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# RATIONALE AND DESCRIPTION OF A COORDINATED COCKPIT DISPLAY FOR AIRCRAFT FLIGHT MANAGEMENT

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16. Abstract

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# RATIONALE AND DESCRIPTION OF A COORDINATED COCKPIT DISPLAY FOR AIRCRAFT FLIGHT MANAGEMENT

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## SUMMARY

The aircraft display designer faces the prospect of designing for display requirements that will be continually increasing and changing over the next 20 years. The information from new complex avionics systems, needed to operate within an increasingly complex air traffic control (ATC) system, will have to be added to, or combined with, the already large array of cockpit displays. The new displays must be structured such that the pilot can easily interpret all data relevant to a safe and efficient completion of his flight. One strategy to minimize future hardware changes will be to develop a cockpit display system that is independent of individual subsystem development or pilot role, and that can accommodate simple element changes through computer software changes. This report suggests for the display system a candidate format which was determined by briefly tracing a thread of perceptual and human factors research through the last 25 years. Then the initial three-display design is described in detail.

## INTRODUCTION

The Man-Machine Integration Branch Flight Management Program at NASA-Ames Research Center is committed to perform study and research on pilot procedures and pilot-systems interfaces that will be required for aircraft operating within the National Airspace System (NAS) of the 1980 - 1990's (ref. 1). Study of pilot information and display requirements is an integral part of this program. These requirements are generated both by systems demands and by pilot perceptual considerations.

This report is divided into three major sections. In the first section, the influences that the National Airspace System and ATC procedures will have on future cockpit displays are explored. In the second section, a rationale for a pictorial approach to cockpit displays is developed by reviewing some relevant human factors research, some dating back 25 years. Based on the concepts presented in the first two sections, the first prototype system was designed, and this system is described in the third section.

The display system is a set of three, beam-penetration color cathode-ray tubes (CRT's). Since one of three orthogonal projections of the aircraft situation will appear on each CRT, the displays will show different views of the same information. The color feature is included primarily to obtain visual separation of information elements, but by the use of red, green, and yellow, respectively, to differentiate control, performance, and navigation information on the three displays, additional advantage is taken of this capability. Therefore, the displays are coordinated in information and color, and the name Coordinated Cockpit Display (CCD) was chosen to emphasize this feature. Changes in internal detail, but not in overall concept, can be expected in subsequent displays.

## NATIONAL AIRSPACE SYSTEM CONSIDERATIONS

To intelligently design an aircraft display system for 10-20 years hence, one must first consider the navigation and ATC system likely to be in operation at that time. The demands of that system will bear heavily upon the role of the pilot operating in that system, which, in turn, will bear heavily upon the displays needed by the pilot to do his assigned task. Herein lies the first problem confronting the display designer. There has been no firm decision concerning the final configuration or the time of implementation of the proposed next step of the ATC system, called the Upgraded Third Generation (UG3RD) System. There are, at present, only a long list of possible improvements or changes to the present ATC system (refs. 2 - 6). Several of these proposed changes infringe on one or another special interest group, so there will be considerable opposition regardless of whichever decision is made. It is quite probable that there will be a series of compromise systems evolving over the next 10 to 20 years. Each of these systems will present the pilot with a slightly different series of tasks.

One thing that does seem certain, however. is that systems designers are going to do everything possible to move more airplanes through the system in a fixed amount of time. This means tighter tolerances in two-dimensional navigation, altitude, and time. This, in turn, means that the pilot will need more help in the form of improved displays and automatic devices. The temptation will be strong to fully automate much of the system to give the required accuracies since automation often appears to be an easier engineering solution than keeping the pilot in the loop. These steps must be taken carefully, because if the pilot is left with any manual backup role whatever, the tighter demands of the new system are likely to impose peak demands on him that are far greater than any now required. The pilot's need to be apprised of current and developing situations, with appropriate alerts announced within the context of those situations, will require the utmost in clarity of presentation.

The second major problem facing the display system designer is the influx of competing ideas for solving separate problems. Each individual idea demands some means of displaying the required information. Some of these systems gain considerable political backing under public pressure. Such political backing is illustrated by Bills S. 1610 and HR 7125 proposed to the 93rd United States Congress (1973) by Senator Goldwater and Congressman Moss, and requiring installation of collision avoidance systems on "certain civil and military aircraft." Regardless of how effective any one of these systems may be for solving an immediate problem, each adds to the display system designer's task in two ways. First, the need to consider how each major innovation will fit into the new ATC system slows down the process of choosing one specific ATC system. Second, each innovation has its own display demands and requirements that add to an increasingly overcrowded and complex instrument panel.

