

AD A119223

AFWAL-TR-81-3156
VOLUME III

PICTORIAL FORMATS
LITERATURE REVIEW



2

T. J. QUINN
MCDONNELL AIRCRAFT COMPANY
MCDONNELL DOUGLAS CORPORATION
P. O. BOX 516
ST. LOUIS, MISSOURI 63166

MARCH 1982

DTIC
ELECTE
SEP 15 1982
S H D

Final Report for Period May 1980 to May 1981

Approved for public release; distribution unlimited.

DTIC FILE COPY

FLIGHT DYNAMICS LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

82 09 14 017

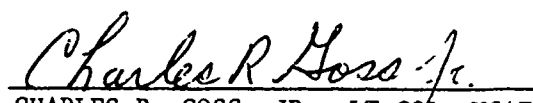
NOTICE

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture use, or sell any patented invention that may in any way be related thereto.

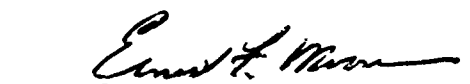
This report has been reviewed by the Office of Public Affairs (ASD/PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.


JOHN M. REISING
Engineering Psychologist


CHARLES R. GOSS, JR., LT COL, USAF
Chief
Crew Systems Development Branch

FOR THE COMMANDER


ERNEST F. MOORE, Colonel, USAF
Chief, Flight Control Division

"If your address has changed, if you wish to be removed from our mailing list, or if the addressee is no longer employed by your organization please notify AFWAL/FIGR, W-PAFB, OH 45433 to help us maintain a current mailing list".

Copies of this report should not be returned unless return is required by security considerations, contractual obligations, or notice on a specific document.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFWAL-TR-81-3156 VOLUME III	2. GOVT ACCESSION NO. AD-A449 223	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) PICTORIAL FORMATS LITERATURE REVIEW		5. TYPE OF REPORT & PERIOD COVERED Final Technical Report August 81
		6. PERFORMING ORG. REPORT NUMBER MDC A7172
7. AUTHOR(s) T. J. Quinn		8. CONTRACT OR GRANT NUMBER(s) F33615-80-C-3601
9. PERFORMING ORGANIZATION NAME AND ADDRESS McDonnell Aircraft Co. McDonnell Douglas Corporation P.O. Box 516, St. Louis, Missouri 63166		10. PROGRAM ELEMENT PROJECT, TASK AREA & WORK UNIT NUMBERS 24030440
11. CONTROLLING OFFICE NAME AND ADDRESS Flight Dynamics Laboratory AF Wright Aeronautical Laboratories Wright-Patterson AFB, Ohio 45433		12. REPORT DATE March 1982
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) Aeronautical Systems Division (ASD/PMRNA) Wright-Patterson, AFB, Ohio 45433		13. NUMBER OF PAGES 195
		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number)		
Aircraft Display Formats Pictorial Display Formats Vertical Situation Display Formats Horizontal Situation Display Formats Head-Up Display Formats		Head Down Display Formats Contact Analog Display Formats
20. ABSTRACT (Continue on reverse side if necessary and identify by block number)		
Volume III of the Pictorial Format Study is a literature review that examines previously designed displays concepts. These displays represent ideas that have been developed over the last three decades. Specifics include the Army-Navy Instrumentation Program (ANIP) that commenced in the early 1950's and led into the Joint Army-Navy Aircraft Instrumentation Program (JANIR) in the 1960's. Although many of these display formats have never flown in an aircraft because of the lack of a display medium, they have been compiled and serve as an		

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

20 (Continued)

cont excellent data base for the development of new display formats.

This section of the study contains a bibliography of over 150 sources.

Volume I of this report contains Pictorial Display Formats generated during this study and Volume II examines preliminary software requirements for generating those formats.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

PREFACE

The report covers work performed for the Air Force Wright Aeronautical Laboratories, Flight Dynamics Laboratory (AFWAL/FIGR) under Contract No. F33615-80-C-3601. Dr. John Reising served as the project manager. The work was performed by the Advanced Crew Station Project Group, Advanced Engineering Division of McDonnell Aircraft Company, St. Louis, Missouri.

The author would like to thank all those who assisted in generating this document including Dr. John Reising, Dr. Lloyd Hitchcock, and especially Capt. C. J. Kopala of AFWAL/FIGR who provided invaluable help in locating many sought after documents. A significant contribution was made by Gerry Jensen at MCAIR.

The invaluable assistance in preparing this report is acknowledged of: Tom Blethroad, Carol Cotner, and Carol Auchly.

TABLE OF CONTENTS

<u>SECTION</u>	<u>Title</u>	<u>PAGE</u>
I	INTRODUCTION	1
II	VERTICAL SITUATION DISPLAYS	3
	2.1 Skeletal Analog VSDs	4
	2.2 Contact Analog Formats	62
	2.3 Sensor Generated Formats	112
III	HORIZONTAL SITUATION DISPLAYS	116
IV	MISCELLANEOUS DISPLAYS	146
V	CONCLUSIONS	160
VI	REFERENCES	161
VII	BIBLIOGRAPHY	167

Accession For	
NTIS GRA&I	☒
DTIC TAB	☐
Unannounced	☐
Justification	
By _____	
Distribution/ _____	
Availability Codes	
Dist	Avail and/or Special
A	



LIST OF ILLUSTRATIONS

<u>FIGURE</u>	<u>Title</u>	<u>PAGE</u>
1	VSD Formats	8, 9
2	MFD Search (Track While Scan) Display	10
3	VSD Display Format	11
4	VSD Symbology	13
5	Coordinated Cockpit Display	14, 15
6	VSD Format	18
7	VSD Format	19
8	Electronic Attitude Director Indicator	20
9	Integrated Situation Display Format	21
10	VSD Landing Mode	22
11	VSD Symbology	23
12	Flight Directors	25
13	Three Dimensional Flight Director	26
14	HUD Format	27
15	Sperry Display	28
16	A.R.L. Display	30
17	Spectocom Display	32
18	Basic Pole-Track	34
19	Flight Situations with a Horizontal Pole-Track	34
20	Pole-Track Landing Mode	35
21	Symbology for Low Level Flight	35
22	Pole-Track Perspective Display	38
23	Experimental Display Configurations	39
24	HUD Format	41
25	Combat Energy Maneuverability Display	42
26	HUD Display	44
27	Typical HUD Displays	45
28	HUD Symbology	47
29	Unreferenced Flight Director	49
30	Referenced Flightpath Display	51
31	Referenced Flightpath Display	53
32	Referenced Flightpath Display	54
33	Referenced Flightpath Display	55
34	Referenced Flightpath Display with Flightpath Index	56
35	Referenced Flight Directors	58
36	Referenced Flight Director	60
37	Contact Analog Horizon References	63
38	Contact Analog Display	65
39	Existing and Suggested Means of Integrated "Contact Analog" Display	66
40	Vertical Display	68
41	Douglas A.N.I.P. Display	69
42	Conceptual Takeoff Displays	70
43	Contact Analog Display	71
44	Contact Analog Display	72
45	VSD Formats	73

LIST OF ILLUSTRATIONS (Continued)

<u>FIGURE</u>		<u>PAGE</u>
46	Contact Analog Display with Pathways	74
47	Contact Analog Display	76
48	Path Configurations	77
49	VSD Flight Path Mode	79
50	Path-in-the-Sky Head-Up Display	80
51	Vertical Display Presentations	81
52	Vertical Display Presentations	82, 83
53	Steering Director Display Showing Aircraft Below and to Right of Desired Path	85
54	Effect of Increasing Cell Size	86
55	Three Types of Ground Texture Elements	87
56	Command Situation Display	88
57	Flight Path Display	89, 90
58	Contact Analog and Flight Path	91
59	Pictorial Display Landing Mode	92
60	Integrated Flight Displays	93, 94
61	Computer - Generated Image	95
62	Command Flight Path	96
63	Symbolic Depth-Azimuth Quickened Display	97
64	Contact Analog Display - Perspective Quickened Tracking	97, 98
65	Symbolic Input to Azimuth Predictor Display	98
66	Computer-Generated Contact Analog Display with Predictive Flight Path	101
67	The Perspective Display	102
68	Different Views of the Perspective Display as Seen from the Indicated Positions on the Localizer Beam . .	103
69	Channel Display	105
70	Proposed Flight Path Display	106
71	Tunnel Display	109
72	Tunnel Display with Vehicle Axis Cross	110
73	Command-Situation Display in Terrain Following Mode .	112
74	Head-Up Display in Automatic Terrain Following Mode .	114
75	Electronic Attitude Director Indicator with Terrain Clearance Presentation	115
76	HSD (HSI MODE) Symbology	117
77	HSD Format	118
78	Horizontal Situation Display	119
79	Horizontal Display	120
80	Horizontal Displays	121
81	Multipurpose-Navigation Display in Projected Map Mode.	122
82	Multipurpose-Navigation Display in Radar Map Mode . .	123
83	Projected Map Display	124
84	Pictorial Navigation Display	125
85	Terminal Area Map; mi per in. (7.3 KM per CM)	126
86	Terminal Area Map; mi per in. (3.65 KM per CM)	127

LIST OF ILLUSTRATIONS (Continued)

<u>FIGURE</u>		<u>PAGE</u>
87	Sample HSDs	128
88	HSD Display Format	130
89	Moving Map Display	131
90	EHSI	132
91	HSD	133
92	Battle Situation Format	134
93	Basic Map Display	135
94	HSD Symbolology for Cruise, North Up	136
95	HSD Display for Landing	137
96	Glideslope and Localizer for Landing	137
97	1D-249 Course Deviation and Relative Heading Indicator	139
98	Symbolic Pictorial Indicator	140
99	Lear LIFE (Lear Integrated Flight Equipment) Flight Director Display	141
100	Integrated Display, Station Keeping Mode	142
101	Integrated Display, Proposed Landing Mode	144
102	Long Range Intercept Display	146
103	Air Combat Maneuver Display	147
104	Integrated Engine Instrument System (IEIS)	148, 149
105	A/A Stores Management Display	151
106	Thermal Monitor Display System	152
107	Aircraft Configuration and System Monitor Display	153
108	Landing Gear Control	155
109	Thrust Vector Indicator	156
110	Aircraft Fuel Quantity Indicator	157
111	Surface Position Indicator	158
112	Aircraft Configuration Status	159

SECTION I INTRODUCTION

This report provides an overview of electro-optical, aircraft crew displays which have been previously proposed or implemented. Many of the ideas incorporated in these displays are becoming increasingly relevant to current and advanced crew stations. The technology necessary to implement many of the displays included here has only become available in recent times -- multipurpose CRTs, color CRTs, program-mable signal processors, computer control, raster/stroke CRTs, computer generated imagery, and so on. It is worthwhile now to compile previous display concepts so that they are available to display format designers working with the new display technology. Pictorial representation of information, the next step beyond symbolic representation, is within our grasp and we should take advantage of past display ideas wherever possible to make the best use we can of pictorials.

The objectives of this report are to:

- o Identify available publications covering display formats, particularly pictorial formats.
- o Compile a group of representative display formats that have previously been investigated.
- o Provide a basis for future pictorial format work.

Available display format literature reviewed is detailed in Section 6, Bibliography. We surveyed several large data bases and display programs for relevant literature. These included NASA STAR (Scientific, Technological and Research), NTIS (National Technical Information Service), CDIC (Wright-Patterson Air Force Base Control Display Information Center), Dialog, McDonnell Douglas Engineering Library, DDC (Defense Documentation Center), ANIP (Army-Navy Instrumentation Program), and JANAIR (Joint Army-Navy Instrumentation Research). Descriptions and illustrations of representative pictorial and symbolic display formats are given in Sections 2, 3 and 4.

The display formats compiled in this report contain representative formats developed for military fighters and transports, commercial aircraft, and vertical takeoff and landing (V/STOL) aircraft. This is by no means an exhaustive compilation. We did not attempt to identify every display ever conceived or investigated, yet we feel that the available literature on this subject has been sufficiently reviewed. Often our attempts were thwarted by referenced but missing documents; or by poor available copies of documents and artwork. The display formats compiled in Sections 2, 3 and 4 represent only a subset of all the displays reviewed, but a subset we consider very representative of the overall set of past pictorial and symbolic displays. The display formats in this report were selected because they were the most interesting and informative. Many also possessed symbology common to many otherwise different display formats, and as such represent many formats.

The display formats in this report are categorized into three broad categories:

- o Vertical situation displays
- o Horizontal situation displays
- o Miscellaneous displays.

Vertical situation displays are further subdivided into: skeletal analog, contact analog, and literal formats.

These categories will assist the designer by allowing him to quickly open to the section that describes the general type of display he is interested in, e.g. a designer working on a new vertical display format and interested in the various ways altitude information has been portrayed would turn to the Vertical Situation Display section and then page through it viewing the different altitude representations. Other classification schemes were tried but the one used seemed to be most efficient.

The format for the display section is: category, title, figure, description, and reference. Titles, figures, and descriptions are taken from the referenced documents wherever possible. Multiple examples of a display format are often provided to highlight different situations, modes or symbology.

2. VERTICAL SITUATION DISPLAYS

The Vertical Situation Display (VSD) presents command and situation information superimposed on a synthetic or sensor-generated representation of the forward view of the real world. The basic dimensions of this type of display are azimuth and elevation. A change in aircraft heading or horizontal flight path is shown on such a display as lateral displacement or translation of the symbology. A change in aircraft pitch or vertical flight path is shown as vertical displacement of the symbology. Aircraft roll is shown as a rotation of the symbology.

The VSD presentation of the real world permits the pilot to fly at night and under instrument flight rules (IFR) almost as instinctively as he does in visual contact flight. He is presented with familiar references which undergo realistic and expected changes when the aircraft's attitude is changed.

Basic parameters suited to display on a VSD include:

- | | |
|-----------------------|------------------------------|
| o Pitch Attitude | o Velocity Vector |
| o Roll Attitude | o Flight Path |
| o Heading | o Ground and Sky Planes |
| o Mach/Airspeed | o Low Light Level Television |
| o Altitude | o Forward Looking Infra-red |
| o Command Information | o Terrain. |

In addition to presenting the pilot with a rapid, qualitative indication of present attitude, the VSD also presents quantitative information such as pitch, roll, heading, altitude, airspeed and vertical velocity. The vertical display can have specialized modes for takeoff, terrain-following/avoidance, enroute, weapon delivery and landing.

VSDs can be presented either head-down or head-up. Head-down VSDs have been the most common since all aircraft information has historically been presented on the main instrument panel. Thus, we have seen the attitude director indicator (ADI) as the most common VSD. This electro-mechanical instrument, typically mounted centrally on the main instrument panel, portrays aircraft attitude in relation to the horizon. Its importance to the pilot is shown by the fact that a smaller backup ADI is located not far from the prime central area of the main instrument panel, just in case the primary ADI fails. The information provided by this instrument is essential for the pilot to fly.

In recent years technology has allowed the head-up position to be utilized for vertical situation information. The head-up display (HUD), from the use of an iron gunsight to the present day wide field-of-view holographic HUD, has given the pilot the flexibility of flying the aircraft while looking forward out of the crew station.

The HUD display superimposes pertinent flight and mission information on the pilot's forward field-of-view of the outside world by means of a combiner. The HUD permits the pilot to maintain visual contact and geographic orientation with the real world and simultaneously assimilate displayed information. Information is more rapidly and easily evaluated when graphically superimposed upon the real world background with which its meaning can be correlated.

The following review of vertical situation displays is subdivided into three categories: 1) skeletal analog, 2) contact analog, and 3) literal.

2.1 SKELETAL ANALOG VSDs

The skeletal VSD portrays the real world with only the barest essentials. Carel (Reference 1) characterized the skeletal display as one which shows "the relationships between a set of inherently related variables by use of a pictorial code." He felt that because flight was dynamic the kinematics of a display had to emulate those of the external visual environment. The way each symbol moved in relation to other symbols was just as important as what form the symbol took.

Skeletal VSDs trade pictorial realism for a more highly stylized and abstract form which uses symbology to convey the real world situation in qualitative and quantitative terms. Often real world cues are simplified to provide more distinct pilot cueing. Exaggeration or distortion of symbology and even using symbols with no real world counterparts can clarify situations and increase precision.

The criteria for choosing symbology for skeletal VSD formats are simply that symbols must be clearly discernible and discriminable from each other and can be readily identified with their real world referents (Reference 2). The information generally displayed on these formats includes attitude reference (e.g., pitch ladder), horizon, aircraft symbol, rotation reference (e.g., roll index), airspeed, altitude and vertical speed indicators as well as other information pertinent to various phases of flight.

Head-up displays represent an extreme in skeletal abstraction. Because HUD symbology is superimposed over the real world counterparts, the problem of proper registration has been a critical one. Therefore HUD formats up to the present have been directed toward less pictorial realism and more skeletal symbology. A typical HUD will display any combination of the following basic information plus specialized information that is required for flight performance:

- o Height
- o Vertical velocity
- o Speed, as Indicated Airspeed (IAS), True Airspeed (TAS) or Mach No.
- o Angle of attack
- o Pitch Attitude
- o Roll Attitude
- o Heading
- o Flight Director and velocity vector in navigation mode
- o Flight Director coupled to ILS in landing mode
- o Weapon delivery symbology
- o Warning symbols

Reviews by Orick (Reference 3) and Green (Reference 4) both give extensive comparisons of HUD symbology on several aircraft.

Head-down displays have also utilized skeletal symbology. The questions of how much information on a display is enough (or too much) and how to generate real world pictorial information have forced many format concepts to the skeletal symbology.

DESCRIPTION:

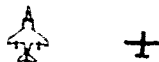
Following are some brief descriptions of various symbology. These are common symbols used on vertical and horizontal displays.

Horizon - The basic reference for attitude in the real world is the horizon. Obviously, a line is the appropriate symbol for this purpose. It may be solid or gapped and may or may not extend all the way across the display. It should be longer than minor pitch lines, and distinct in some way from major pitch lines.



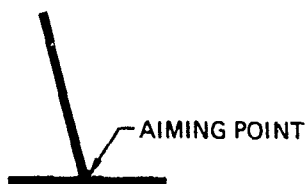
Aircraft Symbol - A number of symbol shapes are considered appropriate for displaying one's own aircraft reference. The desired elements of this symbol are: 1) its pointer function which provides a reference for attitude and perhaps other items such as angle of attack; 2) its gapped center which provides a clutter-free zone to minimize obscuration of other symbols moving in this area; 3) its center dot which establishes a fixed display center reference point, null reference point, and index mark.

The preferred shape is considered superior to alternates because it is especially good for use with the recommended, steering symbol shape, it provides the least obscuration, and it has pictorial qualities. In regard to the latter the "wings" and "wheels" also afford meaningful vertical orientation cues against a dynamic background.

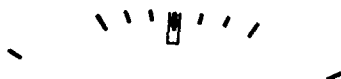


For HSDs a small pictorial aircraft symbol has the virtues of common usage and universal meaning. It serves as a pointer but does not seriously obscure cartographic or other symbols in the same area.

Pitch Lines - Although the horizon is considered to be the basic pitch reference, incremental marks are needed for more accurate reading. Scale type symbols are appropriate for such use. The selected configuration should be readily distinguished from the horizon. Positive and negative values should be clearly indicated. The lines should not be so pronounced in luminance, size, or rendition as to obscure other symbols or to distract from overall display interpretation. When the horizon is outside the field of view major pitch lines should be readily identified as to value and direction.



Roll Scale - The use of a scale to depict roll is generally accepted. A center reference mark with 10° increments to 30° is ordinarily used. Additional marks at 60° and 90° points may or may not be required.



Steering - The recommended symbol for steering is both pictorial and compatible with preferred aircraft reference symbol designs. At the null position a complete aircraft symbol results from the combination of respective symbol shapes, i.e., wings, tail, and wheels (or fuselage) are represented when the steering and aircraft symbols are joined.



The preferred steering symbol is a variation of the cross, which is one of the most easily discriminable symbol shapes. Yet, unlike the cross, it is not readily confused with the common stereotype of location or target so often associated with cross symbols.

Pathway - The pathway symbol is an index of desired performance and encompasses steering, course/track, and sometimes altitude information. It provides an alternative to the steering symbol shown above. As a shape it is more closely allied with the contact analog concept.

The advantages of the recommended shapes are that they afford an easily discriminable pointer in pictorial form. Deformations can be used to indicate parameters such as altitude and course. Obscuration is minimal at symbol apex.

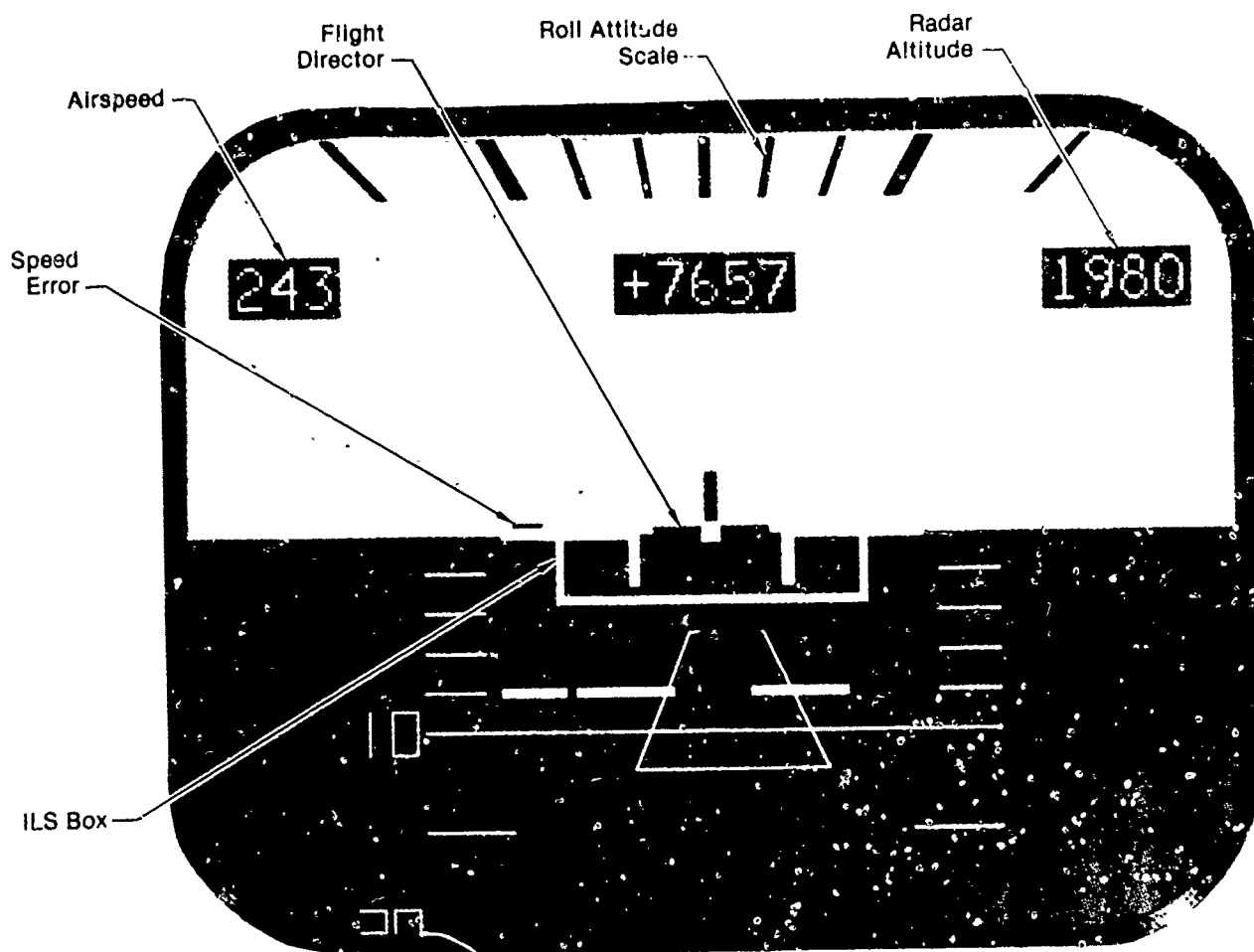


This symbol should be used exclusively as a command symbol, and not as a velocity vector.

Runway/Landing Site - A trapezoidal shape is recommended for representing the runway and landing site, particularly for fixed wing aircraft. Common usage and pictorial qualities are the primary reasons for this selection. The centerline is optional.



SOURCE: Ref 5

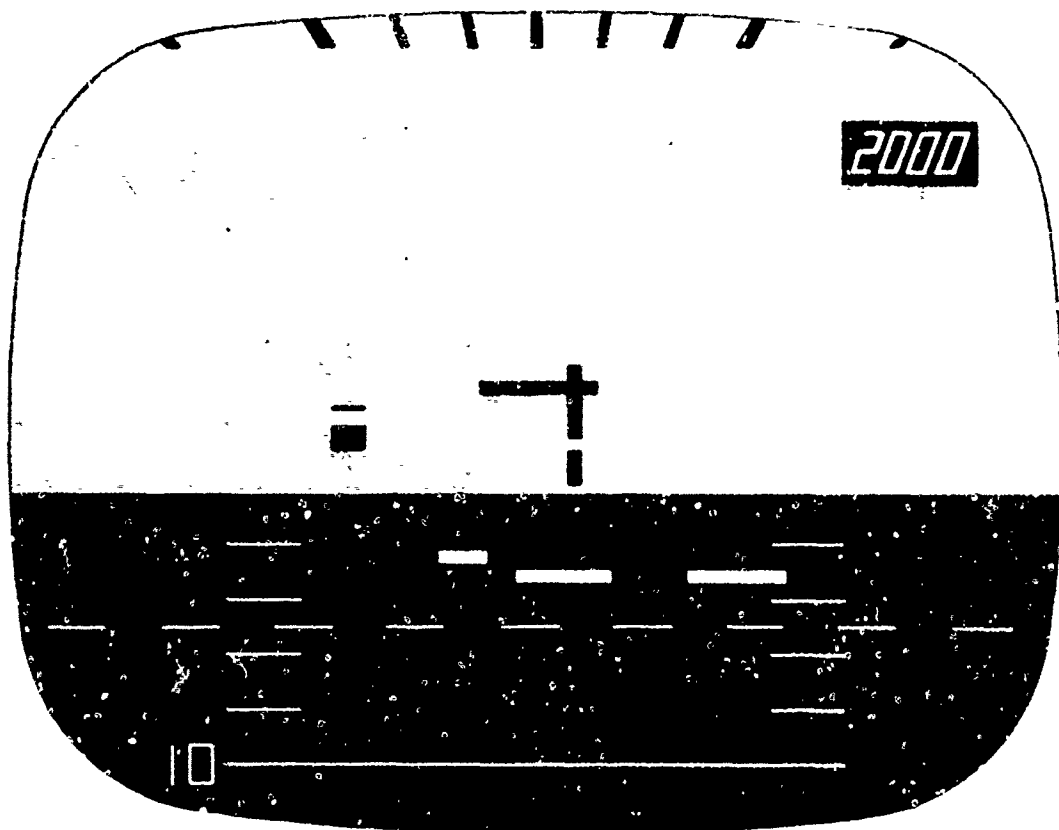


(a) Landing Symbology

Figure 1. VSD Formats

DESCRIPTION:

Figure 1 depicts vertical situation display formats developed by Sperry Flight Systems Division. In (a) the format is for landing symbology on an electronic attitude director indicator (EADI) for a short take off and landing aircraft. Symbology is provided for airspeed, altitude, pitch, shy/ground shading, flight director, roll indices and marker, aircraft reference and runway image.



(b) Flight Display Symbology

Figure 1 (Continued). VSD Formats

In (b) symbology is shown for an EADI for the C-141 aircraft. Altitude is shown numerically in the upper right corner but airspeed is shown graphically by the box on the left member of the aircraft reference. The position of this box relative to the aircraft reference indicated if the aircraft was on, over or below the commanded airspeed. Symbology is a combination of stroke and raster.

These displays, configured in the early 70's, portray the state-of-the-art in electronic attitude indicator formats. They were able to adapt the display format for a specific situation or mission segment (e.g., approach and landing, cruise).

SOURCE: Ref 6

Figures reproduced courtesy of Sperry Flight Support Division.

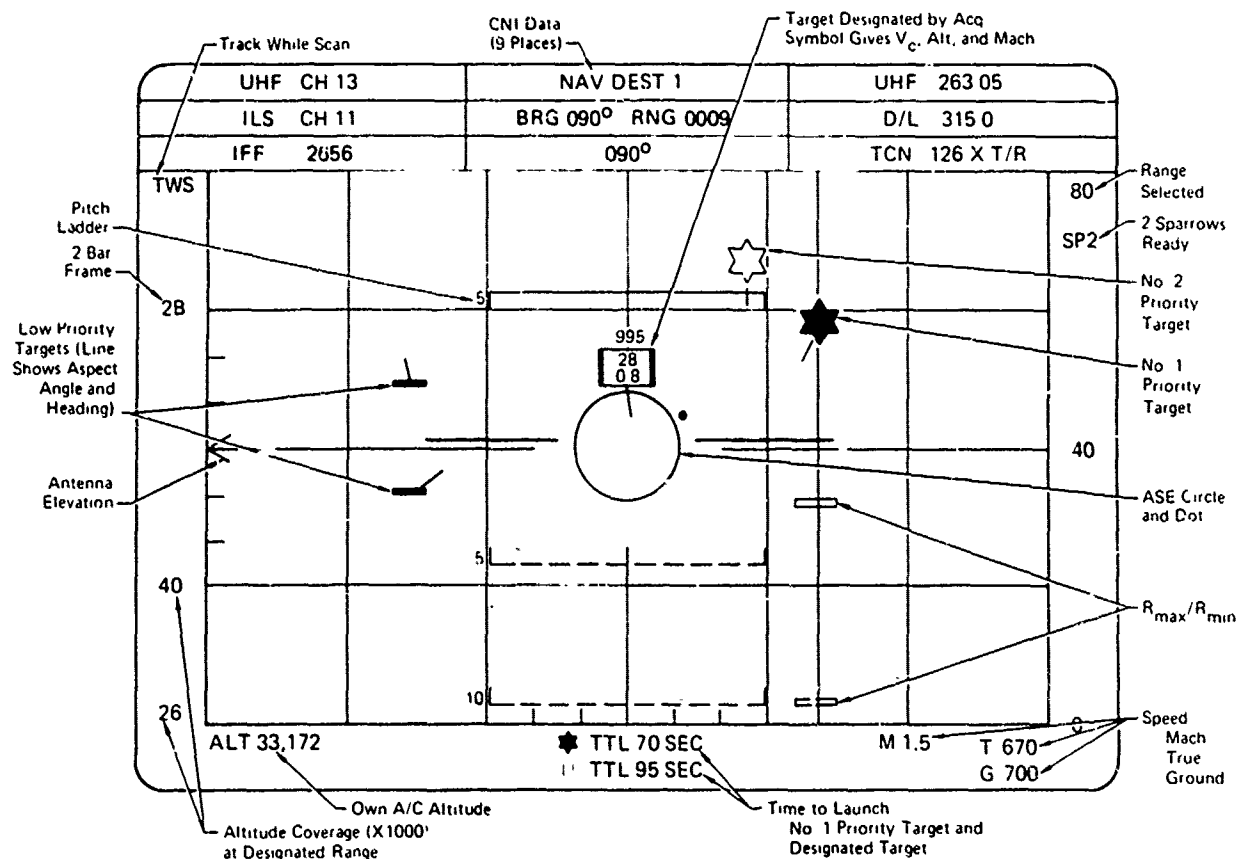


Figure 2. MFD Search (Track While Scan) Display

DESCRIPTION:

Figure 2 shows a vertical situation and radar format for a fighter aircraft. Symbolry shown is for an air-to-air radar track-while-scan mode display. The top of the display brings together in one centrally located area, the Communication, Navigation, and Identification data associated with the Up-Front Control located immediately above the MFD. As shown in the figure, radar targets are coded according to priority, with closing velocity, altitude, and Mach number read outs available for any target by designating it with the acquisition symbol. Scan-to-scan correlation for up to eight targets may be displayed.

SOURCE: Ref. 7

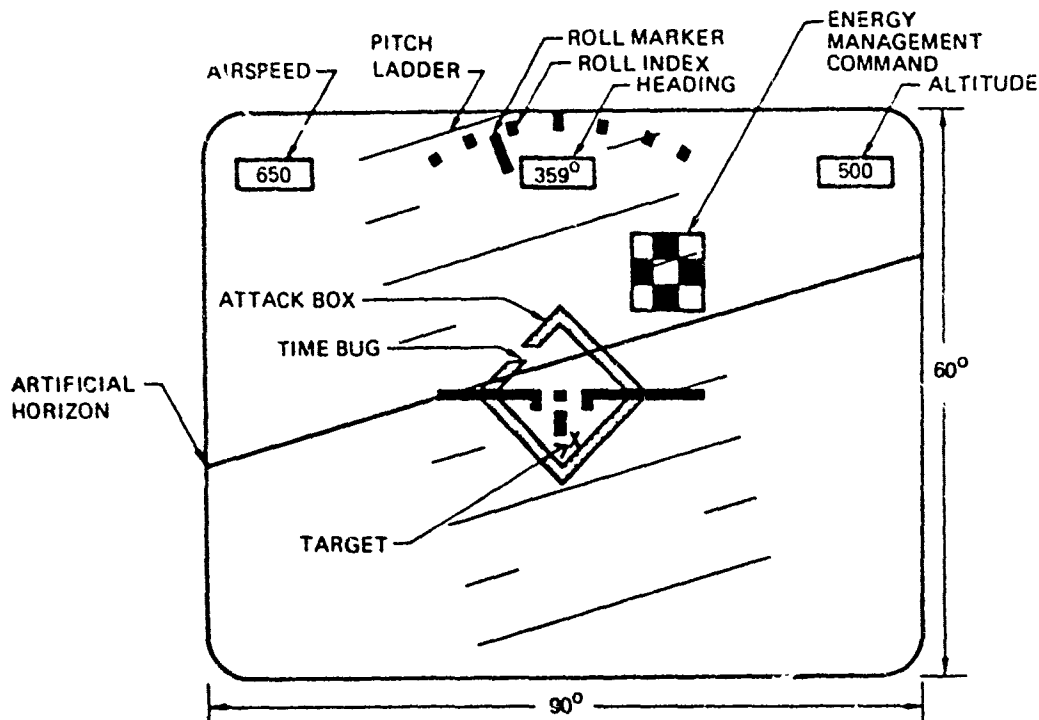


Figure 3. VSD Display Format

DESCRIPTION:

Figure 3 presents a conceptual vertical situation attack format for a fighter aircraft. The aircraft symbol indicates that the aircraft is in a dive as may be seen from its relationship to the horizon bar. Yaw is indicated by the double vertical bars near the center of the aircraft symbol. The energy control director (ECD) may be seen to the right.

The rate of elongation to the desired pitch angle is mechanized to conserve energy by programming the ideal g schedule to the optimum angle of attack under the given conditions. Simultaneously, the rectangle on the right, similarly through the rate of elongation indicates ideal roll rate to the desired bank angle to minimize energy loss due to adverse yaw at that specific angle of attack and drag due to control deflection. It programs the bank angle, again in deference to normal acceleration. The box directs energy requirements along the longitudinal axis. Since altitude represents a form of energy and the mass and drag of the aircraft is known, it may be exchanged for thrust independently or with the throttle directly affecting the box behavior. When longitudinal energy requirements are met, the box is contiguous to the outer tips of the squares. Since a command pitch up and pitch down or turn left and turn right will not occur simultaneously, two of the command indicators will always be squares. A larger than "on energy level" box commands an increase; conversely, a smaller box commands a decrease in longitudinal energy.

A target designation cursor is placed on the target manually, the designation button is used, and the computer uses the selected sensors to track the target.

After target designation, the final attack sequence begins. When the target nears the outer release envelope of the selected weapon, a fire control symbol appears. The energy management symbol is retained. The dot on the fire control symbol represents relative range rate. It appears at the 11 o'clock position and moves counterclockwise. The 6 o'clock position represents the maximum effective range for the selected weapon, and the 12 o'clock position is the minimum effective or safe firing range. The computer continually updates weapon release parameters; therefore, weapons may be dispensed at any time the dot is between the 6 and 12 o'clock positions. The fire control symbol is also used as an aiming window or reticle. For steerable weapons (Walleye, Bullpup) the size decreases with decreasing range, compensating for the weapon maneuver reduction as the target is approached. Nonsteerable weapons require the same aiming accuracy throughout their release envelope; therefore, the fire control symbol is fixed in size for these weapons. Breakaway is represented by a large X on the display.

The weapons on board may be programmed sequentially for use on a single target in a descending order of the weapon's maximum release or firing envelope. In the case of overlapping envelopes, fire control information is dedicated to the maximum range weapon unless the pilot overrides it. Upon reaching minimum range of the weapon, the fire control information for the next weapon in succession is displayed.

SOURCE: Ref. 8

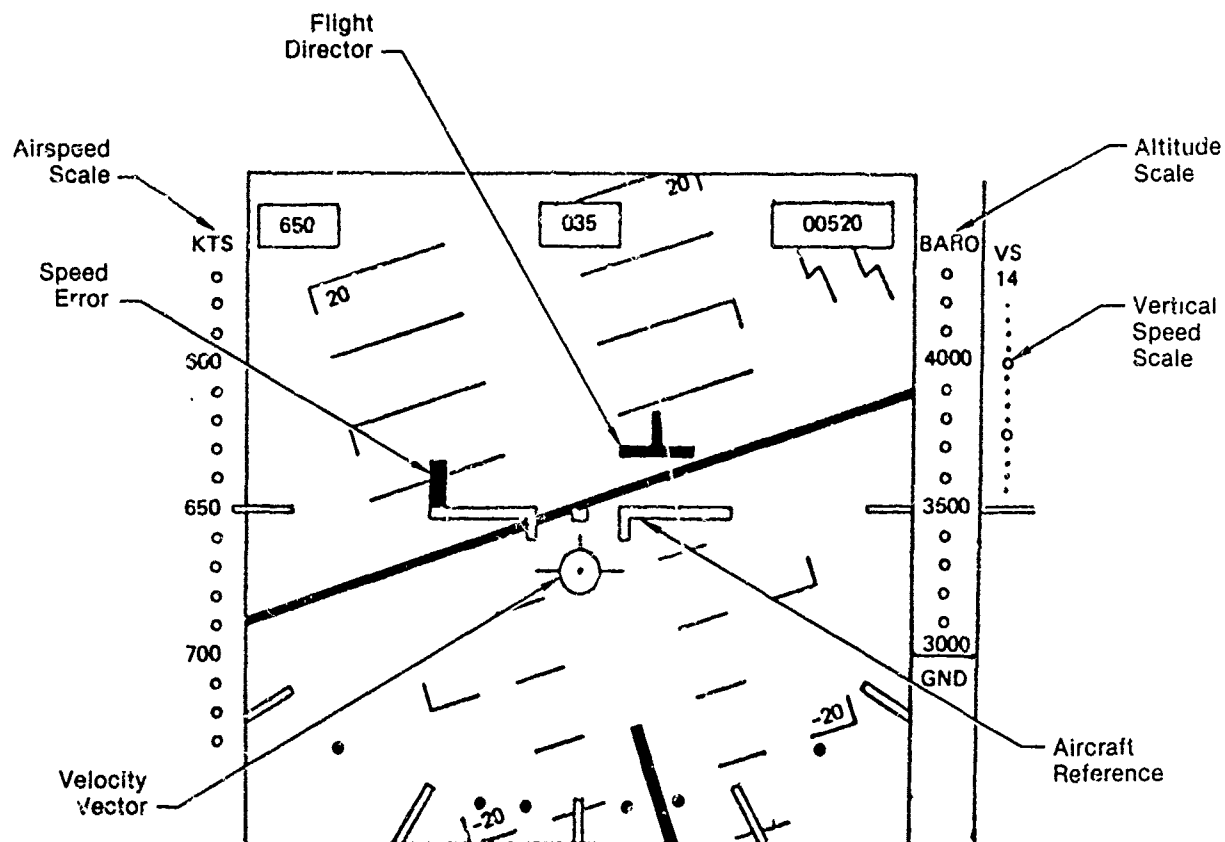


Figure 4. VSD Symbology

DESCRIPTION:

Figure 4 shows a sample vertical situation format. This display incorporates moving vertical scales for airspeed, altitude, and vertical speed. This format was proposed to meet previous pilot complaints about overall clutter, lack of trend information on air data and heading presentations, and lack of flight path or velocity vector information.

SOURCE: Ref. 8

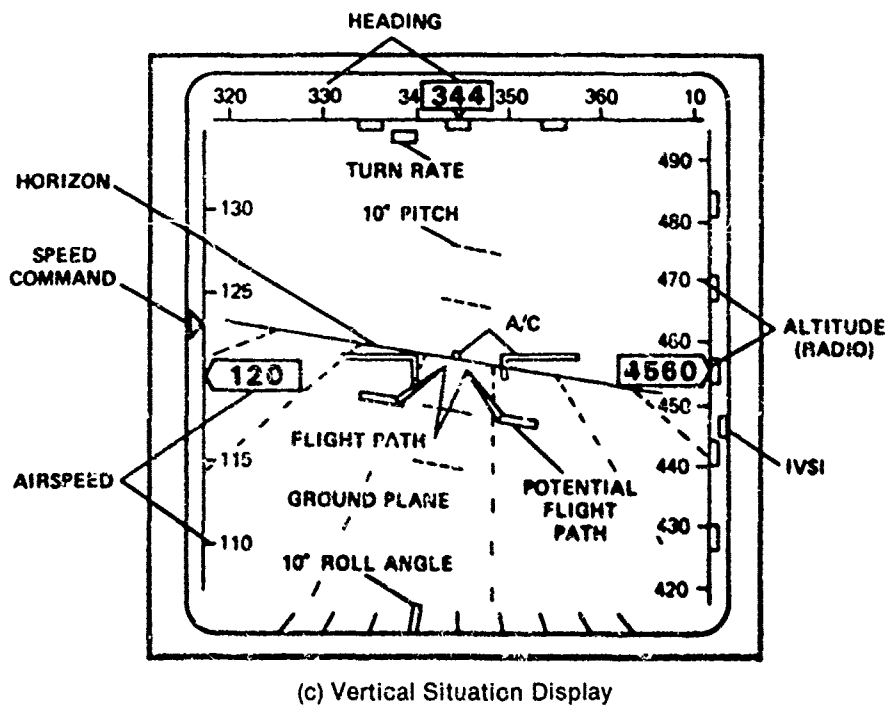
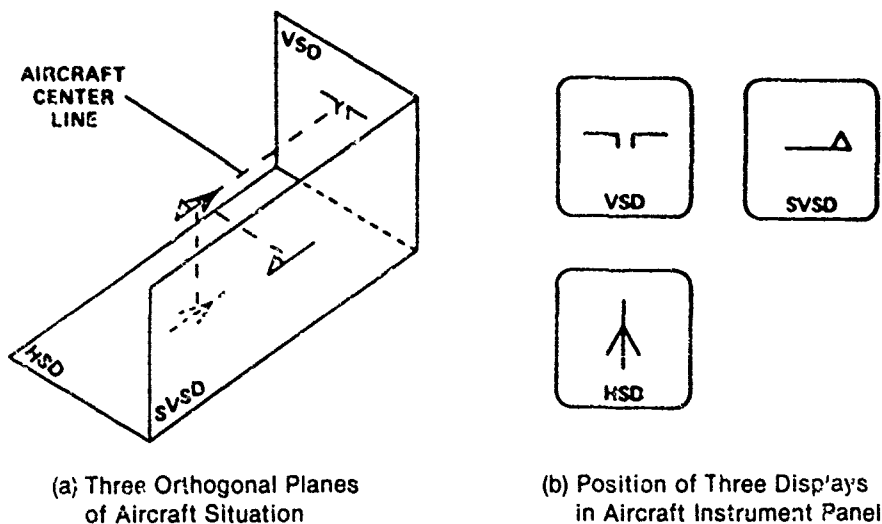
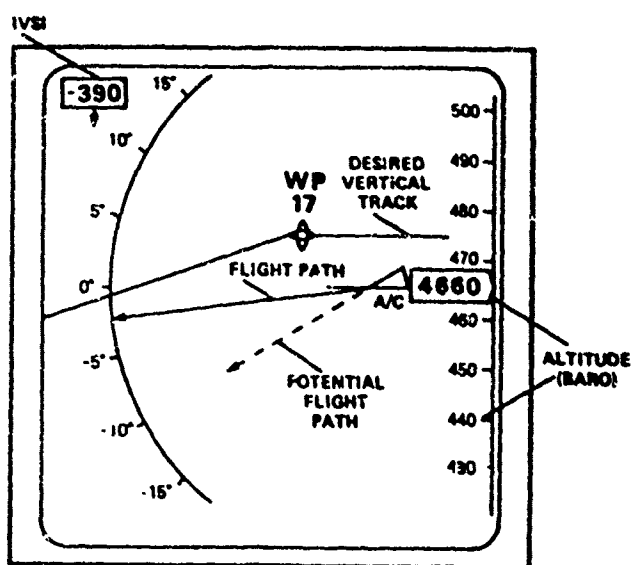


Figure 5. Coordinated Cockpit Display

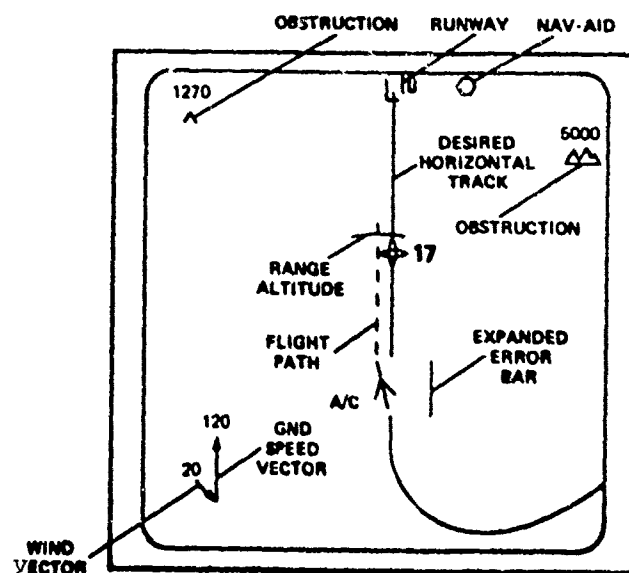
DESCRIPTION:

The Coordinated Cockpit Display (CCD) concept was designed to provide unambiguous total flight situation information. The new displays were structured such that the pilot could easily interpret all data relevant to a safe and efficient completion of his flight. Each display explicitly represents two dimensions in space and shares one of those two dimensions with each of the other two displays.

The Coordinated Cockpit Display (CCD) concept of a three display design is quite simple (Figure 5 (a) and (b)). However, when the amount of specific information that could go on each display is considered, along with the different possible forms that could be given to each piece of information, it is clear that the implementation of CCD could become quite complex.



D. Side Vertical Situation Display



E. Horizontal Situation Display

Figure 5 (Continued). Coordinated Cockpit Display

VSD - This is the primary display for aircraft attitude. Since everything is referenced to the direction of flight, the center of the display can easily become overly cluttered with aircraft symbol, horizon line, pitch marks, runway symbol, and other aiming points. For this reason, everything that might logically go on this display cannot be accommodated at the same time. One configuration of the VSD is shown in Figure 5 (c).

This method of showing the attitude situation is fairly standard, a combination of aircraft symbol (fixed), horizon line, and roll angle marker. The ground plane is differentiated from the sky plane by a perspective dot pattern. It is believed that the most important function of these dots is the ground-plane/sky-plane differentiation and secondarily the general "streaming" effect of the passing ground.

The performance information that will have to be read most precisely during critical maneuvers surrounds the central attitude display. The altitude, airspeed, turn rate, and instantaneous vertical speed indication (IVSI), are displayed adjacent to the appropriate moving tape.

Two pieces of information, flight path angle (FPA) and potential flight path angle (PFPA), have been combined into one symbol. In Figure 5 (c), the midpoint of an imaginary straightline joining the two tips of the FPA marker is the actual direction of aircraft flight at a given moment. This point is also called the aiming point and a line extending from the aircraft toward this point in the real world is called the velocity vector. This symbol can be used to show flightpath angle relative to the horizon or to any spatially located point such as a three-dimensional (3-D) waypoint, runway threshold, or another aircraft.

The PFPA is referenced to the FPA. When the PFPA is level with the FPA, the acceleration along the aircraft flight path is equal to zero; therefore, speed is constant. If PFPA is above FPA, the acceleration is positive and speed will increase; if PFPA is below the FPA, acceleration is negative and speed will decrease.

SVSD - The side vertical situation display, Figure 5 (d) is intended to relate present aircraft altitude to future altitude requirements. The aircraft symbol remains fixed at the altitude digital readout box. Placing the aircraft symbol near the altitude box accomplishes two purposes: (1) the aircraft altitude reference is explicitly established, and (2) a second altimeter is provided as required for certain operations. The altitude on the VSD is from radio and the altitude on the SVSD is barometric. To enhance terrain altitude awareness, significant terrain features can be shown referenced to the moving altitude tape.

