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Human Engineering Report 2

REVIEW OF PROJECTED DISPLAYS OF FLIGHT INFORMATION AND RECOMMENDATIONS FOR FURTHER DEVELOPMENT

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ABSTRACT

Five projected displays of flight information proposed by organizations in the United States, England and Australia have been reviewed and compared in respect to information content, simplicity and compatibility with the outside world. All five have been shown to have associated problems of various types.

A series of new displays, based on similar concepts but designed to eliminate the less desirable features of the others, have therefore been proposed for simulator and flight evaluation. These new displays vary in respect to the type of flight director provided, and a complete test program has been prepared to evaluate them in detail.

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1. INTRODUCTION

The view is widely held in the Development Division of the Systems Research and Development Service, Federal Aviation Agency that the primary landing system for large civil and military transport aircraft going into service after 1965 will be an automatic one based on improved elevation guidance and refined localizer equipment, with radar altimeter assistance for flare-out if required. The secondary system, to be used both for monitoring the automatic system and to enable the pilot to take over control from an unserviceable automatic system and perform a safe landing, will be an advanced command type display, either projected on the windshield or panel mounted, with capacity for flare-out guidance. The tertiary system or back-stop, to be used only on rare occasions when the primary and secondary systems are unserviceable, will be a set of basic panel instruments giving raw data, probably including a tape altimeter with provision for juxtaposition of radar altitude and rate of descent as a guide to flare-out. The latter system, in visibilities close to zero-zero, is only expected to guarantee an arrival which causes no injury to the occupants of the aircraft.

The objective of the study reported here is to evolve a research and evaluation program aimed at finding the best type of information presentation for a projected display. This will then be evaluated against panel displays to determine which provides the best secondary system.

2. REVIEW OF EXISTING AND PROPOSED DISPLAYS

A number of displays of projected flight information have been proposed by various instrument manufacturers and research organizations during the past six years and some of these have been built in prototype form and tested in simulators or in flight.

Certain of the earlier ones were simply windshield projections of conventional Integrated Flight System directors, which took no advantage of the inherent potential of the projected display to integrate instrument information with visual information available from natural sources outside the aircraft. Their only advantage over the panel Integrated Flight System was that they were collimated to appear at infinity and saved the pilot from having to re-accommodate his eyes when transferring his attention from the outside world to his primary director instrument. In most cases they did not display other vital information such as airspeed and heading error, and therefore, did not really solve the accommodation problem. These unsophisticated projected displays will not be further considered.

A limited number of displays conceived in the United States, England and Australia have, however, attempted to exploit the real potential of the projected display. These will now be reviewed in detail with reference to both the means of projection proposed and the form and content of the display.

The following displays will be considered:

(1) The Sperry Display.

(2) The A.R.L. Display (Aeronautical Research Laboratories, Australia).

(3) The Spectocom Display (Specto, England and Computing Devices of Canada).

(4) The Bendix Display.

(5) The Douglas A.N.I.P. Display.

In this section of the report each display will be described in detail to give the reader a full appreciation of the way it operates and is interpreted. Then, in the next section, a critical comparison will be made between the various displays with reference to the criteria which appear most important. Finally, a series of new displays will be proposed, based largely on what seem to be the best features of the displays reviewed, but with the addition of certain original ideas. A test program will be proposed to evaluate these.

Differences in the terminology used by the designers of the various displays will be eliminated by using a standard terminology defined in Appendix A. Two particular features of this terminology are worthy of special emphasis. Firstly, the words "ILS glidepath" (or just "glidepath") will mean the path through the air defined by the ILS localiser and glideslope beams; the words "flight path", on the other hand, will mean the actual path flown by the aircraft which, during landing approach, generally oscillates in the region of the ILS glidepath. Secondly, the word "heading" will mean the azimuth direction in which the horizontal projection of the aircraft axis is pointing and the word "track" will mean the azimuth direction in which the aircraft is travelling, measured relative to the ground. Thus, "heading" corrected for wind drift and any sideslip gives "track". The word "course" will not be used at all because it is ambiguous: in the United States it generally means "track" whereas in British countries it means "heading".

To obtain an appreciation of the differences between the various displays it is desirable to illustrate how each of them would appear in a particular single approach condition. Figure 1 shows an approach condition which seems appropriate as a basis for comparison.

The aircraft is imagined to be above and to the left of the ILS glidepath and the pilot has banked to the right and begun to head downward and to the right in order to capture the glidepath. Although the flight path is aimed below and to the right of the runway aiming point, it has not been turned toward the glidepath sufficiently to achieve the desired closure path indicated by the dotted line. This is the closure path called for by the flight director system.

The various displays will now be discussed with reference to this approach condition. The illustrations of the displays will be drawn on the assumption that the range from the aiming point is 1-1/2 nautical miles, the runway measures 8000 feet x 150 feet, the angle off centerline is 1° and the angle of elevation is $3\text{-}1/4^{\circ}$.

2. 1 THE SPERRY DISPLAY

The Sperry display for landing approach in IFR conditions is shown in Figure 2. It is designed for 1 to 1 compatability with the outside world and is therefore completely gyro-stabilized and collimated to appear at infinity. This display was conceived in 1956 as a head-up flight director for VFR approaches, but it was soon realized that the addition of a projected runway image would provide IFR capability, (Reference 1).

In the present Sperry Phase 2 equipment, which is mounted for demonstration in a DC-3 aircraft, the display is produced partly by reflection of images on a cathode ray tube and partly by reflection of a back-lighted engraved metal reticule, (Reference 2). The reticule is used to produce the flight path and airspeed error images which are orange in color and more intense than the other images produced in green on the face of the cathode ray tube. The display unit is fixed relative to the airframe and is mounted on the cockpit ceiling to the right of the pilot's head. This mounting scheme is not final since the type of mounting is expected to vary with aircraft type. Mirrors are used to stabilize the images relative to the outside world.

The horizon line with its heading reference:

is aligned with the horizontal at all times. The heading marker is set in azimuth by the pilot so that his line of sight to it is in alignment with the runway heading; the stabilizing mirrors then maintain this alignment. Thus, when the aircraft is to the left of the runway center line, the heading marker defines a horizontal line from the aircraft parallel to the runway but offset to the left.

In perspective view* this line and the runway center line appear to converage at infinity.

The flight path marker:

has three modes of operation namely:

(1) Flight path mode

(2) Deviation mode, and

(3) Director mode

In flight path mode it indicates the projection of the flight path vector and, by its relationship to the horizon line, gives an indication of angle of roll. In the ultimate design this would be flight path relative to the ground computed from the three dimensional airspeed vector and the wind vector, but in the present equipment there is only a manual drift adjustment to correct for crosswind and no provision for headwind or tailwind. This indication of flight path is of much more direct use to the pilot than the conventional indication of fuselage pitch attitude. When the system is switched to flight path mode and the flight path marker is placed on the horizon line, the aircraft is accurately set up for zero vertical speed. Any slight rate of climb or descent is clearly shown by a separation between the marker and horizon line. Considering the approach condition illustrated in Figure 1 and assuming the system to be switched to flight path mode, the center of the flight path marker in Figure 2 would be below and to the right of the runway aiming point at the point designated FP.

In deviation mode the flight path marker indicates the position of the aircraft in relation to the ILS glidepath. This may be determined

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*NOTE -that, in this report, any comments or perspective appearance neglect the slight distortions caused by the curvature of the earth's surface.

by defining a line of sight from the pilots eye parallel to the ILS glidepath and finding where its intersection with the ground lies in relation to the runway aiming point (or, in IFR conditions, aiming point image). This parallel line of sight lies in a vertical plane through the heading marker and is inclined downward at the glideslope angle (2-3/4° in this case). The intersection of the line of sight with the ground would appear at point DV in Figure 2; thus in deviation mode the flight path marker would be centered on that point. By reference to the runway aiming point, this would indicate to the pilot that his aircraft was above and to the left of the ILS glidepath.

In director mode a director signal is generated by placing the flight path marker a fixed proportion of the way from the point DV to the point FP, as shown in Figure 2. Then, if the pilot maneuvers his aircraft to bring the flight path marker into coincidence with the runway aiming point or its image, the projection of the flight path vector FP must be on the opposite side of the runway aiming point from the instantaneous position of the aircraft DV. The result is that the aircraft must close with the ILS glidepath. Tests conducted by Sperry have indicated that a satisfactory closure is effected with the DC-3 when the flight path marker in director mode is about one sixth* of the way from DV to FP. With this arrangement an aircraft displaced 1° from ILS glidepath is directed to close at an angle of 5°. As it closes these two angles decrease in constant proportion to produce an asymptotic flight path.

In Figure 2 the flight path marker is shown slightly out of coincidence with the runway aiming point because the aircraft has not been headed down and to the right at a sufficient angle to follow the desired closure path. A further correction is called for.

The lateral response of the display may be quickened by biassing the flight path marker with an angle of roll signal when it is in director mode, the bias being applied in the same direction as the angle of roll. Then, if the aircraft is to the left of the ILS glidepath, the runway aiming point can be captured by the flight path marker as soon as the aircraft is rolled to the right through an appropriate angle. Once the wings are again levelled the relationship between the flight path marker, DV and FP reverts to that described above. This feature, which had its origin in the Zero Reader design, has been built into the present Sperry equipment.

Since the aircraft flight path has minor deviations in azimuth from the fuselage axis due to sideslip and yawing disturbances, a

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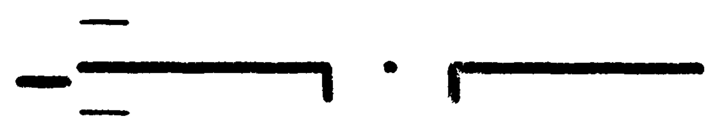
*NOTE-This figure is likely to vary form one aircraft type to another, being related to aircraft speed and dynamics.

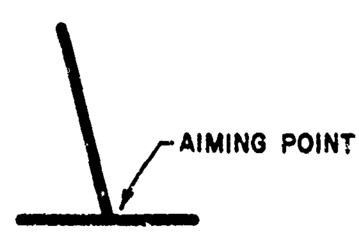
correction should be made for this in flight path and director modes. The omission of any such correction in the present Sperry equipment results in lateral oscillations of the flight path marker which do not represent real flight path changes. Modifications are in hand to rectify this. These oscillations are much more noticeable in flight path mode than in director mode. In the latter case the aircraft image is located by a signal which is mainly a deviation mode signal stabilized relative to the outside world; only one sixth part of it is taken from flight path mode.

The airspeed error indication:



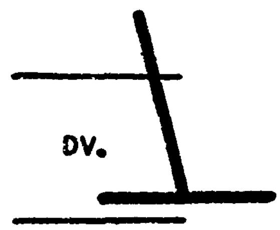
gives an indication of variation from a desired airspeed set by the pilot. Movement of the left hand bar relative to the wing of the flight path marker indicates airspeed error. When the airspeed is too high the bar is above the wing; thus the nose of the aircraft must be raised to bring the wing towards the bar. The two short bars above and below the wing are indices of airspeed error and, as the flight path marker moves over the windshield during aircraft maneuvers, the airspeed display moves as a whole with it.

The runway image:

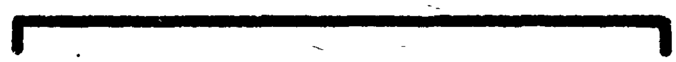


is in the form of an inverted T which defines the runway center line and aiming point, the latter being normally about 1000 feet beyond the threshold. In IFR conditions it is used in place of the actual runway. The size and shape of the runway image are varied with aircraft range and displacement from ILS glidepath so that the inverted T always fits the outline of the runway as seen in perspective from the aircraft.

A quick check on the vertical position of the aircraft relative to the glideslope limits is provided by two parallel bars which may be switched on at the pilot's option and viewed in relation to the runway image. These lines are equally spaced above and below the DV point and, when the runway appears close to the lower line, as shown below, the aircraft is close to the upper glideslope limit.



For landing touchdown an additional terrain clearance image:



is proposed which would move up to the horizon line from below, remaining parallel with it. The spacing between the terrain clearance image and the horizon line would represent the absolute altitude determined from a radar altimeter or a pre-set barometric reference.

For an overshoot after an unsuccessful landing approach the flight path marker is switched from director mode to flight path mode by means of a button on the control column and the aircraft is maneuvered to place it slightly above the heading marker. Since wind drift is allowed for in the positioning of the flight path marker, the aircraft will climb away along the runway center line and the terrain clearance image can be used for monitoring vertical clearance.

For en-route guidance in relation to a VOR range it is proposed to extend the center line of the runway image through to intersect the horizon line at the heading reference and to delete the transverse portion of the runway image (which normally defines aiming point). The heading reference would be set for alignment in azimuth with the selected VOR radial and the extended runway center line would then represent the VOR track. The flight path marker would be set to flight path mode and flown to the left or right of the heading reference to bring the VOR track directly beneath the aircraft. Keeping the flight path marker on the horizon line should maintain level flight, but the terrain clearance image could also be used for monitoring altitude changes from a pre-set barometric flight level.

For dead reckoning navigation en-route the display could be used in a similar manner except that lateral displacements would not be indicated. The heading marker would be set in azimuth for alignment with the track to the next check point and the flight path marker would be held on the intersection of the heading marker and the horizon line.

For monitoring of automatic approaches Sperry envisages the use of the system in director or flight path mode with the addition of a dotted maneuvering boundary surrounding the runway threshold area. The shape and position of this boundary would be computed from the relevant variables to ensure that while the flight path marker remained within it, a successful approach to the threshold could be made without exceeding prescribed conservative maneuvers.

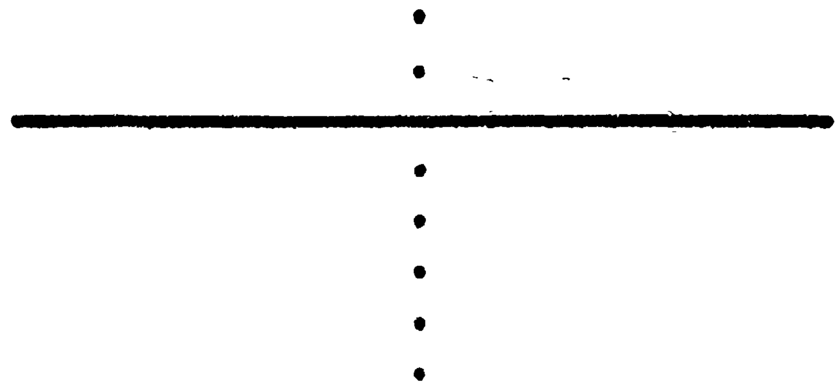
For monitoring of landing, a continuous prediction of touchdown point is proposed, based on instantaneous flight conditions and the dynamics of the aircraft and control system. The predicted touchdown point would be displayed as an image on the runway surface and monitored in relation to a dotted boundary representing the acceptable touchdown zone. The shape and position of the latter would be computed from the touchdown ground speed, ground track error and runway conditions.

2.2 THE A. R. L. DISPLAY

The Aeronautical Research Laboratories (Australia) display for landing approach in IFR conditions, is shown in Figure 3. It is designed to give 1 to 1 compatibility with the outside world and is, therefore, completely gyrostabilized and collimated to appear at infinity. In contrast with the Sperry display, an image of the runway is not included. The position of the runway is shown by dotted lines in Figure 3, but it would not actually be visible until after emerging from cloud. This display was conceived originally in 1956 as an alternative to ground based visual glidepath systems for VFR approaches, but it was soon seen that IFR capability could be provided by the addition of an ILS director image. (Reference 3) Application to visibilities below 1 mile and 200 feet was not envisaged so flare and touchdown guidance was not considered.

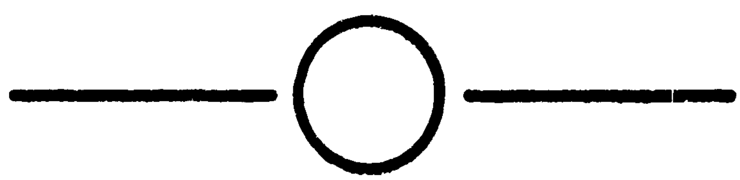
In the present equipment the display is produced partly by reflection of images on a cathode ray tube and partly by reflection of an edgelit plastic reticule. (Reference 4). To provide a wide angle of view the whole display unit, including cathode ray tube and optics, is arranged to move about a virtual center near the pilots eyes and is gyrostabilized relative to the runway and horizon. It is mounted above and forward to the pilots head in a DC-3 aircraft.

The horizon line with its attached scale of vertical angle:



is aligned with the horizontal at all times. The dotted scale of vertical angle which is calibrated in degrees, is set in azimuth by the pilot for alignment with the runway heading; the gyrostabilization then maintains this alignment. Thus, when the aircraft is to the left of the runway center line, the dotted scale delineates a vertical plane parallel to the runway but offset to the left. In perspective view this plane and the runway center line appear to converge at infinity. When the aircraft is lined up with the runway the dotted scale appears over the runway center line and can be used to read off the angle of declination of the aiming point, which is equal to the angle of elevation of the aircraft from the aiming point.

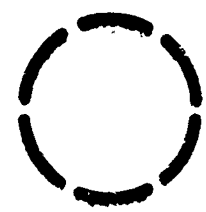
The flight path marker:



represents the projection of the flight path of the aircraft relative to the ground and gives an indication of angle of roll. Its position is computed from the three-dimensional airspeed vector and the wind vector. In contrast with the Sperry display, it retains this one meaning in all phases of flight; there is no mode switching. Thus in Figure 3 it appears centered on the point which was marked FP in Figure 2.

The procedure for VFR approaches is to line up the aircraft with the dotted scale of vertical angle over the runway and approach in level flight until the runway aiming point is at a suitable angle of declination from the aircraft; for a 2-3/4° approach it would be at point DV. The aircraft is then nosed down to place the flight path marker on the runway aiming point and it is held there. During descent the declination of the aiming point is monitored against the dotted scale.

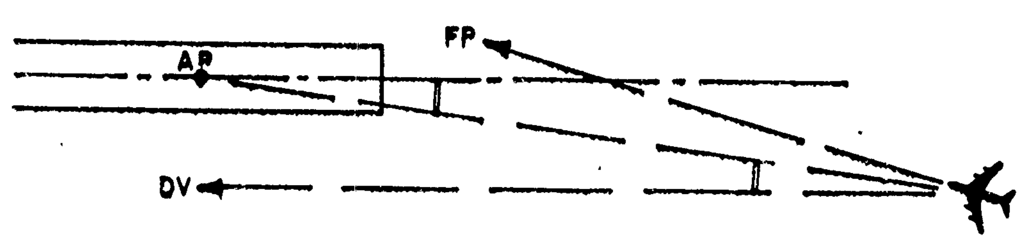
The ILS director image:



is used in conjunction with the flight path image to provide a flight director facility during IFR approaches. In the case illustrated in Figure 3, where the aircraft is above and to the left of the ILS glidepath, the director image is below and to the right of the runway aiming point. When the pilot maneuvers to bring the flight path marker into coincidence with the director image, the aircraft closes with the ILS glidepath. During closure the director image moves back toward the runway aiming point to produce an asymptotic flight path.

In Figure 3 the flight path marker is shown slightly out of coincidence with the director image because the aircraft has not been headed down and to the right at a sufficient angle to follow the desired closure path. A further correction is called for.

For a simple form of director display no computation is required to determine the position of the ILS director image; it is positioned solely by amplified ILS displacement signals. If point DV in Figure 3 is again the ground intersection of a line of sight parallel to the ILS glidepath, then the position of DV in relation to the aiming point AP indicates the position of the aircraft relative to the ILS glidepath. Also the visual angle subtended at the pilots eye by a line from AP to DV equals the angular displacement from glidepath. The following diagram, showing the lateral components of these angles, clarifies this:



To achieve the simplest type of asymptotic closure, the requirement is to place the center of the director image (DR in Figure 3) on the opposite side of AP from DV and make the visual angle from AP to DR proportional to the visual angle from AP to DV. The pilot should then make his flight path vector FP coincide with DR.

This may be expressed:

Visual angle AP, DR = K (Visual angle AP, DV) where K is a constant found from flight tests to give a comfortable closure with the ILS glidepath.