One answer to this dilemma is an approach to display design that will minimize future changes in the display hardware due to (1) changes in the ATC system, (2) changes in the pilot's role, and (3) changes in individual data-input sensors and hardware. One built-in benefit of this approach is that emphasis will be focused directly on the total perceptual requirements of the pilot as opposed to the present standard approach which calls for separate evaluation of each instrument proposed by researchers or manufacturers. (This approach is not to be confused with "integrated displays" which often are simply collections of standard display elements squeezed into a small space.)

These considerations call for two basic design goals: (1) Display the information to the pilot in such a manner that he always uses the same display configuration regardless of the role he is actively taking, and (2) Divorce the display configuration from individual air data and avionics devices. The resulting display will anticipate pilot needs based on presently known requirements, and will present this information in a format easily used by the pilot under all task conditions. This format will be such that any new information requirements are easily introduced as an integral part of the display.

## HUMAN PERCEPTION CONSIDERATIONS

Sound principles for display design were given by Paul Fitts 25 years ago (ref. 7) and have changed little since then. He wrote: "Qualitative displays should conform to population stereotypes. The required interpretation should be in harmony with the configurational properties of the environment in which the display is to be used" (ref. 7, p. 1311). Regarding the nature of the population stereotype applicable to aircraft displays, he wrote: "...there are many situations in which an overall 'pictorial' display is needed.... Displays are needed to provide cues for the direct perception of spatial relations and for the performance of perceptual-motor tasks, such as flying aircraft without any vision outside the cockpit" (ref. 7, p. 1306).

The ideal "pictorial" display would be one in which the position of an object in three-dimensional space is seen in depth as well as relative to up-down and left-right. To date, no scheme satisfactory for aircraft application has been perfected. The next best solution is to use the two-dimensional flexibility of currently available CRT's and build a two-dimensional analogue of a three-dimensional situation. J. J. Gibson (ref. 8) has given us the means to do this by isolating the cues in our environment that give us impressions of depth-motion, aiming point, etc. For example, "...the gradation of texture elements, not the familiarity of elements, is the principal cause of depth impression" (ref. 8, p. 69).

We are, however, constrained by the use of a two-dimensional representation of the three-dimensional world. As R. L. Gregory points out, "...it is strictly impossible to compress three dimensions into two without loss of information.... The remarkable thing is that we are able to make any sense of them (two-dimenisional pictures) for any projection is infinitely ambiguous; it could represent an infinity of different objects, but generally we see but one" (ref. 9, p. 33).

There is one obvious way to remove the ambiguity of a two-dimensional projection of a three-dimensional situation — provide at least one other view of the same situation, which thereby provides information contained in the third dimension. This reduction in ambiguity is one of the two main reasons for choosing the three-display format to be described in the next section.

The second reason for choosing the three-display format is that it provides important space for quantitative information, not just space for rows of dials or digital readouts, but rather space that can be called "related space." There is no question that the pilot needs quantitative information about his flight situation, even in perfect visual flight rules (VFR) weather. The choice of the way to display this quantitative information is not always obvious. Fitts answered his own question about why the design of quantitative displays presents a problem. "It is because (quantitative) displays must often serve multiple functions. Displays must be designed so that, in addition to being easy to read quantitatively, they will show the rate and direction of change of a variable, and will provide the sensory cues necessary for the performance of psychomotor tasks" (ref. 7, p. 1302). By relating the quantitative information to pictorial representations of the flight situation, the meaning of changes in rate and direction will be clear. The cathode-ray tube area provided by three displays will allow significant amounts of information to be displayed with a minimum of clutter.

There is an implicit assumption that goes along with this idea earlier quoted from Fitts that "there are many situations in which an overall pictorial display is needed" (ref. 7). This assumption is that if the situation and information are presented to the pilot in this way, his workload is less than if they were presented as a set of separate instrument readings. The fact that pilots themselves believe they have a workload problem is borne out by this quote from an airline pilot: "One of the hardest things for a pilot to learn is the scan of the instrument panel. It is essential that a pattern be reduced to a reflex so that his mind is free to assess the reading" (ref. 10). This "assessing the reading" is a process of making sure everything is correct for the present situation, or in other words, building a mental picture of the situation — where he is, where he's going, and how fast. The intuitive evidence is strong that a direct presentation of flight information in a spatially related format will reduce the pilot's workload. This is not yet supported by direct comparative measurement between such a display and a standard instrument system.