Flight-path angle and potential flight-path angle are accurately read against an expanded angle scale. The aircraft symbol rotates about its midpoint to indicate aircraft attitude.

An IVSI digital readout in the upper left corner supplies vertical speed information. An arrow appearing above or below the box reinforces the sign information regarding up or down velocity of the aircraft.

A segmented line moving toward the aircraft symbol indicates the desired vertical track. Relevant tags are shown at waypoints, marker beacons, and so forth.

HSD - The horizontal situation display, Figure 5 (e), relates the aircraft to its geographic position. This may be shown as aircraft position relative to a desired course line, navigation aids, waypoints, runways, or prominent geographic features, all of which would be shown. The range altitude symbol shows the point at which the next waypoint altitude will be reached if the present vertical component of the velocity vector is maintained.

SOURCE: Ref. 9

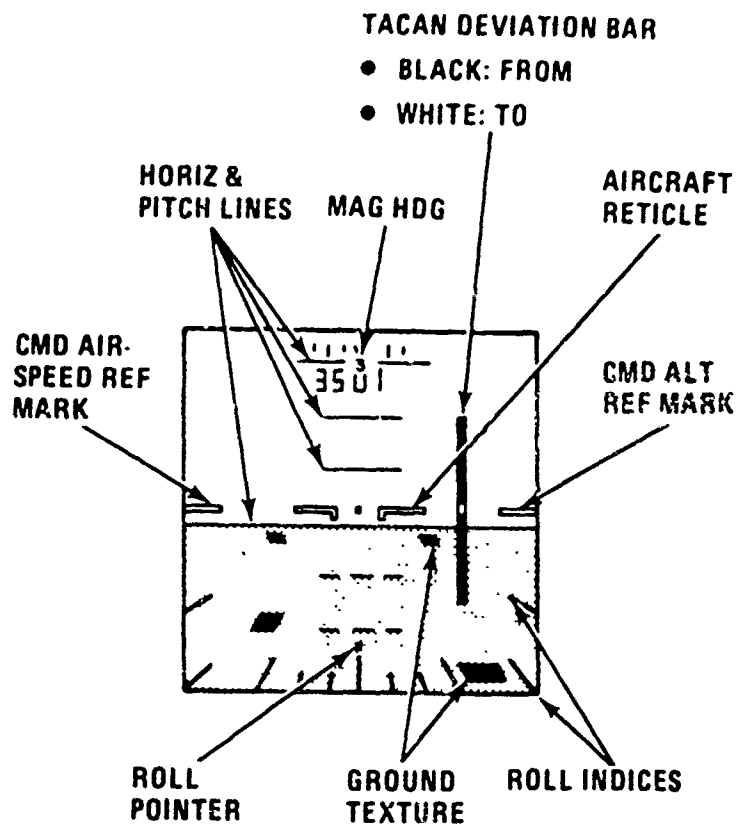


Figure 6. VSD Format

DESCRIPTION:

The format shown in Figure 6 is from the F-14's visual display indicator. It is in the takeoff mode/TACAN submode. This is one mode of the head-down vertical situation display in the F-14. (No additional information was available.)

SOURCE: Ref. 10

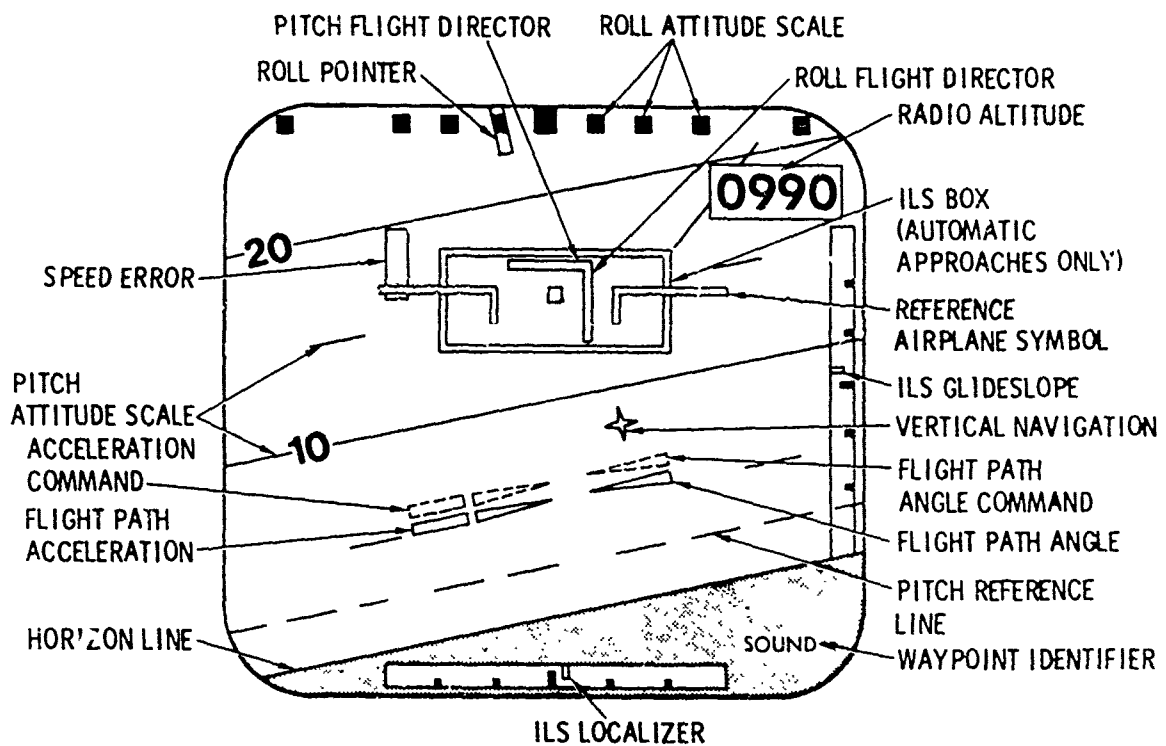


Figure 7. VSD Format

DESCRIPTION:

The VSD format illustrated in Figure 7 shows the types of information that can be provided by a digital flight management system. Not all the information shown in the figure is displayed simultaneously. Some of the data shown is mode dependent so that the display is not as cluttered as indicated. (No additional information available.)

SOURCE: Ref. 11

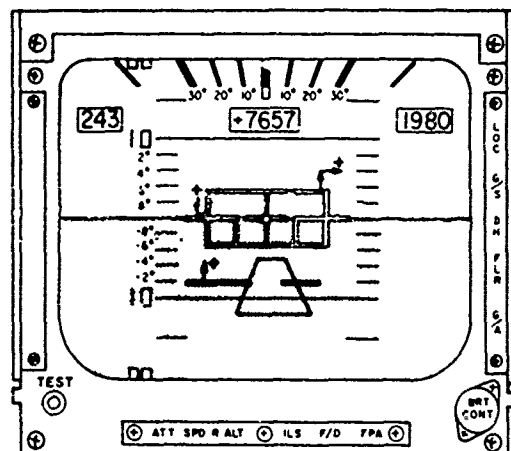


Figure 8. Electronic Attitude Director Indicator

DESCRIPTION:

Figure 8 shows an integrated electronic attitude director display EADD in the landing mode. This figure illustrates the wealth of information that can be displayed to the pilot in any given mode (Here, the landing mode). Information shown could be deselected by the pilot or complemented with additional information. This is a key advantage of the EADD.

SOURCE: Ref. 12

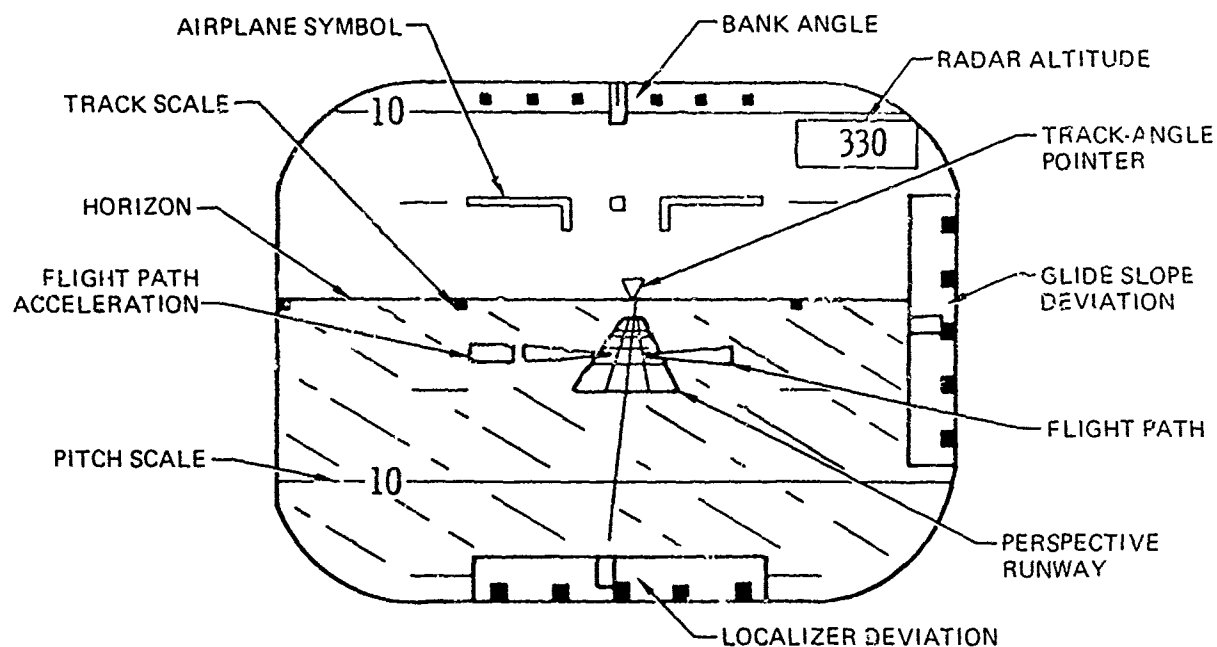


Figure 9. Integrated Situation Display Format

DESCRIPTION:

Figure 9 illustrates a VSD landing format. While this format shows mainly vertical situation information, the localizer deviation indicator at the bottom of the display provides a measure of horizontal flight information. (No additional information available.)

SOURCE: Ref 13

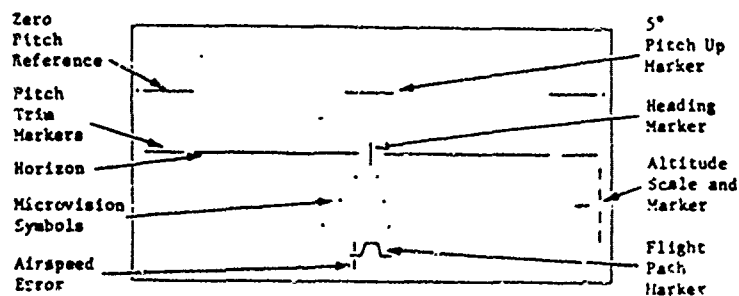
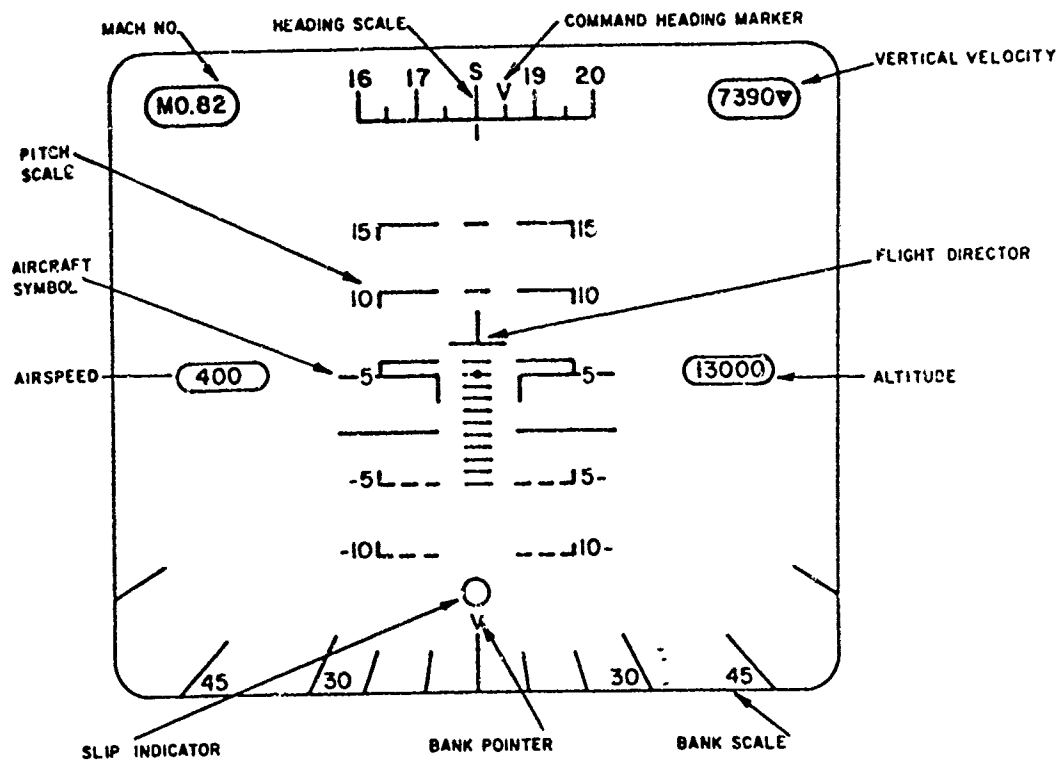


Figure 10. VSD Landing Mode

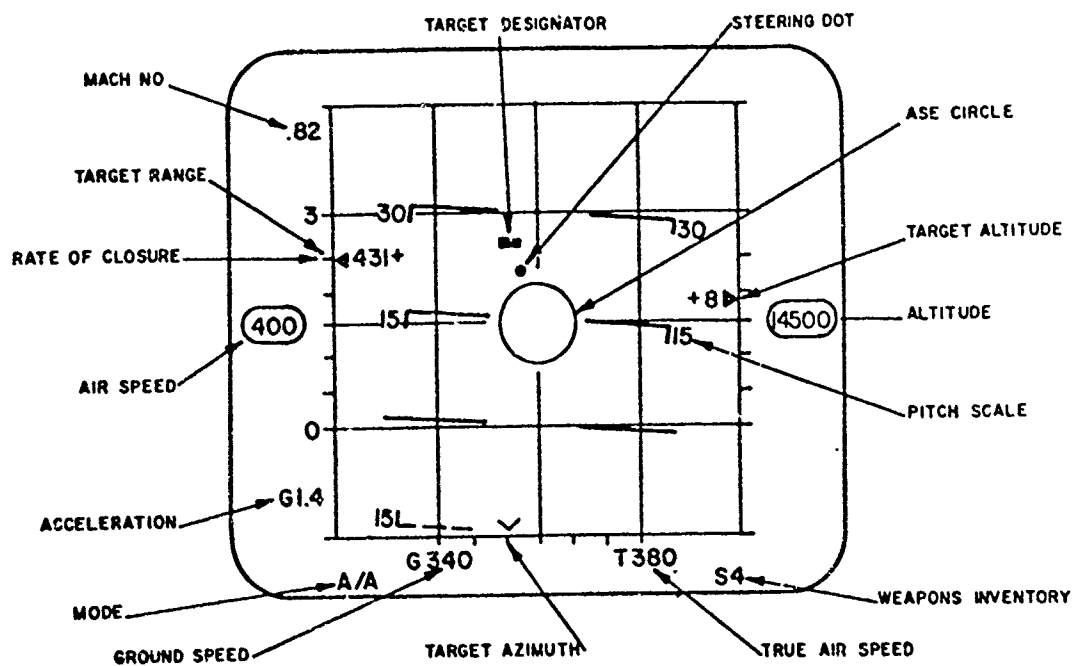
DESCRIPTION:

The VSD format in Figure 10 is for a head-up landing display. The display as shown is stroke written. The display unit is a binocular device presenting a collimated image. Transponders located along the edge of the runway are displayed in this format. En route, terrain avoidance and weapon delivery modes are also available. (No additional information available.)

SOURCE: REF 5



(a) Air-to-Ground Weapon Delivery



(b) Air-to-Air Attack Mode

Figure 11. VSD Symbology

DESCRIPTION:

The VSD must display TV-type information, as well as alphanumerics and vector-graphics. Of all cockpit displays, the VSD is perhaps the most critical for flight safety. It is simultaneously the display that requires the most information integration and content variability.

Representative VSD display formats are shown for air-to-ground weapon delivery, Figure 11(a), and air-to-air attack, Figure 11(b). It must be remembered that video information (i.e., TV) can be superimposed on this symbology at all times. (No additional information available.)

SOURCE: Ref. 14

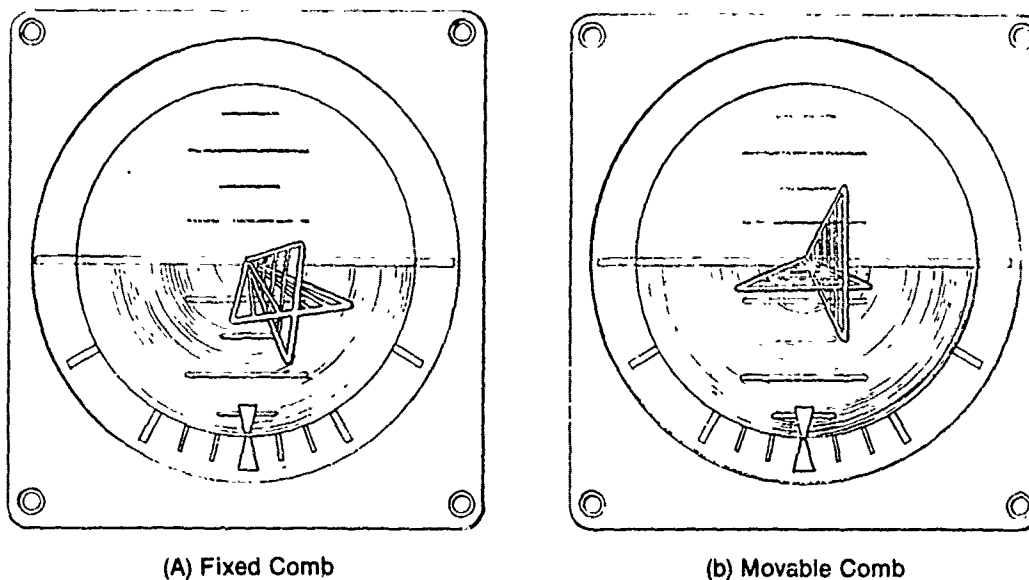


Figure 12. Flight Directors

DESCRIPTION:

The flight director in Figure 12 (a) consisted of three dimensional permanently fixed crossed planes. These planes were pivoted from their apex. As can be seen, the vertical lines in the vertical directors changed angles as the director was tilted up or down. This did not create a favorable impression with pilots.

Figure 12 (b) shows an alternate flight director configuration utilizing separate vertical and horizontal "combs". These combs moved independently of each other, thereby maintaining vertical and horizontal alignment. This arrangement gave a very realistic image of a flight path in the sky and the position of the aircraft with relation to the desired flight path.

These displays were electromechanical in nature.

SOURCE: Ref 15

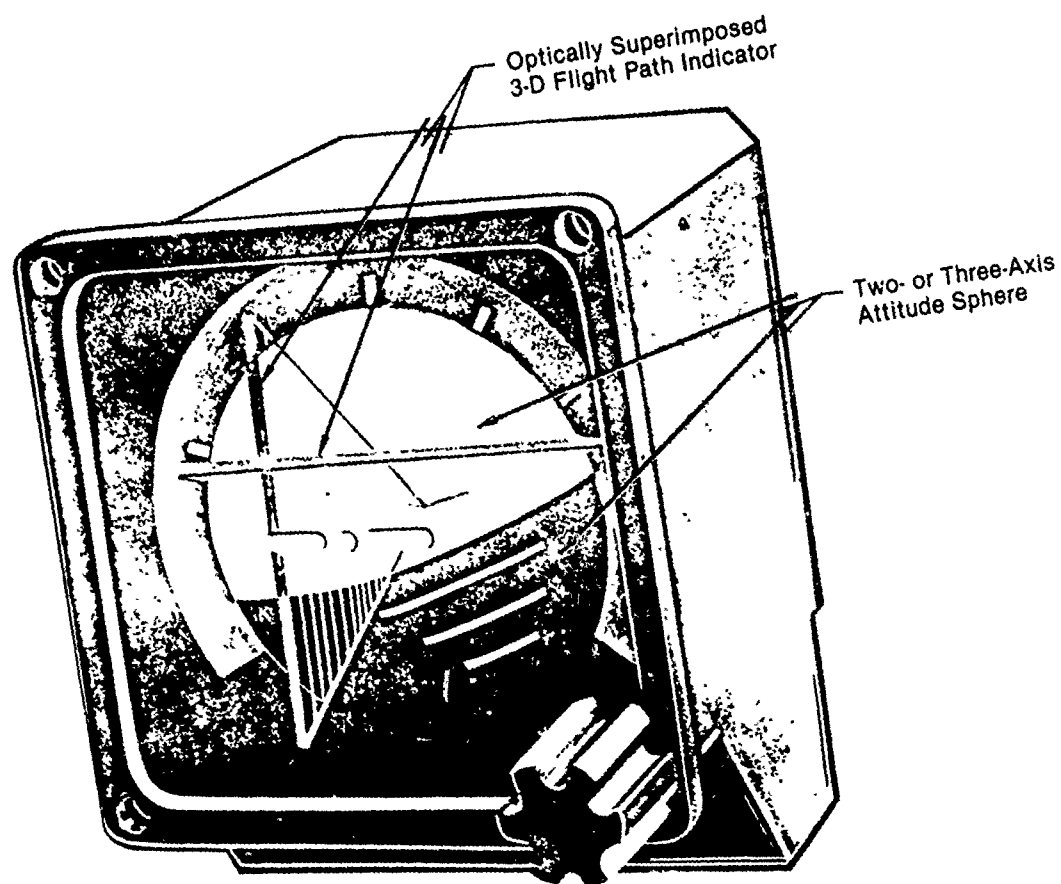


Figure 13. Three Dimensional Flight Director

DESCRIPTION:

The integrated display in Figure 13 is an optically superimposed three-dimensional flight path indicator of the "Phantom-Plane" type on an attitude indicator. It is an electromechanical display. This optically integrated system would show the "phantom" director planes in front of a two- or three-axis sphere with the vanishing point of the planes at the reference center of the sphere. The miniature reference airplane would be mounted in the plane of the cross members at the face of the instrument and thus would be oriented properly with the director system. Such a display would be realistic with its three-dimensional cue and would lack the clutter of a system restricted to two-dimensions. When the director display was not required, it could be optically removed from the picture and the attitude indicator used alone.

SOURCE: Ref 15

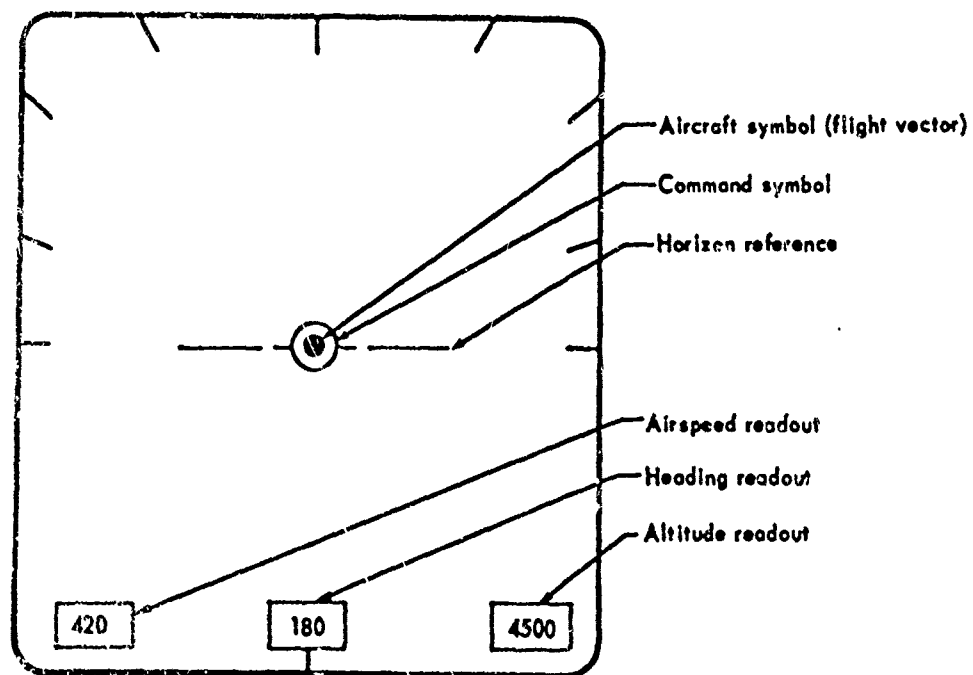


Figure 14. HUD Format

DESCRIPTION:

The HUD format shown in Figure 14 is austere in nature, displaying only basic flight information. The pilot is provided with the necessary information to fly head-up. Needless clutter on the display which can block pertinent ground or target information in the pilot's forward field of view have been kept to a minimum. The digital readouts of airspeed, heading, and altitude along the bottom of the display provide excellent quantitative information but at the expense of trend data. Pitch reference is by inference of the distance between the aircraft symbol and the horizon reference. (No additional information available.)

SOURCE: Ref 16

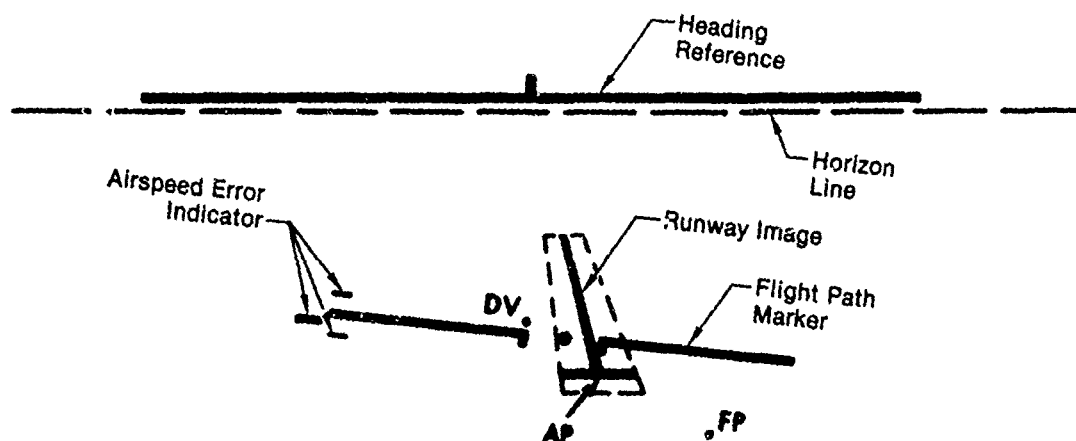


Figure 15. Sperry Display

DESCRIPTION:

The Sperry landing approach display for IFR conditions is shown in Figure 15. It was designed for 1:1 registration 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 upgraded to provide IFR capability by the addition of a projected runway image.

The horizon line with its heading reference was aligned with the horizontal at all times. The heading marker was set in azimuth by the pilot so that his line of sight to it was aligned with the runway heading. 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.

The flight path marker has three modes of operation: flight path mode, deviation mode, and 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 roll angle. When the flight path marker is placed on the horizon line, the aircraft is set up for zero vertical speed. Any slight rate of climb or descent is shown by a separation between the marker and horizon line.

In deviation mode the flight path marker indicates the position of the aircraft in relation to the ILS glidepath. This may be determined by defining a line of sight from the pilot's eye parallel to the ILS glidepath and finding where its intersection with the ground ILS in relation to the runway aiming point (or, in IFR conditions, aiming point image). This intersection would appear at point DV. In this mode the flight path marker would be centered on that point. Reference to the runway aiming point in Figure 15, indicates to the pilot that his aircraft is 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. 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 closes with the ILS glidepath.

In Figure 15, 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 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. The two short bars above and below the wing are indices of airspeed error and, as the flight path marker moves during aircraft maneuvers, the airspeed display moves as a whole with it.

The runway image in the form of an inverted T, defines the runway center line and aiming point. In IFR conditions it is used in place of the actual runway. The size and shape of the runway image are varied with the 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.

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.

SOURCE: Ref. 17

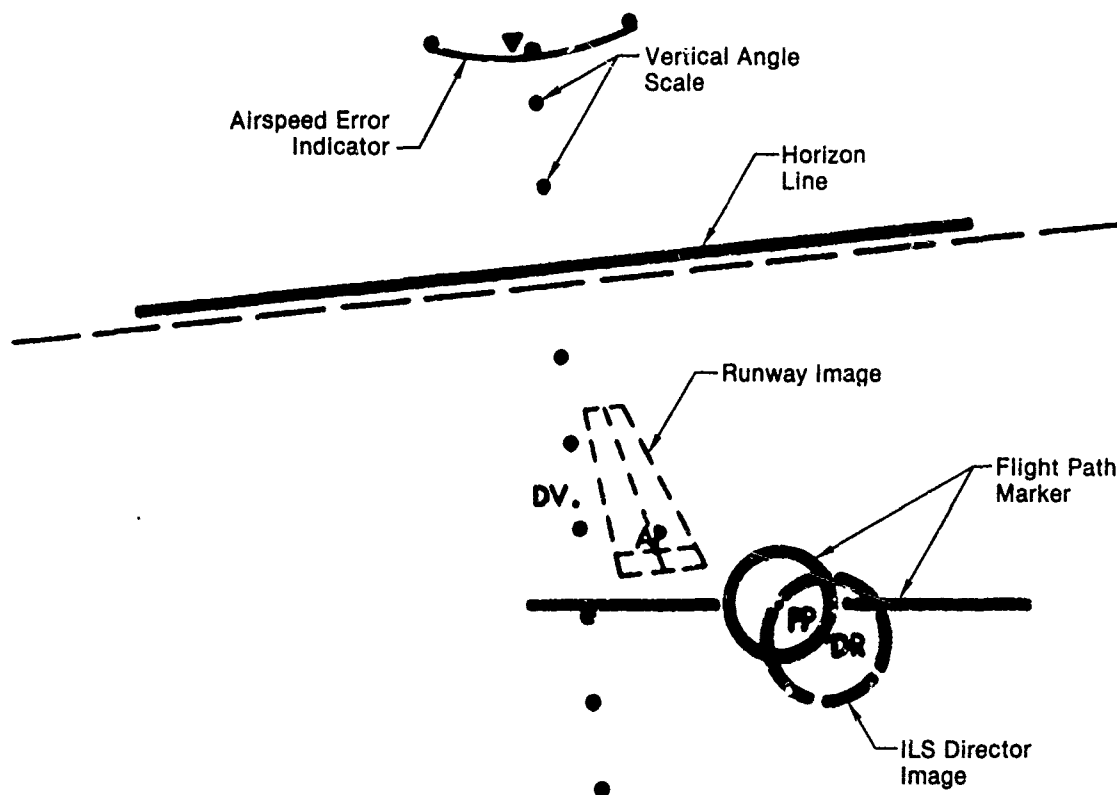


Figure 16. A.R.L. Display

DESCRIPTION:

The Aeronautical Research Laboratories (Australia) display for landing approach in IFR conditions is shown in Figure 16. It is designed to give 1:1 compatibility with the outside world and is, therefore, completely gyro stabilized and collimated to appear at infinity. The position of the runway is shown by dotted lines, but it would not actually be visible until after emerging from cloud. This display was conceived originally in 1956 based on the Sperry HUD format. The ARL display was an alternative to ground based visual glidepath systems for VFR approaches, with IFR capability provided by the addition of an ILS director image.

The horizon line with its attached scale of vertical angle was aligned with the horizontal at all times. The dotted scale of vertical angle, calibrated in degrees, was set in azimuth by the pilot for alignment with the runway heading; gyro stabilization maintained this alignment. Thus, when the aircraft was to the left of the runway center line, the dotted scale delineated a vertical plane parallel to the runway but offset to the left. When the aircraft was lined up with the runway the dotted scale appeared over the runway center-line and could be used to read off the angle of declination of the aiming point, which was equal to the angle of elevation of the aircraft from the aiming point.

The flight path marker (FP) represented the projection of the aircraft flight path relative to the ground and gave an indication of roll angle.

The procedure for VFR approach was to line-up the aircraft with the vertical angle scale over the runway and approach in level flight until the runway aiming point was at a suitable angle of declination from the aircraft; for a 2.75° approach, it would be at point DV. The aircraft would then be nosed down, placing the flight path marker on the runway aiming point (AP) and holding it there.

The ILS director image was used in conjunction with the flight path image to a flight director commands during IFR approaches. In the case illustrated in Figure 16, 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.

An airspeed error indication gave an indication of variation from a desired airspeed set by the pilot. The central point on the scale represented the desired airspeed and any increase in airspeed was shown by a movement of the pointer to the right.

SOURCE: Ref. 17

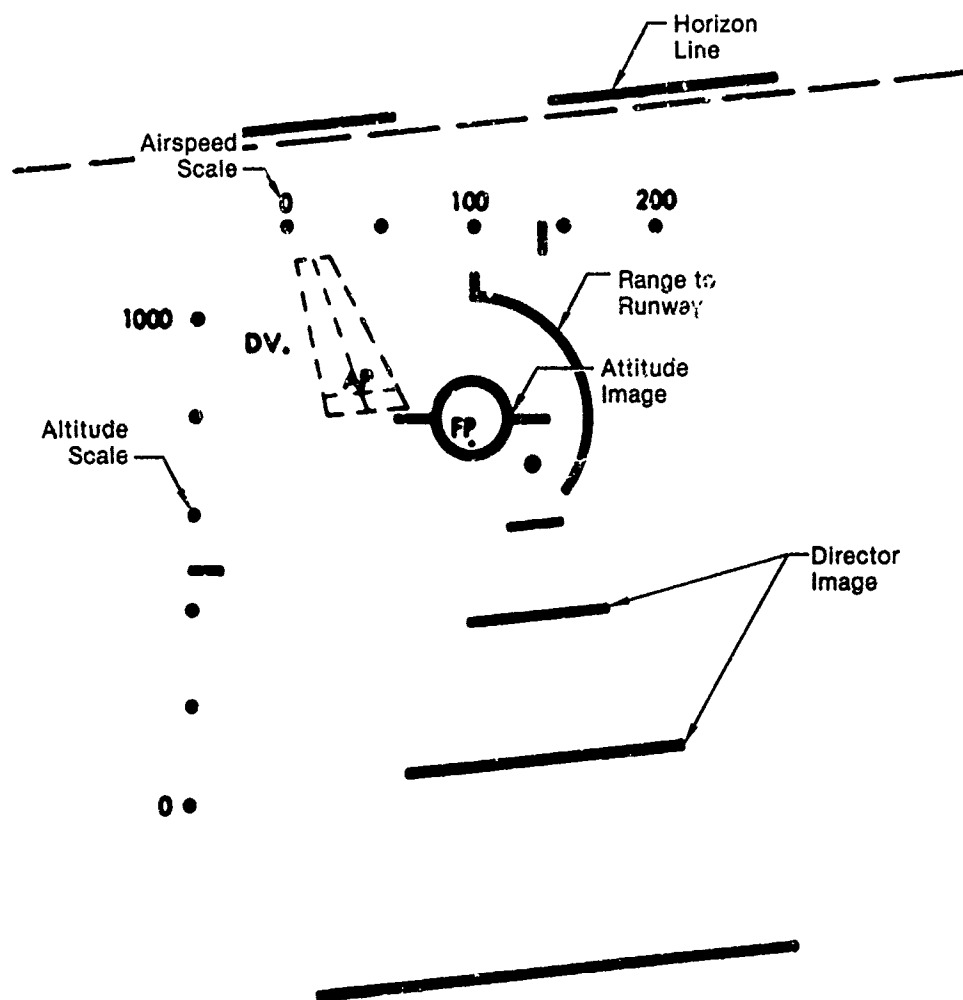


Figure 17. Spectocom Display

DESCRIPTION:

The Spectocom display, produced jointly by Specto, Ltd., (England), and Computing Devices of Canada, Ltd., was 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 was, however, fully collimated to appear at infinity.

The display shown in Figure 17 is for landing approach in IFR conditions. It does not include a runway image, but the dotted outline of the runways has been shown in the figure where it would appear on emerging from cloud.

The horizon line 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.

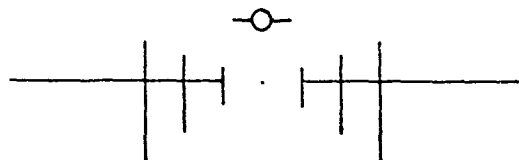
The attitude image defines a convenient reference line in the aircraft and has wings parallel to the transverse axis of the aircraft. It is fixed on the display and its relationship to the horizon line gives an indication of angle of pitch and roll.

The director image system consists of a pyramid of horizontal, logarithmically spaced lines, with a dot at its apex which works in conjunction with the attitude image as a flight director.

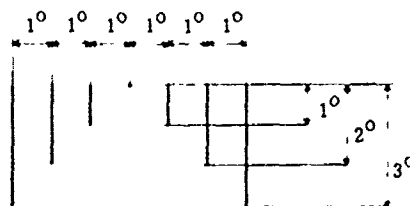
The base of the pyramid remains vertically below the center of the horizon line. The pyramid extends or contracts vertically, or leans to either side, to place the director dot where it is required to be. In the figure, the attitude image and director dot are shown slightly out of coincidence because the aircraft has not been headed down and to the right at a sufficient angle to follow the desired closure path.

A 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.

SOURCE: Ref 17

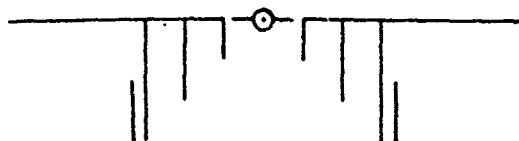


(a) Pole-Track Format

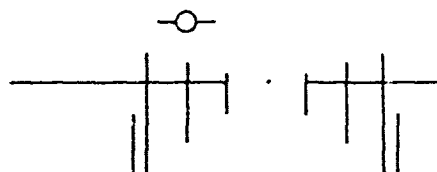


(b) Dimensions of Pole-Track

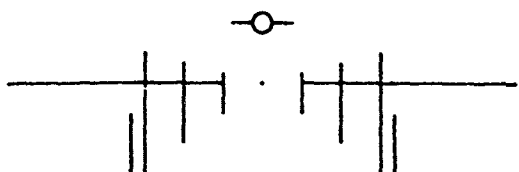
Figure 18. Basic Pole-Track



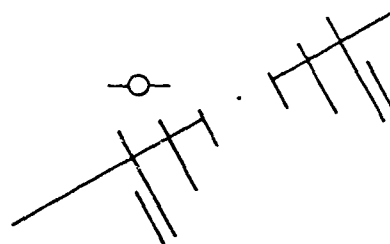
(a) Aircraft on Desired Flight Path



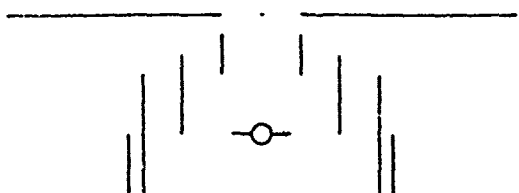
(d) Aircraft Below Desired Flight Path and Climbing
Heading Error 2°



(b) Aircraft Below Desired Flight Path and Climbing

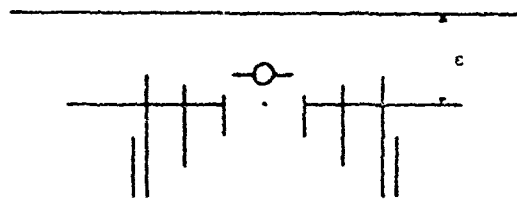


(e) Aircraft Banked 30° Right, Otherwise Same
Situation as Above.

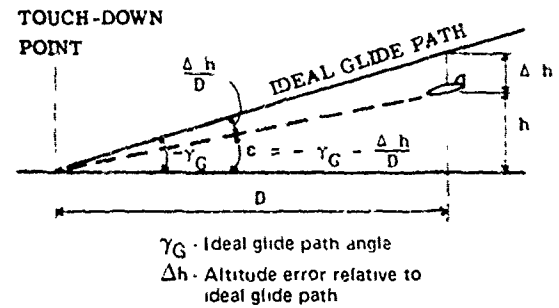


(c) Aircraft Above Desired Flight Path and Diving

Figure 19. Flight Situations with a Horizontal Pole-Track

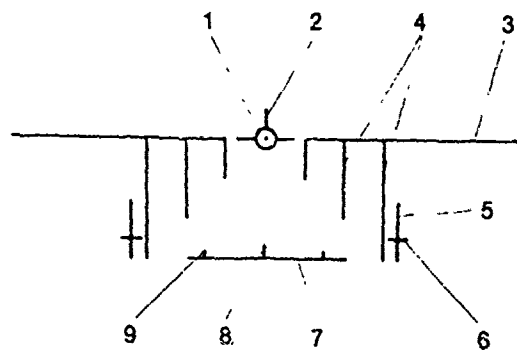


(a) Proposed Pole-Track for Landing

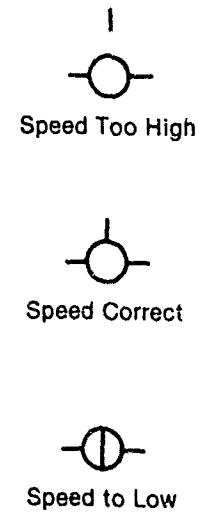


(b) Landing Geometry

Figure 20. Pole-Track Landing Mode



(a) Symbology Used for Low-Level Flight



(b) Speed Error Indicator

Figure 21. Symbology for Low Level Flight

DESCRIPTION:

The SAAB Pole-Track Display represents the flight situation in relation to a desired flight path and in relation to the ground in a simple and natural way using a perspective pole-track. The easily interpreted symbol configuration provides an immediate overall picture of the flight situation with facilities for both qualitative and quantitative readings. The design emphasis here was placed on a natural integration of height information with regard to applications of special interest concerning low altitude flight including landing.

The vertical lines Figure 18 (a), represents vertical poles standing on the ground with their upper ends at the desired height and on the desired flight path. The intersections of the horizon line with the height poles, or their extensions, represent the present altitude of the aircraft.

The six vertical poles are of constant length, subtending angles of 1° , 2° and 3° at the eye, and the distance between them is constant at 1° , Figure 18 (b). The dimensions chosen for the pole-track provide angular scales in both elevation and azimuth serve as a guide in making small, precise corrections to the direction of flight.

A pair of reference height poles adjacent to the outermost height poles, Figure 19 (a), can be added to supply the scale for the outermost height poles and serve as gauge lengths for assessment of altitude in absolute terms. The reference height poles always represent the same height, 100 m being suggested. Their length on the indicator will then be equal to that of the outermost height poles when the desired altitude is 100 m. Where a higher flight altitude is desired the reference height poles will be smaller, for say, 200 m they will be half as long as the outermost height poles. The accuracy of reading absolute altitude thus increases with decreasing altitude. A number of different flight situations represented by a horizontal pole-track are shown in Figures 19.

Landing is one case in which the height poles can rest on the ground. This makes it possible to display information about height over the ground, which is particularly important in this case. The factor that enables this to be done is that the desired glide path makes a small angle (about 3°) with the horizontal plane and that a certain approximation of the perspective representation is therefore permissible. The height poles represent height above the ground to the ideal glide path at the appropriate distance from the point of touch-down. The intersections between the height poles and the horizontal reference line through the aiming point represent present height above the ground. The length of the reference height poles (100 m) on the indicator increases as the aircraft approaches the touch-down point. The distance between the aiming point and the horizon line should correspond to the angle between a sight line to the touch-down point and the horizontal plane, Figure 20 (a). Owing to the finite distance to the touch-down point this angle will not be constant.

The complete display proposal for low-level flight, Figure 21, contains the following symbolic elements:

- o Velocity vector symbol (1)
- o Speed error indicator (2)
- o Horizon line (3)
- o Pole-track with aiming dot (4)
- o Reference height poles (5)
- o Radar height index (6)
- o Range line (7)
- o Reference index for range line (8)
- o Range markers (9)

SOURCE: Ref 18

(Figures reprinted courtesy of SAAB-Scania AB)

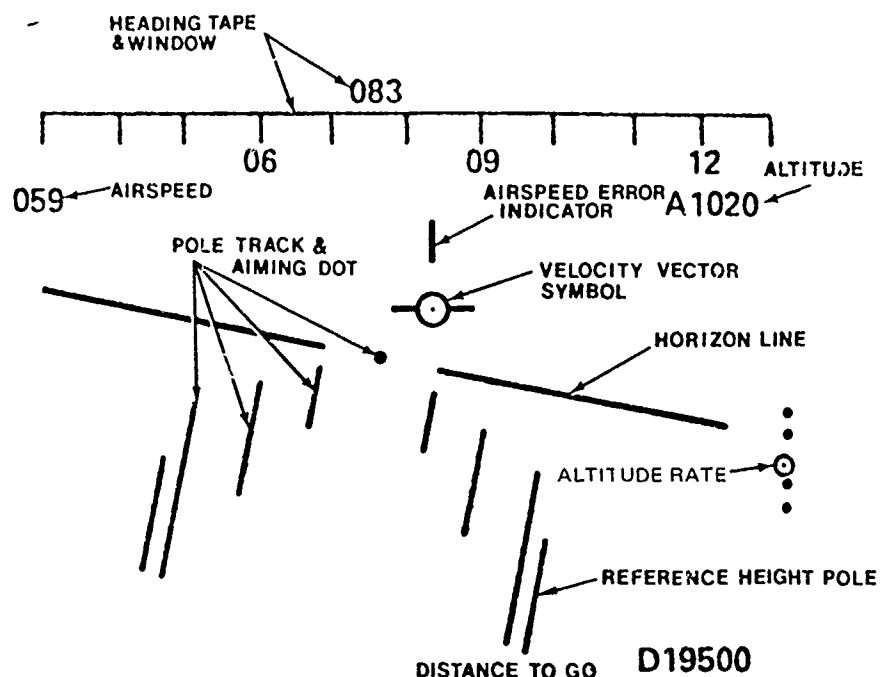


Figure 22. Pole Track Perspective Display

DESCRIPTION:

Figure 22 shows a modified pole track perspective display. Flight path angle and course are indicated by use of a velocity vector and an aiming dot in a "fly-from" orientation. Altitude error and bank information are presented in conventional "fly-to" orientations. A reference height pole is provided for determining absolute altitude. Distance of the airspeed error indicator from periphery of the velocity vector symbol indicates airspeed error. Altitude rate is indicated similar to a glideslope indicator. Digital readouts for altitude, airspeed, and distance to go appear on the display. A heading tape and window indicate heading. The pilot's task is to align the pole track and aiming dot with velocity symbol.

SOURCE: Ref 19

Figure reproduced courtesy of SAAB-Scania AB.

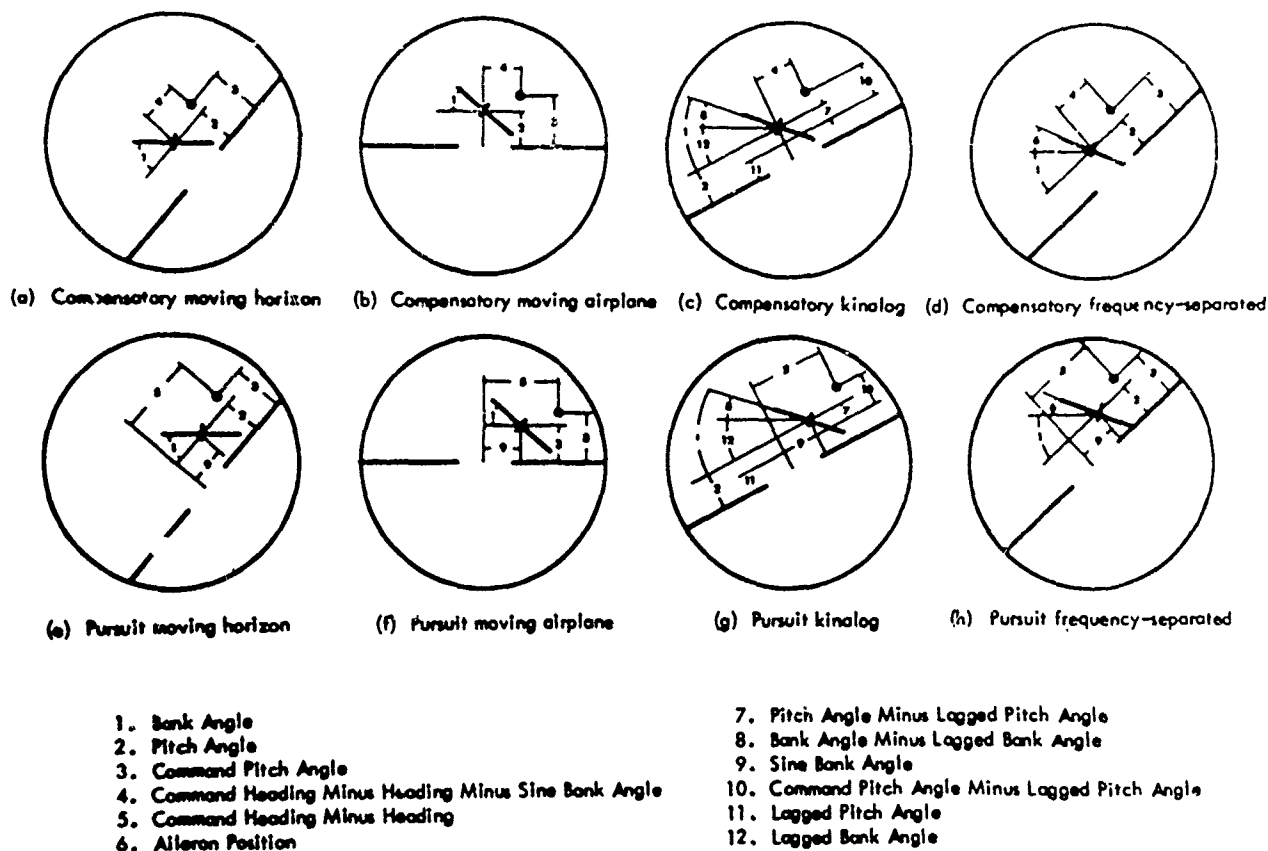


Figure 23. Experimental Display Configurations

DESCRIPTION:

The display configurations in Figure 23 employed the same three symbols, the same signals, and signal scale factors, combined in various ways, to drive the three symbols.