It follows that:

Visual angle DV, DR = (K+1)x (Visual angle AP, DV)
= (K+1)x (Angular displacement from ILS glidepath)

The two ILS displacements signals (lateral and vertical) are, therefore, amplified and used to locate the director image relative to DV. DV itself is easy to locate because it is simply a point on the dotted scale at an angle of declination equal to the glideslope angle; this is set in by the pilot.

The airspeed error indication:

gives an indication of variation from a desired airspeed set by the pilot. The central point on the scale represents the desired airspeed and any increase in airspeed is shown by a movement of the pointer to the right.

For an overshoot after an unsuccessful landing approach the aircraft is maneuvered to raise the flight path marker up the dotted scale of vertical angle to an appropriate angle of climb. Since the dotted scale has been aligned in azimuth with the runway heading and wind drift is built into the motion of the flight path marker, the aircraft will climb away along the runway center line.

For en-route guidance in relation to a VOR range the director image could be arranged to move in relation to the intersection of the horizon line with the dotted scale of vertical angle. An aircraft displacement to the left of the VOR range would result in a movement by the director image to the right, and sinking below a pre-set barometric level would result in an upward movement of the image. It would then only be necessary to set the dotted scale in azimuth for alignment with the selected VOR radial and fly the flight path marker in coincidence with the director image as on landing approach.

For dead reckoning navigation en-route the display could be used in a similar manner except that lateral signals would not be available. The dotted scale would be set in azimuth for alignment with the track to the next check point and altitude corrections would be given by vertical movements of the director image.

2.3 THE BENDIX DISPLAY

The original Bendix integrated display presented at the I.A.T.A. Conference at Lucerne in May 1960, was designed primarily for cathode ray tube presentation on the panel. (Reference 5). It is not suitable for windshield projection because the relative location of symbols is such that they would not be compatible with the outside world. Bendix engineers are, therefore, in the process of developing a new display, more suitable for projection, which will include a "Microvision" runway image and a flight path marker (Reference 6). They are not yet certain what other flight information will finally be added to these basic images, but are building up a simulation facility with a visual attachment, which will enable them to conduct human factors experiments to properly evaluate additional elements of information.

Figure 4 shows a windshield display containing the images considered by Bendix to be worthy of evaluation. The central portion would be generated on a cathode ray tube and the other portions would be reflections of mechanical instruments. All would be collimated to appear at infinity. This presentation will be referred to as the "Bendix proposed display" and, before commenting on any of its features, the authors would emphasize that it is still regarded by its designers as an interim proposal.

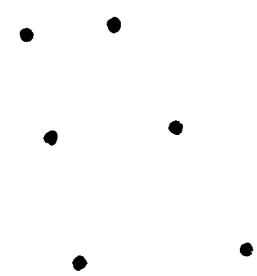
The proposed display is shown in Figure 4 for the landing approach in IFR conditions, with the aircraft orientation illustrated in Figure 1. It is stated that it is designed to fit into a 12 inch square combining reflector mounted near the windshield. It is not clear how this would allow sufficient movement of the central elements to cater for an approach with 10 to 15 degrees of drift; presumably the vertical scale elements at the sides would be moved laterally in such a case. It is understood that Bendix would probably project such a display through a multiplexed mosaic lens system mounted behind the instrument panel.

The attitude image:

which is called the "bore-sight" at Bendix, defines some convenient reference line in the aircraft such as the fuselage axis, and has wings parallel to the aircraft transverse axis. It is a fixed image in the display.

The horizon line is a straight transverse line which is gyro-stabilized to define a horizontal plane. Its position in relation to the attitude image gives an "inside-out" indication of pitch and roll attitude.

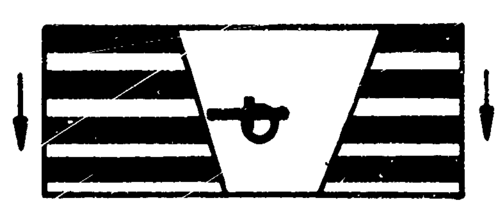
The runway image:



consists of a series of dots produced by "Microvision"; that is a high resolution radar scan of a series of transponders placed at equal intervals along both sides of the runway. If a sufficient number of transponders are used, the image appears very similar to a pattern of runway lights and gives a clear impression of the runway outline in perspective as seen from the aircraft.

The flight path marker is a small circle which appears in the cathode ray tube display in addition to the attitude and runway images and the horizon line. It represents the projection of the aircraft flight path relative to the ground and would be computed from the three-dimensional airspeed vector and wind vector.

The director element of the display:



is a mechanical instrument which provides a combination of status and director information. The fixed cross in the center represents the aircraft and the circle works in conjunction with this as a "fly-to" flight director. In the case illustrated the pilot is being directed to depress the nose and turn further to the right.

The position of the fixed cross in relation to the clear trapezoidal area gives an indication of lateral position relative to ILS glidepath; in this case, the aircraft is to the left of the localizer center line. An indication of vertical position is given by the coding and motion of the striped area outside the trapezoid. When the aircraft is above the ILS glideslope, the stripes move downward (i.e., toward the glideslope) and both the speed of their motion and their thickness vary in proportion to deviation from glideslope. As the aircraft closes with glideslope the stripes slow down, become thinner and eventually blend into a homogenious shaded area.

The width of the clear trapezoidal area is varied according to range. Thus, when the aircraft is on the ILS glidepath, it may also be regarded as an indication of altitude, becoming narrower as the aircraft approaches the runway.

The vertical tape instrument on the extreme left shows the actual lift coefficient opposite the lubber line, and the maximum operating limit is indicated by a pre-set bug on the tape. This is equivalent to the airspeed error indications in the other displays but is a more fundamental quantity from the operational viewpoint. The stall, in any given airframe configuration, occurs at a certain lift coefficient, whereas the airspeed at which this is achieved varies with all-up weight.

The vertical scale instrument on the right of the lift coefficient tape gives a "fly-from" indication of displacement from the ILS glideslope. The moving bar represents the aircraft and the fixed diamond is the glideslope. This instrument appears to duplicate some of the information at the bottom of the display.

The instrument with the vertical scale and two vertical tapes on the extreme right is the U.S.A.F. Phase 3 altimeter (Bendix Type 18002). Reading it from right to left, it shows gross altitude in thousands of feet, vernier altitude within the thousand foot bracket and vertical speed in thousands of feet per minute. The first two are read against the lubber line while the latter is indicated by the moving triangular index. The pointer at the bottom of the vertical speed scale  , which is colored red, gives an indication of absolute altitude above the runway surface by its spacing from the lubber line. It starts to move up towards the lubber line at about 200 feet, and if rate of descent is reduced in such a way that the triangular index remains close to the pointer, an asymptotic flare-out will be achieved.

For an overshoot after an unsuccessful landing approach the aircraft would be maneuvered to place the flight path marker slightly above the horizon and the lift coefficient tape would be monitored to ensure that a safe flight attitude was maintained. At a comfortable altitude the pilot would refer back to his instrument panel to turn on to the required heading.

The proposed display does not seem well suited to en-route navigation because it does not include any indication of heading or track. Possibly the director could be switched to a VOR mode and the trapezoidal area used to show lateral position relative to the beam. However, when turning from one track to another, there would be no guidance of the type given by the Sperry heading reference or the A.R.L. dotted scale.

2.4 THE SPECTOCOM DISPLAY

The Spectocom display has been produced jointly by Specto, Ltd., (England), and Computing Devices of Canada, Ltd. It is based on a projected flight director display developed at the Royal Aircraft Establishment, Farnborough, for low level intruder operations below the enemy radar screen. As a consequence of this background, the images other than the horizon line and the lines below the director are fixed relative to the aircraft rather than being ground stabilized. The display is, however, fully collimated to appear at infinity.

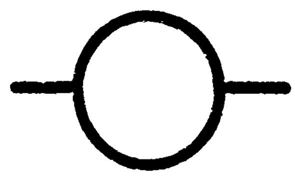
It is believed that the scientists at Farnborough, in modifying their display for landing approach work at the Blind Landing Experimental Unit, Bedford, have introduced a greater measure of ground stabilization. At the time of writing this report, insufficient information is available to fully describe the operation of the display in its modified form. It will therefore, be described in the form offered for sale in North America by Computing Devices of Canada, Ltd. (Reference 7).

The display is shown in Figure 5 for the landing approach in IFR conditions, the orientation being again as illustrated in Figure 1. Like the A.R.L. display, it does not include a runway image, but the outline of the runway has been shown dotted in Figure 5 in the position where it would appear on emerging from cloud.

The equipment offered by Computing Devices of Canada, Ltd. contains an image generator, which produces all the images in green on the face of a cathode ray tube, and has an attached lens and plane reflector. It is claimed to be very flexible in respect to any changes in design of the display and to have capacity for as many as 36 separate images at one time. With the present lens and mirror the angular spread of the display is only $\pm 7^{\circ}$, but presumably the same image generator could be used with other optical systems. Clearly this system was designed to produce a display fixed relative to the aircraft, which does not require a large angular spread because the images are not aligned with the runway during crosswind approaches. A particular virtue of the equipment appears to be its lightness and compactness. The power unit and waveform generator together weigh 13 pounds and the display unit (image generator plus lens and mirror) weigh 22 pounds.

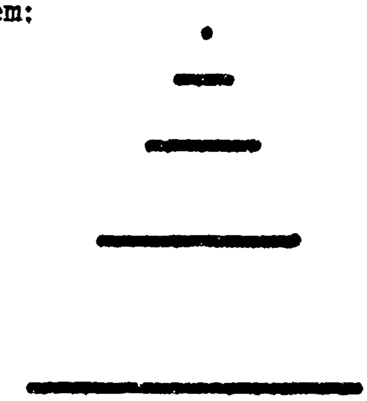
The horizon line, which is a straight transverse line with a break in the center, is gyrostabilized to define a horizontal plane. It and the parallel lines below the director are the only stabilized elements in the display, and it is stabilized only in pitch and roll; its center point always remains in the plane of symmetry of the aircraft (i.e., the xz plane).

The attitude image:



defines a convenient reference line in the aircraft and has wings parallel to the aircraft transverse axis. It is a fixed image in the display and its relationship to the horizon line gives an indication of angle of pitch and roll. The relationship between the attitude image and the aircraft flight path must vary with angle of attack (i.e., with airspeed and weight). However, in the absence of a flight path marker, it is presumed that the attitude image would be related to a reference line which is in close proximity to the flight path at normal approach speeds. For this reason, it has been shown only about 1/2^{o} above the flight path projection FP in Figure 5.

The director image system:



consists of a pyramid of horizontal lines, logarithmically spaced, with a dot at its apex which works in conjunction with the attitude image as a flight director. The illustrations in Reference 7 seem to suggest that the center of the base of the pyramid remains vertically below the center of the horizon line. The pyramid then extends or contracts vertically or leans to either side to place the director dot where it is required to be. In Figure 5 the attitude image and director dot are shown slightly out of coincidence because the aircraft has not been headed down and to the right at a sufficient angle to follow the desired closure path. A further correction is called for.

A scale of airspeed is provided along the top of the display and a scale of altitude runs vertically up the left hand side. A circular segment around the attitude image gives an indication of range from the runway, the scale being such that a quadrant of the circle represents one nautical mile. In the case illustrated in Figure 5, the airspeed is 140 knots, the altitude is 480 feet and the range is 1-1/2 nautical miles.

For phases of flight other than the landing approach, the airspeed, altitude and range symbols are switched off and the display operates in exactly the same way as a conventional panel mounted flight director instrument. Having no heading marker or flight path marker, its only advantages over the conventional instrument are its greater size and lack of parallax effects.

2.5 THE DOUGLAS A.N.I.P. DISPLAY

The Douglas display, developed under the Army-Navy Instrumentation Program, was designed for IFR operation in all phases of flight. It consists of a forward view (vertical) display, shown in Figure 6 for the landing approach condition, and a horizontal navigation display which shows the plan position of the aircraft. (Reference 8)

It is possible to present the forward view display either on a normal cathode ray tube mounted in the instrument panel, or on a thin transparent cathode ray tube replacing the windshield, or on a cathode ray tube behind the pilot's head with an optical system designed to collimate it and project it against the outside world.

The latter possibility justifies the inclusion of the A.N.I.P. display in this review of projected displays although the panel mounted cathode ray tube is presently favored by Douglas for two reasons:

(1) Accommodation of the eyes to close range is necessary for scanning the horizontal navigation display and other cockpit instrumentation. Therefore, it is best to present the forward view display at close range also.

(2) Adjustment of relative contrast between an artificial display and a view of the real world can be facilitated by presenting

the real world as a TV picture on a conventional cathode ray tube and superimposing the artificial display.

Irrespective of how the forward view display is presented, it is generated by a digital computer and arranged to move toward the aircraft from a vanishing point at infinity in exactly the same way as the outside world would do. Furthermore, rotations of the aircraft about its three axes produce motions of the display similar to those which would be seen by looking at the outside world from the aircraft.

The ground plane, as shown in Figure 6, appears as a set of dark circles forming a random pattern on a lighter background. An alternative presentation shown in some brochures is made up of a series of lines forming a rectangular pattern in perspective.

The sky appears above the horizon line of the ground plane as a series of white clouds against a gray background.

Guidance in respect to flight path and roll angle is given to the pilot by a "path in the sky". In Figure 6, which shows the landing approach case, the ILS glidepath appears as a straight path made up of rectangular stepping stones running down to a spot on the ground which represents the runway aiming point. In other cases, where banked turns are called for, the path appears as a twisted ribbon in the sky. In the brochures showing the ground plane as a rectangular grid, it is usually made up of a series of flat disks rather than stepping stones.

Airspeed variations from a desired airspeed set by the pilot are shown by a series of rectangles along the left hand side of the stepping stones. When an increase in speed is called for these rectangles move forward in relation to the steppong stones and when a decrease is called for they move back toward the observer.

The Grumman A.N.I.P. display, which is scheduled for installation in the A2F, differs from the Douglas display in that the "path in the sky" runs from the observer to the destination at all times. In the Douglas display it always runs directly from the point of departure to the destination; if the aircraft is off track it appears to the left or right of the observer.

3. EVALUATION OF THE DISPLAYS

3.1 DISCUSSION OF DESIGN CRITERIA

It is considered that a projected display should be designed to meet the following criteria:

(1) To simplify the pilot's job by integrating all the vital flight information, both status and director, into essentially a single symbolic display.

(2) To present this display on the windshield in collimated form, so that it can be used in parallel with the natural visual information from the outside world.

(3) To include in the display all the flight information normally required during the last five miles of the landing approach, so that the pilot will not have to re-accommodate his eyes to the instrument panel and then back to the outside world at this critical stage.

(4) To use the same symbols, so far as practicable, to present the majority of the flight information required during other phases of flight. An auxiliary navigation display, also collimated but situated beneath the coaming, is envisaged as a later development.

(5) To present the maximum amount of useful information with the minimum number of symbols.

(6) To use symbols which, after a minimum of training, will come to have a clear unambiguous meaning to the pilot. This suggests simple pictorial symbols.

(7) To ensure that any symbols representing features of the outside world are aligned with those features when the ground comes into view. Any incompatibility between the symbols and the real world is likely to cause confusion at the most critical stage of a low minima approach.

These criteria may be summarized as a requirement for:

> "A collimated projected display which provides, through a single information channel, the maximum amount of useful flight information with the minimum number of correlated unambiguous symbols arranged to be compatible with the outside world."

3.2 INFORMATION CONTENT OF THE DISPLAYS

The top portion of Table I at the rear of this report, shows the difference in information content between the five displays discussed previously, during IFR and VFR flight conditions on the landing approach. The figures for VFR include those elements of information from the outside world which may be absorbed while looking through the projected display.

A maximum of two points has been allotted to each element of information and only one point has been allotted when the information is presented in a form which seems to be somewhat less that the optimum. No attempt has been made to weight the elements of information according to their value to the pilot because any such weighting would be essentially subjective. The Table should, therefore, be regarded as a summary of amount of information rather than value of information.

The lower part of Table I shows, for the purpose of comparison, the information content of the view of the outside world through a clear windshield in VFR conditions and of a modern instrument panel including an Integrated Flight System and Distance Measuring Equipment. A figure is also given for the information obtainable by scanning the panel and the outside world under VFR conditi s.

3.3 SIMPLICITY AND COMPATIBILITY OF THE DISPLAYS

On the right hand side of Table I the five displays have been rated for simplicity of display generation, simplicity of pilot interpretation and outside world compatibility. Up to three stars have been given for each of these desirable qualities, according to the following scale:

Three stars	Very good
Two stars	Reasonable
One star	Poor
No stars	Completely lacking in simplicity or compatibility.

Since these ratings are essentially subjective it seems advisable to add some comments about the bases on which they were allotted.

Simplicity of display generation:

The Spectocom display seems to be the simplest of all because it has a relatively small number of symbols and only the horizon line and the parallel lines below the director are stabilized relative to the outside world; the other symbols all move in relation to the fuselage axis. Three stars have, therefore, been allotted.

The Sperry and A.R.L. displays also have a relatively small number of symbols, but all of them are stabilized relative to the outside world, so a two star rating has been given.

The proposed Bendix display has a very large number of images, some of which can be produced relatively easily by projecting standard instruments. The central and lower displays alone seem comparable in complexity with the A.R.L. or the Sperry display, so a one star rating has been given.

The Douglas A.N.I.P. display has a very complex array of symbols which have to be generated by a digital computer and moved in a complex relationship, and all are stabilized relative to the outside world. It seems a tribute to the ingenuity of the electronic engineers that such a display can be built into a package which is practicable for aircraft use. The equipment presently planned for the U.S. Army version weighs 155 pounds, quite apart from the sensors and radar equipment required to supply its basic information; thus, it cannot be rated as technically simple in any sense.

Simplicity of Pilot Interpretation:

The Douglas A.N.I.P. display seems to be the simplest to interpret because it is just a reproduction of the outside scene with the addition of a desired flight path and a simple indication of variations from the desired airspeed. It has been given three stars. The A.R.L. display is also simple to interpret in the sense that each of the symbols has a single physical meaning, but there are two ways of operating them, depending on whether ILS is available. With ILS, the aircraft image is flown on to the director image and held there; without ILS, it is held on the horizon until the runway is at a chosen declination and then lowered on to the aiming point. Also, when the runway is not visible, status information is minimal and there could be a tendency to regard the dotted vertical scale as the runway center line, which it is not. Therefore, only two stars have been given.

The Spectocom display is a pure director system apart from the horizon line, and yet it includes a triangular pattern of parallel lines which look like the approach lights of a runway. Since the apex of the triangle is not anchored to the runway aiming point and is simply a director symbol moving relative to the horizon line, this symbol is considered likely to cause confusion and only two stars have been given.

The Sperry display has been given a low rating of one star purely because of the confusion which is likely to arise from switching the flight path marker between three modes of operation. Any one mode on its own would probably be worthy of three stars; certainly flight path mode would because this is a simple concept for the pilot to grasp. If deviation mode were omitted, which would seem logical with the provision of the glideslope limit bars, a two star rating might seem appropriate to a combination of only flight path and director modes. However, confusion has been experienced even between these two modes (see Appendix B).

The proposed Bendix display, although very high in total information content, would seem difficult to interpret for a number of reasons:

(1) The five vertical indicators include examples of three out of four possible control-display relationships. If the control column were pulled back, the tape would move up relative to the lubber line on the left hand indicator, the tapes would move down relative to the lubber lines on the two right hand indicators (B & C scales) and the moving indices would move up relative to the fixed scales on the two inboard indicators.

(2) The sensing of vertical instruments can often be made more natural by symbolic coding of lubber lines, moving indices and command bugs. For example, a winged symbol can be used for something which represents the position of the aircraft in relation to the instrument background, such as the lubber line of a tape altimeter. In these five indicators there appears, at first glance, to be one such example of symbolic coding. The glideslope indicator includes a winged diamond which resembles an aircraft and a horizontal bar which could logically represent the ILS glideslope; however, the former represents the glideslope and the latter the aircraft.

(3) Information on the position of the aircraft relative to ILS glideslope is given by indications of different types on two separate instruments. Vertical position is given by a "fly-from" indication on the glideslope instrument and lateral position by a "fly-to" indication on the director instrument.

(4) Vertical position relative to glideslope is repeated on the director instrument by a motion-type display which could easily be interpreted as a command rather than as status information. If the aircraft were above glideslope and the pilot had over-corrected by pitching down too sharply, the cross-and-circle director would say "pitch up" and the stripes would be moving down, tending to suggest "pitch down".