There is, however, one prolific area of research — stereotypes and compatibility relationships — that lends strong indirect evidence in favor of a workload advantage for spatially constructed displays. McCormick (ref. 11) has summarized the work of 10 to 12 researchers who were busy in this area in the 1950's. Defining compatibility, McCormick says: "Compatibility can be considered to refer to the spatial, movement, or conceptual relationships of stimuli and/or responses, individually or in combination, that are consistent with human expectations" (ref. 11, p. 300). As a gross summary of the results of all these studies, one can say that the highest compatibility, as evidenced by shorter reaction times and fewer errors between stimulus and response, occurred when the stimulus and the required response corresponded spatially and in direction of motion. Some of the abstractions as described by Gibson (ref. 8) that give rise to a perception of space are similar in many respects to the conditions used in the experiments on "stimulus - response compatibility" (ref. 12). The conclusion is made that simple spatial cues are sufficient to evoke patterns of response developed through a lifetime of learning. The initial display design to be described is based on this conclusion. Additional re-enforcing depth and motion cues may be incorporated as the display generation capability allows.

It is interesting to note that the Airline Pilots Association (ALPA) Basic "T" (ref. 10), which is standard for virtually all civil transports, does more than merely standardize placement of instruments. The instruments are strategically placed to help the pilot visualize his situation in three dimensions. The attitude instrument is placed "top center," as close as possible to the pilot's "out the window" line of sight. Other information associated with a plane perpendicular to the pilot's line of sight, such as glideslope and localizer, are commonly included on this instrument. Directly below the attitude instrument is the direction or course indicator, which gives information related to a plane perpendicular to the attitude plane and parallel to the earth. The altimeter is directly to the right of the attitude indicator. It supplies information about a plane perpendicular to both of the other two. By relating these side-by-side locations to the three planes orthogonal in space, the pilot can more easily transfer instrument readings into situational space. Foxworth has extended these relational principles and included them in his proposed instrument panel (ref. 10).

With the prospect of additional systems being automated, there has been considerable speculation that, in the role of flight manager to automatic systems, the pilot will become detached from the ongoing situation and become less interested and less vigilant. This concern was recently put into words in the report of the Department of Transportation (DOT) Secretary's Task Force on the Federal Aviation Administration (FAA) Safety Mission. "Air crews at times become bored, complacent, and inattentive. Modern cockpit layouts, improved aircraft handling qualities, and simple, reliable systems all seem to contribute to this problem" (ref. 13, p. 24). Related to this issue, Wernicke (ref. 14) pointed out that a pictorial display format may have side advantages other than perceptual efficiency when he proposed, "The pictorial display is suitable as a substitution for the lost motivation... (with) its clear, realistic and dynamic picture" (ref. 13).

## THE COORDINATED COCKPIT DISPLAY (CCD)

The discussion in the prior two sections has explained why the three-plane pictorial approach to a cockpit display was chosen for the Flight Management Program. Within this concept, there is tremendous latitude for design — many choices are to be made and evaluated. Wherever possible in the following description of the initial display configuration, reasons are given for each choice of elements.

### General Features of the CCD

The three-display configuration described here is based on three orthogonal projections of the aircraft situation: (1) perpendicular to the pilot's forward line-of-sight, (2) parallel to the ground, and (3) perpendicular to the other two. Figure 1 illustrates the relationships.

The first display is most closely related to the pilot's view out the front window and is perpendicular to the earth. For the CCD system, this is called the Vertical Situation Display (VSD) (fig. 1). Because the frame of reference moves in response to aircraft attitude, the first CRT presentations of this type were called Electronic Attitude Director Indicators (EADI) and that designation has remained (ref. 15). This reference to attitude is too restrictive and the term Vertical Situation Display is currently more descriptive of the broader function visualized for this display.

The second display represents the horizontal situation and is thus called the Horizontal Situation Display (HSD). This plane is parallel to the earth surface, and is the plane in which maps are commonly drawn.

The display that will show the pilot's situation in a plane perpendicular to the earth and parallel to the pilot's forward line of sight is called the Side Vertical Situation Display (SVSD). In the past, very little attention has been given to this view of the flight situation. In addition to other features to be described, this pictorial view will be ideal for explicitly showing the altitude situation, which should enable the pilot to maintain easily his altitude awareness.