In the compensatory moving horizon display, Figure 23 (a), the airplane symbol was fixed in the center and oriented parallel to the X axis. The symbol representing the horizon rotated by an amount equal to the actual angle of bank, thereby maintaining a parallel relation to the real horizon, and translated from the center of the display by an amount proportional to the pitch angle of the airplane. The command steering dot translated perpendicular to the horizon line by an amount proportional to the desired pitch angle and parallel to the horizon line by an amount proportional to the command heading minus the actual heading of the airplane combined with the sine of the bank angle appropriately scaled. Therefore, after the command dot was displaced in the horizontal dimension and the pilot initiated a change in bank angle, the dot immediately moved toward the center of the display by an amount proportional to the sine of the bank angle. When the desired bank angle had been achieved and the airplane approached the command heading, the dot continued to translate in a direction opposite to its original displacement, thus calling for a lessening of the bank angle. When the airplane reached the command heading, a wings-level bank attitude was required.

In the compensatory moving airplane display, Figure 23 (b), the horizon symbol was fixed across the center of the display. The airplane symbol rotated to indicate bank angle and translated vertically to indicate pitch angle. The command dot translated vertically by an amount proportional to the desired pitch angle. Translation of the command dot in the horizontal dimension was driven by the heading command minus the actual airplane heading and the sine of the bank angle.

The compensatory kinalog display, Figure 23 (c), was implemented with the dynamics that when the pilot initiated a roll, the initial rotation of the airplane symbol was in the same direction as the roll of the airplane, as in the moving airplane presentation. As the airplane rolled toward the new bank angle, the entire display symbology slowly rotated counter to the direction of the roll of the airplane. This counterrotation occurred as an exponential decay with a time constant of five seconds. Thus, the appearance of the display asymptotically approached that of the moving horizon presentation as the airplane maintained any constant attitude. Consider, for example, the case in which the pilot rotates the airplane clockwise until a 45-degree bank is achieved as shown in Figure 23 (c). The conspicuous movement depicted on the display is a clockwise rotation of the airplane symbol. Concurrently, the entire display presentation slowly rotates counterclockwise, eventually appearing identical to the conventional moving horizon display (airplane symbol parallel to the x axis of the display, horizon line rotated 45 degrees). The presentation of pitch on the compensatory kinalog display operated in a manner similar to that of bank angle. After initiating a change in pitch, the conspicuous movement on the display was the translation of the airplane symbol in the same direction as the pitch of the airplane itself. Over time the entire display symbology translated in the direction opposite to the pitch change until it eventually became a moving horizon presentation. Translation of the command dot was driven horizontally along a line parallel to the horizon symbols by the amount of command heading minus the actual heading and minus the sine of the bank angle. The command dot translated perpendicular to the horizon line by command pitch angle.

The pursuit moving horizon, moving airplane, and kinalog display configurations shown in Figures 23 (e), (f), and (g), respectively, operated in the same manner as their compensatory counterparts with one exception. Instead of the command dot translating toward the center of the display by an amount proportional to the sine of the bank angle, the aircraft symbol moved out by an equal amount in the opposite direction. In effect, the airplane symbol was quickened by the sine of the bank angle, thereby causing it to pursue the command dot rather than quickening the return of the command dot to the center of the display. This allowed for a pure presentation of heading error on the command dot.

Performance scores indicated that differences existed within both attitude presentation and command presentation effects. Within the attitude presentation factor, the moving airplane presentation was found to be superior to the moving horizon presentation. Within the command presentation factor, pursuit command was superior to compensatory command. In addition, these two factors produced a significant interaction, the pursuit moving airplane being disproportionately superior to all others.

SOURCE: Ref. 20

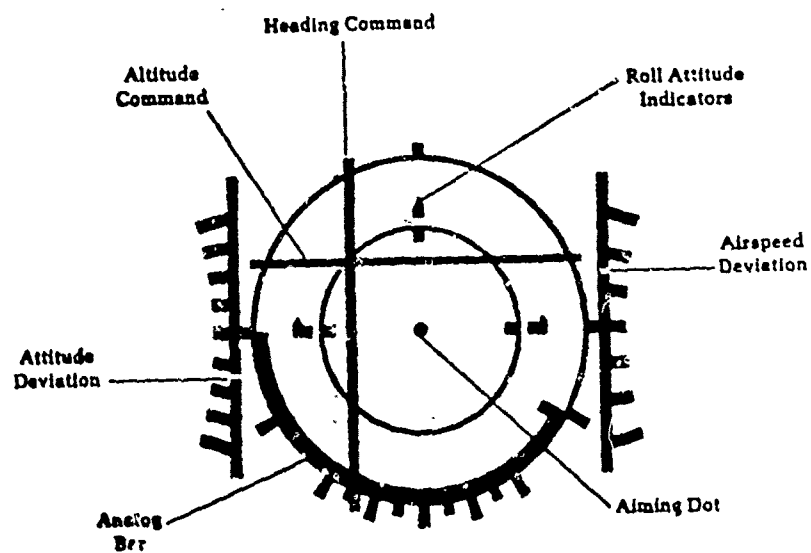
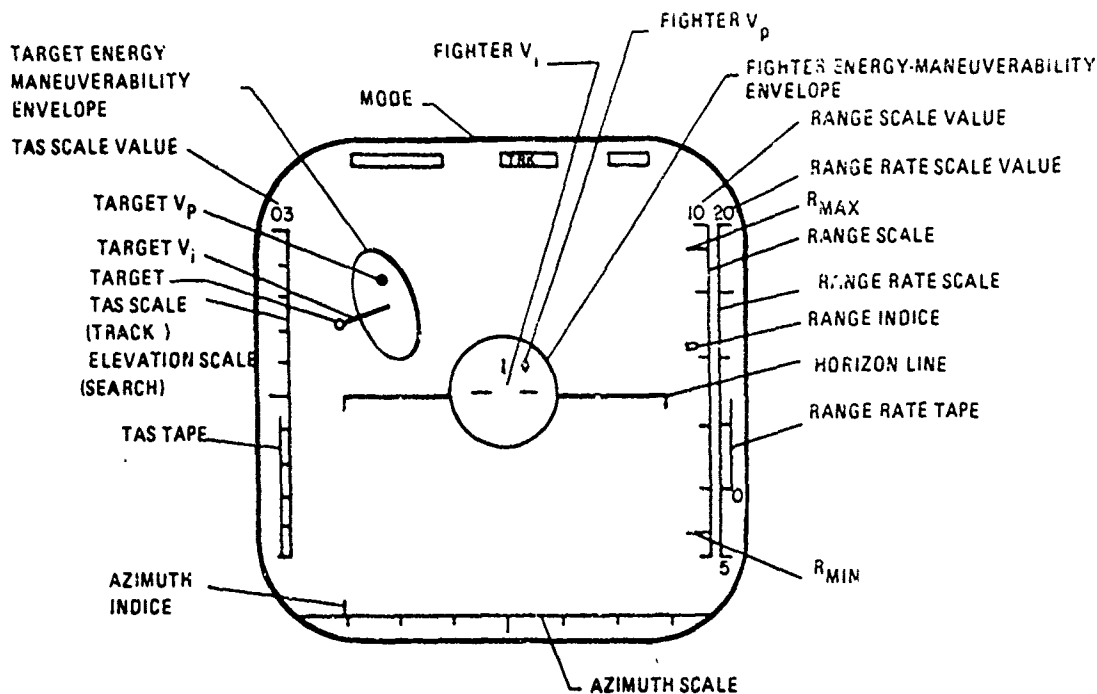


Figure 24. HUD Format

DESCRIPTION:

Figure 24 represents a sample vertical situation format suitable for HUD presentation. (No additional data available.)

SOURCE: Ref. 21



V_p - Projected velocity vector
 V_i - Instantaneous velocity vector

Figure 25. Combat Energy Maneuverability Display

DESCRIPTION:

Figure 25 represents a proposed vertical situation format for HUD presentation that utilizes an energy maneuverability envelope of own aircraft and target to aid the pilot in engaging the target. This display was generated in response to the challenge of presenting a tactical situation type display, in an air combat maneuvering sense, that compares own energy maneuverability capability with that of the adversary.

In Figure 25, the fighter present position is represented by an inverted T symbol with an open center approximately 10 mils in diameter. Since the fighter instantaneous velocity vector is always essentially directly in front of the aircraft, neglecting drift and angle of attack, the symbol is fixed in the center of the display. Drift angle and angle of attack must be factored into the computation to derive the geometrical relationship with the hostile. A horizon line, referenced to the aircraft is provided with vertical movements of +90 degrees and roll of 360 degrees. In addition, horizon tabs have been provided extending from the perimeter of the circle to provide easier correlation with the horizon line when

the aircraft pitch angle is relatively large. The energy maneuverability envelope is displayed as a one-inch diameter circle fixed in the center of the display. The projected velocity vector (V_p) is displayed as a diamond shaped symbol and is displaced within the circle as a function of that point projected into space where the aircraft will be at selected time "t" if the present state of maneuver is continued. The scaling factor of the circle represents the airspace required to execute a 90 degree coordinated maneuver. This scaling factor was chosen as an interim selection until the fire-control solution has been integrated into the computation. The 90 degree turn scale is a logical choice since in maneuvering from a head-on encounter into an offset it provides a good indication of the lateral offset desired to maneuver into a tail chase position. The symbol also provides an indication of acceleration normal to the instantaneous velocity vector assuming execution of a coordinated turn. If the symbol is driven to the circle perimeter, a maximum turn capability under the current air speed, altitude, aircraft weight, etc. is indicated. The hostile present position symbol represented a small circle approximately 2 mils in diameter is displaced relative to the fighter V_i symbol as a function of target bearing from the fighter V_i . Assuming a radar scan angle limit of $\pm x$ degrees, which is represented by the width of the horizon line, the hostile V_i symbol is displaced on a linear scale relative to the target bearing from the fighter V_i . The instantaneous velocity vector of the hostile is displayed as a line which is oriented in a true aspect angular relationship to the bearing angle between the hostile and the fighter. The hostile combat energy maneuverability envelope is displayed as a circle translating into an ellipse rotating in space as a function of hostile aspect angle relative to the fighter. The scaling factor of the hostile envelope is identical to the fighter envelope circle. The future position of the hostile is displayed as a dot approximately 2 mils in diameter and is displaced with the hostile maneuverability envelope as a function of acceleration in a direction normal to the instantaneous velocity vector. The length of the displayed hostile velocity vector is a function of hostile airspeed as computed by radar tracking. No scaling factor has been selected as yet.

To provide an analog indication of range to the hostile, the size of the hostile envelope increases from a minimum displayed size at maximum radar tracking range to a maximum displayed size equal to the fighter envelope circle when the future position of the hostile is coincident in range with the fighter maneuverability envelope.

The relative size and rate of change of the maneuverability envelopes is also a function of range-rate. The hostile displayed envelope increases in size for closing and decreases in size for opening range-rates.

It is also necessary to provide ancilliary information. This includes true air speed, target range and range-rate, and target bearing.

A true air speed tape and scale is vertically oriented along the left edge of the display with a numeric scale value readout at the top end of the tape. A range-rate scale and tape is vertically oriented along the right edge of the display with a numeric scale value readout at the top. A range scale with an associated range index is located adjacent to and to the left of the range-rate scale with a numeric range scale value readout at the top. An azimuth scale providing radar target bearing is located horizontally along the bottom edge of the display. The center of the scale represents the lubber line and is coincident with the fighter V symbol.

SOURCE: Ref. 22

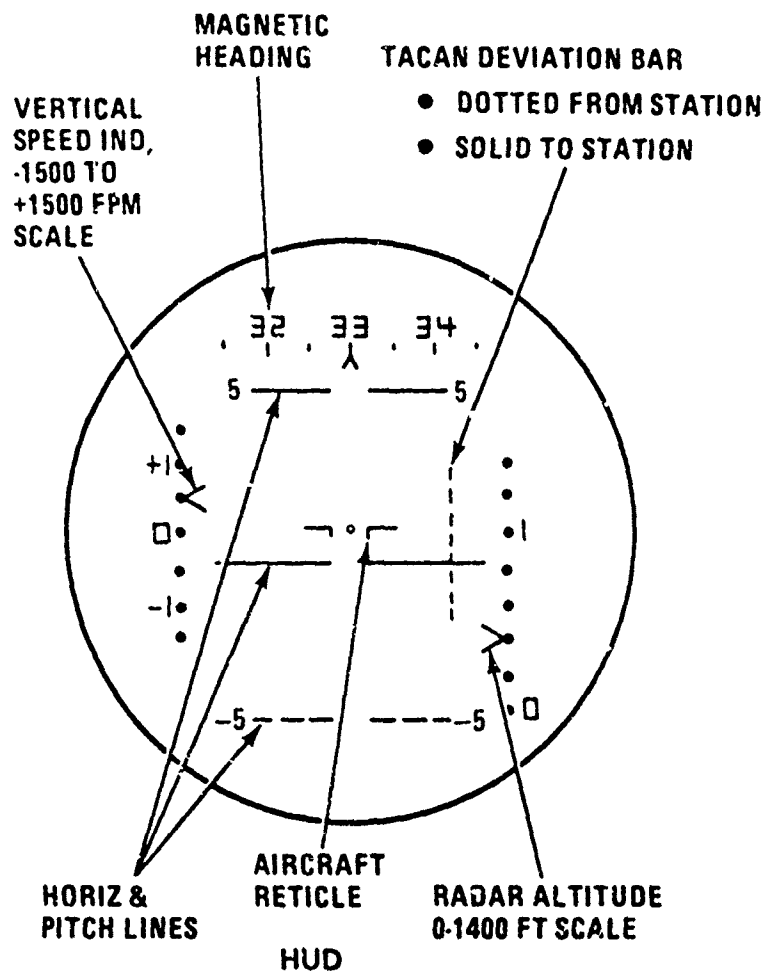


Figure 26. HUD Display

DESCRIPTION:

The format shown in Figure 26 is from the F-14's head-up display. This format is in the takeoff mode/TACAN submode. This is only one mode of the HUD in the F-14. (No additional information was available.)

SOURCE: Ref. 10

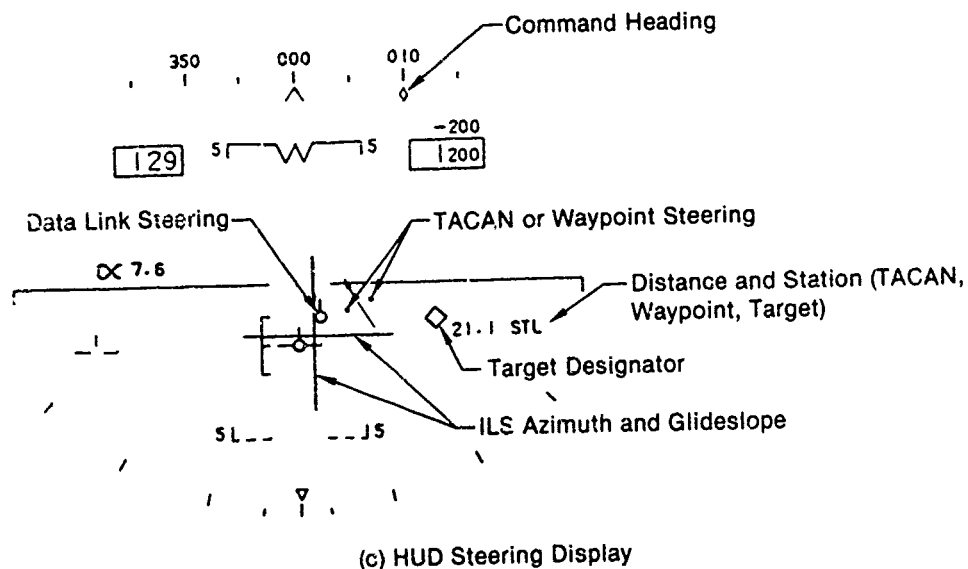
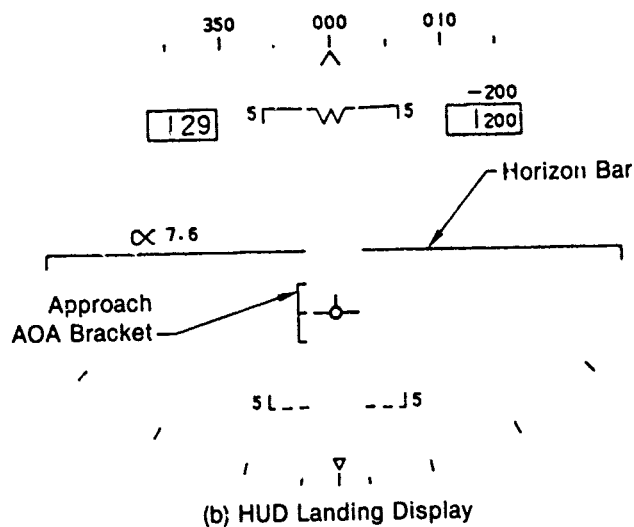
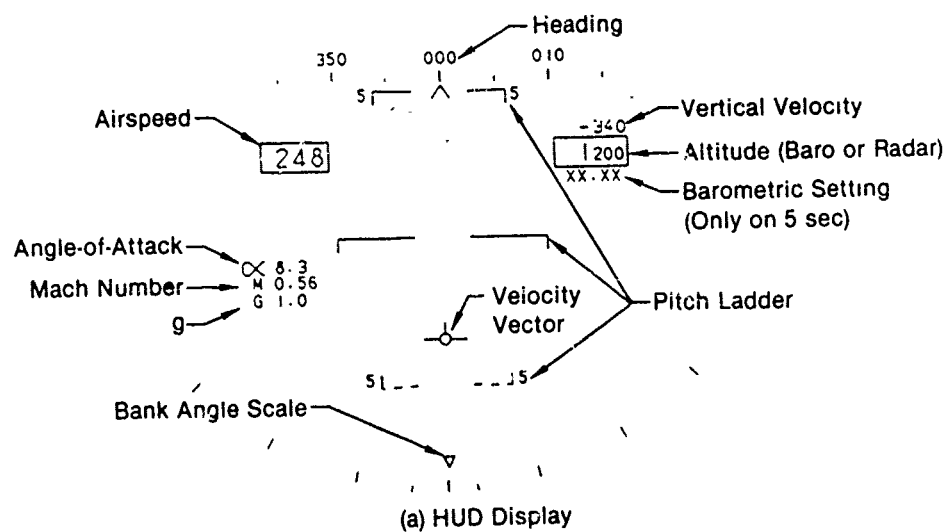


Figure 27. Typical HUD Displays

DESCRIPTION:

Figure 27 presents various HUD display formats for the F/A-18 aircraft. These formats are but a few of the many formats utilized for the many modes available.

SOURCE: Ref. 23

DESCRIPTION:

Figure 28 (a) illustrates a representative HUD symbology for air-to-air attack, and Figure 28 (b) illustrates one for air-to-ground weapons delivery. (No additional information available.)

SOURCE: Ref 14

An artificial horizon (2) is provided in the form of a bar with a gap spanning the aircraft circle. It shows bank angles in the usual way and elevation ("pitch attitude") at reduced scale, which is a convenient device for keeping the symbol within the display field and is sufficient to indicate the nature of the maneuver required by the flight director. Another supporting element is a digital readout of radio height (4) which changes in intervals of ten feet, as is convenient for a stabilized approach. Peripheral elements include a "fast-slow" speed indicator (5) showing departures in 10 knot intervals from a set speed (positive upward), and scales showing "raw" (unprocessed) glideslope (6) and localizer (7) deviations which are also conventional in interpretation (e.g., if the scale center is above the movable "bug" in the glide-scope indicator the aircraft is high). Finally a square symbol (8) is provided as a master warning. It may be noted in passing that the ILS scales are the only elements of the display which are not uniquely identifiable by shape alone.

SOURCE: REF 24

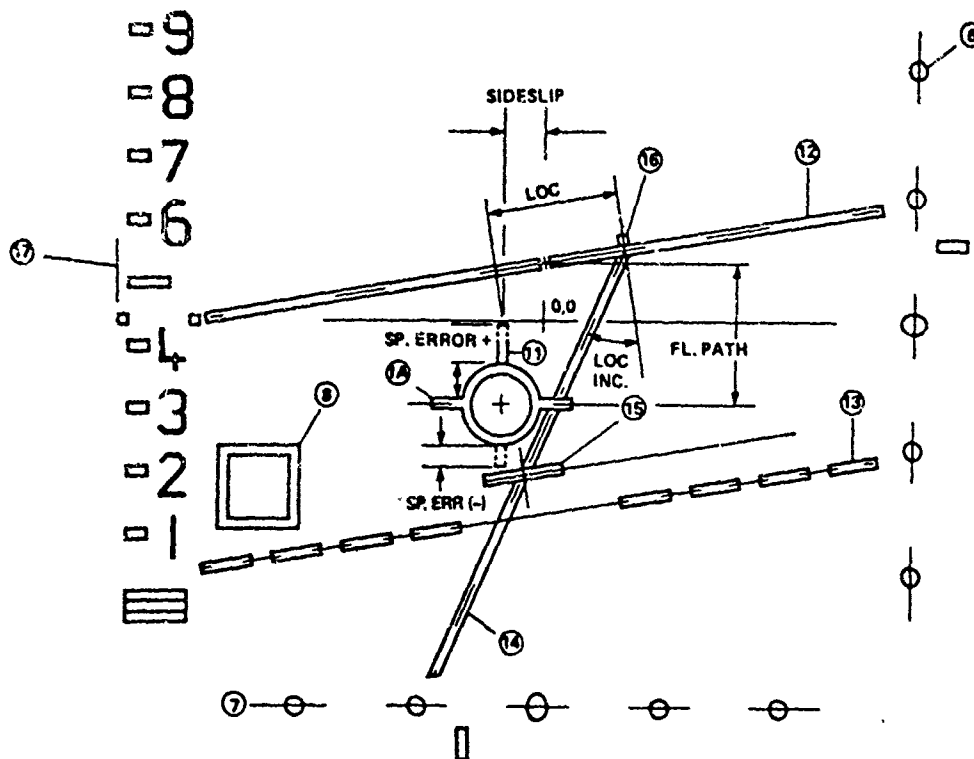


Figure 30. Referenced Flightpath Display

DESCRIPTION:

In this display flightpath information is referred to an aimpoint on the runway. The information is essentially elementary in nature (unprocessed) and is of two kinds: the position of the flightpath, whether displaced above or below an ideal path (usually a 3° path through the glide slope origin at the touchdown zone), and the direction of the flightpath, expressed as a point of eventual impact with the ground. It is a fly-to display, in the sense that path displacement and direction symbols have to be brought to the runway aimpoint. Lateral guidance is confirmed by the appearance of the runway itself. This is essentially a true angle display.

In this format the artificial horizon (12) is a line with a small gap which is always above the display center on a line parallel to aircraft vertical. The artificial horizon is, of course, displaced from the visible horizon because of the earth's curvature.

Guidance is provided in this display partly by the relation between the displacement symbol (13) and the aimpoint. The symbol is a series of dashes, with a central gap, and is parallel to the horizon at an angular distance of, say, 3°. When it is below aim the aircraft is below the ideal (3) path, and when it is above aim the aircraft is above this path. Guidance is also provided by the relation

between the flightpath symbol (1A) and the aimpoint. This symbol is moved beyond aim by the pilot's control action, to the side remote from the displacement symbol (13). The amount of movement is chosen to reduce displacement at a suitable rate, and as the displacement becomes less the flightpath symbol is brought closer to aim, so as to reduce the rate of closure. The two symbols (1A, 13) eventually converge on aim unless there is a wind effect, which may require the flightpath to be maintained at an offset. The flightpath symbol is the aircraft symbol (1) of Figure 29, with a fin added. It is oriented and moved (at true angular scaling) in aircraft coordinates, so that guidance, horizon, and aimpoint symbols form hybrid (geographical-aircraft) system.

The other elements follow the layout of Figure 29 and include the same ILS glideslope (6) and localizer (7) scales but the fast-slow speed element is replaced by the vertical fin (11) of the flightpath symbol, which shows positive and negative departures from a set speed by upward and downward extension, respectively. There is no digital readout of height; instead, there is a moving scale with intervals of 100 ft (17) which moves through a "window" in the format. The master warning symbol (8) is the same as in Figure 29, and it is again true that the ILS scales are the only elements not uniquely distinguished by form.

SOURCE: Ref 24

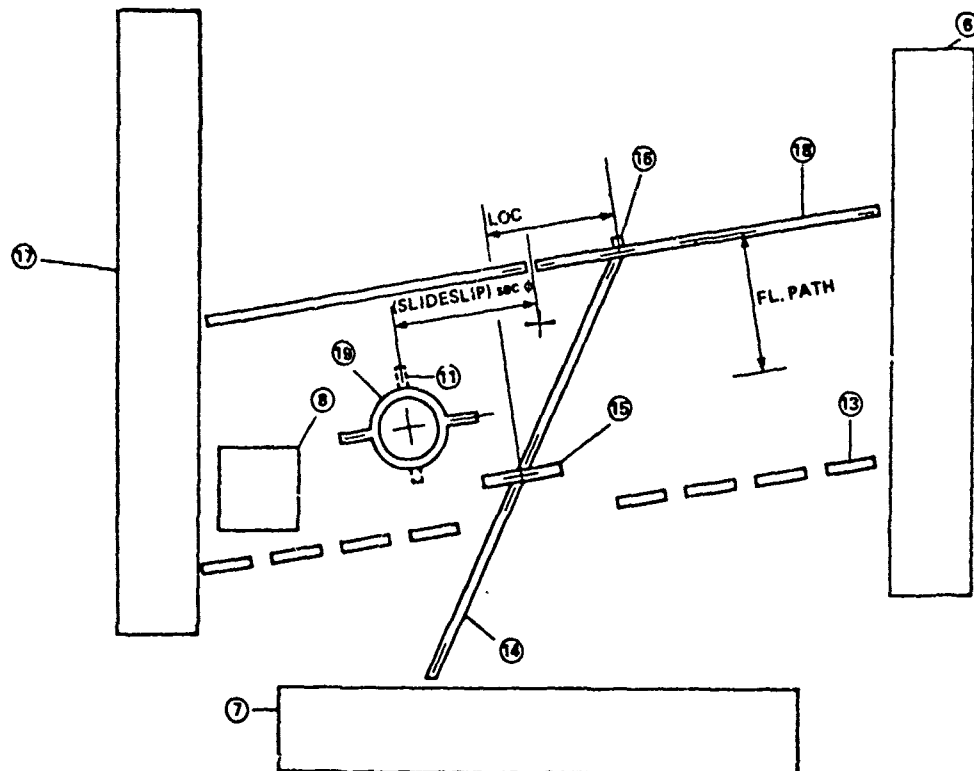


Figure 31. Referenced Flightpath Display

DESCRIPTION:

The concept for the display in Figure 31 is similar to that of Figure 30. This display differs from Figure 30 in the shape and orientation of the flightpath (direction) symbol and in its coordinate frame of motion. There are also differences in peripheral elements of the formats. This display is also essentially a true angle display.

In Figure 31 the artificial horizon (18) has a gap which is always above the display center in the geographical vertical, thus providing a heading reference point which is itself in true angle.

Guidance is again provided by the relation of the fixed depression (13) and flightpath (19) symbols to the aimpoint, but in this case the flightpath symbol is oriented and moved in geographical coordinates. The horizon, aimpoint, and guidance symbols thus form a pure geographical system.

Other elements are the same as in Figure 20. The ILS scales (6, 7) and the master warning symbol (8) are carried forward from Figure 29, the moving height scale (17) replaces the digital height readout, and speed error is shown by a fin (11) on the flightpath symbol.

SOURCE: Ref 24

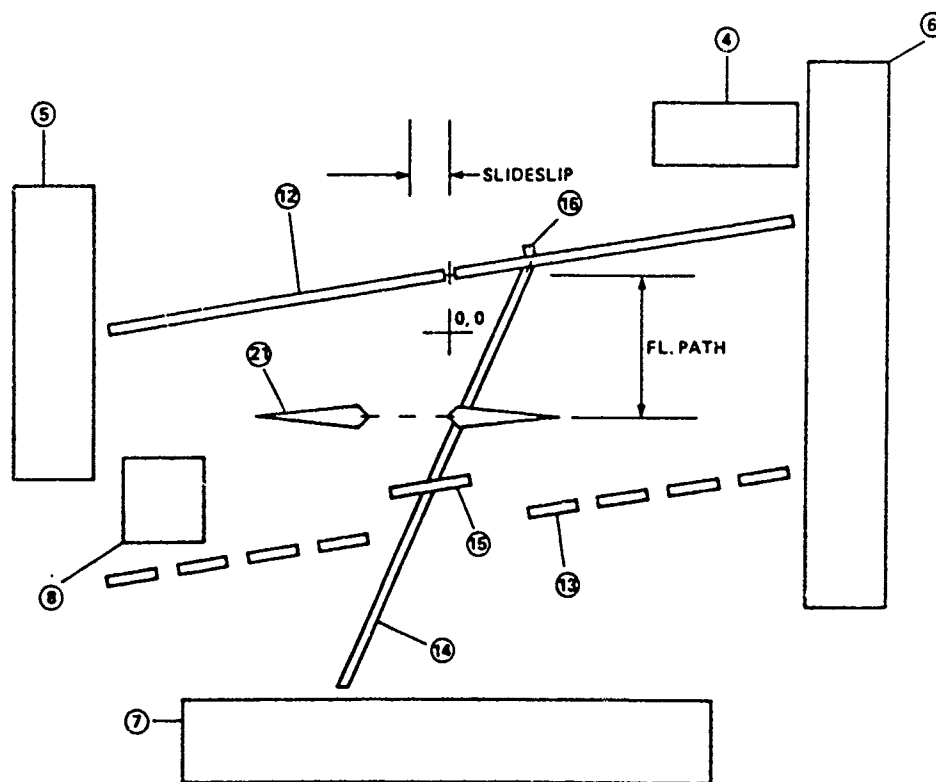


Figure 32. Referenced Flightpath Display

DESCRIPTION:

Figure 32 is similar conceptually to Figure 30 and 31, differing in shape and orientation of the flightpath (direction) symbol, coordinate frame of motion, and peripheral format elements.

In Figure 32 the elements of the central zone are closely similar to corresponding elements in the format in Figure 30. The horizon (12) is the same symbol with its gap again located on the aircraft vertical. The fixed depression symbol (13) is the same symbol and is used in the same way, by observing its displacement from the intersection of localizer line (14) and crossbar (15) symbols, which are also the same as in Figure 30. The main difference is in the shape of the flight-path symbol, which is in the form of two aircraft coordinates. It is used in the same way as the Figure 30 flightpath symbol, and guidance, horizon, and aimpoint symbols again form a hybrid system.

The other elements of the format are exactly the same as in Figure 29. In other words, the digital height readout (4), the fast-slow indicator (5), glide slope (6) and localizer (7) scales and the master warning symbol (8) have the same forms, positions, and orientations as in Figure 29 format, while the moving height scale and "fin" speed error are not used. As before, all symbols except the ILS scales are distinguishable by form alone.

SOURCE: Ref 24

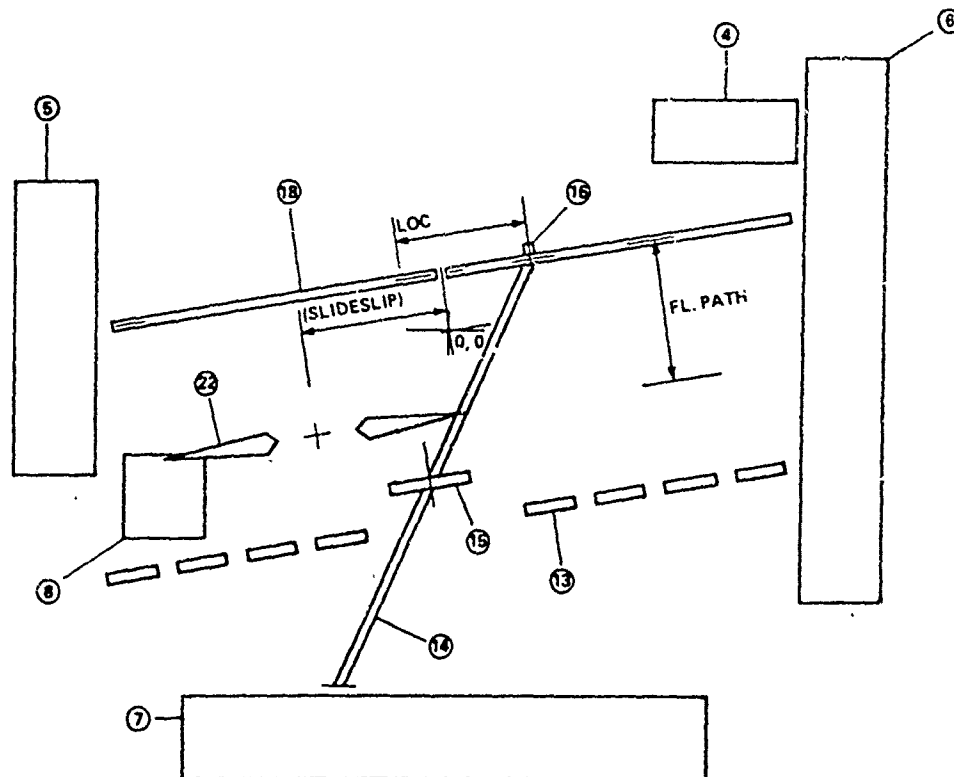


Figure 33. Referenced Flightpath Display

DESCRIPTION

Figure 33 is conceptually similar to Figures 30, 31, and 32, differing in shape and orientation of the flightpath (direction) symbol, coordinate frame of motion, and peripheral format elements.

The format shown in Figure 33, is derived from the format in Figure 32 by modifying the flightpath symbol. The difference lies in orienting and moving this symbol in geographical coordinates, in true angle (22). It follows that the relation between Figure 32 and this format, which includes a shift in horizon gap, is the same as the relation between Figure 30 and Figure 31 formats. Thus, the artificial horizon is changed from symbol (12) to symbol (18), with dependent changes in position for the heading marker (16), localizer line (14), and crossbar (15), which are otherwise unchanged. The fixed depression symbol (13), which is entirely unchanged, together with the flightpath (22) and "background" (14, 15, 16) symbols form a pure geographical system similar to that of the Figure 31 format and are used in a similar way.

Digital height (4), speed error (5), ILS scale (6, 7), and master warning (8) elements are the same as in Figure 29, with the same degree of individual uniqueness among all the symbols.

SOURCE: Ref 24

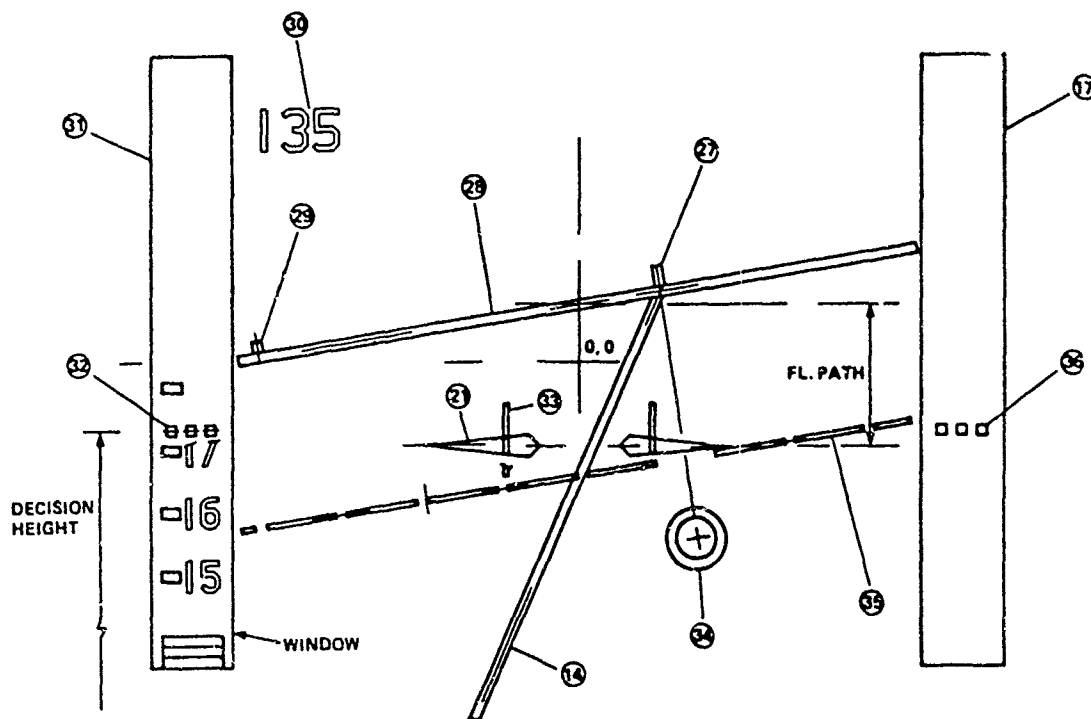


Figure 34. Referenced Flightpath Display with Flightpath Index

DESCRIPTION:

Guidance in Figure 34 is again provided through unprocessed information about the position and direction of the flightpath in relation to the horizon and runway, but the directional aspect is managed with the help of a flightpath index, instead of a runway aimpoint. This leads to some loss of conformity but the display is otherwise in true angle and is still of the "fly-to" kind. Besides these changes, there are modifications to the supporting elements to provide more height information, while removing the ILS scales.

Background symbols include an artificial horizon (28), which is an unbroken bar with an enlarged runway heading marker (27) and smaller markers (29) at regular intervals (such as 5°). The localizer line (14) is drawn in the usual way from the runway heading marker, and guidance is confirmed by the apparent perpendicularity of this line. The background symbols either reinforce or replace corresponding features of the external visual world.

The flightpath symbol (21) has the same form and orientation as the corresponding symbol of the format in Figure 32, and it is also moved in the vertical axis of the aircraft but it remains with its center on this axis; that is, sideslip is not shown. The fixed depression symbol of the other formats (13) is replaced by a circle (34) which is at the same angle below the horizon but remains on the geographical vertical through the runway heading marker (27). This symbol is no longer the primary means used to decide how to place the flightpath symbol. Its function is taken over by the flightpath index (35) which is a thin line of dashes, each longer than in symbol (13). The flightpath index is parallel with the horizon and it is depressed by an angle calculated to secure an optimum rate of reducing displacement when the flightpath symbol is aligned with it. The index represents no physical feature of the real world and is conformal only in its coordinate system. When the flightpath symbol is held on the index the two symbols (21, 35) tend to converge on the fixed depression circle (34). The situation is complicated, however, by the presence of a longitudinal wind component, especially if this is unknown. The background and guidance symbols form a hybrid system.

The display is flanked by two vertical scales. Altitude is shown on the left hand scale (31), with the main sea level altitude of the runway indicated by the top of a bar symbol. Radio height is shown on the right hand scale (17), the zero value corresponding with landing. These scales are similar to the moving height scale of the format in Figure 30, but a three-dot symbol is added to each of them to show decision heights (32, 36). Speed error is shown by fins extending from the flightpath symbol, rising upward from the upper surfaces for a positive error (33) and falling from the lower surfaces for a negative error. A digital readout of airspeed is provided in support of the speed error symbol and this is seen at the upper left corner of the format (30). The master warning symbol and ILS scales are omitted from the format, and there is a reasonable degree of uniqueness among symbols except for the similarity of height scales.

SOURCE: Ref 24

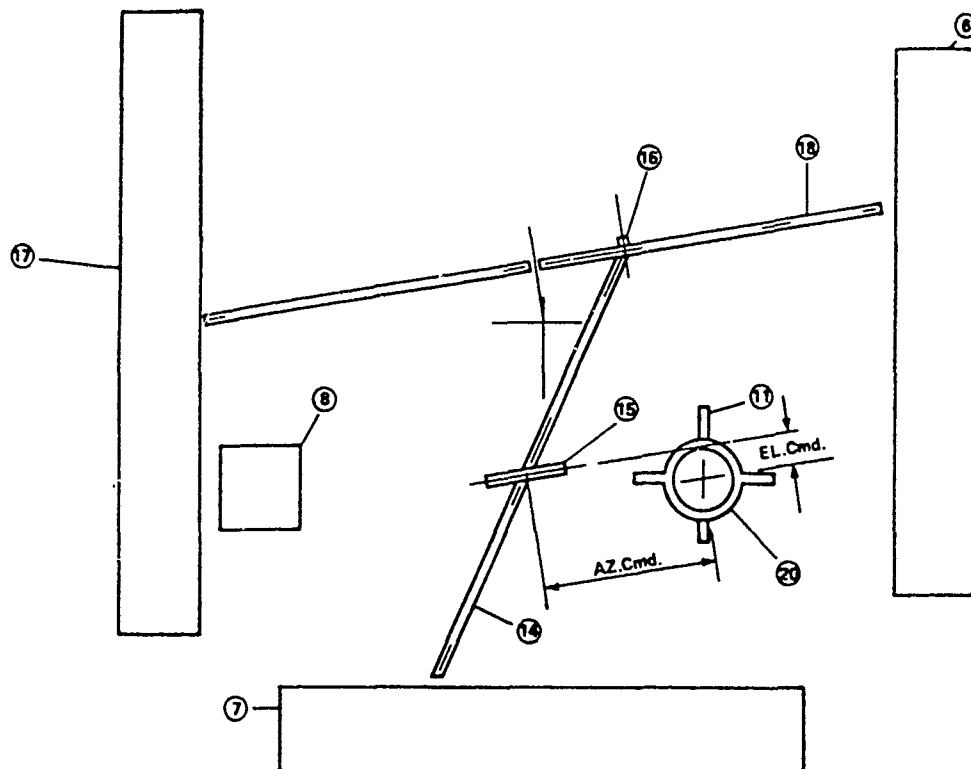


Figure 35. Referenced Flight Directors

DESCRIPTION:

The Figure 35 format makes use of processed information in providing guidance with respect to a ground object. It is a "fly-to" display in the sense of requiring action to move a guiding symbol to an aimpoint. The background elements are in true angle, in geographical coordinates. The guiding element is not in true angle but is moved in geographical axes.

Guidance is provided by the relation between the flight director symbol (20) in Figure 35 and the aimpoint, which may be indicated by symbols (14, 15) or it may be the touchdown zone on the real runway. The director symbol is the flightpath symbol of Figure 30, which is moved in geographical axes for azimuth and elevation commands. No displacement information is provided and the user is not required to interpret unprocessed information in order to surmount a difficult (wind) situation, though he may use supporting elements for monitoring purposes. The background and guiding elements together form a pure geographical system, as far as the coordinate framework is concerned, but the director symbol has no one-to-one correspondence with any feature of the real world. Also, it is oriented in aircraft axes to provide an attitude reference.

The ILS glide slope (6) and localizer (7) scales, and the master warning symbol (8) of Figure 29 are provided, together with the moving height scale (17) of Figure B. Speed error is shown by a fin(11) added to the director symbol. Once again, the ILS scales are the only elements not distinguishable by form alone.

SOURCE: Ref 24

The ILS glide slope (6) and localizer (7) scales, and the master warning symbol (8) of Figure 29 are provided, together with the moving height scale (17) of Figure B. Speed error is shown by a fin(11) added to the director symbol. Once again, the ILS scales are the only elements not distinguishable by form alone.

SOURCE: Ref 24

The periphery of the format is occupied by the fast-slow display (5), ILS scales (6, 7) and master warning symbol (8) of Figure 29. A change is made, however by introducing a digital display showing the relation of present height to decision height. The value set for the decision height is labeled DH and appears always in the same position, in the upper right corner of the format (24). Above it is a digital readout of present height (23) which appears only when the aircraft is above decision height. Below it is a similar readout (25) which appears only when below decision height. As before, all elements of the display have unique forms except the ILS scales.

SOURCE: Ref 24

2.2 CONTACT ANALOG FORMATS

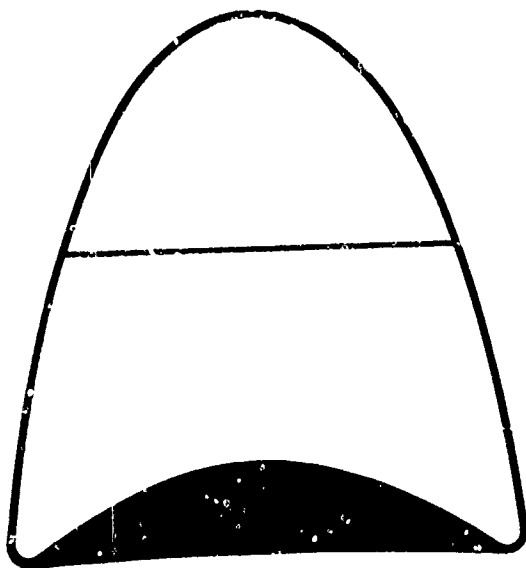
The contact analog display is a pictorial representation of the real world view which the pilot would have under conditions of visual contact flight. Contact analog displays are not camera images or television pictures of the real world, they are an artificial recreation of the real world. Carel (Reference 1) has defined them as "point perspective projections of a three-dimensional model (of the real world) to a picture plane." Every real world detail is not rendered in the contact analog presentation, it is a selective, abstract, and stylized picture of the real world. Display elements obey the same laws of motion and perspective as their real world counterparts. The contact analog contains reference objects significant for flight performance such as a surface representing local horizontal, usually called ground plane, a surface representing command flight path, and other surfaces or objects useful during different phases of the mission.

The basic assumption upon which the contact analog is founded is that the pilot can fly an aircraft solely by visual cues from the extra-cockpit environment. The contact analog is the means of recreating VFR day cues within the cockpit at all times. Because there is a 1:1 correspondence between the contact analog display and the real world, pilots should have little trouble in transferring to the contact analog (Reference 5).

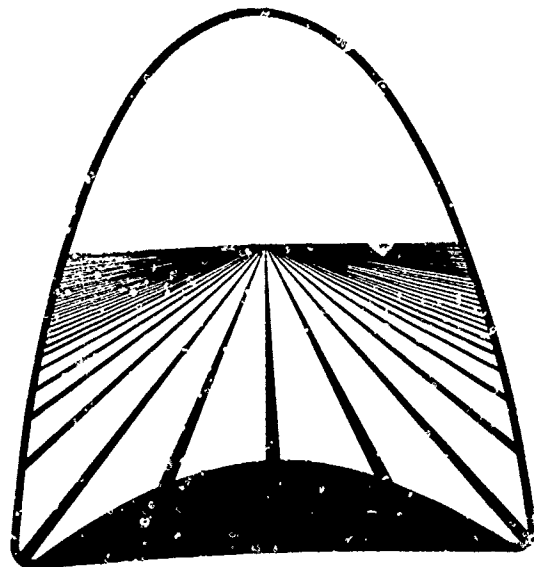
Advantages of the contact analog include: reduced uncertainty and ambiguity due to the naturalness of the presentation; ease of maintaining three dimensional orientation in all flight situations; and simplicity of learning and using. Disadvantages are basically two: problem of overemphasizing pictorial realism (how much is too much); and it is relatively poor (as is any pictorial realistic format) in providing immediate and precise quantitative information.

