Development and Evaluation
of an Airplane Electronic
Display Format Aligned With
the Inertial Velocity Vector

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particularly in turbulent and/or crosswind conditions, were identified. Even though the control system was designed to assist the pilot in managing the inertial velocity vector, the display format was still aligned with the aircraft's attitude, with velocity-vector (VV) information as an additional feature. In addition, the TSRV flight deck arrangement included a navigation display which was normally presented in a track-aligned format for a number of years, with wide acceptance by the research pilots. Thus, the two electronic display formats, directly in front of the pilot, were aligned with different orientations.

In an attempt to improve the transfer of information, the PFD format was aligned with the inertial velocity vector. This report presents the development of the velocity-vector-aligned primary flight display (VVPFD) format, a simulation comparison of two PFD formats (one aligned with attitude and the other with inertial velocity vector), and flight test results of the VVPFD format. Simulation runs were conducted along a curved, descending approach-to-landing path. Runs were made using the velocity-vector control-wheel steering mode (ref. 5) for pilot-in-the-loop examinations. Also, fully automatic runs were conducted to examine pilot performance during monitoring situations. Commentary and performance data from two NASA test pilots were analyzed and are presented and discussed. After the simulation experiment, flight tests were conducted in the Transport Systems Research Vehicle (TSRV) with the VVPFD format. The same NASA test pilots and an almost identical approach-to-landing task at the NASA Wallops Flight Center were used.

ACRONYMS

ANOVA	analysis of variance
ATOPS	Advanced Transport Operating Systems
ATTPFD	attitude-aligned primary flight display
CRT	cathode ray tube
MLS	microwave landing system
PFD	primary flight display
RFD	research flight deck
RMS	root mean square
TSRV	Transport Systems Research Vehicle
VLDS	Visual Landing Display System
VV	velocity vector
VVPFD	velocity-vector-aligned primary flight display

SIMULATION FACILITIES

The ATOPS Program employs a variety of research tools to reach its objectives. One such tool is the Langley Transport Systems Research Vehicle Real-Time Simulator.

SUMMARY

This report describes the development of an electronic primary flight display format aligned with the aircraft velocity vector, a simulation evaluation comparing this format with an electronic attitude-aligned primary flight display format, and a flight evaluation of the velocity-vector-aligned display format.

Earlier tests in turbulent conditions with the electronic attitude-aligned display format had shown an objectionable unsteadiness in the displayed information. A primary objective of aligning the display format with the velocity vector was to take advantage of a velocity-vector control-wheel steering system to provide a steadiness of display information during turbulent conditions. Better situational awareness through an improved arrangement of related display symbology under crosswind conditions was also achieved. The simulation evaluation task was a curved, descending approach with turbulent and crosswind conditions. Category II and III visual scene presentations were provided in the front window. Both primary flight display formats used in the simulation tests contained computer-drawn perspective runway images and flight-path angle information. The flight tests were conducted aboard the NASA Transport Systems Research Vehicle (TSRV) at the Wallops Flight Center. Nearly identical tasks and the same pilots were used for both the simulation and the flight evaluation of the new format.

The comparative results of the simulation and flight tests were principally obtained from subjective commentary. Statistical examination of simulation performance data is also presented. Overall, the pilots preferred the display format aligned with the velocity vector. The results of statistical examination of performance parameters were mixed and thus somewhat inconclusive. The flight results basically confirmed the research findings in simulation. The flight and simulation tracking performances for glide-slope and localizer signals were excellent and would meet category II or III requirements.

INTRODUCTION

A primary objective of the National Aeronautics and Space Administration Advanced Transport Operating Systems (ATOPS) Program is the research and development of electronic display concepts that will improve the pilot-vehicle interface for complex approach-to-landing tasks in low visibility weather conditions. A principal focus has been the continuing determination of information essential to the pilot's performance of the task and the presentation of this information to the pilot in a form that is simple, integrated, and easily understood (refs. 1-5). The study reported herein furthers this objective with the development and evaluation of a revised electronic primary flight display (PFD) format. This display, referenced to the inertial velocity vector, was implemented and tested on the Langley Transport Systems Research Vehicle (TSRV) Real-Time Simulator and in the research flight deck (RFD) aboard the TSRV.

Reference 5 documented a study involving substantial improvement of a computer-assisted control system and a PFD, tailored for use with a semiautomatic control system. However, several problem areas relating to presentation of information,

Another is a specially equipped B737-100 airplane with an aft RFD (described in more detail under "Flight Facility"). The NASA TSRV and its RFD (shown in figs. 1 and 2) are represented in a real-time simulation with a near replication of the RFD hardware (fig. 3) and its functional operations. The TSRV is represented by a six-degree-of-freedom set of nonlinear equations of motion. Functional aspects of the advanced flight control configuration of the airplane (fig. 4) are also represented in the simulation including nonlinear models of servo-actuators. The processing of the equations is performed by a Control Data Corporation (CDC) CYBER 175 digital computer at 32 times per second. Verification and validation of the simulation had been conducted prior to this experiment by comparisons with flight data and test pilot evaluations.

For external visual scenes, the TSRV RFD simulation facility is equipped with an "out-the-window" virtual image system. This is part of the Langley Visual Landing Display System (VLDS). The image system is located on the left (pilot's side) and is a beam-splitter, reflective-mirror type. The system, located 1.27 m (50 in.) from the pilot's eye, presents a nominal 48° wide by 36° high field of view of a 525-line TV raster system and provides a 46° by 26° instantaneous field of view. The picture is in full color with unity magnification and a resolution on the order of 9 minutes of arc. A terrain model used in the VLDS contains a 1500/1 scale airport representation with a runway equipped for operations under instrument flight rules. The runway is 3505 m (11 500 ft) long and 81 m (267 ft) wide. This runway is accurately marked for operations in accord with Federal Aviation Administration Circular AC 150/5300-2B. Approach lights, sequenced flashers, centerline lights, touchdown zone lights, runway edge lights, taxiway lights, runway distance remaining lights, and end of runway lights are provided. Additional details of the visual equipment can be found in reference 6.

The two electronic displays, primary and nagivation, at each pilot station in the cockpit are generated on an Adage AGT 340 graphics computer. The graphics computer is linked via a digital buffer to the CDC CYBER 175 computer. The displays are stroke drawings and contain no raster features. For this study, the primary display was presented on a penatron type cathode ray tube (CRT) of approximately 20-cm (8-in.) diagonal. Five colors could be presented (red, green, yellow, amber, and orange), but were not a factor in this study. The navigation display was presented on a monochromatic CRT of approximately 23-cm (9-in.) diagonal. The cockpit arrangement of these displays can be seen in figures 3 and 5.

FLIGHT FACILITY

The TSRV is a B737-100, twin-engine jet transport as shown in figure 1. Equipped with triple slotted trailing-edge flaps, leading-edge slots, and Krueger trailing-edge flaps, this vehicle was designed for short-haul operations into small airports with short runways. An elevator and movable stabilizer provide basic longitudinal control, and a combination of ailerons and spoilers provides basic lateral control. The spoilers also function as speed brakes. This vehicle has been modified to serve as a research airplane by the inclusion of several experimental systems.

