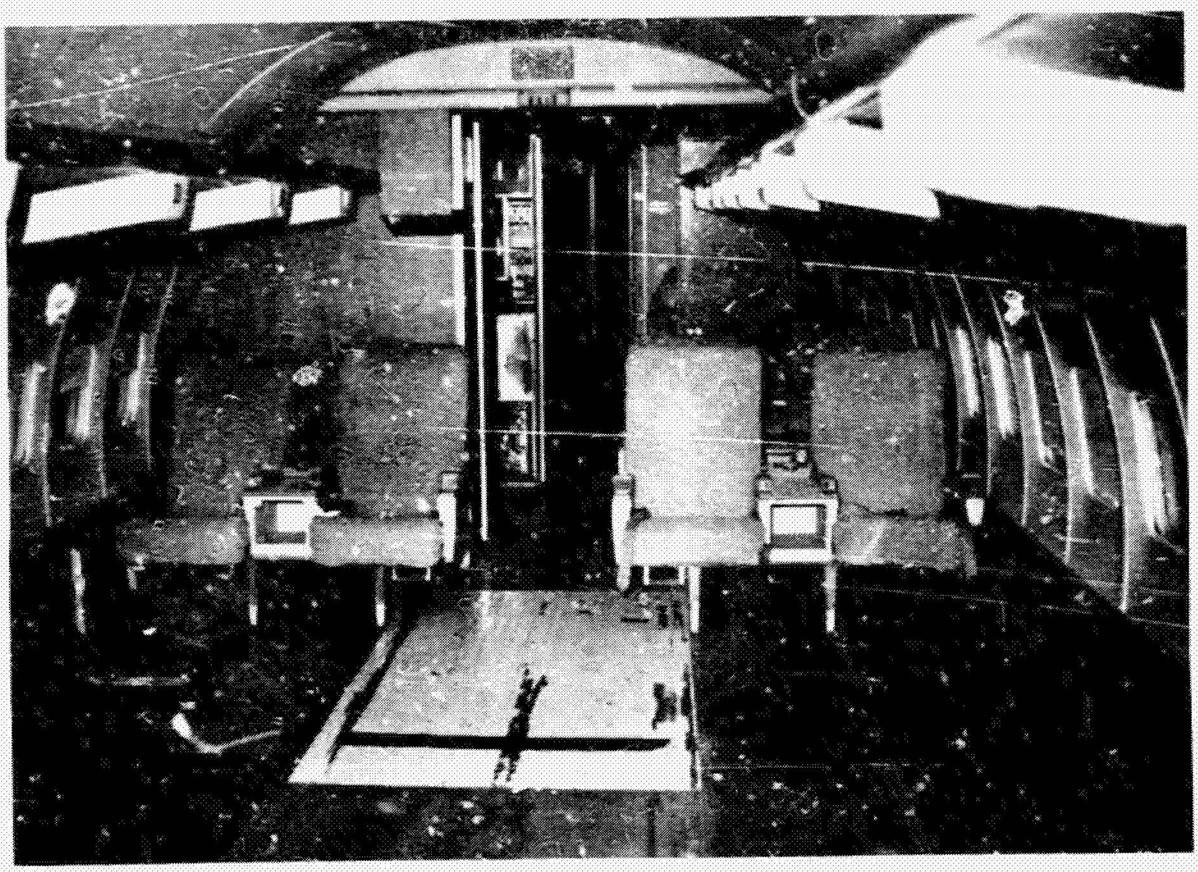


Figure 24 - Aft cabin area, coach section.

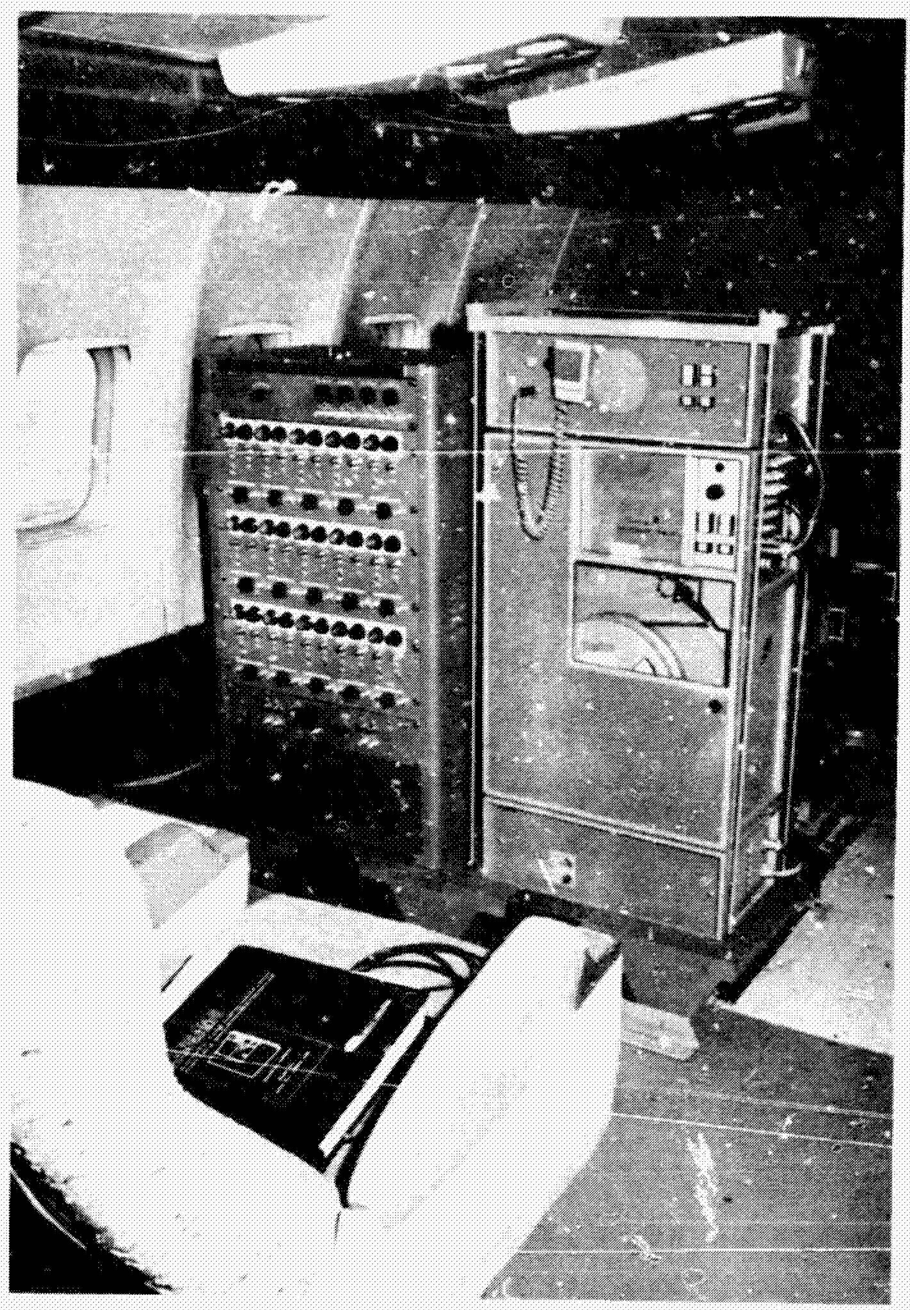


Figure 25 - Data recording station.

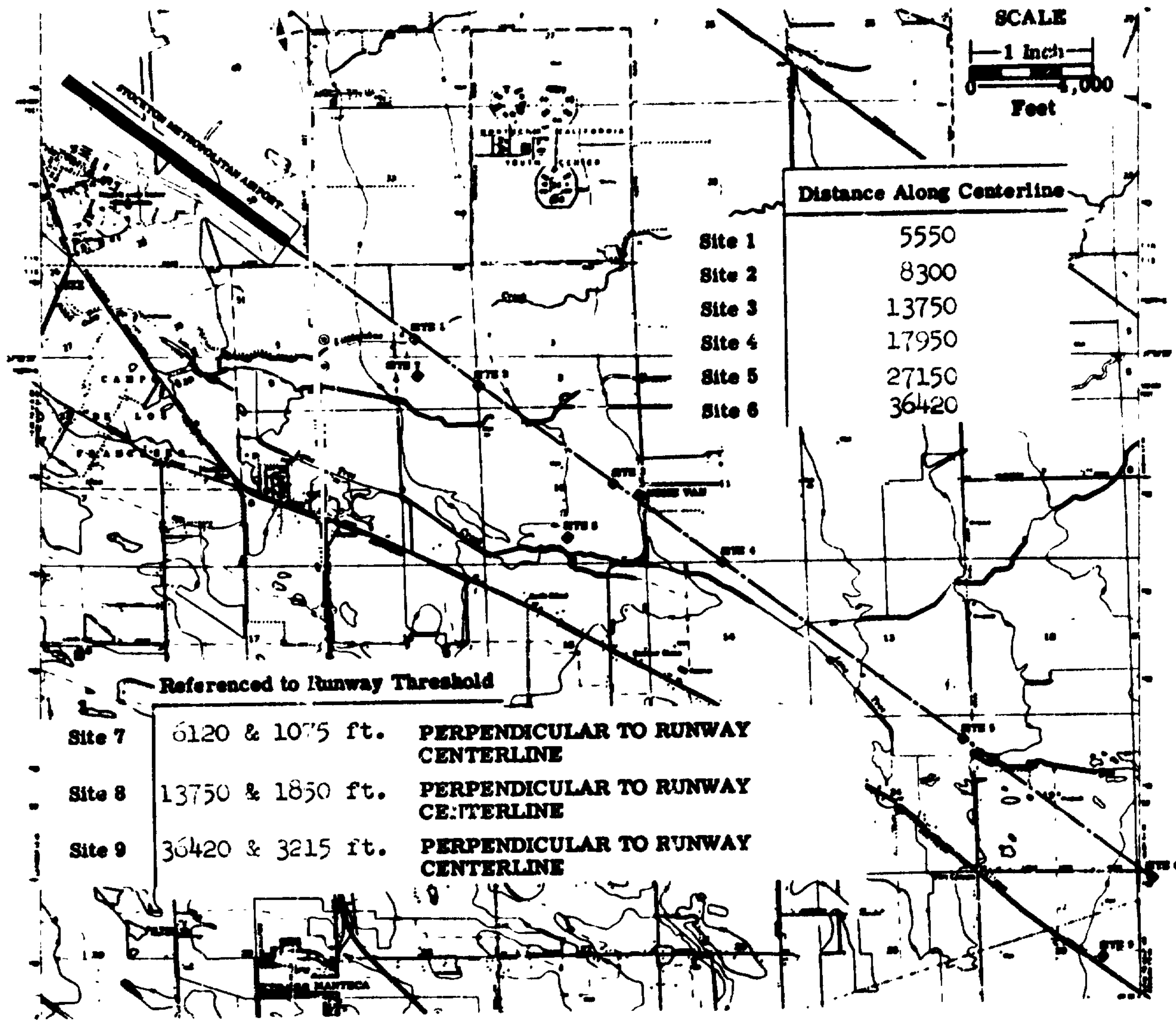


Figure 26 - Noise measurement site locations.

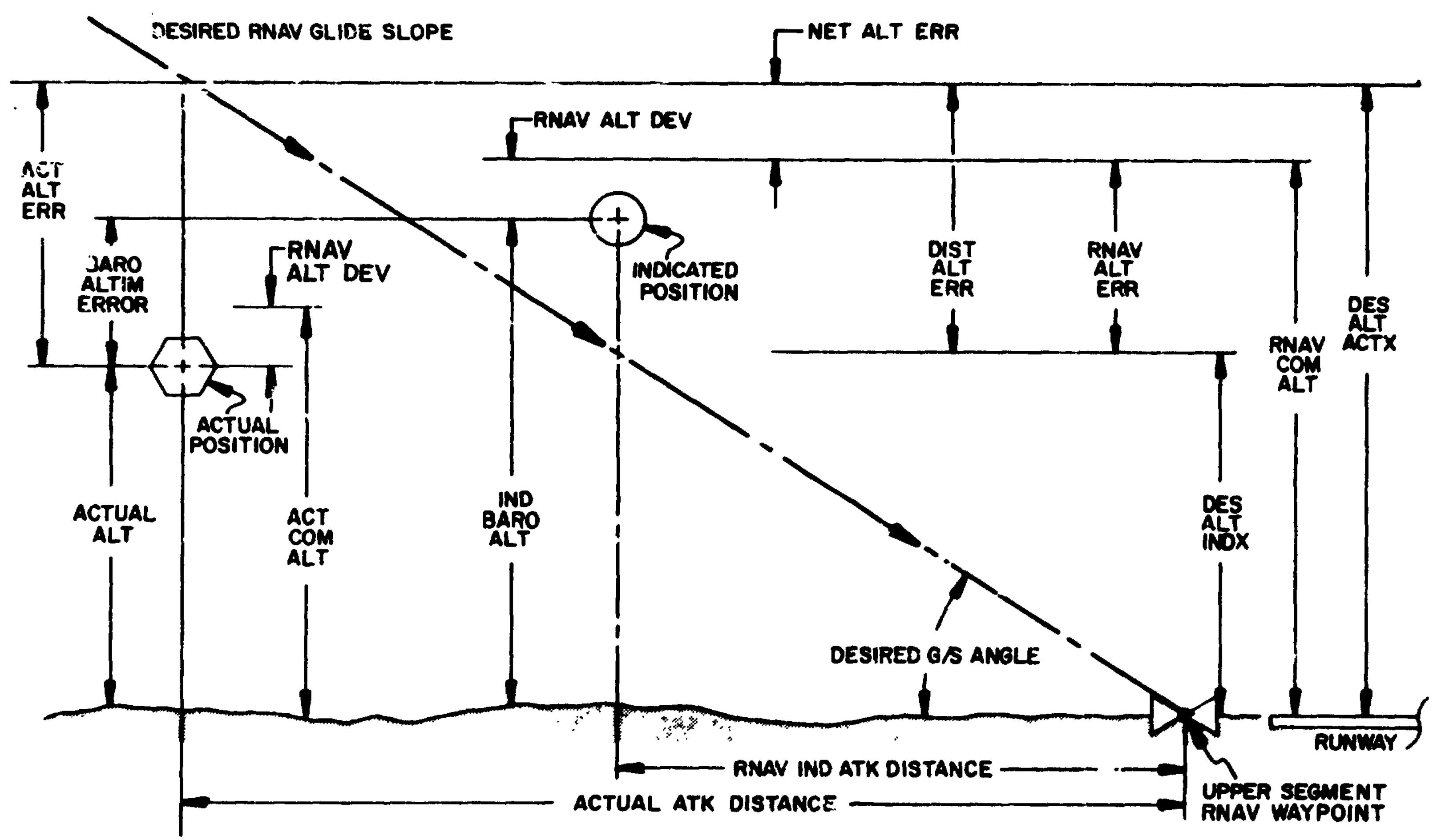


Figure 27 - Vertical error model.

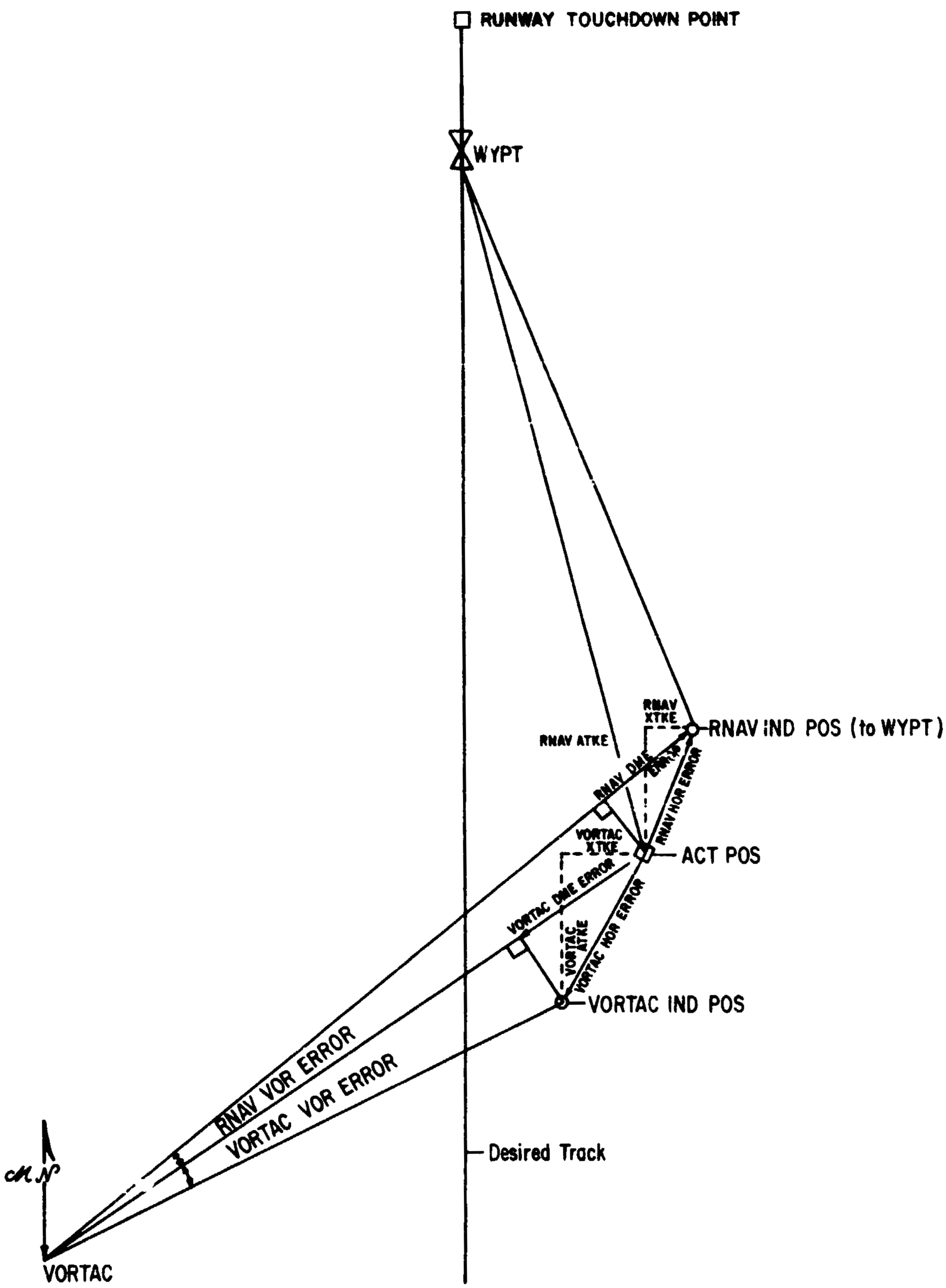


Figure 28 - Horizontal error components.

IND ATK DIS WPT	Indicated Along Track Distance to Waypoint as read from the console.
DES ALT INDX	Computed Altitude of the Glide Slope using Indicated Distance to Waypoint and Desired Glide Slope Angle.
RNAV COM ALT	RNAV Commanded Altitude of the Glide Slope using IND Altitude and Altitude Deviation indicated on the console.
ACT COM ALT	Actual Commanded Altitude using ACT ALT and ALT DEV.
ACT ATK DIST WPT	Actual Along Track Distance to Waypoint.
DES ALT ACTX	Computed Altitude of the Glide Slope using actual Distance to Waypoint and Desired Glide Slope Angle.
ACT ALT	Actual Aircraft Altitude.
ACT ALT ERR	Algebraic difference between DES ALT ACTX and ACT ALT noted above.
DES ALT ERR	Algebraic difference between DES ALT INDX and DES ALT ACTX noted above. This value reflects the error in Glide Slope Altitude caused by differences between Indicated and Actual Distance to Waypoint.
RNAV ALT ERR	Algebraic difference between RNAV COM ALT and DES ALT INDX noted above.
NET ALT ERR	Algebraic difference between RNAV COM ALT and DES ALT ACTX noted above. This is the most relevant Approach Model Error Computation. It represents the difference between the Indicated Glide Slope Altitude value determined by the airborne electronics, and the Glide Slope Altitude which should have been indicated on the crosspointers, based on actual aircraft position.
RNAV ALT DEV	Altitude Deviation is the recorded value as read from the horizontal bar of the console crosspointers. A minus sign denotes the indicated position is below Desired Altitude and a plus sign denotes above Desired Altitude.
IND BAR ALT	Indicated Barometric Altitude is the recorded value of indicated altitude (MSL), as read from the console altimeter.
BARO ALTIM ERR	Barometric Altimeter Error is the algebraic difference between recorded IND BARO ALT and Actual Altitude as computed from recorded radar altitude data.

Figure 29 - Vertical model definitions.

WPT	Indicates waypoint being used. See the diagram of Stockton Waypoint Coordinates for Waypoint number definitions, including coordinate values. (Fig. 19)
ACT ATK DIST WPT	Actual Along Track Distance to Waypoint as determined from the radar recordings.
RNAV LAT DEV	RNAV Lateral Deviation is the recorded value of Lateral Deviation, as read from the vertical bar of the console crosspointers.
ACT XTK DEV	Actual Crosstrack Deviation is the perpendicular distance from the actual aircraft position to desired track.
RNAV HOR ERR	RNAV Horizontal Error is the computed distance from the computed actual aircraft position to the indicated aircraft position, as computed from onboard indicated RNAV parameter values.
RNAV XTK ERR	RNAV Crosstrack Error is the computed distance from the actual aircraft position to the perpendicular projection of indicated position on a line from actual aircraft position perpendicular to the desired track.
RNAV ATK ERR	RNAV Along Track Error is the perpendicular projection of RNAV HOR ERR onto Desired Track.
RNAV VOR ERR	RNAV VOR Error is the computed bearing at the VORTAC station from a projection through the actual position to a projection through the RNAV indicated positions. A minus sign denotes a counter clockwise rotation and a plus sign denotes a clockwise rotation.
RNAV DME ERR	RNAV DME Error is the difference between the computed distance from the VORTAC station to the RNAV indicated position and the computed distance from the VORTAC station to the actual position. A minus sign denotes the indicated distance is less than the actual distance and a plus sign denotes the indicated distance is greater than the actual distance.
VORTAC HOR ERR	VORTAC Horizontal Error is the computed distance from the computed actual aircraft position to the indicated aircraft position, as computed from onboard indicated VORTAC parameter values.

Figure 30 - Horizontal model definitions.