Much of the early work on contact analog displays was performed under the wide-reaching ANIP (Army-Navy Instrumentation Program) study (Reference 25) conducted by Douglas Aircraft Company and a host of subcontractors in the 1950's and 1960's. The successor to this program, the JANAIR (Joint Army-Navy Aircraft Instrumentation Research) program, continued research and evaluation of contact analog displays through Bell Helicopter (References 26-33) and the Naval Missile Center (References 34-37).

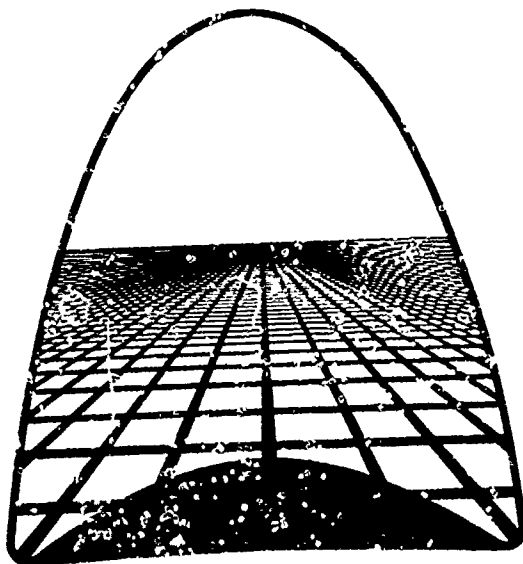
The examples of contact analog displays on the following pages are provided to give the reader a quick overview of historical contact analog conceptions. It is by no means meant to be an exhaustive presentation of every contact analog format ever devised.



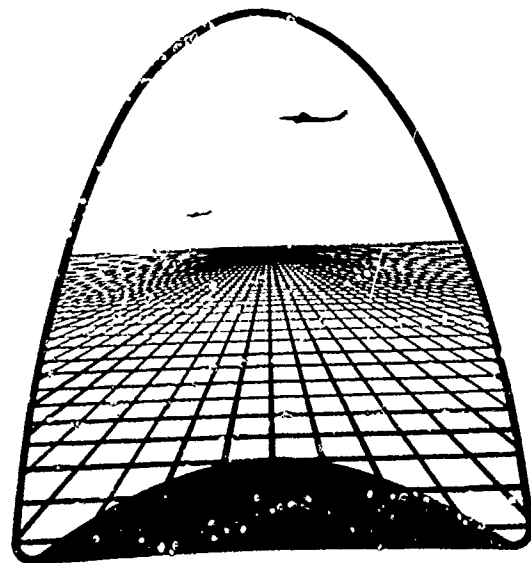
(a) Simple Horizon Line



(b) Linear Perspective



(c) Texture



(d) Size Cue

Figure 37. Contact Analog Horizon References

DESCRIPTION:

A pilot judges his relationship to space and time under contact conditions, primarily by reference to visual cues. One important visual cue was found to be an internal reference, which permits the pilot to regard himself and his aircraft as a single unit. Such a reference normally is available to the pilot in the form of a windshield. A second important visual cue is external reference. To the pilot, one of the most common external references is the horizon, Figure 37 (a). It enables him to determine the relationship of his aircraft to external objects. This information alone, quite often gives rise to misinterpretations. Parallel lines, apparently converging, represent linear perspective, Figure 37 (b), helping the pilot to judge angular and altitude changes as witnessed in a dive. The texture of a reference surface is used by the pilot to determine slant of the surface, altitude and distance, Figure 37 (c). This powerful visual cue is sufficient in itself to establish orientation without reference to the horizon. A textured surface representing the sky, composed of a distinctly different pattern from the ground pattern, provides orientation when the ground plane is not available, Figure 37 (d). In air-to-air orientation, the closer of two similar aircraft would appear to be larger, indicating size is also an important cue. Movement over the surface results in an apparent distortion of the visual field, and this is known as motion parallax. Motion parallax provides a compelling cue to distance, speed, and direction of motion.

SOURCE: Ref 38

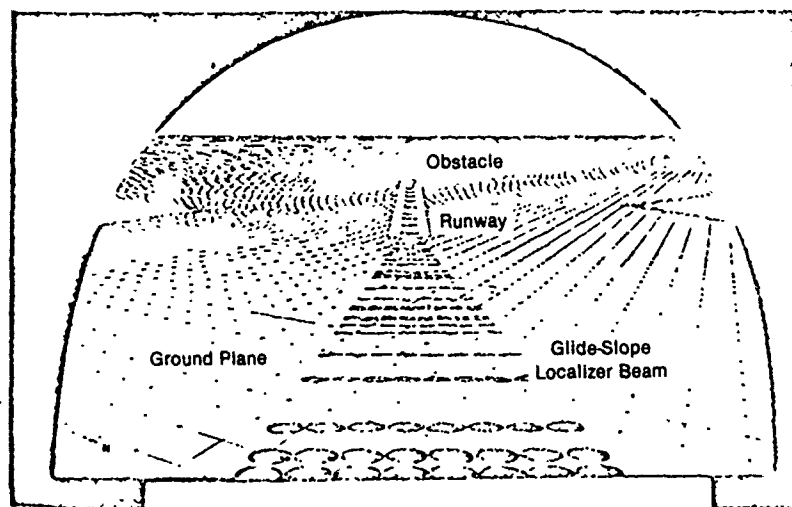


Figure 38. Contact Analog Display

DESCRIPTION:

The contact analog display is the point perspective projection of a three-dimensional model to a picture plane. The model contains reference objects significant for flight performance such as a surface representing the local horizontal, usually called the ground plane, a surface representing the command path for the pilot to follow, usually called the flight path, and other surfaces or objects useful during different phases of the mission. The computer that paints the display may also paint conventional non-perspective symbols in the plane of the display; circles, crosses, and the like.

The major elements in the contact analog display are the ground plane and the command flight path -- the "highway in the sky." The use of the ground plane is fairly well understood, although it must be said in passing that it does not necessarily represent the ground but, for aircraft application, simply a horizontal reference surface that, on the display moves precisely in the same way as does the real ground in response to aircraft maneuvers. The intended application of the command flight path represents a fixed path in space along which the pilot flies much like driving a car down the road. Presumably the trajectory of this pathway is generated to realize the optimum safe performance potential of the aircraft. It represents, in short, the best path to the end goal.

SOURCE: Ref 1

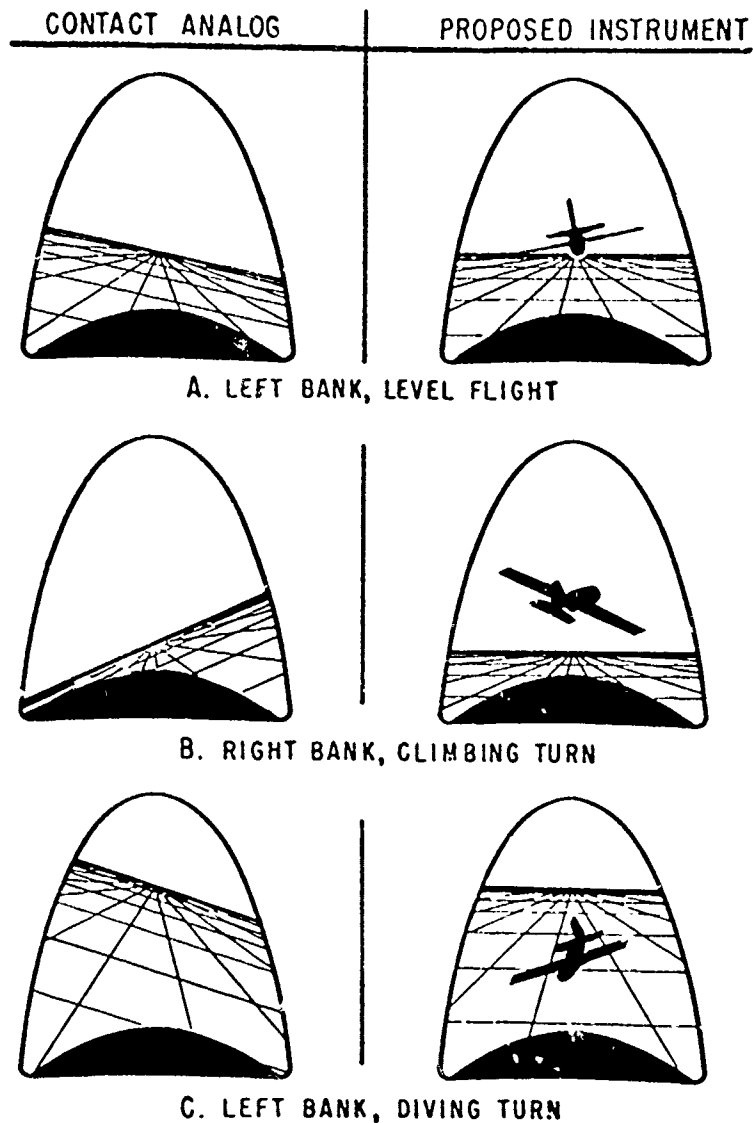


Figure 39. Existing and Suggested Means of Presenting Roll Information on an Integrated "Contact Analog" Display

DESCRIPTION:

The moving horizon display (Figure 39) presents a relative motion problem because, while the horizon should form the stationary reference framework with respect to which the instrument panel and vehicle move, the horizon display is naturally perceived as moving with respect to the instrument panel.

The presentation of a frame of reference for vehicle motion within a display results in what has been termed an "inside-out" display. If instead a miniature moving aircraft were shown against a horizon that was fixed with respect to the instrument panel, as when painted onto a stationary part of the instrument, the display would be termed "outside-in."

In a display for instrument flight, it is possible to avoid the confusion due to roll motion entirely by changing the display design. One means of doing this adds an aircraft symbol to the display to indicate roll. Pitch is shown by up and down motion of the horizon, as at present, with the aircraft symbol as an added reference.

SOURCE: Ref 39

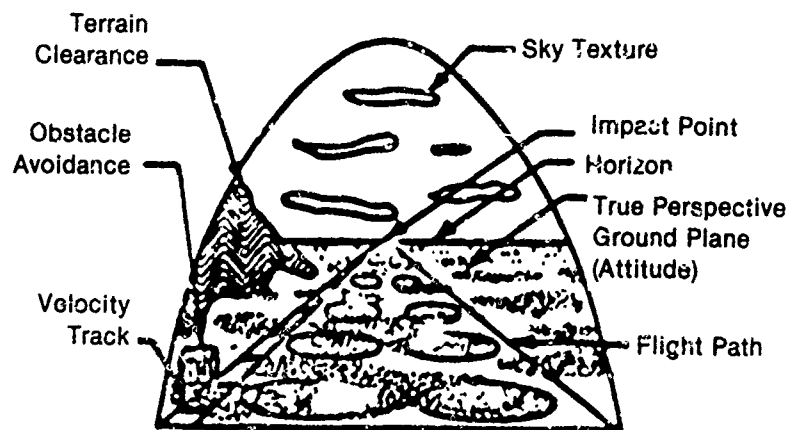


Figure 40. Vertical Display

DESCRIPTION:

Figure 40 shows an early ANIP Contact Analog format with ground and sky texture. (No additional information available.)

SOURCE: Ref 40

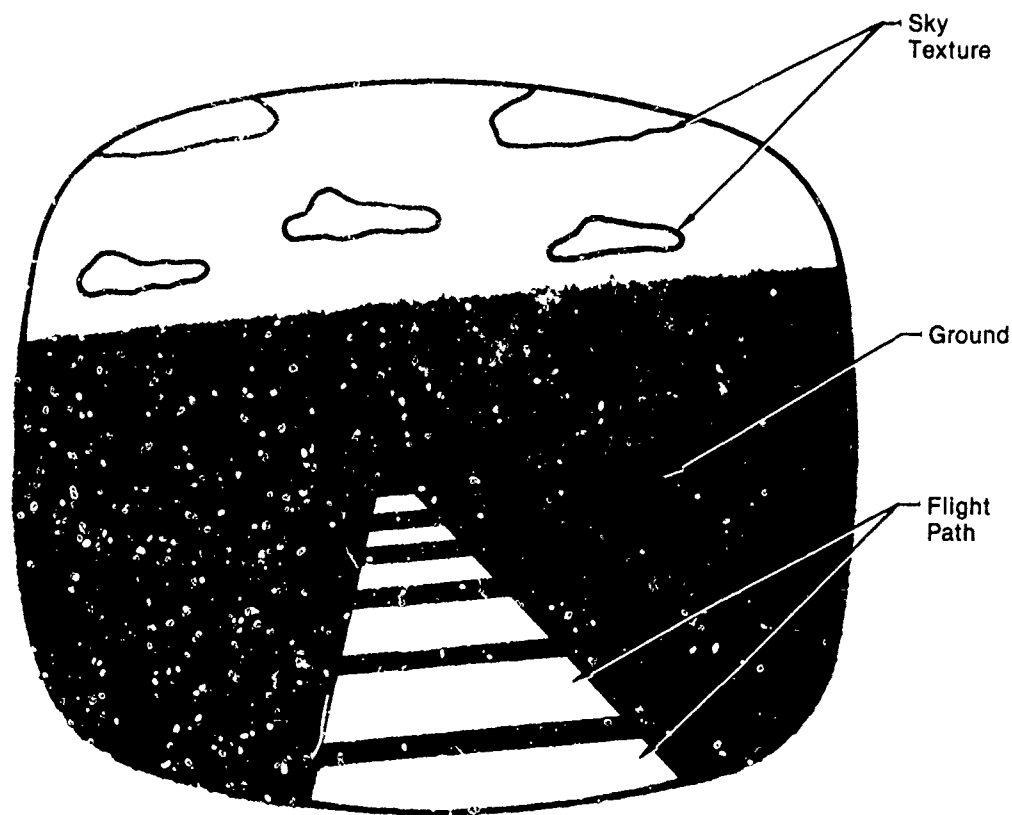


Figure 41. Douglas A.N.I.P. Display

DESCRIPTION:

Aircraft guidance with respect to flight path and roll angle can be given to the pilot by a "path in the sky." In Figure 41, 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.

Variations from a desired airspeed set by the pilot are shown by the series of small rectangles along the left side of the stepping stones. When actual airspeed is less than the commanded these rectangles move forward in relation to the stepping stones indicating a need to increase speed. Similarly, they move back toward the observer when a decrease is required.

SOURCE: Ref. 17

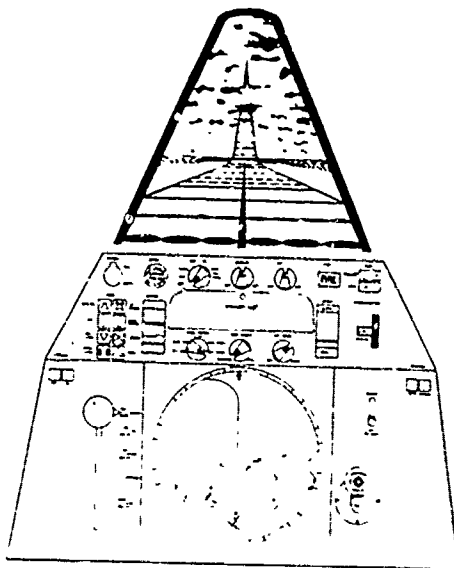


Figure 42. Conceptual Takeoff Displays

DESCRIPTION:

Figure 42 shows a proposed ANIP main instrument panel replete with a head-up contact analog display and a complementary geographic plot. The contact analog display has distinctive sky and ground textures and a pathway in the sky. The geographic plot shown is a horizontal display format of intended flightpath, map features and where your aircraft is in relation to these features.

SOURCE: Ref 41

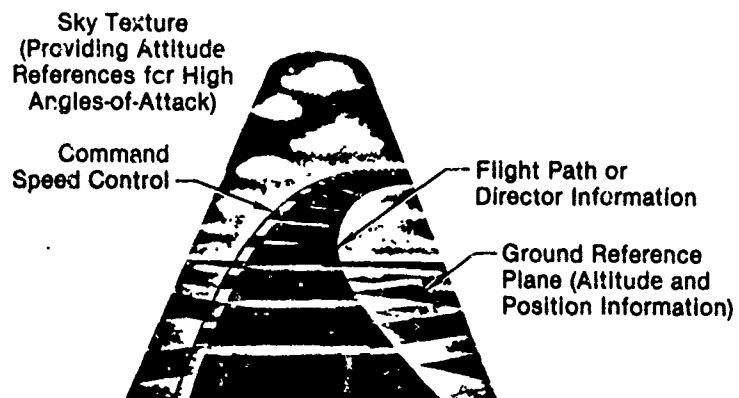


Figure 43. Contact Analog Display

DESCRIPTION:

The vertical reference, contact analog display, shown in Figure 43, consists of a ground reference plane, a flight path or a flight director, sky texture, and command speed.

SOURCE: Ref 41

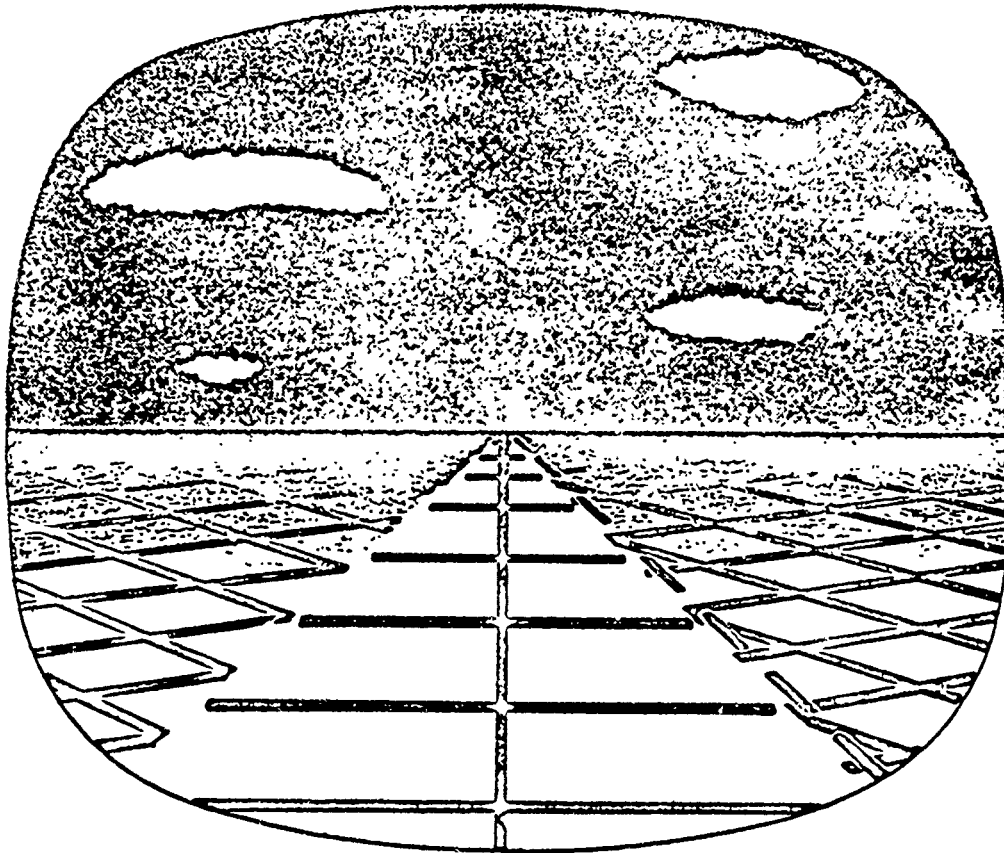
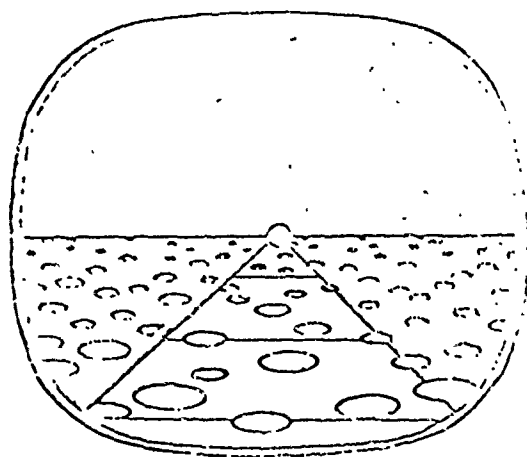


Figure 44. Contact Analog Display

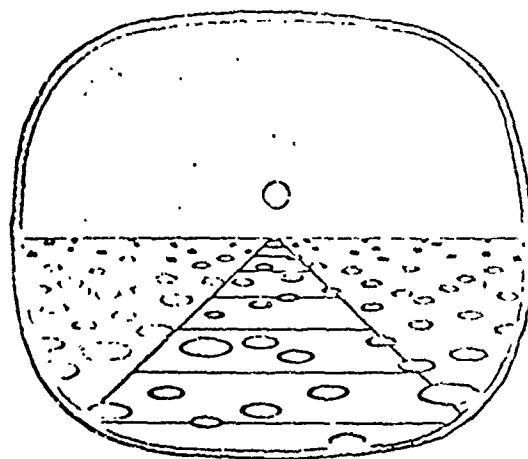
DESCRIPTION:

The contact analog VSD in Figure 44 shows a gridded surface, sky texture including clouds, flight path with centerline and "tar strips," and airspeed indicator dashes located on the right side of the pathway. These dashes would remain stationary with respect to the pathway when the aircraft is "on speed." They would move towards the observer at a rate greater than the pathway to indicate an "overspeed" condition and "decrease speed" command. They would move away from the observer at a rate greater than the pathway to indicate an "underspeed" condition. The ground grid is fixed with respect to the earth and, as shown in Figure 44, an indication of heading is provided by the relationship of the flightpath and the ground grid.

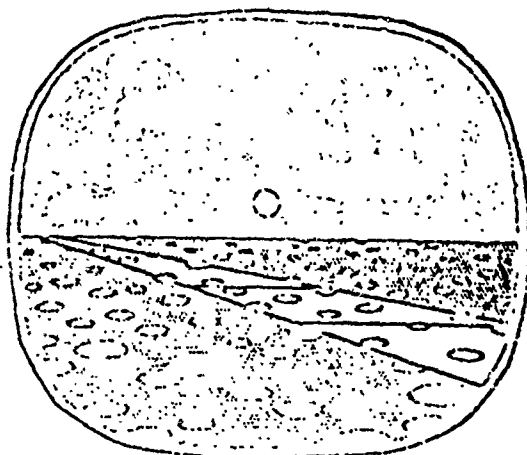
SOURCE: Ref 42



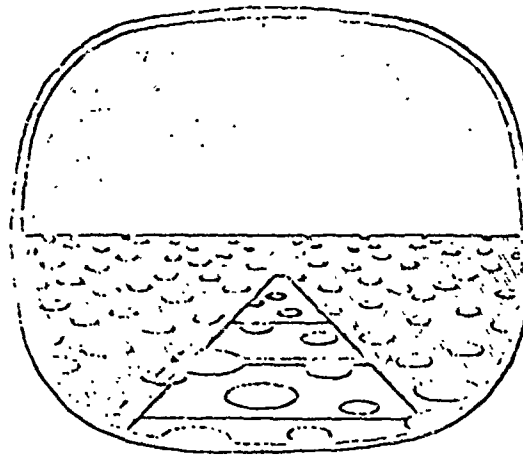
(a) Level - On Course



(b) Pitched Up - On Course



(c) Left of Course - Pitched Up
Headed to Right of Course



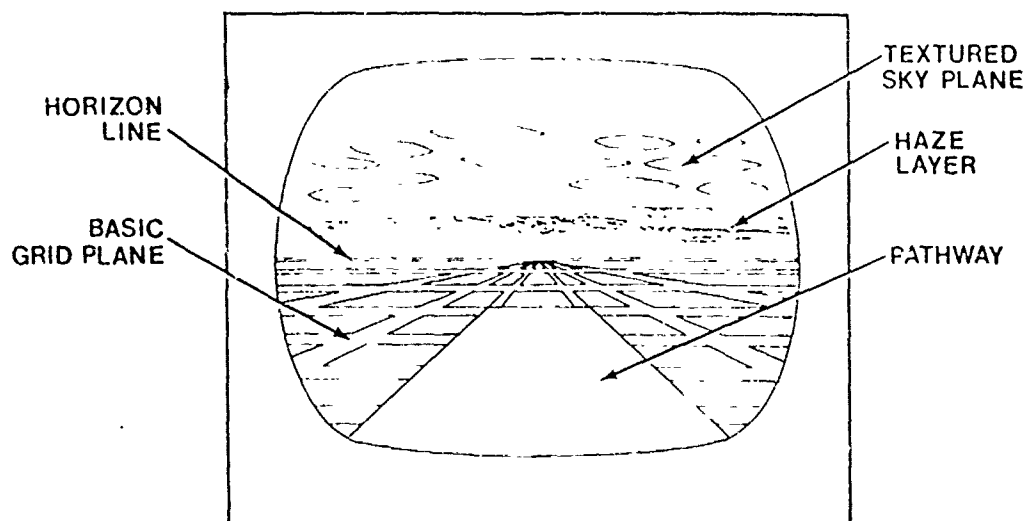
(d) Landing Display

Figure 45. VSD Formats

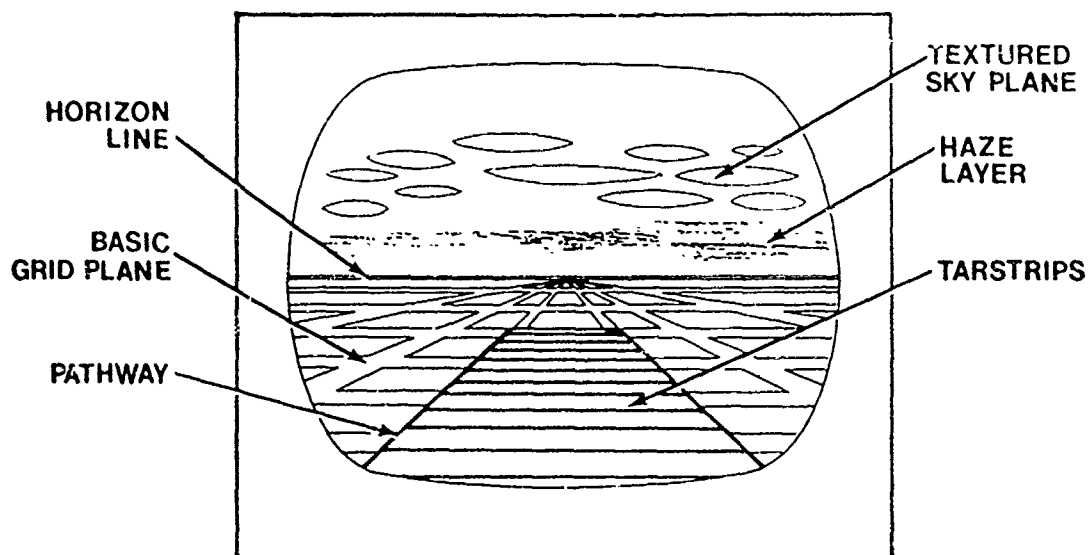
DESCRIPTION:

Figure 45 illustrates a contact analog VSD for four separate flight conditions. The ellipses on the surface (actually circles seen in perspective) and the stripes on the pathway move towards the viewer as the aircraft traverses the ground. The circle centrally located on these examples represents your aircraft's relation to the pathway and the horizon.

SOURCE: Ref 42



a) Basic Pathway



b) Pathway with Tarstrips

Figure 46. Contact Analog Display with Pathways

DESCRIPTION:

Two types of pathway displays for helicopter flight maneuvers (which, by nature, differ from airplane flight maneuvers) were developed to investigate their effect on helicopter pilot performance. The first, Figure 46 (a), had a basic grid plane which moved perspectively with movement of the aircraft, relating lateral and vertical flight deviations to the pilot. The grid was presented with real world perspective (a 360° turn presentation capability) with four vanishing points, termed cardinal heading. The squares decrease in size as the aircraft increases its altitude and vice versa. A sky texture was shown above a fixed, accentuated horizon line. A simulated haze layer (5° viewing angle) appears just above the horizon line to prevent confusion during convergence of grid lines forming linear perspective. The earth stabilized command pathway represents a 30-foot wide area over the grid plane. The pathway lies across the grid line during lateral deviations and remains fixed in size, appearing to move with the pilot during vertical deviations.

The second pathway display (Figure 46 (b)) includes "tarstrips" (cross bars situated 30 feet apart) which move toward the observer to provide ground speed information. Correctly flying the aircraft with the display required the pilot to maneuver the aircraft so that the grid appeared to be moving straight toward the pilot to prevent and/or correct for grid lines slanting diagonally.

SOURCE: Ref. 19.

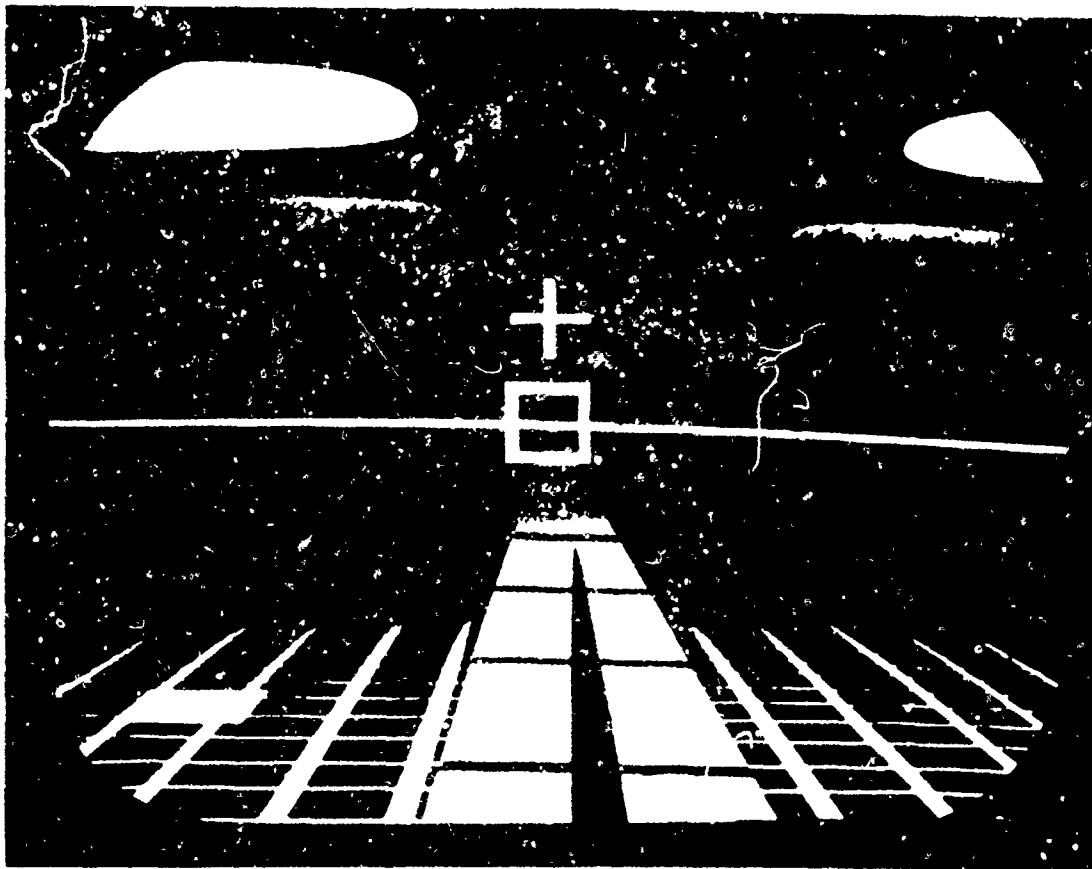
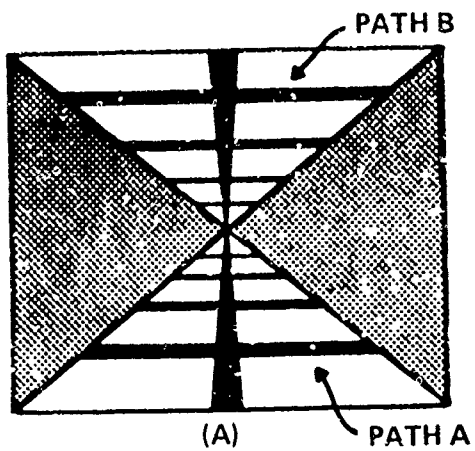


Figure 47. Contact Analog Display

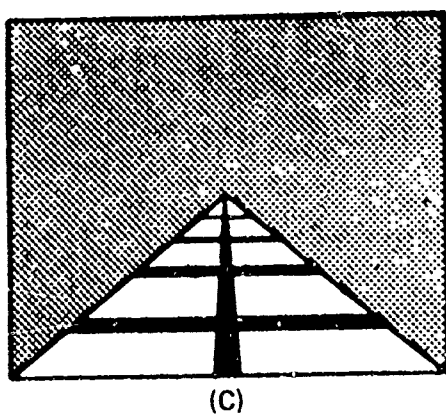
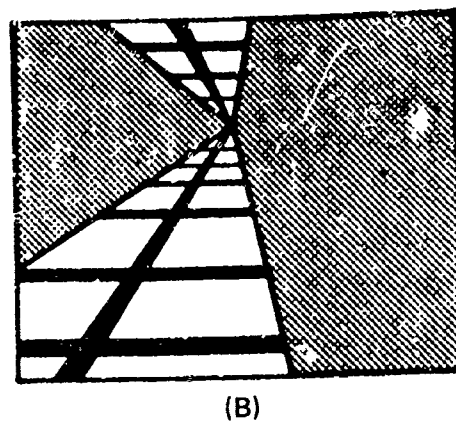
DESCRIPTION:

The contact analog display shown in Figure 47 was designed to investigate a new means of display integration for the X-15 hypersonic research vehicle. The basic picture contains a ground plane with textural elements shown in true perspective, an artificial horizon, and a sky with clouds. A flight path is superimposed on this background giving command flight information. The square represents the vehicle's longitudinal axis. The hollow center permits viewing the tip of the pathway at null, thus, permitting greater accuracy. The cross used in conjunction with the square represents flow direction (α and β). Heading error and pitch error are displayed with the cross during portions of the flight when these parameters are of prime importance. The ground position identifier is used to indicate the terminal landing area or any of the emergency landing areas with suitable mode switching. It could also represent high or low key checkpoints, but some visual extrapolation would be necessary since the ground position identifier is in ground coordinates.

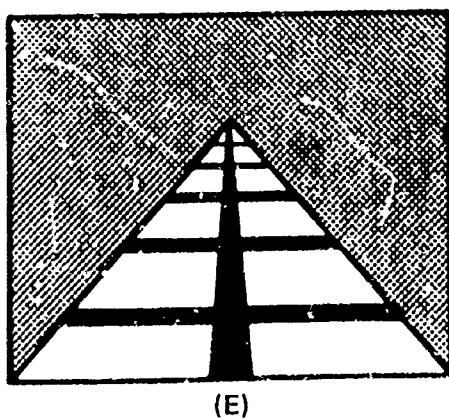
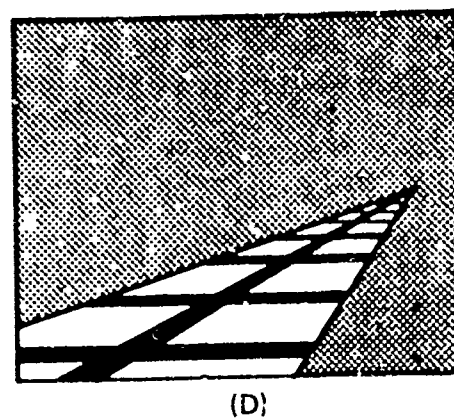
The ground texture represents the surface of the earth by a plane containing a pattern of shaded squares. The orientation of the vehicle with respect to the earth is described by roll, pitch, and heading angles and is shown by corresponding motions of the display elements. Vehicle altitude is displayed by variations in the apparent size of the squares which make up the ground texture pattern. The pattern has motion in proportion to the aircraft velocity in the direction opposite the vehicle motion.



REENTRY



NAVIGATIONAL



COMMAND

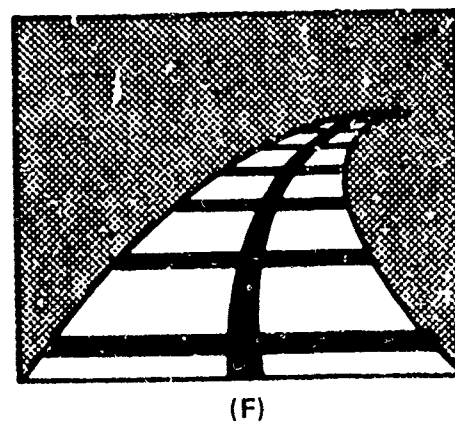


Figure 48. Path Configurations

The command path contains a centerline and tarstrips which move toward the vehicle. Path orientation is described by roll, pitch, heading error, slope error, altitude error, and lateral offset. A typical system contains several modes of pathway presentation. These include command, navigational and reentry modes. Various path configurations are shown in Figure 48.

In the command mode, the pathway is vehicle-stabilized, i.e., fixed to a point beneath the aircraft. During normal flight, the path is approximately 15 feet below the aircraft and vanishes at the center of the screen. Heading errors cause the path tip to bend left or right, and slope errors move the tip up or down. Roll angles cause a corresponding roll motion of the path. A lateral displacement will cause the near-end of the path to move right or left while the tip remains fixed. The primary advantage of this mode is that the path does not disappear from the screen under conditions of large heading and slope errors.

The navigational mode is similar to the command mode except that the path is earth-stabilized. The path does not bend in this mode to indicate a command turn, but merely changes apparent heading. (As a result, excessive heading errors could cause the path to move off the screen.) This mode is used primarily in situations where input information is available in navigational form.

The reentry mode contains two paths which form a "corridor" for displaying upper and lower limits of flight, such as those defined by heating limits, deceleration limits, and minimum entry angles. The corridor has the same degrees of freedom as the navigational pathway.

SOURCE: Ref 43

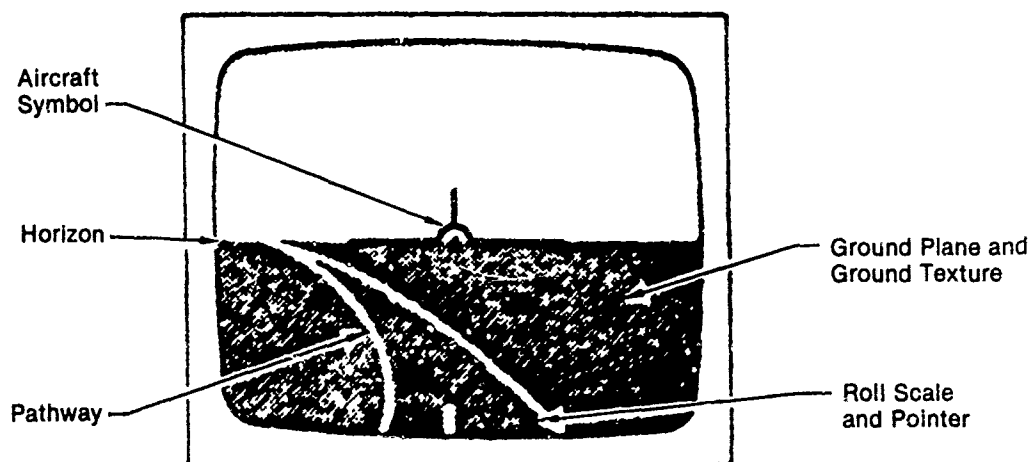


Figure 49. VSD Flight Path Mode

DESCRIPTION:

The VSD shown in Figure 49 is raster flight path mode format. The sky and ground are differentiated by texturing. The commanded flight path is shown relative to your aircraft symbol. Flight path commands would be generated from compass, VOR/OMNI, ILS, or ADF data. (No additional information available.)

SOURCE: Ref 5

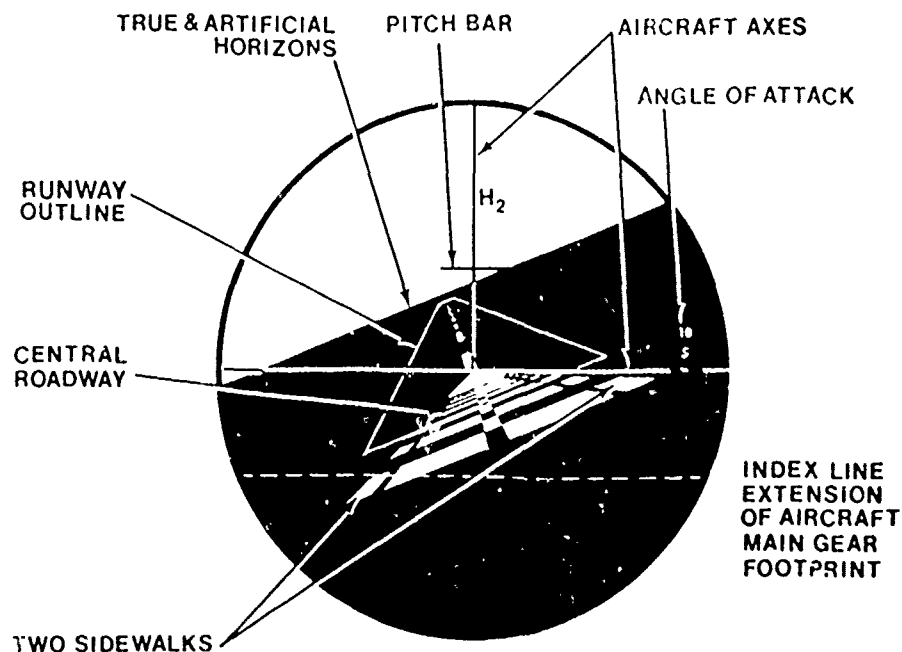


Figure 50. Path-in-the-Sky Head Up Display

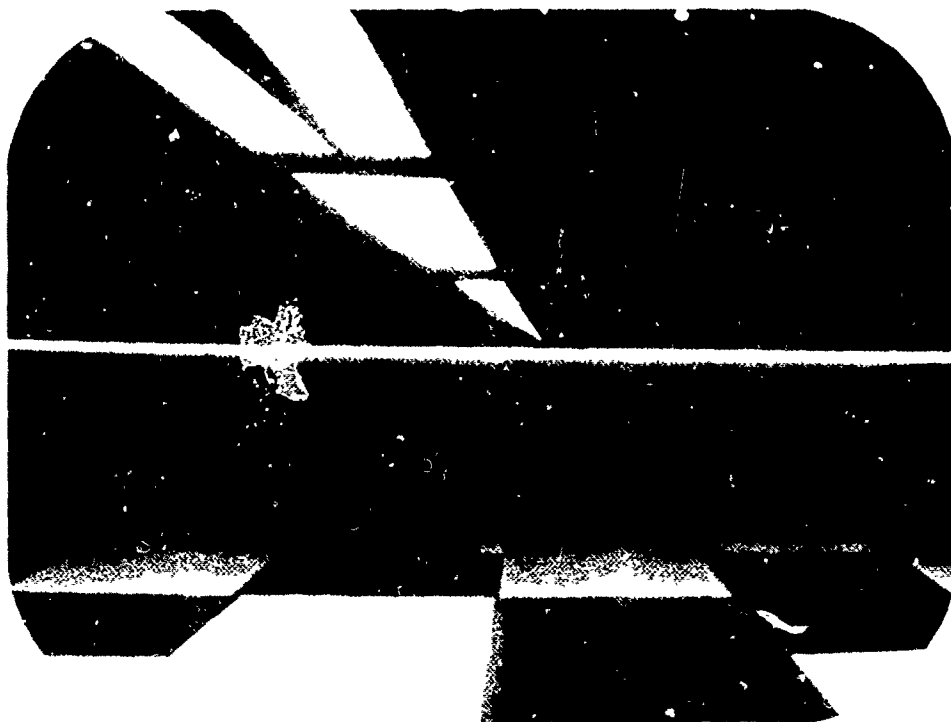
DESCRIPTION:

Path-in-the-Sky head-up display in Figure 50 provides a true three-dimensional roadway in the sky projected through the windscreen and superimposed on the real world. The path can be made to extend from the aircraft to any desired location. Additionally, actual airspeed, desired airspeed, steering errors, crab angle, roll attitude, angle of attack, runway outline and an artificial horizon are provided as picture analogs.

An artificial horizon, aircraft axes, a central "roadway" and two "sidewalks" on either side of the roadway combine to create an inside-out perspective of the flight conditions. The index line which appears on the lower half of the display depicts an extension of the aircraft main gear footprint along the aircraft velocity vector to a point forward of the aircraft where the roadway should first become visible to the pilot.

The pilot's task is to "guide" his aircraft down the command path, maintaining command pitch angle and level flight by utilizing the pitch bar and aircraft axes as vertical and horizontal references with which to align the horizon line and roadway centerline. As the aircraft flies over the road, the pattern in the road appears to roll under the aircraft at actual speed. The sidewalks, depending on whether they move at a slower or faster rate than the central pathway, provide cues for increasing or decreasing velocity.

SOURCE: Ref 19

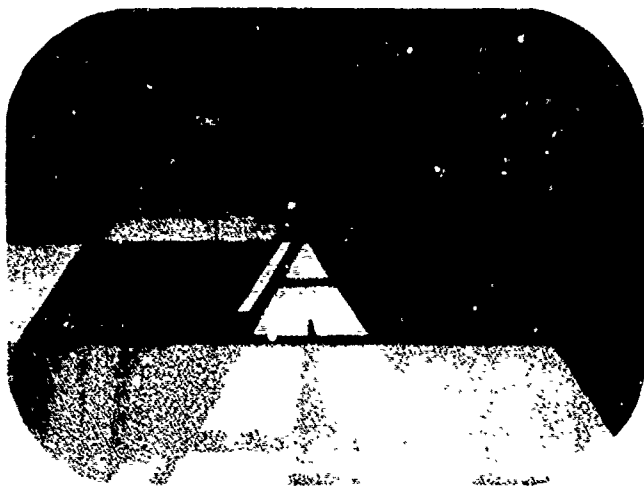


(a) Vehicle Below Nominal Path and to the Right

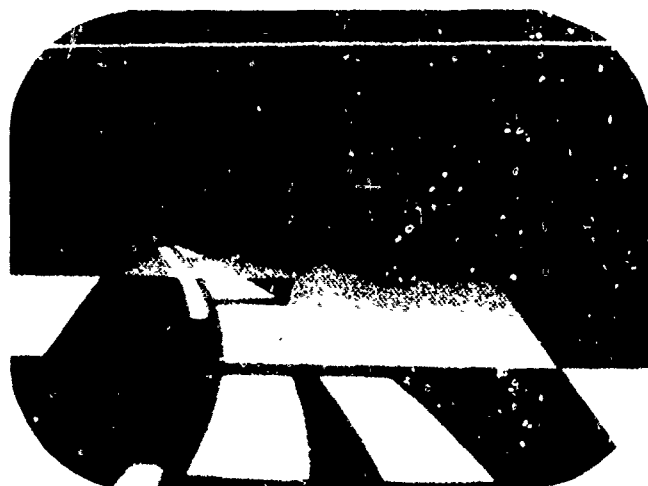


(b) Vehicle Above Nominal Path and to the Left

Figure 51. Vertical Display Display Presentations - Space Vehicle Attitude Mode



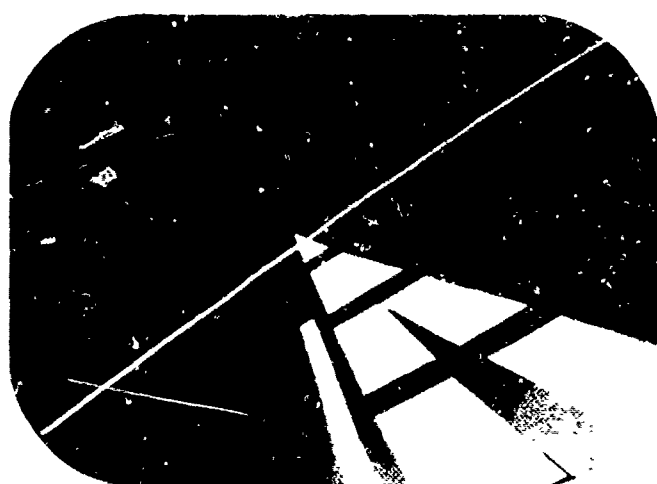
(a) Vehicle on Command Path



(b) Vehicle on Path with Yaw Left Command

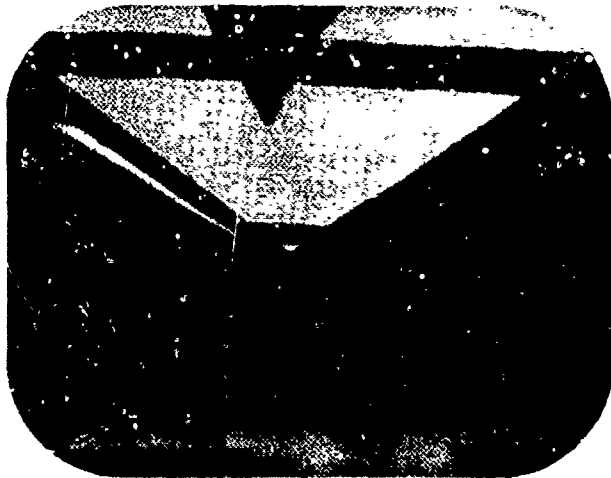


(c) Vehicle on Path with Yaw Left Command



(d) Vehicle on Path and Rolled to Right

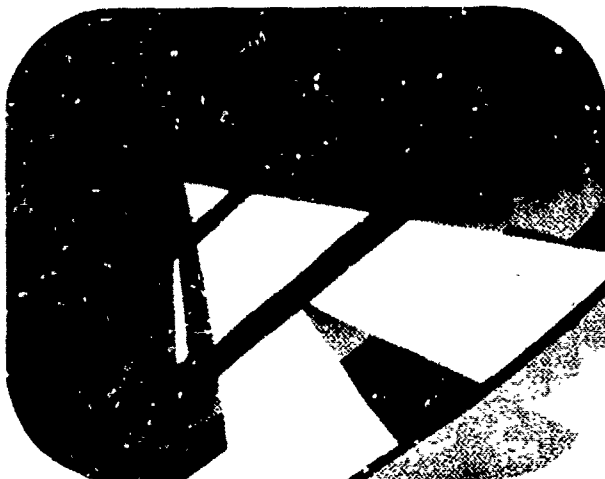
Figure 52. Vertical Display Presentations - Space Vehicle Command Attitude Mode



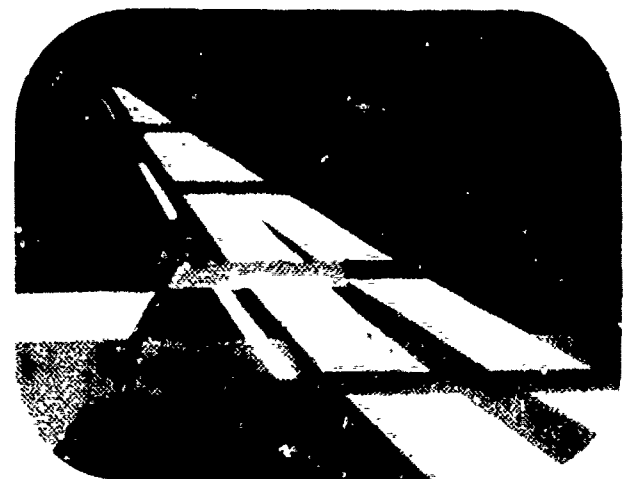
(e) Vehicle on Nominal Path but Slightly Below Required Altitude.