Major components of the research system consist of a standard forward cockpit, an aft RFD, guidance and navigation computer, electronic display equipment, and flight control computers. An advanced guidance and control system is provided. Figure 4 shows a generalized block diagram of the research system components. The flight functions of navigation, guidance, and various levels of automation are achievable. However for these flight tests, only the semiautomatic control mode of VV control-

wheel steering with autothrottle was used. The operation of onboard airplane systems is described in reference 7. Research equipment aboard the airplane is generally arranged in pallets and is shown in figure 2.

The two-man RFD (fig. 3) has panel-mounted controllers (PMC) and conventional rudder pedals for pilot inputs. A fly-by-wire interface is provided to the airplane control systems. The forward flight deck contains the means to disconnect or manually override the RFD controls. Electronic displays are provided with the primary flight display above the navigation display. These displays are presented on monochromatic CRT's with a combination of raster and stroke writing techniques.

<center>DISPLAY FORMAT DEVELOPMENT</center>

In the attitude-aligned primary flight display (ATTPFD) format (fig. 6), the airplane attitude symbol is fixed relative to the CRT screen and all other information except fixed scale quantities moves relative to this attitude presentation. This format is analogous to that of electromechanical counterparts. (The display symbols are defined and use of the display is described in ref. 7.) For example, the VV symbol must be drawn with its vertical and horizontal displacement relative to the attitude symbol on the screen. Likewise, the horizon line and pitch grid must be presented relative to the attitude symbol. During previous studies, numerous pilots have commented negatively on the seemingly constant movement in the electronic primary display, especially in turbulent conditions. The increased resolution within this display is probably the major contributing factor to this annoying movement. Additional pilot comments have focused on the location of an aligned runway image within an ATTPFD format. During crosswind conditions, the position of the runway and extended centerline image is displaced from the center of the display as shown in figure 7. The displacement of the computer-drawn image to the right is caused by a crab angle being maintained in order to compensate for a crosswind. The view of the runway and centerline is that of an eye coordinate system placed along the body axis of the airplane. Note that the VV of the airplane indicates that the flight path is aimed along the runway to a point inside the threshold. In the no crosswind situation, assuming heading equals track angle, the runway and centerline plus flight-path angle are in the center of the display as was shown in figure 6.

As the benefits of providing VV information to the display and integrating it with control laws accrued (refs. 1, 3, and 5), it became apparent that the display format should be aligned with the VV rather than attitude. For the TSRV application, the choice was made to align the display format with the commanded VV being generated within the VV control-wheel steering system rather than actual flight-path angle. (See ref. 5 for a complete description and the operational benefits of commanded VV information.) The advantage of orienting the display format with the commanded VV is the steadiness of the display under changing outside influences, since the commanded VV changes only through pilot input. Thus a major portion of the displayed information moves only when the pilot makes a control input. In addition to reducing movement in the display format, the selection of VV as the alignment point also results in the primary and navigation displays both being aligned along the VV components when the navigation display is in the preferred track-oriented mode of operation (ref. 4).

The conversion of the primary flight display format from attitude aligned to VV aligned was readily accommodated for most symbols inasmuch as relative displacements were summations of readily available measurements. Scales and readouts required no

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changes at all. However, the proper placement of the perspective runway information required a new location for the eye coordinate system. The eye coordinate system that was previously located along the body axis of the airplane now had to be transformed along the commanded VV. Two angular rotations from the body (attitude) axis are used to form an additional transformation matrix D defined as

$$D = \begin{bmatrix} \cos b \cos a & \sin a & \cos b \sin a \\ -\sin b \cos a & \cos a & -\sin b \sin a \\ -\sin b & 0 & \cos b \end{bmatrix}$$

where a is the pitch angle minus the flight-path angle and b is the track angle minus the heading angle. The transformation matrix D applied to the pertinent runway location variables relocated these variables in the new eye coordinate system and then the methods of drawing the perspective runway and extended centerline were applied as outlined in reference 1.

Figure 8 shows the VVPFD format corresponding to the same condition as was shown in figure 7 for the ATTPFD format. Aside from the differences previously discussed, several other subtle changes should be observed. The scales and pointers are now in line with the VV indicator. When the localizer error is zero and the proper track is being maintained, the extended centerline of the runway image passes through the center of the localizer scale regardless of crosswind. Everything but the scales is shifted higher in the screen, and the glide-slope scale is directly aligned horizontally with the flight-path angle.

SIMULATION EXPERIMENT

The major objective of the simulation experiment was to create a controlled study in which the assumed benefits of aligning the display format with the VV could be evaluated. These assumed benefits were (1) an improved situational awareness, (2) a steadiness across major elements of the display format, and (3) similar orientations of the PFD and navigation display. The experiment was primarily a comparison of the VV-aligned with the attitude-aligned display format under crosswind and turbulent conditions. The selected task required both primary and navigation information.

The approach path used for the experiment is shown in figure 9. The path involves deceleration, descent, a 90° turn, a 3-n.mi. final approach segment, and a landing. The airplane was initialized on the path at an airspeed of 170 knots with flaps deflected 15° in level flight, and it was reconfigured for a 125-knot landing with flaps deflected 40°. A single run took approximately 3 minutes from start to touchdown. Tracking data were gathered throughout the run and strip chart recordings of selected variables were taken. Subjective pilot opinion was gathered during and after each simulation session.

Two NASA test pilots were used in the experiment. The pilots were thoroughly familiar with the TSRV simulation facility and had spent over 7 years with the ATOPS Program including involvement in numerous simulations and flight tests. Each pilot flew four complete sets of eight runs during two 3-hour simulation sessions.

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A set of eight runs with varying displays, control modes, and visual breakout points was formulated. (See table 1.) Each run was performed under a left to right or a right to left crosswind, and a turbulence factor was present in all three axes with zero mean and 0.9-m/sec (3-ft/sec) standard deviation. The order of the eight runs was reversed from set to set in order to offset learning and fatigue effects. Each run condition was flown in the velocity-vector control-wheel steering mode with autothrottle. In addition, each run condition was repeated in a fully automatic control mode (three-dimensional navigation, autothrottle, and autoland) to determine the suitability of the display formats for automatic approach monitoring purposes. Subjective data only were obtained from the fully automatic run conditions. To examine pilot situation awareness, each run involved a visual breakout either at 30 m (100 ft), with runway visual range of 335 m (1100 ft), or at 61 m (200 ft), with runway visual range of 914 m (3000 ft) (category II or III conditions).

Situation awareness offered by the VVPFD format was further investigated under the following: automatic control mode condition with misalignment of the visual scene, so that no runway was in view at visual breakout. The latter constituted a missed approach and neither pilot was aware that such a condition was included in the run set. Each pilot had been briefed on the approach geometry including a missed approach procedure. High-frequency sampling of data just prior to and during visual breakout allowed an analysis of this special event as well as any unusual actions during the transitions to visual conditions. These performance measures were then used as an indication of situational awareness.

SIMULATION RESULTS AND DISCUSSION

The results of the simulation are divided into two parts: (1) subjective and (2) objective. The subjective findings are presented first and include all runs regardless of control mode, manual or automatic.

A strong subjective preference for the VVPFD format was expressed by both test pilots. The steadiness of the horizon, runway image, and pitch grid during turbulent conditions was unanimously cited as a principal reason for their preference. The pilots felt that the notable reduction in display element movement resulted in less distraction and better situational awareness. The effects of crosswinds and turbulence were easily discernible through motions of the airplane attitude symbol, and thus no loss of situation awareness occurred. Additional favorable comments were received from the pilots regarding the alignment aspects of the VVPFD format, both within the PFD and between the PFD and the navigation display.