The central cathode ray display gives an easily interpreted indication of attitude, direction of flight and orientation relative to the runway, but all the other elements of the display seem difficult, Therefore, only one star can be given to the display in its present early stage of development. It seems likely the human factors experiments planned by Bendix will resolve most of these problems.

Outside World Compatibility:

The Sperry and A.R.L. displays are both fully gyro-stabilized and none of their images are incompatible with corresponding elements of the outside world, so a three star rating has been given to each.

The Douglas A.N.I.P. display is similarly stabilized and all the images are fully compatible, except for the ground plane. Since this is a plane horizontal image, it can only be matched with the real world at one point. For the landing approach it is normally matched at the runway aiming point, but the real ground is likely to be higher in other areas. It is hoped that it will be possible at a later date to present a more complete representation of the ground by adding the output of a forward scanning radar. In the meantime, a two star rating has been given.

In the proposed Bendix display, the three images which have an important relationship with the outside world are gyro-stabilized and properly aligned; they are the horizon line, the runway image and flight path marker. However, the other elements of the display are not stabilized and would oscillate relative to the outside world at the aircraft pitched and yawed. Therefore, only two stars have been allotted.

The Spectocom display has only one element which is gyro-stabilized and intended to remain in alignment with the outside world; that is the horizon line. The parallel lines below the director are stabilized but have no meaning relative to the outside world. The other elements of the display are all related to the fuselage axis and would, therefore, oscillate relative to the outside world as the aircraft pitched and yawed. This arrangement only seems to justify a one star rating for compatibility.

3.4 OVERALL COMPARISON

Table I may be summarized in this form:

Display			Relative Information Content	Simplicity: Display Generation	Simplicity: Pilot Interpretation	Outside World Compatibility
SPERRY	FP DR and DV Modes	IFR VFR	26 27	**	*	***
	FP and DR Modes	IFR VFR	26 27	**	**	***
	FP Mode	IFR VFR	22 23	**	***	***
A.R.L.		IFR VFR	14 24	**	**	***
BENDIX		IFR VFR	30 29	*	*	**
SPECTOCOM		IFR VFR	13 21	***	**	*
DOUGLAS A.N.I.P.		IFR VFR	14 16	—	***	**
MODERN PANEL & OUTSIDE VIEW		VFR	23	***	*	Not Applicable
OUTSIDE VIEW		VFR	12		***	
MODERN PANEL		IFR	18	***	*	

Of the three available versions of the Sperry display, the second one seems to be the best compromise (Flight path and director modes.) The eddition of deviation mode provides a better indication of "aircraft position relative to glidepath," but without deviation mode this information is still available from the ILS glideslope limit bars and the orientation of the runway image. Therefore, for the purpose of comparisons between systems, the Sperry display will be taken as the flight path and director mode combination.

<u>In VFR conditions</u> both the Sperry and A.R.L. displays appear better than the "modern panel plus outside view" in regard to information content and simplicity of interpretation. In addition, both displays are fully compatible with the outside world and should be quite effective for head-up flying. There is, however, a basic difference between the mode of operation of these two systems, which it is important to clarify.

In the A.R.L. display (as shown in Figure 3 and described in 2.2), the aircraft image always represents the flight path. The director image indicates the point toward which the flight path should be directed to effect the desired closure with the ILS glidepath. The basic information used by the system to locate the director image in relation to the aircraft, and hence the flight path, is:

Runway heading (set in). Aircraft heading (from compass). ILS glideslope angle (set in).	To locate, relative to aircraft, a line parallel to ILS glidepath (i.e., line to point DV).
Both components of aircraft displacement from glidepath (From ILS receiver).	To determine where AP lies in relation to DV <u>and</u> where DR should be placed relative to AP.

If follows that the director function will <u>only</u> operate <u>when the runway is equipped with ILS</u>.

In the Sperry display (as shown in Figure 2 and described in 2.1), the aircraft image represents the flight path during some phases of flight, but is switched to become part of a flight director system for the landing approach. In director mode, the placing of the aircraft image on the runway aiming point ensures that the flight path will be correctly directed to effect the desired closure with the ILS glidepath, but the flight path itself is not displayed to the pilot. The basic information used by the system to locate the flight path is:

Runway heading (set in). Aircraft heading (from compass). ILS glideslope angle (set in).	To locate, relative to aircraft, a line parallel to ILS glidepath (i.e., line to point DV).
Both components of aircraft displacement from glidepath (from visual angle between DV and AP, aircraft image being at AP).	To determine where flight path should be placed in relation to AP.

Since the display includes an image which is placed at the aiming point AP, it can derive the information it requires without using an ILS signal. It follows that the director will function on any runway.

It is apparent that the Sperry display has an advantage over the A.R.L. in that it provides a director function on runways without ILS. However, it has the disadvantage that mode switching of the aircraft image is required.

In VFR conditions none of the other three displays show up as well as the Sperry and A.R.L.

The Bendix display is very high in information content but falls down badly in simplicity of interpretation. It might be said to contain a lot of poorly correlated information.

The Spectocom display is lower in information content, satisfactory in simplicity of interpretation, but poor in compatability. If compatability with the outside world is, in fact, as important as the authors believe it to be, this is a serious drawback. However, it is recognized that elimination of the need to gyrostabilize that images would greatly simplify the equipment required to generate the display and result in real savings of cost and weight. Therefore, an experiment should be planned to establish objectively whether a display largely aircraft-referenced and oscillating relative to the outside world is as disconcerting as the authors would expect.

Computing Devices of Canada, Ltd., claim a 3 to 1 improvement in the pilot's ability to maintain track when using the Spectocom display as compared with a standard panel display. Nevertheless, pilot performance could possibly be improved very much more by gyrostabilization, particularly in turbulent conditions.

The Douglas A.N.I.P. forward view display, although the best in respect to pilot interpretation of the information it contains and reasonably compatible with the outside world, contains a very limited amount of information in comparison with the other displays. In fact, it contains little more than the outside world, and it would be very surprising if it enabled a pilot to capture and hold a desired flight path with the same degree of accuracy as a display containing flight path information or flight director (i.e., positive rate information). Since the display is also very complex and costly to generate compared with the others, it cannot be regarded as a competitive type of projected display.

It is recognized that Douglas propose to locate other flight instruments, such as a tape altimeter and airspeed indicator, adjacent to the forward view display and these would increase the information content of the system as a whole, as would the information in the accompanying horizontal navigation display. However, the purpose of this study is to compare projected displays rather than complete cockpit systems. Possibly the basic reason for the poor rating of the A.N.I.P. system in such a study is that only one section of it is capable of projection.

In IFR conditions the relative rating of the Sperry, Bendix, and Douglas A.N.I.P. displays is not changed, but the A.R.L. and Spectocom displays both show a sharp fall in information content. The reason is the same in each case; the display does not include a runway image. Thus, when the real runway cannot be seen, the information on yaw relative to runway, aircraft position relative to glidepath and runway position relative to fuselage is not available. The pilot is left with director information and practically no status information—merely angle of roll and either angle of pitch or vertical flight path angle. This would make either of these displays poor monitors of an automatic approach in IFR conditions.

Clearly, if it should be desired to develop something similar to the A.R.L. display as a means of achieving a director function without mode switching, it would be almost essential to improve the IFR information content by adding a runway image.

4. DEVELOPMENT OF NEW DISPLAYS FOR SIMULATOR AND FLIGHT EVALUATION

The overall comparison of the existing and proposed displays suggests that for the landing approach, which is the most critical phase of flight, none of them is ideal. A series of new displays, based on similar concepts but designed to eliminate the less desirable features of the proposed displays, seems to be required. These new displays should be designed primarily for the landing approach and extended to the landing flare-out, the overshoot, the take-off, climb and en-route phases and the monitoring of automatic approaches. The assumption will be made at this stage that subsequent flight tests will show gyro-stabilization of the images and compatibility with the outside world to be necessary features of any effective projected display.

The improved systems will be developed by considering in turn the arious necessary elements of information, namely:

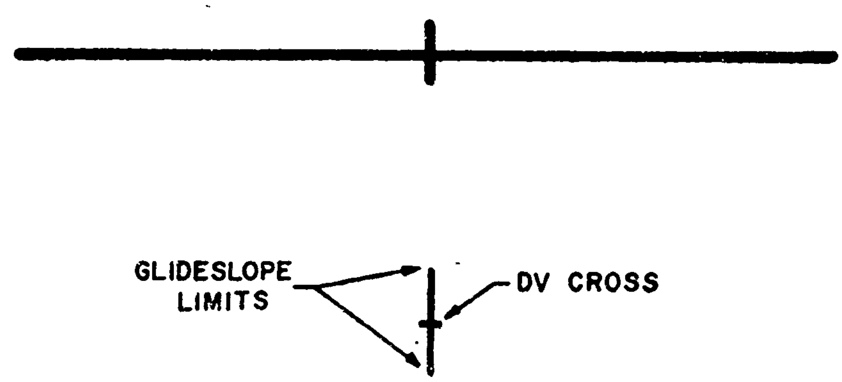
(1) Horizon and vertical angle
(2) Runway
(3) Flight path and airspeed
(4) Director
(5) Altitude

4.1 HORIZON AND VERTICAL ANGLE ELEMENT

The Sperry display includes a stabilized horizon line and a heading marker, which indicates the direction of the desired track. For the landing approach this is set to the runway heading and, when the aircraft is laterally displaced from the runway center line, it indicates a horizontal line parallel to the runway.

The A.R.L. display includes the same horizon line with a dotted scale of vertical angle in lieu of a heading marker. The dotted scale is aligned in azimuth with the desired track and the scale is calibrated in degrees. Thus, for a typical 2-3/4^{o} ILS glidepath, a point 2-3/4^{o} down on the scale indicates a line parallel to the ILS glidepath (referred to as the DV point), and the position of that point relative to the runway aiming point indicates aircraft position relative to ILS glidepath.

It is considered that the concept of defining the direction of the desired flight path vertically as well as laterally is a good one, but the use of a calibrated scale, on which the pilot must establish and visualize the point he is interested in, is not advisable. The alternative recommended is a horizon line and heading marker, which can be set in azimuth for alignment with the desired track, and a small cross which can be moved vertically from the heading marker and set to the desired angle of climb or descent:



For landing approach the cross would be set to the ILS glideslope angle and its center would represent the DV point. If the heights of the vertical arms of the cross were made to correspond with the glideslope limit angles (i.e., the angles corresponding to five dots deflection on the ILS indicator), the cross would serve a dual function. Its position relative to the runway would show the position of the aircraft relative to the ILS glideslope and its extent would show whether the aircraft was within the vertical glideslope limits. For convenience this symbol will be referred to as the "DV cross."

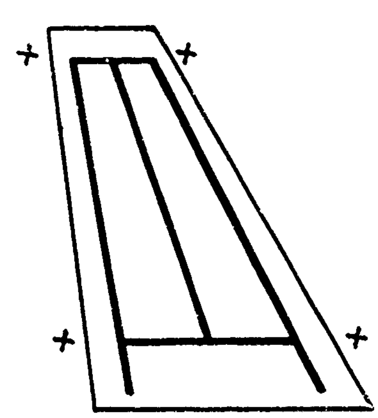
4.2 RUNWAY ELEMENT

It has been shown already (in section 3.4) that the A.R.L. and Spectocom displays suffer a severe loss of status information in IFR conditions because of the omission of a runway image. This status information would be of particular value if the display were used for monitoring of automatic approaches. It is therefore considered essential to include a runway image.

The runway image in the Sperry display is a simple inverted T, in which the vertical bar represents the runway center line and the cross bar represents a transverse line at the ILS aiming point. The size and shape of the image are varied with range and displacement from ILS so that it always appears in the correct perspective.

Flying experience on the Sperry display showed that, when the aircraft was displaced laterally from the ILS glidepath, it was difficult to gain an impression of how far it was displaced. In particular, at close range, it was difficult to judge whether the aircraft was within the corridor defined by the edges of the runway.

It is therefore recommended that the runway edges be included in the projected image as well as the center line. It is not proposed that the image should be adjusted in size to take account of individual variations in runway length or width or in distance from threshold to ILS aiming point. On the contrary, it would probably be advantageous for the image to represent in proper perspective a standard section of runway, say 8000 feet long and 150 feet wide, commencing at the ILS aiming point. The pilo would tend to become accustomed to the appearance of this standard section at various ranges and displacements from glidepath and would derive more information from it than from an image adjustable to fit runways of various sizes. In case the pilot should forget that there was some runway between him and the aiming point and become anxious at close range on a low minima approach, the edges of the runway image could be continued beyond the aiming point cross bar. In relation to a 10,000 foot runway 200 feet in width, the runway image would appear like this:



"Microvision" is proposed by Bendix as a means of outlining the runway in a projected display (Reference ( ). The authors agree that it could be used for this purpose, but consider that more value could be extracted from it if it were used as a means of aligning a runway image generated on a cathode ray tube with the real runway.

In the absence of some device such as "Microvision," the projected runway image would have to be located in relation to the fuselage axis by computations based on the following data:

Runway heading (set in)
Aircraft heading (from compass)
Lateral displacement from glidepath (from ILS)

Pitch angle of fuselage (from artificial horizon)
ILS glideslope angle (set in)
Vertical displacement from glidepath (from ILS)

With normal aircraft sensors the computation of runway position relative to fuselage axis could often be in error by as much as 2° laterally and somewhat less vertically.* The angular width of the runway image at various ranges would be of this order:

Range (Nautical Miles)	Angular Width (Degrees)
10	0.1
5	0.3
2	0.7
1	1.4

Hence, the runway image would often appear badly out of alignment with the real runway as the aircraft emerged from cloud.

If, on the other hand, the runway were represented solely by Microvision images and no element of the projected display were aligned with it, the relationship between the runway and the other images could be misleading. For example, the cross at the DV point, which indicates aircraft position relative ILS glidepath, could appear on the wrong side of the runway. Furthermore, the runway aiming point could not be adequately defined because a transponder could not be placed in the center of the runway.

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* In the Sperry demonstration at MacArthur Field, the final adjustment of the runway image was made by aligning it visually with the real runway. This is only possible in a VFR demonstration.

If Microvision were used to align the projected runway image, a minimum of four transponders would be required and these would be arranged as shown by the crosses in the runway illustration above. The ILS aiming point at each end of the runway would be marked by a transponder on each side of the runway opposite it and the runway image would be adjusted so that its aiming point cross bar was centered between the two nearest Microvision images.

The following advantages would accrue from using Microvision in this manner:

(1) The runway image could be located more precisely than it could with any practicable set of aircraft sensors.

(2) Any errors made by the pilot in setting up the runway heading and the glideslope angle would be shown up by an unusually large disparity between the runway and Microvision images.

(3) The knowledge that the Microvision images were positioned directly by a radar scan of the ground rather than by a computer would give the pilot increased confidence in his display.

(4) The finding, in most cases, that there was a close agreement between two independent sources of information (the compass plus ILS information locating the projected runway image, and the information from the radar scan) would also increase pilot confidence.

4.3 FLIGHT PATH AND AIRSPEED ELEMENT

It is considered that, apart from the basic concept of displaying collimated and gyrostabilized flight information in the windshield, the most significant advance made by the Sperry Gyroscope Company and A.R.L. was the concept of using an image representing the projected flight path of the aircraft. For the first time the pilot was given real information on his direction of flight in relation to the ILS glidepath and the ground, rather than merely information on his present position. For the rapid correction of any error in the form of a displacement from ILS glidepath, this direction (or rate) information should have great value.

Thirty years ago, when the aircraft fuselage usually projected well ahead of the cockpit, the pilot had a good impression of fuselage orientation and, having some knowledge of wind conditions and an impression of his angle of attack at approach airspeed, he was able to make a reasonable estimate of direction of flight relative to the ground. As aircraft approach speeds and inertia increased, the need for a good indication of direction of flight also increased. Yet the trend was to remove the information from which the pilot could estimate this, by placing him in a glazed enclosure in the nose of the fuselage where he had almost no impression of fuselage orientation.

The engineering solution to this problem was to provide a complex array of radio beams, fan markers and panel instrumentation from which status information could be derived by scanning of numerous dials. However direction information could only be extracted by observing the change in status information with time and mentally comparing it with an expected pattern of change. When the altitude was reached where the instruments had to be abandoned in favor of the outside view (or at airfields without full ILS facilities), the pilot was presented with a conglomeration of natural visual cues giving good status information in azimuth, very little in elevation and virtually no impression of direction of flight. The result was a spate of undershoot accidents, usually in good visibility conditions but at airfields having less than the average aggregate of natural visual cues. (Reference 3)

These undershoot accidents increased in frequency with the upward trend in aircraft approach speeds and inertia, and the problem became critical with the introduction of jet transports. The first answer to the problem was the development of a number of groundbased visual glidepath systems designed to give improved status information in elevation. Three such systems developed in England and Australia have been fully evaluated in the United States and the British system is presently being installed at a number of airfields. (References 9 and 10).

These three ground-based systems give an indication of flight path direction in the vertical plane if they are watched for a period of time to note any change in signal. However, even the most sensitive of them cannot give an immediate and clear indication of direction of flight; that is to say quantitative rate of departure from or approach to the ILS glidepath.

The inclusion in the projected display of a flight path element, fully corrected for wind and representing instantaneous path relative to the ground, therefore constitutes a significant advance over the most recent combinations of panel instrumentation and ground-based aids. It is of interest to note that the Sperry Gyroscope Company and A.R.L. have agreed that their recognition of the value of this element of information as part of a projected display occurred independently at approximately the same time about six years ago (References 1 and 3, published June and May 1956). It has now been incorporated in the proposed Bendix Microvision display (Reference 6), and its possible advantages have recently been reiterated by Calvert at the Royal Aircraft Establishment in England. It therefore has widespread support.

Having established the case for a flight path element, it is necessary to decide on its symbolic form. It should have wings parallel to the transverse axis of the aircraft so that the relationship between the wings and horizon bar will give the pilot a clear impression of roll angle. This is another piece of information which has become degraded by the use of glazed cockpits in the nose of the aircraft with side-by-side seating and curved coamings.

The opportunity to re-establish a clear indication of roll angle should not be missed.

Airspeed:

In the Sperry display the airspeed error indication is placed on the left wing tip of the flight path marker. The concept of making it part of the flight path marker rather than part of the background seems a good one, since frequent reference must be made to it while controlling the flight path. However, flight experience on the Sperry display showed that, even with the wing tip location, there was a need for a certain amount of scanning which would be better avoided if a more central location could be arranged.

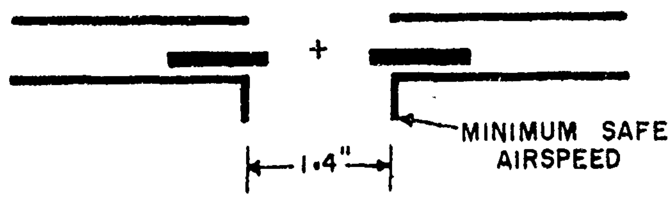
One possibility which has some appeal is to place a short horizontal bar in the center of the display which would be regarded an analogous to the tailplane of the small aircraft. When the airspeed rose above the desired value, the short bar would rise above the wing just as the tailplane of an aircraft rises with an increase in speed. Similarly, a fall in airspeed would be shown by a lowering of the tailplane bar.

With a monoplane type of flight path marker there would be a tendency to lose the tailplane bar when it became aligned with the wing bar in the "on airspeed" condition. The use of a biplane type of flight path marker therefore has some merit. The tailplane bar would lie midway between the wing bars in the "on airspeed" condition, and the distance between the wing bars would represent the range within which the pilot would endeavor to maintain his airspeed. The biplane type would also be convenient for centering on the horizon line when zero vertical speed was required on the cruise. The flight path marker would appear like this:

The gap in the center has been provided because of problems which could arise when a number of images are superimposed in the final stages of the appraoch. For the same reason, a fuselage image has not been included. If the gap were arranged to subtend 1.4° at the eye, it would give a rough indication of range from the runway because the aiming point bar of the runway image would span the gap at a range of one nautical mile. An overall image breadth of about 5° is envisaged.