VORTAC XTK ERR	VORTAC Crosstrack Error is the computed distance from the actual aircraft position to the perpendicular projection of indicated position on a line from actual aircraft position perpendicular to the desired track.
VORTAC ATK ERR	VORTAC Along Track Error is the perpendicular projection of VORTAC HOR ERR onto Desired Track.
VORTAC VOR ERR	VORTAC VOR Error is the computed bearing at the VORTAC station from a projection through the actual position to a projection through the VORTAC indicated positions. A minus sign denotes a counter-clockwise rotation and a plus sign denotes a clockwise rotation.
VORTAC DME ERR	VORTAC DME Error is the difference between the computed distance from the VORTAC station to the VORTAC indicated position and the computed distance from the VORTAC station to the actual position. A minus sign denotes the indicated distance is less than the actual distance and a plus sign denotes the indicated distance is greater than the actual distance.
LOC ERR	Localizer Error is the computed difference between the localizer deviation and the actual horizontal deviation. A minus sign denotes the indicated localizer deviation is left of the actual localizer deviation and a plus sign denotes the indicated localizer deviation is to the right of the actual localizer deviation where the viewer is facing the runway.
GLS ERR	Glide Slope Error is the difference between the glide slope deviation and the actual vertical deviation. A minus sign denotes the indicated glide slope deviation is below the actual glide slope deviation and a plus sign denotes the indicated glide slope deviation is above the actual glide slope deviation.
PITCH STEER	Pitch Steer is the deflection of the pitch command bar. A minus sign denotes a fly-up command. A plus sign denotes a fly-down command.
ROLL STEER	Roll Steer is the deflection of the roll command bar. A minus sign denotes a fly-left command and a plus sign denotes a fly-right command.

Figure 30 - Horizontal model definitions (cont'd.)

Bell Aerospace Radar Parameters (Actual Aircraft Position)	Source
Centerline component of Slant Range - to aircraft Altitude - above runway Horizontal deviation - from runway centerline *Clock time	Bell Aerospace data recorded on analog magnetic tape
Onboard Parameters (Cockpit Panel)	
*NASA Clock Time Voice Received VOR Bearing to VORTAC Station Received DME Distance to VORTAC Station Indicated Barometric Altitude Indicated Distance to RNAV Waypoint Indicated Bearing to RNAV Waypoint RNAV Indicated Altitude Deviation RNAV Indicated Lateral Deviation ILS Indicated Altitude Deviation (G/S) ILS Indicated Lateral Deviation (Localizer) Pitch Command Roll Command	Battelle data listings recorded on analog magnetic tape by Battelle unit
Log Data	
Inserted VOR/DME Position Waypoint Two-Segment Profile Being Flown Avionic System Being Used FM Tape Calibrating FM Tape Number/Runs Prime Synchronization Difference Between Onboard and Ground Clocks	AA and Battelle Engineer Log Books
Prestored Data	
Latitude/Longitude of Radar Site Latitude/Longitude of Waypoint Latitude/Longitude of runway touchdown point True Bearing of Each Flight Leg Latitude/Longitude of VORTAC Stations	FAA and U.S. Coast and Geodetic Quadrangle Maps

*Denotes common NASA Time Code Generator value, used for data correlation between NASA radar data and onboard aircraft data.

Figure 31 - Position error model data (Battelle CDC 6400).

Channel	Range	Instrument	Recorder	Computer
1. Time	0-5v		0v = -1.4 FMV 5v = +1.4 FMV	$\pm$ 1.4 FMV = + 1.4
2. Voice				
3. Received VOR Bearing	180-360°	180° = 2.23v 360° = -7.89v	-7.89v = +1.4 FMV +2.23v = -1.4 FMV	Bear. = $270^\circ \frac{+90^\circ}{1.4}$ FMV
4. Received DME Distance	0-10 nm	.428 nm = 0v 10 nm =-5v	-5v = +1.4 FMV 0v = -1.4 FMV	Dist. = $5.214 + \frac{4.786}{1.4}$ FMV
5. Spare Channel				
6. Barometric Altimeter	0-4000 ft	4000 ft = + 6v 0 ft = -10v	+ 6v = -1.4 FMV -10v = +1.4 FMV	Alt. = 2000 ft - $\frac{2000}{1.4}$ ft FMV
7. RNAV Distance to WYPT (Along Track Component)	0-8 nm	0 nm = 0v 8 nm = .1229v	0v = 1.4 FMV .1229v = 1.4 FMV	Dist. = 4 nm - $\frac{4}{1.4}$ nm FMV
8. RNAV Bearing to WYPT	$\pm$ 2.5°	+2.5° = – 2.221v -2.5° = – 1.880v	-2.221v = +1.4 FMV -1.880v = -1.4 FMV	Bear. = $\frac{2.50^\circ}{1.4}$ FMV
9. RNAV Vert. Dev.	$\pm$ 280 ft	$\pm$.175v	$\pm$.175v = $\mp$1.4 FMV	Dev. = $\frac{-280}{1.4}$ ft FMV
10. RNAV Lateral Dev.	$\pm$ 4 nm	$\pm$ .0637v	$\pm$ .0637v = $\mp$ 1.4 FMV	Dev. = $\frac{-4}{1.4}$ nm FMV
11. ILS Vert. Path Dev.	$\pm$ 2 dot. def.	$\pm$ .156v	$\pm$ .156v = $\mp$ 1.4 FMV	Dev. = $\frac{-2}{1.4}$ dot FMV
12. ILS Hor. Path Dev.	$\pm$ 1 dot. def.	$\pm$ .0753v	$\pm$ .0753v = $\mp$ 1.4 FMV	Dev. = $\frac{-1}{1.4}$ dot FMV
13. Pitch Command	Fly up Fly Down	-.400v +.750v	- .400v = + 1.4 FMV + .750v = - 1.4 FMV	Com = + .175 $-\frac{.575}{1.4}$ FMV
14. Roll Command	Fly left Fly right	-.500v +.500v	$\pm$.500v = $\mp$1.4 FMV	Com = $-\frac{.500}{1.4}$ FMV

Note: FMV-Freq. Modulated Voltage

Figure 32 - Onboard measurement scale factors.

Channel		Range	Recorder	Computer
1.	Time	-1V - +1V	$\pm 1V = \mp 1.4FMV$	$\pm 1.4FMV = \pm 1.4$
2.	X	25,000 - 45,000	35,000 ft = 0 FMV 45,000 ft = 1.4FMV	$35,000 + \frac{10,000}{1.4}$ FMV
3.	X	15,000 - 25,000	20,000 ft = 0 FMV 25,000 ft = 1.4FMV	$20,000 + \frac{5,000}{1.4}$ FMV
4.	X	5,000 - 15,000	10,000 ft = 0 FMV 15,000 ft = 1.4FMV	$10,000 + \frac{5,000}{1.4}$ FMV
5.	X	0 - 5,000	2,500 = 0 FMV 5,000 = 1.4FMV	$2,500 + \frac{2,500}{1.4}$ FMV
6.	Y	500 - 2,000	1,250 = 0 FMV 2,000 = 1.4FMV	$1,250 + \frac{750}{1.4}$ FMV
7.	Y	-500 to +500	0 = 0 FMV 500 = 1.4FMV	$\frac{500}{1.4}$ FMV
8.	Y	-500 to-2,000	-1,250 = 0 FMV - 500 = 1.4FMV	$-1,250 + \frac{750}{1.4}$ FMV
9.	Z	5,000 - 3,000	4,000 = 0 FMV 5,000 = 1.4FMV	$4,000 + \frac{1,000}{1.4}$ FMV
10.	Z	1,000 - 3,000	2,000 = 0 FMV 3,000 = 1.4FMV	$2,000 + \frac{1,000}{1.4}$ FMV
11.	Z	0 - 1,000	500 = 0 FMV 1,000 = 1.4FMV	$500 + \frac{500}{1.4}$ FMV

Note: FMV-Freq. Modulated Voltage

Figure 33 - Radar measurement scale factors.

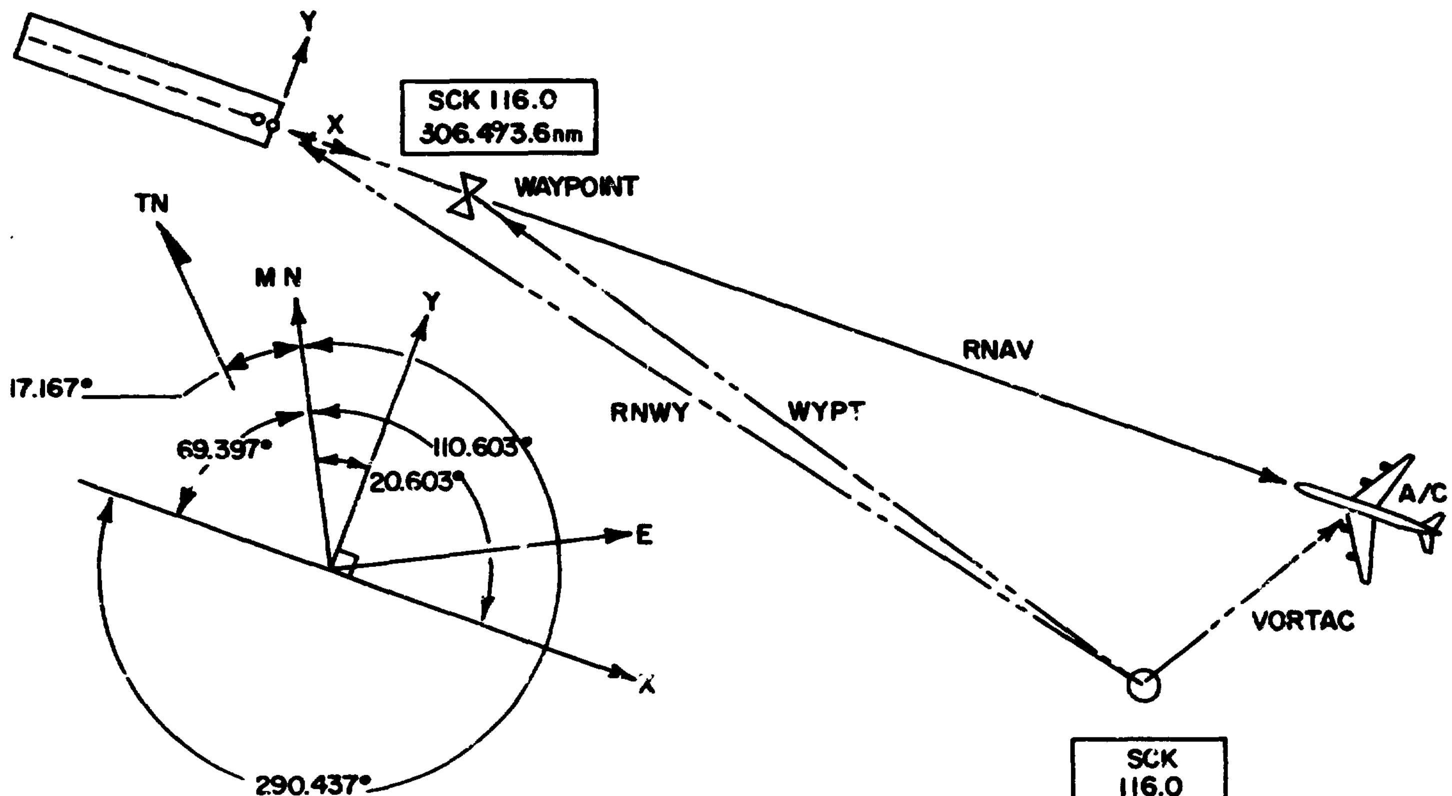


Figure 34 - Geometric relationships (not to scale).

NASA-AA TWO SEGMENT APPROACH STATISTICAL ANALYSIS DISTANCE TO TOUCHDOWN = 1.4NM

STATISTICAL MEASURES OF THE SAMPLES

	RNAV XTKE	RNAV YTKE	RNAV HORE	RNAV VORE	RNAV DMEE	VRTAC XTKE	VRTAC YTKE	VRTAC HORE
MINIMUM	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00
MAXIMUM	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00
RANGE	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00
SAMPLE SIZE	1.40000E+01	1.40000E+01	1.40000E+01	1.40000E+01	1.40000E+01	1.40000E+01	1.40000E+01	1.40000E+01
SUM	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00
MEAN	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00
MEAN DEVIATION	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00
SUM OF SQUARES	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00
VARIANCE	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00
STD DEVIATION	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00
STD ERROR MEAN	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00
COEF VARIATION	9.90000+320	9.90000+320	9.90000+320	9.90000+320	9.90000+320	9.90000+320	9.90000+320	9.90000+320
SKEWNESS	9.90000+320	9.90000+320	9.90000+320	9.90000+320	9.90000+320	9.90000+320	9.90000+320	9.90000+320
KURTOSIS	9.90000+320	9.90000+320	9.90000+320	9.90000+320	9.90000+320	9.90000+320	9.90000+320	9.90000+320
RUNS	1.00000E+00	1.00000E+00	1.00000E+00	1.00000E+00	1.00000E+00	1.00000E+00	1.00000E+00	1.00000E+00
EXP NUMBER RUNS	9.00000E+00	9.00000E+00	9.00000E+00	9.00000E+00	9.00000E+00	9.00000E+00	9.00000E+00	9.00000E+00
STD DEV OF RUNS	1.47196E+00	1.47196E+00	1.47196E+00	1.47196E+00	1.47196E+00	1.47196E+00	1.47196E+00	1.47196E+00
TEST FOR RUNS	5.43493E+00	5.43493E+00	5.43493E+00	5.43493E+00	5.43493E+00	5.43493E+00	5.43493E+00	5.43493E+00
SERIAL COR COEFF	-0.E+00	-0.E+00	-0.E+00	-0.E+00	-0.E+00	-0.E+00	-0.E+00	-0.E+00
MEAN CONFID. LB	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00
MEAN CONFID. UB	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00
VAR. CONFID. LB	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00
VAR. CONFID. UB	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00
MEDIAN	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00
RANK CORR COEFF	5.00000E-01	5.00000E-01	5.00000E-01	5.00000E-01	5.00000E-01	5.00000E-01	5.00000E-01	5.00000E-01
T-TEST OF RANK	2.00000E+00	2.00000E+00	2.00000E+00	2.00000E+00	2.00000E+00	2.00000E+00	2.00000E+00	2.00000E+00

Figure 35 - Statistical measures of RNAV: XTKE, HORE, VORE, DMEE; and VRTAC: XTKE, YTKE, and HORE.

NASA-AA TWO SEGMENT APPROACH STATISTICAL ANALYSIS DISTANCE TO TOUCHDOWN = 1.4NM

STATISTICAL MEASURES OF THE SAMPLES

	VRTAC VORE	VRTAC DMEE	VRT DEV	LAT DEV	PITCH STR	ROLL STEER	LOC ERR	GLS ERR
MINIMUM	0.E+00	0.E+00	-3.42000E+00	-4.39590E+02	-3.43000E-01	-5.00000E-01	-1.65070E+02	5.47060E+01
MAXIMUM	0.E+00	0.E+00	-4.10000E-01	-1.42570E+02	2.99000E 01	3.43000E-01	1.21226E+02	1.78579E+02
RANGE	0.E+00	0.E+00	3.01000E+00	2.97020E+02	6.42000E-01	8.43000E-01	2.86296E+02	1.23873E+02
SAMPLE SIZE	1.40000E+01	1.40000E+01	1.40000E+01	1.40000E+01	1.40000E+01	1.40000E+01	1.40000E+01	1.40000E+01
SUM	0.E+00	0.E+00	-2.74940E+01	-3.83750E+03	-6.55000E-01	-8.74000E-01	4.21457E+02	1.57221E+03
MEAN	0.E+00	0.E+00	-1.96386E+00	-2.74107E+02	-4.67857E-02	-6.24286E-02	3.01041E+01	1.12372E+02
MEAN DEVIATION	0.E+00	0.E+00	7.84449E-01	5.71006E+01	1.52643E-01	2.05143E-01	5.28755E+01	3.34177E+01
SUM OF SQUARES	0.E+00	0.E+00	6.57551E+01	1.14461E+06	[illegible]	9.06998E-01	8.26267E+04	[illegible]
VARIANCE	0.E+00	0.E+00	9.20063E-01	7.13299E+03	[illegible]	6.55720E-02	5.37993E+03	1.53875E+03
STD DEVIATION	0.E+00	0.E+00	9.59199E-01	[illegible]	[illegible]	2.56070E-01	7.33480E+01	3.92269E+01
STD ERROR MEAN	0.E+00	0.E+00	2.56357E-01	[illegible]	[illegible]	6.84376E-02	1.96031E+01	1.04838E+01
COEF VARIATION	9.90000+320	9.90000+320	-4.88426E-01	[illegible]	[illegible]	-4.10181E+00	2.43648E+00	3.49079E-01
SKEWNESS	9.90000+320	9.90000+320	[illegible]	[illegible]	[illegible]	-4.47735E-02	-1.13140E+00	2.09931E-01
KURTOSIS	9.90000+320	9.90000+320	[illegible]	[illegible]	[illegible]	1.89495E+00	4.30711E+00	[illegible]
RUNS	1.00000E+00	[illegible]	[illegible]	[illegible]	[illegible]	1.10000E+01	1.00000E+01	9.00000E+00
EXP NUMBER RUNS	9.00000E+00	[illegible]	[illegible]	[illegible]	[illegible]	9.00000E+00	9.00000E+00	9.00000E+00
STD DEV OF RUNS	1.47196E+00	[illegible]	[illegible]	[illegible]	1.47196E+00	1.47196E+00	1.47196E+00	1.47196E+00
TEST FOR RUNS	5.43493E+00	[illegible]	[illegible]	[illegible]	6.79366E-01	1.35873E+00	6.79366E-01	0.E+00
SERIAL COR COFF	-0.E+00	-0.E+00	[illegible]	-2.74449E-02	4.67647E-01	-3.01183E-01	-1.32491E-01	1.31229E-01
MEAN CONFID. LB	0.E+00	[illegible]	[illegible]	-3.28271E+02	-1.67107E-01	[illegible]	-1.69359E+01	[illegible]
MEAN CONFID. UB	0.E+00	0.E+00	[illegible]	-2.19943E+02	7.35356E-02	[illegible]	7.71440E+01	1.37330E+02
VAR. CONFID. LB	0.E+00	0.E+00	[illegible]	3.74869E+03	1.84987E-02	3.44613E-02	2.82742E+03	8.08088E+02
VAR. CONFID. UB	0.E+00	0.E+00	[illegible]	1.85907E+04	9.17395E-02	1.70902E-01	1.40218E+04	4.01048E+03
MEDIAN	0.E+00	0.E+00	[illegible]	-2.73258E+02	-6.40000E-02	-7.16000E-02	[illegible]	1.13638E+02
RANK CORR COEFF	5.00000E-01	[illegible]	[illegible]	-1.74725E-01	8.19780E-01	-4.61539E-02	3.18681E-01	5.60440E-01
T-TEST OF RANK	2.00000E+00	2.00000E+00	-3.59755E-01	[illegible]	4.95881E+00	-1.60052E-01	1.16467E+00	2.34416E+00

Figure 36 - Statistical measures of VRTAC: VORE, DMEE; and VRT DEV, LAT DEV, PITCH STR, ROLL STEER, LOC ERR and GLS ERR.

NASA-AA TWO SEGMENT APPROACH STATISTICAL ANALYSIS DISTANCE TO TOUCHDOWN = 1.4NM

STATISTICAL MEASURES OF THE SAMPLES

	ACT ALTE	DIST ALTE	RNAV ALTE	NET ALTE	ALTIM ERR	RECD VOR	RECD DME	ACTUAL ALT
MINIMUM	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	2.67709E+02
MAXIMUM	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	3.90816E+02
RANGE	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	1.23107E+02
SAMPLE SIZE	1.40000E+01	1.40000E+01	1.40000E+01	1.40000E+01	1.40000E+01	1.40000E+01	1.40000E+01	1.40000E+01
SUM	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	4.66341E+03
MEAN	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	3.33101E+02
MEAN DEVIATION	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	3.30100E+01
SUM OF SQUARES	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	1.57299E+06
VARIANCE	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	1.50791E+03
STD DEVIATION	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	3.88318E+01
STD ERROR MEAN	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	1.03782E+01
COEF VARIATION	9.90000+320	9.90000+320	9.90000+320	9.90000+320	9.90000+320	9.90000+320	9.90000+320	1.16577E-01
SKEWNESS	9.90000+320	9.90000+320	9.90000+320	9.90000+320	9.90000+320	9.90000+320	9.90000+320	-2.15525E-01
KURTOSIS	9.90000+320	9.90000+320	9.90000+320	9.90000+320	9.90000+320	9.90000+320	9.90000+320	1.74927E+00
RUNS	1.00000E+00	1.00000E+00	1.00000E+00	1.00000E+00	1.00000E+00	1.00000E+00	1.00000E+00	9.00000E+00
EXP NUMBER RUNS	9.00000E+00	9.00000E+00	9.00000E+00	9.00000E+00	9.00000E+00	9.00000E+00	9.00000E+00	9.00000E+00
STD DEV OF RUNS	1.47196E+00	1.47196E+00	1.47196E+00	1.47196E+00	1.47196E+00	1.47196E+00	1.47196E+00	1.47196E+00
TEST FOR RUNS	5.43493E+00	5.43493E+00	5.43493E+00	5.43493E+00	5.43493E+00	5.43493E+00	5.43093E+00	0.E+00
SERIAL COR COEF	-0.E+00	-0.E+00	-0.E+00	0.E+00	-0.E+00	-0.E+00	-0.E+00	1.21671E-01
MEAN CONFID. LB	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	3.08197E+02
MEAN CONFID. UB	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	3.58005E+02
VAR. CONFID. LB	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	7.92479E+02
VAR. CONFID. UB	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	3.93010E+03
MEDIAN	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	3.33171E+02
RANK CORR COEFF	5.00000E-01	5.00000E-01	5.00000E-01	5.00000E-01	5.00000E-01	5.00000E-01	5.00000E-01	-5.20879E-01
T-TEST OF RANK	2.00000E+00	2.00000E+00	2.00000E+00	2.00000E+00	2.00000E+00	2.00000E+00	2.00000E+00	-2.11377E+00

Figure 37 - Statistical measures of ACT ALTE, DIST ALTE, RNAV ALTE, NET ALTE, ALTIM ERR, RECD VOR, RECD DME, and ACTUAL ALT.

FREQUENCY DISTRIBUTION AND HISTOGRAM OF VARIABLE - VRT DEV

PERCENT	COUNT	RANGE	
21.43	3.	-3.50	-2.88
21.43	3.	-2.88	-2.26
21.43	3.	-2.26	-1.64
14.29	2.	-1.64	-1.02
21.43	3.	-1.02	-0.40
TOTAL	14.		