Within the VVPFD, the alignment of the glide-slope indicator with the flight-path angle and the alignment of the localizer indicator with the extended centerline made scanning and recognition of the situation more natural. Between displays, primary flight and navigation, coordination was also more natural with both displays aligned with elements of the same information. Although the pilots had considerable experience and had shown adaptability over the years with the track-oriented navigation display and the ATTPFD, their comments clearly indicated a preference for the alignment offered by the combination of the VVPFD and the track-oriented navigation display. Rather than looking up from an aligned navigation presentation to a displaced runway image (under crosswind conditions), a centered runway image was preferred. The crab or drift angle was still easily determined by the horizontal displacement of the attitude symbol.

Situational awareness was thoroughly examined during the transitions from the PFD to the out-the-window scene. Postrun examinations indicated that the pilots were fully aware of the airplane relationship to the runway. For the unannounced missed approach situation, both pilots were surprised but easily recognized the situation and properly initiated a missed approach procedure.

Objective data were gathered for each of the run conditions in which VV control-wheel steering was involved. For the analysis of those data, the prescribed path was blocked into three zones. Figure 10 shows these zones graphically. The first zone encompassed the portion of the path from the starting point to the beginning of the required horizontal turn. The second zone began at the horizontal turn and ended at the start of the 3-n.mi. final approach leg. The third zone began at the end of the second zone and ended at an altitude of 30 m (100 ft). Each of the three zones encapsulates different requirements of the overall task.

The analytical performance results from this experiment were formulated as root-mean-square (RMS) measurement metrics. After preliminary examination of the horizontal and vertical RMS tracking data, it was noted that the two test pilots placed different priorities on which axis to focus their primary attention. This made individual analysis of horizontal and vertical performance difficult, so a weighted metric that allowed both axes equal contributions to the total was formed. The individual tracking (still treated as RMS) was normalized by the overall mean from all runs and the sum of these normalized values formed the new combined metric used in the following analysis. Analysis of variance (ANOVA) tests were performed on the data (combined metric) for each of the three zones. The principal focus was placed upon the pilot and display factors of the experiment. A summary of the findings for pilots, display formats, and pilot-display interaction per zone is provided in table 2.

In zone 1, the mean (averaged across pilots) performance per display format was not statistically significant, but the interaction between displays and pilots was. Further examination of this interaction, via Newman-Kouls testing, showed that differences in display formats were being canceled by pilot differences. Mean (averaged across display) performance per pilot was statistically significant. Pilot performances with the VVPFD were nearly equal, but one pilot performed slightly better with the ATTPFD and the other pilot performed much worse with the ATTPFD.

In zone 2, again the mean performance per display format was not statistically significant, but the interaction between displays and pilots was. Examination of the interaction revealed that one pilot performed best with the VVPFD, but the other pilot's performance remained nearly the same for either display format. The mean performance per pilot was statistically significant.

In zone 3, statistical significance was indicated between display formats, pilots, and the interactions of displays and pilots. The mean performance obtained with the VVPFD was improved over that obtained with the ATTPFD. Both pilots performed nearly equally well with the VVPFD. One pilot performed better with the ATTPFD than with the VVPFD, but the other pilot's performance was opposite. Again one pilot's performance was better than the other pilot's.

In summary, the analytic mean performance findings were as follows:

1. Performances with the two displays differed, but often the trends toward improvement were reversed between the two pilots or shown by one pilot and not the other. No statistical support was found for one display format over the other.

2. Differences occurred between the performances of the two pilots but were mostly confined to runs when the ATTPFD was being used.

Performance with the VVPFD within zone 3 regarding the tracking of glide-slope and localizer signals was excellent and would easily meet catetory II or III requirements. Mean performance plots for each pilot using the VVPFD are shown (along with flight data) in figures 11 and 12.

FLIGHT EXPERIMENT

The objective of the flight experiment was to confirm pilot acceptance and preference for the VVPFD format as obtained from the simulation study. These tests did not duplicate the simulation experiment since only the VVPFD format was used (in conjunction with the VV control-wheel steering mode). The information content of the display format was identical to that of the format used in the simulator. The principal results of the flight experiment were expected to be subjective pilot evaluations.

The NASA Wallops Flight Center was the test site. A microwave landing system (MLS) was used for accurate positioning of the test airplane. The MLS signals were used to properly draw the runway image and these same signals were converted to instrument landing system signals for glide-slope and localizer presentations. Velocity-vector information came from onboard inertial systems.

A path nearly identical to the simulation experiment design (fig. 9) was used in conjunction with runway 22 at Wallops. A crosswind of approximately 8 to 10 knots and slight to moderate turbulence was present during the tests. The approach-to-landing conditions for the airplane were an airspeed of 125 knots, flaps deflected 40°, and gear down. All approaches were terminated by passing control to the front safety pilots at an altitude of approximately 30 m (100 ft).

The two NASA test pilots who conducted these tests were the same two who had participated in the simulation experiment. Each flew six approaches using the VVPFD, VV control-wheel steering, and autothrottle throughout each approach run. Commentary was taken after each run, while the safety pilots flew the airplane to the starting position.

FLIGHT RESULTS AND DISCUSSION

The subjective results from the flight experiment commentary were the same for both test pilots. The flight experience using the VVPFD format confirmed the simulation experience: (1) a centered runway image was desirable when the aircraft was properly aligned; (2) the steadiness of the new display information, due to aligning the display format with pilot-commanded VV, solved a complaint of unsteadiness in previous display formats; (3) situation awareness was easily maintained (including crosswind effects) because of better alignment of information groupings; and (4) transitions between primary and navigation displays were easier with both displays aligned along common information elements.

The analytic measurements during the flight experiment were obtained via MLS readouts during the final portion of the approach. The first two runs for each pilot were treated as practice, and only the last four runs were used in the analysis. The data were placed in RMS form for both the glide-slope and localizer errors.

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The general trends between flight and simulation data clearly show a slight degradation in performance in flight. However, the performance in flight was still considered quite good. Figure 11 contains comparison plots, for each pilot, of the RMS glide-slope error between simulation and flight performance. A statistically significant difference was noted in the variance for pilot 1, but none of the other comparisons (means and variances) yielded any statistical differences.

Figure 12 contains comparison plots, for each pilot, of the RMS localizer error between simulation and flight performance. Within these data, a statistically significant difference was noted for the mean RMS performance for pilot 1, but no other statistically significant differences among the means and variances were detected.

The flight performances shown in figures 11 and 12 are considered to be excellent even though not quite as good as the simulation results. These results would also meet category II or III requirements.

CONCLUSIONS

An electronic display format aligned with the aircraft inertial velocity vector was developed, and an advanced transport airplane simulation experiment was conducted to evaluate the velocity-vector-aligned display format versus the traditional attitude-aligned format. Then the velocity-vector-aligned format was also evaluated in flight. This project resulted in the following conclusions:

1. Subjective commentary, from both simulation and flight evaluations, indicated a clear preference for the velocity-vector-aligned display format. Reasons cited were the steadiness of major information elements of the display during turbulence and the better arrangement of information sets during final approach to landing.