The tailplane bar should be made with a smaller gap than the wing bars to reduce the possibility of losing it. Also to assist in distinguishing it at a glance, it could be made thicker. For reasons discussed later, the use of an engraved metal reticule rather than a cathode ray tube image to generate the flight path marker seems likely. In this case, the tailplane bar would probably be produced by an edge-lit glass or plastic overlay and distinctions in thickness would be quite easy to arrange.

Some thought has been given as to whether a definite indication of the minimum safe airspeed should be provided. At first sight it might appear that this is essential. On the other hand, audible stall warning devices are normally built in for the same purpose. Furthermore, the provision of an additional mark outside the recommended airspeed range represented by the two wings might weaken the pilot's endeavors to keep his airspeed within that range. The latter hypothesis should probably be checked by experiment and, if the provision of a minimum safe airspeed indication is decided upon, it should be kept away from the center of the display. The arrangement shown below would be one possibility which would have the additional advantage of reinforcing the 1.4° angular subtend.



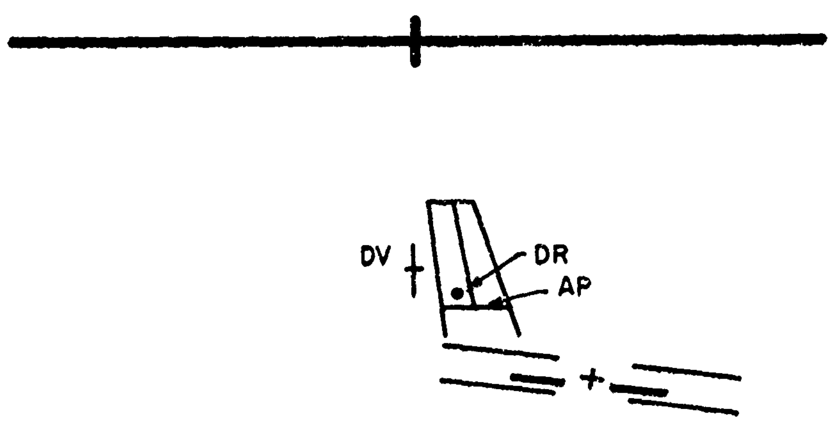
4.4 DIRECTOR ELEMENT

It seems almost certain that the full potential of a projected display will only be developed if it includes a director element which enables the man to act in his most effective capacity. This is as simple amplifier, responding in terms of direction and magnitude to a single signal, although dealing with a problem containing higher order terms. However, it must be agreed that a display containing only the elements so far discussed (horizon line with DV cross, runway image and flight path marker with airspeed signal) would give the pilot much more useful information than he is able to derive from the outside world alone, and would present it in a simple and convenient form. Therefore, this basic configuration should be subjected, among others, to simulator evaluation. For the purposes of this report it will be referred to as the Type A configuration. It is shown in full in Figure 11.

The Sperry director concept, based on extracting information directly from the runway or its image and working independently of ILS in VFR conditions, is ingenious and universal in its application. It could even be used to fly a director approach on to a highway if this should ever be desired. However, the use of mode switching to temporarily convert the flight path marker from a pure indication of flight path to an element in a director system seems unfortunate.

Mode switching conflicts with the desire to use symbols which have a clear unambiguous meaning to the pilot, and the incident described in Appendix B illustrates the type of problem which can arise. Furthermore, the deletion of the flight path indication during director approaches seems to represent a partial reversion to the old philosophy of expecting the pilot to fly a pure director with little other background information. This was the philosophy behind the Zero Reader, which failed to gain universal acceptance until other information was added to make a complete Integrated Flight System. It also appears to be the philosophy behind the Parafoveal Visual Director (i.e., Smith's PVD), as a back-up to triplex auto-landing.

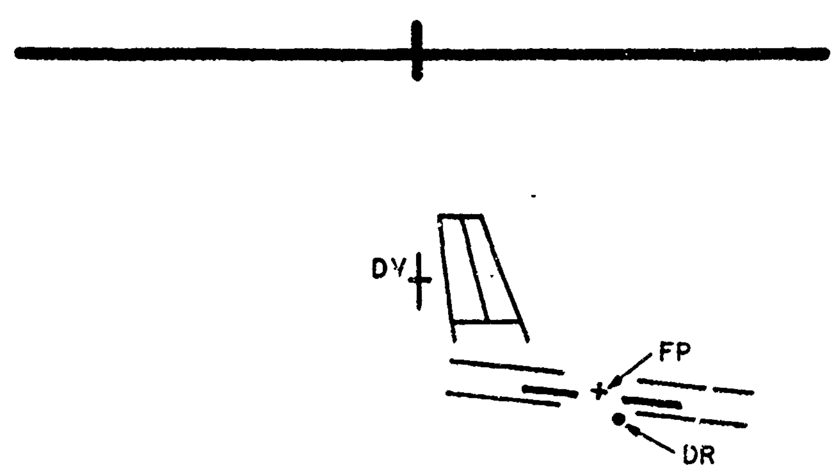
It is the belief of the authors that a flight director is highly desirable element of any display and should be regarded as the primary aid to flight control. However, if it is at all possible without making the display too complex, switching to director should not involve the loss of any other useful information—either status or rate. Being based on the output of a computer which mixes several pieces of information, the director is more likely to fail than any single element of the display. If it should fail, it is important for its failure to be made obvious by incompatibilities with the other elements and for as many other elements as possible to be immediately available to the pilot. It would therefore seem desirable that an evaluation be made of a display including the horizon line with DV cross, the runway image, the pure flight path marker with airspeed signal and a director dot working in conjunction with the runway aiming point.



This might be regarded as a Sperry display without mode switching, all the modes being switched on at once and differentiated by distinctive symbols. It will be referred to as the Type B configuration.

One criticism of this arrangement which has been voiced within the FAA is that the pilots eyes would have to scan back and forth between the runway image with its director dot and the flight path marker with its airspeed signal. This objection is really only valid for a short period while the aircraft is capturing the ILS glidepath in the region of the outer marker. After that, if the motion of the director dot is properly matched with the aircraft flight characteristics, the flight path marker should never deviate so far from the runway image that scanning is required.

An alternative arrangement is to make the director dot work in conjunction with the flight path marker. The pilot would fly the flight path marker to capture the director dot and hold there, monitoring airspeed continuously. It would only be necessary to ensure, by occasional glances at the runway image, that the flight path marker was closing on to the runway. The aircraft position relative to ILS glidepath could also be monitored by occasional glances at the DV cross.



This is similar in principle to the A.R.L. display,but with the addition of a runway image and relocation of the airspeed error indication. As in the A.R.L. display, the director would only work if ILS were available. Such a display should also be evaluated in a simulator. It will be referred to as the Type C configuration.

Quickening:

If two configurations containing a director image are to be experimentally evaluated, it is necessary to decide what degree of quickening should be built into the director.

The simplest director is the type which is positioned by only one variable and therefore does not require a computer.

In the Type B configuration (or the Sperry display), the simplest director would be one in which the visual angle from the DV cross to the director DR was a specified fraction of the visual angle from the DV cross to the flight path marker FP, and the pilot would place DR on AP. In the Type C configuration (or A.R.L. display), the visual angle from the DV cross to the director would be the angle off ILS glidepath amplified by a specified ratio, and the pilot would place FP on DR. In either case, the pilot would obtain a signal enabling him to point his flight path vector in a desired direction, but no indication of the optimum control movements to do this. It might be called a first stage director or flight path director.

To place DR on AP or FP on DR by both lateral and vertical rotations of the aircraft axis requires a more complex control judgment in the lateral plane than in the vertical. To achieve the required lateral traverse, a roll angle must be applied to obtain a rate of change of heading judged to be appropriate, this must be held for a certain time and then a smooth roll-out must be judged as the desired heading is approached. The vertical displacement, on the other hand, is simply achieved by combining a pitch angle change with the lateral traverse.

The next degree of quickening is one designed to guide the pilot's judgment of what roll angle he should apply initially and at what rate he should remove it as the new heading is approached. A lateral displacement dependent on roll angle is added to the motion of the director symbol. Then the aircraft is simply rolled and pitched to achieve the appropriate matching of symbols (i.e., DR with AP in configuration B or FP with DR in configuration C), and this matching is maintained by continual adjustment of roll and pitch angles. The roll angle input to the motion of the director symbol would be in the direction of roll in configuration B, but in the opposite direction in configuration C; in each case the application of the appropriate roll would tend to null the mismatching of symbols. This arrangement might be called a second stage director or roll and pitch angle director. It is type used in the Sperry Zero Reader and most of the Integrated Flight Systems.

A further degree of quickening would be one designed to guide the pilot's judgment of what control forces or control movements should be applied to smoothly achieve the required angles of roll and pitch. For modern jet aircraft with their small control movements, control forces would seem more appropriate than control movements and, for ease of sensing, angular velocities in pitch and roll might be more convenient than either. All these quantities are, of course, closely related. Longitudinal and lateral control force inputs or pitch and roll velocity inputs would be added to the motion of the director symbol in such a way that the appropriate symbols would be matched when suitable control forces or angular velocities were applied. The result might be called a third stage director or control force director.

It is recommended that the comparison between the Type A, B and C configurations be made in a simulator with a second stage (or roll and pitch angle) director in configurations B and C. Then further tests should be made on the chosen configuration to measure the effects of changing to a first stage and a third stage director. This program would involve a simulator comparison between five types of display, assuming that one of the configurations with a director was chosen (i.e., or B or C). Two or three of these displays would be further tested in flight in a heavy transport aircraft and the best of them should have a final validation check in a variety of weather conditions in a jet transport.

4.5 ALTITUDE ELEMENT

If any of the displays discussed above is to be capable of giving flare-out guidance as well as landing approach guidance, it is necessary to provide some indication of altitude above the runway surface. If this is to be done it seems logical to make the same symbolism capable of being used as an altitude reference in other phases of flight.

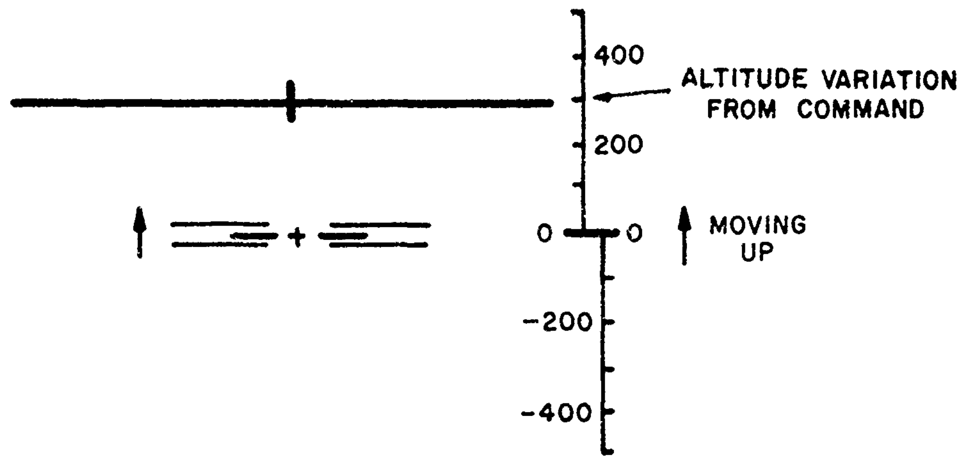
Two of the displays have a terrain image which appears at the base of the display at a low altitude and moves up toward the other images as the aircraft approaches the ground. This presentation is not favored because there is already a problem with superposition of images in the runway threshold area during the final stages of the approach. The location of altitude data on one side of the display seems preferable.

An altitude presentation of the "moving scale and fixed lubber line" type has the advantage that it can be used in conjunction with a vertical speed index to achieve a smooth asymptotic blending on to a command altitude; the flare-out is a particular case of this. Assuming that suitable scale ratios have been chosen and that the zero point of the vertical speed scale has been placed opposite to the altitude lubber line, the tracking of the command altitude on the moving scale with the vertical speed index will cause the aircraft to blend on to that altitude.

In this case, the flight path marker is effectively an index of vertical speed with the horizon line as its zero point. Hence, the horizon line has to be the lubber line for the moving scale of altitude. This is quite a logical relationship because, in spite of the name that has been attached to it, the horizon line defines a horizontal plane at aircraft altitude; it does not lie on the horizon at sea level.

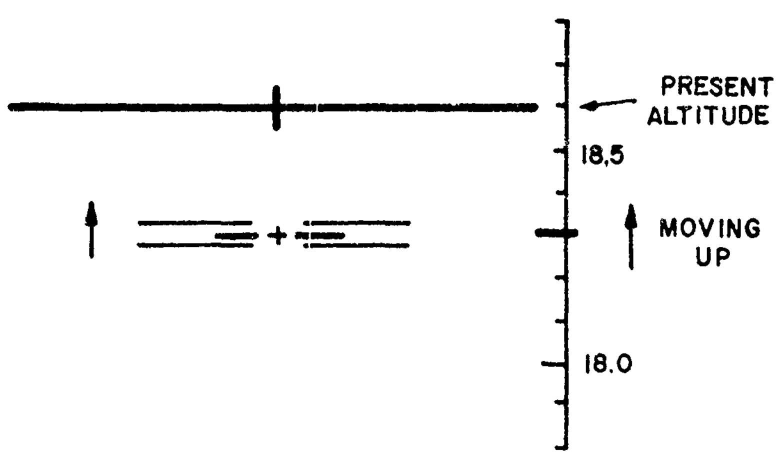
The moving scale could be either a scale of altitude variation from a pre-set command, on which the zero point always represents the command altitude, or it could be a scale of absolute altitude measured from sea level (QNH), aerodrome surface (QFE) or standard pressure level (1013 millibars).

The altitude variation type of scale would be easiest to generate because it would be a short scale with zero in the center and a range of perhaps ± 1000 feet, or something of that order. For landing approach the system could be switched to a radar altimeter mode with the zero representing the ground level beneath the aircraft; alternatively it could be switched to a barometric mode with the zero representing a present command altitude or pressure level. In either case, the pilot would track the zero of the moving scale with his flight path marker during the blending on (or flare-out) maneuver as shown below:



BLENDING ON TO COMMAND ALTITUDE
BEING NOW 300 FEET ABOVE IT

The absolute altitude type of scale would be more difficult to produce because it would involve having the capacity to generate a very long numbered scale (perhaps from 0 to 50,000 feet), and display only a small portion of it at any one time. On the other hand it would be easier for the pilot to use because he would not have to refer back to the pre-set command when checking his altitude. It would be necessary to provide a bug on the moving scale to indicate command altitude and the pilot would track the bug with his flight path marker during the blending on maneuver as shown below:



BLENDING ON TO 18 300 FEET
BEING NOW AT 18,600 FEET

For the landing flare-out the system would be switched to a radar altitude reference and the bug would be placed at zero on the moving scale. To allow more altitude for blending on in the low density air at the higher altitudes, a gradual closing of the scale would be desirable as altitude increased. Possibly a scale which was linear in respect to atmospheric pressure but calibrated in altitude would be appropriate.

The absolute altitude scale is preferred to the altitude variation scale if technically feasible. If neither seems feasible, a third alternative would be a tape altimeter mounted immediately beneath the coaming and viewed through a collimating lens. An index moving in relation to the altimeter lubber line in accordance with the angle between the flight path marker and the horizon line would have to be mounted beside the tape altimeter.

Further refinement applicable only to Type C configuration:

The location of the altitude scale on one side of the display in order to avoid clutter in the threshold region during the final stages of the approach has one apparent disadvantage. It requires the pilot to transfer his attention from the center of the flight path marker to a point on one side of it during a flare-out. While doing this he would be diverted from monitoring the lateral position of the flight path marker in relation to the runway center line. Only simulator or flight tests will show how much lateral deviation is likely to occur during the few seconds of flare-out.

However, a simple means of avoiding the problem is available in the particular case of the Type C configuration. The pilot flying this configuration is trained to track the director dot with his flight path marker. If it were so arranged that, during the flare-out, the director dot moved up the runway center line remaining at the same horizontal level as the zero point of the moving altimeter scale, a smooth flare with no lateral deviation should be achieved. The director dot could be arranged to stop just below the horizon at a point giving a satisfactory rate of sink for touchdown.

This refinement could not be applied to Type A because it has no director dot and would not be compatible with Type B because of the different mode of operation of its director dot. Possibly, in the latter case, a different symbol such as a small triangle could be activated at the start of flare-out and the pilot could be trained to track this up the runway center line. However, this would add to the problem of clutter in the threshold region, as would a horizontal line.

4.6 COLOR CODING

It is considered that the number of elements in the proposed displays is such that the use of color to assist in discriminating between them would be highly desirable. This argument applies particularly to the final stages of the landing approach when a number of elements become superimposed.

The arrangement of colors in the Sperry display is strongly favored; that is an orange flight path marker and airspeed indication against a background of green real world images. Its adoption almost certainly leads to some form of reticule as a means of generating the flight path marker, combined with a cathode ray tube presentation of the real world images. This combination has the following points in its favor:

(1) The flight path marker is the element being controlled by the pilot in relation to the outside world. It therefore seems logical to make it a bright sharply defined image (as produced by a graticule) and to make the other images less bright and less sharp.

(2) The color green seems a natural one to represent objects on the ground.

(3) The three degrees of freedom required by the real world images and the changes in perspective of the runway image make it almost essential to generate these on a cathode ray tube.

(4) The flight path marker has no roll motion relative to the aircraft axis. It has moderate motion in pitch and a small amount of motion in the yaw plane. A graticule and mirrors should be quite compatible with these motions.

The director dot in the Type B and C configurations should logically be the same color as the image it works in conjunction with. This would make it a green dot generated on the cathode ray tube in Type B and an orange dot generated by a reticule in Type C. Since the Type C dot moves in relation to the DV cross on the cathode ray tube it may not be a practical engineering proposition to make it orange.

The moving scale of altitude, being in the nature of background information and working in conjunction with the horizon line, should be green. T o establish the practicability of generating and positioning such a scale on a cathode ray tube, some engineering research will be required.

The Type A configuration is shown in the recommended colors in Figure 11 for the flight condition shown in Figure 1. The Type B configuration is similar except for the addition of a green director dot at point B, which works in conjunction with the aiming point AP. The Type C is again similar, but its director dot is at point C instead of B and works in conjunction with the center of the flight path marker; if practicable this dot will be orange.

4.7 OPERATION IN OTHER PHASES OF FLIGHT

Although the Type A, B and C configurations have been developed mainly for the landing approach they can be widely applied to other phases of flight.

For the overshoot after an unsuccessful landing approach, the flight path marker would be raised to a point slightly above the heading marker on the horizon line and the aircraft would accelerate along the extended runway center line with a slow rate of climb. If it were then desired to climb out on a certain track, the heading marker would be set in azimuth to correspond with that track, and the DV cross, which moves vertically from the heading marker, would be set to a suitable angle of climb. The flight path marker would then be flown to the DV cross. If the requirement were to reach a certain altitude within a specified DME distance, the angle of climb could be computed mentally from the fact that, for practical purposes, one degree is equivalent to 100 feet per nautical mile. If, on the other hand, the requirement were to climb at a specified airspeed, the airspeed error indicator could be appropriately set and used for guidance.

It will be noted that for the climb and en-route flying, the term "heading marker" (which was derived from its alignment with the runway heading during the landing approach) is really a misnomer. It is more correctly a "track marker" since the flight path marker, which is flown to it, is corrected for wind and represents the ground speed vector.

The dead reckoning navigation on cruise, the heading marker would again be set to the required track and the DV cross set in coincidence with the heading marker. The altitude scale on the right hand side would be monitored and, if a change in altitude were called for, the command bug would be set to the new altitude and used to guide the vertical motion of the flight path marker as described in section 4.5.

For VOR navigation on cruise a suitably computed flight director signal could be used to displace the director dot either relative to the DV cross (for Type B) or relative to the flight path marker in the opposite sense (for Type C). For ease of operation by the pilot, the degree of quickening used in this director signal should be consistent with that chosen for the landing approach.

For monitoring of automatic approaches the Sperry concept of generating a maneuvering boundary surrounding the threshold, within which the flight path marker must remain throughout the approach, seems quite reasonable.

4.8 OVERALL EVALUATION

The Type A, B and C displays have been analyzed for information content, under both IFR and VFR conditions, in Table II. The basis of scoring is exactly the same as that applied to the other displays in Table I, so the totals are comparable.