FREQUENCY DISTRIBUTION AND HISTOGRAM OF VARIABLE - LAT DEV

PERCENT	COUNT	RANGE	
14.29	2.	-500.00	-420.00
0.00	0.	-420.00	-340.00
50.00	7.	-340.00	-260.00
21.43	3.	-260.00	-180.00
14.29	2.	-180.00	-100.00
TOTAL	14.		

FREQUENCY DISTRIBUTION AND HISTOGRAM OF VARIABLE - PITCH STR

PERCENT	COUNT	RANGE	
21.43	3.	-0.40	-0.26
7.14	1.	-0.26	-0.12
35.71	5.	-0.12	00.02
28.57	4.	00.02	00.16
7.14	1.	00.16	00.30
TOTAL	14.		

FREQUENCY DISTRIBUTION AND HISTOGRAM OF VARIABLE - ROLL STEER

PERCENT	COUNT	RANGE	
21.43	3.	-0.50	-0.32
14.29	2.	-0.32	-0.14
28.57	4.	-0.14	00.04
21.43	3.	00.04	00.22
14.29	2.	00.22	00.40
TOTAL	14.		

Figure 38 - Frequency dist·ibution and histogram of VRT DEV, LAT DEV, PITCH STR, and ROLL STEER.

FREQUENCY DISTRIBUTION AND HISTOGRAM OF VARIABLE - RECD DME

PERCENT	COUNT	RANGE	
100.00	14.	0.00	0.00
0.00	0.	0.00	0.00
0.00	0.	0.00	0.00
0.00	0.	0.00	0.00
0.00	0.	0.00	0.00
TOTAL	14.		

FREQUENCY DISTRIBUTION AND HISTOGRAM OF VARIABLE - ACTUAL ALT

PERCENT	COUNT	RANGE	
0.00	0.	200.00	240.00
14.29	2.	240.00	280.00
21.43	3.	280.00	320.00
28.57	4.	320.00	360.00
35.71	5.	360.00	400.00
TOTAL	14.		

FREQUENCY DISTRIBUTION AND HISTOGRAM OF VARIABLE - LOC ERR

PERCENT	COUNT	RANGE	
7.14	1.	-200.00	-120.00
0.00	0.	-120.00	-40.00
42.86	6.	-40.00	40.00
42.86	6.	40.00	120.00
7.14	1.	120.00	200.00
TOTAL	14.		

FREQUENCY DISTRIBUTION AND HISTOGRAM OF VARIABLE - GLS ERR

PERCENT	COUNT	RANGE	
0.00	0.	0.00	40.00
28.57	4.	40.00	80.00
21.43	3.	80.00	120.00
35.71	5.	120.00	160.00
14.29	2.	160.00	200.00
TOTAL	14.		

Figure 39 - Frequency distribution and histogram of RECD DME, ACTUAL ALT, LOC ERR, and GLS ERR.

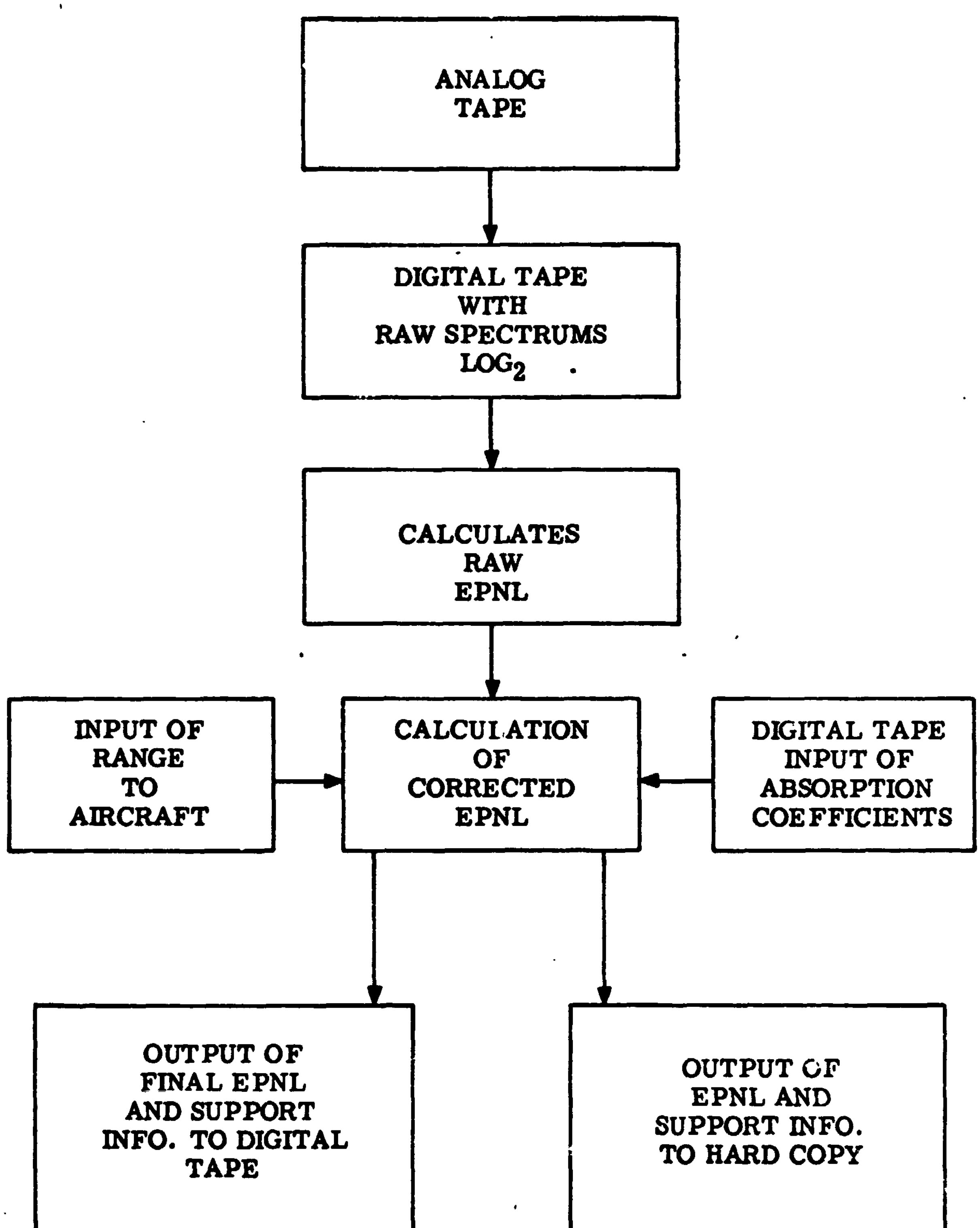


Figure 40 - Processing block diagram.

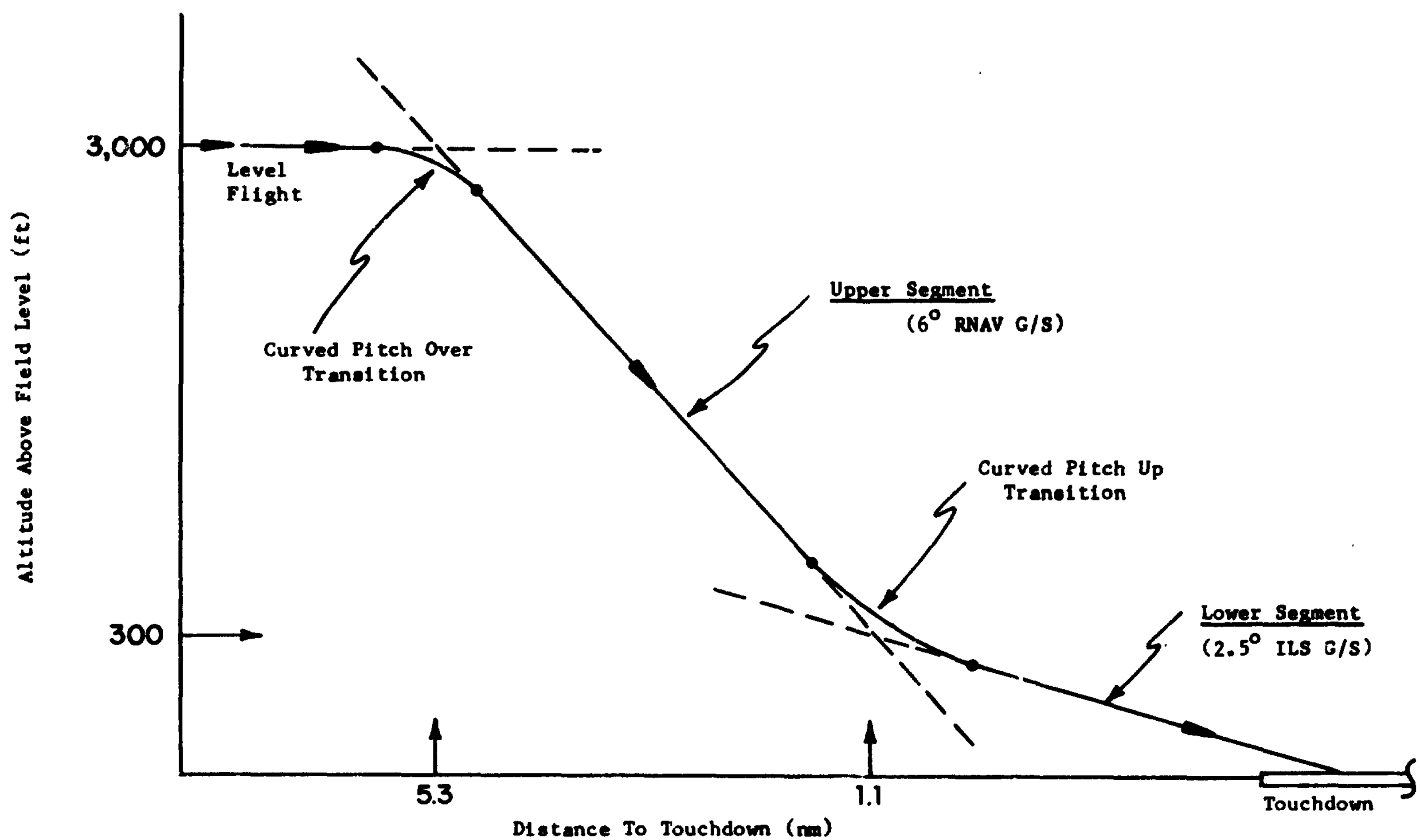


Figure 41 - Two-segment approach profile evaluated by guest pilots at Stockton (not to scale).

Question Number

(4) ALL THINGS CONSIDERED, WHAT ALTITUDE DO YOU FEEL IS MOST COMPATIBLE FOR TRANSITIONING TO THE ILS G/S?

Altitude	No. of Responses	Why
400 ft	12	Represents an eventual minimum. Would expect to use a higher altitude during initial introduction to scheduled service to allow for expected range of IFR conditions and pilot inexperience. Must have fully coupled autopilot capability to go this low. Allows plenty of time to arrest high sink rate. Would like autothrottle, too, if altitude intercept is set this low, but not a necessity.
500 ft	5	Sufficient for pilot to satisfy himself that automatic transfer from RNAV to ILS has taken place, and if transfer has not occurred, to execute a missed approach. Consistent with point where pilots find the "slot" during normal ILS angle approaches.
700 ft	1	For time to regain good stabilized flight on the ILS glide slope.
800 ft	1	Realistic for initial compliance. Allows for expected range of weather, tailwinds, cross-winds, and slippery runways.
1,000 ft	2	As operational experience is gained, it may be feasible to gradually decrease the altitude intercept. Same philosophy as used for achieving lower weather minimums (i.e., Cat I, II, and III). Would like approximately 1.5 minutes to stabilize on lower ILS segment.

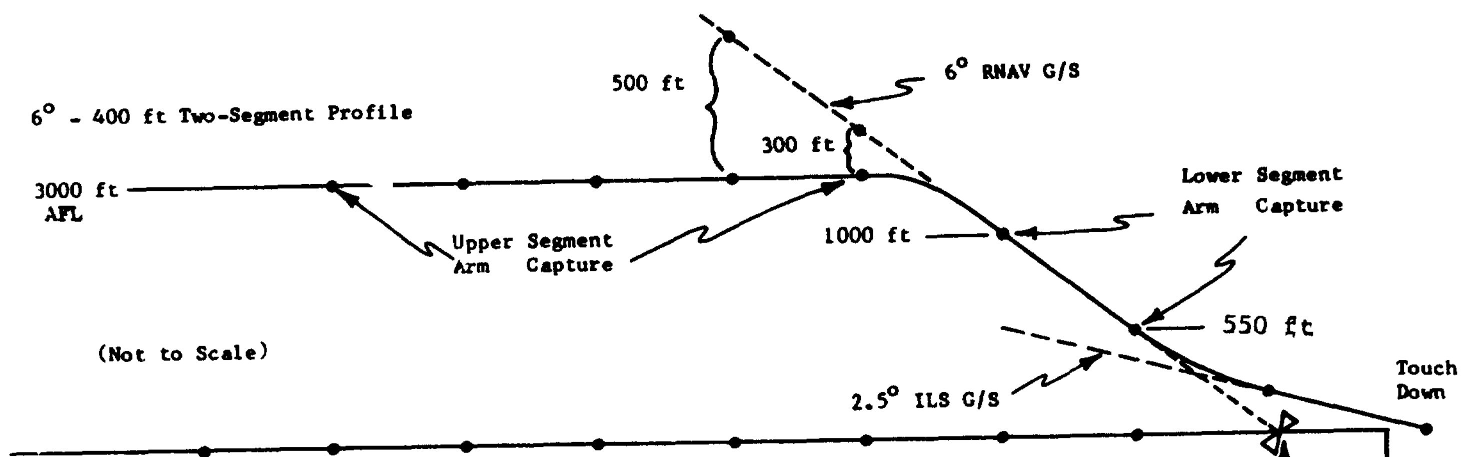
(9) WHAT DID YOU THINK OF THE LOWER ILS G/S BEAM CAPTURE?

Reaction	No. of Responses	Why
Good	17	Adequate anticipation. Startling pitch-up is not required. No tendency to go below ILS beam. Autothrottle not needed if full autopilot coupling is provided. Upper segment airspeed cushion a necessity.
Satisfactory	2	A larger radius pitch-up curve would be more desirable. Need more pitch-up authority at moment of initial ILS beam capture.
Unsatisfactory	2	A high degree of pilot concentration required. Little margin for distractions and contingencies. High sink rate before capture increases accident probability.

(8) WHAT DID YOU THINK OF THE UPPER 3D-RNAV BEAM (6°) CAPTURE?

Reaction	No. of Responses	Why
Good	19	Easy to enter, smooth, comfortable, no noticeable pitchover. Would be even better if capture was entered from an altitude hold mode. RNAV distance to runway waypoint was a helpful anticipation cue.
Satisfactory	2	Need more pitch-down authority at moment of initial capture to avoid overshoot tendency and higher sink rate required to recenter on the upper segment.

Figure 42 - Pilot questionnaire results for profile variables.



Distance To Upper Segment RNAV Waypoint	10.0	8.0	7.0	5.5	5.2	1.6	0.8	Upper Segment RNAV Waypoint	
Navigation Mode Select Switch	RNAV	RNAV-LOC							
No. 1 Receiver Frequency	Enroute VORTAC	RNAV W/P VORTAC							
No. 2 Receiver Frequency	Alternate VORTAC	ILS G/S							
Flaps (deg)	Up		20	30	40	30			
Gear	Up				Down				
Airspeed (knots)	250	V_{REF} + 50	REF + 30	REF + 20				REF + 10	
Engine Fuel Flow (lb/hr)	3400	3400				1500			3000
Cockpit Progress Display Lights — V/L	Off	Amb _ Grn							
Cockpit Progress Display Lights — RNAV	Green	Off							
Cockpit Progress Display Lights — RNAV/GS	Off	Amber				Green		Off	
Cockpit Progress Display Lights — G/S	Off	Off					Amber	Green	

Figure 43 - Pilot procedure.

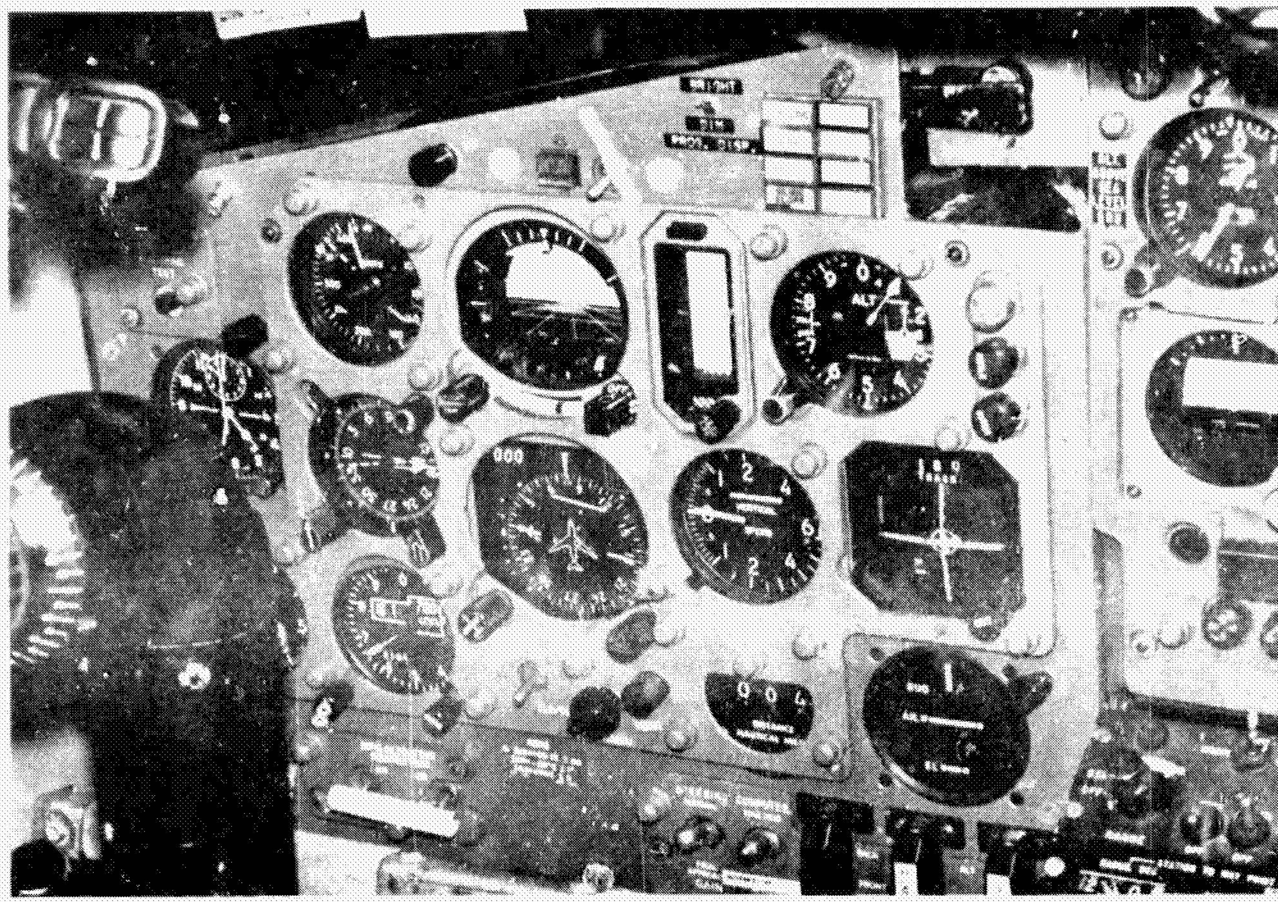


Figure 44 - Captain's instrument panel.

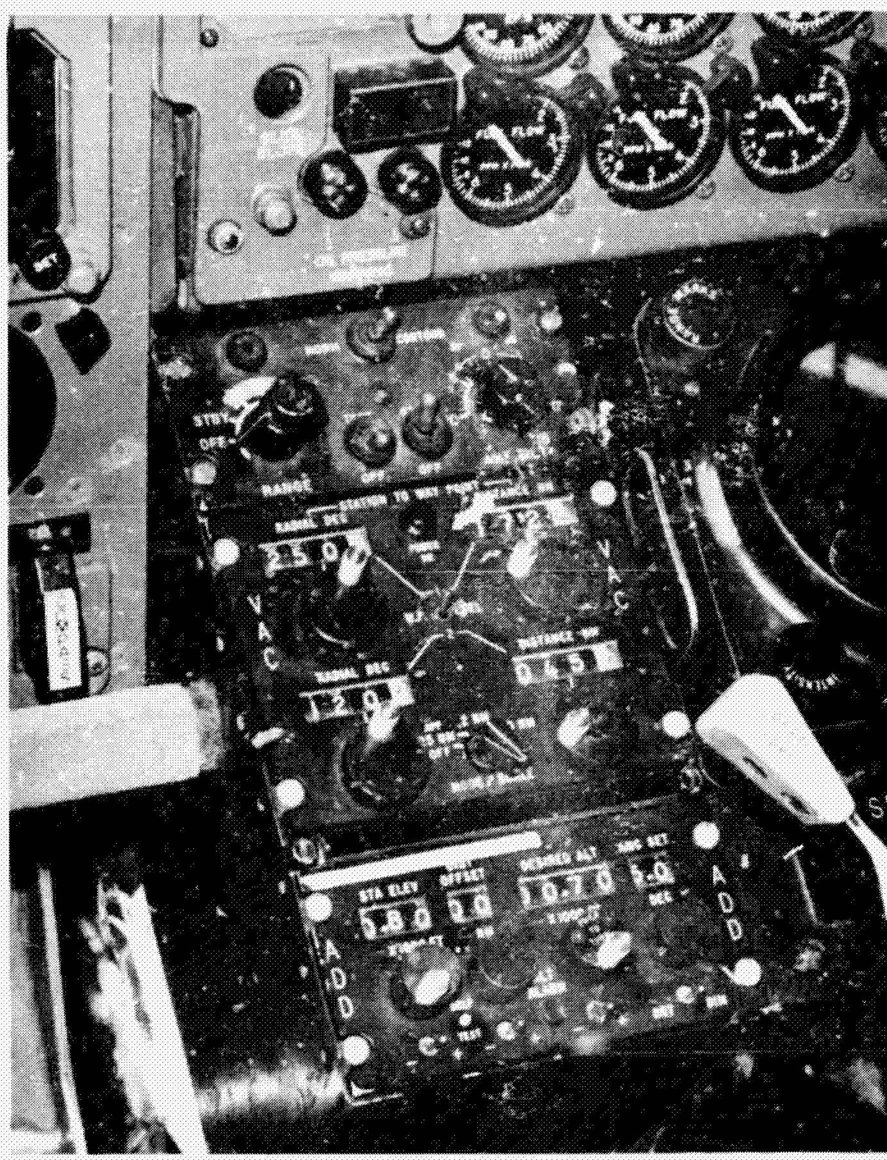


Figure 45 - RNAV control panels.