The combination of these three displays unambiguously shows the total flight situation. Each display explicitly represents two dimensions in space and shares one of those two dimensions with each of the other two displays. For example, the display elements to be shown on the SVSD will represent up/down and fore/aft situation information; the up/down dimension is also one of the VSD dimensions, and the fore/aft dimension is one of the HSD dimensions. Therefore, each of the three displays is capable of showing different views of the same information, e.g., a waypoint in space with a line joining the aircraft with the waypoint. By constructing these different views of selected information the displays tie together, or coordinate, their information content. The display elements are also to be color coded according to three (perhaps four) classes of function that will be the same on all three displays.

As prime instruments, the three CRT's will be mounted in the center of the aircraft instrument panel with the display surfaces perpendicular to the pilot's line-of-sight. This is not ideal since the pilot will have to mentally rotate coordinates to correspond with the real world. However, the alternative of positioning the scope faces parallel to the planes they represent, either at the instrument panel or closer to the pilot, present major practical difficulties. So that this mental rotation will be simple as possible, the three displays will be positioned as shown in figure 2. This is the relationship that results if the three planes depicted in figure 1 were folded outward as if they were three sides of a box.

*Color coding* — As already mentioned in the Introduction, color will be used as part of this display system, primarily to obtain visual separation of the information elements. The usefulness of different colors to separate display elements is well demonstrated by current mechanical flight directors. Because monochrome CRT's lack color separation, they become visually cluttered by even a few elements. Shape, intensity, and line coding do little to relieve the problem. The beam-penetration CRT's to be used with the initial display system can generate three basic colors — red, green, and yellow. (Other intermediate colors, such as orange, can also be generated, but red, green, and yellow are the most easily discriminated.) Because it was thought undesirable to arbitrarily assign a color to each display element, a search was made for some consistent color assignment scheme that would also fulfill the visual separation requirement. An instrument classification scheme used by the Air Force provides three categories to match the three basic colors.

Air Force Manual 51-37 divides flight instruments into three categories — control, performance, and navigation instruments (ref. 16). The control instruments indicate first response to control inputs such as aircraft attitude and engine power; the performance instruments indicate the effects of changes in the control parameters, such as pitch changes resulting in altitude and airspeed changes; and the navigation instruments indicate aircraft position relative to ground references. These three categories can also be referred to as inner, middle, and outer loop control.

The colors red, green, and yellow have been assigned to control, performance, and navigation information, respectively. (This is probably not critical from a perceptual standpoint.) Red was chosen for control information for three reasons: (1) pilot response to control requirements must be relatively quick, and red is traditionally associated with a requirement for immediate action; (2) there are fewer elements of control information than is the case for performance and navigation so less demand to "look at red"; and (3) red elements will probably require two beam tracings to attain the desired brightness level so assigning fewer elements to red will save computer time. The present green and yellow assignments were given because early color drawings of potential displays were aesthetically more pleasing to the writer.

*Research hardware* — The lines and dots which make up the display elements are generated by an Evans and Sutherland LDS-2, modified to drive beam-penetration color CRT's. Each color CRT measures 17.7 × 17.7 cm (7" × 7"). An SEL-840 computer interfaces with the LDS-2 to generate aircraft dynamics, navigation and guidance equations, and performance recording.

## Features of the Individual CCD Displays

The CCD concept as outlined so far is quite simple. However, when the amount of specific information that could go on each display is considered, along with the different possible forms that could be given to each piece of information, it is clear that the implementation of CCD could become quite complex. In the following description of the individual CCD displays, only one form of selected information is described. It is to be understood that changes will be made to accommodate the requirements of specific experiments, and the purpose of these experiments will be to seek better forms of the displays.

*VSD* — This is the primary display for aircraft attitude. Since everything is referenced to the direction of flight, the center of the display can easily become overly cluttered with aircraft symbol, horizon line, pitch marks, runway symbol, and other aiming points. For this reason, everything that might logically go on this display cannot be accommodated at the same time. One configuration of the VSD is shown in figure 3. Element color assignments given in the text below are summarized in table 1.

This method of showing the attitude situation is fairly standard. The combination of aircraft symbol (fixed), horizon line, and roll angle marker show a 10° left bank and 0° pitch angle. These elements will all be shown in red.

The ground plane is differentiated from the sky plane by a perspective dot pattern. The rate of downward motion could be programmed to be a function of forward velocity and/or altitude and may be studied at a later time. It is believed, however, that the most important function of these dots is the ground-plane/sky-plane differentiation (ref. 17) and secondarily the general "streaming" effect of the passing ground (ref. 8). Altitude and velocity coding would encounter range problems, e.g., the dots would be so far apart — close to the ground — that the visual illusion of the ground plane would be lost. The ground-plane dots will be yellow.