2. Situational awareness, especially under crosswind conditions, was improved with the velocity-vector-aligned display format because of better alignment of information groupings.

3. Flight evaluation of the velocity-vector-aligned display format confirmed the simulation subjective findings.

4. Statistical analysis of objective simulation performance was inconclusive with regard to display formats. Differences between test pilots were noted.

5. Tracking performances along glide-slope and localizer signals were excellent and met category II or III requirements.

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   Configured Vehicle Electronic Attitude Director Indicator. NASA CR-159195,
   1980.

TABLE 1.- BASIC EXPERIMENT TEST MATRIX

$$\begin{bmatrix} \text{All runs involved autothrottle and a turbulence factor. Crosswind} \\ \text{conditions were balanced across replicate sets of runs} \end{bmatrix}$$

Run	Display format	Control mode	Visual breakout altitude, m (ft)	Crosswind direction
1	Velocity vector	Velocity vector	30 (100)	Left-Right
2	Velocity vector	Velocity vector	61 (200)	Right-Left
3	Velocity vector	Automatic	30 (100)	Left-Right
4	Velocity vector	Automatic	61 (200)	Right-Left
5	Attitude	Velocity vector	30 (100)	Left-Right
6	Attitude	Velocity vector	61 (200)	Right-Left
7	Attitude	Automatic	30 (100)	Left-Right
8	Attitude	Automatic	61 (200)	Right-Left

TABLE 2.- PARTIAL LIST OF ANALYSIS OF VARIANCE
TESTS ON COMBINED RMS MEASURE

Factor	Result
Zone 1, range and navigation	
Displays	—
Pilots	**
Interaction of pilots and displays	**
Zone 2, turn to final approach	
Displays	—
Pilots	**
Interaction of pilots and displays	**
Zone 3, final approach	
Displays	**
Pilots	**
Interaction of pilots and displays	**

**Indicates statistically significant
differences at 99% confidence level.

L-73-6283

Figure 1.- NASA Transport Systems Research Vehicle (TSRV).
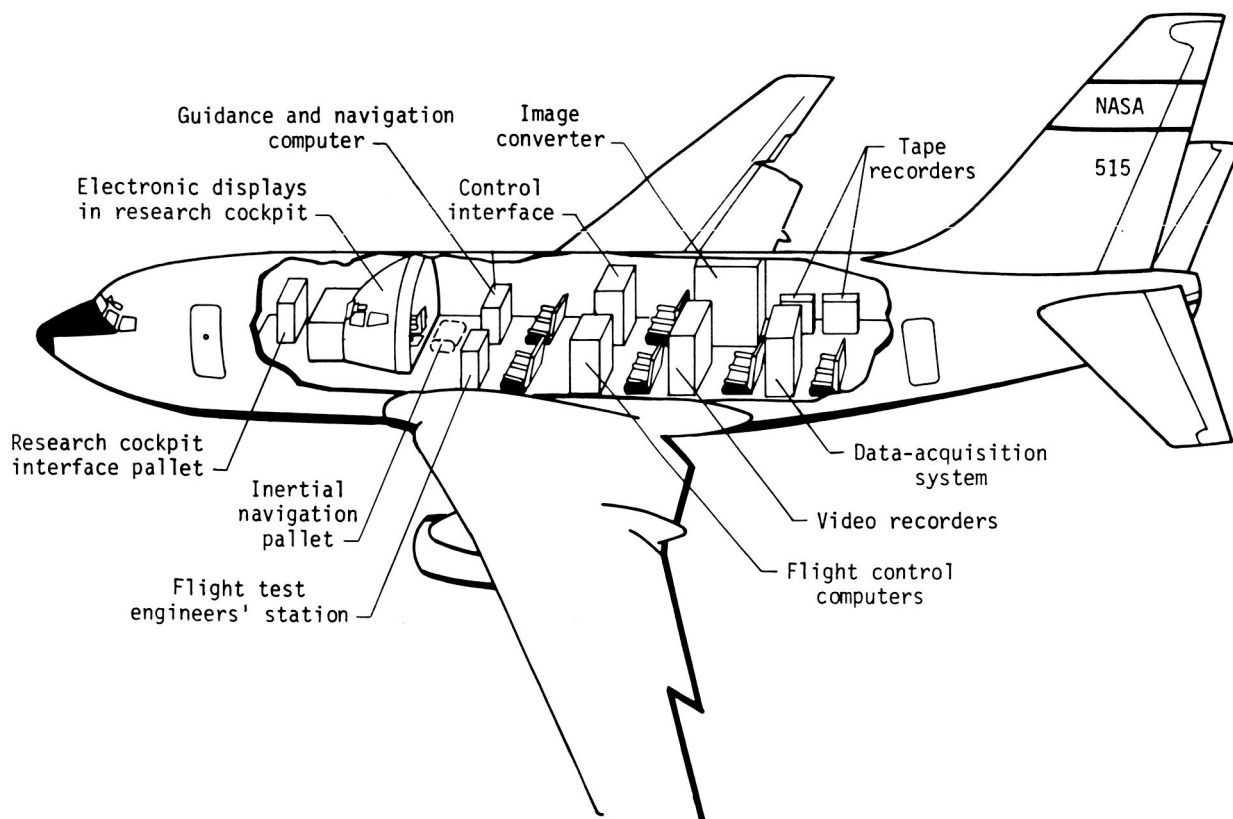
Figure 2.- Internal arrangement of NASA Transport Systems Research Vehicle.

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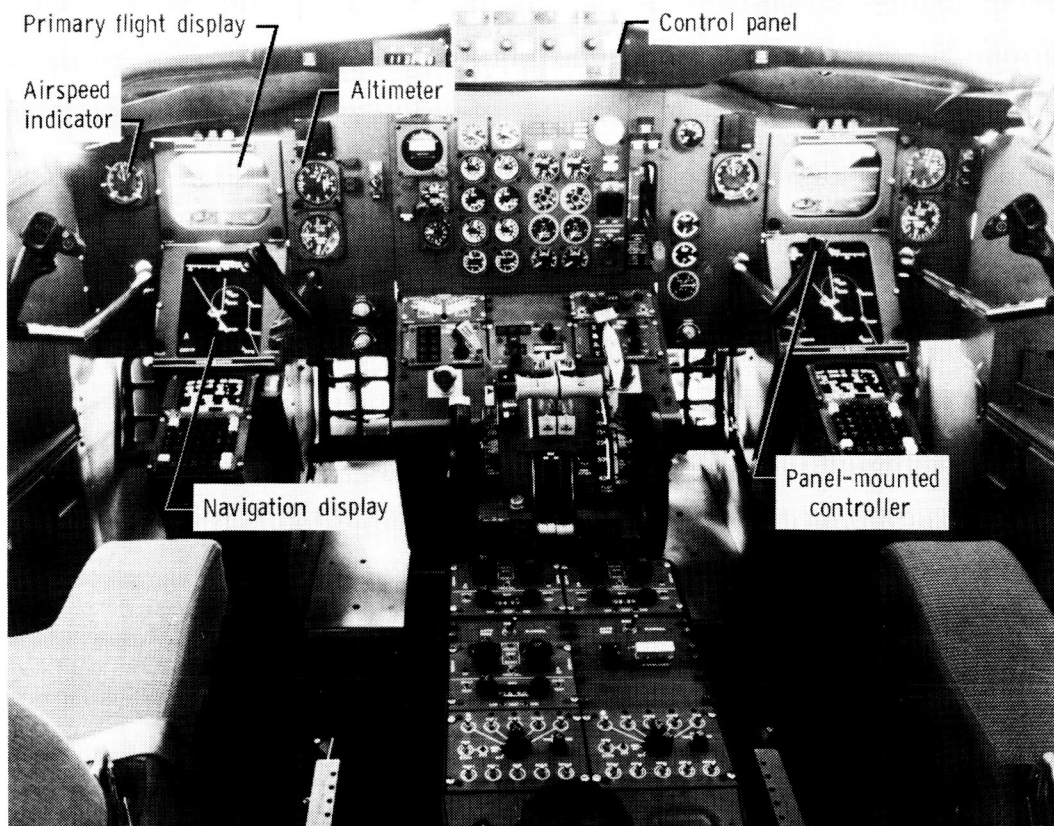
L-80-2514