(f) Vehicle Required Altitude but to Left of Nominal Path. On Intercept Course.



(g) Vehicle Above Nominal Path and Rolled Right. About to Pass Through Path and Cross Over to the Right.



(h) Vehicle Above and to Left of Nominal Path On Intercept Course.

Figure 52 (Continued). Vertical Display Presentations - Space Vehicle Path Mode

DESCRIPTION:

The vertical displays in Figure 51 and 52 depict a space analog presentation developed to investigate advanced integrated display-control requirements for post-apollo space vehicles. The electronically generated scene was a view looking forward over the nose and along the thrust axis of the vehicle. The viewed scene was in 1:1 relationship with the real world. The background scene consisted of a ground plane, horizon line, and starfield presentation for displaying vehicle orientation, velocity and heading relative to the local horizontal plane. In addition, the ground plane grid indicated variations in altitude, the size of the grid varying inversely with altitude. A pathway, converging at infinity, is superimposed on the background scene with the function of the path varying with the selected display mode - ATTITUDE or COMMAND ATTITUDE. Figures 51 and 52 show typical vertical display presentations for each mode.

In the attitude mode the pathway represented the nominal (or required) orbital path, and conveyed vehicle attitude, velocity, vertical (altitude) and lateral (horizontal) displacements relative to it. For vehicle roll displacements the path rotated with the background scene - i.e., with the ground plane. Vehicle yaw and pitch motions with respect to the path were depicted by rotations of the path with the pilot as the center, and displacement of the path vanishing point (tip) from display center, right - left parallel to the ground plane, and up - down normal to the ground plane, respectively. Vehicle velocity along the path was displayed by bars ("tar strips") across the path, and parallel to the horizon line, which translated along the path. The width of the path varied inversely with altitude error (vehicle altitude relative to that of the nominal path), the near end of the path being full display width for zero altitude error. Direction of altitude error was presented by the relative position of the path with respect to the center of the screen; the path appearing in the lower half of the screen when the vehicle was above the path and vice versa. The near end of the path was displaced left and right of display centerline parallel to the ground plane for lateral (horizontal) displacement of the vehicle from the nominal path.

In the command attitude mode the path presented required attitude at present vehicle position. The near end of the path remained at full width of the display, parallel to the ground plane, and centered in the display (zero altitude error and lateral displacement) representing present vehicle position. Yaw and pitch attitude changes required for controlling the commanded flight path were presented by lateral displacements of the path tip - by bending the pathway right and left parallel to the ground plane; and vertical displacement of the path tip by rotation of the pathway up and down about its near end normal to the ground plane, respectively. Present velocity was displayed by the "tar strips" as for the attitude mode, while the velocity error from the required value was displayed by speed markers, bars adjacent and parallel to the left side of the pathway, which translated along the path at a rate that was a direct function of the velocity error, the direction of motion relative to that of the "tar strips" denoting the error sense.

SOURCE: Ref 44

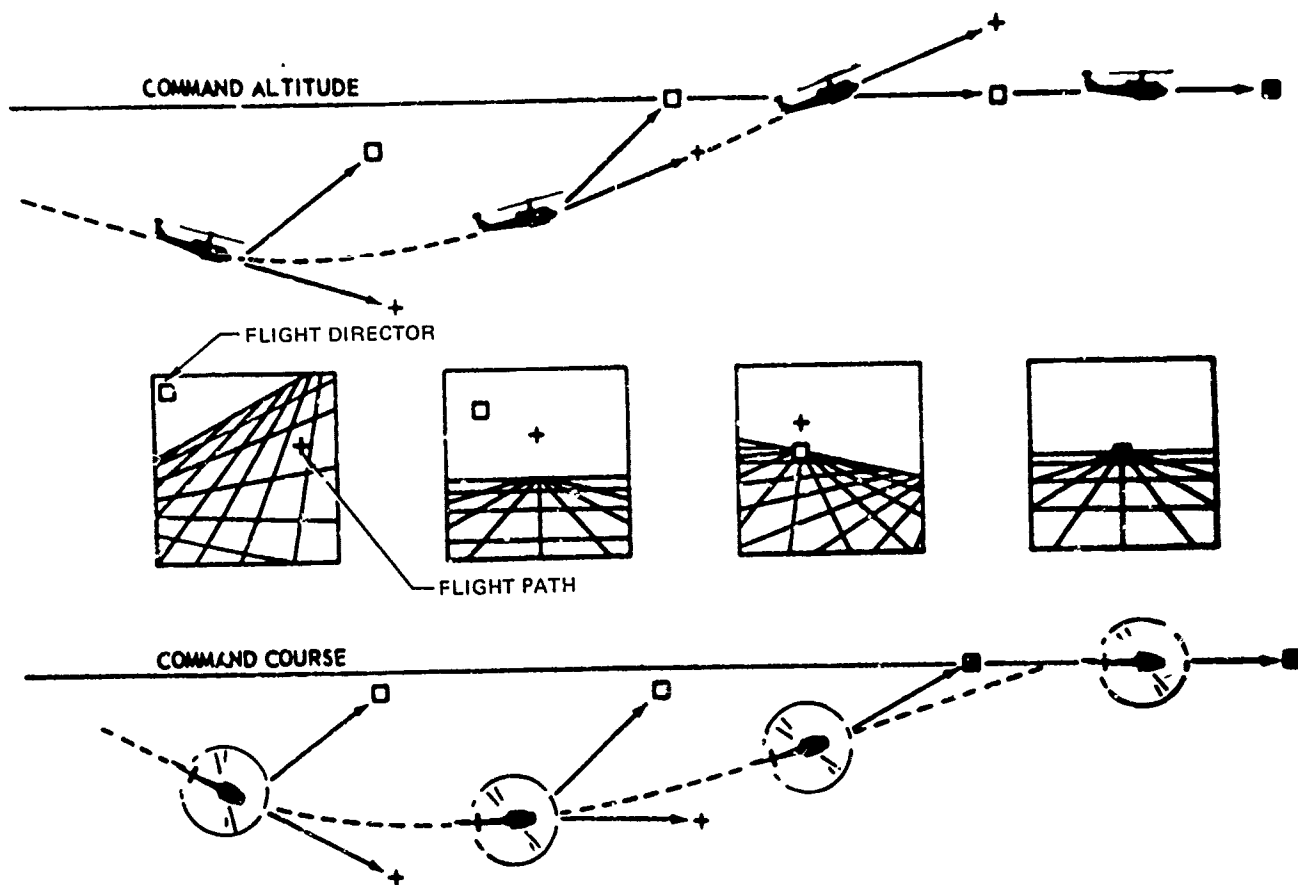
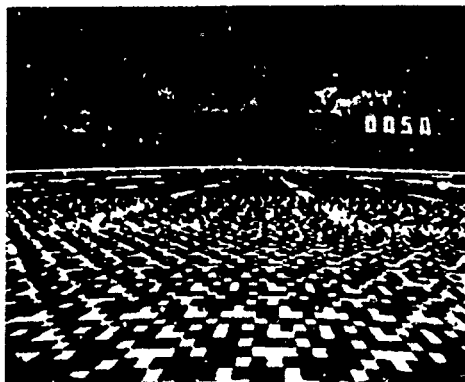


Figure 53. Steering Director Display Showing Aircraft Below and to Right of Desired Path

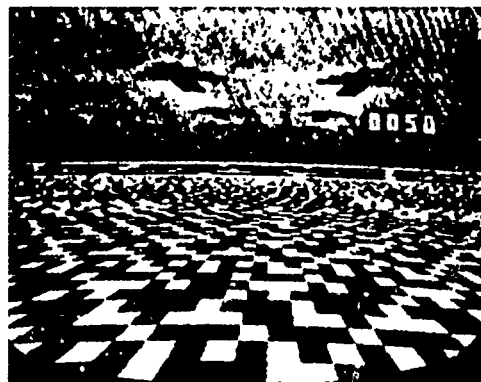
DESCRIPTION:

Figure 53 illustrates a contact analog display for rotary-wing aircraft with flight direction information in various flight situations. (No additional information available.)

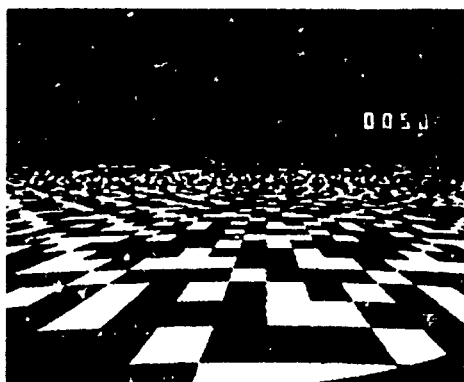
SOURCE: Ref 45



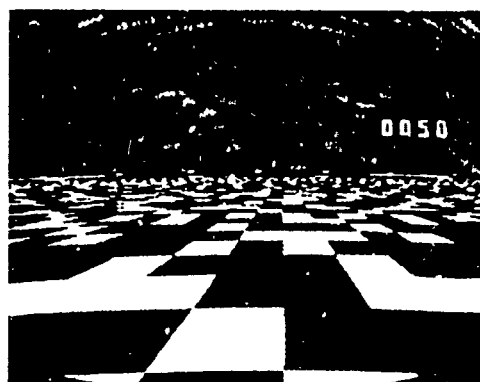
(a) Four-foot cell size.



(b) Eight-foot cell size.



(c) Sixteen-foot cell size.



(d) Thirty-two-foot cell size.



(e) Sixty-four-foot cell size.

Figure 54. Effect of Increasing Cell Size

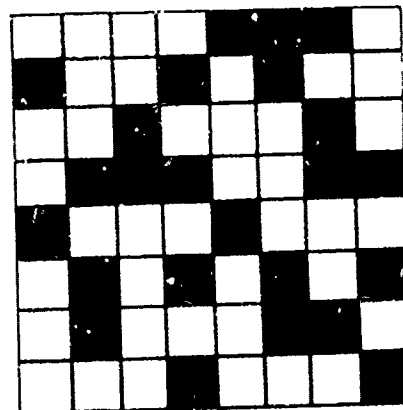
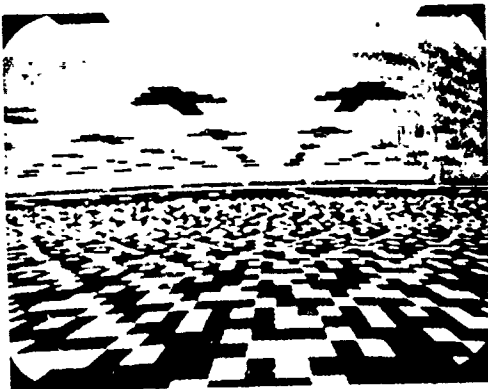
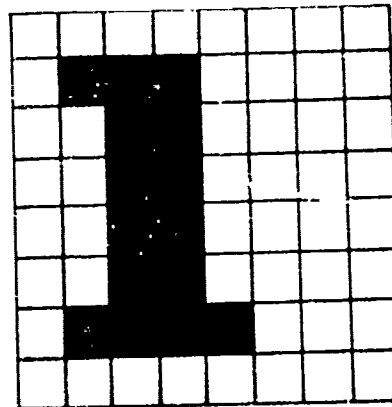
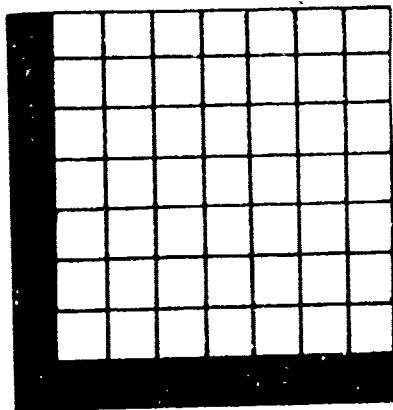
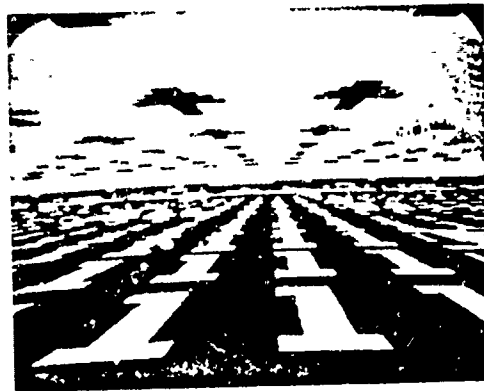
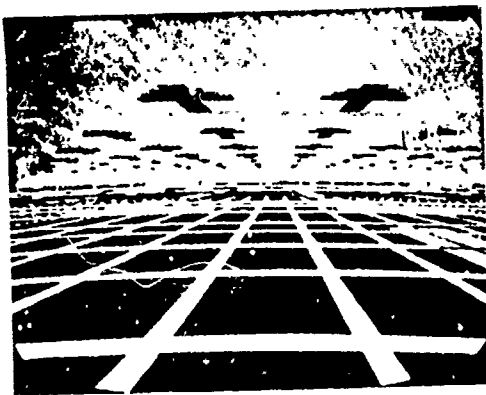


Figure 55. Three Types of Ground Texture Elements.

DESCRIPTION:

The illustrations in Figures 54 and 55 show the effect of varying ground plane texture in a contact analog format. Figure 54 shows how an altitude cue can be provided on the contact analog by simply varying ground texture cell size. Figure 55 looked at types of ground texture and the resulting display appearances.

SOURCE: Ref 34

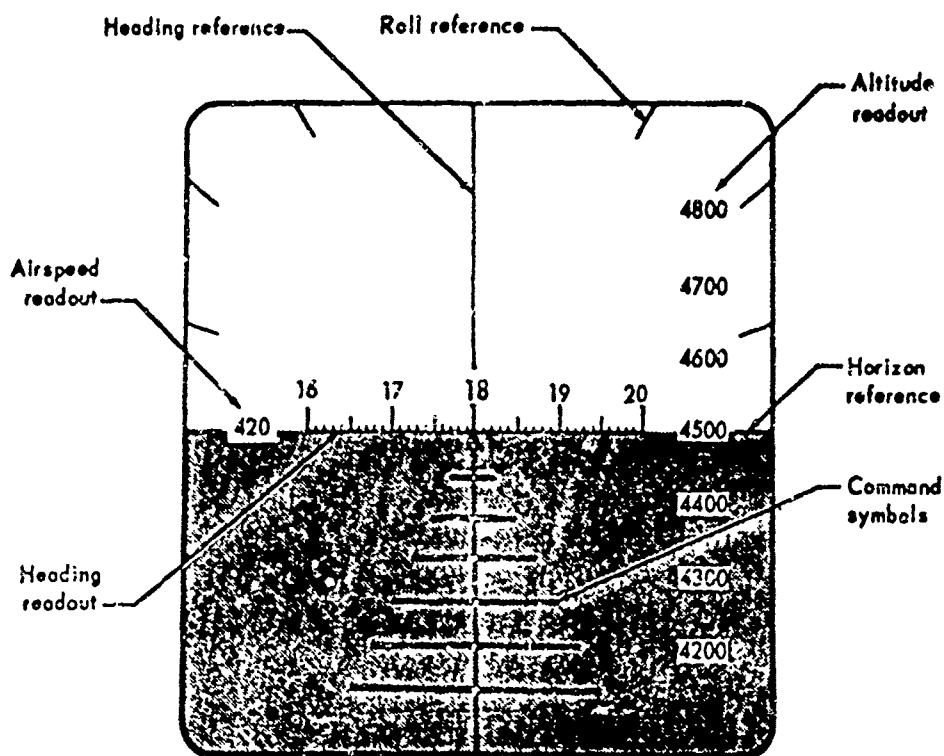


Figure 56. Command Situation Display

DESCRIPTION:

The display in Figure 56 was developed as an example of a basic vertical command situation display for a fighter aircraft. It utilizes command symbol movement to present rate information. For example, the control command symbols will appear to advance or recede to indicate speed control errors. Symbols will remain fixed when speed is on command. The altitude readouts will appear to move up or down furnishing altitude rate information.

SOURCE: Ref 16

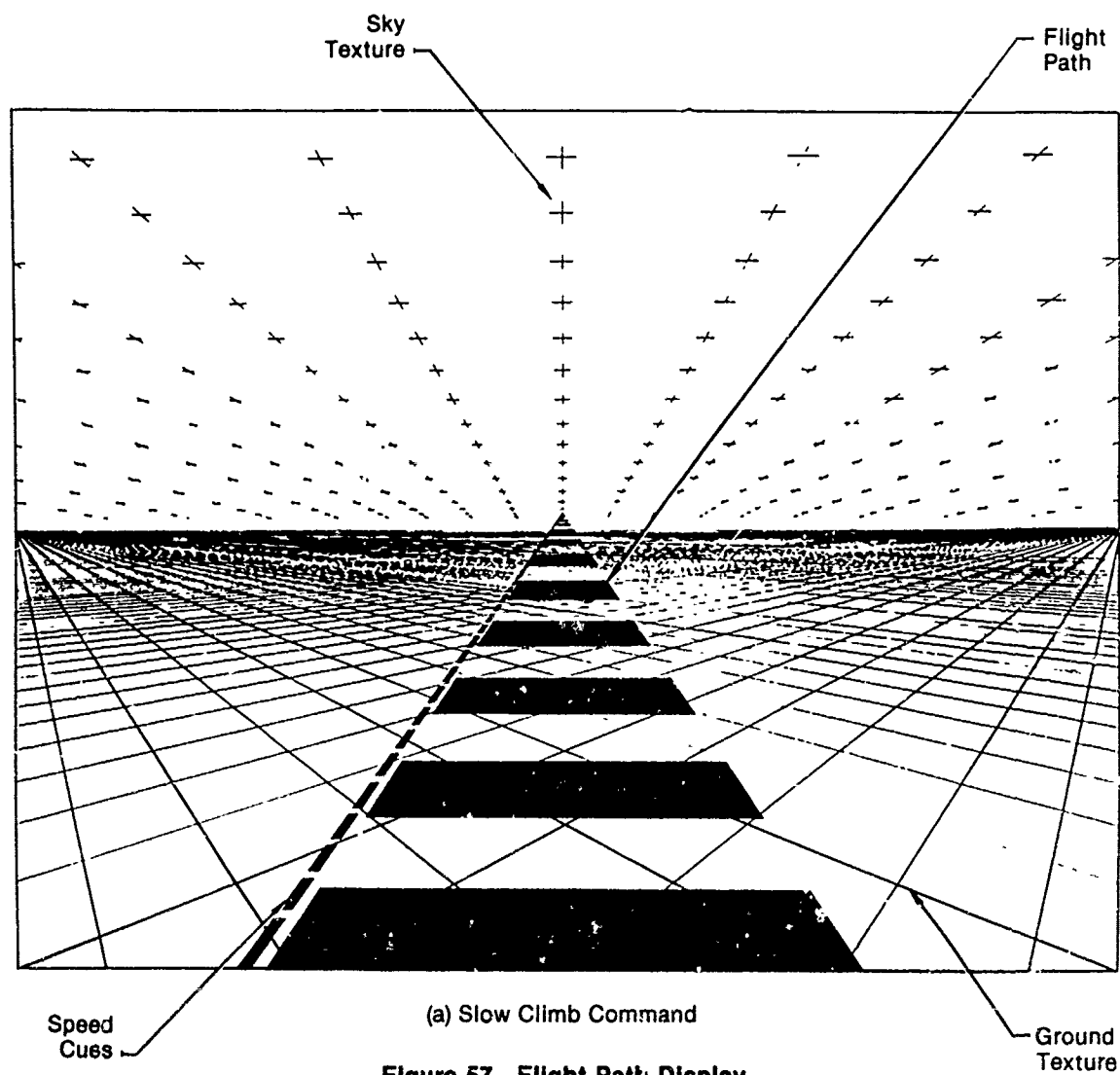


Figure 57. Flight Path Display

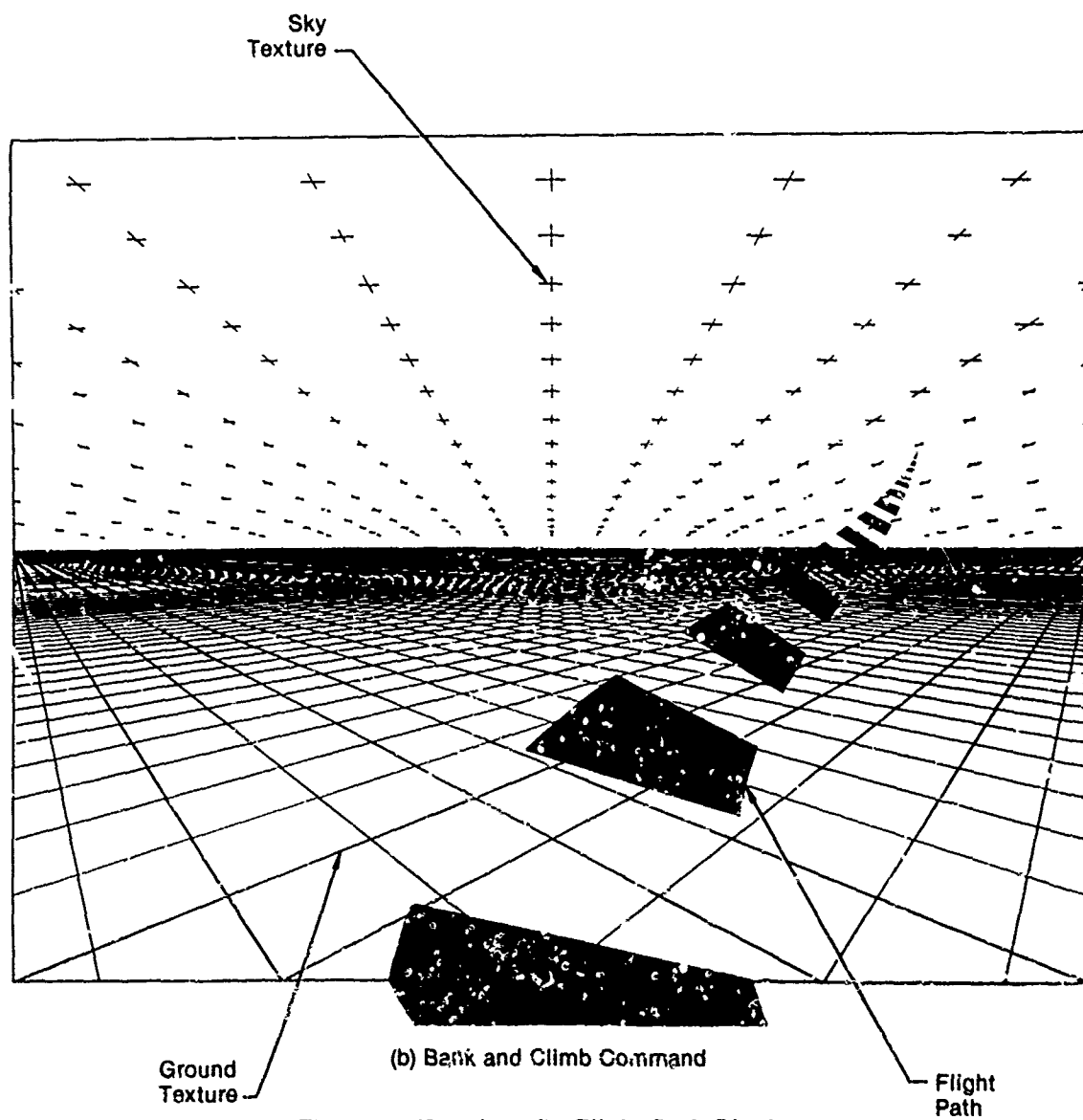


Figure 57 (Continued). Flight Path Display

DESCRIPTION:

Figure 57 depicts two later ANIP contact analog displays showing the command pathway and sky and ground plane texture. (No further information available.)

SOURCE: Ref 38

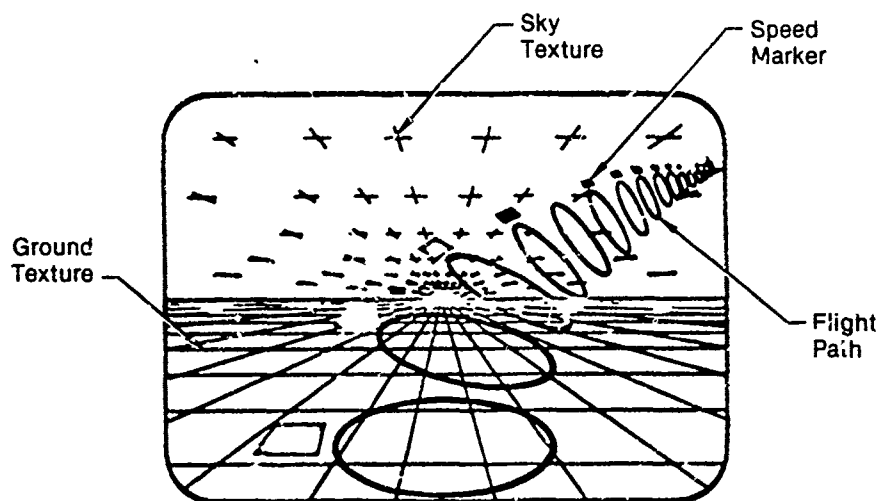


Figure 58. Contact Analog and Flight Path

DESCRIPTION:

Aircraft attitude and position are presented in Figure 58 by means of two planes generated in two dimensions with proper perspective, one plane representing the ground, the other representing the sky. A horizon will be formed when the two planes, each ground-stabilized, appear to meet at infinity. The resulting display will indicate aircraft attitude in exact agreement with that which the pilot would see while viewing the surrounding terrain through the display area.

Flight-director information will be presented to the pilot in the form of a "highway in the sky," shown in Figure 58 as a path of diminishing ellipses. This flight path will appear to have no thickness, to have a finite width and to be indefinitely long. Command speed will be given by means of the "velocity track," shown as boxes alongside the flightpath. The elements of the velocity track will appear to be fixed out in front, move toward, or away from the vehicle to indicate either excessive, or insufficient vehicle speed.

SOURCE: Ref 40

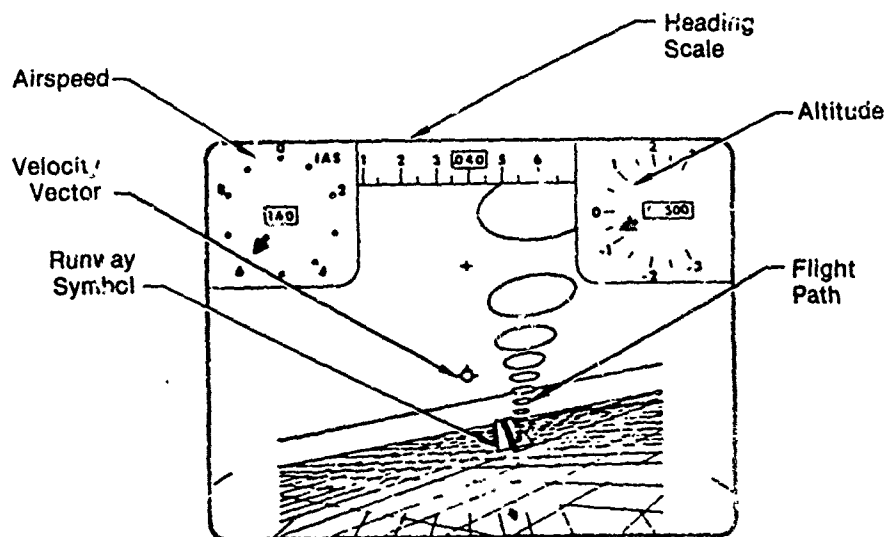
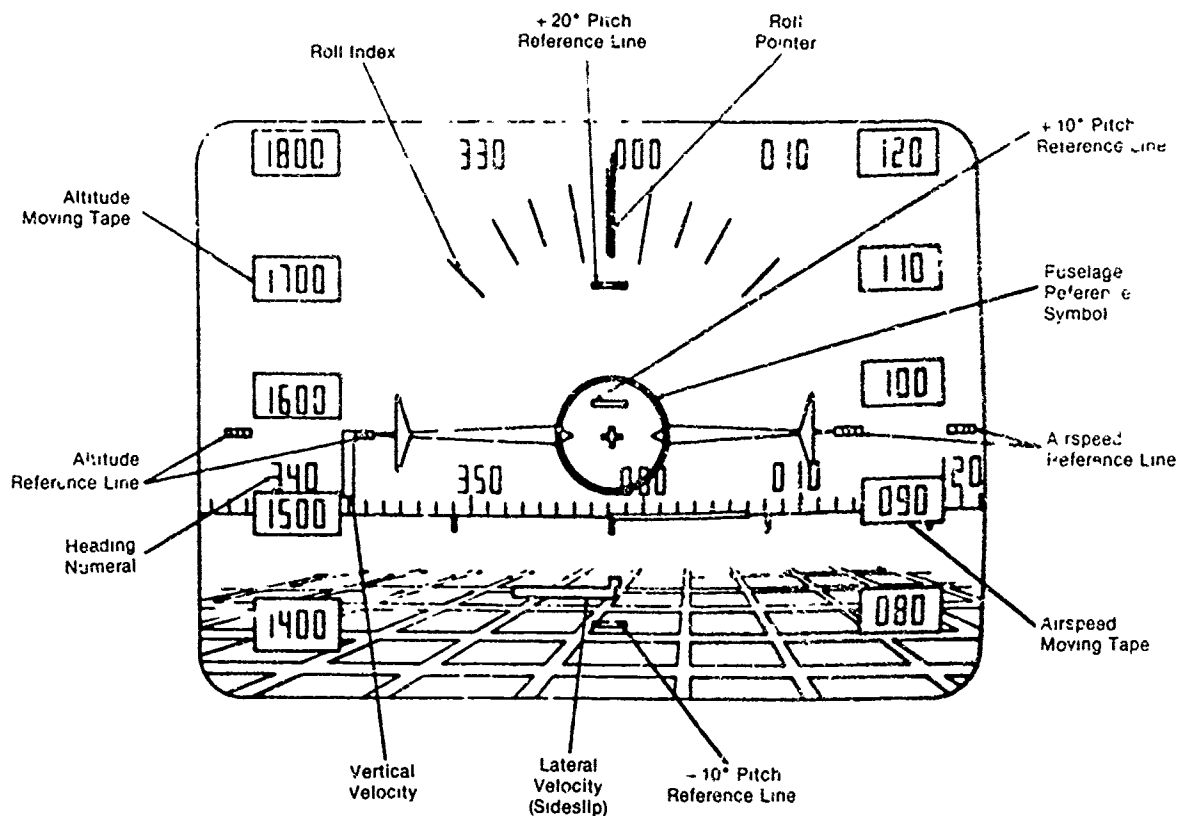


Figure 59. Pictorial Display, Landing Mode

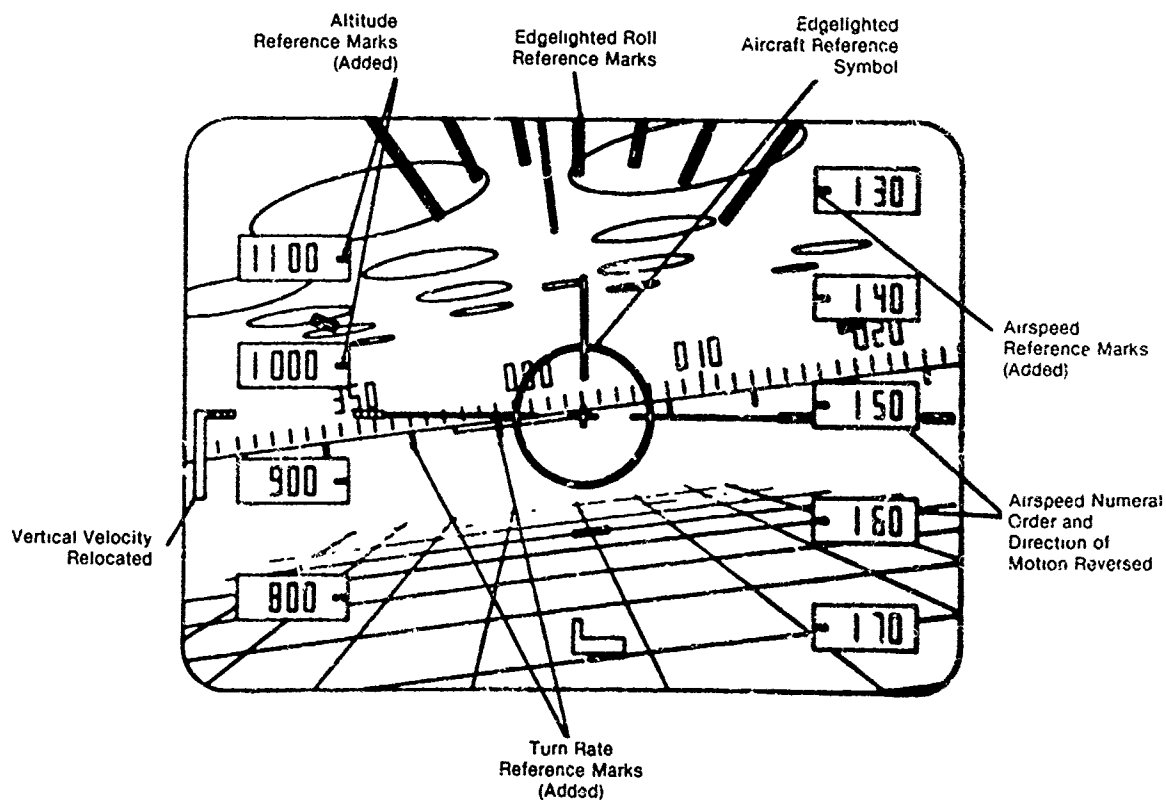
DESCRIPTION:

The integrated pictorial display in Figure 59 shows a proposed landing mode configuration. The basic vertical situation is shown in a contact analog format with the desired glideslope displayed as stepping stones down to the runway centerline. Airspeed, heading, vertical speed, and roll are displayed quantitatively. (No additional information available.)

SOURCE: Ref. 12

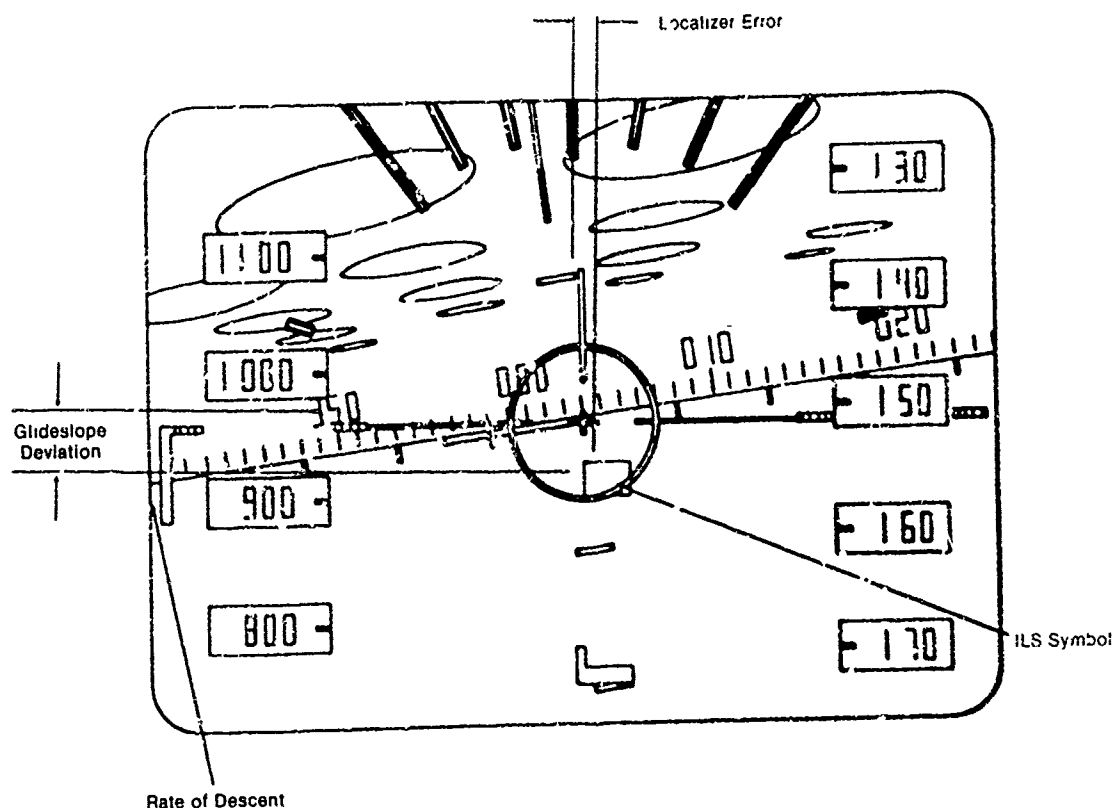


(a) Fixed-Wing Basic Format (Original Version)



(b) Fixed-Wing Basic Format (Revised Version)

Figure 60. Integrated Flight Displays



(c) Fixed-Wing Landing Format

Figure 60 (Continued). Integrated Flight Displays

DESCRIPTION:

The formats are shown in Figure 60 the result of simulation studies of an integrated electronic vertical display developed for a raster scan TV integrated flight display, suitable for use in fixed-wing, rotary-wing, and VTOL aircraft.

It is interesting to note in these formats that the ground is gridded except in Figure 60 (c) and the sky uses circles (ellipses when seen in perspective) to provide texture. Figure 60 (b) represents a revision of (a) following simulation studies.

SOURCE: Ref 46

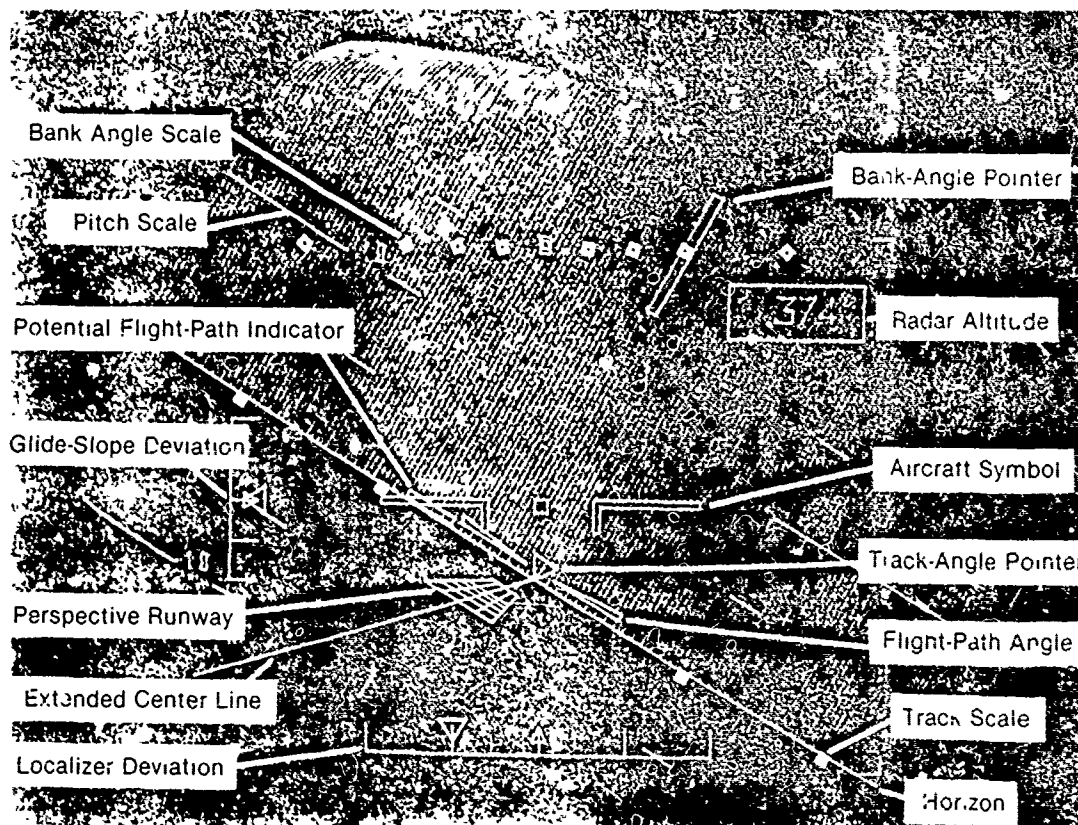


Figure 61. Computer-Generated Image

DESCRIPTION:

The EADI format shown in Figure 61 was used in a piloted simulation evaluation of the benefits of the addition of runway symbology and track information to an EADI for the approach-to-landing task. Results of this evaluation showed that the addition of a perspective runway image and relative track information improved tracking performance both laterally and vertically during the approach-to-landing task and mental workload necessary to assess the approach situation was reduced.

SOURCE: Ref 47

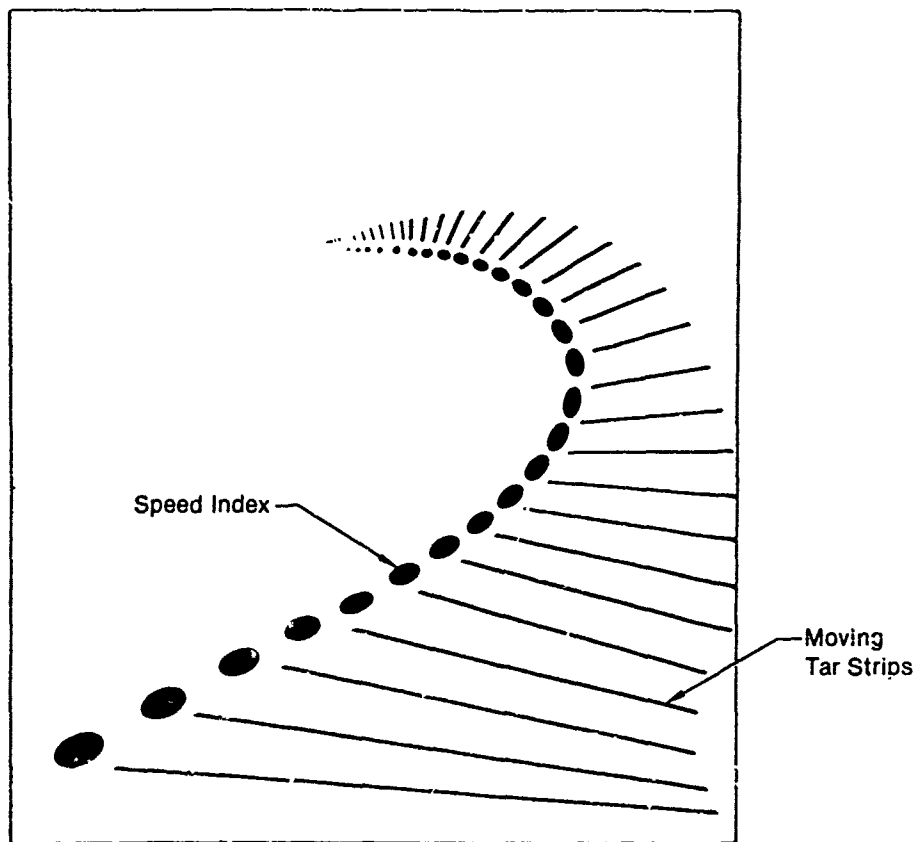


Figure 62. Command Flight Path

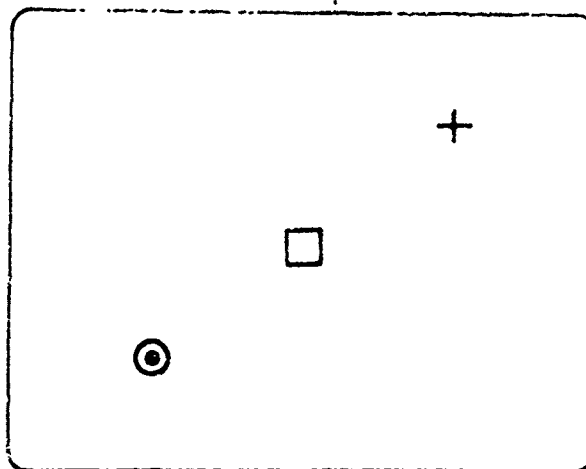
DESCRIPTION:

The display in Figure 62 was developed as part of a program investigating new integrated visual displays. It is a natural "solution" display in that it simultaneously presents "what to do" as well as "how to do it" information. A flight path is shown composed of moving "tar strips" and a speed index. The aircraft stabilized, commanded flight path extends out in front of the aircraft, displayed to the pilot with complete geometric fidelity. Thus all elements will appear with proper perspective.

The flight path is displayed as though the aircraft is taxiing on it. The "tar strips" appear to move under the aircraft at a speed proportional to the airspeed. The speed index is nulled with the "tar strips" when commanded and actual speed are equal. The index will move forward or aft in relation to the "tar strips" if commanded speed is different from actual aircraft speed.

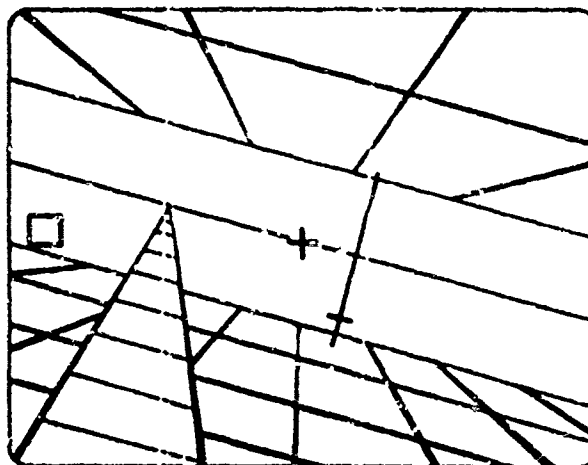
The command flight path would be applicable to many different mission situations. These include takeoff, rendezvous, air-to-ground attack, and landing.