The performance information that will have to be read most precisely during critical maneuvers surrounds the central attitude display. The altitude position reading on the right has a natural up/down relationship on this display. Also the heading readout at the top of the display has a natural right/left relationship. Airspeed has no natural position correspondence so the standard population stereotype — reading upward for larger values — was adopted (ref. 11). Heading, altitude, and airspeed are each read as a combination moving tape and digital readout, taking advantage of the best features of both. Digital readouts can be read more quickly and accurately than an analogue readout, but are poor for rate judgments. A moving tape provides rate and lead information. In operation, the moving tape numbers are blanked from the digital readout box so that the visual effect is that of the tape moving and disappearing behind the box. The digital readout is stationary with changing digits. For this simulation, there will also be provision for choosing either moving tape or digital readout separately before beginning a flight.

The rate of change of heading and altitude, more commonly known as turn rate and instantaneous vertical speed indication (IVSI) respectively, are displayed adjacent to the appropriate moving tape. Turn rate is normally shown in terms of a standard 3°/sec turn (although for short take-off and landing (STOL) aircraft, this will probably need modification). In like manner, the IVSI will be scaled for one or two standard sink and climb rates. If needed, a speed command or error bug will run along the airspeed tape. All these elements on left, top, and right of the VSD will be green.

Two pieces of information, flight path angle (FPA) and potential flight path angle (PFPA), have been combined into one symbol so that the relationship between the two pieces of information cannot be lost among other symbols on the display. In figure 3, the midpoint of an imaginary straightline joining the two tips of the FPA marker is the actual direction of aircraft flight at a given moment. This point is also called the aiming point and a line extending from the aircraft toward this point in the real world is called the velocity vector. This symbol can be used to show flight-path angle relative to the horizon or to any spatially located point such as a three-dimensional (3-D) waypoint, runway threshold, or another aircraft. Flight path can be computed relative to the ground or relative to the air mass. At present, there are arguments pro and con for each of these frames of reference. These arguments involve both pilot interpretation and hardware implementation problems. Green is the color from the inner tips of the symbol to the pivot or bending point.

The PFPA is referenced to the FPA. When the PFPA is level with the FPA, the acceleration along the aircraft flight path is equal to zero; therefore, speed is constant. If PFPA is above FPA, the acceleration is positive and speed will increase; if PFPA is below the FPA, acceleration is negative and speed will decrease. These two indicators make the effect of changes in throttle setting, flaps, landing gear, etc., immediately apparent to the pilot. As an illustration of the use of these two display elements, consider the example shown in figure 3. The potential flight path is shown as being 4° below current flight path. The pilot can use the information to increase throttle until the potential flight path reads the same value as for flight path, thereby maintaining current flight path and airspeed. Or, as can be seen in the example in figure 3, by pitching down until the flight path equals the potential flight path — indicated when the FPA/PFPA symbol becomes a straight line — the pilot can maintain current airspeed without changing thrust. Potential flight path is a directly controlled variable; therefore, the "flat," or level, portion of the symbol is red. Not shown in figure 3, but planned for evaluation, are waypoint guidance, runway and touchdown point, and a method for showing a 3-D perspective of desired flight path (e.g., tunnel or channel display (ref. 18)).

*SVSD* — This display is intended to relate clearly and unambiguously the present aircraft altitude to future altitude requirements (fig. 4). The aircraft symbol (red) remains fixed at the altitude digital readout box (green). Placing the aircraft symbol near the altitude box accomplishes two purposes: (1) the aircraft altitude reference is explicitly established, and (2) a second altimeter is provided as required for certain operations such as category II and III landing. The altitude on the VSD is from radio and the altitude on the SVSD is barometric. The operation of the moving tape/digital readout is the same as described for the VSD. To enhance terrain altitude awareness, significant terrain features (yellow) can be shown referenced to the moving tape. Logic will have to be provided to change these features as a function of lateral displacement from desired ground track.

Flight-path angle (green) and potential flight-path angle (red) are accurately read against an expanded angle scale (3:1 in fig. 4). The vertical relationships are the same as previously explained for the VSD. The aircraft symbol rotates about its midpoint to indicate aircraft attitude.