In regard to simplicity of display generation the Type A, B and C displays without the altitude scale at the side would be comparable in complexity with the Sperry and A.R.L. displays, which were given a two star rating. An altitude scale of the type envisaged, which works in relation to the gyro-stabilized horizon line could be quite difficult to generate, so only one star will be allotted to the displays with this feature included.

All three displays are considered worthy of three stars for ease of interpretation because the images are few in number, all have been designed to symbolize the objects they represent, none have more than one meaning and they are used in exactly the same manner under both IFR and VFR conditions. These are considered most important criteria from the pilot's viewpoint.

Since all three displays are fully gyro-stabilized and none of the images are incompatible with the corresponding elements of the outside world, three stars have also been allotted for outside world compatibility.

Thus, the overall evaluation of the Type A, B and C displays may be summarized in this form:

Display		Relative Information Content	Simplicity		Outside World Compatibility
			Display Generation	Pilot Interpretation	
WITH ALTITUDE					
Type A	IFR VFR	25 26	*	***	***
Type B	IFR VFR	29 30	*	***	***
Type C	IFR VFR	29 28	*	***	***
WITHOUT ALTITUDE					
Type A	IFR VFR	23 24	**	***	***
Type B	IFR VFR	27 28	**	***	***
Type C	IFR VFR	27 26	**	***	***

This summary is comparable with the one at the beginning of Section 3.4, which deals with the other displays.

Taking "information content plus simplicity of interpretation and compatability" as a suitable pilot criterion and considering firstly the displays without directors, Type A without altitude has a slight edge on the Sperry FP mode, and Type A with altitude leads by a greater margin. Taking the same criterion and considering comparable displays with directors, Type B is considered to have a greater advantage over the Sperry FP and DR modes because of the advantages which accrue from the elimination of mode switching.

These results look very encouraging in view of the demonstrated capability of the present Sperry equipment.

4.9 POSSIBLE SUPPLEMENTARY DEVELOPMENTS

Presentation of Pre-set Information:

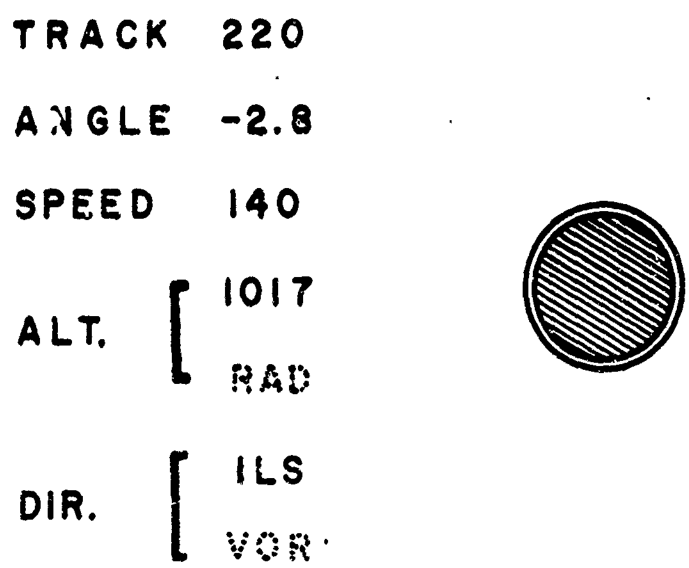
To use any projected display of flight information, it is necessary to pre-set certain variables in order to align the images with the outside world. In the particular case of the Type A, B and C displays, these variables are:

(1) Desired Track(Runway heading for the approach)
(2) Desired Angle of Climb or Descent (Glideslope angle for the approach)
(3) Desired Airspeed
(4) Barometric reference for the Altimeter Scale.

A control panel will be required with setting knobs for these quantities, which will presumably be displayed as back-lighted numerals in line with the normal practice for displaying radio frequencies. Switches for operations such as Display "off-on," Runway "off-on," Director "off-ILS-VOR" and Altimeter "barometric-radar" will also be required on the same panel.

One additional feature which would greatly assist the pilot would be a small reflector in the lower left hand corner of the windshield to display the basic settings in collimated form.

A display such as the following is envisaged:



When the altimeter was switched from barometric reference to radar, the millibar setting would be extinguished and the letters RAD would show in their place. The circle to the right of the numerals represents a large warning light, which would light if a failure flag should appear on any of the basic instruments feeding information to the projected system.

It is recommended that consideration be given to the development of such an auxiliary projection system in parallel with the main systems.

Navigation Display:

If the projected display of flight information can be developed to the point where it provides the pilot with all the information he needs during the landing approach and a useful portion of what he needs en-route, a valuable supplementary development would be a display of navigation information situated beneath the coaming. This would initially be a map display similar to the A.N.I.P. horizontal display, but could be collimated to appear at infinity in order to reduce the accomodation problems.

At a later stage, it could possibly be developed to provide information on the position of other aircraft and enable the pilot to participate with ground based Air Traffic Control in helping to solve the collision problem.

Take-off Monitoring:

During the short critical period of the take-off run, it is almost essential for the pilot to be looking forward along the runway. Therefore, the projected windscreen display appears to provide the obvious area in which to present a display of take-off monitoring information. The detailed form of such a display will depend on a later decision as to which variables provide the best warning to the pilot of a sub-standard take-off situation.

During the take-off run the flight path image should also be very helpful in assisting the pilot to detect and correct any lateral swing at an early stage in its development.

Before the start of take-off, the DV cross could be set to the desired flight path angle for climb-out and the airspeed error indication could be set to the rotation speed. Then, if the aircraft maintained required take-off performance throughout the ground run, the lift-off procedure would be to raise the flight path marker to the DV cross as soon as the airspeed error reached its null position.

Control Stick Steering:

If the pilot's function during landing approach can be successfully reduced to the tracking of one director element with another and both are projected on the windshield and integrated with a complete display of status and rate information, the next stage in easing his task would be to give him a more direct control of aircraft flight direction than is provided by a conventional control column. As discussed in Section 4.4, under the heading "Quickening," the latter merely provides a control of rate of pitch and rate of roll. Thus, a complex series of control motions are required to traverse the flight path marker in azimuth and elevation from one point to another and stabilize it in its new position. The next stage could provide a means of control through the auto-pilot to give:

(1) A direct control of vertical and horizontal angular velocity.

or (2) A direct control of vertical and horizontal angle of rotation of the flight path relative to the ILS glidepath.

A control designed for either of these functions should be quite different in form from the conventional vertical control column or joystick for two reasons:

(1) So that its mode of operation will not be instinctively assumed to be the same as that of the conventional control. Such an assumption could be dangerous as the pilot transferred from one control to another.

(2) Because tests on controllable gunsights have shown that moving an aiming point in a vertical plane by means of a vertical joystick, which requires the hand to move horizontally, is a confusing task for trained pilots. Vertical and lateral motions of the aiming point are easy, but a 90° error often occurs when the pilot attempts to move it diagonally.

Possibly a horizontal joystick or a ball control would be the best answer.

Control stick steering should be considered as a possible complimentary aid to a projected display in any program aimed at achieving consistently safe landings in zero-zero conditions with the pilot in the control loop. In such a program, a series of carefully planned tests would be required to determine the best type of control function and the best type of control (e.g., joystick, ball, etc).

5. REVIEW OF ENGINEERING HARDWARE CONCEPTS

A number of companies have been working on the engineering and optical hardware suitable for the projection of windscreen displays, without necessarily concerning themselves in detail with the development of the optimum display configuration. The engineering aspects have been discussed with Autonetics, Douglas Aircraft Company, Bell Helicopter Company, Bendix Corporation (Eclipse Pioneer Division), Sperry Gyroscope Company and Computing Devices of Canada, Ltd.; also a written proposal has been received from the Farrand Optical Company. It is not the purpose of this report to attempt to resolve all the engineering and optical problems; it is primarily a report on the design and development of displays. It is necessary, however, to review the present thinking on hardware in order to evolve a logical test program.

5.1 IMAGE GENERATION

The images may be produced initially by one or more of three methods:

(1) They may be generated on the face of a cathode ray tube, using Lissajous techniques and sequence switching. Some of the equipment already developed has the capacity to produce up to thirty-six separate elements in this manner. This method produces images made up of lines of much the same thickness with rather indistinct edges. They are moved electronically over the face of the display.

(2) They may be engraved through a thin metal sheet and illuminated from the rear by conventional filament or fluorescent lamps or by electroluminescent elements. The reticules so produced may include lines of different thicknesses which will have sharply defined edges. The images may be made to move over the display by moving the reticules or by placing movable mirrors or prisms between the reticules and the projection system.

(3) They may be engraved into one surface of a piece of transparent material (glass or plastic) which is illuminated from one edge. Again, the lines may differ in thickness and will be sharply defined. This technique provides a means of moving one image over the face of another without obscuring it. However, there may be some scattered light from the face of the transparent material where it is not engraved. Motion may be achieved by moving the material or by interspersing mirrors or prisms.

5.2 IMAGE REFLECTION TECHNIQUES .

The projected images are reflected in a piece of partially transparent and partially reflective material through which the pilot views the outside world. This may be mounted on the coaming or hung from the cockpit ceiling, or may be inserted in spectacles worn by the pilot. If the "semi-reflector" is attached to the airframe, it may be arranged to hinge back in the event of it being struck by the pilot's head.

Proposals by two companies to reflect the images in spectacles are of interest, but they involve devices to compensate for the pilots head rotations which would require considerable development. Also, some resistance by pilots to the use of spectacles would be anticipated. For the test program presently being planned, it would be wise to use a semi-reflector attached to the airframe.

Considerable work has been done, mainly by Autonetics, on the development of specially coated glasses which are transparent to light of most wavelengths but highly reflective to particular wave length bands. A most promising material is "trichroic" combining glass, which is said to transmit more than 80% of the light outside a narrow band thirty to fifty millimicrons wide centered on 525 millimicrons, but only 0.1% of the light within this band. The band has been chosen to contain the yellowish-green light omitted from cathode ray tubes coated with P1 or P2 phosphor. Of the 99.9% of light of this color which is extracted, about 90% is said to be reflected and only 10% absorbed. This should make it an ideal semi-reflector for use with cathode ray tube images.

5.3 OPTICAL SYSTEMS FOR COLLIMATION OF IMAGES

If the images were merely generated in the cockpit area and positioned in front of the pilots eyes by means of a flat semi-reflector, they would appear to be only a few feet in front of the windshield. Small movements of the pilot's head would then produce large angular motions between the images and the outside world. Collimation is therefore necessary, not only to eliminate the need to re-accommodate the eyes when transferring attention from the projected images to the outside world, but also to make it possible to fix the position of the images relative to the outside world, regardless of head position.

The images may be collimated either by placing a lens or lenses between the image generator and the semi-reflector or by using a curved semi-reflector which acts as a lens and reflector combined, as shown in Figure 7.

The <u>curved semi-reflector</u> is simple in the sense that it can give an arrangement with few components. However it introduces other problems.

For collimation, the image generator is placed in the focal plane of the semi-reflector and offset vertically or laterally so that the light rays from it are not blocked by the pilot's head. From the equality of the angles marked by double lines in Figure 7, it is seen that the angle subtended at the pilot's eye by the projected image equals the angle subtended at the semi-reflector R by the generated image G.

Thus, if the angular spread of the display as seen by the pilot is to be $\pm\theta$, the required breadth of the image generator is $2\theta.RG$.

If the lateral head movement to be tolerated is $\pm m$ and the pilot's eye spacing is e, the required breadth of the semi-reflector is:

$2\theta.ER + 2m + e$ for binocular vision,
or $2\theta.ER + 2m - e$ for monocular vision.

The instrument panel is normally about 28 inches from the pilot's eyes, so, assuming the semi-reflector to be mounted on the rear of the coaming, typical values would be:

ER = 20 ins.	RG = 32 ins.
m = 3 ins.	e = 2-1/2 ins.

For a desired display spread of $\pm 25^0$, based on 15^0 drift on crosswind approaches and a horizon line breadth of 20^0, it follows that:

Image generator breadth = 28 ins.
and Semi-reflector breadth = 26 ins.(binocular)
or 20 ins. (monocular)

This shows that the simple design leads to a large image generator, which would be difficult to position in the rear of the cockpit without having it partly blocked by the pilot's head or shoulder. Also, the curved semi-reflector is rather large and would be expensive to manufacture with sufficient accuracy.

The size of the image generator may be reduced by placing a lens in front of it to erect an aerial image forward of the pilot's eyes and making the focal plane of the semi-reflector coincident with the aerial image as shown in Figure 8.

In this case the required breadth of the aerial image is 2θ RA and the required breadth of the image generator is $2\theta.RA\,\frac{LG}{AL}$.

Taking the same desired display spread of $\pm 25^0$ and assuming:

$$\left.\begin{array}{l} RA = 12 \text{ ins.} \\ AL = 20 \text{ ins.} \end{array}\right\} \quad RL = 32 \text{ ins.}$$

LG = 10 ins.

we obtain: Aerial image breadth = 10.4 ins.
Image generator breadth = 5.2 ins.
Lens diameter = 15 ins. (binocular)
or 6.6 ins. (monocular)

The size of the lens is determined by the requirement to transmit the ray which passes from the edge of the image generator to the eye in its extreme position (shown dotted in Figure 8). With this design there is a large reward in terms of lens size for accepting monocular vision at the extremes of head movement.

The breadth of the semi-reflector is the same as in the simpler design (26 ins. binocular or 20 ins. monocular), being governed solely by the distance of the pilot's eye from the semi-reflector.

The <u>lens and plane semi-reflector</u> combination allows greater flexibility than the curved semi-reflector when it comes to positioning the image generator. In the Sperry and A.R.L. equipment the cathode ray tube is on the cockpit ceiling facing forward, with a 45^{o} plane mirror to deflect the light rays downward, a collimating lens below this and a 45^{o} semi-reflector suspended beneath the lens to return the images to the pilot. In other proposed layouts the plane semi-reflector is mounted on top of the coaming with the lens and image generator adjacent to the instrument panel, either beneath the semi-reflector or offset to one side of it. In all of these arrangements the optical system is similar in principle to that shown in Figure 9, although there may be additional plane mirror in some systems.

For collimation, the image generator is placed in the focal plane of the lens. From the equality of the angles marked with double lines in Figure 9, it is seen that the angle subtended at the pilot's eye by the projected image equals the angle subtended at the lens L by the generated image G.

Thus, using the same notation as previously, the required breadth of the image generator is $2\theta.LG$ and the required breadth of the lens is:

$2\theta.ERL + 2m + e$ for binocular vision
or $2\theta.ERL + 2m - e$ for monocular vision.

For an optical system behind the instrument panel, typical values would be:

$$\left.\begin{array}{l} ER = 32 \text{ ins.} \\ RL = 6 \text{ ins.} \end{array}\right\} ERL = 38 \text{ ins.}$$
$LG = 12$ ins.
$m = 3$ ins. $e = 2\frac{1}{2}$ ins.

For a display breadth of $\pm$ 25°, these give:

Image generator breadth = 10-1/2 ins.
and Lens diameter = 41-1/2 ins. (binocular)
or 36-1/2 ins. (monocular)

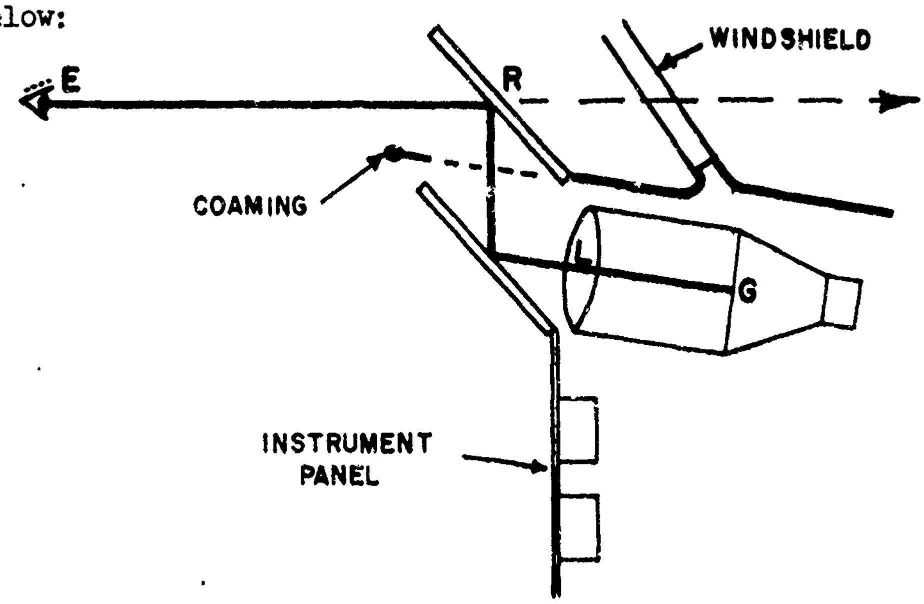
The size of the image generator is quite acceptable, but, assuming a single lens, the diameter required is completely unreasonable. This has led to proposals by two companies to build multiplexed mosaic lens systems with a number of image generators fed from the same computer (Reference 6).

If the angular size of the display were to be 50° x 16° (to meet a requirement for 25° on each side of the center line, 6° up and 10° down), a convenient arrangement would be a mosaic of four lens systems, each subtending 16° x 16° at the pilot's eye as shown in Figure 10. A different section of the display is generated on each image generator and the sections are overlapped and matched so that all light rays coming from a particular feature of the display are parallel, irrespective of which lens they come through.

The light rays shown in Figure 10 are from the extreme end of a sample image, which subtends 50° at the pilot's eye when projected at infinity. It is apparent that such a lens system allows a broad range of head movement. The 7° difference between the $\pm$ 32° of the lens spread and the $\pm$ 25° of image spread allows for an outward eye movement of about 4 inches without losing sight of the end of the image. If the sections are correctly matched, the viewer is not aware that, in many cases, one eye is looking through one lens and the other eye through the adjacent one.

Apart from their wide angle of view and broad range of permissible head movement, these systems have the advantage that the individual lenses are relatively small and the bending of the extreme light rays is not excessive. Hence, spherical abberation should not be a problem.

For the sake of simplicity, the semi-reflector has not been shown in Figure 10. Various reflector arrangements could be used. A fairly compact one recently suggested would involve mounting the mosaic horizontally beneath the coaming with a mirror and semi-reflector arranged as shown below:



The advantage of suspending the semi-reflector from the ceiling rather mounting it on the coaming is that it can be placed nearer to the pilot's eyes. Thus the lens size, which is proportional to the eye-to-lens distance ERL, can be reduced. The problem is to find sufficient space in the ceiling area.

In the ceiling mounted A.R.L. equipment, a wide effective angle of view is provided with a small lens and semi-reflector by gyrostabilizing the whole image generator and optical system and setting it in alignment with the runway heading. The problem with this arrangement is to achieve a fast enough response in the three servo systems used for gyro-stabilization.

Test Requirements:

A great deal of laboratory testing and development work will be required on any optical system designed to provide the display spread of $50^{\circ} \times 16^{\circ}$, which is presently envisaged.

However, before launching into the development of any system which requires the image generator and semi-reflector to be mounted in separate parts of the cockpit (e.g., the curved semi-reflector systems), it is considered that one basic flight test should be made. This would aim to establish whether it is possible to achieve the required image stability with the components separately mounted in a relatively flexible pressurized fuselage when flying in turbulent conditions. The requirements is for image stability of the order of $\pm 1/10^{\circ}$, which implies a maximum semi-reflector rotation of $\pm 1/20^{\circ}$ relative to the image generator. With an aerial image system (Figure 8) any rotation of the image generator and its lens also becomes critical.

For the flight test envisaged, a very simple display would be adequate. It might, for example, only include a horizon line and flight path marker uncorrected for wind. These elements would, however, need to be gyro-stabilized to show up any image movements caused by lack of rigidity of the optical components.

6. PROPOSED TEST PROGRAM

A number of tests have been suggested in earlier sections of this report. It is necessary now to integrate these into a test program and consider the test procedures in detail. The tests fall into five distinct series:

(1) Preliminary flight checks on basic concepts.
(2) Simulator comparison of three new displays.
(3) Simulator comparison of three degrees of director quickening.
(4) Simulator checks on various details of images.
(5) Final flight validation.