SOURCE: Ref 48



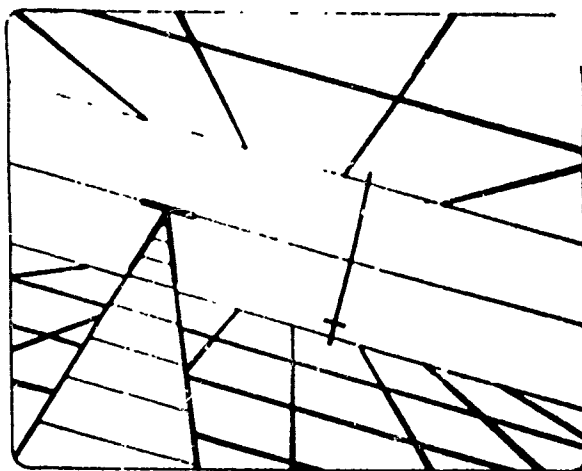
- Ordered Z,
- Tracking Symbol
(Nonlinear Quickening)
- Obstacle
- + Ship's Z,

Figure 63. Symbolic Depth-Azimuth Quickened Display



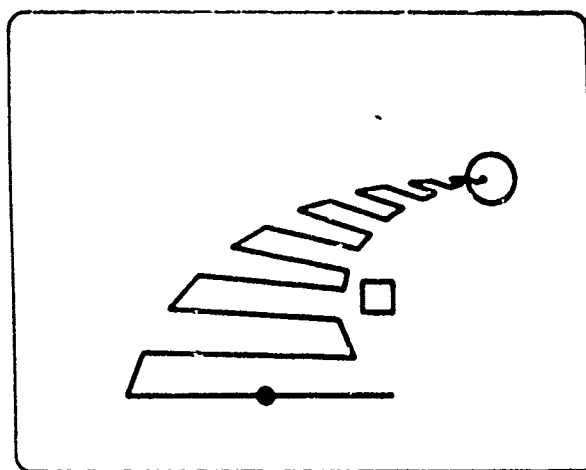
- Quickened Compensatory Tracking
Symbol (Includes Ordered Z,)
- + Ship's Bow Reference ("Steered"
to Quickened Symbol, But Fixed in
Center of Window)
- ⋈ Obstacle

Figure 64(A). Contact Analog Display: Symbolic Quickened Tracking



- ▲ Ordered Z,
- ⋈ Tracking Symbol (Perspective Tracking Symbol)
- ↓ Obstacle
- Ship's Z, Given by Total Window View, Grids, Path, Horizon

Figure 64(B). Contact Analog Display: Perspective Quickened Tracking



- Ordered Z,
- ▣ Tracking Symbol (Predicted Path)
- Obstacle
- Ship's Z,

Figure 65. Symbolic Input to Azimuth Predictor Display

DESCRIPTION:

The four displays in Figures 63, 64 (a,b) and 65 were used in a comparative evaluation of pictorial vs. symbolic displays for submersibles.

Figure 63 is the depth-azimuth display with symbolic quickened tracking. The four shape-coded symbols are set in a depth-azimuth coordinate frame. They indicate ordered position, actual position, obstacle or target position, and quickened tracking reticle.

Figure 64 (a) is a contact analog, a pictorial inside-out "window" display, with a superimposed symbolic compensatory tracking task. This concept represents real-world geometry consistent with available sensors and on-board navigational computation, on a two-dimensional perspective plane. The symbolic tracking task permits the introduction of quickened information without loss of vehicle status information with respect to the earth coordinate reference frame. In Figure 64 (a) the operator is shown a horizon, grid structure representative of the sea surface, and a parallel structure representative of the sea floor or test depth of the vehicle. Between these surfaces, a command path is displayed which is earth stabilized in depth, and offers cues of depth and azimuth errors. These display cues are not actively employed in the tracking process, which consists of merely nulling the bow reference marker into the quickened compensatory tracking symbol. In this display, the obstacle appears as a pole between the grid structures with a short horizontal bar to indicate obstacle depth. Range is determined by perspective cues.

Figure 64 (b) shows the contact analog display with a perspective tracking symbol. Introduction of quickened tracking information in the three-dimensional perspective of the contact analog space give the operator a consistent display rooted in real-world geometry. Consistency is obtained because vehicle situation and tracking functions are perceptually integrated. The operator forces the tracking symbol to conform to the perspective of the pathway element in the contact analog by appropriate control column deflections in a pursuit tracking task. This action brings his vehicle to the ordered depth and azimuth of the pathway. The quickened tracking symbol is made up of an element of the horizon and elements of the left and right curbstones of the pathway. As shown in Figure 64 (b), the tracking symbol is matched, in a pursuit tracking manner, with the appropriate elements of the real-world analog.

Figure 65 shows the symbolic depth-azimuth predictor display. This technique utilizes the two time scale computer method of prediction, where a model of the vehicle in a fast-time simulation is employed to determine future trajectories of the vehicle with prevailing initial conditions, and various control input programs. The operator selects a desired future time to rendezvous with the ordered depth-azimuth position, and within the known programmed system dynamics, he can apply appropriate control column deflection to effect this solution.

Evaluation results showed the choice of any one display or any class of displays (such as contact analog vs. the depth-azimuth format) would depend on the mission requirements of the vehicle.

SOURCE: Ref 49

(Figure reprinted courtesy of AIAA)

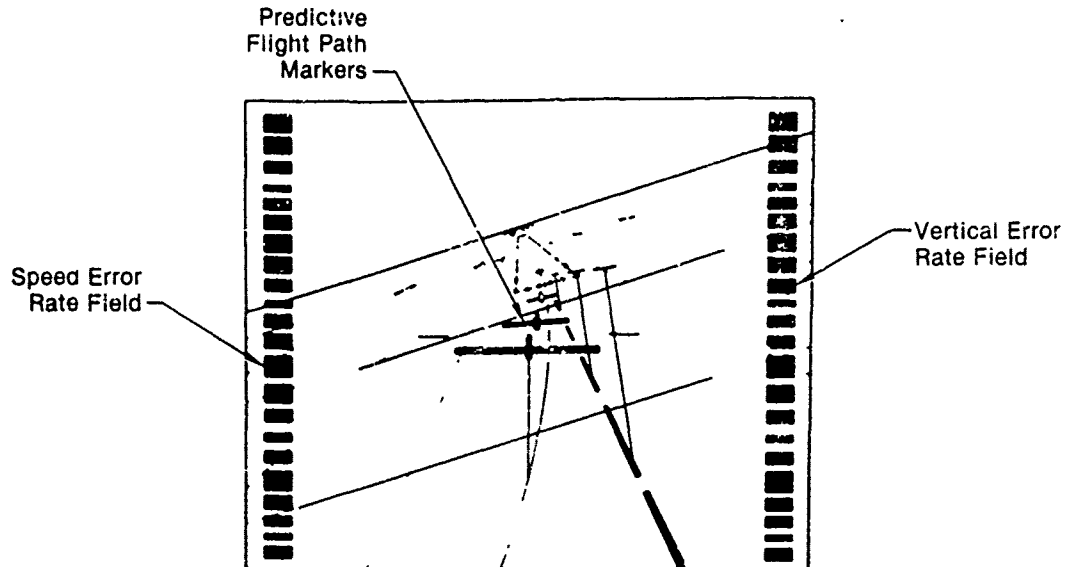


Figure 66. Computer-Generated Contact Analog Display with Predictive Flight Path

DESCRIPTION:

Figure 66 was generated as part of a research effort directed toward (1) isolation of minimum sets of visual image cues sufficient for spatial and geographic orientation in the various ground-referenced phases of representative flight mission, and generation and spatially integrated presentation of computed guidance commands and past-time flight path predictors. The computer-generated VSD landing scene, shown above, would be quite skeletal to accommodate the superpositioning of dynamic forward-looking infrared or lowlight TV imagery without serious rivalry. Both command guidance and a frequency separated projection of the predicted flight path, as shown by the successively smaller airplane symbols would be superposed in true perspective upon the computer-generated scene. Such a predictor display shows the pilot the future consequences of his immediate control inputs. Predictor symbols represent the position of the aircraft at three particular future points in time (7, 14, and 21 seconds as shown) given a specified control input by the pilot.

As shown, the airplane is low and to the left of a normal straight in approach and banked to the right, but the pilot has made the proper control input to pull up and roll left to bring the airplane to the desired touchdown point.

The prominent vertical rate fields to the left and right may be used to present speed and vertical flight path guidance. By nulling the rate-field motion, the pilot nulls the errors relative to the computed desired values of the moment. In mission phases other than the landing approach depicted, the rate fields might present command guidance for speed and altitude.

SOURCE: Ref 50

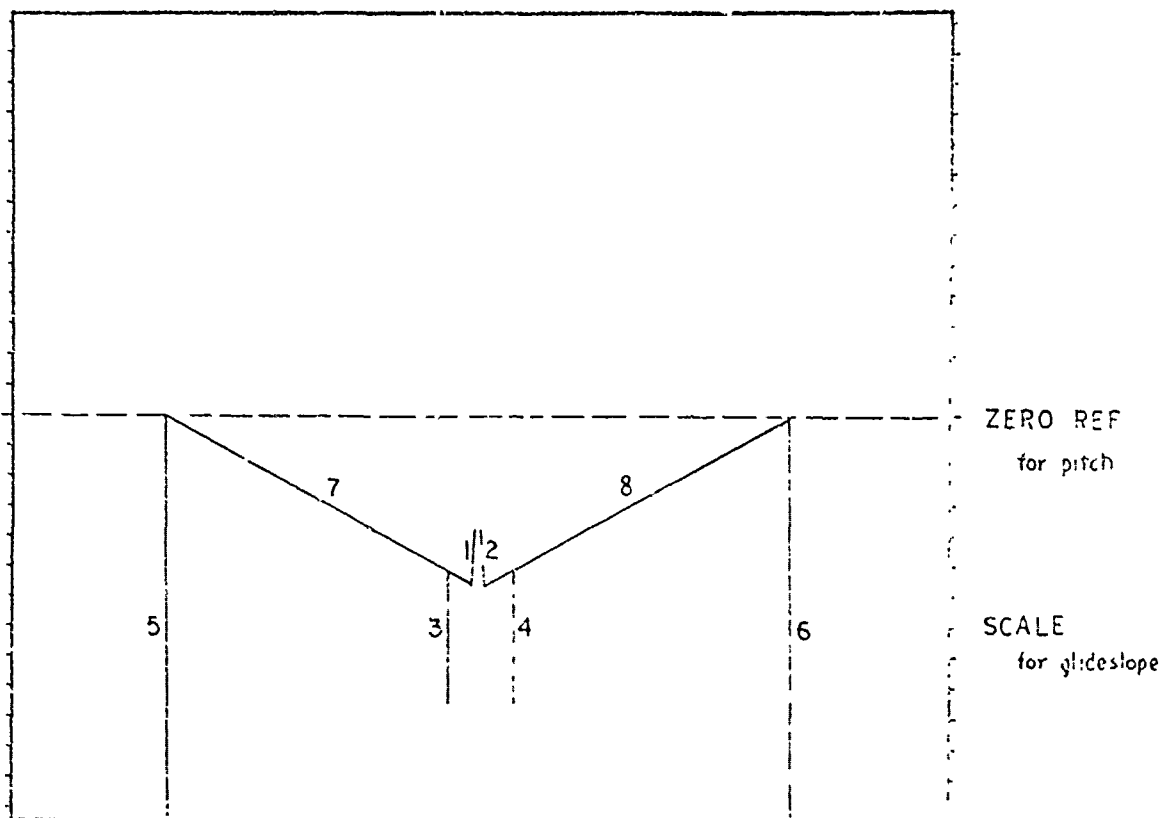


Figure 67. The Perspective Display

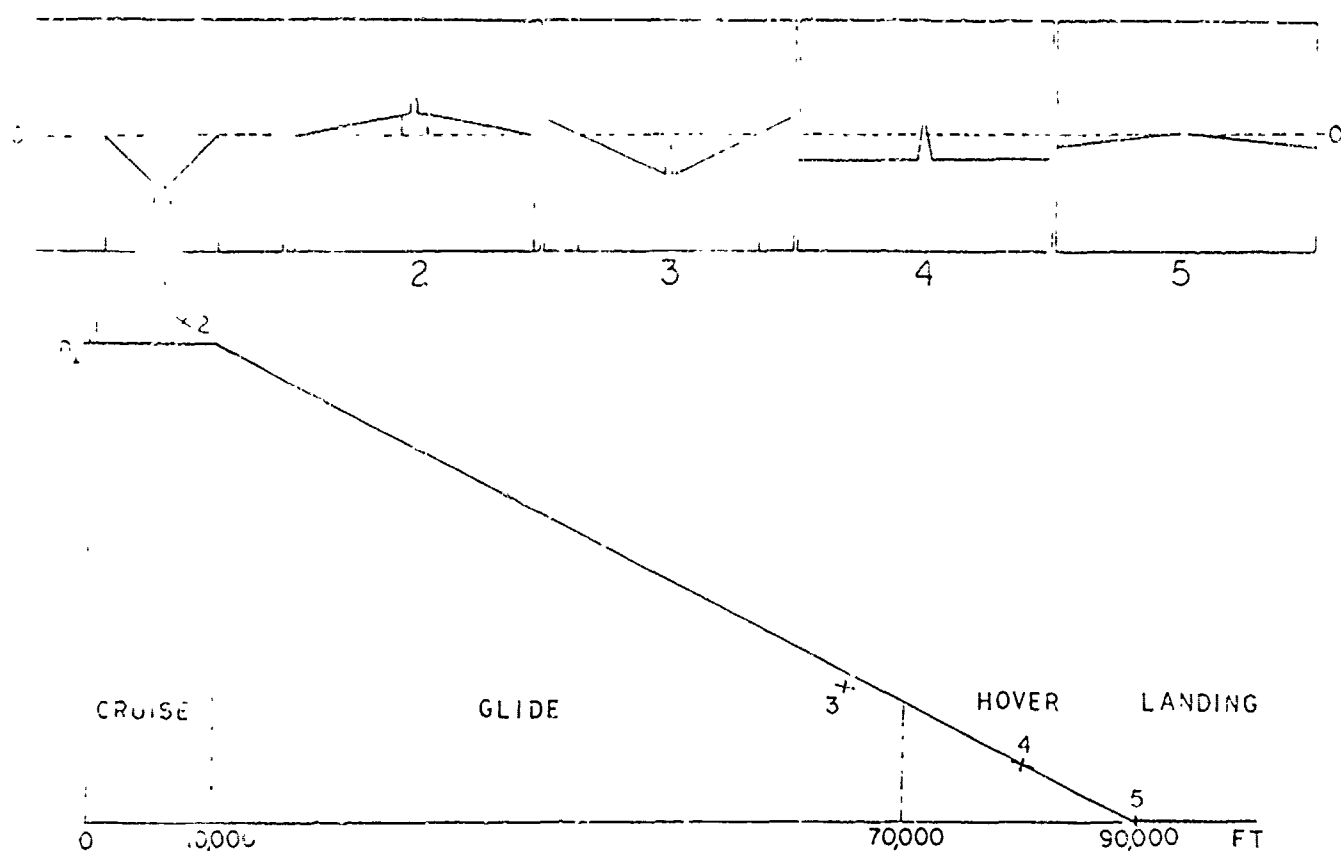


Figure 68. Different Views of the Perspective Display as Seen from the Indicated Positions on the Localizer Beam

DESCRIPTION:

A perspective glideslope indicating system has been evaluated as an alternative to conventional aircraft displays for landing or contact analog displays.

The perspective glide slope display above is composed only of straight lines. It is a "skeleton-type" display and it is the view the pilot would get through the windshield of an aircraft if there were indeed a glideslope "roadway in the sky." The picture is symmetrical when flying only in one plane and has, at the far end, two parallel runway lines. Theoretical intersection of these two lines (1, 2) is the horizon. Two vertical poles (3, 4) are set at 20,000 ft. from the runway threshold and are an aid in indicating the beginning of transition in the flight. The two nearest poles (5, 6) are set at the beginning of the glidepath. Glideslope itself is given by lines (7, 8) which intersect the ground plane at the runway threshold. For the first part of the flight (level flight) the pilot must keep the top of nearby vertical poles on the reference to get to the glideslope. Lines (7, 8) at first indicate that the aircraft is too low with respect to the glideslope. They will become more and more parallel, indicating the aircraft is approaching to the glideslope. Once they are parallel the pilot must keep them that way, and he learns immediately where to put the runway on the screen to stay on glideslope. As the time lines (3, 4) come by, the pilot starts transition to landing, still trying to stay on glideslope. Closer to the ground the runway lines (1, 2) will spread open and at touchdown they both become horizontal.

The value of the perspective glideslope display has been shown 1) in the case of performing coordinated maneuvers, allowing large but quite precise changes of the flight variables, 2) in the consistency of touchdown, 3) in accuracy of tracking the glideslope with dead beat response, 4) in the learning curve, and 5) in the effectiveness of the representation of the integrated real world outside picture.

SOURCE: Ref 51

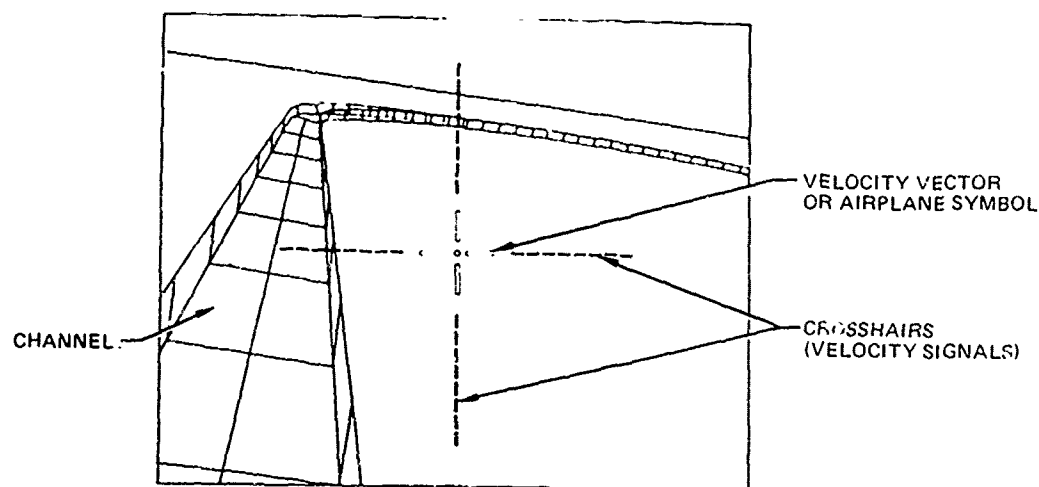
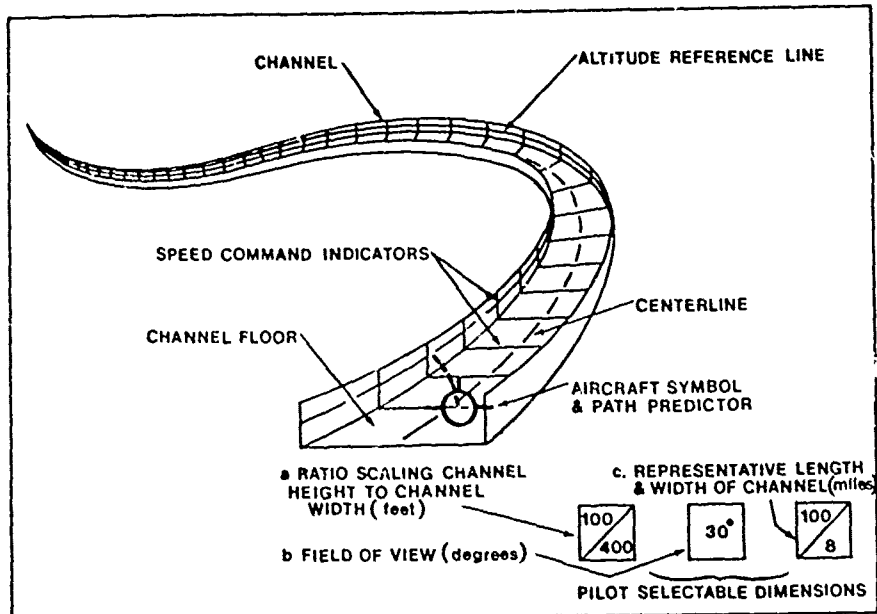


Figure 69. Channel Display

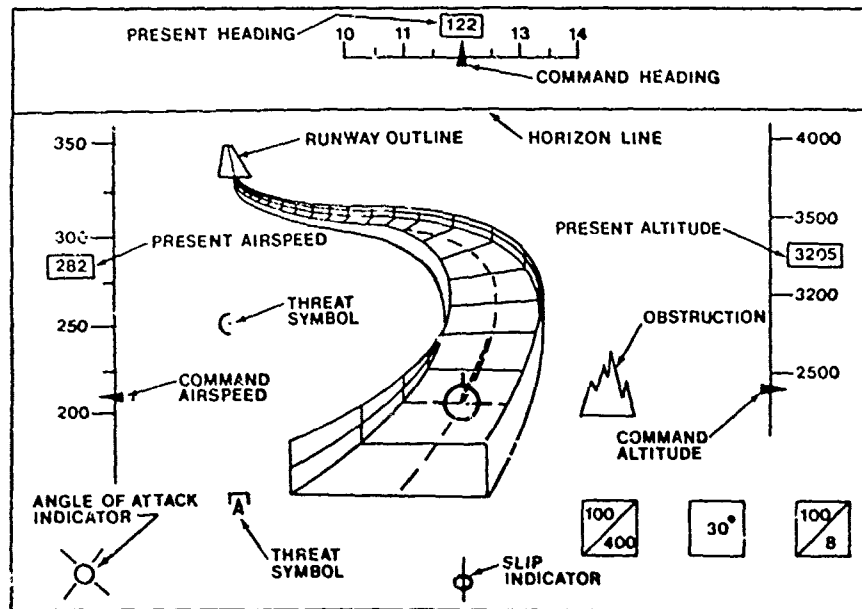
DESCRIPTION:

Figure 69 is a proposed format to provide velocity and path-guidance information using a pictorially quantitative and true perspective channel display. In this true perspective, contact-analog, inside-out display (Figure 69), path guidance is shown as a curved channel incorporating space-fixed structural elements. Attitude angle is similar to that for visual contact. The pilot is required to guide the aircraft down the middle of the channel, with the velocity vector aligned in its center. A "flow" of cross hair images from the velocity vector indicate reduced or increased velocity. If actual speed matches commanded the velocity signals appear stable. Otherwise they withdraw inward (velocity too fast) or emanate outward (velocity too slow).

SOURCE: Ref 19



(a) Basic Symbolology



(b) Full-Up Symbolology

Figure 70. Proposed Flight Path Display

DESCRIPTION:

Figure 70 shows flight path displays resulting from conclusions drawn from a study of previous flight path display studies. The proposed flight path display in Figure 70 (a) may appear either on a head-up or head-down display. It consists primarily of a three-dimensional perspective channel and an aircraft symbol. The aircraft symbol is a stationary symbol, and the channel moves about it with changes in lateral and vertical direction.

The pilot's task requires him to guide the aircraft symbol through the center of the channel in order to accurately stay on course. When the pilot is flying the command path, the channel floor and wings of the aircraft symbol will appear parallel and horizontal. The tail of the aircraft symbol will indicate lateral accuracy when aligned with the channel's centerline and vertical (altitude) accuracy will be indicated when the wings are aligned horizontally with altitude reference lines on either side of the channel's entrance.

Inner and outer channel walls contain vertical line segments perpendicular to horizontal lines on upper (inside) view of the floor. Floor lines are perpendicular to the centerline. These line segments serve as (1) a speed command indicator (via a strobing effect) and (2) an aid to pilot visual orientation with respect to aircraft symbol and channel. The aircraft symbol is augmented by a dashed line path predictor. Each of the four consecutive dashes represents a time period of 10 seconds, indicating future aircraft position 10, 20, 30 and 40 seconds later if aircraft were to maintain present flight conditions.

The channel extends into the distance so that upcoming curves in the path may be anticipated. The channel is designed to be viewed from all angles. This implies that even though the channel might appear in the form of a tiny configuration in a far corner of the display, indicating extreme lateral and vertical deviation from the path, or as a backward view of the entrance to the channel indicating that the pilot is directed 180° away from the command heading, some perspective of the channel would still be in view of the pilot and never completely disappear from the display surface. Thus, the inability to intercept the path due to a loss of display would never be a problem.

If the display were to appear on a head-down CRT (as opposed to a HUD), the channel's inner and outer portions may be shade- or color-coded in some way that makes differentiating them easy for the observer. Questions arising with respect to direction of orientation, then, could be answered more quickly, especially when deviations from command path are great, and channel is obscure.

Information addition to channel and aircraft symbol may be displayed (Figure 70 (b) by pilot selection. This information may include moving heading, altitude and airspeed scales all of which can provide command indicators, current readouts, plus rate and direction of change. Also angle-of-attack and slip indicators may be made available on the display to enhance accuracy of flight path control.

The option of including a textured surface, with sky, horizon line and ground could be available. As the channel turns, or banks, the horizon line (and accompanying ground/sky texture) would bank also, in conjunction with the path. Radar-detected obstructions or threats may be indicated on the display per pilot's command. Finally, a runway outline would appear on the display at the end of the channel during approach and landing modes. Outline of runway would become proportionately larger as pilot approached touchdown, and outer edges would stream by his view once he reached the runway, approximating view seen by a pilot landing VFR.

The pilot may change the scale of several dimensions of the format anytime throughout his flight. He may adjust: (1) channel height-to-width ratio (aircraft symbol remains fixed in size, regardless of channel or actual aircraft proportions); (2) field of view; and (3) length and breadth of channel in terms of their representative dimensions. These dimensions would appear on display at all times, and their values could be changed whenever the pilot deemed it necessary.

SOURCE: Ref. 19.

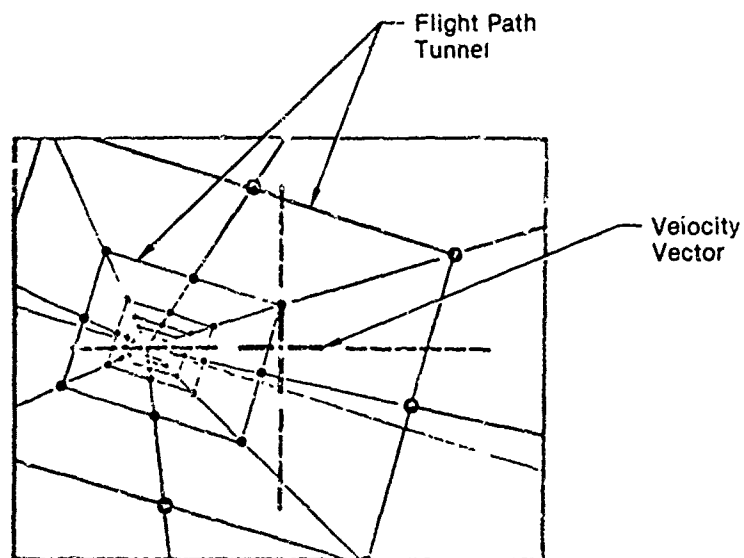


Figure 71. Tunnel Display

DESCRIPTION:

Figure 71 shows a flight path tunnel display. It is assumed that the basic operation of this display is similar to the channel display in Figure 70, the main difference in this display is that the flight path is completely enclosed forming a tunnel appearance. (No additional information available.)

SOURCE: Ref. 12

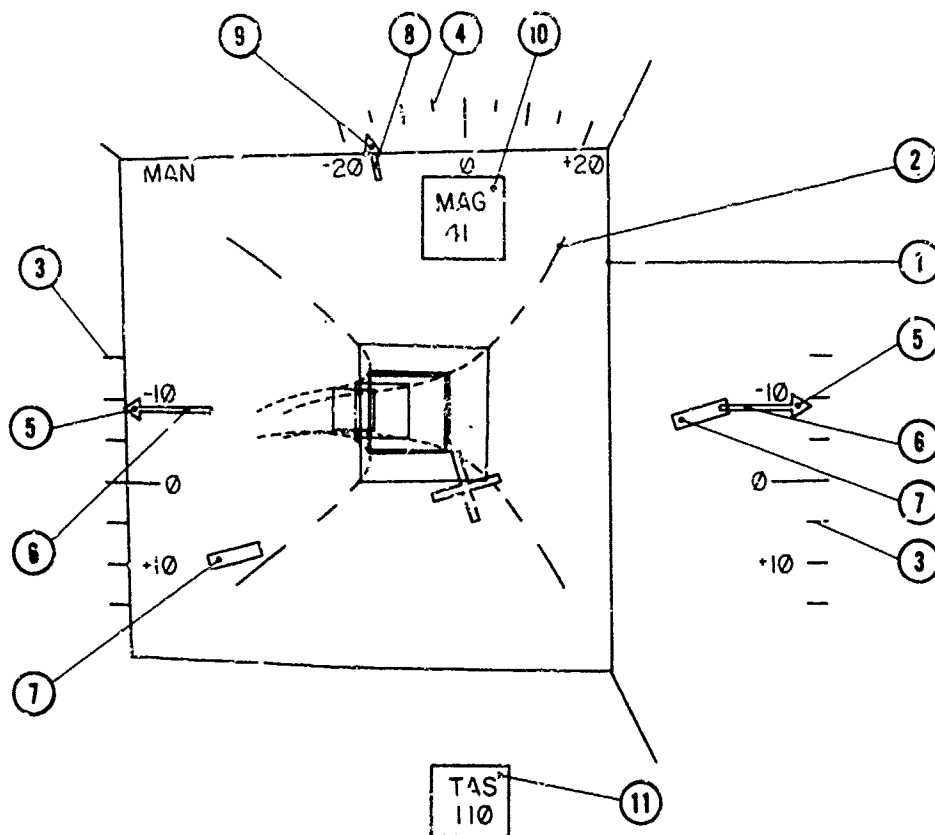


Figure 72. Tunnel Display with Vehicle Axle Cross

DESCRIPTION:

In this investigation of advanced display concepts, control information was presented to the pilot in a format similar to the "through-the-windshield" visual field. A simplified computer-generated perspective image of the visual field was presented to the pilot as if it were a "tunnel in the sky," in which the three-dimensional (3-D) approach path is to be followed. In contrast with conventional instrument displays, the control information was integrated into one format, natural to the pilot. This characteristic makes the display very suitable for following, with great accuracy, approaches which are complicated, strongly curved, and steep. This type of approach might become a necessity in heavily congested fixed-wing and helicopter traffic areas.

A conceptual tunnel display is shown in Figure 72. The trajectory to be followed is presented as a perspective image of a tunnel with a square cross section. The perspective appearance of the tunnel changes with the vehicle position. Positional cues are derived from this perspective appearance, while rate cues are derived from the rate of change in the appearance.

The tunnel cross section is constant and square with a scale width of 45.7 m (150 ft), which corresponds to the width of a typical runway. An experimental configuration was chosen in which the tunnel squares (1) are drawn a scale distance of 91.4 m (300 ft) apart. In order to augment the impression of forward velocity, the cornerlines (2) are dashed. Only the five squares nearest to the vehicle are drawn. Thus, the number of lines drawn is substantially reduced, which prevents cluttering of the display. The tunnel is shown in the viewing range from 0 to 762 m (2500 ft). The maximum horizontal and vertical field of view is from +45° to -45°. Pitch scales (3) and pitch pointers (5) are located at the left and right sides of the image, and a roll scale (4) is located at the top. Pitch motion is also visualized by an equivalent rotation of the optical axis. For small angles, this is equivalent rotation of the optical axis. For small angles, this is equivalent to a vertical displacement of 0.22 cm per degree pitch angle of the tunnel image. The pitch pointer and the tunnel image are displaced, while the pitch scales remain vertically fixed.

Digital readouts of magnetic heading (MAG) (10) and airspeed (TAS) (11) are displayed in boxes on the vertical centerline at the top and bottom of the image, respectively. These boxes also provide a reference for estimating the center of the image. Note that a large area in the center of the display is kept clear of symbology to prevent cluttering the tunnel image.

The tunnel image, pitch scales, horizon, and roll scales are and the bank angle is visualized by rotating the wing bars (7) and the roll pointer (9), in fixed-wing aircraft. This image does not conform to the through-the-windshield visual field and can only be used in head-down type displays.

The cross represents the vehicle at a specified distance ahead. The cross is locked in the center of the image and rolls with the vehicle.

Conclusions from simulation evaluations included:

1. The perspective tunnel image provides adequate positional and directional information and yields markedly better accuracy in trajectory following and trajectory entry than the conventional EADI/map display.
2. The basic tunnel display yields poor damping, due to the lack of rate information (caused by the narrow visual field).
3. A vehicle axis cross, superimposed on the tunnel image does not contribute to better tracking. The error between vehicle axis cross and director square does not provide the correct control cues in trajectory following in a fixed-base simulator.
4. The roll and roll-stabilized versions of the tunnel display perform equally well in trajectory following and entries. This leaves the option open, for applying the roll version to head-up displays, in which the image has to be conformal with the visual world.

SOURCE: Ref 52

2.3 SENSOR GENERATED FORMATS

Sensor generated formats pertain to vertical situation displays that are a direct projection of a TV, FLIR, or RADAR sensor image. Various symbology is usually overlaid on these sensor displays representing reference information pertinent to flight performance.

Roscoe (Reference 2) considered that, based on what little evidence was available, an unaided, literal TV or infrared vertical raster-scan display was inadequate as the primary instrument for landing. The consideration can probably be made for low level flight using such displays. The addition of guidance information to these displays for navigation and flight control appears to provide the necessary support for the pilot's spatial and geographic orientation as well as being an independent monitor of the reasonableness of the flight situation.

Typically such displays are presented head-down. Technology is now being developed to present this same information on a HUD.

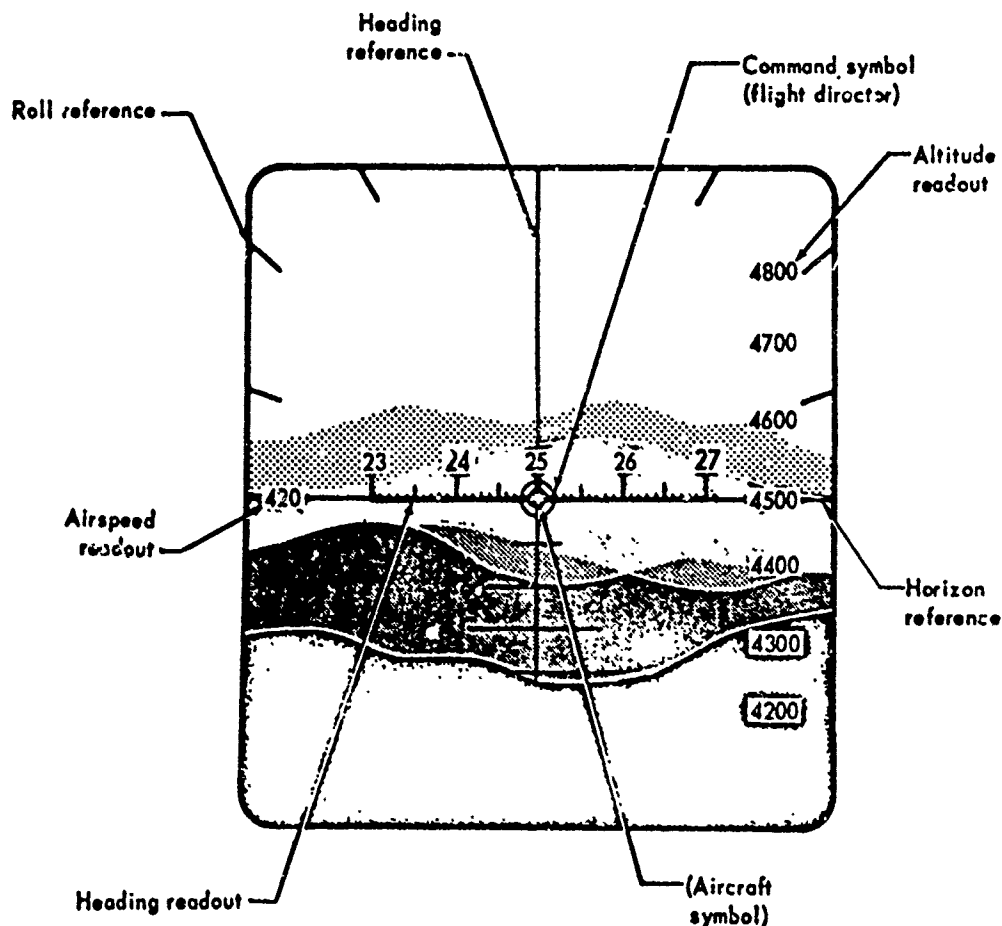


Figure 73. Command-Situation Display in Terrain Following Mode

DESCRIPTION:

The head-down display in Figure 73 was designed as an example integrated flight display for fighter aircraft. It is shown here in the terrain-following mode. Terrain profiles are shown at specified ranges, each succeeding profile in a darker shade of gray. Key flight information is arranged near the center of the display to give the pilot quick reference to it without wandering too far from the critical central display area.

SOURCE: Ref 16

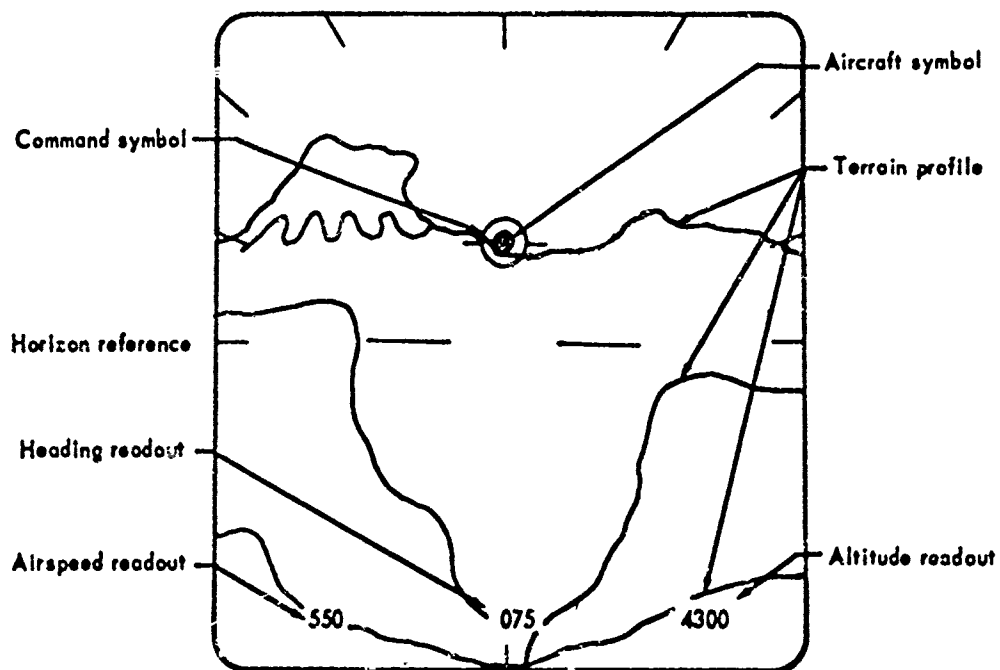


Figure 74. Head Up Display in Automatic Terrain Following Mode

DESCRIPTION:

Figure 74 was designed as an example automatic terrain-following mode for a head-up display on a fighter aircraft. In an automatic terrain following mode only necessary information is presented head-up. In Figure 74 the most important data are the terrain "slice" profiles, the aircraft symbol and the flight path command symbol. The other presented data, roll index, airspeed, heading and altitude readouts and the horizon reference are secondary to this format.

SOURCE: Ref 16

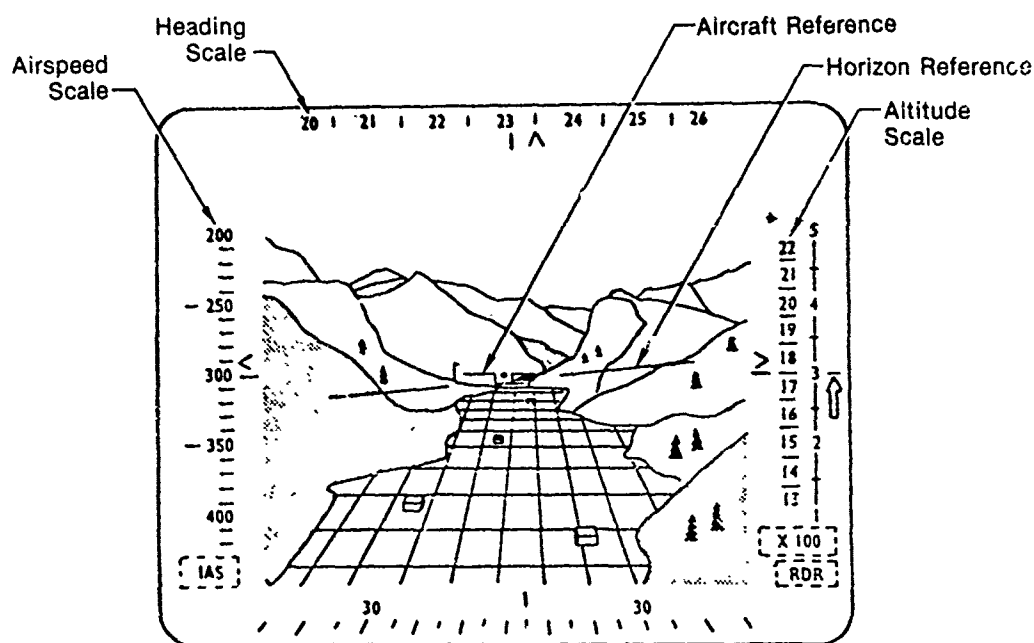


Figure 75. Electronic Attitude Director Indicator with Terrain Clearance Presentation

DESCRIPTION:

The display in Figure 75 is a detailed contact analog. Elements selected for display could be based on sensor data such as radar returns or FLIR data, or could be computer-generated scenes from geographical data stored in computer memory. Flight information could be added as shown as required.

This type format could be presented head-down or perhaps even head-up for use in all-weather or night attack. Use of color would also enhance this display. (No other information available.)

SOURCE: Ref 21

3. HORIZONTAL SITUATION DISPLAYS

The horizontal situation display (HSD) is a projection of the aircraft's situation on the horizontal plane beneath the aircraft (Reference 44). In this format the aircraft's flight path is displayed as it would be seen from above looking down on a horizontal plane such as the ground. The frames of reference for this display are Cartesian coordinates as in road maps and azimuth and range coordinates as in polar coordinates.

HSDs differ from VSDs not only in point of view but also in the speed of display symbology movement. The geographic area covered by the HSD is usually so broad and the scaling of the display is such that the symbol movement on the display is very slow. This results in lowered immediacy as a result of misinterpretation or misdirection and makes the HSD less dangerous than the VSD in terms of time available to correct mistakes (Reference 5).

HSDs presently take two forms, projected and electronic. Projected maps can be self contained or remote. The self-contained map system consists of the necessary electronics, optics and film strips in a black box. The remote projected map uses a film strip being scanned by a TV camera, apart from the display unit. This allows the map video to be displayed on any CRT that has TV video capability.

Electronic maps are generated from stored computer data. The amount of information displayed is a function of the available computer case.

Whatever the source, HSD's are a valuable navigational and tactical aid to the pilot. In addition to typical geographical data, the ability to overlay calligraphics such as a compass rose, aircraft symbol, waypoint, targets, threats, Ta an stations and course lines have proved to be enhancing. The ability to change map orientation (e.g., track-up, north-up) as well as decentering the map to give the pilot more look-ahead capability has proven to be desirable.

Electronic maps could offer declutter options that selectively eliminate types of geographical features not required to perform a specific task.

Both types of maps can be utilized to update the Inertial Navigation System (INS) using prominent landmarks.

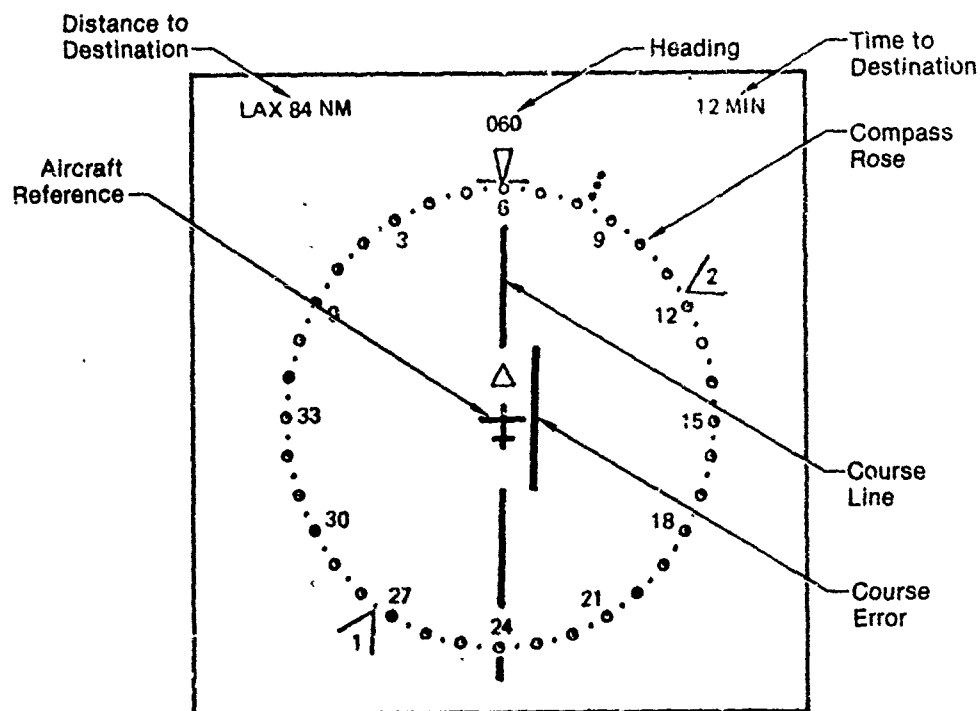


Figure 76. HSD (HSI Mode) Symbology

DESCRIPTION:

The display in Figure 76 was used as a representative EHSD format in a simulation evaluation of an advanced crew station. It shows an electronic horizontal situation indicator (EHSI), very similar in symbology to the traditional HSI. Destination distance and time to destination are shown in the upper corners. (No other information available.)

SOURCE: Ref 8

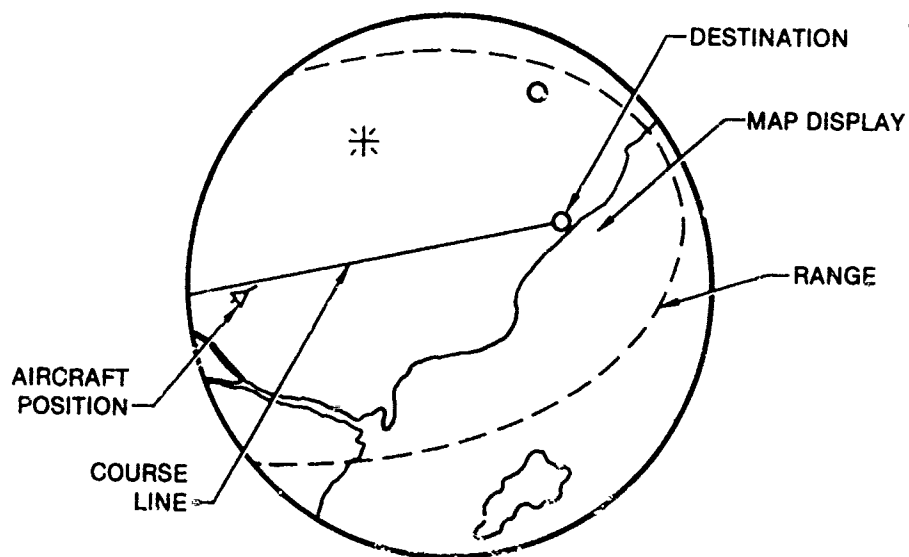


Figure 77. HSD Format

DESCRIPTION:

Figure 77 was developed as part of the ANIP study to provide navigation information. This head-down projected map shows course line, aircraft position, destination, range limit as affected by wind, fuel, etc., and other landmarks of interest.

SOURCE: Ref 53

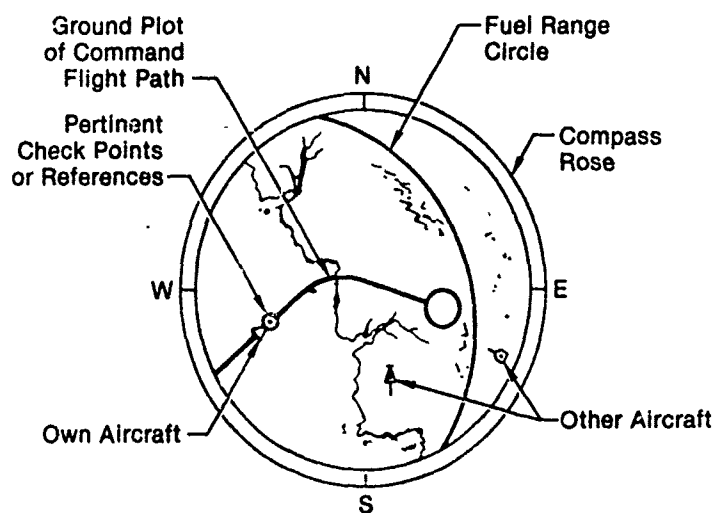


Figure 78. Horizontal Situation Display

DESCRIPTION:

The HSD in Figure 78 shown a geographic display of map data with aircraft-pertinent information superimposed. (No additional information available.)