An IVSI digital readout (green) in the upper left corner supplies absolute vertical speed information, supplementing the analogue readout on the VSD. An arrow appearing above or below the box reinforces the sign information regarding up or down velocity of the aircraft. There is a ± 15.24 m/min (50 ft/min) dead band about zero m/min so that the arrow is not continually flipping over when the aircraft is flying straight and level. In keeping with the philosophy of relating quantitative information to qualitative information, this vertical speed information should be closely related to the flight path angle or the aircraft symbol. Initial attempts to do so resulted in excessive clutter and loss of other information. As with all items on these displays, its final form is yet undetermined.

A segmented line (yellow) moving toward the aircraft symbol indicates the desired vertical track. Relevant tags are shown at waypoints, marker beacons, and so forth. Vertical and horizontal scaling must be compatible with the flight-path angle scaling.

*HSD* — This display (fig. 5) relates the aircraft (red) to its geographic position. This may be shown as aircraft position relative to a desired course line, navigation aids, waypoints, runways, or prominent geographic features, all of which would be shown in yellow.

The horizontal projection of the velocity vector or flight path, the range altitude symbol, and ground speed and windspeed vectors would be green. The range altitude symbol shows the point at which the next waypoint altitude will be reached if the present vertical component of the velocity vector is maintained.

If this display is to be used for manual control, the lateral track error can be expanded by some factor and shown by a bar parallel to the aircraft, as if a portion of the guide line had been cut out and expanded.

Sufficient work has been done to show the utility of a predictor on the HSD (refs. 19,20), so an evaluation of a predictor (not shown in fig. 5) will be part of this work. (This may eventually include evaluation of predictors on the VSD and SVSD as well.) Also not shown but candidates for HSD presentation are time slot information for four-dimensional (4-D) navigation and symbols showing other aircraft for traffic situation information (refs. 21,22).

## CONCLUDING REMARKS

The goal of the CCD concept is to present flight information explicitly in its situational context. The advantages and disadvantages of this approach remain to be studied. In the first simulator study, pilots will manually fly a complex, decelerating landing approach with go-around at 60.96 m (200 ft) before touchdown. Using this task, pilot performance will be compared when using the Coordinated Cockpit Display (CCD) or standard instruments. Pilots will be interviewed for opinions, comments, suggested changes, and additions or deletions.

As display ideas evolve, it is expected that differing configurations of the CCD will be compared so that new ideas on display content and form can be evaluated. In a parallel effort, the CCD will also be integrated into a full mission simulation and evaluated in the larger context of complex navigation with an air traffic control system.

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TABLE 1.— DISPLAY ELEMENT COLOR ASSIGNMENTS

| Display | Element | Red | Green | Yellow |
|---|---|---|---|---|
| VSD | Horizon line & pitch marks | X | | |
| | Aircraft symbol | X | | |
| | Roll angle | X | | |
| | Ground plane dots | | | X |
| | Altitude tape & digital readout | | X | |
| | Airspeed tape & digital readout | | X | |
| | Heading tape & digital readout | | X | |
| | Turn rate | | X | |
| | IVSI | | X | |
| | Flight path (FPA) | | X | |
| | Potential flight path (PFPA) | X | | |
| | Waypoint guidance (not shown) | | | X |
| | Runway (not shown) | | | X |
| | Tunnel or channel (not shown) | | | X |
| SVSD | Aircraft symbol | X | | |
| | Altitude tape & digital readout | | X | |
| | Terrain features (not shown) | | | X |
| | Flight path (FPA) | | X | |
| | Potential flight path (PFPA) | X | | |
| | Angle scale | | X | |
| | IVSI | | X | |
| | Desired vertical track | | | X |
| | Waypoints, beacons, etc. | | | X |
| HSD | Aircraft symbol | X | | |
| | Flight path | | X | |
| | Range altitude | | X | |
| | Ground/windspeed vectors | | X | |
| | Desired course line | | | X |
| | Expanded error bar | | | X |
| | Navigation aid | | | X |
| | Waypoint | | | X |
| | Runway | | | X |
| | Obstructions | | | X |

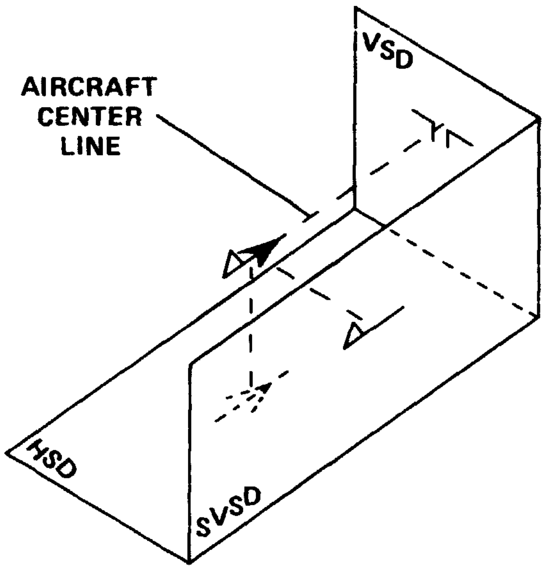

Figure 1.— Three orthogonal planes of aircraft situation.