Question Number

(6) ON THE UPPER BEAM SEGMENT, DID THE HIGHER THAN NORMAL SINK RATE CONCERN YOU?

Answer	No. of Responses	Why
No	19	Radio altimeter tape display adjacent to ADI was very helpful as back-up reference. Not after several practice approaches were flown. No concern if extra 15 knots airspeed cushion and spooled-up engine power level is included in upper segment procedure. Liked having ILS G/S displayed continuously on CDI as a backup if automatic ADI switching from RNAV G/S to ILS G/S did not occur. Not concerned if pitch-up transition started at or above 500 ft.
Yes	2	Not concerned in fair weather, VFR conditions, but would be more concerned in adverse weather and mountainous terrain. Some concern when occasionally sink rate exceeded 1800 ft/min during a correction from above the 6° path and lower ILS G/S capture was about to take place.

(7) DO YOU THINK AN AIRSPEED LESS THAN V_{REF} + 20 KNOTS COULD BE USED ON THE UPPER 3D-RNAV BEAM?

Answer	No. of Responses	Why
No	14	Easy to fly bleed off, better control response, and a good safety margin. Minimizes chances of getting too slow during pitch-up transition to the lower ILS G/S segment. Anything less than 20 knots cushion increases need for autothrottle. The time to bleed off to REF + 10 provides extra time for engines to reach ILS G/S power level. A good compensation for higher than normal sink rate on the upper segment.
Yes	7	Lower cushion could be used, but would require tighter pilot technique during pitch-up transition. With more experience, less cushion could be tolerated in fair weather, VFR conditions. Less cushion would reduce upper segment sink rate. Prefer same airspeeds for upper and lower segments to avoid need for setting up two separate airspeeds.

Figure 46 - Pilot questionnaire results for pilot procedures.

Question Number

(3) WHAT ADDITIONAL FLIGHT INSTRUMENTATION OR AIRCRAFT SYSTEMS DO YOU FEEL ARE NEEDED TO FLY TWO-SEGMENT APPROACHES (OTHER THAN WHAT YOU SAW TODAY)?

Answer	No. of Responses	Why
None	8	If used in fair weather VFR conditions, but need more exposur to range of adverse weather before can be certain for IFR.
Other	13	Fully coupled autopilot, lateral and vertical throughout. Full avionics signal source and display redundancy. Autothrottle would be desirable but not essential for pitch-up transition maneuver during low ceiling IFR weather. Utilize the same basic information in a Heads Up Display (HUD). Redefine the upper segment RNAV waypoint to a 400-foot altitude point and implement the automatic level-off, altitude hold function of the RNAV system for backup if flight director switching does not take place during the transition maneuver.

(10) WHAT TYPES OF AIRCRAFT MALFUNCTIONS DO YOU THINK WOULD PRECLUDE MAKING TWO-SEGMENT APPROACHES?

Answer	No. of Responses	Why
Avionics and Flight Instruments	13	Same kinds of malfunctions that rule out Category I or II IFR approaches. Loss of command data redundancy in ceilings below 300 feet IFR. Loss of raw ILS data redundancy in ADI or CDI during either upper or lower segment. Inconsistency or inoperation of the two-segment progress display lights.
Flight Controls	12	Any flight control malfunction, especially hydraulic failure and flaps. A jammed stabilizer the worst condition, especially if during pitch-up transition. Revert to "normal" emergency procedure approach for any control malfunction.
Loss of Engine	9	Any engine loss, due to asymmetric thrust, especially during pitch-up transition. Any airplane too light to have adequate engine spool speed on upper segment. Experience could show that some malfunctions could be managed.

Figure 46 - Pilot questionnaire results for pilot procedures (cont'd.).

Question Number	Answer	No. of Responses	Why
(10)	(CONT'D.)		
	None Beyond Present Policies	4	Provided lower segment transition altitude not lower than 1000 feet. Provided approach is being made in fair weather, VFR conditions.
(11)	AFTER FLYING TWO-SEGMENT APPROACHES, AND THEN FLYING NORMAL ILS APPROACHES; WHAT DIFFERENCES DID YOU NOTICE?		
	Conditions Noticed During Upper Portion of Two-Segment		Low onboard noise permits better pilot concentration. Above smoke, smog, and local airport traffic. Good view of airport, runway environment and terminal area traffic. Less exposure to terminal area terrain. In the event of an emergency, the pilot has more time, aircraft energy, and altitude to respond. More positive flight control response for airspeed management, etc. Liked DME distance to waypoint readout. Requires pilot to stabilize aircraft for two different, descending flight paths. Transition maneuver from upper to lower segment must be performed at a relatively low altitude (i.e., 550 feet - 350 feet AFL). In low ceiling IFR weather, the pilot would be faced with the transition maneuver and his normally required Decision Height (DH) judgment. Not flying to a point located on the destination runway, during the upper segment.
	Conditions Noticed During Normal ILS		Too low, too flat, too slow, too long. More of a feeling that the approach was being dragged in. More exposure to local traffic. More obscure view of the destination runway. Noisy cockpit for a longer time. Missed having a DME distance to runway readout. Requires pilot to stabilize for only one descent path at a comfortable altitude (i.e., 1000 feet AFL).

Figure 46 - Pilot questionnaire results for pilot procedures (cont'd.).

Question Number

(1) DO YOU FEEL THERE IS A NEED TO REDUCE AIRCRAFT NOISE?

Answer	No. of Responses	Why
Yes	21	Needed to help improve overall quality of the environment. Consistent with traditional airline efforts to be a "good neighbor." Noise pollution is one of biggest reasons the airline PR image is tarnished. Concerted effort needed to improve airport community environment and general public acceptance. Mandatory noise abatement legislation will be enacted if voluntary efforts are not made. Relief must be provided to insure the continued growth of aviation (avoid curfews, allow further runway extensions and new airport contruction). The industry <u>must</u> find means of dealing with the problem. Like it or not, the industry is going to have to be as responsive as possible.
No	0	

Question Number

(2) DO YOU FEEL NOISE ABATEMENT EFFORTS SHOULD BE DIRECTED TOWARD ENGINEERING CHANGES, OPERATIONAL PROCEDURES, AIR TRAFFIC CONTROL PROCEDURES, OR ALL OF THESE?

Answer	No. of Responses	Why
All	16	They are all highly interrelated. Each, by itself, is too limited in its ability to achieve significant noise reductions. Must be achieved without derogation in operational safety and at reasonable cost. ATC and operational solutions are interim measures. Eventual solution is noise reduction at the source and this should continue to be given major emphasis. Engineering solutions are a "state-of-the-art" matter. Takeoff noise is by far the greatest problem. The appetite of local noise committees for continuing noise reduction is insatiable and may never be satisfied.
ATC Procedures	4	Far more could be done in rerouting traffic, such as sterilized corridors, away from noise sensitive areas. 3D-RNAV, by untying routes from geographic waypoints, would provide more flexibility to air crews and ATC. Two-segment profiles are consistent with the new "Keep 'Em High" policy.
Other (Airport Zoning)	4	More emphasis needed on local ordinances for compatible land use.

Question Number

(2) (Cont'd.)

Answer	No. of Responses	Why
Operational Procedures	3	Operational procedures (such as two-segment, among others) offer the simplest and quickest way to bring about immediate relief. Must be compatible with the most demanding situation foreseeable in line operation. Airplanes were certified to one set of airworthiness performance guarantees. Adjustments to cope with 6° landing configuration descents must be handled through normal rule change procedures. Standardize the approach procedure for use in all kinds of weather, not just VFR. Put more emphasis on engineering and ATC solutions first.
Engineering	2	If engines were "quiet," normal procedures would do at any airport and there would be no need to introduce further variation into crew member procedures. Just as airplanes were designed to go higher, faster, and further, they can be made quieter. More applicable to future powerplants. Too expensive for most present-day engines. We have done about all we can in asking the pilot to alleviate noise through maneuvering and power reduction.

Figure 47 - Pilot questionnaire results for attitudes toward noise abatement.

Question Number

(12) DID FLYING THE TWO-SEGMENT APPROACH UNDER THE HOOD HAVE ANY EFFECT ON YOU?

Answer	No. of Responses	Why
No	13	After flying two-segment approaches in VFR conditions, anxiety under the hood was no more than normally experienced. Ease of flying under the hood increased overall confidence in the procedures. Runway alignment was sufficient to permit successful landing after removing hood at 200 feet. Anticipation cues and cockpit displays kept pilot "ahead of the airplane."
Yes	2	Same types of differences as experienced between normal approaches when made VFR and IFR, but feelings amplified for two-segment. More things to be concerned about and watch during two-segment. Having a VFR safety pilot in the right seat minimized apprehension.

(5) WHAT WEATHER MINIMUM DO YOU FEEL TWO-SEGMENT APPROACHES COULD BE FLOWN TO IN SCHEDULED AIRLINE SERVICE?

Minimums	No. of Responses	Why
Category II (100 ft)	7	This type of approach should not increase present-day airline minimums. Could be an eventual minimum for a 400-foot — 500-foot ILS transition, but first need extensive experience at higher ILS transition altitudes. Should only use this minimum initially if ILS transition is set at 800 feet — 1000 feet to provide sufficient time to stabilize on the ILS before reaching the decision height. This minimum assumes a fully-coupled autopilot throughout the two-segment approach. Autothrottle would be desirable, but not necessary.

Figure 48 - Pilot questionnaire results for weather minimums.

Question Number

(5) (CONT'D.)

Mini-Mums	No. of Responses	Why
Category I (200 ft)	4	200 feet ceiling a good compromise between safety margin and noise abatement objectives for a 400-foot ILS intercept. Depends on further developments, and pilot familiarity through practice. 500 feet — 600 feet ILS transition needed initially.
300 ft	1	For a 400-foot ILS transition.
400 ft	2	Should initially be a 400-foot ceiling for a 400-foot ILS transition until more operational experience is acquired.
500 ft	2	The ILS transition is not difficult enough to warrant a ceiling higher than ILS transition (in this case, 500 feet ceiling for a 500-foot transition). Visibility under the ceiling after transition is more important.
600 ft	2	A good initial ceiling for a 400-foot or 500-foot ILS transition. Want to be visual before starting pitch-up transition to the ILS.
1000 ft (VFR)	3	To gain initial pilot confidence, transition to ILS at 400 feet should be visual. Full autopilot/autothrottle system will permit lower ceilings.
None	2	Two-segment approach has too many liabilities to consider for IFR airline operation at the present time.

Figure 48 - Pilot questionnaire results for weather minimums (cont'd.)

# Of Guest Pilots	Relation of ILS Intercept (4) To Minimum Ceiling (5)	Average Difference (Buffer)	Range
12	Above	(+) 350 ft	100 ft - 900 ft
5	At	0	0
4	Below (Visual at Intercept)	(-) 400 ft	100 ft - 600 ft

REFERENCE:

Pilot Questionnaire Items # (4) and # (5) figure 22.

Figure 49 - Inter-relation between ILS intercept and minimum ceiling.

RNAV Output to Flight Director/Display	RNAV Scale Selected* Approach	Enroute (2 nm)	Enroute (10 nm)
(1) **ADI Vertical Command Data**			
Maximum Output 28 vac p-p (equivalent to 6° pitch command)	15 mvac/ft	15 mvac/ft	15 mvac/ft
(2) **ADI & CDI Vertical Raw Data**			
Vertical Dev. (VTK) Full Scale = 2 dots	± 150 ft	± 500 ft	± 500 ft
(3) **ADI & A/P Horizontal Command Data**			
Maximum Output 300 mvdc	120 mv/nm	30 mv/nm	30 mv/nm
(4) **ADI, CDI, & SPI Horizontal Raw Data**			
Crosstrack Dev. (XTK) Full Scale = 2 dots	± 1.25 nm	± 10 nm	± 50 nm
Alongtrack Dev. (DX to WPT) SPI only	± 1.25 nm	± 10 nm	± 50 nm

*RNAV Scale Selector located on VAC Control Panel to change area depicted in the face of the SPI. The scale setting is used as follows:

APPROACH:

Devoted to lateral and vertical RNAV guidance (as opposed to ILS guidance) for final approaches.

ENROUTE (2 nm):

Utilized for normal enroute waypoint-to-waypoint RNAV navigation and tracking. This setting was also chosen as the most desirable vertical raw data scale for the two-segment profile.

ENROUTE (10 nm):

Primarily used as an enroute orientation device to establish relative position of waypoint and aircraft heading with regard to waypoint position.

Figure 50 - Display sensitivities for RNAV glide slope guidance.

(1) Pitch-down bias at upper-segment capture (stated in terms of pitch attitude angle change):

Bias ($\Delta\theta$)	Resistance (Ohms)
1°	1.00 K
2°	2.00 K
3°	3.10 K
4°	4.25 K
5°	5.50 K
6°	6.68 K
7°	7.88 K
8°	9.22 K
9°	10.60 K
10°	12.00 K
11°	13.50 K
12°	15.10 K

(2) ILS Glide slope deviation at initiation of capture from above beam centerline:

Trip Point (μa)	Resistance (Ohms)
20	150 K
30	125 K
45	104 K
60	90 K
75	78 K
90	68 K
105	59 K
120	53 K
135	48 K
150	44 K

Figure 51 - Adjustable flight director variables for a two-segment approach profile.

"TWO-SEGMENT" APPROACH

Row/Seat Number	# Responses	
2A	2	First-Class 41 Responses
4D	1	
4E	1	
5D	3	
5F	2	
6B	1	
6C	1	
6E	3	
6F	5	
7E	1	
7F	2	
8A	4	
8C	1	
8E	1	
8F	5	
9A	1	
9B	1	
9E	1	
9F	2	
10A	1	
10E	1	
10F	1	
22A	7	Coach 37 Responses
22C	2	
22D	4	
22F	11	
23A	10	
23B	1	
23C	2	

Other Locations Noted:

First Class	1
Forward Lounge	2
Behind Jump Seat	1
Next to Last Row - Coach	1
Rear Seat in Coach	1
No Answer	15
Total Responses	99

"NORMAL" APPROACH

Row/Seat Number	# Responses	
4E	1	First-Class 19 Responses
5D	2	
5E	1	
6B	1	
6D	1	
6E	2	
6F	2	
8A	1	
8C	1	
8F	1	
9B	1	
9F	2	
10A	1	
10E	2	
22A	3	Coach 20 Responses
22C	1	
22D	2	
22F	8	
23A	4	
23C	2	

Other Locations Noted:

Forward Lounge	1
Cockpit Jump Seat	1
No Answer	6
Total Responses	46

Figure 52 - Respondent seat locations from the passenger questionnaire.

Question	Normal Approach Response	Two-Segment Approach Response
B. Number of Approaches Experienced During Visit (Prior to Response)		
1 to 4	2%	13%
5 to 7	11	48
8	20	10
9	13	7
10	11	5
11 to 14	43	10
Over 14	-	3
No Answer	-	4
TOTAL	100%	100%
E. Occupation		
Aerospace	9%	6%
Airline	13	24
Engineer	9	11
Pilot	0	5
Other	4	8
Airport Planning	11	-
Aircraft Safety (R&D)	2	2
ATA	7	5
Aviation	13	18
Clerical	4	1
Education	9	8
Electronics	2	2
Government	4	4
NASA	20	22
Publishing	2	2
Research	2	4
Retired	2	2
TOTAL	100%	100%
F. Sex		
Male	91%	95%
Female	7	4
No Answer	2	1
TOTAL	100%	100%

Figure 53 - Respondent characteristics from the passenger questionnaire.

Question	Normal Approach Sample	Two-Segment Approach Sample
C. Number of Commercial Airline Trips Made in Past 12 Months		
For Business Reasons		
1	2%	3%
2 to 5	15	11
6 to 10	24	23
11 to 20	24	21
Over 20	11	23
None	9	5
No Answer	15	14
TOTAL	100%	100%
For Personal/Pleasure Reasons		
1	2%	2%
2 to 5	42	34
6 to 10	2	10
11 to 20	2	3
Over 20	-	2
None	24	18
No Answer	28	31
TOTAL	100%	100%
D. Pilot Experience		
Yes	52%	63%
Private	20	19
Commercial	47	31
Air Transport Rating	13	23
Military	20	18
Other	-	9
No	44	37
No Answer	4	-
TOTAL	100%	100%

Figure 54 - Respondent flying experience from the passenger questionnaire.

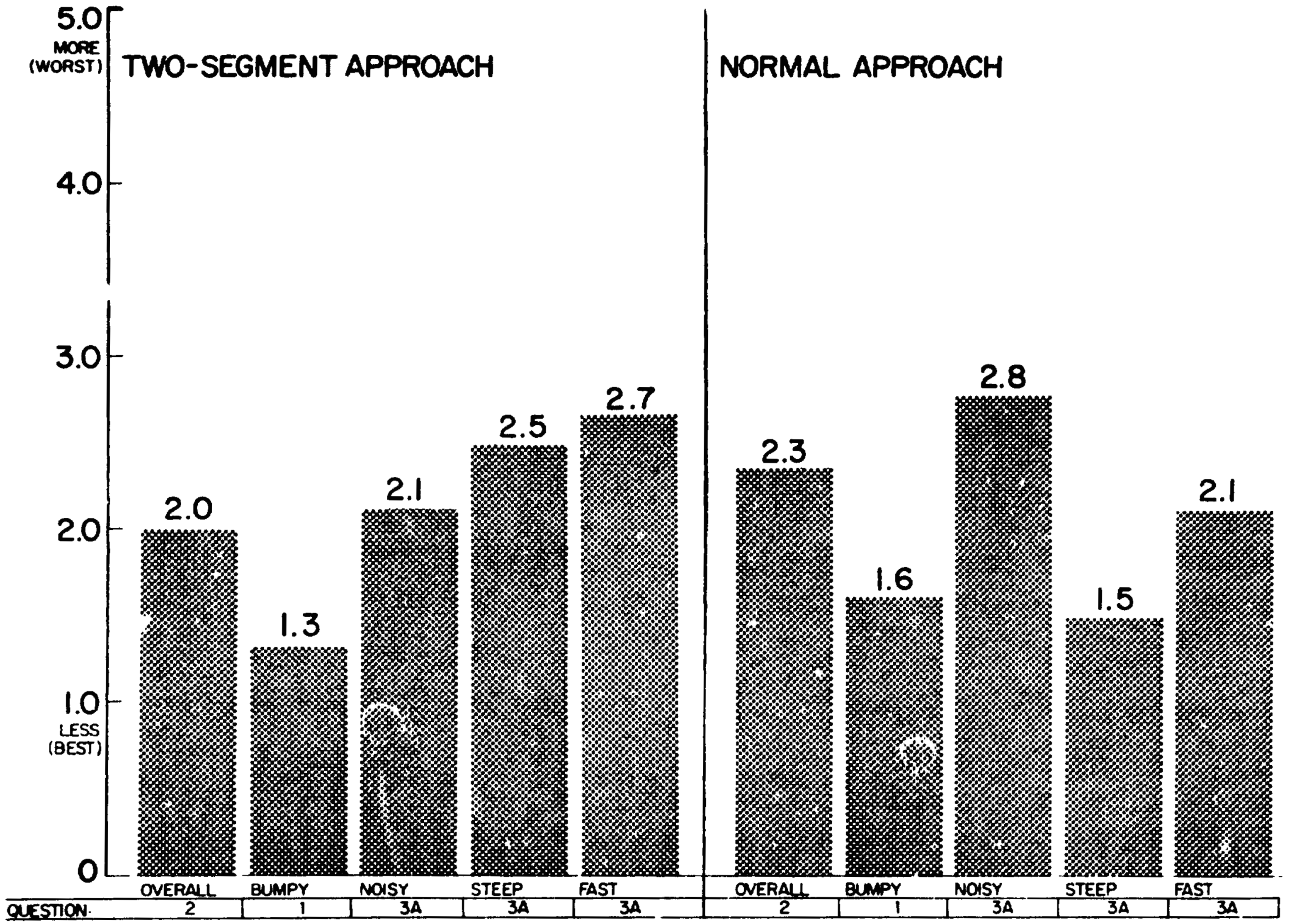


Figure 55 - Respondents overall assessment of two-segment ride quality (passenger questionnaire).

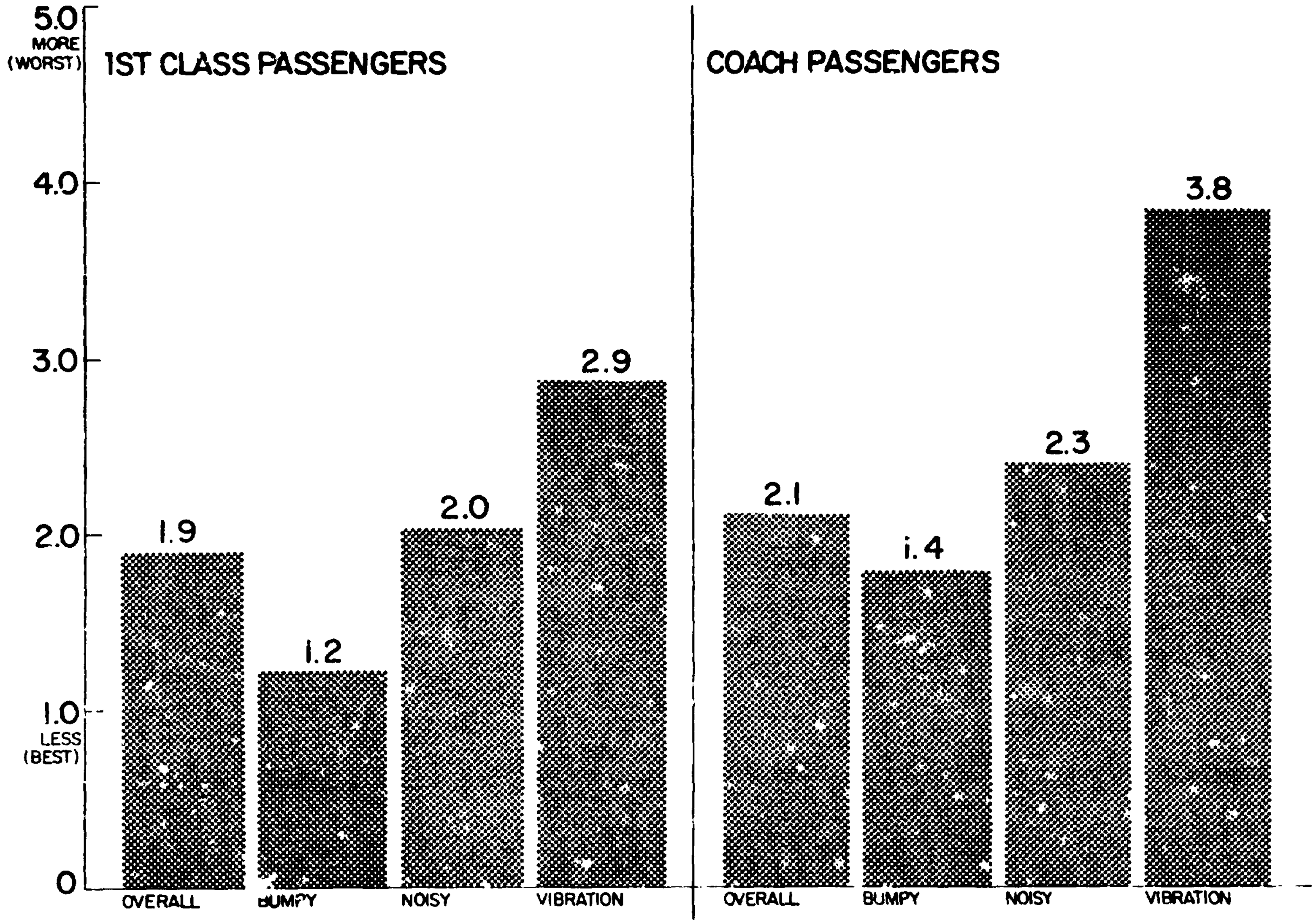


Figure 56 - Respondents assessment of the upper segment 6^o ride quality (passenger questionnaire).