The tests in the first series could be done in the near future with pieces of equipment presently available, suitably matched and modified. The later tests will require the development of advanced image generation and projection equipment with capacity to mix cathode ray tube and reticule generated images, provide full gyro-stabilization and give a field of view of the order of $50^{\circ} \times 16^{\circ}$. They will also require the provision of a representative flight simulator with a daylight visual attachment or, as a possible alternative if waiting for a simulator would involve too much delay, a small high performance aircraft for several hundred hours of flight testing.

6.1 PRELIMINARY FLIGHT CHECKS ON BASIC CONCEPTS

To ensure that the efforts of the many companies working on projected displays and projection equipment are usefully expended, and to provide basic data on the value of projected displays at an early stage in the program, the first series of tests should be aimed at answering two basic questions:

(1) How does the pilot's performance on standard panel instruments compare with his performance on a projected display fixed relative to the aircraft and on a similar display fully gyro-stabilized relative to the outside world?

(2) Can the required image stability ($\pm 1/10^{\circ}$ at the eye) be achieved in turbulent conditions with the image generator and semi-reflector separately mounted in the relatively flexible pressurized fuselage of a typical modern transport aircraft?

These tests must be done in flight for two reasons. Firstly, the difference between the two basic types of projected display will only show up fully in turbulent conditions and, secondly, both turbulence and fuselage flexibility combined with pressurization effects are required for the second phase of the tests. The first phase, which represents the major effort in this test series, could be done in any aircraft of reasonable size and speed. However, the second phase, which would be a relatively small experiment in terms of flying hours, would require a typical large transport aircraft.

The equipment requirements are relatively simple and the same equipment could be used for both phases of the tests. Any compact image generator such as the Sperry or the Spectocom would be quite suitable after small modifications. Thus there should be little delay in getting the program under way.

For the first phase of the tests, the equipment should be mounted on the cockpit ceiling, as in the Sperry DC-3, and only horizon, director and aircraft images would be required. The horizon image would necessarily be stabilized at all times, but provision would be made to have the director and aircraft images either working relative to the aircraft axis or gyro-stabilized.

The tracking element in the stabilized director would be a flight path marker while the corresponding one in the aircraft based director would be an attitude image.

Tests should be made with a minimum of six pilots, preferably experienced airline pilots (5000 hours experience or better), and their performance on landing approach should be measured and analyzed statistically under three test conditions:

(1) Standard panel instruments.
(2) Projected images working relative to aircraft axis.
(3) Projected images fully gyro-stabilized.

Under each test condition, a training period of at least three practice approaches should be given to each pilot, followed by at least six recorded approaches from 5 miles to 1/4 mile range. All six possible orders of presentation of the three test conditions would be used and, as far as possible, the recorded approaches should be made in the afternoon on sunny days to achieve maximum air turbulence. The test criteria would be deviation from ILS glidepath and deviation from desired airspeed. The former data would provide the background for an analysis of the economic gains achievable in airline operation as the result of using a projected display.

Such a program would require about 60 hours of usable flight time, excluding time lost due to aircraft unserviceability, weather and ATC requirements.

For the second phase of the tests, the image generator required for the first phase could be used in its gyro-stabilized form. It would be mounted high on the bulkhead behind the pilots seat with a lens designed to erect an aerial image forward of his eyes, and a curved trichroic semi-reflector would be mounted on the coaming. Stabilization of the images would be essential in this case to distinguish image movements caused by relative motions between the optical elements from those caused by angular motions of the fuselage.

An extensive experimental program would not be required. The important requirement would be to find some really turbulent air and measure any image oscillations, while endeavoring to maintain horizontal flight by placing the flight path marker on the horizon. This could be done by test pilots with the aid of a suitable photographic recording technique.

6.2 SIMULATOR COMPARISON OF THREE NEW DISPLAYS

The new displays developed in Section 4 by compounding the best features of the existing and proposed displays and adding certain original ideas were these:

(1) Type A containing only status and rate information (as shown in Figure 11).

(2) Type B containing also a director working with the runway aiming point (as shown in Figure 11 with a dot at point B).

(3) Type C containing also a director working with the flight path marker (as shown in Figure 11 with a dot at point C).

The object of the second series of tests is to compare these three configurations both objectively and subjectively.

An advanced type of image generator will be required and, and logically, the location of this and the design of the semi-reflector should depend on the results of the first series of tests. However, if it is necessary to proceed with the design of equipment for the later test series before the the results of the first series are available, as seems very likely, the conservative assumptions should be made that full gyro-stabilization is necessary and separation of the image-generator and semi-reflector is not practicable. The first assumption has been made in designing the details of the three new displays and the second one implies that the projection equipment should be mounted on the cockpit ceiling or in the upper instrument panel area.

Extensive tests should be made in a flight simulator representative of a two place high performance aircraft and equipped with a daylight visual attachment. At least twelve experienced airline pilots should be used and their performance on landing approach should be measured and analyzed statistically, using each of the three configurations.

In these tests, the object is to compare the effects of fairly fine differences between three sophisticated displays. These effects may well be related to the training and background of the pilots who have to use the equipment. It is, therefore, considered important to obtain experienced airline pilots, and to measure their performance on a large number of simulated approaches, even if this involves purchasing their services from the airlines for a number of days each.

With each configuration, each pilot should be allowed a training period of at least six practice approaches and touchdowns. The fog simulator should be used on the last two of these to simulate a low altitude breakout. Then, at least eight recorded approaches and touchdowns should be made by each pilot on each configuration, the fog simulator being used on 50% of occasions, randomly interspersed. Naturally, all six possible orders of presentation would be used equally (i.e., twice each for twelve pilots). The test criteria would be deviation from ILS glidepath, deviation from desired airspeed, touchdown point on the runway and vertical speed and heading at touchdown.

After completing his approaches on each configuration, each pilot should be interviewed by an experimental psychologist to elicit his views on that presentation. The interviews should be largely unstructured, but points of special interest would be raised by the interviewer if the pilot did not volunteer any information on them. For example, during the last of his three interviews, each pilot would be asked to express preference between the configurations, taken two at a time.

6.3 SIMULATOR COMPARISON BETWEEN THREE DEGREES OF QUICKENING

In Section 4.4 three types of flight director with different degrees of quickening were discussed, namely:

(1) Flight path director with no quickening.
(2) Roll and pitch angle director with roll angle input.
(3) Control force director with roll angle and either control force or angular velocity inputs.

The comparison between configurations discussed in the previous section would be made with one particular type of director. The roll and pitch angle director used in most Integrated Flight Systems would seem most appropriate. An estimate of suitable ratios for mixing of the inputs could be obtained from previous work on Integrated Flight Systems.

Prior to commencing the full scale comparison between types of director it would be necessary to conduct some pilot experiments, using local subjects, to obtain an estimate of suitable mixing ratios for the control force or angular velocity inputs to the third stage director.

The ideal arrangement would then be to bring back six of the twelve airline pilots used previously in the comparison between configurations to participate in the comparison between types of director on the configuration found to be most suitable.*

They would already have a very useful background of experience, and little training would be required. Experience has shown that, for administrative reasons, it is almost impossible to obtain a return visit from all of a group of airline subjects used in a previous experiment, but a 50% sample should be obtainable.

Assuming six pilots from the original group, two practice approaches and touchdowns followed by six recorded ones on each type of director should be sufficient. Since the effect of using the fog simulator would already be established from the previous test series, it should not be necessary to do approaches with and without it in this instance; it could be used on all approaches. Again, all six orders of presentation would be used and the test criteria would be as before, but with the addition of director dot deviation.

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* If Type A, which has no director, were found to be the best configuration, this experiment would not be necessary.

A series of interviews by an experimental psychologist should be conducted after each pilot's approaches on each type of director.

6.4 SIMULATOR CHECKS ON VARIOUS DETAILS OF IMAGES

In Section 4.3 there was some discussion on the merits of including an indication of minimum safe airspeed, and a small experiment was suggested. As the first three series of tests proceed, other small details of this type are almost sure to arise. The unstructured interviews might very well raise some; there might, for example, be a widespread opinion in favor of trying a change in the mixing ratio of the director inputs. It therefore, seems essential to make allowance for a fourth test series to resolve such matters.

If the number of details to be resolved were small, the fourth series might well be integrated with the third, so that the same six airline pilots could be used while they were readily available.

Six recorded approaches by each of six pilots in each test condition, followed by an interview to obtain subjective data, should be sufficient. The test criteria would depend on the particular feature of the display being investigated. For example, in the case of the minimum safe airspeed indication, airspeed variation would be the primary criterion.

6.5 FINAL FLIGHT VALIDATION

The final phase of the experimental program would be the flight validation of the simulator results from the second and third series of tests. At this stage, there would be simulator data pointing to a best and second best configuration and a best and second best type of director. Also, certain detailed changes to the display would have been decided upon and others, which had been proposed, would have been rejected.

The detailed changes suggested by the simulator tests should be incorporated and the equipment mounted in a modern transport aircraft. Then approach tests from five miles to 1/4 mile should be made under three conditions:

(1) Best configuration and best type of director.
(2) Best configuration and second best director.
(3) Second best configuration and best director.

Six experienced airline pilots would be required and it would be extremely desirable to draw them from among those who had participated in the simulator tests; in fact, for reasons of safety as well as economy of training time, this should be regarded as a test requirement.

Each of the six pilots should be allowed two practice approaches and then make twelve recorded approaches in each condition - six by day and six by night. If the simulator data on touchdown sink rate, position and heading looks encouraging, some of these approaches should be continued to the touchdown with the fog simulator, at the discretion of the safety pilot. Again, all six orders of presentation would be used and the test criteria would be as for the second series of tests. The statistical analysis would be aimed at showing no significant difference between the trends observed in the simulator and those found in flight.

Each pilot should be interviewed by an experimental psychologist at the conclusion of his flight program to obtain his impressions of the effectiveness of the equipment in the aircraft as compared with the simulator and its effectiveness by night as compared with day. Again, the interview should be as unstructured as possible to ensure that a wide range of relevant topics is covered, but certain specific points would have to be raised by the interviewer if not previously mentioned.

Such a program would require about 90 hours of usable flight time in a modern transport aircraft.

6.6 SUMMARY OF PROPOSED TESTS

The number of pilots, test conditions and runs proposed are summarized below:

Test Series	Flight or Simulator	Number of Pilots	Number of Conditions	Runs per Condition: Practice	Runs per Condition: Recorded	Total Runs	Usable Flying Hours
1 (1)	F	6	3	3	6	162	60
1 (2)	F	Not Applicable					10
2	S	12	3	6	8	504	
3	S	6	3	2	6	144	
4	S	6	?	2	6	?	
5	F	6	3	2	12	252	90

If the tests in the fourth series are assumed to be approximately twice as extensive as those in the third series, the total requirement is for about 1000 approaches in the simulator, which might take 200 hours, and 160 hours of useful flying time in a modern transport aircraft, which might take a total of 220 hours in the air. If a suitable simulator were not available, about 350 hours of useful flying time in a small high performance aircraft would be a possible alternative to the former requirement; this might take a total of 500 hours' flying time in the small aircraft.

It should be noted that the tests proposed here relate only to the development of a display suitable for the landing approach. Its extension to other phases of flight would require further testing.

7. SUMMARY

Five projected displays of flight information, devised in the United States, England and Australia as aids to the pilot during approach to landing, have been reviewed and analyzed with respect to information content, simplicity and compatibility with the outside world. The analysis shows some deficiencies in all of them, so a series of three new displays have been developed by combining what appear to be the best concepts in the present displays and adding some original ideas. The new displays differ only in respect to the flight director function, and the application to them of the same analysis procedure mentioned above gives them all a high rating. Some possible additional developements to supplement the projected display as an aid to low visibility approach have been briefly discussed.

A simulator and flight test program has been prepared to check two basic concepts related to the design of projected aids, to compare the new displays now proposed, to compare various degrees of quickening for flight directors, and to resolve certain details of display design. This program would require about 220 hours of flying time in a transport aircraft and about 200 hours in a representative simulator with a daylight visual attachment. If such a simulator were not available, a possible alternative would be about 500 hours of flying time in a small high performance aircraft.

The equipment required for the first series of flight tests could be produced quite soon by matching and modifying available equipment, but the equipment for the later simulator and flight tests would require considerable engineering development. It is recommended that this development be carried on in parallel with the installation of suitable simulation facilities, while the first series of flight tests are in progress.

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APPENDIX A
TERMINOLOGY

Aerial Image	An optical image of the display produced in the air in the cockpit area by a lens system in front of the image generator. This image is not normally visible but would be seen if an opaque screen were placed at its location.
Aiming Point	A point on the runway, normally about 1000 feet beyond the threshold, towards which the pilot should aim his eyes in order that the aircraft wheels will safely clear the threshold. (The ILS Glideslope, when projected, intersects the runway in the region of the aiming point.)
Binocular Vision	Vision of an object in conditions such that it can be seen by both eyes.
Collimator	A lens or mirror so placed that, when the light rays radiating from an object strike it, they emerge on the other side in a parallel stream. An object viewed through a collimator appears to be at infinity (i.e., at extreme range).
Deviation	Displacement of the aircraft, either laterally or vertically (or both), from the center of the ILS glidepath.
Director or (Flight Director)	A needle on an instrument or an image in a projected display which must be tracked by another needle or image, controlled by the pilot. The motion of the director is usually computed from a number of elements of flight information derived from different sources.
Display	A set of flight instruments or projected images designed to give the pilot a complete picture of his flight situation.
Flight Path	The actual path through the air which is flown by the aircraft.
Flight Path Marker	An element of a projected display which represents the instantaneous flight path vector projected out to infinity (i.e. the point toward which the aircraft is presently flying).
Glidepath or (ILS Glidepath)	The path through the air defined in azimuth by the ILS localizer beam and vertically by the ILS glideslope beam.

Glideslope or (ILS Glidepath)	The vertical component of the ILS glidepath, as seen when it is viewed from the side.
Heading	The azimuth direction in which the horizontal projection of the aircraft axis is pointing (usually measured in degrees from Magnetic North).
I. L. S.	Instrument Landing System. A system which defines a desired approach path to the runway (the glidepath) by means of two radio beams at right angles - the localizer beam defining its position in azimuth and the glideslope beam defining its position in the vertical plane.
Image	An optical reproduction of an illuminated object (e. g. a figure on a cathode ray tube or a back lighted reticule), produced by bringing the light rays from that object into focus some distance from it.
Image Generator	A piece of electro-mechanical or electronic equipment designed to produce illuminated objects of desired shape, which may be optically projected to produce images.
I. F. S.	Integrated Flight System. A set of panel instruments presenting flight information from a number of sources in an integrated semi-pictorial form. A director is usually included, in addition to information on instantaneous aircraft position.
Localizer or (ILS Localizer)	The azimuth component of the ILS glidepath, as seen when it is viewed from above.
"Microvision"	Bendix trade name for a high resolution radar system used to reproduce, on a cathode ray tube in the aircraft, a pattern generated by a series of transponders on the ground.
Monocular Vision	Vision of an object in conditions such that it can only be seen by only one eye.
Projected Image	A reflection of a collimated optical image on a semi-transparent screen in front of the pilot's eyes. The projected image appears to be superimposed on the outside world.

Quickening	Feeding back to a display certain elements of control system output (e.g. angle of roll), so that the display will be nulled as soon as the correct action is taken to commence eliminating a system error. An unquickened display would not be nulled until the error had been completely eliminated.
Semi-reflector	A coated glass plate, used for the projection of images, which reflects part of the light impinging on it and also transmits part of it. It may be selective to certain wavelength bands.
Track	The azimuth direction in which the aircraft is travelling, measured relative to the ground.
V. O. R.	Visual Omni Range. A radio navigation system which defines a series of radial paths, emanating from a transmitter on the ground. An instrument presentation in the aircraft enables the pilot to select any desired radial path and fly inbound or outbound on it.

APPENDIX B

EXPERIENCE WITH SPERRY DISPLAY AT MACARTHUR FIELD ON APRIL 5, 1962

Both of the authors made landing approaches using the Sperry display in a DC-3 aircraft at MacArthur Field, Long Island on April 5, 1962. The wind conditions on the test runway were rather unusual at the time; there was a considerable tailwind (about 20 knots) and a marked wind gradient at 100 to 200 feet. The runway could not be used for touchdown under these conditions, but approaches were made on it because it was equipped with ILS and cross checks against the glideslope needle were required.

Six approaches were made from about 5 miles range with the system in director mode and a board covering the windshield. Five of these approaches were continued down to the runway threshold without any problems. The board was then removed and an overshoot was initiated.

On the other approach, however, some confusion was experienced, caused basically by a tendency to "chase the airspeed" too closely. Because of the tailwind, the power was almost off during most of the approach (about 10 inches of boost) and the elevator trim was wound well back. At about 200 feet the airspeed fell sharply to the lower limit bar and the power was increased. The airspeed did not respond so a further power increase was made. At that stage the whole display appeared to fall as a unit to the bottom of the reflector plate, where the images became distorted by imperfections in the peripheral portion of the collimating lens. The safety pilot took control and, when he removed the board from the windshield, it was apparent that the aircraft had pitched up through an angle of 5 to 10 degrees. This had not been recognized previously, the initial impression being that the display had become unserviceable.

In retrospect it was realized that, because the system had been in director mode, the flight path marker had not risen to the horizon or above it. The pilot, after flying in flight path mode a short time previously, had subconsciously regarded the flight marker as a representation of his flight path vector and consequently had not recognized the pitch up. The present Sperry display images only have $\pm 4^o$ of vertical movement before they come up against their stops. Thus, when they reach their lower stops in director mode, the separation between the flight path marker and runway image is only $2/3^o$ plus any separation caused by vertical displacement from ILS glidepath. Compared with a glideslope angle of about 3^o and a flight path marker wing span of about 5^o, this does not represent a very impressive demand to push the control column forward.

While it is agreed that the wind conditions were abnormal, the pilot was inexperienced on the system and a production system would have more than $\pm 4^{\circ}$ of vertical movement, this incident does illustrate the type of confusion which can arise from mode switching, particularly when the flight path marker is used to represent something other than flight path or pitch attitude.