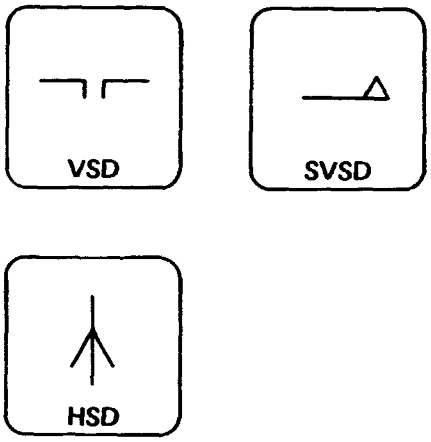

Figure 2.— Position of three displays in aircraft instrument panel.

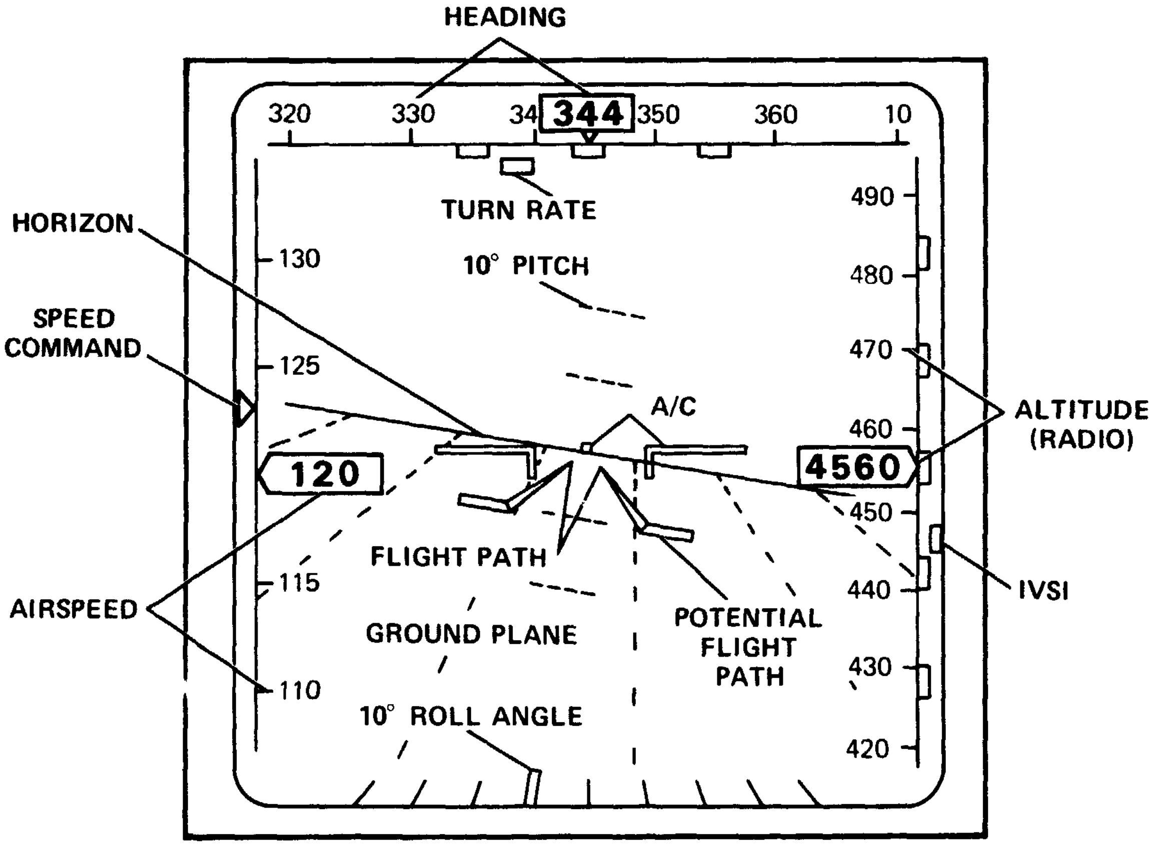

Figure 3.— Vertical situation display.