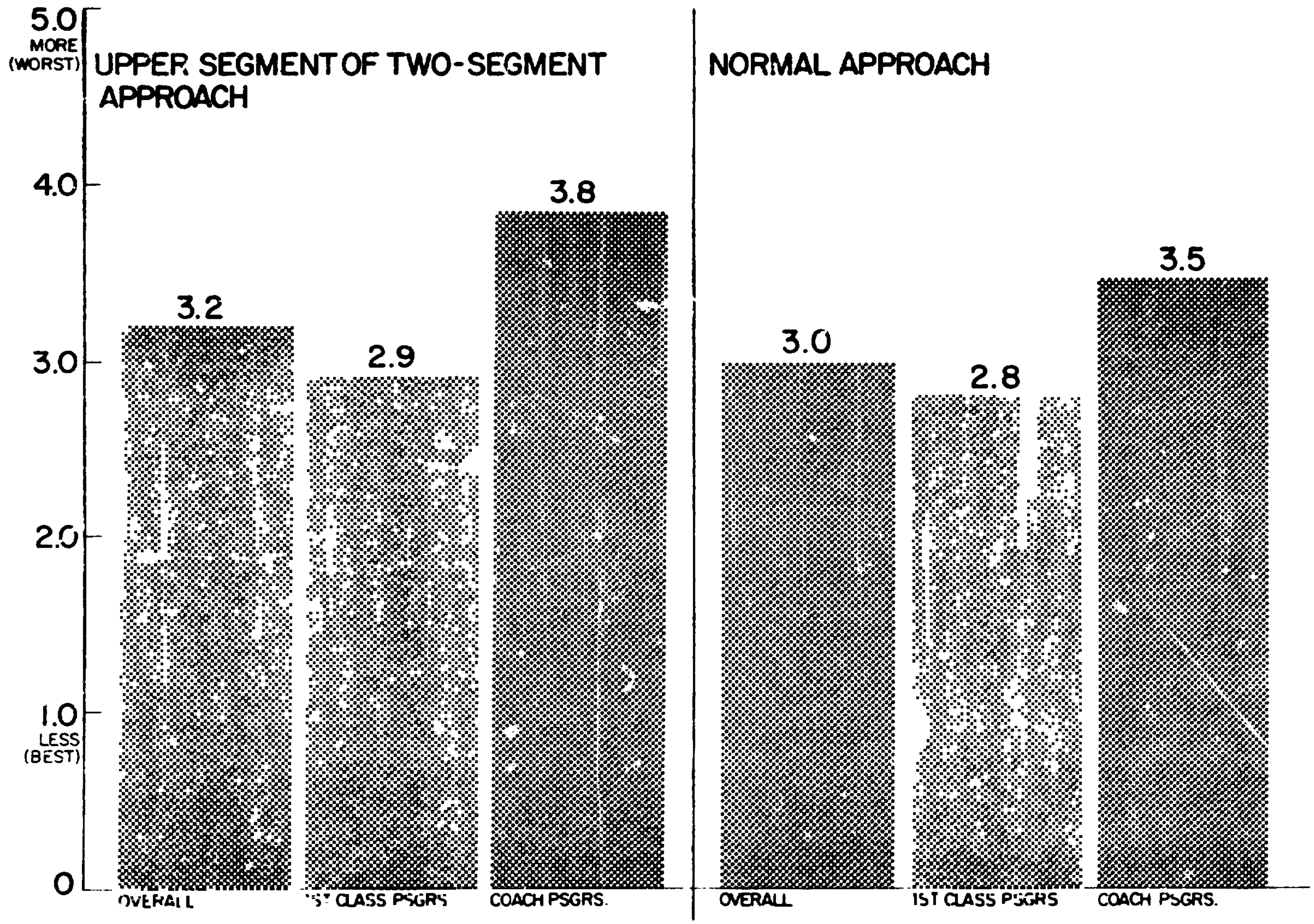


Figure 57 - Respondents assessment of vibration (passenger questionnaire).

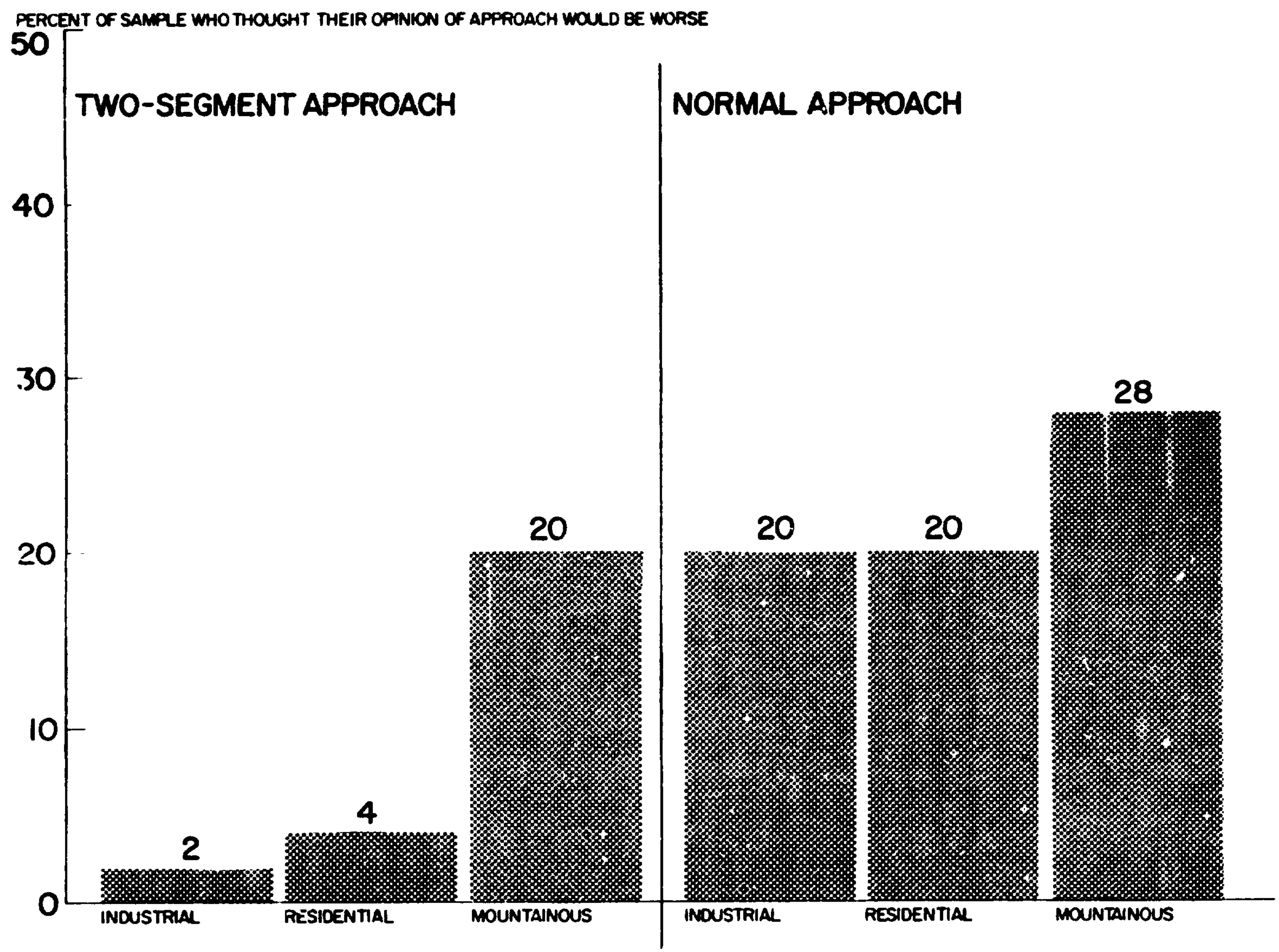


Figure 58 - Respondents concern for terrain features (passenger questionnaire).

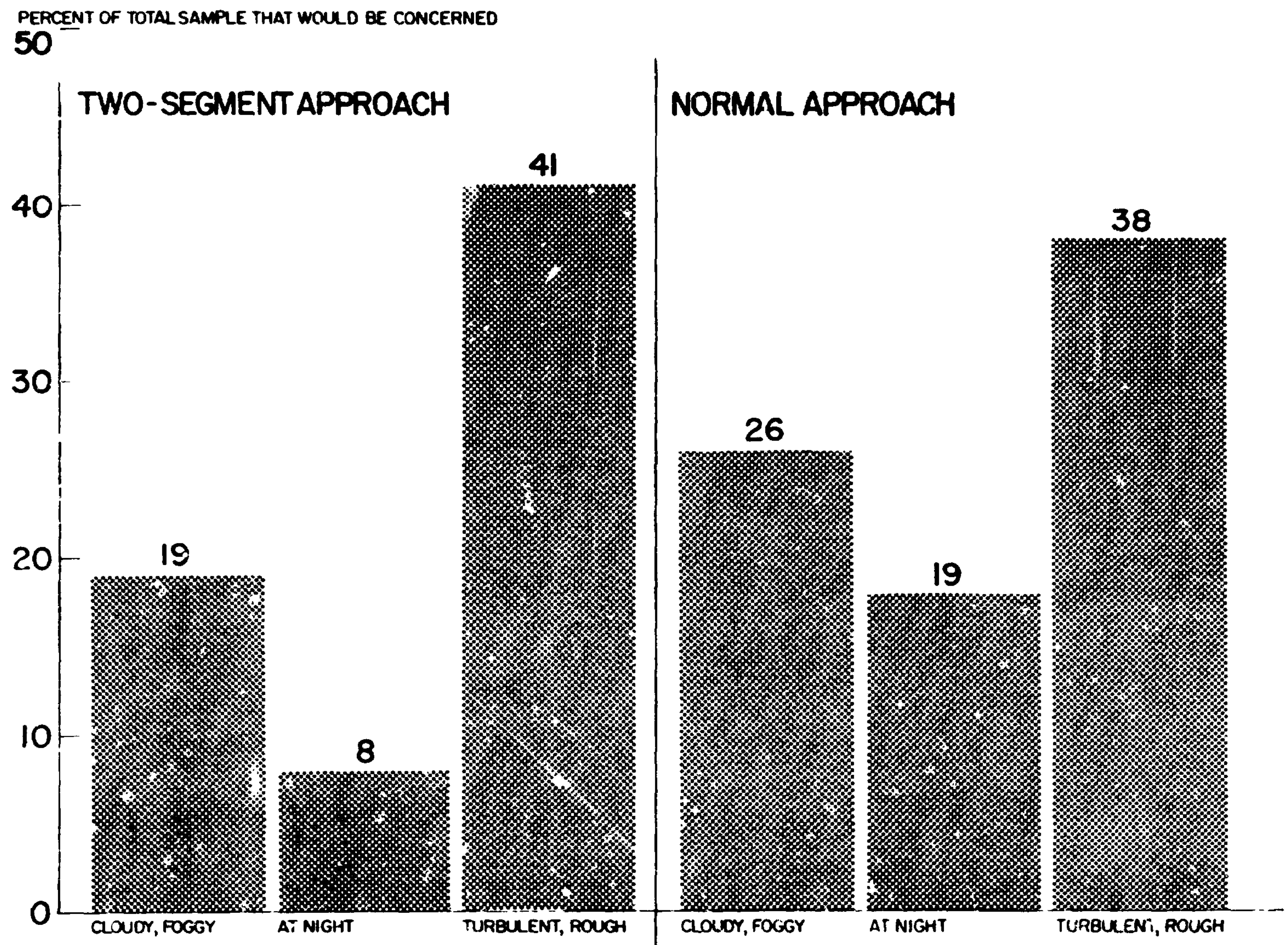


Figure 59 - Respondents concern for adverse weather (passenger questionnaire).

TIME	TEMP (^oF)	HUMIDITY (%)	WIND SPEED (mph)	WIND DIRECTION (True North)
17 August				
0800	62	62	8	230
0900	67	50	9	310
1000	68	45	5	260
1100	74	40	6	90
19 August				
0700	53	--	0	320
0800	57	89	5	320
0900	60	83	5	330
1000	64	70	5	360
1100	68	57	5	340
23 August				
1300	76	54	11	270
1400	79	47	5	280
24 August				
1000	74	50	5	290
1100	76	54	8	280
1200	80	39	7	320
25 August				
0900	70	60	0	040
1000	72	49	5	[illegible]
1100	75	47	5	310
26 August				
0900	64	78	7	320
1000	68	73	10	360
27 August				
0800	56	94	5	340
0900	64	68	5	360
31 August				
1000	63	59	12	300
1100	65	56	15	300
1 September				
0800	59	82	0	270
0900	61	72	5	290
1000	63	72	12	280
2 September				
0800	58	88	5	260
0900	64	68	8	290
1000	65	68	10	300
3 September				
0800	57	63	7	320
0900	62	48	9	320
1000	65	49	15	320

Figure 60 - Stockton weather summary near noise site #3.

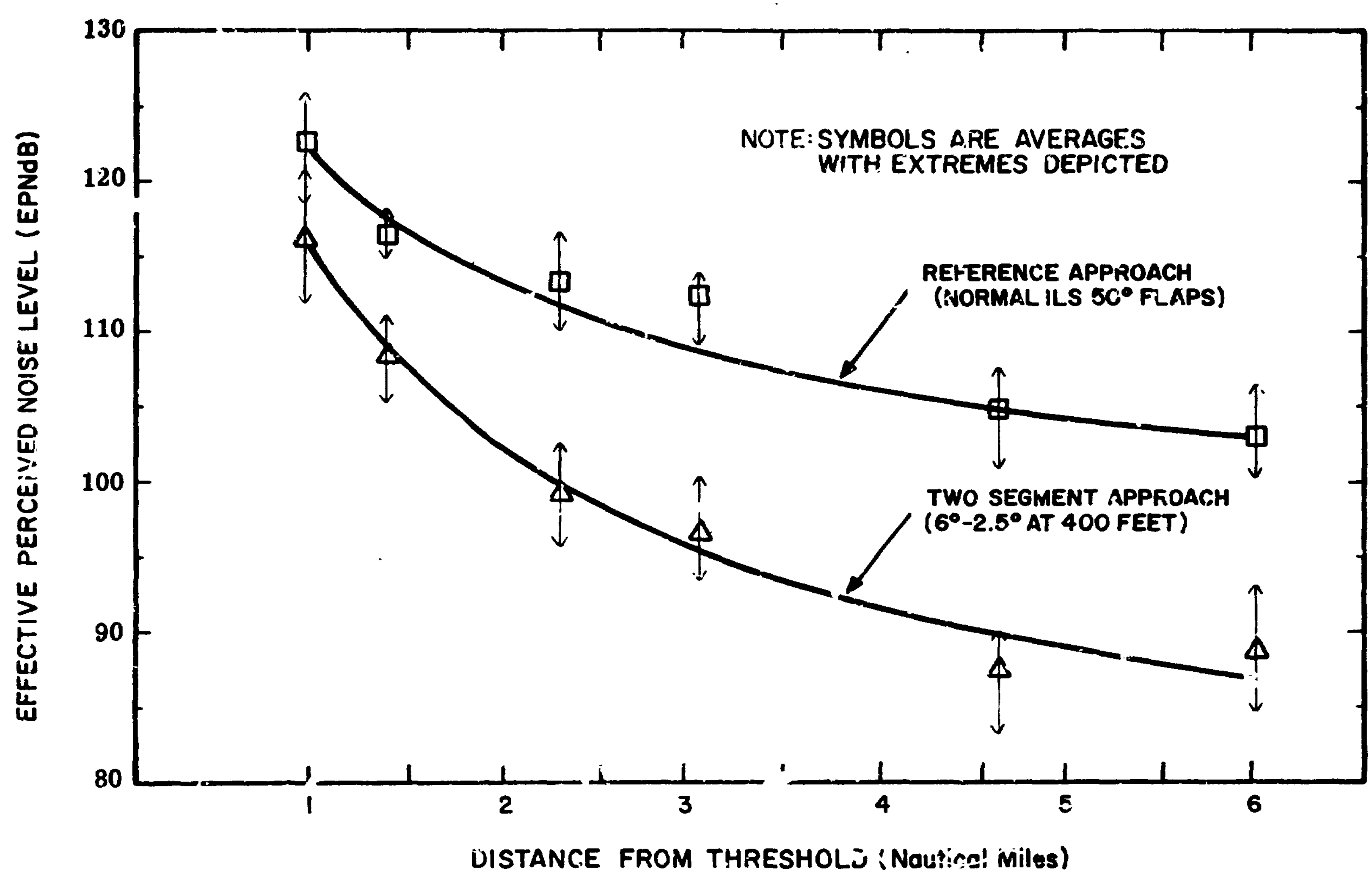
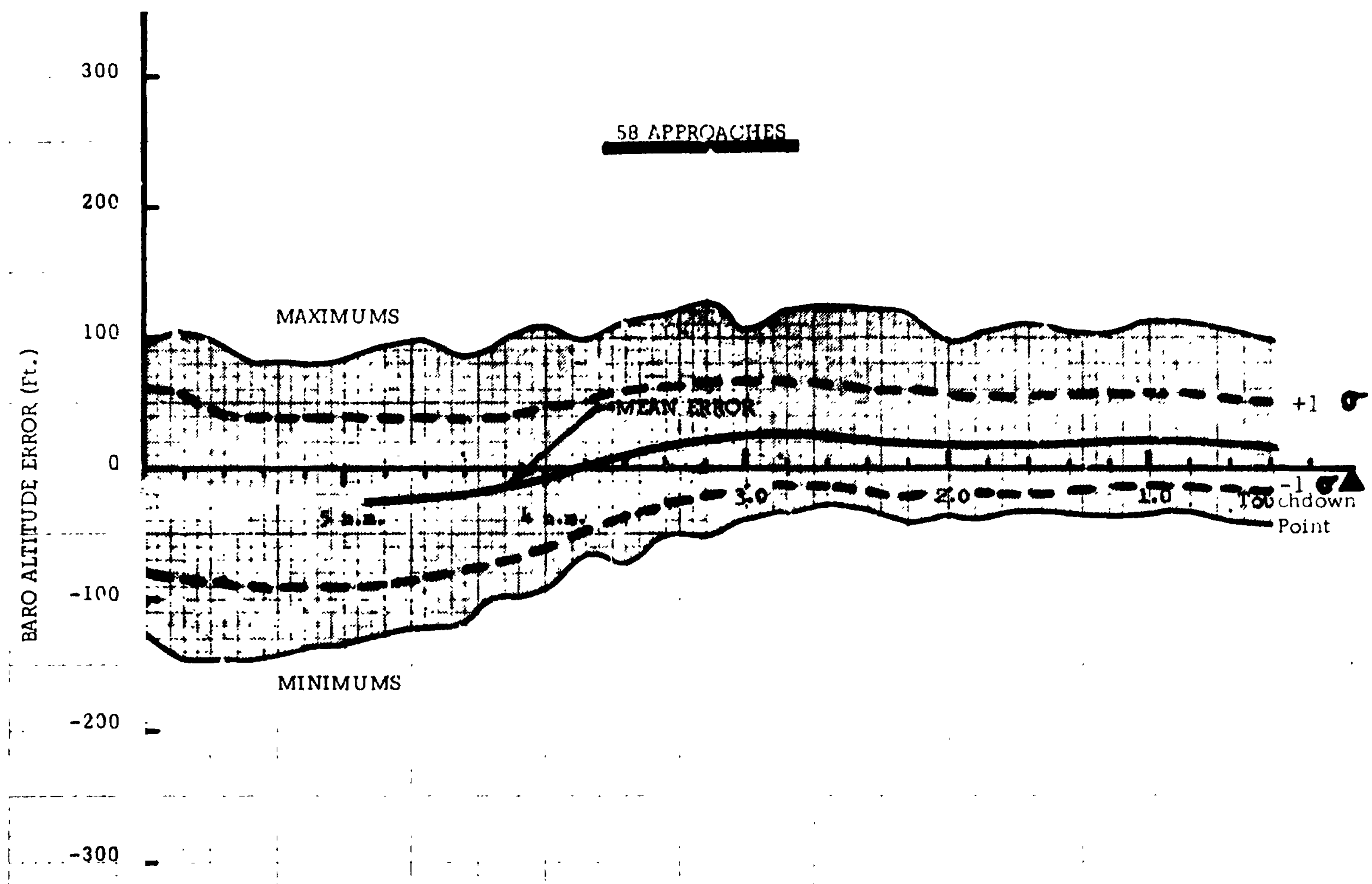
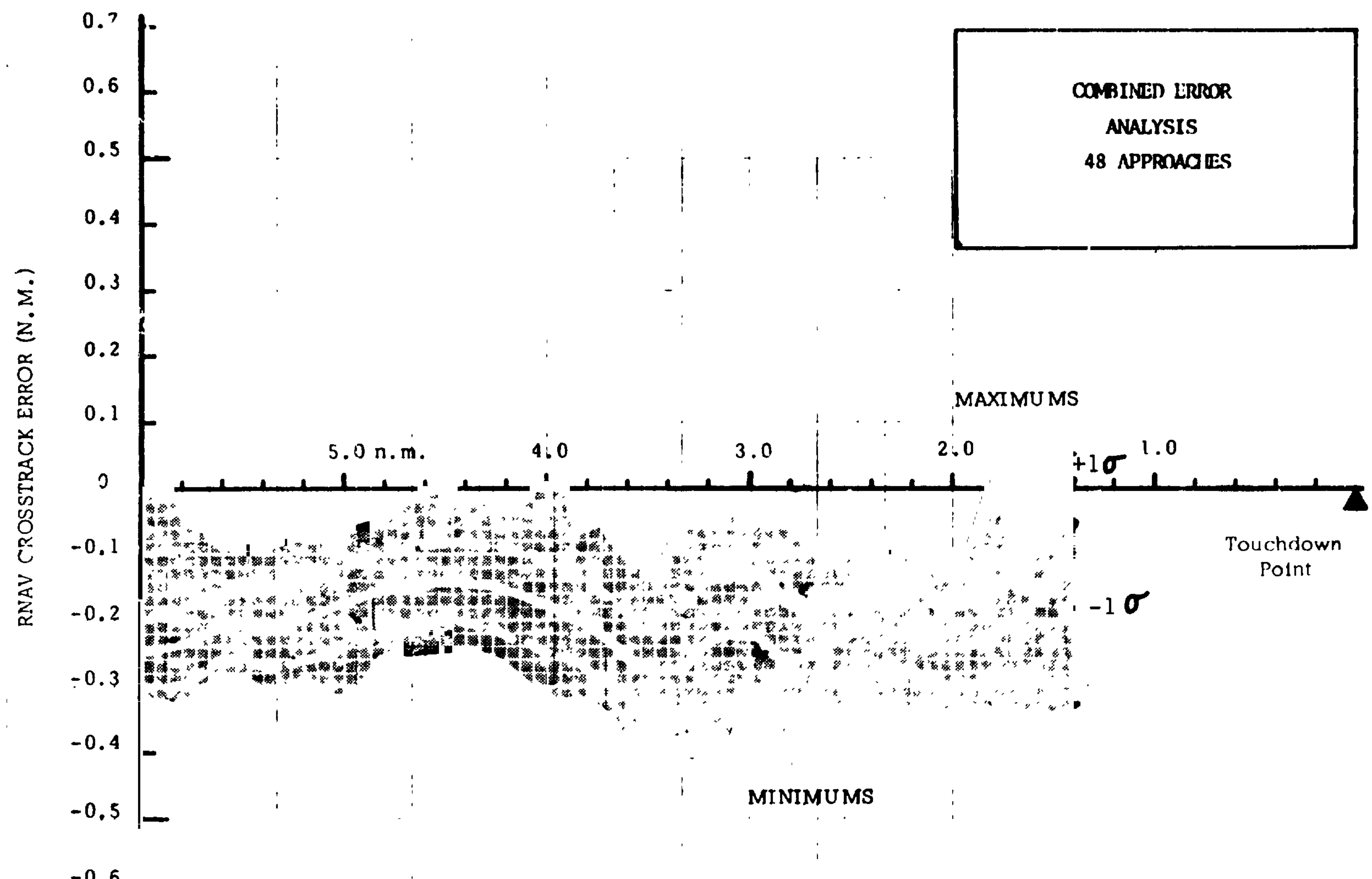


Figure 61 - Maximum reduction in EPNdB along an extension of the runway centerline.