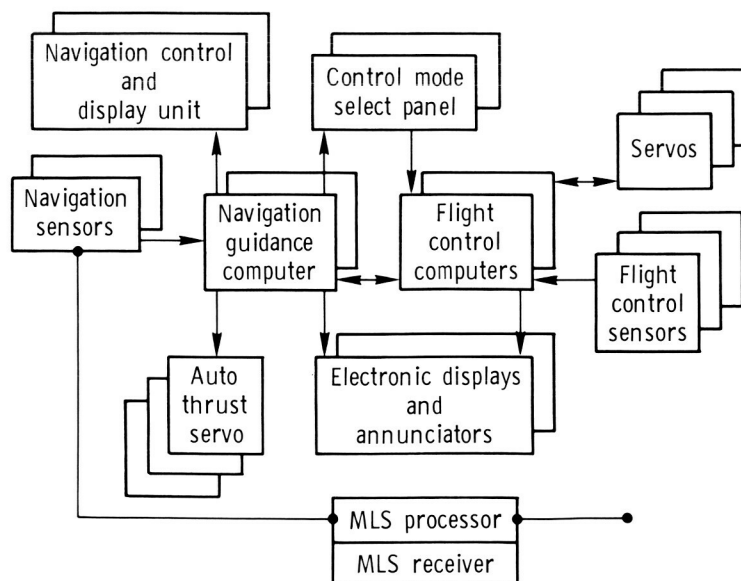Figure 3.- Research flight deck (RFD) display arrangement.

Figure 4.- NASA Transport Systems Research
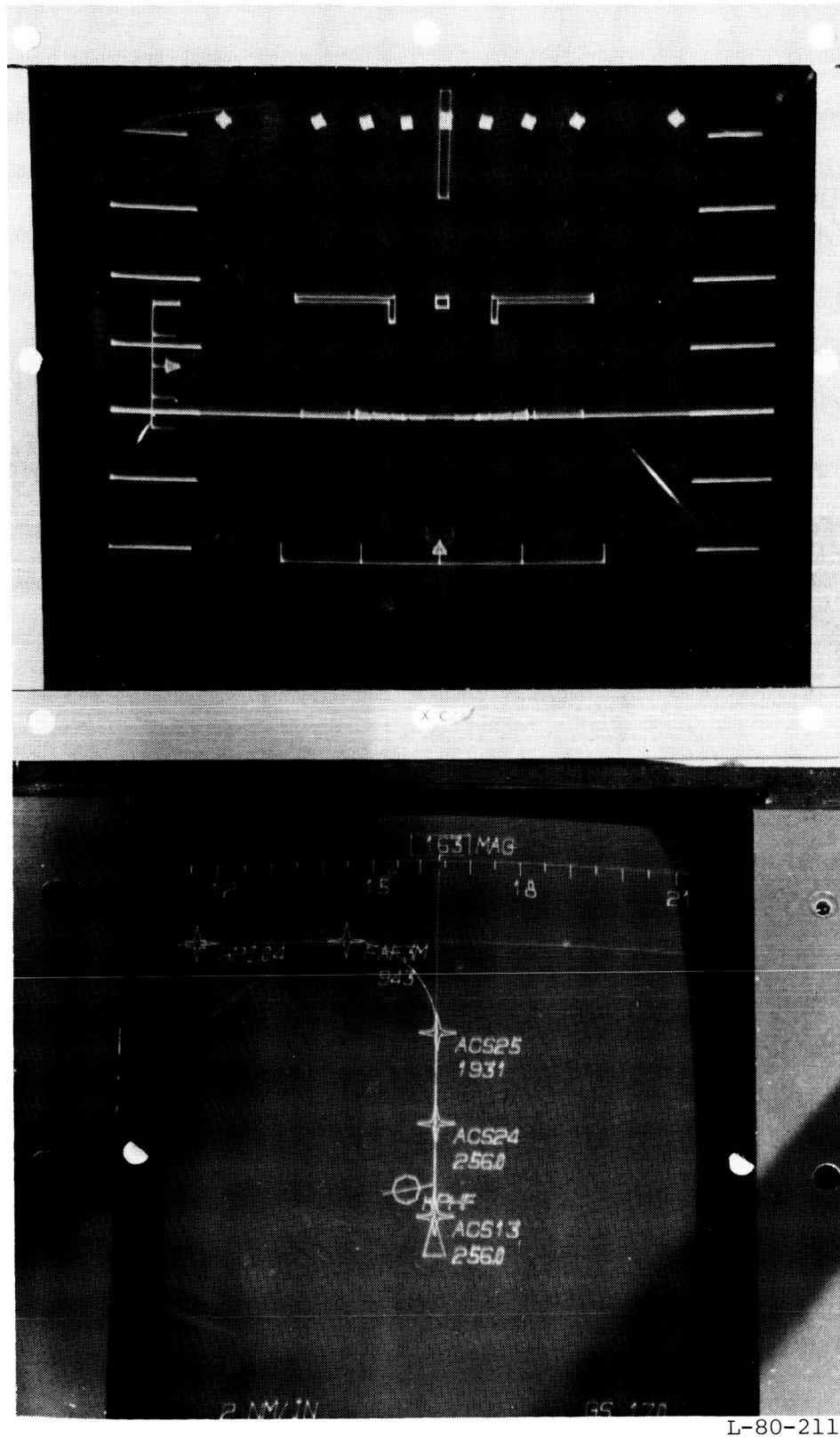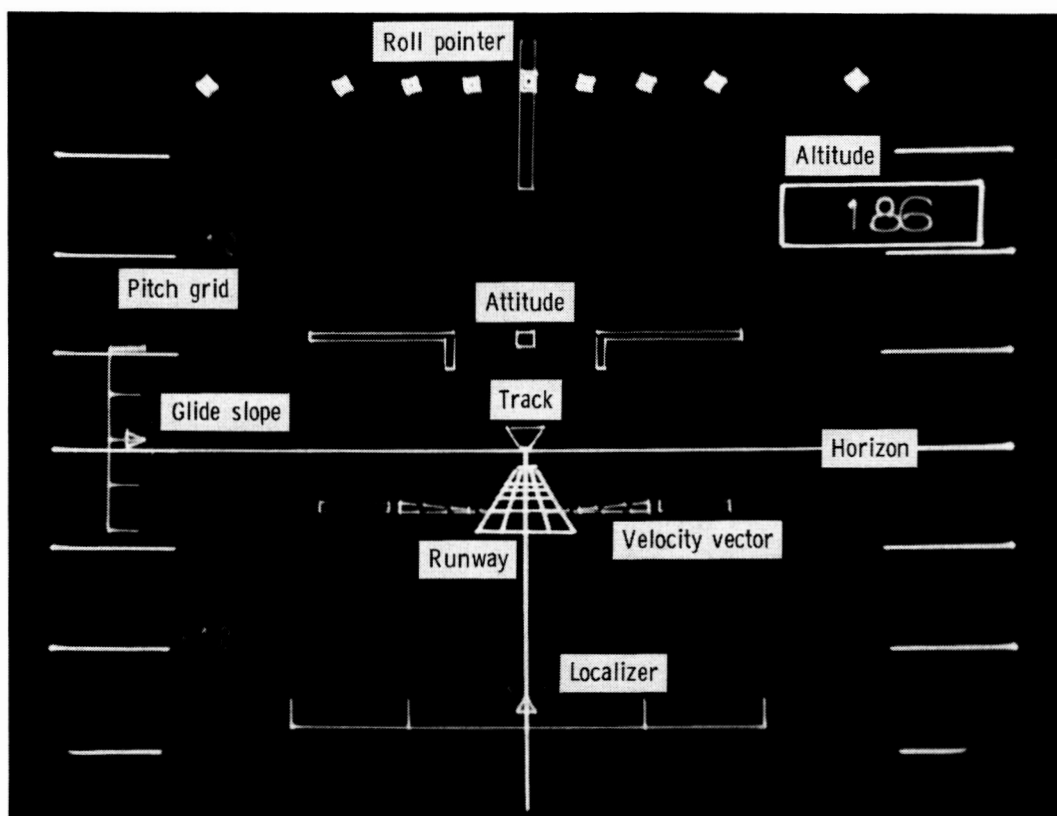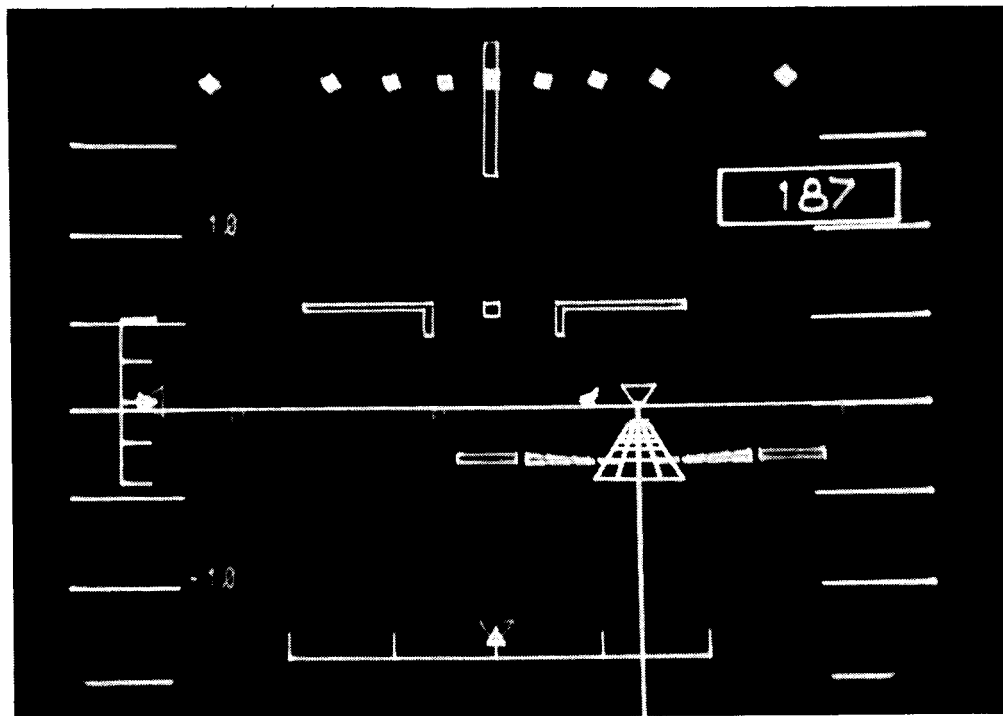Vehicle (TSRV) systems layout.