TABLE I

ANALYSIS OF VARIOUS DISPLAYS

		INFORMATION CONTENT																	OTHER ASPECTS		
		FUSELAGE ATTITUDE							FLIGHT PATH		FLIGHT DIRECTOR		AIRCRAFT POSITION RELATIVE TO GLIDEPATH		RUNWAY POSITION RELATIVE TO FUSELAGE				SIMPLICITY		
		ROLL	PITCH RELATIVE TO HORIZON	YAW RELATIVE TO RUNWAY	ALTITUDE ABOVE RUNWAY	RATE OF DESCENT	RANGE TO THRESHOLD	AIRSPEED OR LIFT COEFFICIENT	VERTICAL	LATERAL	VERTICAL	LATERAL	VERTICAL	LATERAL	VERTICAL	LATERAL	GROUND PLANE IN PERSPECTIVE	TOTALS	DISPLAY GENERATION	PILOT INTERPRETATION	OUTSIDE WORLD COMPATABILITY
SPERRY FP Mode	IFR	2	0	2	2	2	0	2	1	2	0	0	2	2	2	2	1	22 BY SWITCHING BETWEEN MODES 26			
	VFR	2	0	2	2	2	0	2	1	2	0	0	2	2	2	2	2	23 BY SWITCHING BETWEEN MODES 27			
SPERRY DP Mode	IFR	2	0	2	2	0	0	2	0	0	2	2	2	2	2	2	1	21			
	VFR	2	0	2	2	0	0	2	0	0	2	2	2	2	2	2	2	22			
SPERRY DV Mode	IFR	2	0	2	2	0	0	2	0	0	0	0	2	2	2	2	1	1[illegible]			
	VFR	2	0	2	2	0	0	2	0	0	0	0	2	2	2	2	2	18			
ARL	IFR	2	0	0	0	2	0	2	2	2	2	2	0	0	0	0	0	14			
	VFR	2	0	2	0	2	0	2	2	2	1	1	2	2	2	2	2	24			
BENDIX	IFR	2	2	2	2	1	2	2	2	2	2	2	2	2	2	2	1	30			
	VFR	2	2	2	2	1	2	2	2	2	1	1	2	2	2	2	2	29			
SPECTOCOM	IFR	2	2	0	2	0	2	1	0	0	2	2	0	0	0	0	0	13			
	VFR	2	2	2	2	0	2	1	0	0	1	1	0	2	2	2	2	21			
DOUGLAS A N I P	IFR	2	0	0	0	0	0	2	0	0	0	0	2	2	2	2	2	14			
	VFR	2	0	2	0	0	0	2	0	0	0	0	2	2	2	2	2	16	-		
BASIS OF SCORING		2 ANALOGUE OR PICTORIAL 1 NUMERICAL ONLY						2 RELATIVE TO OPTIMUM 1 ABSOLUTE	2 RELATIVE TO GROUND 1 RELATIVE TO AIR		2 ON ALL APPROACHES 1. ONLY ON ILS RUNWAYS		2 ANALOGUE OR PICTORIAL 1. NUMERICAL ONLY				2 COMPLETE 1 RUNWAY PLANE ONLY				
OUTSIDE VIEW (CLEAR WINDSHIELD)	VFR	2	0	2	0	0	0	0	0	0	0	0	0	2	2	2	2	12 MODERN PANEL AND 23 OUTSIDE VIEW VFR			NOT APPLICABLE
MODERN PANEL INSTRUMENTS	IFR	2	2	1	1	2	1	1	0	0	2	2	2	2	0	0	0	15			
	VFR	2	2	1	1	2	1	1	0	0	1	1	2	2	0	0	1	1[illegible]			

TABLE II

ANALYSIS OF THE NEW DISPLAYS FOR INFORMATION CONTENT

		FUSELAGE ATTITUDE			ALTITUDE ABOVE RUNWAY	RATE OF DESCENT	RANGE TO THRESHOLD	AIRSPEED OR LIFT COEFFICIENT	FLIGHT PATH		FLIGHT DIRECTOR		AIRCRAFT POSITION RELATIVE TO GLIDEPATH		RUNWAY POSITION RELATIVE TO FUSELAGE		GROUND PLANE IN PERSPECTIVE	TOTALS
		ROLL	PITCH RELATIVE TO HORIZON	YAW RELATIVE TO RUNWAY					VERTICAL	LATERAL	VERTICAL	LATERAL	VERTICAL	LATERAL	VERTICAL	LATERAL		
TYPE A	IFR	2	0	2	2	2	2	2	2	2	0	0	2	2	2	2	1	25
	VFR	2	0	2	2	2	2	2	2	2	0	0	2	2	2	2	2	26
TYPE B	IFR	2	0	2	2	2	2	2	2	2	2	2	2	2	2	2	1	29
	VFR	2	0	2	2	2	2	2	2	2	2	2	2	2	2	2	2	30
TYPE C	IFR	2	0	2	2	2	2	2	2	2	2	2	2	2	2	2	1	29
	VFR	2	0	2	2	2	2	2	2	2	1	1	2	2	2	2	2	28
BASIS OF SCORING		2. ANALOGUE OR PICTORIAL 1 NUMERICAL ONLY						2. RELATIVE TO OPTIMUM 1 ABSOLUTE	2 RELATIVE TO GROUND 1 RELATIVE TO AIR		2 ON ALL APPROACHES 1 ONLY ON ILS RUNWAYS		2 ANALOGUE OR PICTORIAL 1. NUMERICAL ONLY				2 COMPLETE 1 RUNWAY PLANE ONLY	

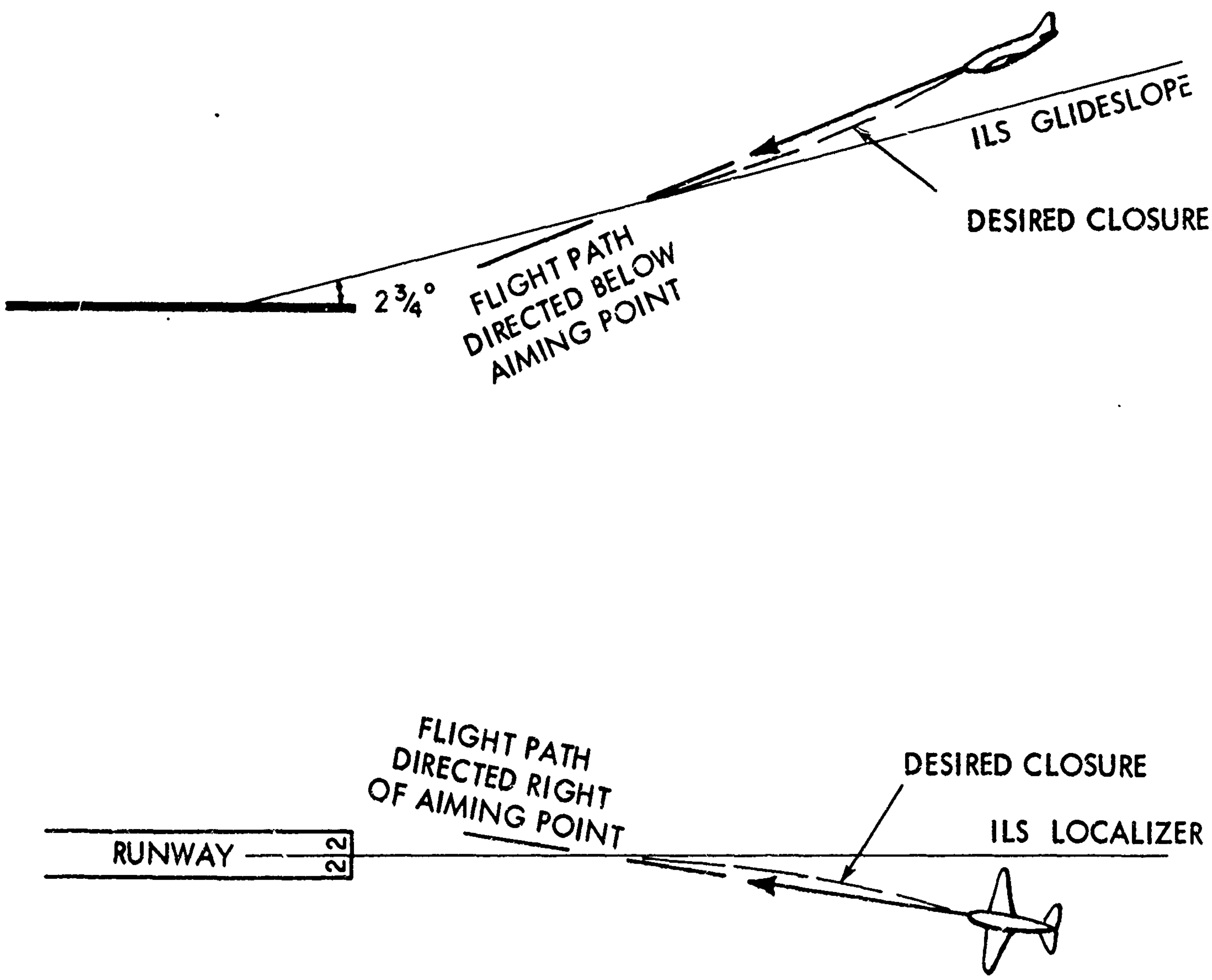

FIG. 1 TYPICAL AIRCRAFT APPROACH CONDITION
(EXAMPLE FOR ILLUSTRATION OF VARIOUS PROPOSED WINDSHIELD DISPLAYS)