SOURCE: Ref 41

Figure 78 reprinted courtesy of

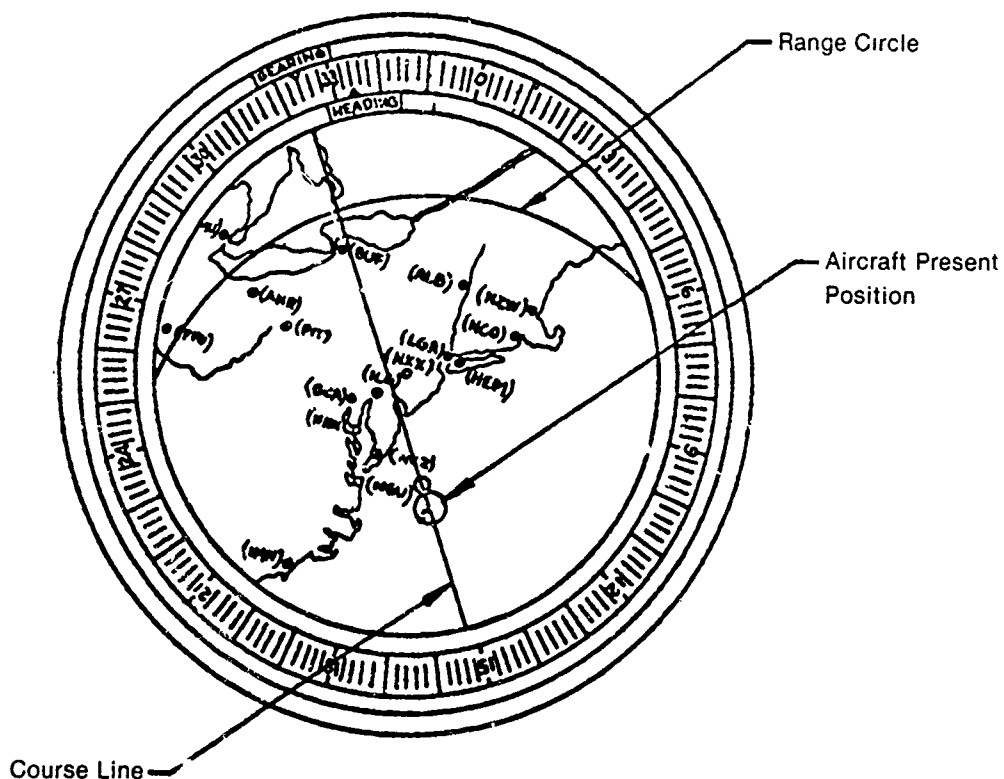


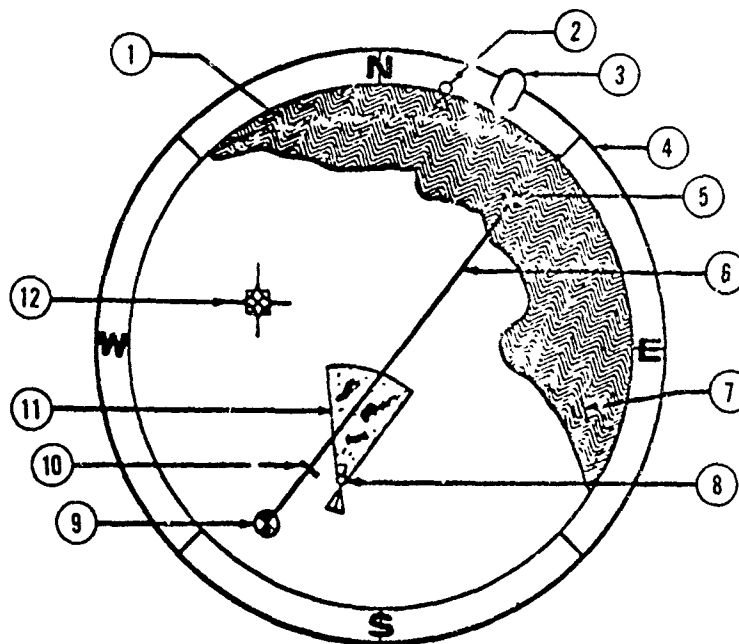
Figure 79. Horizontal Display

DESCRIPTION

Figure 79 was developed as part of the AAAIS (Advanced Army Aircraft Instrumentation System) program. It shows an early proposed moving map display with fuel range circle and course line. (No further information available.)

SOURCE: Ref 54

- 1 Fuel Range
- 2 Heading Cursor
- 3 Course Cursor
- 4 Compass
- 5 Destination or Target Symbol
- 6 Command Course Line
- 7 Map Display
- 8 Aircraft Symbol (Reticle)
- 9 Base Symbol
- 10 Command Position Symbol
- 11 Radar Display
- 12 NAVAID Symbol



- 1 Friendly Aircraft Symbol
- 2 Map Display
- 3 Compass
- 4 Heading Cursor
- 5 Navaid Symbol
- 6 Command Course Cursor
- 7 Enemy Aircraft Symbol
- 8 Command Course Line
- 9 Acquisition Circle
- 10 Holding Pattern Symbol
- 11 Fuel Range
- 12 Radar Display
- 13 Own Aircraft Symbol
- 14 Base/Destination Symbol
- 15 Command Position Symbol

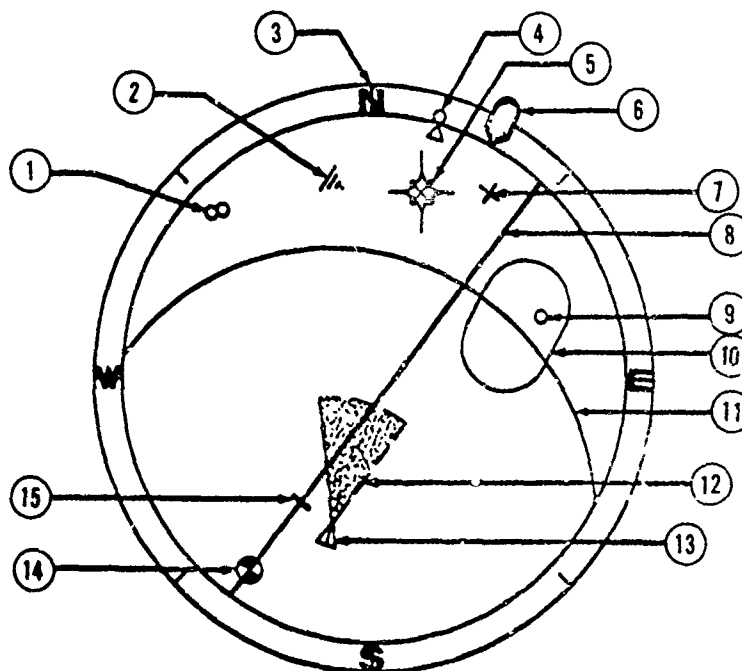


Figure 80. Horizontal Displays

DESCRIPTION:

The horizontal situation formats illustrated in Figure 80 were developed under ANIP to provide a more gross display, suitable for flight and tactical planning, and long-range navigation. The use of various displayed information symbols is illustrated.

SOURCE: Ref 40

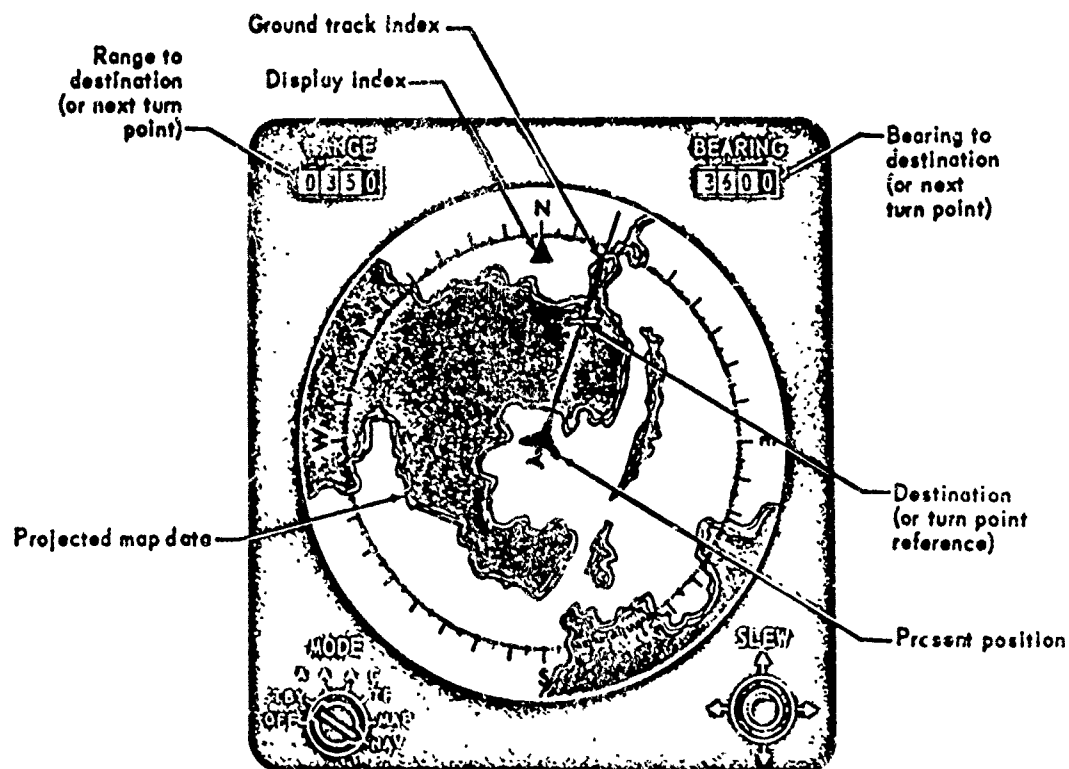


Figure 81. Multipurpose-Navigation Display in Projected Map Mode

DESCRIPTION:

Figure 81 presents a projected map display containing aircraft present position centered on display, destination, ground track, and compass rose. Range and bearing are provided as digital readouts. (No additional information available.)

SOURCE: Ref 21

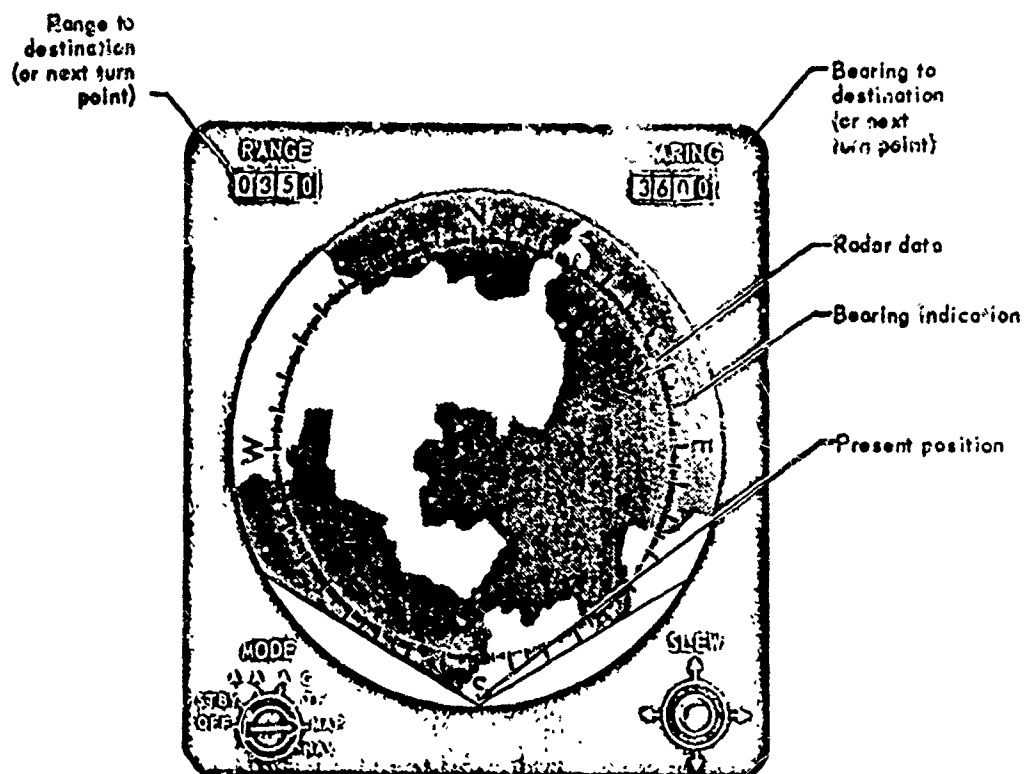


Figure 82. Multipurpose-Navigation Display in Radar Map Mode

DESCRIPTION:

The radar map format in Figure 82 has aircraft present position decentered to lower section of display. This is another mode of operation of the same display shown in Figure 81. (No additional information available.)

SOURCE: Ref 21

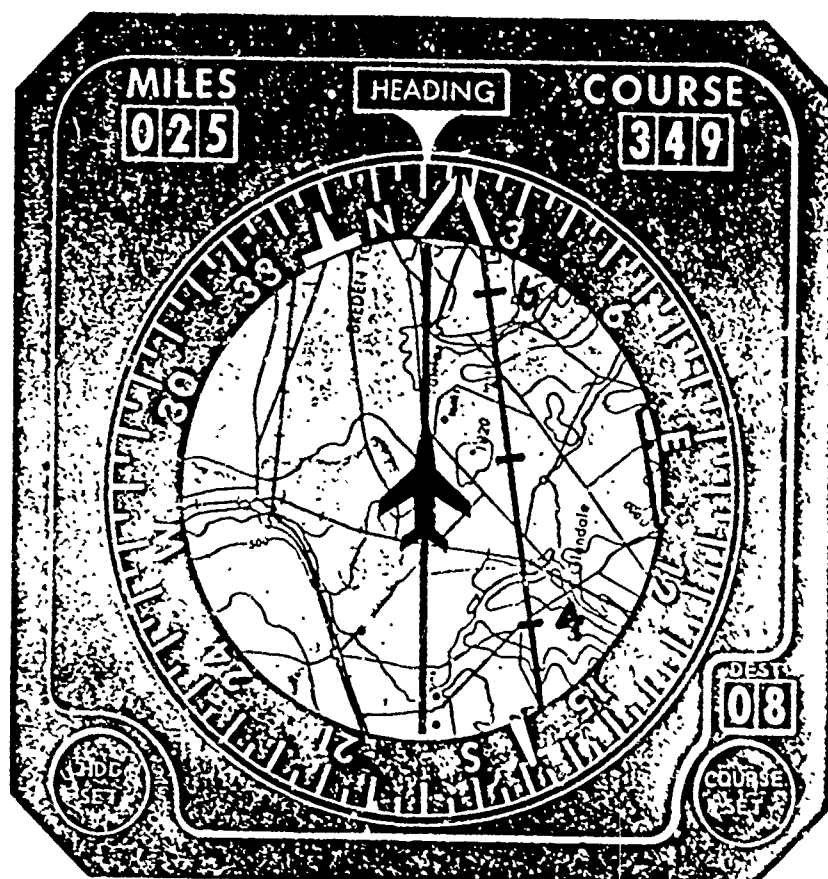
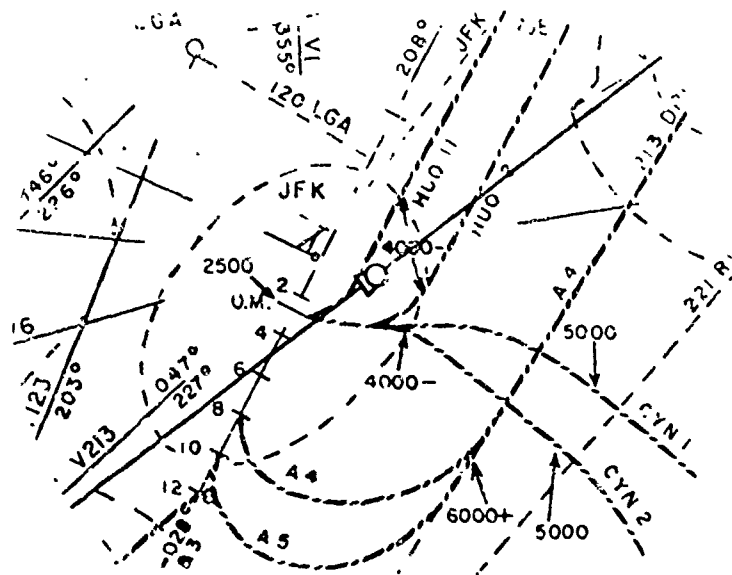


Figure 83. Projected Map Display

DESCRIPTION:

Figure 83 was proposed as a possible configuration for an integrated HSI/moving map navigation display. It is a moving map display with present position indicated by an aircraft symbol. A course line and digital readouts for distance and course are also incorporated. Aircraft heading is always oriented toward the top of the display (Heading-Up).

SOURCE: Ref 55



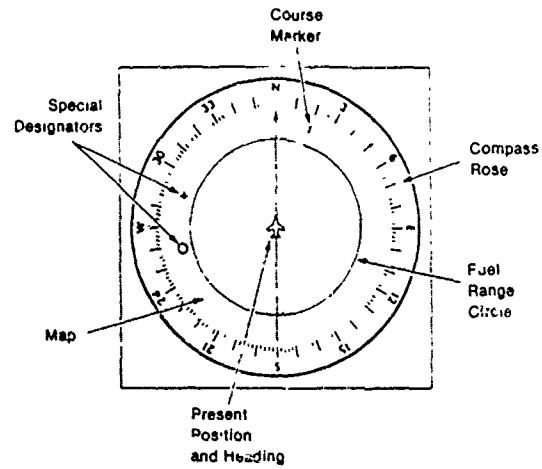
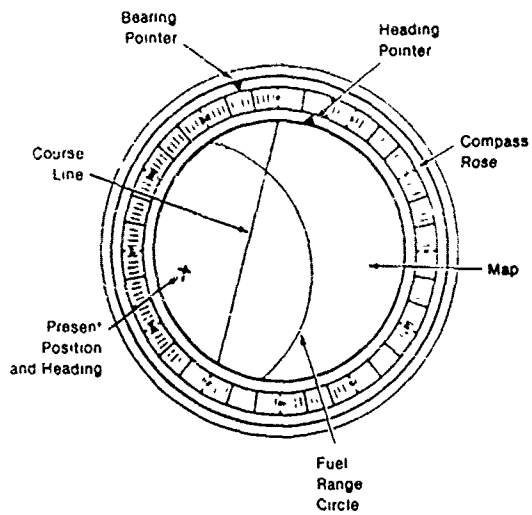
DESCRIPTION:

Figures 84, 85 and 86 present a suggested navigation display for commercial aircraft, with various scale maps. Features of the display include a north-oriented moving map with an aircraft symbol fixed in position in the center of the screen. As a heading change is initiated, the aircraft symbol and attached cursor rotate, heading scale information being depicted at the edge of the screen.

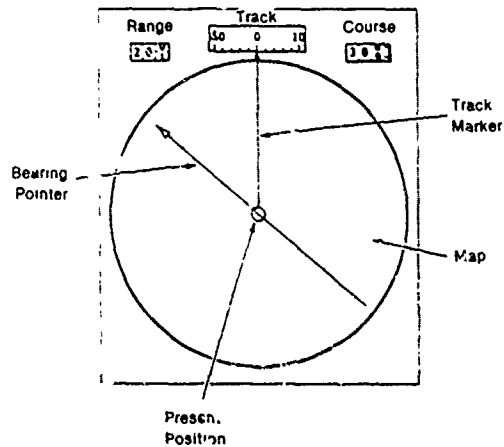
The ground track maps used in the study depicted basic airway, navigation, and some air traffic control information. Maps covering two different areas (en route and terminal) were utilized in the test. The en route map covered the total test area of 400 by 400 nm whereas the terminal map covered an area of 120 by 120 nm in the vicinity of the airport. For the en route map, three scales (40, 20, and 10 nm per inch) were tested whereas for the terminal map, two scales (10 and 5 nm per inch) were tested.

According to tests performed, pilots preferred a 5 nm per inch scale for a terminal map and 10 nm per inch scale for enroute. However, some pilots preferred a 20 nm per inch scale for enroute to have improved look-ahead capability.

SOURCE: Ref 56



Type	Navigational map and radar.	Type	Navigational map
Features	Fixed or moving map modes Rotatable for north or heading up Map in shades of gray	Features	Moving map Rotatable for north or heading up Map in color



Type	Navigational map
Features	Moving map; present position offsetable to periphery Selectable for north or heading up Map in color.

Figure 87. Sample HSDs

DESCRIPTION:

Figure 87 illustrates three early HSD formats. The format in (a) was developed under the Advanced Army Aircraft Instrumentation System (AAAIS). It used a projected navigational map or radar map as its basis. Both fixed and moving map modes were available. The system was rotatable for either north-up or track-up formats. The maps were monochrome but used shades of gray.

In (b) a moving navigational map was used. It was rotatable for north-up or track up and could be projected in color. This display, the MK II HSD, was developed by ITT Gilfillan.

The moving map display in (c) was developed by Computing Devices of Canada. The present aircraft position could be offset to the display periphery. Both north-up and track-up modes were available and the projected map could be in color. (No additional information available.)

SOURCE: Ref 5

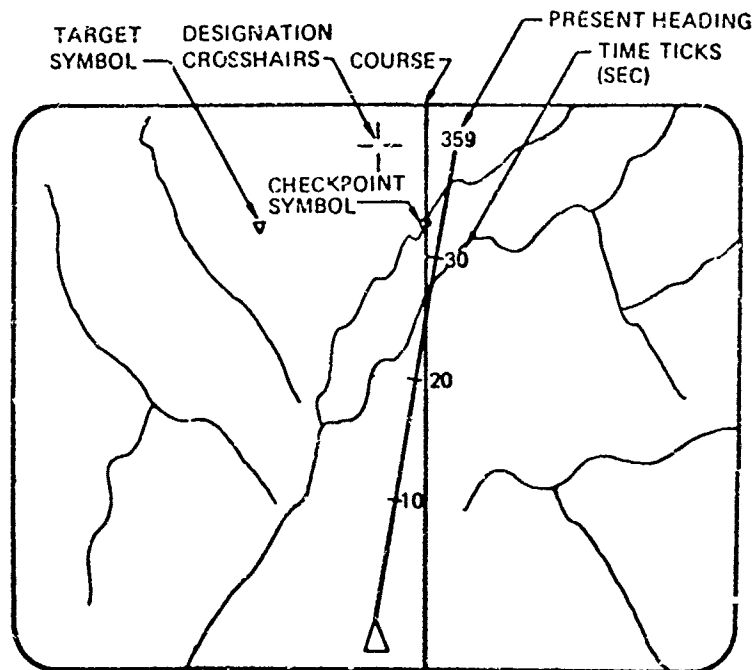
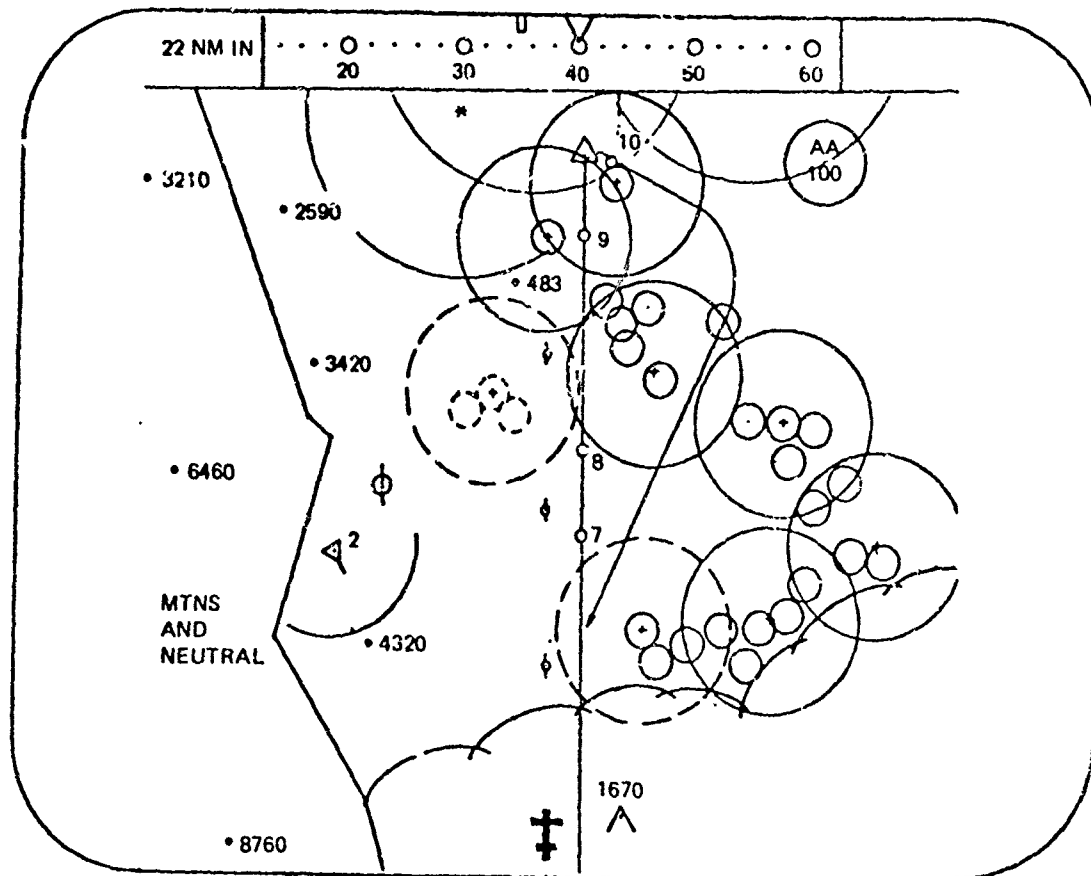


Figure 88. HSD Display Format

DESCRIPTION:

The HSD format in Figure 88 is an electronic map type proposed for an advanced fighter aircraft. The geographical and cultural features (if shown) are computer-generated and then displayed. Symbolology is overlaid on that map. Present aircraft position is projected 10, 20 and 30 seconds into the future to show the pilot the consequences of remaining on the present heading. Other navigation and target designation symbolology are also presented. (No additional information available.)

SOURCE: Ref 8



DESCRIPTION:

The electronic moving map display shown in Figure 89 provides combat tactical situation information to the pilot. The aircraft symbol is decentered to the bottom of the display to allow the pilot a view of a greater forward area. Threat defense areas are depicted for both ground and air threats. Neutral and hostile areas are bordered. Mountains and their heights are also displayed. (No additional information available.)

SOURCE: Ref 8

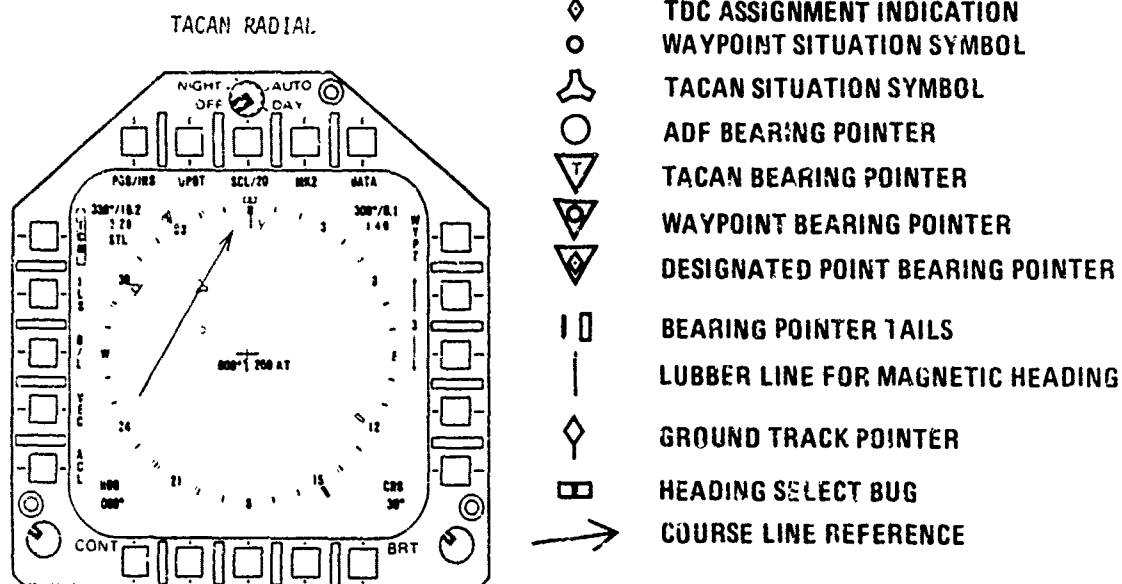


Figure 90. EHSI

DESCRIPTION:

Figure 90 illustrates a present day electronic horizontal situation indicator (EHSI) in an operational advanced aircraft. Mode selections are presented adjacent to selection pushbuttons around the periphery of the display. Pertinent navigation data is given in each corner of the display.

SOURCE: Ref 23

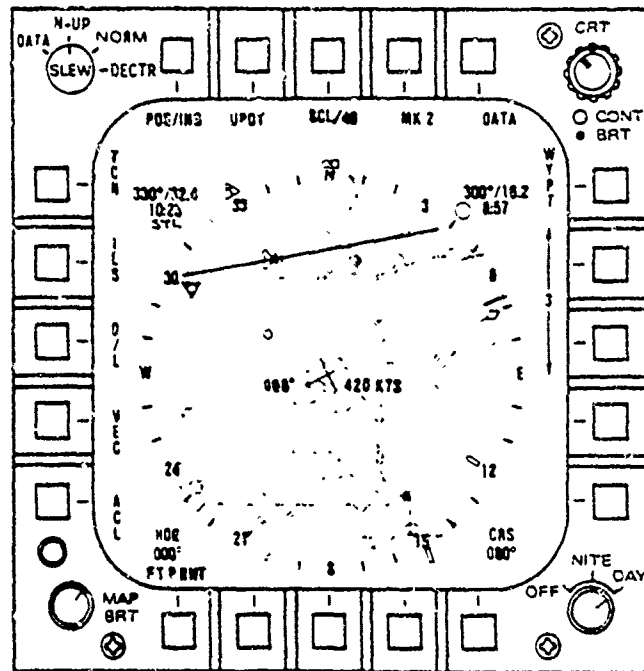


Figure 91. HSD

DESCRIPTION:

Figure 91 shows a horizontal situation display which uses a projected, color, moving map with overlaid navigation symbology. The aircraft symbol is centered on the map. Mode selections are arranged around the display adjacent to selection pushbuttons.

SOURCE: Ref 23

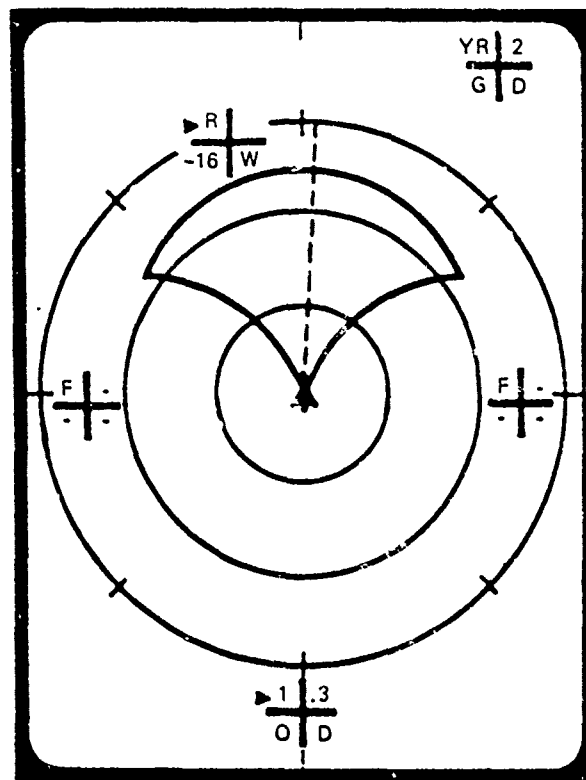


Figure 92. Battle Situation Format

DESCRIPTION:

Figure 92 presents tactical situation data in plan view. Own aircraft is centered, range rings indicate relative distance and bearing from own aircraft. Friendly aircraft and threat aircraft are indicated by the cross symbols and attendant alphanumeric. Radar zone of own aircraft is also presented to show the relationship between your radar coverage and targets in azimuth. (No additional information available.)

SOURCE: Ref 8

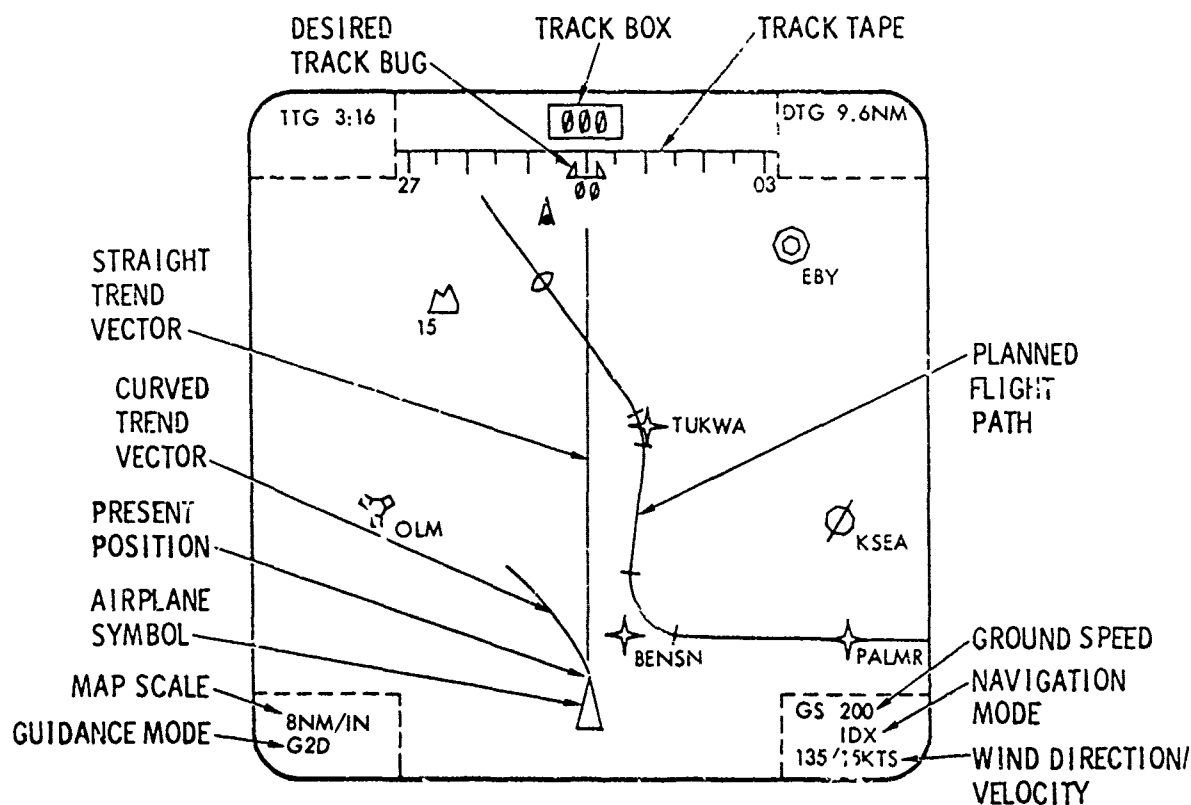


Figure 93. Basic Map Display

DESCRIPTION:

The electronic map display in Figure 93 contains computer generated symbology. Typical navigation data is displayed as well as aircraft trend vectors. (No additional information available.)

SOURCE: Ref 11

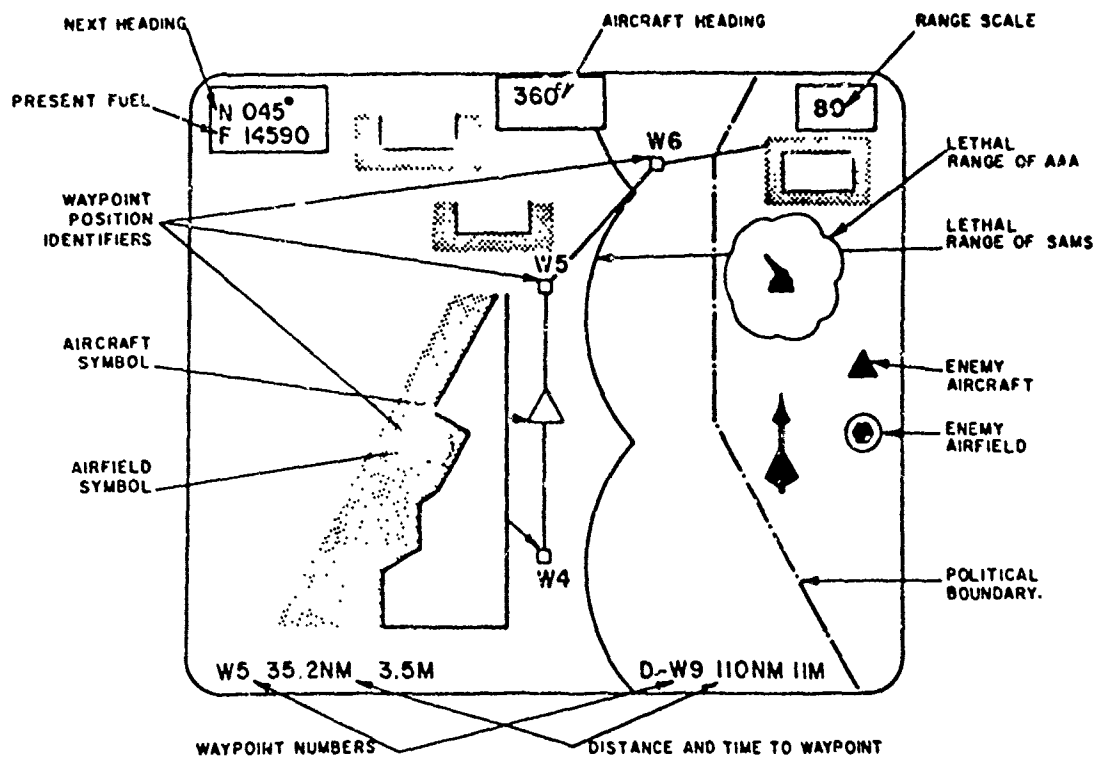


Figure 94. HSD Symbolology for Cruise, North Up

DESCRIPTION:

The displays in Figure 94 show an electronic HSD with tactical situation information. Important flight and navigation data is arranged along the top and bottom of the display. Color symbology could be used to provide easier recognition of different symbols. (No additional information available.)

SOURCE: Ref 14

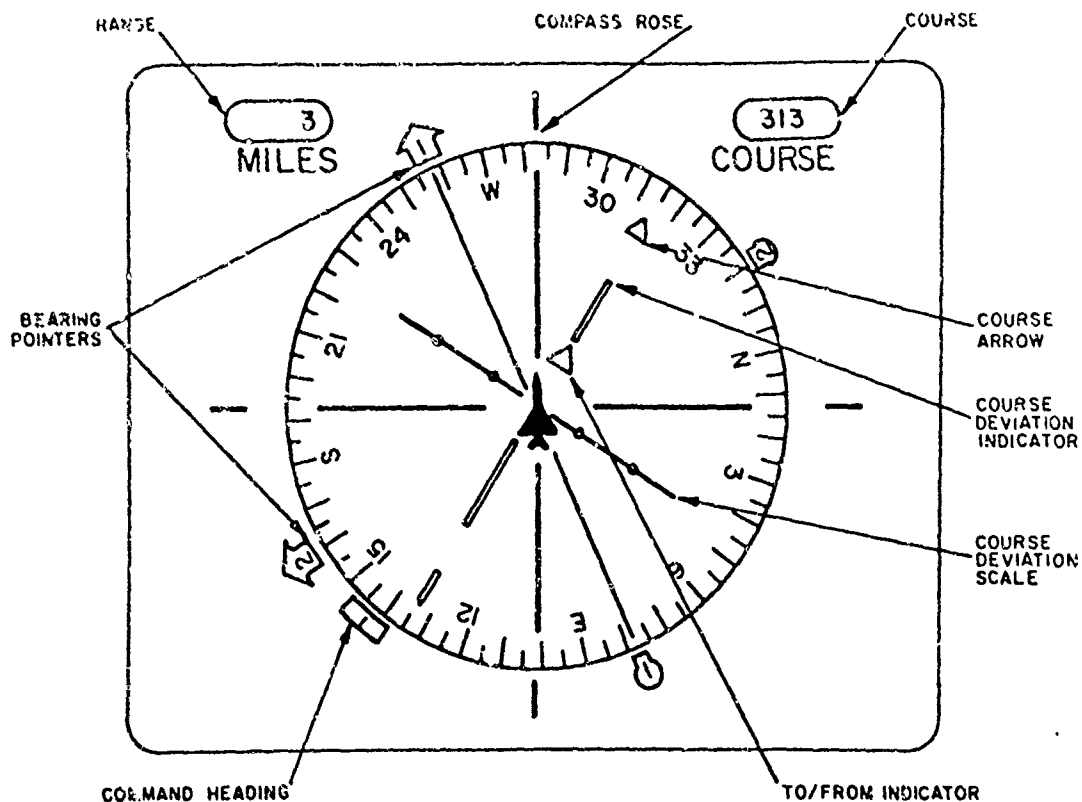


Figure 95. HSD Display for Landing

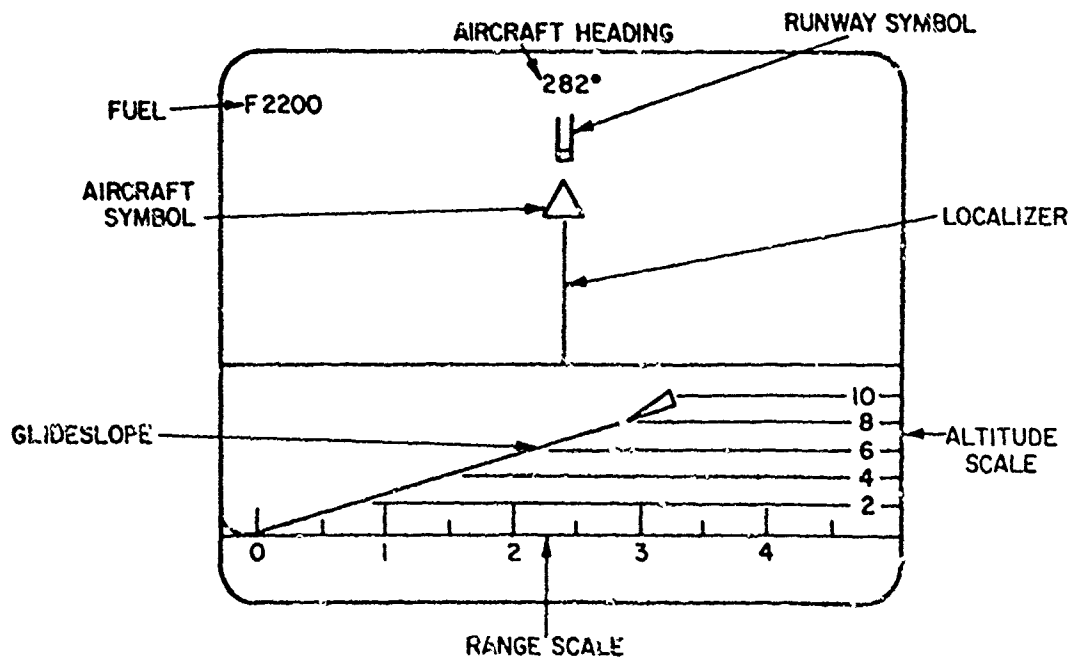


Figure 96. Glideslope and Localizer Information for Landing

DESCRIPTION:

The displays in Figures 95 and 96 show complementary landing mode HSD's. In Figure 95, an electronic HSI is depicted in traditional form. In Figure 96, the display is divided into separate horizontal and side vertical situation displays. The information shown on these two displays is similar to the paper approach plates in standard use. The aircraft's relationship to the localizer and glide-slope is the central information on this display. (No additional information available.)

SOURCE: Ref 14

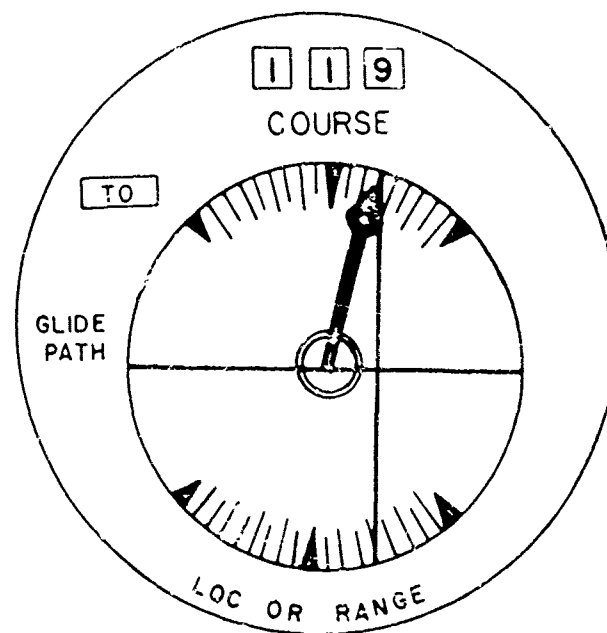


Figure 97. ID-249 Course Deviation and Relative Heading Indicator

DESCRIPTION:

The ID-249 shown in Figure 97 is a frequency separated display in which the aircraft's slowly changing displacement from the selected course is presented inside-out, while the more rapidly changing heading relative to the selected course is presented outside-in. The relation between the two graphically presents the desired course interception angle. (No additional information available.)

SOURCE: Ref 57

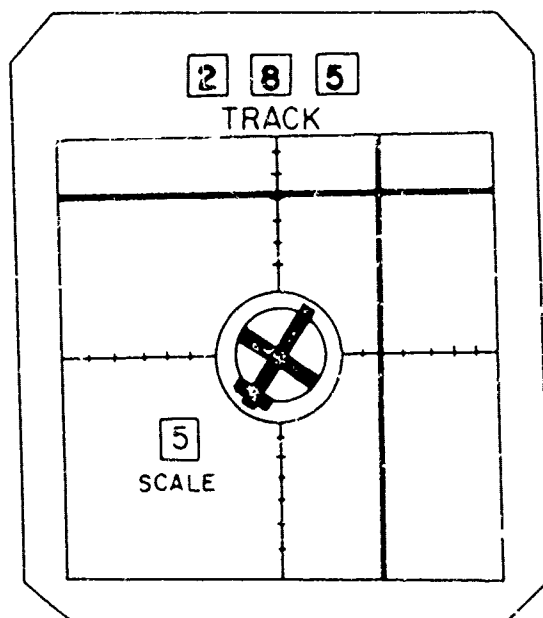


Figure 98. Symbolic Pictorial Indicator

DESCRIPTION:

The display in Figure 98 utilizes frequency separation. Linear displacement from desired course, as depicted by the vertical needle, and linear distance to waypoint, as depicted by the horizontal needle, are inside-out presentations. Heading relative to selected track (or course) is presented in the outside-in manner. The intersection of the needles relative to the airplane symbol presents a plan view of the horizontal flight geometry. (No additional information available.)

SOURCE: Ref 57

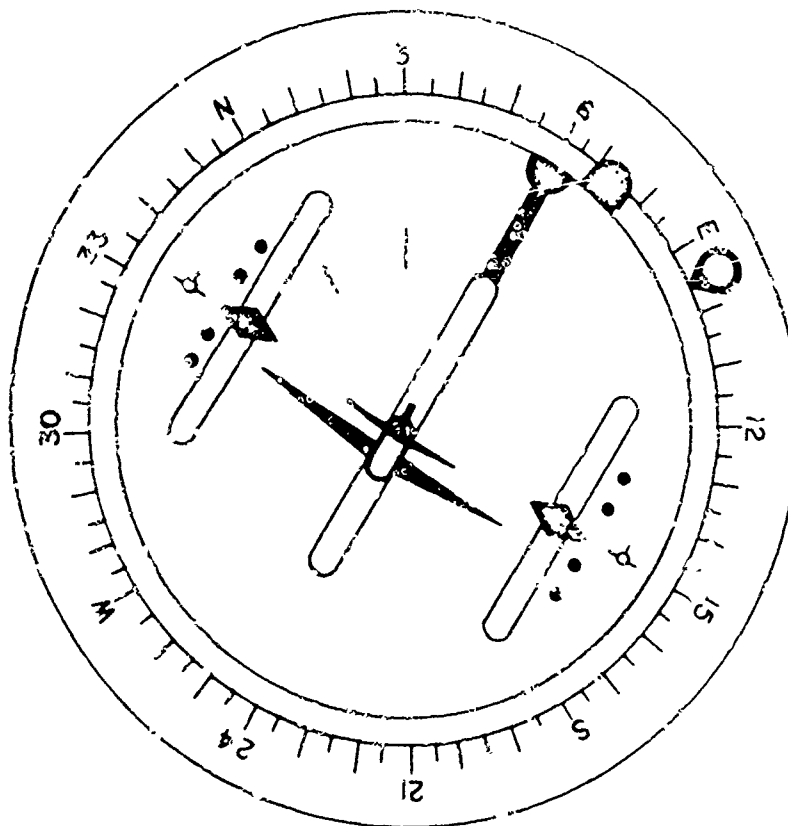


Figure 99. Lear LIFE (Lear Integrated Flight Equipment) Flight Director Display

DESCRIPTION:

Figure 99 shows the Lear LIFE (Lear Integrated Flight Equipment) flight director display. It presented aircraft attitude outside-in and aircraft heading inside-out in a manner such that the display's peripheral bank index could be aligned with the desired heading index in a pursuit tracking fashion. Angular course deviation is represented in an inside-out manner by the vertical needle. Heading relative to selected course is represented in an outside-in manner by the relative heading pointer. The relation between the two graphically presents desired course interception angle. (No additional information available.)