L-80-2110

Figure 5.- Simulator arrangement of primary flight
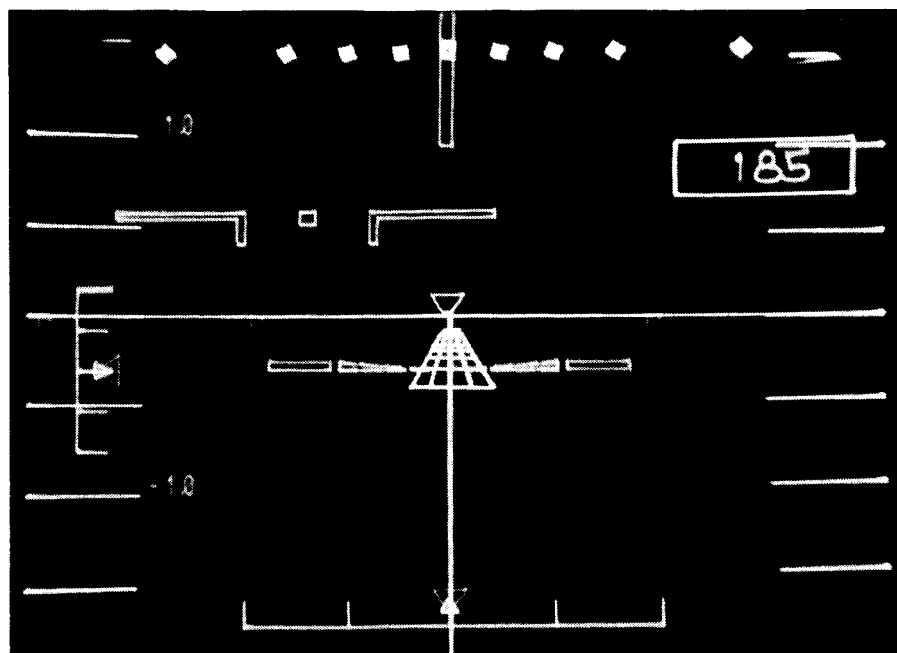and navigation displays.

L-80-2107

Figure 6.- Attitude-aligned primary flight display
(ATTPFD) for no wind.

L-80-2102

Figure 7.- Attitude-aligned primary flight display (ATTPFD)
with a 15-knot left to right crosswind.

L-80-2106

Figure 8.- Velocity-vector-aligned primary flight
display (VVPFD) with a 15-knot left to right
crosswind.

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Missed approach procedure:
  Climb to 1000 ft
  Turn left to 50° heading

Aim point
1000 ft

Approach
speed
125 knots

Middle marker
209 ft

3 n.mi.