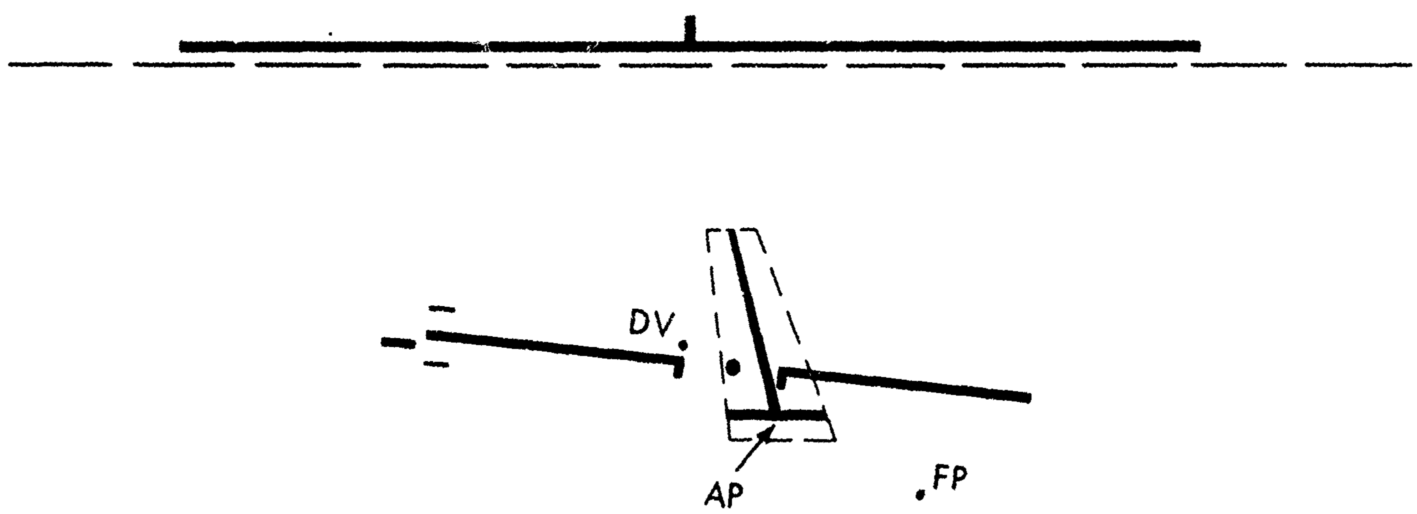

FIG. 2 SPERRY DISPLAY

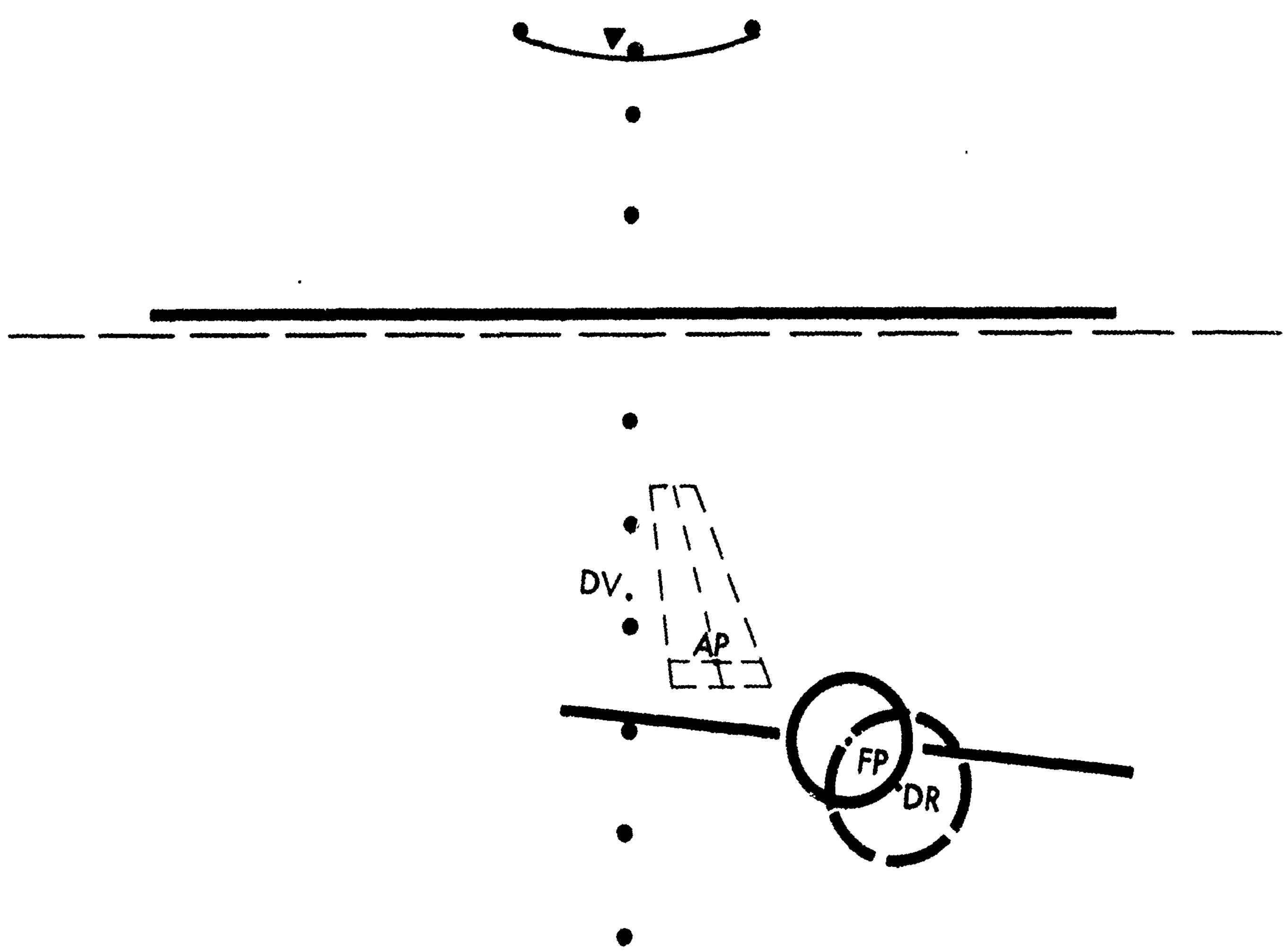

FIG. 3 A.R.L. DISPLAY

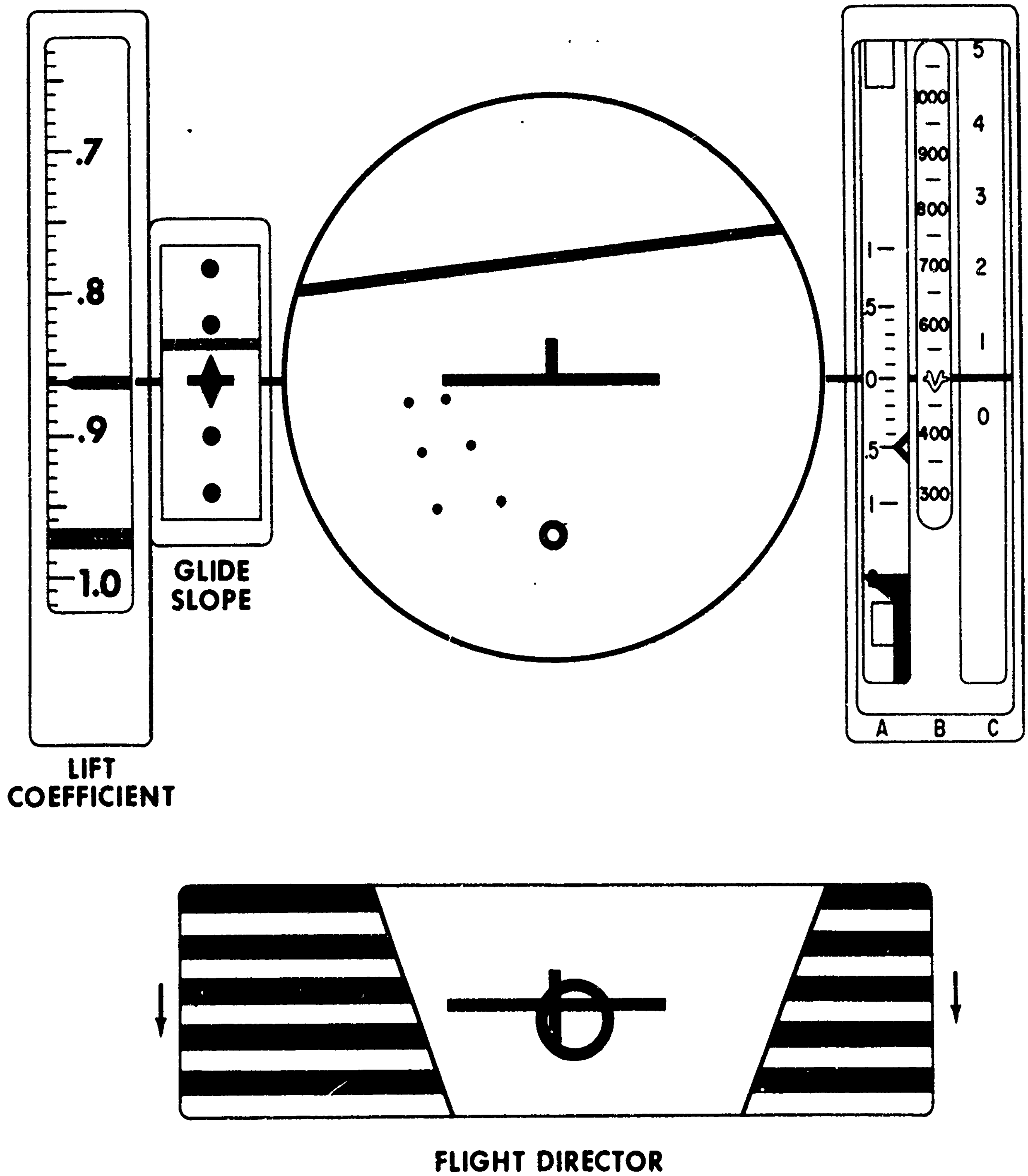

FIG. 4 BENDIX PROPOSED DISPLAY

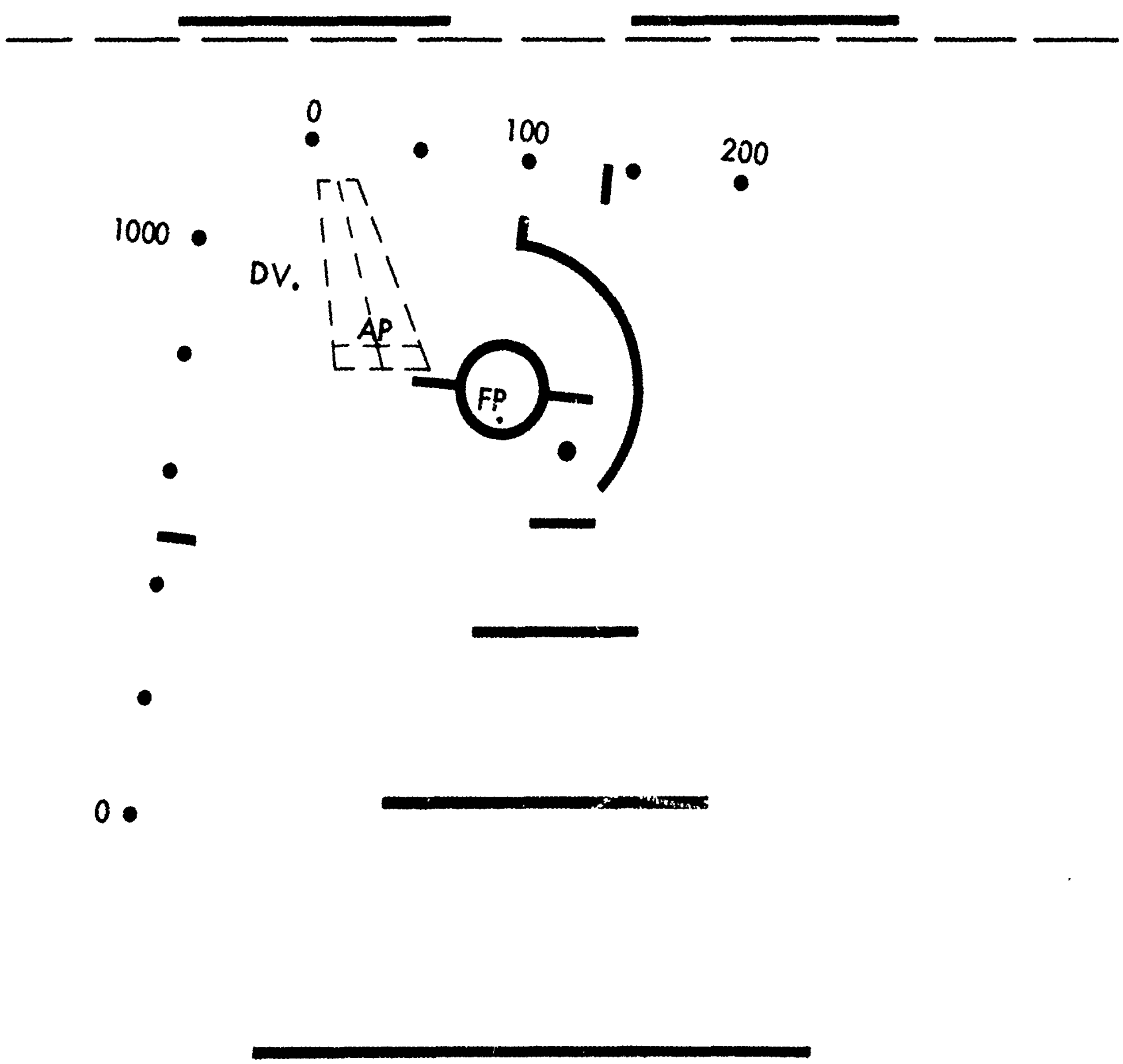

FIG. 5 SPECTOCOM DISPLAY

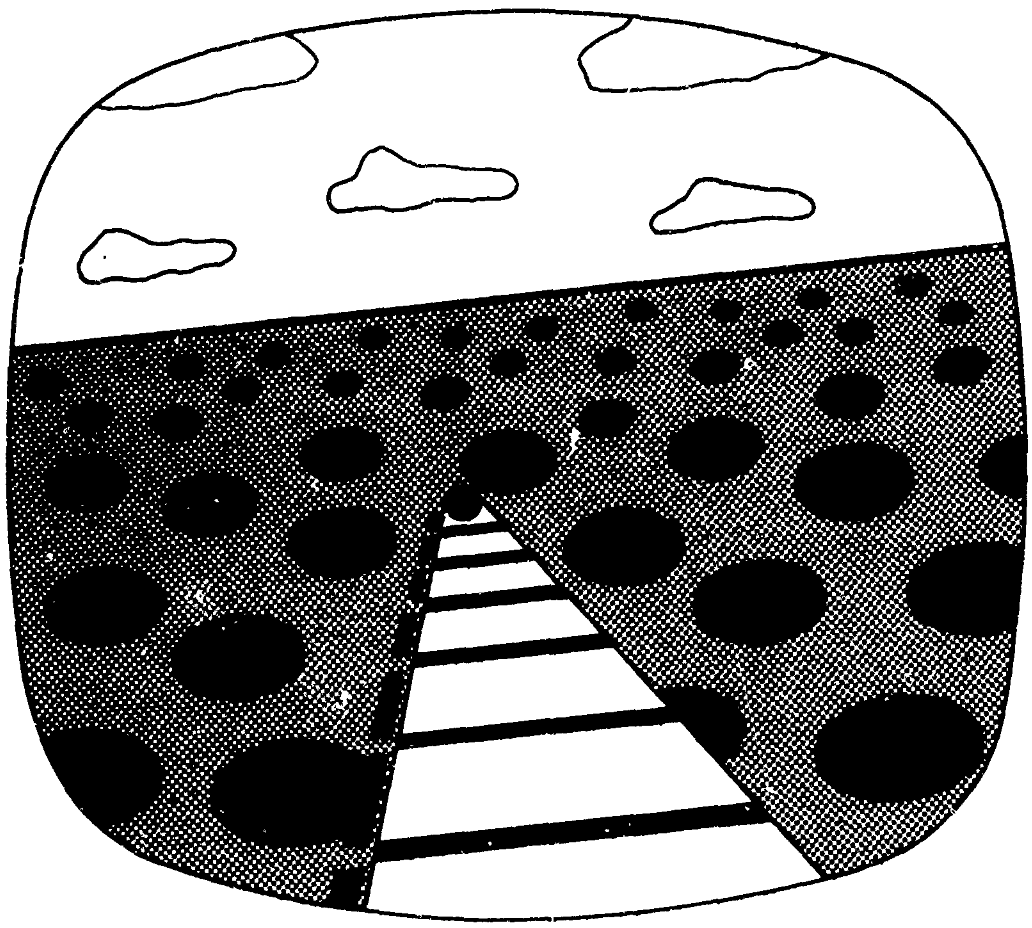

FIG. 6 DOUGLAS A.N.I.P. DISPLAY

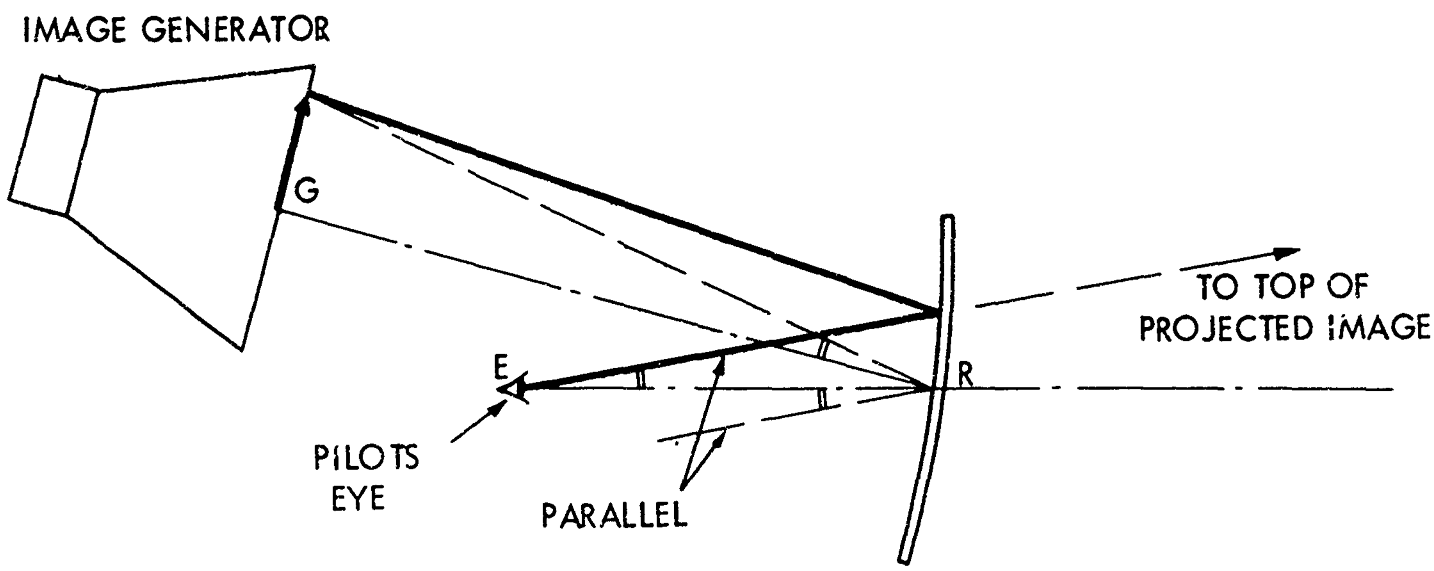

FIG. 7 CURVED SEMI-REFLFCTOR LAYOUT

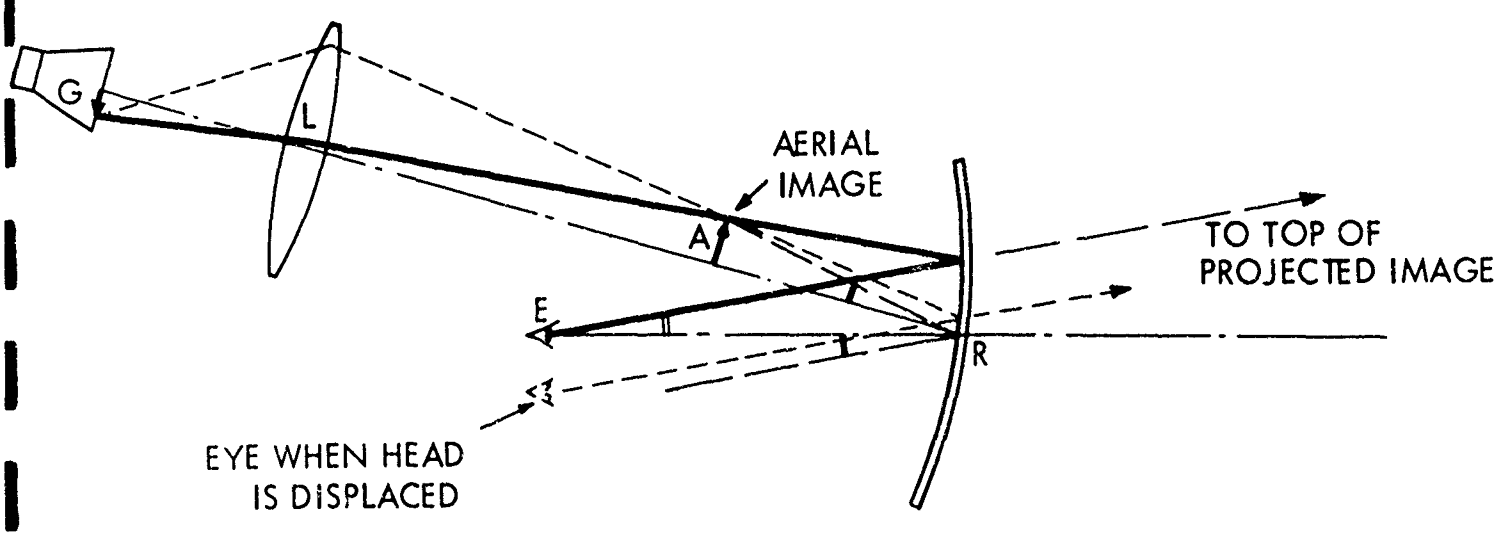

FIG. 8 CURVED SEMI-REFLECTOR WITH AERIAL IMAGE

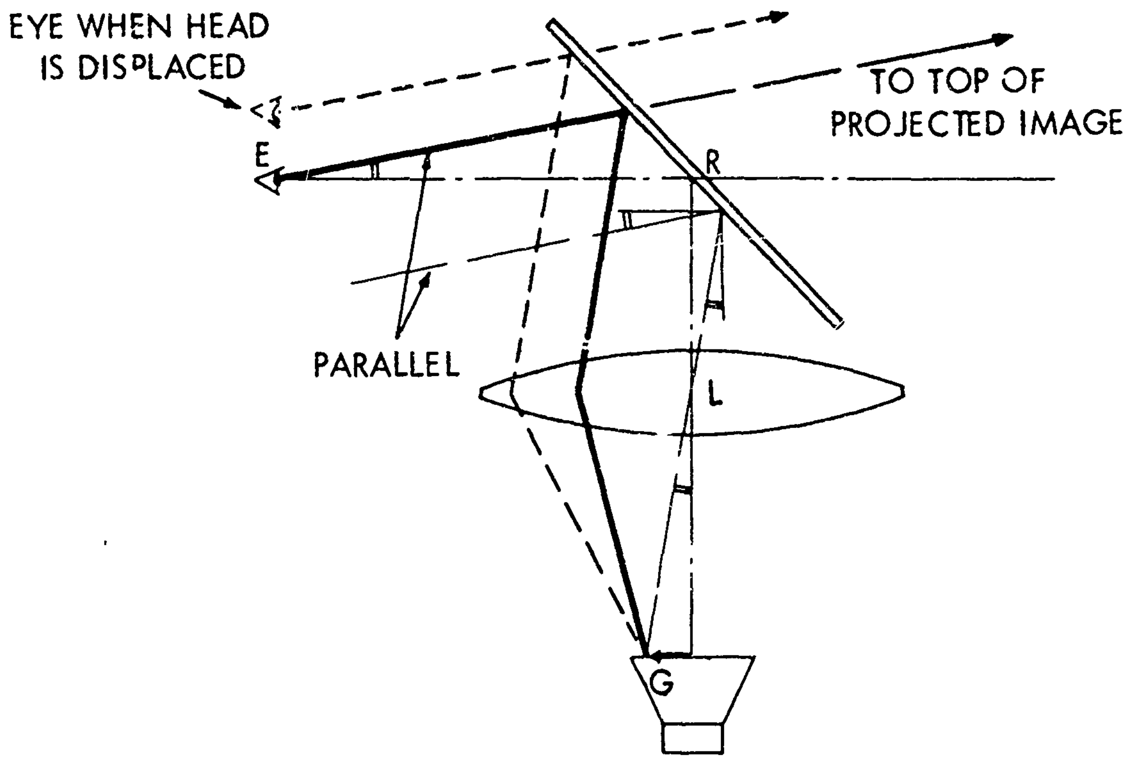

FIG. 9 PLANE SEMI-REFLECTOR WITH LENS

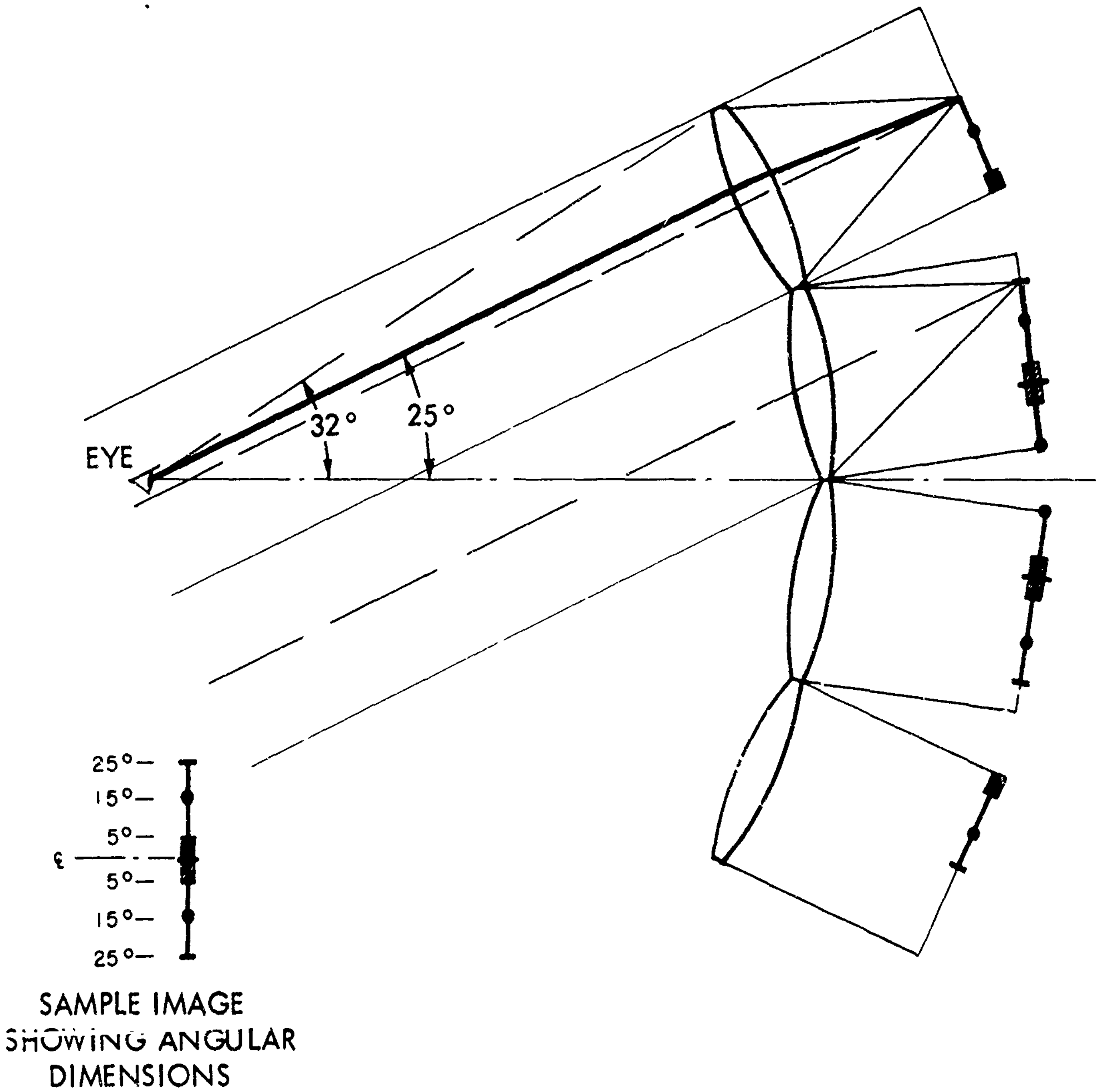

FIG. 10 FOUR LENS MOSAIC FOR 50° IMAGE SPREAD

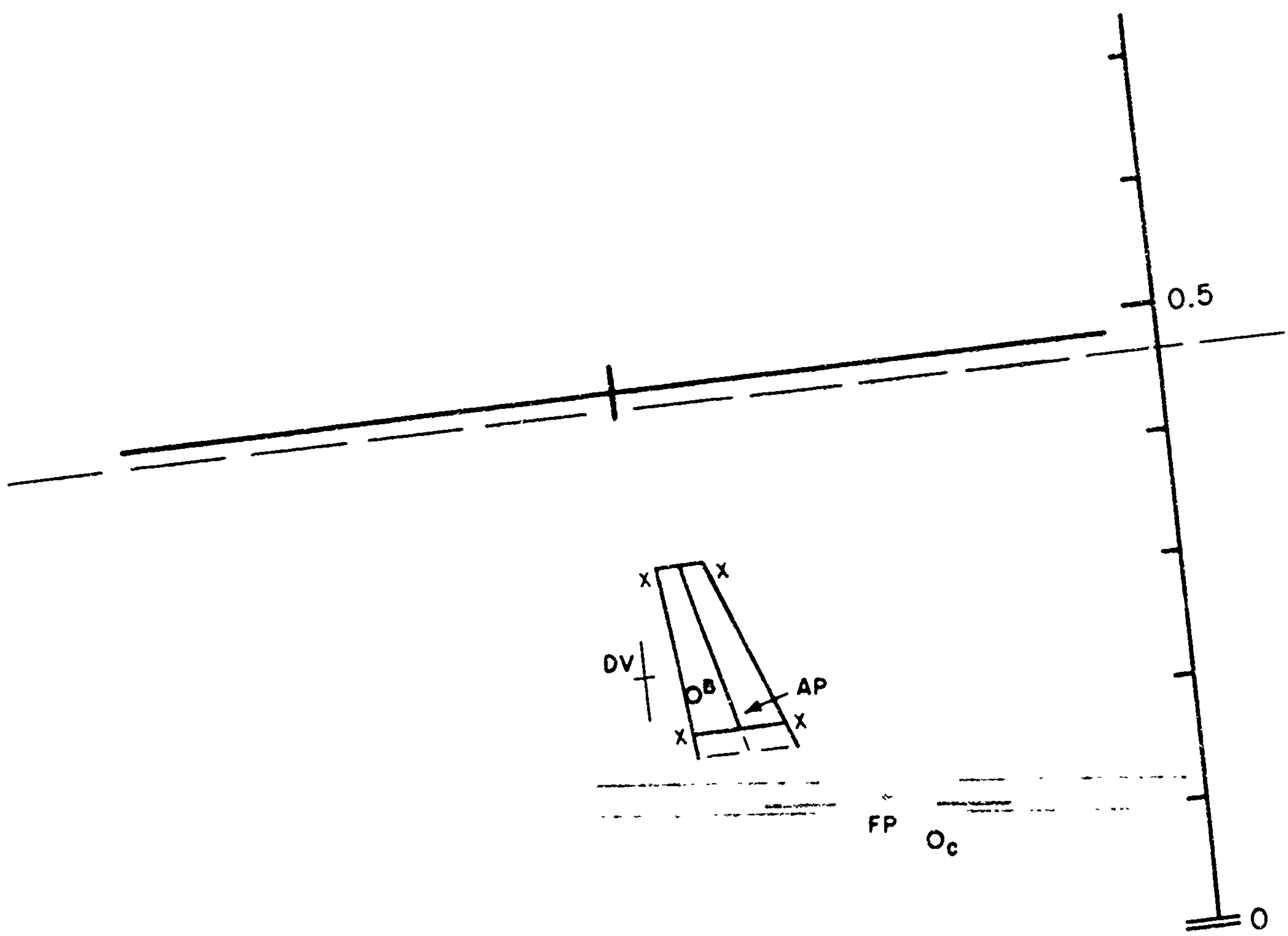

FIG. 11 TYPE 'A' DISPLAY