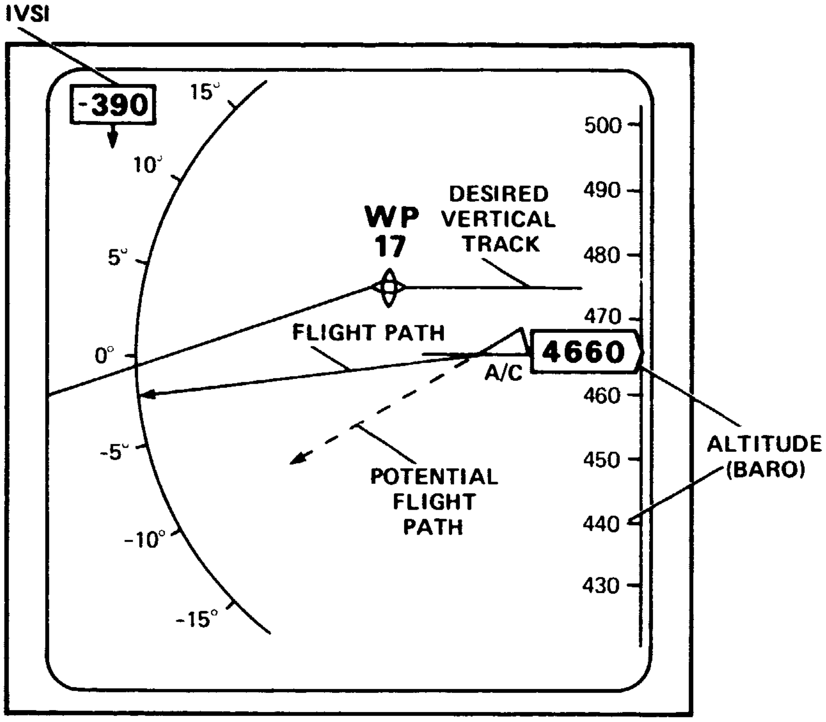

Figure 4.— Side vertical situation display.

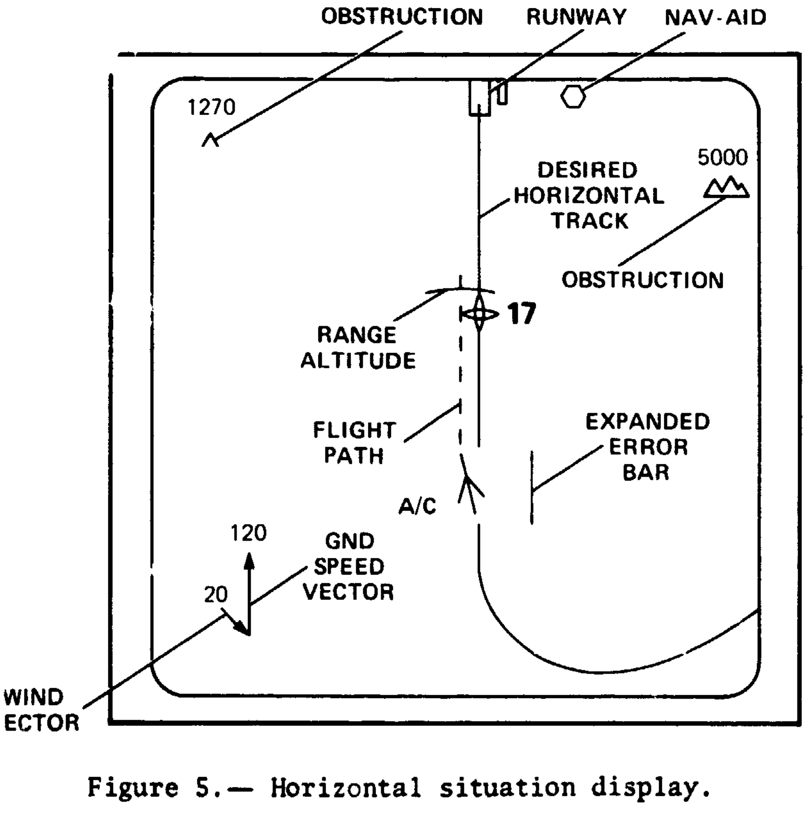

Figure 5.— Horizontal situation display.