Switch to land display mode

Airspeed 125 knots
Full flaps

Begin 3° descent

Gear down
Airspeed
150 knots

Flaps 25°
Airspeed
150 knots

Initial conditions
Gear up, flaps 15°

Airspeed
170 knots

164° heading

9½° bank
required

2560 ft   2560 ft

1931 ft

164° heading

943 ft

90° turn

Decision heights
200 ft or 100 ft
as stated

3° descent angle
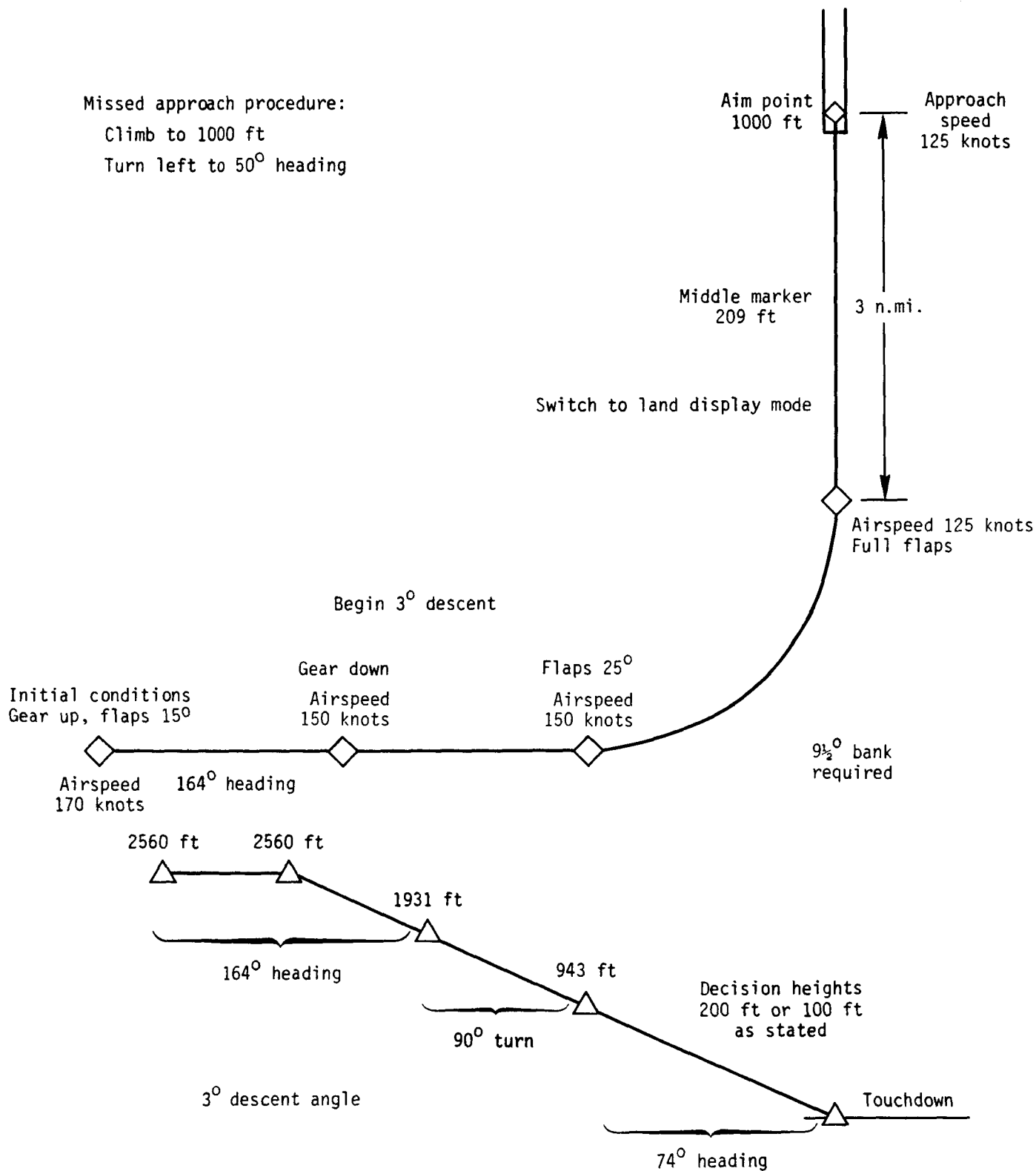
Touchdown

74° heading

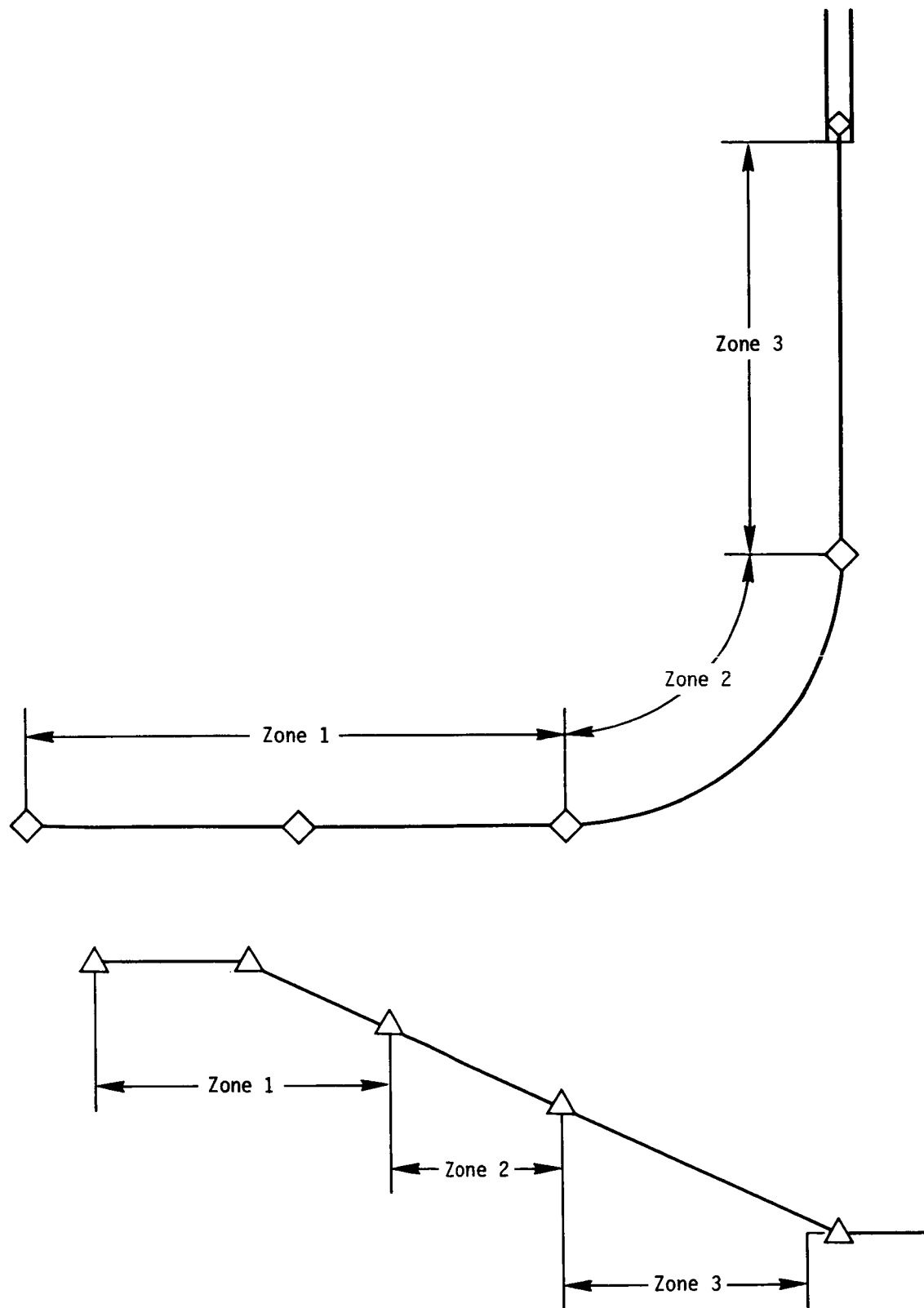Figure 9.- Approach path geometry for simulation task.