NOTE: Error is indicated minus actual altitude.

Figure 64 - Baro Corrected Altitude Error



NOTE: Error is indicated minus actual crosstrack distance.

Figure 65 - System Crosstrack Error.

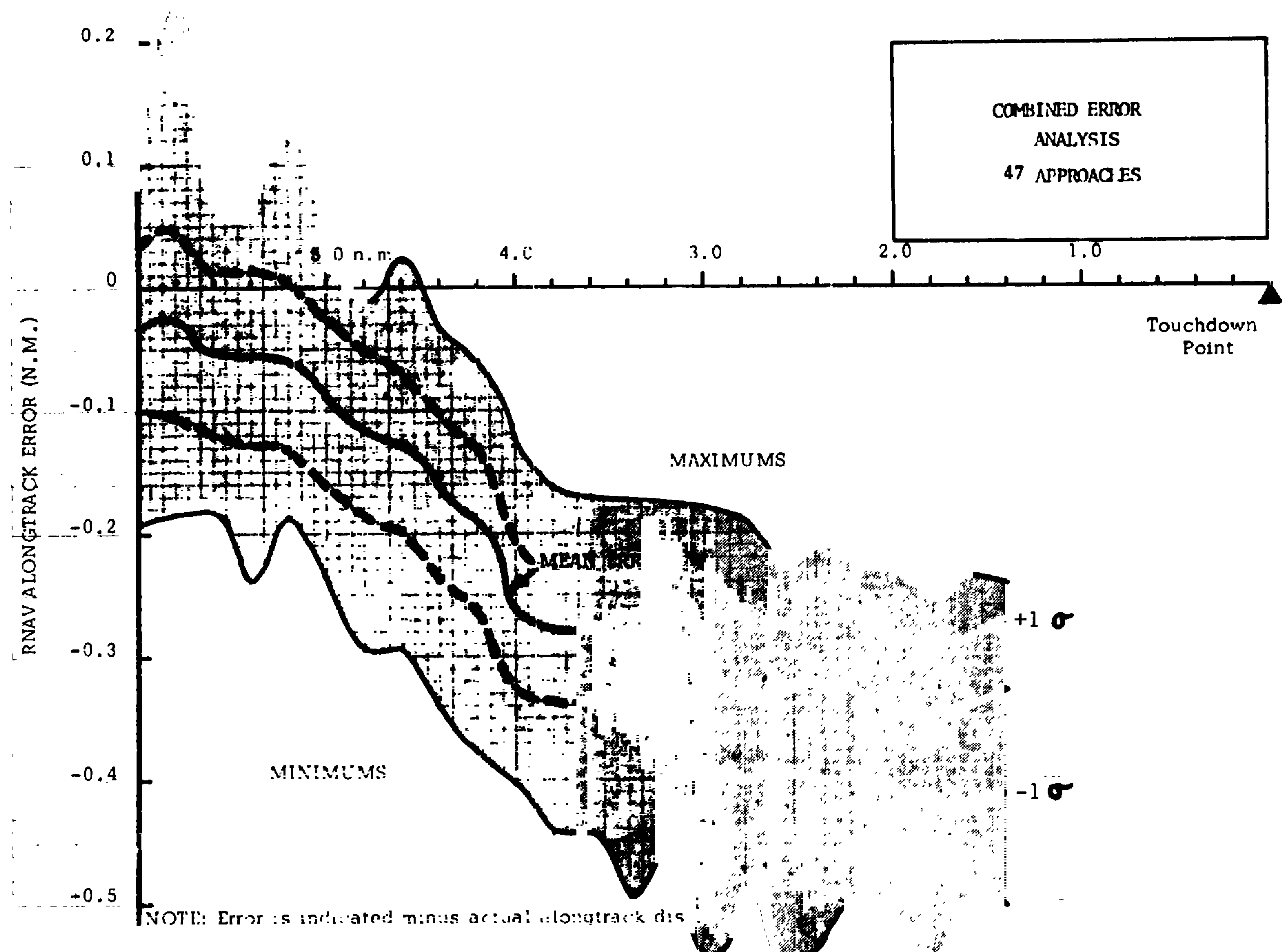


Figure 66 - System Alongtrack Error

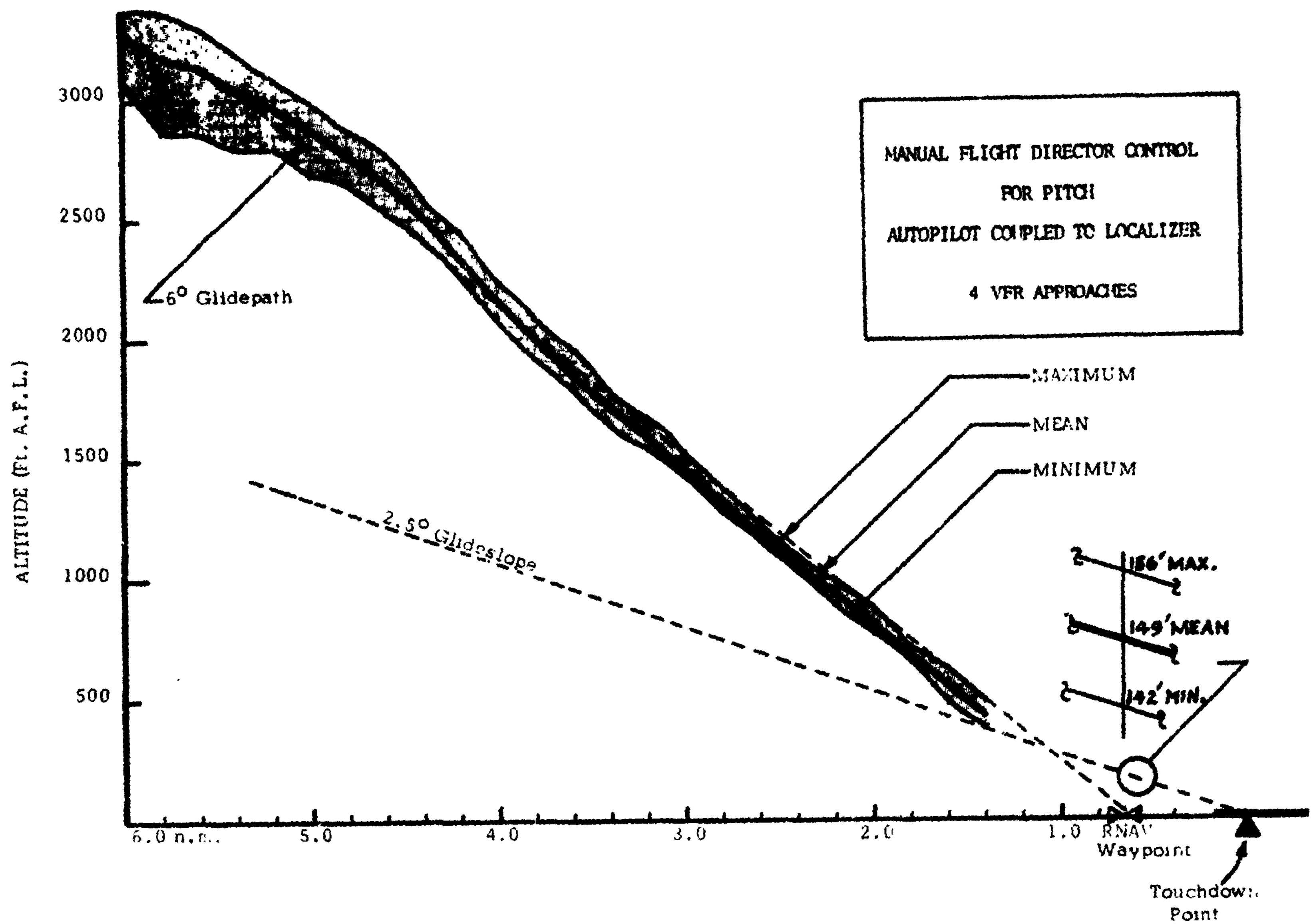


Figure 67 - RNAV System Computed Glideslope.

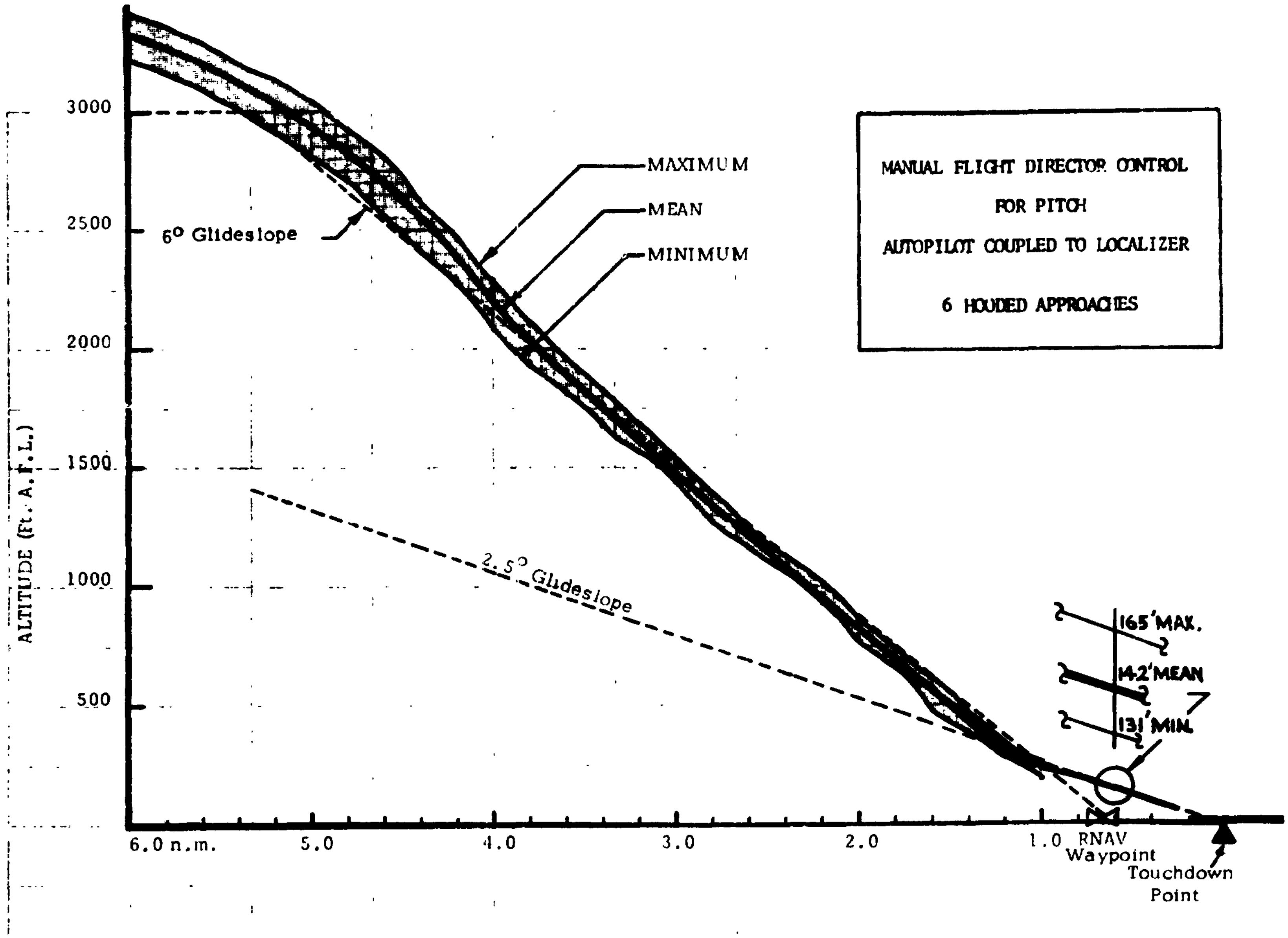


Figure 68 - RNAV System Computed Glideslope.

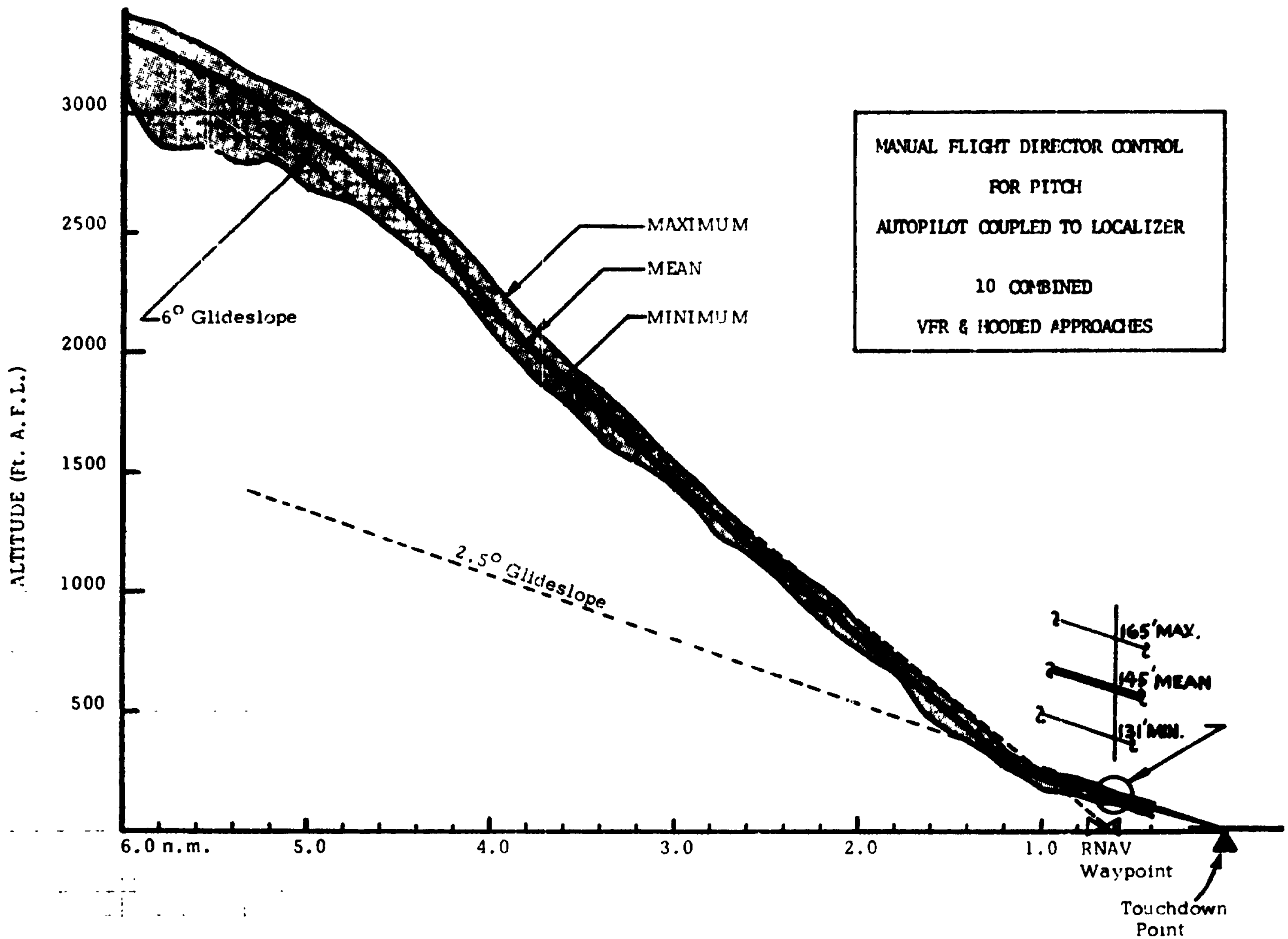


Figure 69 - RNAV System Computed Glideslope.

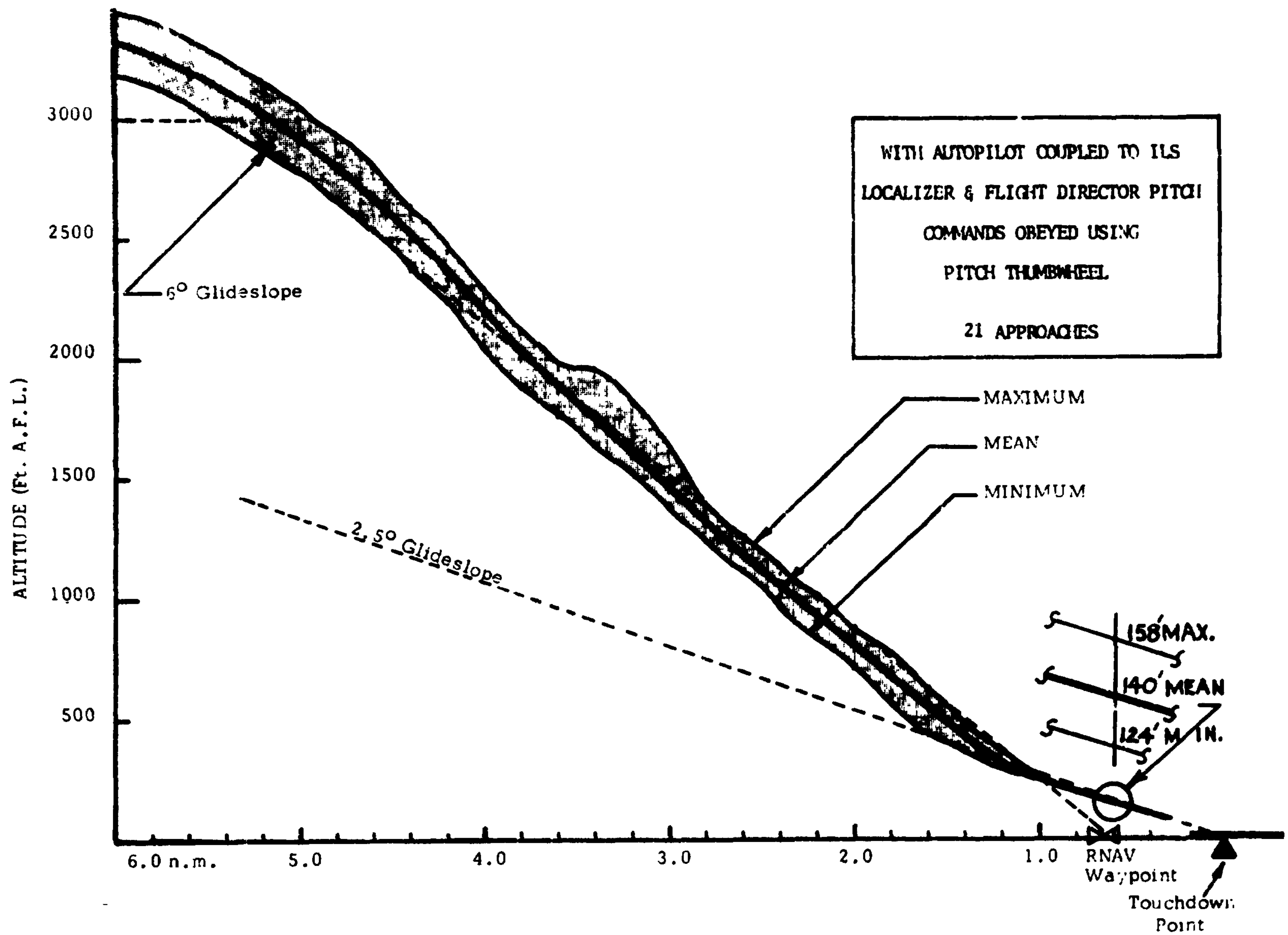


Figure 70 - RNAV System Computed Glideslope.

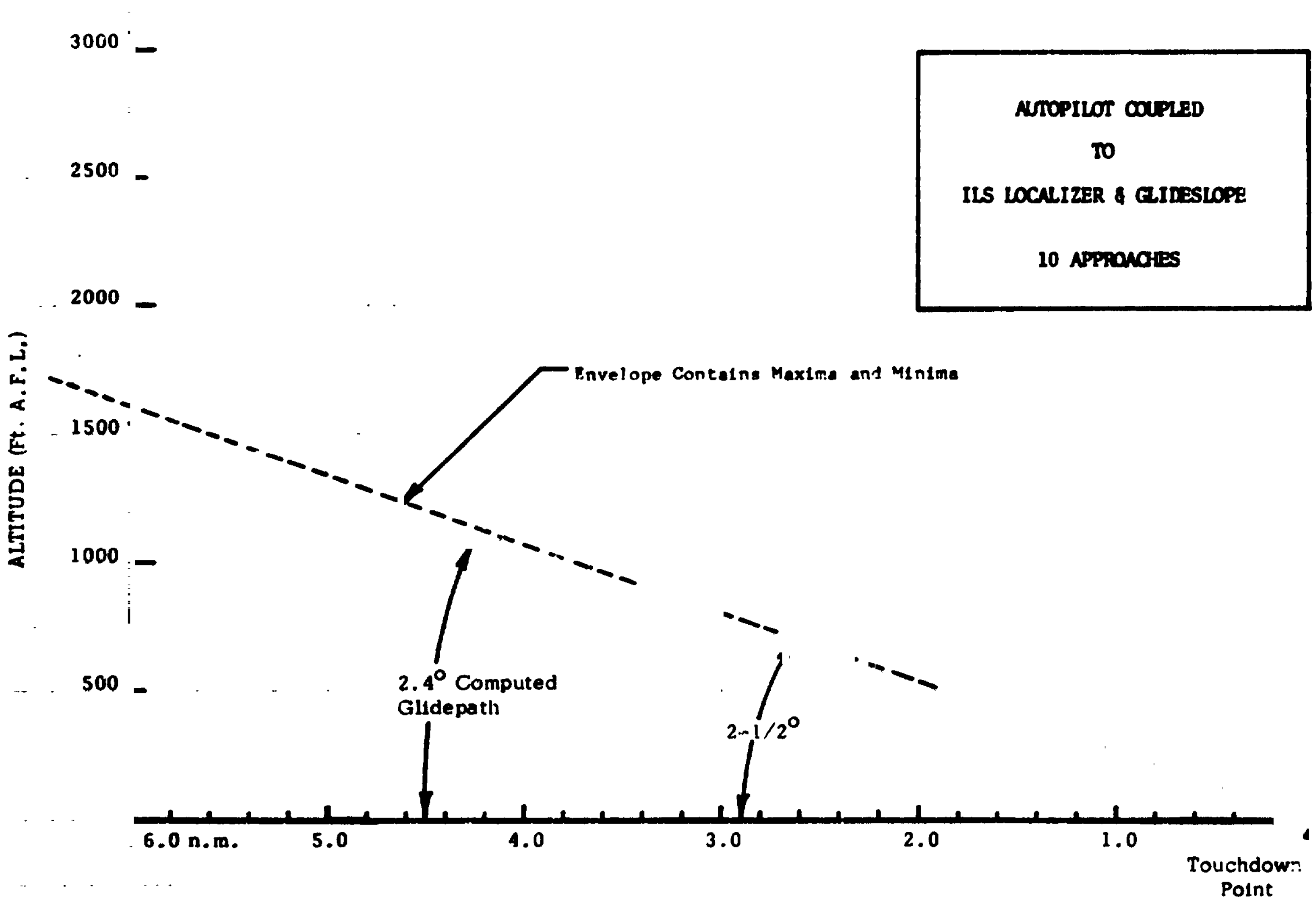


Figure 71 - System Computed ILS Glideslope.

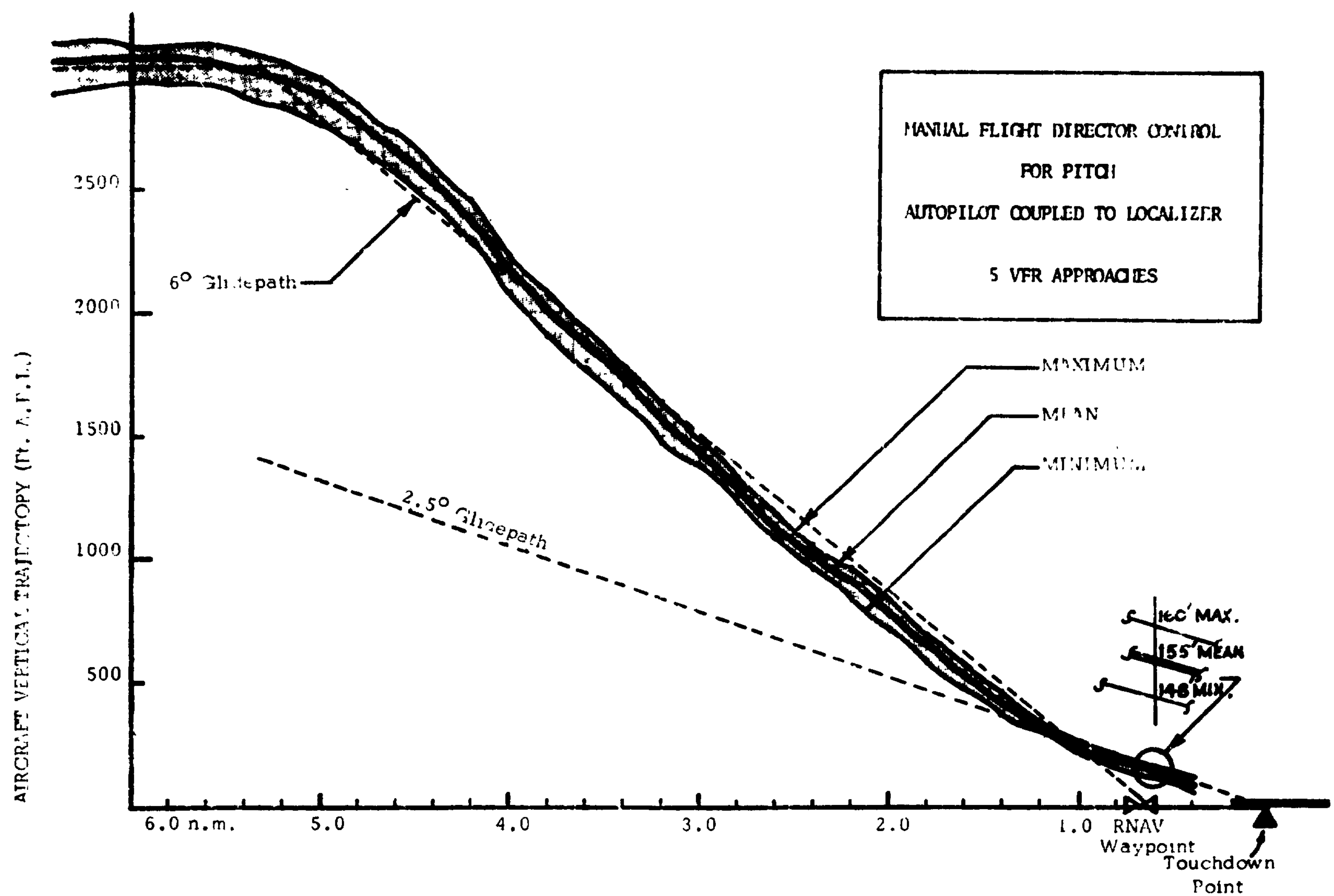


Figure 72 - Actual Two-Segment Vertical Trajectory.

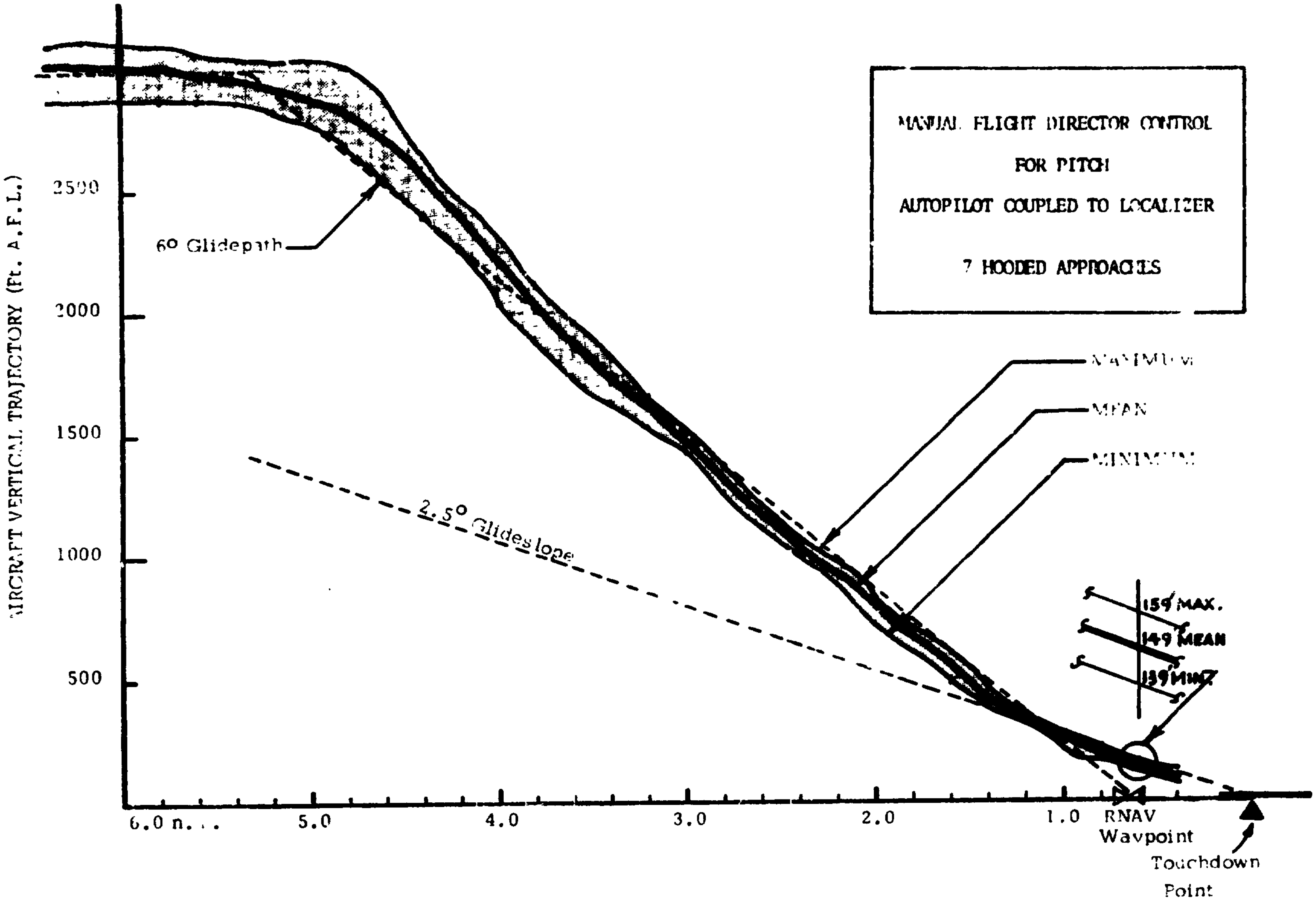


Figure 73 - Actual Two-Segment Vertical Trajectory.

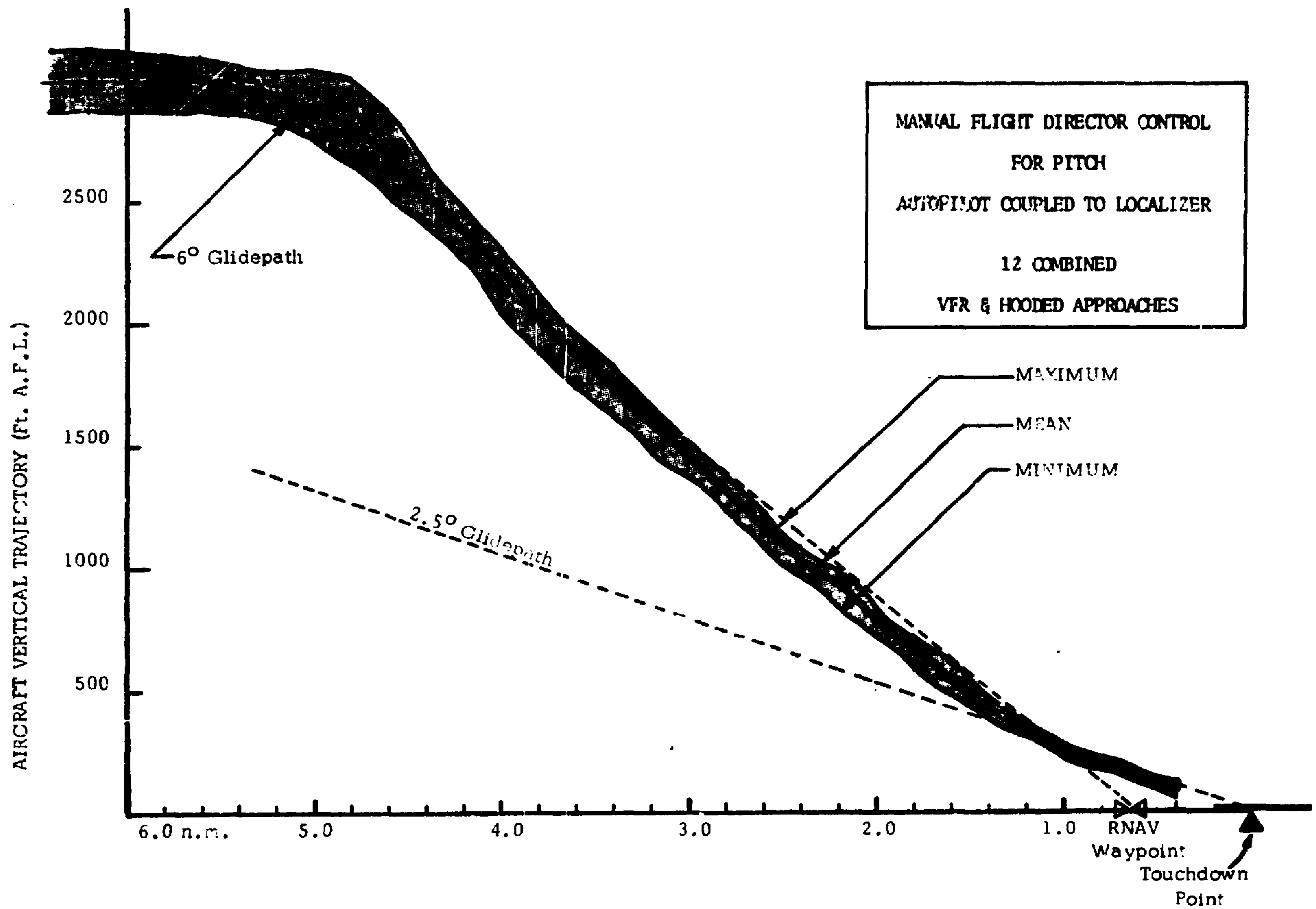


Figure 74 - Actual Two-Segment Vertical Trajectory.

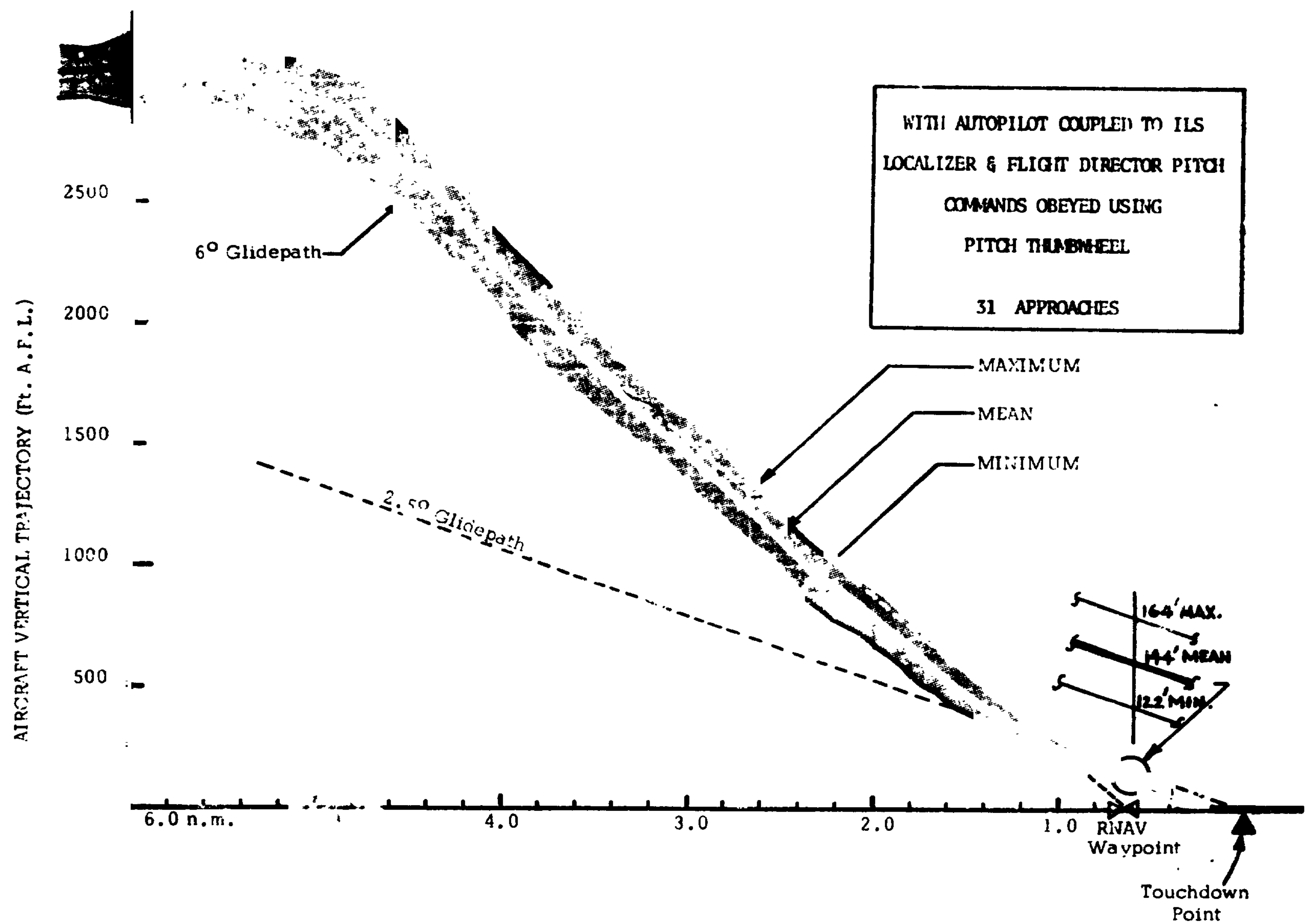


Figure 75 - Actual Two-Segment Vertical Trajectory.

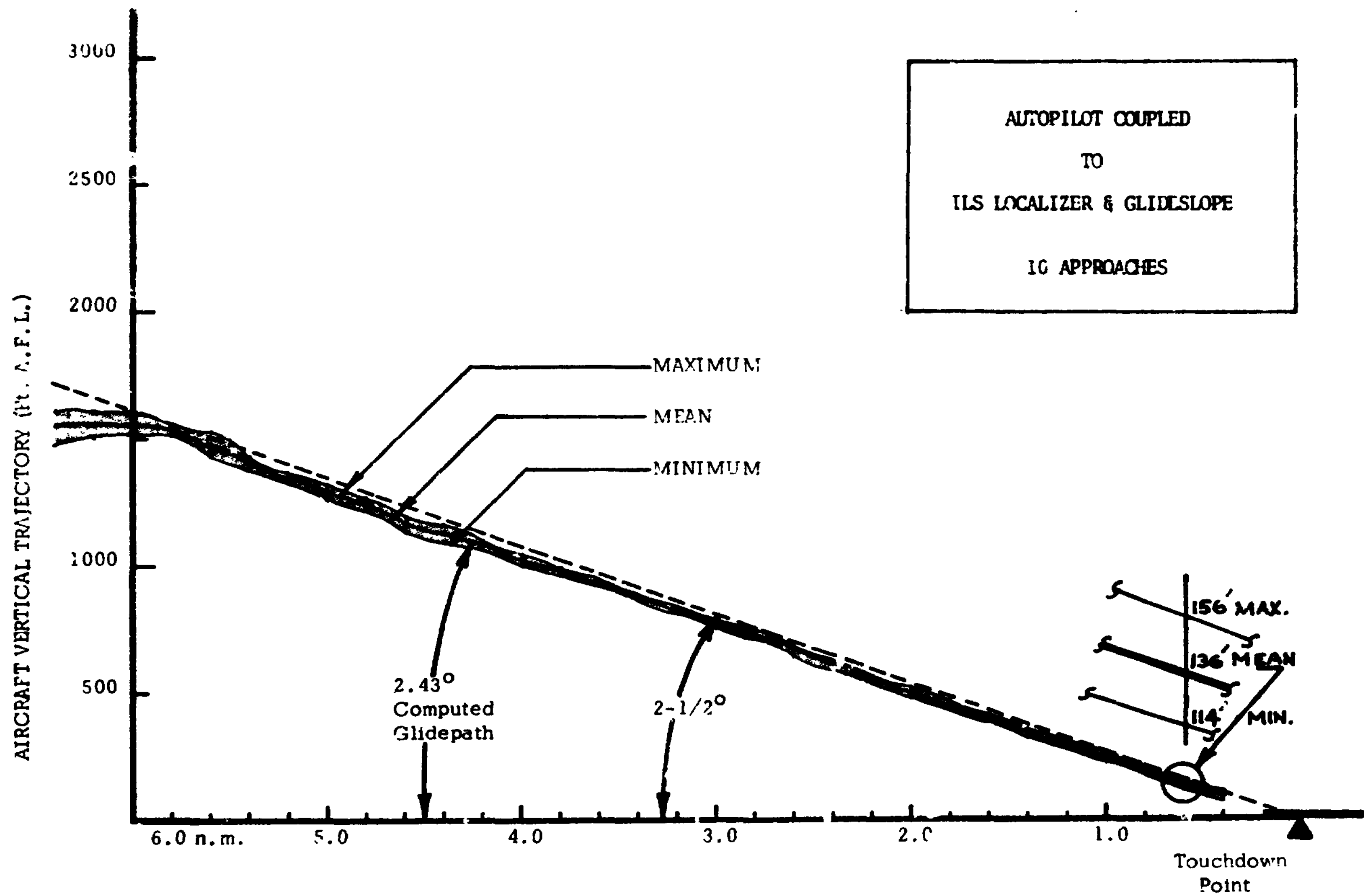
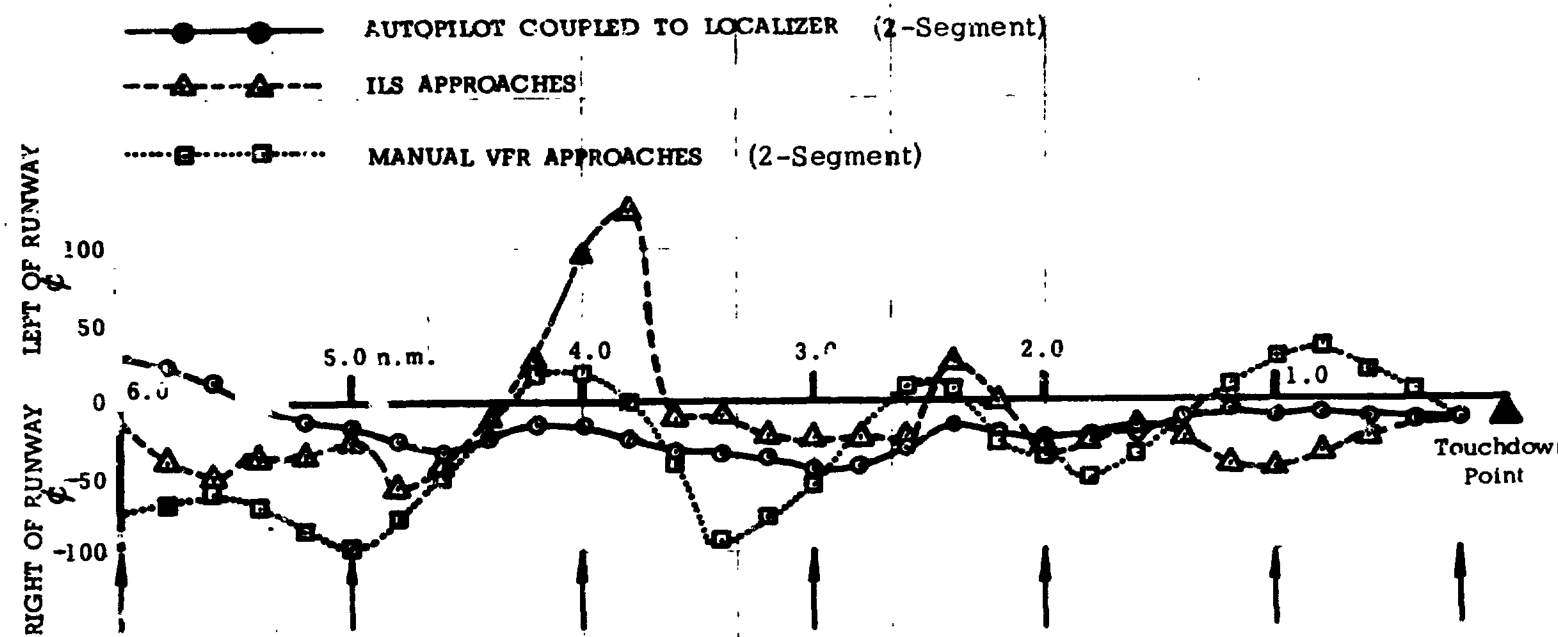


Figure 76 - Vertical Trajectory for ILS Approaches.