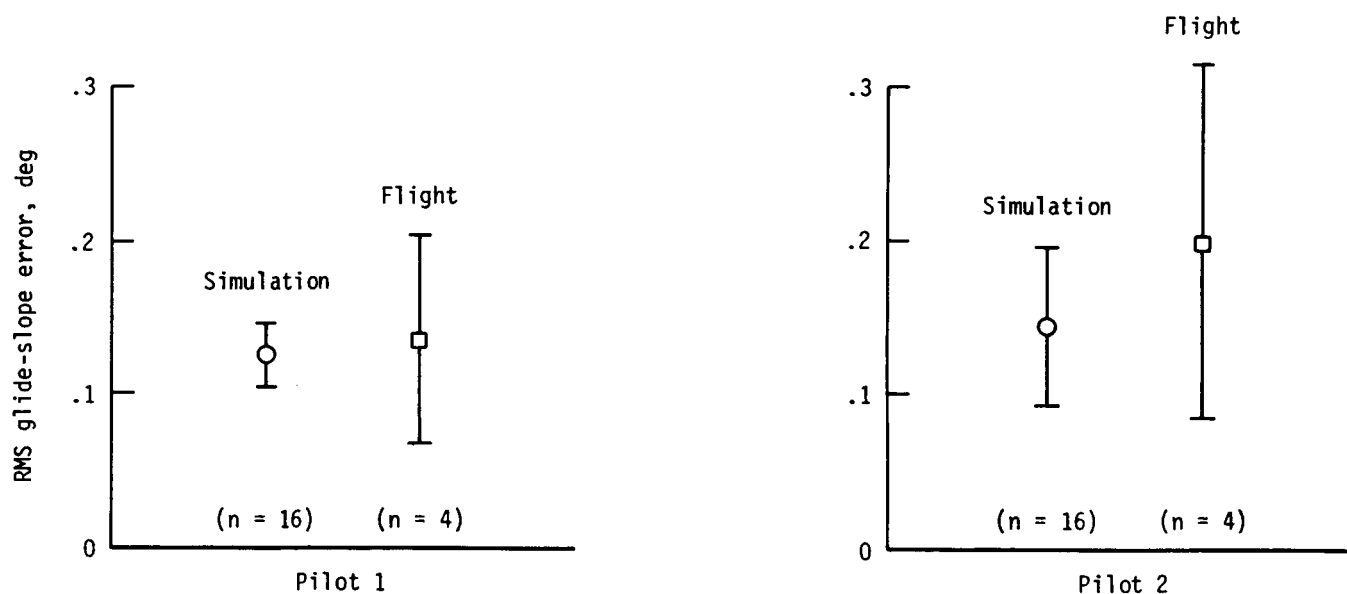Figure 10.- Data recording zones along approach path.

Figure 11.- Means and standard deviations of flight and simulation
root-mean-square glide-slope performance on final approach.
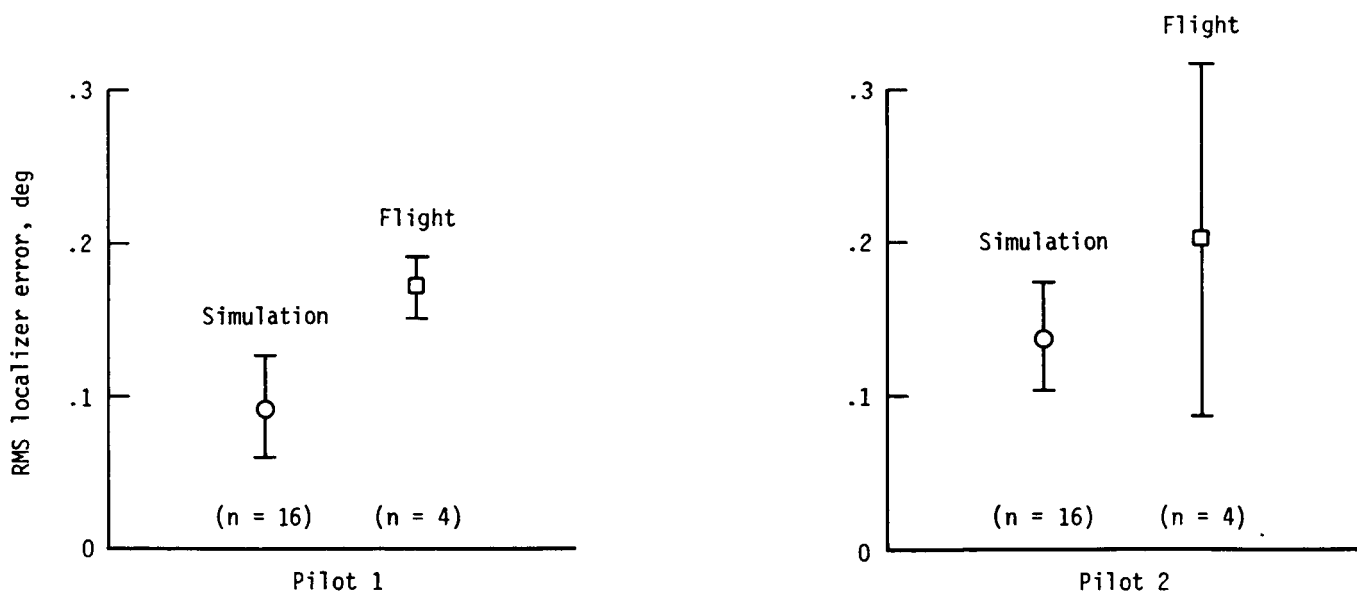n = Number of runs.

Figure 12.- Means and standard deviations of simulation and flight
root-mean-square localizer error performance on final approach.
n = Number of runs.

Standard Bibliographic Page

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16. Abstract

This report describes the development of an electronic primary flight display format aligned with the aircraft velocity vector, a simulation evaluation comparing this format with an electronic attitude-aligned primary flight display format, and a flight evaluation of the velocity-vector-aligned display format. Earlier tests in turbulent conditions with the electronic attitude-aligned display format had shown an objectionable unsteadiness in the displayed information. A primary objective of aligning the display format with the velocity vector was to take advantage of a velocity-vector control-wheel steering system to provide a steadiness of display information during turbulent conditions. Better situational awareness under crosswind conditions was also achieved. The evaluation task was a curved, descending approach with turbulent and crosswind conditions. Primary flight display formats contained computer-drawn perspective runway images and flight-path angle information. The flight tests were conducted aboard the NASA Transport Systems Research Vehicle (TSRV). The comparative results of the simulation and flight tests were principally obtained from subjective commentary. Overall, the pilots preferred the display format aligned with the velocity vector. Statistical examination of performance parameters was inconclusive. The flight results basically confirmed the simulation findings. The tracking performance for glide-slope and localizer signals was excellent and would meet category II or III requirements.

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