1σ (FT)

A/P	93	50	41	36	45	38	22
ILS	55	30	Not Available	25	30	34	7
MAN	70	46	Not Available	43	21	55	27

Figure 77 - Aircraft Mean Lateral Position.

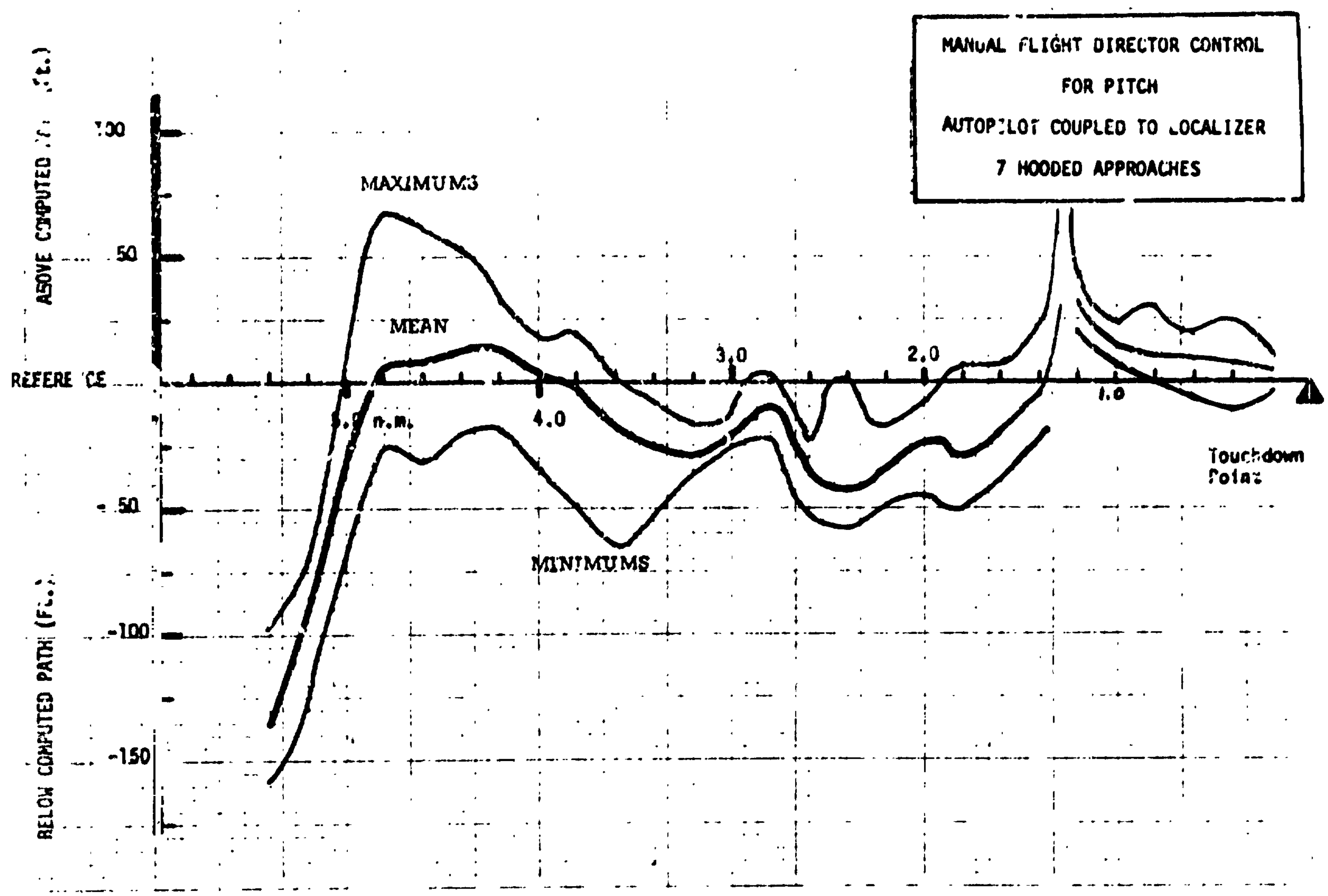


Figure 78 - Vertical Deviations, Hooded Approaches

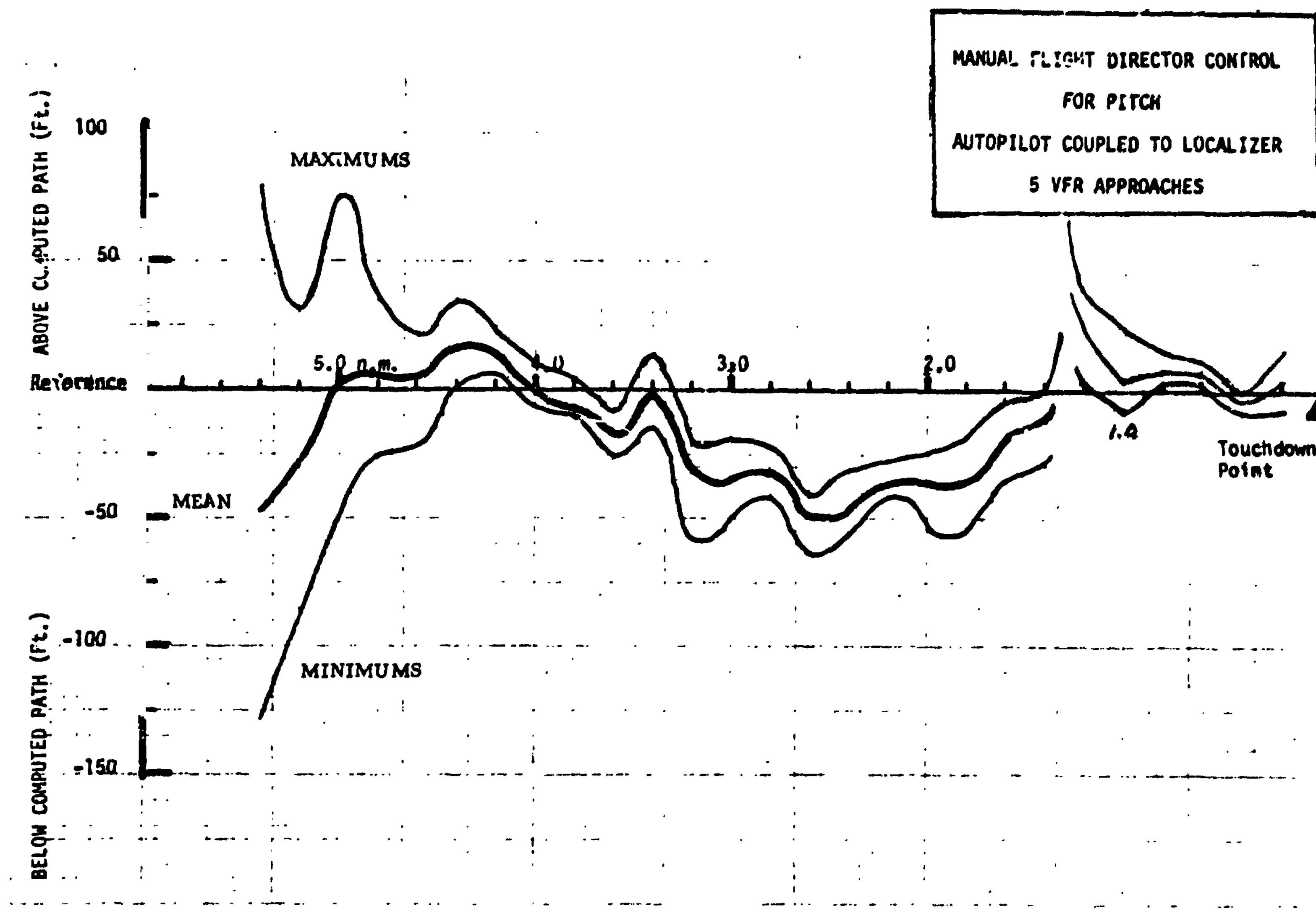


Figure 79 - Vertical Deviations, VFR Approaches

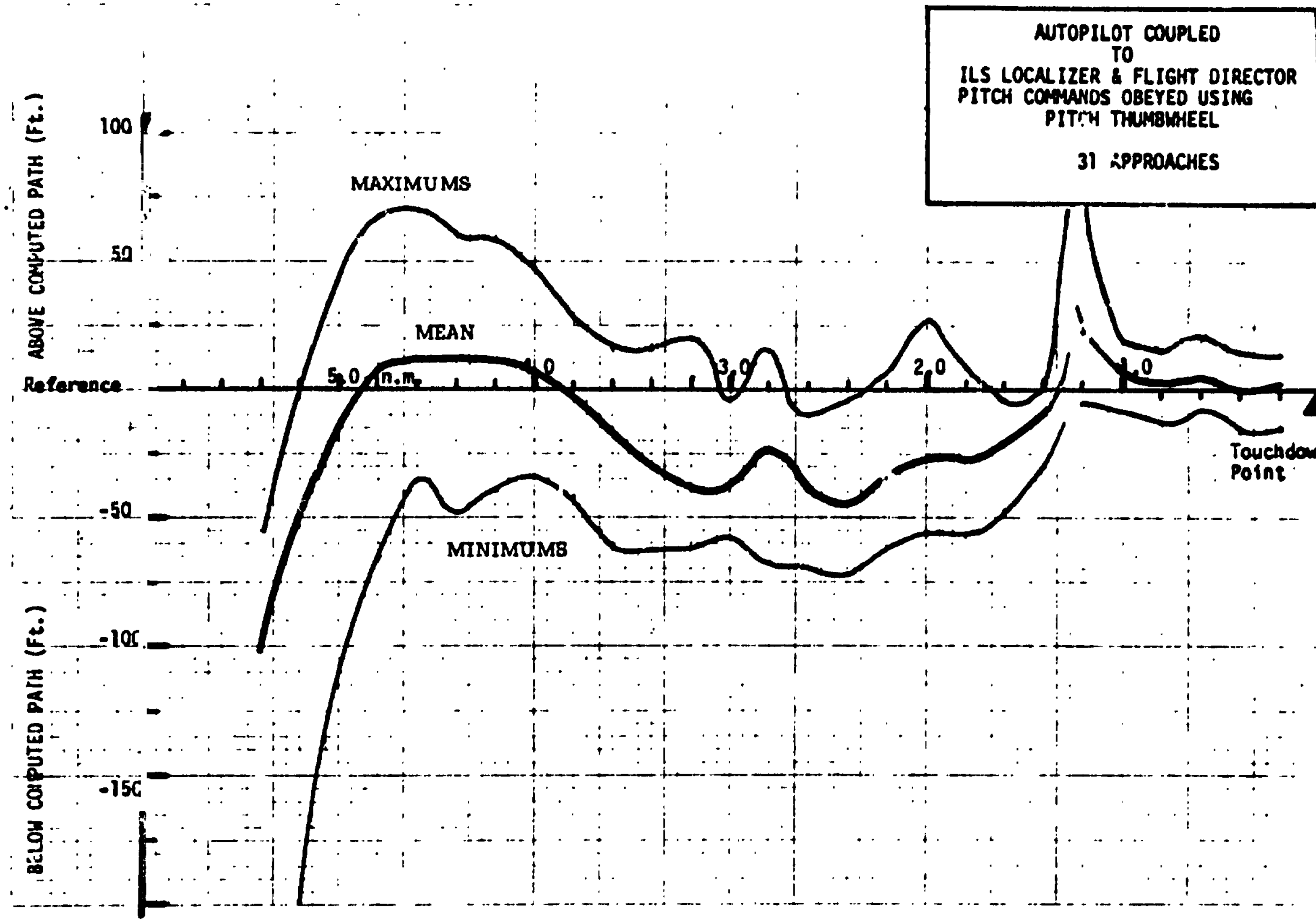


Figure 80 - Vertical Deviations, Pitch Thumbwheel Approaches

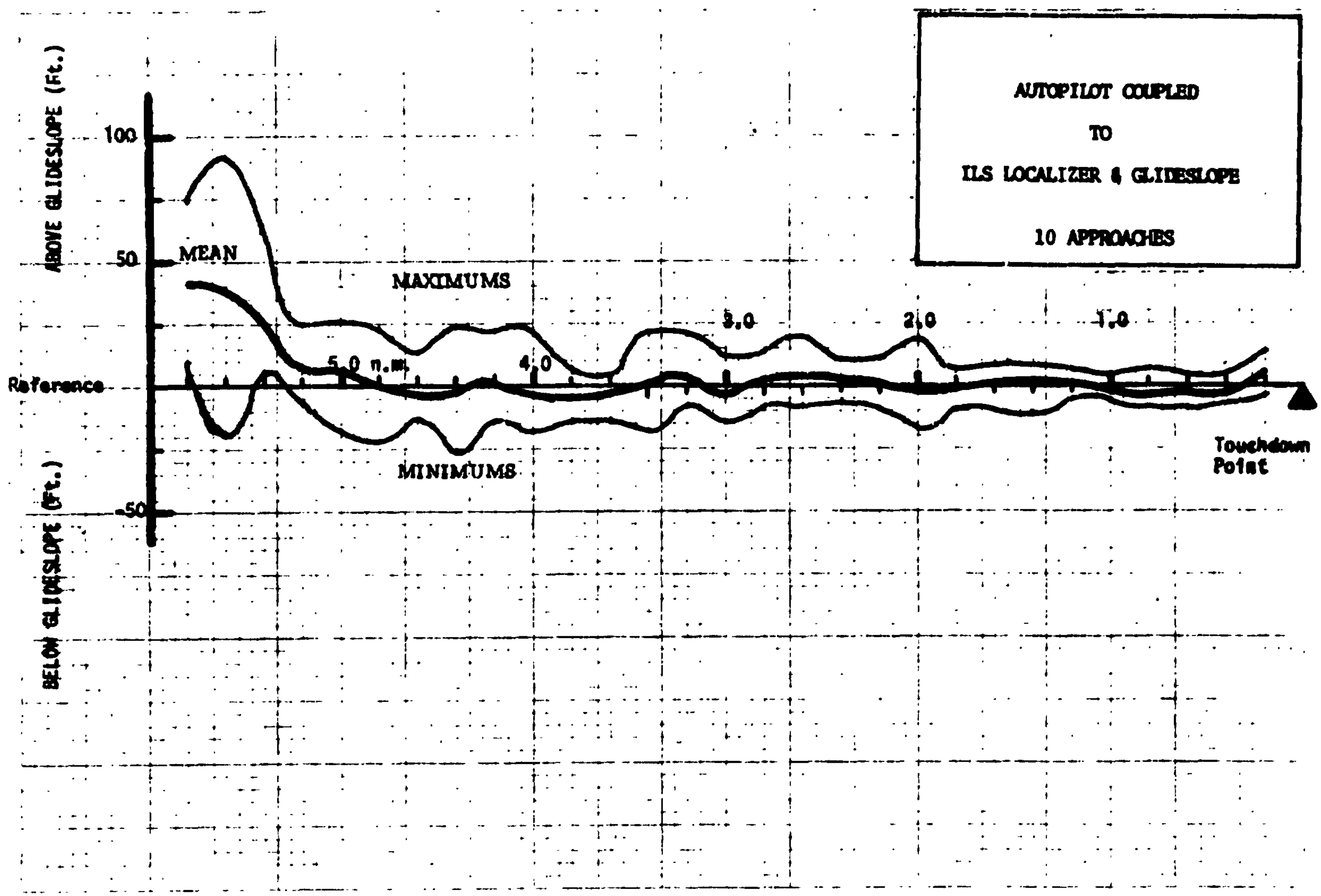


Figure 81 - Mean Vertical Deviation

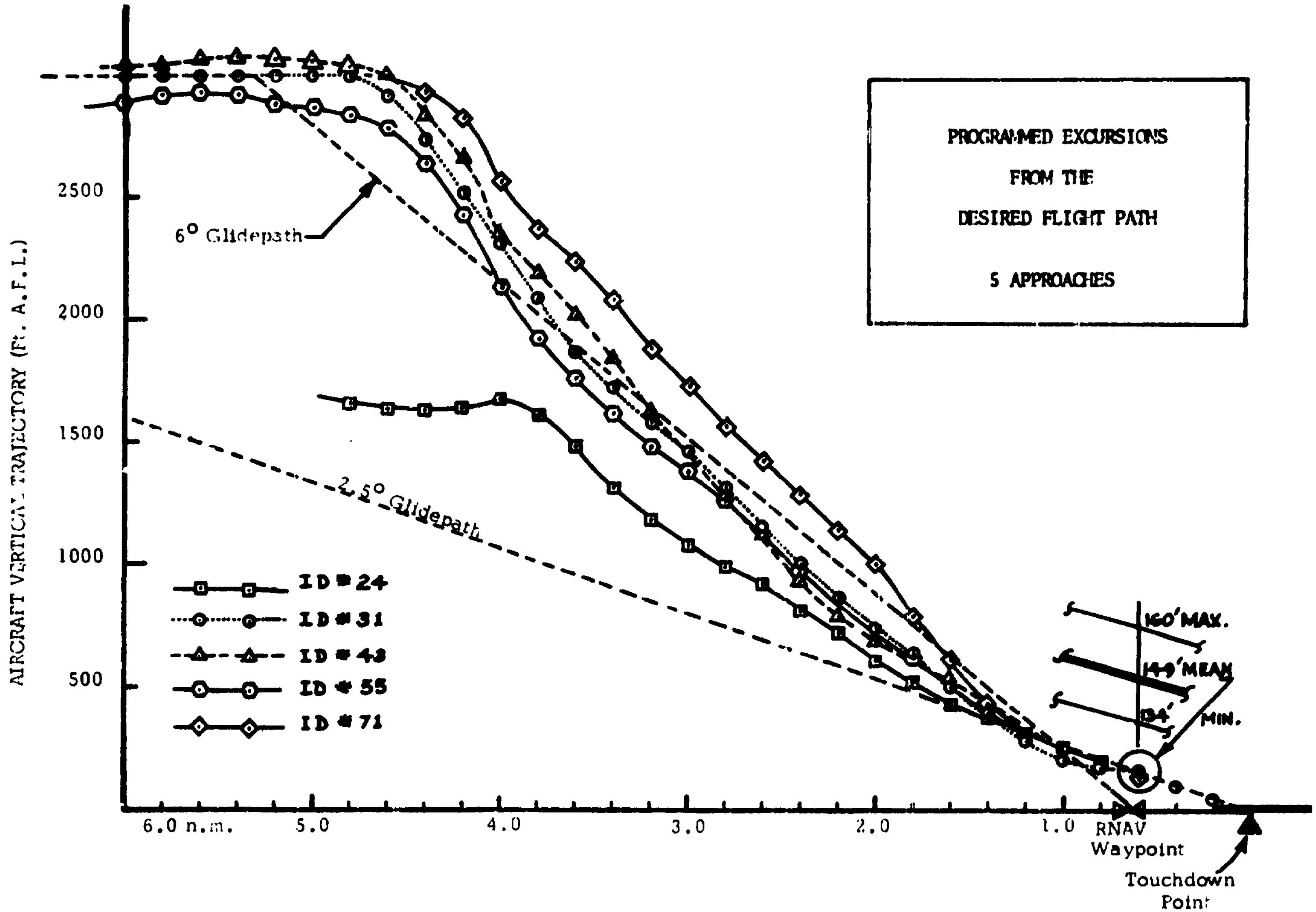


Figure 82 - Actual Vertical Trajectory.