SOURCE: Ref 57

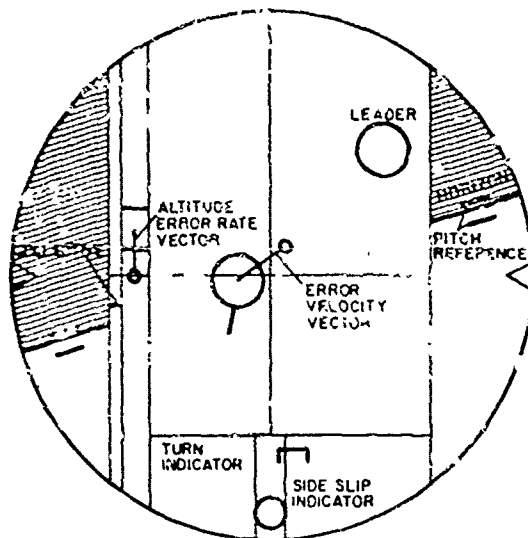


Figure 100. Integrated Display,
Station Keeping Mode

DESCRIPTION:

The symbolic display shown in Figure 100 is an integrated concept for helicopters. It can be envisioned as an area for the translational information in front of the central area of a large attitude gyro. The position in the horizontal plane is displayed as the symbolic top view of a helicopter in a fixed coordinate system. The origin of this coordinate system is the "desired point" on the desired flight path, and the x-axis (pointing up) represents the horizontal projection of the tangent to the desired flight path. The helicopter symbol in this error coordinate system also presents the deviation in heading from the x-axis. The position error along the vertical axis is displayed by a double bar at the left of the horizontal display area.

The size of the rotor symbol and the distance between the two altitude bars provide a sense of scaling of the display by representing the own rotor diameter to scale and a fixed altitude difference of 50 feet, respectively. The rates of motion of these two symbols are presented explicitly by error rate vectors originating in the centers of the symbols. These vectors "predict" the motion of the helicopter and altitude error symbols. The vector tips are emphasized by means of small circles. Since the motions of the vector tip symbols on the display present the sum of position and rate, these vector tips are equivalent to quickened position displays. The explicit presentation of the error rate provides instantaneous rate information and eliminates the need to derive this information from the motion of the symbol. The fact that not only the resultant is shown, but position and rate are separately identifiable, provides the pilot with true situation displays and lets him make decisions about how he wishes to make his corrections.

Information related to the accelerations in all three translational degrees of freedom is also displayed. The acceleration along the longitudinal axis is closely related to the pitch attitude of the helicopter. The horizon symbol and the "sky" are shown on both sides of the central display area described so far. The integration of the attitude gyro into the display is extremely significant since this makes it unnecessary for the pilot to refer to another instrument for the information which he needs most for his inner loop closures, his confidence, and his safety. The two pairs of bars which roll together with the horizon are reference symbols for the pitch attitude and are adjustable by the pilot or could be used as flight director inputs. The lateral acceleration with respect to a nominal flight path can be represented by a turn needle symbol which is seen at the bottom of the central display area. A ball indicator is also added for completeness and represents lateral acceleration at and near hover. The second derivative of the vertical displacement is basically the thrust variation, and as a measure of this a small symbol showing the deviation of the collective stick position from a set reference has been included at the left of the altitude information. An alternative for this symbol is to represent torque rather than collective position.

SOURCE: Ref 58

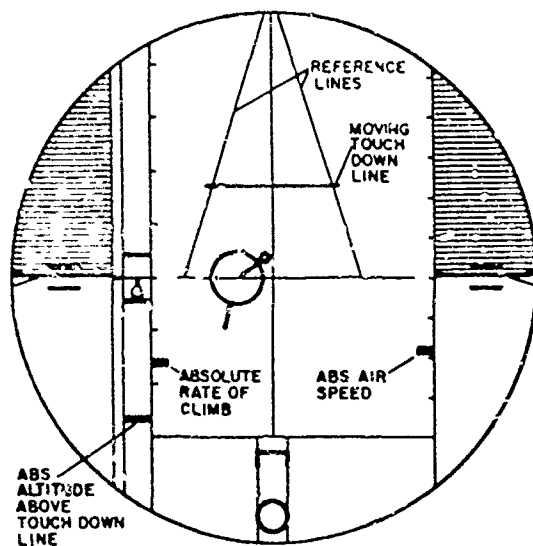


Figure 101. Integrated Display, Proposed Landing Mode

DESCRIPTION:

The horizontal/vertical integrated display in Figure 101 shows a proposed landing mode format. A consistent application of the stated principles to approach and landing results in a break with the conventional basic ILS display. In order to keep the same close coordination between display and control motions under all flying conditions, the fundamental arrangement of horizontal plane and vertical axis should be maintained. The input obtained from the localizer signal determines the lateral error. Longitudinally the helicopter symbol does not leave the reference axis since there is no need for continuous position loop closure along the glide path. The longitudinal error rate vector component is determined by the deviation from a set airspeed. The deviation from the glideslope is the input to the vertical error display.

It is proposed that for landing the basic integrated display (Figure 100) should be augmented in two ways. In the vertical error display strip a ground proximity line (in red) should be moving up from the bottom for the last 200 feet of altitude above the touchdown point, as an "absolute" altitude indicator. The other added symbolism, shown in the top half of the central display area is interpreted as follows. Imagine the view of the touchdown line during approach as seen from a point fixed to, but above, the helicopter. During descent, this line is seen to come closer to the nominal point, and at the same time it grows compared with the top view of the helicopter itself. Its endpoints would describe two loci on the display as certain nonlinear curves if the helicopter would fly exactly on the glideslope. If these loci are shown on the display they can be used as reference lines for displaying the glideslope error. If the helicopter is below the glideslope the view of the touchdown line extends beyond the reference lines; if the helicopter is above the glideslope the end points of the touchdown line do not reach the reference lines. On the proposed relatively simple version of the landing display the reference lines are straight instead of curved without any loss of actual information. This augmentation of the display combines an indication of the distance to touchdown with a display of vertical error.

In order to avoid the need for scanning other instruments, provision has been made to add two absolute scales to the display. Each division on the absolute rate of climb scale represents 500 feet/minute, each division on the absolute airspeed scale represents 25 mph.

SOURCE: Ref 58

4. MISCELLANEOUS DISPLAYS

The displays highlighted in this section are generally status information displays. They are concerned with pictorially depicting the current or predicted status of some aircraft systems. Thus we have collected engine, energy management, thrust, fuel, aircraft surface and other status displays.

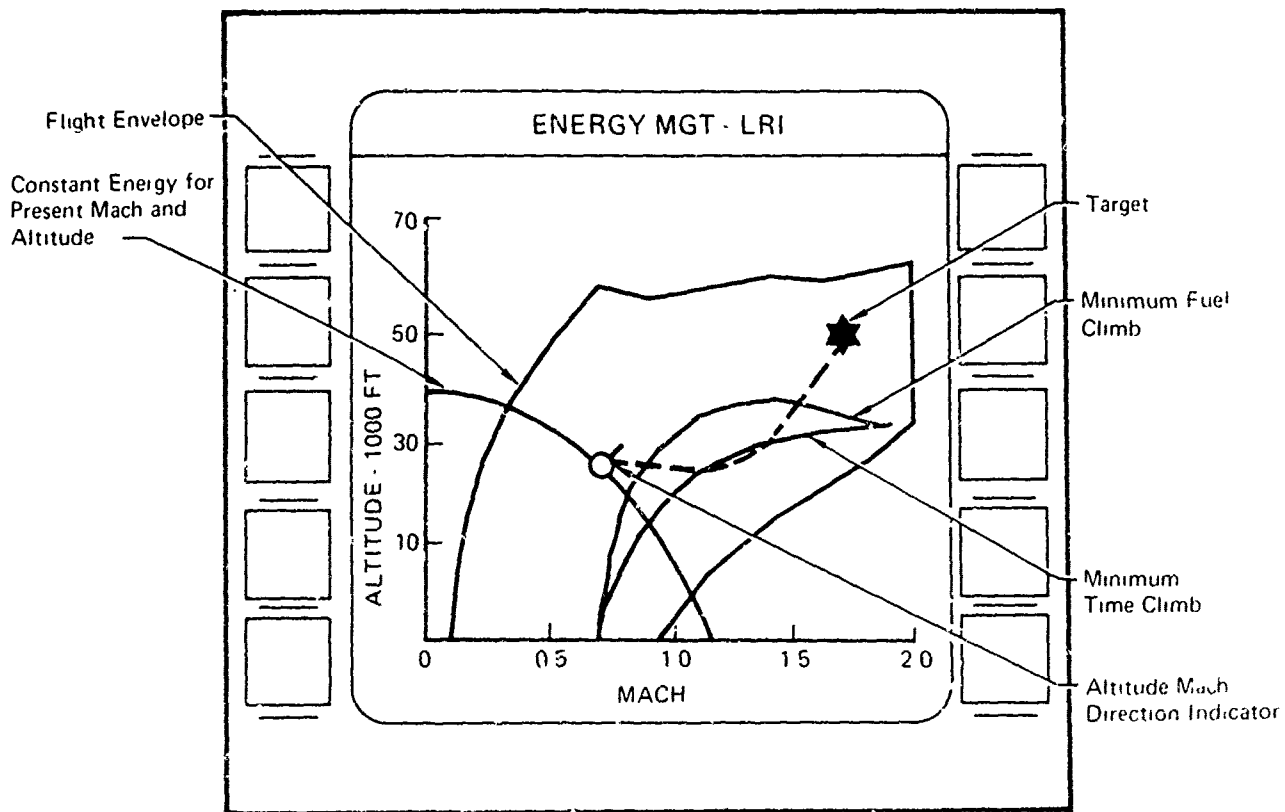


Figure 102. Long Range Intercept Display

DESCRIPTION:

Energy management displays provide advisory data to enhance combat position in relation to the enemy. Data requirements fall into two general categories: Long Range Intercept (LRI), and Air Combat Maneuver (ACM).

LRI requires a display aimed at attaining a specific launch position in the most timely or efficient manner. Figure 102 shows an example of such a display format. The immediate target is shown in relation to our aircraft flight envelope. The pilot no longer has to guess if his aircraft has the performance capability to intercept a given target. He is also provided with graphic solutions to how best to intercept the target, utilizing minimum fuel or time to climb profiles as required.

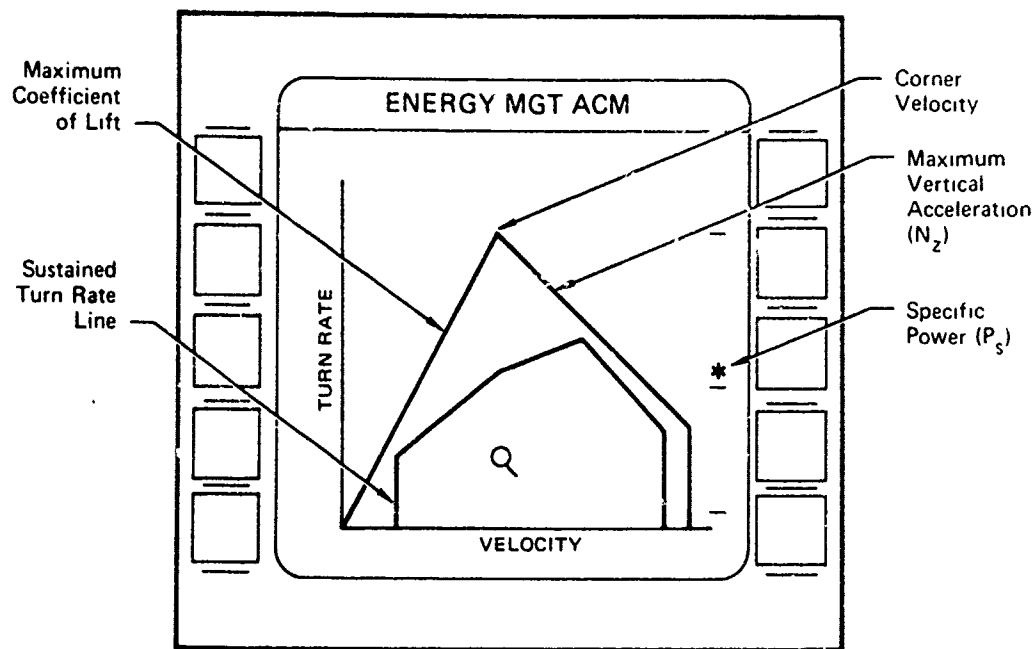
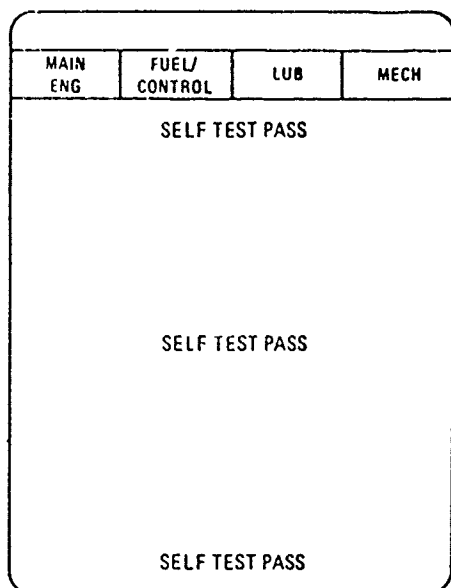


Figure 103. Air Combat Maneuver Display

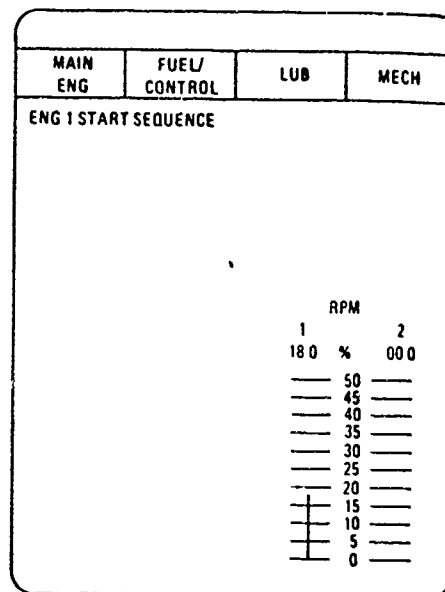
ACM engagements require a display that assists in attaining and maintaining high energy levels. Figure 103 shows an example of such a display. The fighter pilot is provided with key performance parameters such as corner velocity, sustained turn rate limits, and specific power (P_s) which are particularly important in ACM.

Both displays respond dynamically to changes in aircraft situation and status.

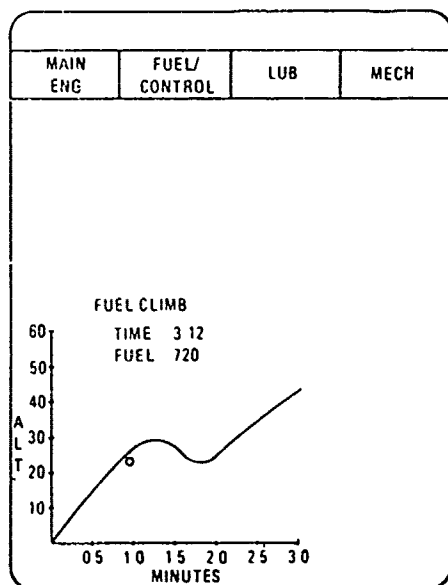
SOURCE: Ref 7



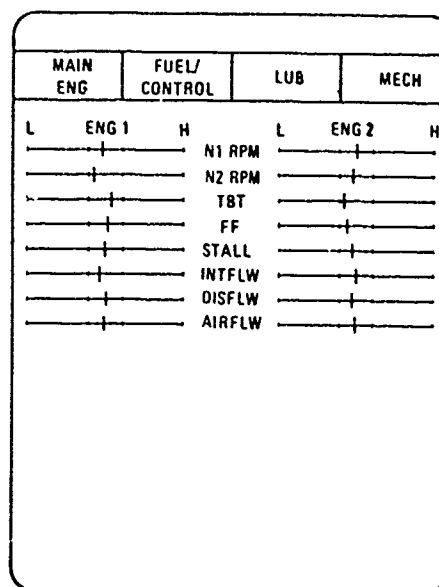
A. Self Test



B. Engine Start

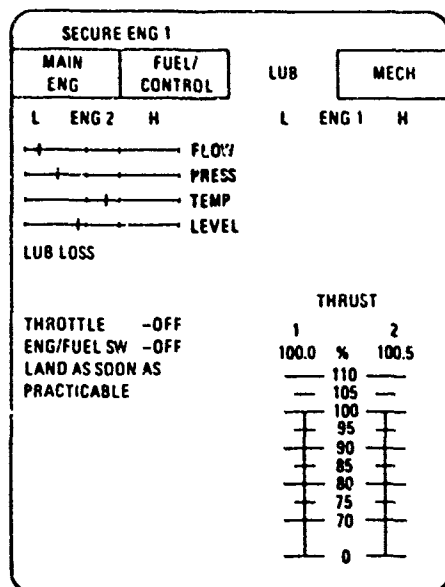


C. Minimum Fuel Climb

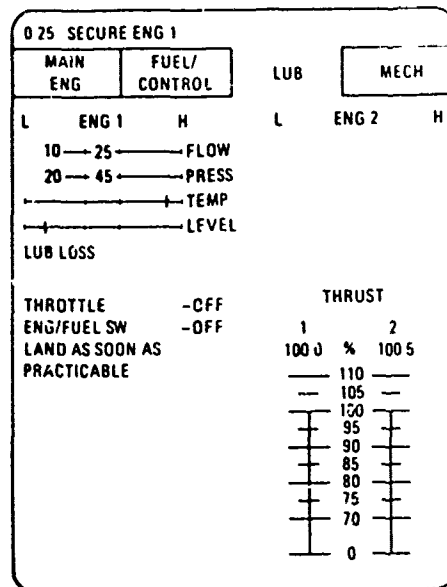


D. Engine Parameters

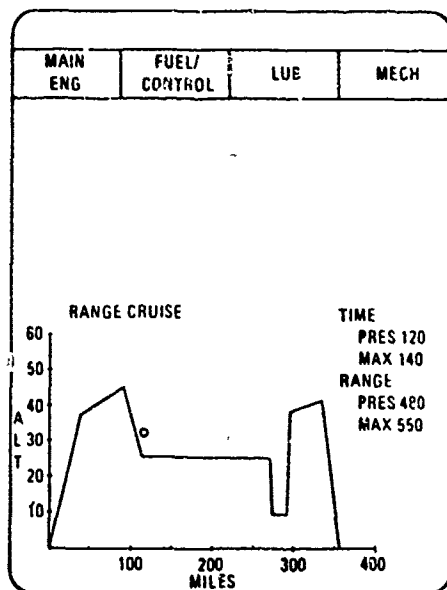
Figure 104. Integrated Engine Instrument System (IEIS)



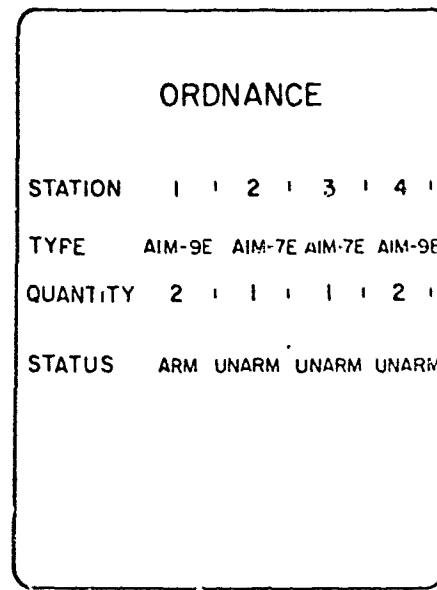
E. Lubrication Problem



F. Lubrication Problem



G. Range Cruise



H. Ordnance

Figure 104. (Continued) Integrated Engine Instrument System (IEIS)

DESCRIPTION:

The example displays shown in Figure 104 illustrate the different formats available on a multifunction display. In this case the formats are the set for an integrated engine instrument system.

Figure 104 (a) is a format that initially appears to verify that the system has passed a self-checking function. If any part of the system had failed the self test, a failure message would be presented. The status bar on top is a key ingredient in the display philosophy. This status bar divides the engine into four subsystems. Twenty-five display parameters are contained in these four groups which are main engine, fuel control, lubrication, and mechanical. The parameters are within their normal range whenever the status bar is continuous, i.e., no broken horizontal line.

Figure 104 (b) represents a start sequence where RPM is presented in numerical and vertical bargraph form where the lower portion of the bargraph is expanded.

Figure 104 (c) represents a minimum fuel climb with the aircraft's position represented by a circle. The time in minutes and seconds and the fuel in pounds reflect the time and fuel estimated to make the climb.

Figure 104 (d) shows the parameters in the main engine group. These are normalized in that the actual value is compared to the value stored in the computer model for those flight conditions. All of the tick marks would line up making a dashed vertical line located in the center of the horizontal bargraphs, if every parameter shown was exactly in agreement with the value determined by the model. The vertical indices on the horizontal bargraph denote areas of normal and abnormal performance. The critical ranges are those to the left or right of the horizontal bargraphs.

Figure 104 (e) represents a situation where a marginal condition has occurred in the engine lubrication subsystem, highlighted by the broken status bar. The affected and related parameters are automatically displayed. The computer has diagnosed the situation as a lubrication loss and indicates that fact along with instructions to secure engine 1. Oil flow, oil pressure and oil level are in the marginal region.

Figure 104 (f) shows a critical condition for oil flow and oil pressure. When the condition degrades from a marginal to a critical condition, data is displayed in digital form along with lower acceptable limits. A flashing "Secure Engine 1" warning message appears and a timer is initiated showing the time elapsed for this critical condition.

Figure 104 (g) shows a range cruise profile with the aircraft's position indicated by a circle. Energy management information relating to optimum performance and present conditions is given for range and time.

Figure 104 (h) shows the ordnance information. The ARM nomenclature for the status of station 1 is blinking in this format.

SOURCE: Ref 59

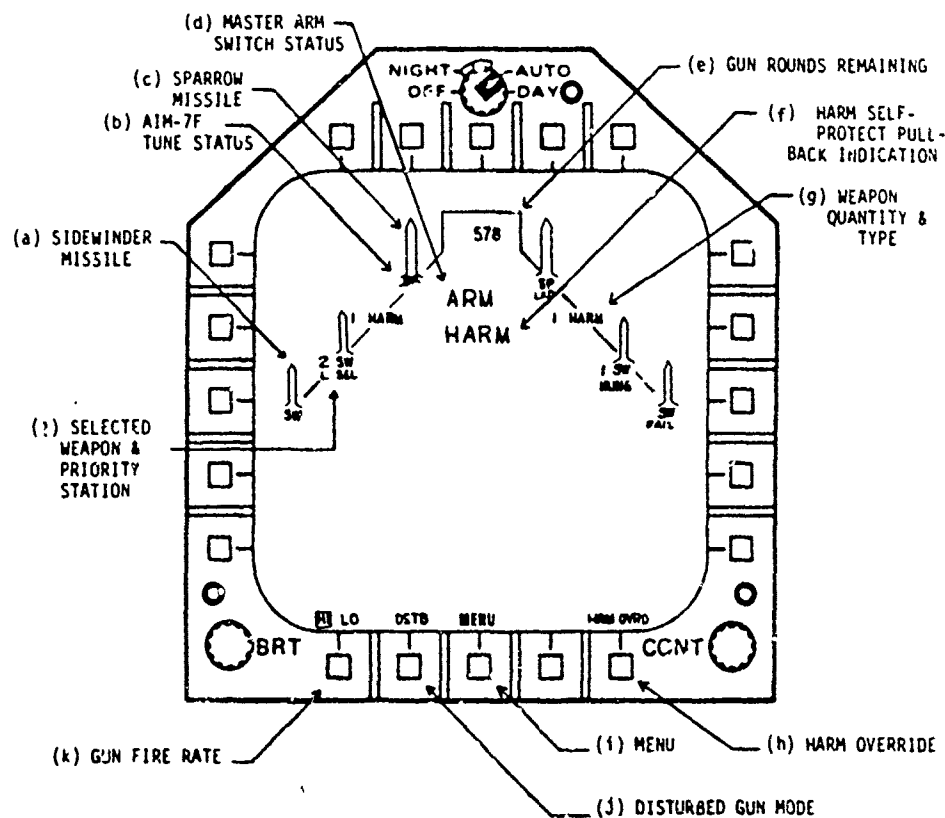


Figure 105. A/A Stores Management Display

DESCRIPTION:

Figure 105 presents a sample armament status display. Weapons are shown pictorially relative to their store station. This format would automatically appear when A/A mode is selected. Note that some selections can be made on the display.

SOURCE: Ref 23

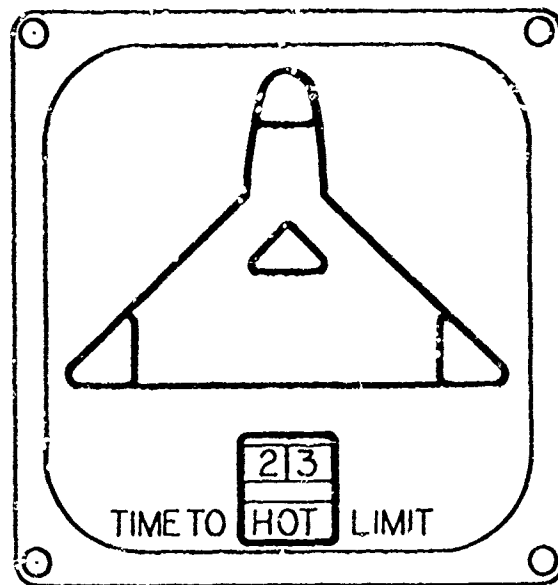


Figure 106. Thermal Monitor Display System

DESCRIPTION:

Figure 106 shows an early version of a mechanical pictorial display. This display consisted of an aircraft planform outline with four apertures, (nose, fuselage, and wing tips) which were utilized to display temperature conditions by the use of colored flags (green-cold, yellow-warm, red-hot). The two-drum digital counter located below the aircraft outline provided the time-to-thermal limit display. Heating or cooling condition is displayed in a window below the digital readout by the appearance of the appropriate word, "hot" or "cold."

This arrangement allows an ample time display for reentry or a supersonic dash at low altitude to or from targets with a minimum of clutter on the display.

SOURCE: Ref 15

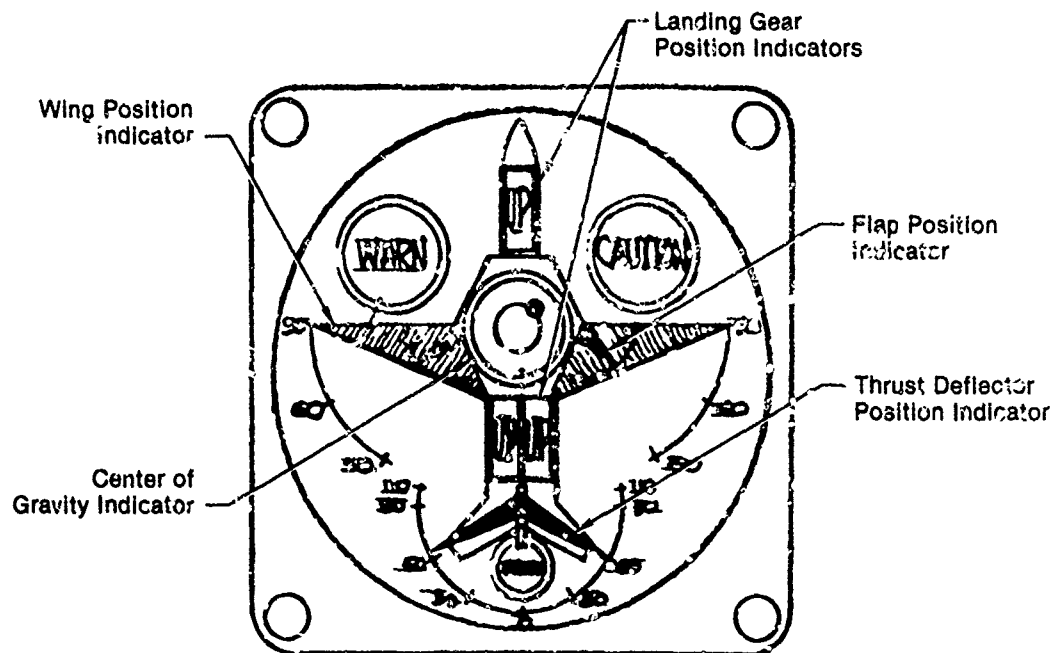


Figure 107. Aircraft Configuration and System Monitor Display

DESCRIPTION:

The display in Figure 107 was designed to furnish information about many of the aircraft systems; however, it is concerned predominately with the vehicle's external configuration. The information is arranged to represent a plan view of the aircraft which, in the case of the wing, flap, and thrust displays, results in dual pointers. This redundancy was justified on the grounds that the image of the whole vehicle outline would allow for quicker peripheral evaluation of the configuration.

In the stylized vehicle presented in the display, the fuselage consists of four elements. The nose and aft sections illustrate the position of the landing gear. They are mechanical devices which present three different colored flags in the windows, a light yellow flag with a white "UP" inscribed to signify gear up, a light green flag with a white "DN" inscribed to indicate gear down and locked, and an amber flag (with barber poles) to indicate gear in transition or in an unsafe condition. The fourth element in the fuselage portion is a center of gravity indicator.

The Center-of-Gravity (C.G.) display is envisioned as an electromechanical device resembling a bubble mechanism on a carpenter's level. When the black spot is out of the center circle, it is an indication that, due to an asymmetric storage of fuel or weapons, the center of gravity has shifted beyond the capability of the reaction control system for vertical flight. This information is required before attempting a transition and vertical landing at the end of a mission.

The wings of the display vehicle move up or down within approximately 60° arcs and serve as analog representatives of the real aircraft wing position. Superimposed on these is another set of pointers which represent flap position, while another set of black pointers is located over the empennage of the vehicle symbol to represent thrust deflector position. When these latter symbols overlap one another and are pointing aft, the thrust is deflected aft. When they sweep out on either side of the vehicle, they indicate by their relative positions the amount of thrust that is being deflected downward. As the transition is begun and the thrust is deflected downward for lift, compressor bleed air is also being diverted to the reaction control jets located at the extremities of the wing and fuselage. A small indicator below the tail shows when the reaction control system has been pressurized.

SOURCE: Ref 60

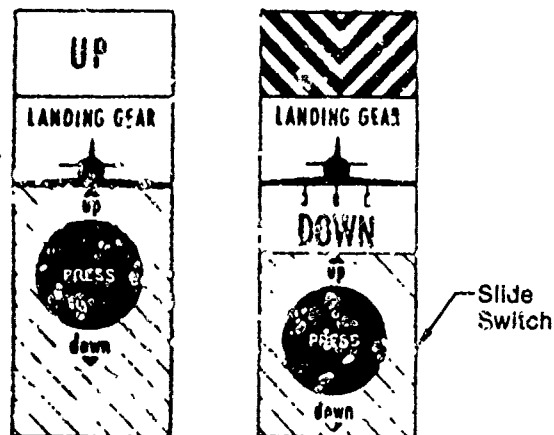


Figure 108. Landing Gear Control

DESCRIPTION:

The two landing gear positions, retracted "UP" or extended "DOWN," are achieved in Figure 108 by activating a sliding switch in the direction of the gear position desired. When the slide switch is in the full down position the extended landing gear is depicted on the central aircraft symbol as well as the word "DOWN" appearing below the aircraft symbol. When the slide switch is in the full up position the aircraft symbol is presented without the landing gear with the word "UP" appearing above the aircraft symbol. (No additional information available.)

SOURCE: Ref 61

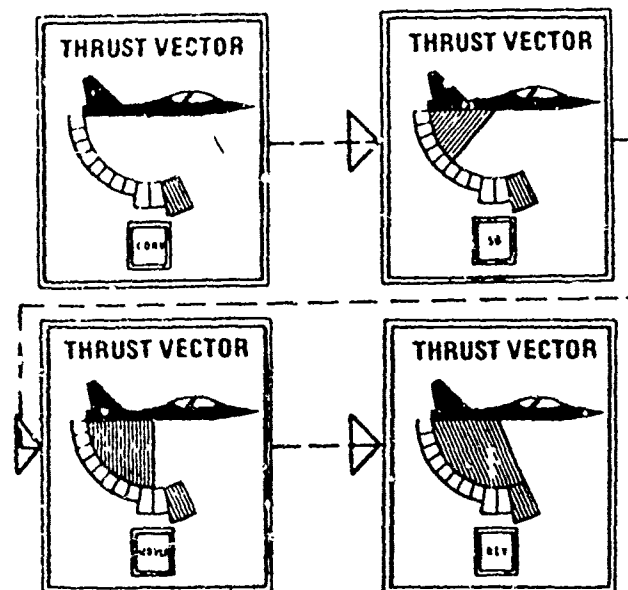


Figure 109. Thrust Vector Indicator

DESCRIPTION:

The Thrust Vector Indicator in Figure 109 provides continuous monitoring of the aircraft's thrust vector configuration. The thrust vector is graphically and numerically displayed in increments of 10° with conventional flight configuration ("CONV"), hover ("HOVER") and reverse ("REV") specifically identified in word form in the display window immediately below the graphic, along with a numerical readout in number of degrees corresponding to the graphic thrust vector presentation. (No additional information available.)

SOURCE: Ref 61

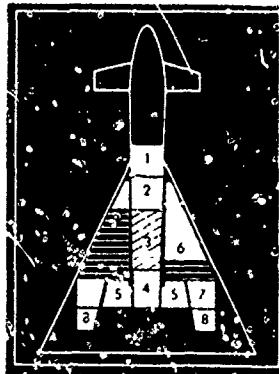


Figure 110. Aircraft Fuel Quantity Indicator

DESCRIPTION:

The display in Figure 110 shows an electroluminescent pictorial representation of an aircraft's fuel tanks and their status. Tanks are keyed as to location in the aircraft, shape and numerically by category. The fuel level is graphically represented in each tank by shading or cross hatching. (No additional information available.)

SOURCE: Ref 62

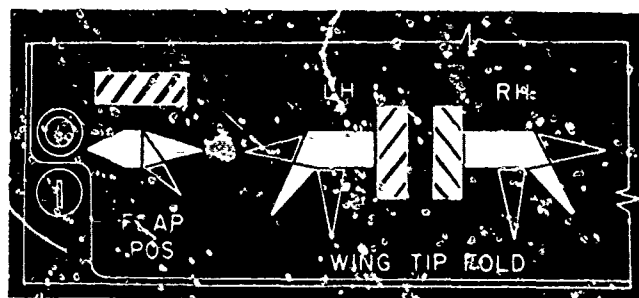


Figure 111. Surface Position Indicator

DESCRIPTION:

The electroluminescent display in Figure 111 provides information pictorially as to the status of various aircraft surfaces and systems. (No additional information available.)

SOURCE: Ref 52

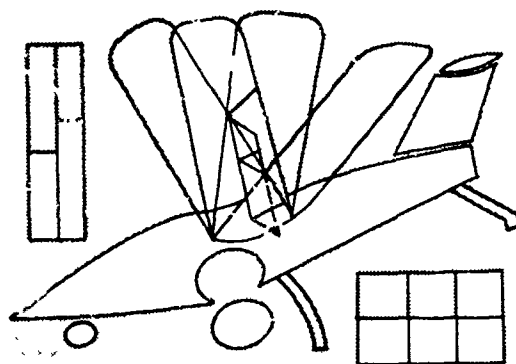


Figure 112. Aircraft Configuration Status

DESCRIPTION

This electroluminescent display (Figure 112) depicts the position of various aircraft surfaces. A pictorial representation of the surfaces, referenced to the aircraft, are provided. (No additional information available.)

SOURCE: Ref 62

5. CONCLUSIONS

This review was nothing if it was not interesting. The last 30 years of display history is rich with examples of conceptual display formats.

The following conclusions were noted.

1. The majority and widest variety of formats are for head-down VSD displays.
2. There were few "wild" concepts. Most were variations of basic formats.
3. The ANIP program was the pioneer in tackling electronic displays. It was undoubtedly ahead of it's time especially in the area of the contact analog display. It is unfortunate that the technology was not available to exploit those concepts.
4. HUD formats have dealt only with skeletal analog symbology to the exclusion of detailed contact analog formats mainly because of the problem of registering the real scene with the generated one.
5. True pictorial formats found in the literature were quite few. It is unclear as to whether they were just missed (doubtful), if such concepts were not fully explored in the past because technology was not available to support them, or perhaps that they appeared too silly for print.
6. This review is by no means exhaustive. Many more sources are referenced in the literature (although finding them is another problem) than were found.

We believe that a review in greater depth would not produce substantially more or different results.

6. REFERENCES

1. Carel, W.L. Pictorial Displays for Flight. Culver City, Ca.: Hughes Aircraft Co., JANAIR TR 2732.01/40, Dec. 1965.
2. Roscoe, S.N. Aviation Psychology. Ames, Iowa: Iowa State Univ Press, 1980.
3. Orrick, W.P., Jr., and York, P. E. Head-Up Display Symbolology. Warminster, Pa.: Naval Air Development Center, NADC-75267-40, Dec. 1975.
4. Green, G.N. Head-Up Display Symbolology. Farnborough, England: Royal Aircraft Estab, TR 77050, Apr. 1977.
5. Ketchal, J.M. and Jenney, L.J. Electronic and Optically Generated Aircraft Displays - A Study of Standardization Requirements. Washington, D.C.: Office of Naval Research, JANAIR Rpt 680505, May 1968.
6. Sperry Flight Systems Division. Electronic Display Systems. Phoenix, Az.: Displays Brochure, (No Date).
7. McDonnell Aircraft Co. Cockpit Controls, Displays, and Instruments. St. Louis, Mo.: McDonnell Aircraft Co., MDC A3200 Vol II, Book 16-5, Dec. 1974.
8. Willich, W. and Edwards, R.E. Analysis and Flight Simulator Evaluation of an Advanced Fighter Cockpit Configuration. Wright-Patterson AFB, Oh.: USAF Avionics Laboratory, AFAL-TR-75-36, Mar. 1975.
9. Baty, D.L. Rationale and Description of a Coordinated Cockpit Display for Aircraft Flight Managements. Moffett Field, CA.: NASA Ames Research Center, NASA TM X-3457, Nov. 1976.
10. Dowd, C. Integrated Displays and E-O Sensors for F-14 CILOP Program. Patuxent River, Md.: Presented at Fourth Advanced Aircrew Display Symposium, Naval Air Test Center, May 1978.
11. Smyth, R.K. State of the Art Survey of Technologies Applicable to NASA's Aeronautics, Avionics, and Controls Program. Washington, D.C.: NASA, NASA-CR-159050, May 1979.
12. Streeter, E., DuPuis, T. A., Carel, W. L., Gunther, J. E., Graig, D. W., and Opitek, E. W. Research on Visual Display Integration For Advanced Fighter Aircraft. Wright-Patterson AFB, Oh.: Aerospace Medical Research Lab., AMRL-TR-78-121, Mar. 1979.
13. Morello, S.A., Knox, G.E., and Steinmetz, G.G. Flight-Test Evaluation of Two Electronic Display Formats for Approach to Landing Under Instrument Conditions. Washington, D.C.: NASA, NASA Technical Paper 1085, Dec. 1977.

14. Snyder, Harry L. Human Visual Performance and Flat Panel Display Image Quality. Virginia Polytechnical Institute & State University, HFL-80-1/ONR-80-1, July 1980.
15. Andres, J.R. Instrument Technique Development Program. Wright-Patterson AFB, Ohio: Wright Aeronautical Development Center, WADC-TR-60-30, Feb. 1960.
16. Eddowes, E.F. and Newgent, W.L. An Integrated Display System for High Performance Aircraft: Human Factors and Engineering Design Recommendations. St. Louis, Mo.: McDonnell Aircraft Company, MDC Rept B608, Apr. 1965.
17. Baxter, J.R. and Workman, J.D. Review of Projected Displays of Flight Information and Recommendations for Further Development. Melbourne, Aus.: Human Aeronautical Research Laboratory, Australian Defense Scientific Service, Engineering Rpt #2, Aug. 1962.
18. Nordstrom, L. Eyelevel Flight Information by a Perspective Pole-Track. Linkoping, Sweden: Saab Aircraft Co., TN 58, Jan. 1965.
19. Warner, D.A. Flight Path Displays. Wright-Patterson AFB, Oh.: USAF Flight Dynamics Laboratory, AFFDL-TR-79-3075, June 1979.
20. Johnson, S.L., Williges, R.C., and Roscoe, S.N. A New Approach to Motion Relations for Flight Director Displays. Savoy, Ill.: Aviation Research Laboratory, University of Illinois, TR ARL-71-20/ONR-71-3/AFOSR-71-6, Oct. 1971, AD 735 916.
21. Shrager, J.J. Advanced Flight Control and Electronic Display Systems for All-Weather Flight Operations: A Literature Review and Bibliography. Washington, D.C.: FAA, FAA-NA-73-78, Jun. 1974.
22. Cloud, E.L., Fendley, J. N., and Stinnett, T. A. Combat Energy Maneuverability Display. Patuxent River, Md.: Presented at Second Advanced Aircrew Display Symposium, Naval Air Test Center, April 1975.
23. Lightstone, J.L., Janowski, G.A., Zavich, V., Brown, T.G., Smith, K.C., and Volsen, A.J. Operation of the F/A-18 Avionic Subsystem. St. Louis, Mo.: McDonnell Aircraft Co., Report No. MDC A5769, Jan. 1979.
24. Naish, J.M. and Miller, D. An Experimental Evaluation of Head-Up Display Formats. Moffett Field, Ca.: NASA Ames Research Center, NASA TP-1550, July 1980.
25. Douglas Aircraft Company. Army-Navy Instrumentation Program: Historical Report. Long Beach, Ca.: Douglas Aircraft Company, June 1962 AD 610 249.

26. Sgro, J. A. and Dougherty, D. J. Contact Analog Simulator Evaluations: Hovering and Air Taxi Maneuvers. Fort Worth, Tx.: Bell Helicopter Company, TR D228-421-016, July 1963. AD 424 485.
27. Abbott, B. A. and Dougherty, D. J. Contact Analog Simulator Evaluations, Altitude and Ground Speed Judgements. Fort Worth, Tx.: Bell Helicopter Company, TR D228-421-015, March 1964. AD467 203.
28. Emery, J. H. and Dougherty, D. J. Contact Analog Simulator Evaluations: Climbout, Low Cruise and Descend Maneuvers. Fort Worth, Tx.: Bell Helicopter Company, TR D228-421-017, May 1964. AD 603 744.
29. Dougherty, D. J., Emery, J. H., and Curtin, J. G. Comparison of Perceptual Work Load in Flying Standard Instrumentation and the Contact Analog Vertical Display. Ft. Worth, Tx.: Bell Helicopter Company, TR D228-421-019, Dec. 1964. AD 610 617.
30. Emery, J. H. and Dougherty, D. J. Contact Analog Simulator Evaluations: The Influence of Screen Size and Image Field. Fort Worth, Tx.: Bell Helicopter Company, TR D228-420-007, April 1965. AD633 107.
31. Emery, J. H. and Koch, C. A. Contact Analog Simulator Evaluations: Numeric Augmentation of Grid Plane Encodement. Fort Worth, Tx.: Bell Helicopter Company, TR D228-420-007, December 1965. AD 633 107.
32. Curtin, J. G., Emery, J. H., Dougherty, D. J., and Elam, C. B. Flight Evaluation of the Contact Analog Pictorial Display. Fort Worth, Tx.: Bell Helicopter Company, TR D228-420-009, Feb 1966. AD 640 597.
33. Dougherty, D. J. Final Technical Report, JANAIR Contract 4429(00). Fort Worth, Tx.: Bell Helicopter Company, TR D228-420-009, Feb 1966. AD 645 492.
34. Cross, K.D. and Bittner, A.C., Jr. Accuracy of Altitude, Roll Angle, and Pitch Angle Judgments as a Function of Size of Vertical Contact Analog Display. Pt. Mugu, Ca.: Naval Missile Test Center, Janair Report No. 680713, Jan. 1969.
35. Cross, K. D. and Bittner, A. C., Jr. JANAIR Vertical Contact Analog Display Evaluation Program (Annual Report January 1967 - January 1968). Pt. Mugu, Ca.: Naval Missile Test Center, TM68-23, JANAIR 680713, January 1969. AD 833 302.
36. Cross, K. D., Powers, O. M., Cavallero, F. R. and Bittner, A. C., Jr. JANAIR Vertical Contact Analog Display Evaluation Program (Annual Report January 1968 - January 1969). Pt. Mugu, Ca.: Naval Missile Test Center, TP-70-12, JANAIR 690111, March 1970.

37. Cross, K. D. and Cavallero, F. R. Utility of the Vertical Contact Analog Display for Carrier Landings: A Diagnostic Evaluation. Pt. Mugu, Ca.: Naval Missile Test Center, TP-71-52, JANAIR 701212, September 1971.
38. Douglas Aircraft Company. Army-Navy Instrumentation Program. El Segundo, Ca.: ES-29101, Contract NONR1076(00), (No Date).
39. Kelley, C.R., deGroot, S., and Bowen, H.M. Relative Motion III: Some Relative Motion Problems in Aviation. Washington, D.C.: NAVTRADEVENC Naval Training Devices Center, TR-316-2, Jan. 1961.
40. Douglas Aircraft Company. Airborne Research Systems (Fixed Wing-General Attack Mission). El Segundo, Ca.: Report No. ES-40026-A, Aug. 1961.
41. Howard, J.H. Electronic Information Display Systems. Washington, D.C.: Spartan Books, Inc., 1963.
42. Douglas Aircraft Company. Advanced Army Aircraft Instrumentation System. El Segundo, Ca.: Report No. ES-40634A, June 1962.
43. Schaefer, C.F. and Williams, P.R. A Study of Display Integration for Hypersonic Research Vehicles, 1st Qtrly Prog Rpt. Washington, D.C.: NASA, NASA-CR-77937, Sept. 1963.
44. Burke, J.E., Huchingson, R.D., Koppa, R.J., and Sewell, H.E., Jr. First and Second Simulator Evaluations of Advanced Integrated Display and Control Systems. Washington, D.C.: NASA, NASA CR-762, June 1967.
45. Emery, J.H., Koch, C.A., and Curtin, J.G. Contact Analog Simulator Evaluation: Investigations of Director Symbols, Display Alteration, and the Presentation of Secondary Flight Information. Ft. Worth Tx.: Bell Helicopter Co., JANAIR-TR-D228-420-008, Jan. 1967.
46. Williams, P.R. and Kronholm, M.B. Technical Report on Simulation Studies of an Integrated Electronic Vertical Display. Norwalk, Conn.: United Aircraft Corp., Norden Div., 1161-R-0021, Dec. 1965. AD 629157.
47. Steinmetz, G. G., Morello, S. A., Knox, C. E., and Person, L. H., Jr. A Piloted Simulation Evaluation of Two Electronic Display Formats for Approach and Landing. Hampton, VA.: NASA Langley Research Center, NASA TN D-8183, April 1976.
48. Watler, J.F., Jr. The Maneuvering Flight Path Display. Patuxent River, Md.: Presented at the Third Advanced Aircrew Display Symposium, Naval Air Test Center, May 1976.
49. McLane, R. G. and Wolf, J. D. A Comparative Evaluation of Pictorial vs. Symbolic Displays for Submersibles. San Diego, Ca.: Presented at the AIAA/USN Marine Systems and ASW Conference, AIAA Paper No. 65-246, Mar. 1965.

50. Roscoe, S.N., Eisele, J.E., and Bergman, C.A. Advanced Integrated Aircraft Displays and Augmented Flight Control. Vol I. Savoy, Ill.: University of Illinois Aviation Research Laboratory. TR ARL-75-12/ONR-75-2, June 1975.
51. Van Houtte, N.A.J. A Perspective Glideslope Indicating System. Wright-Patterson AFB, Oh.: In Proceedings of the Sixth Annual Conference on Manual Control. April 1970.
52. Gruenwald, A.J., Robertson, J.E., and Hatfield, J.J. Evaluation of a Computer-Generated Perspective Tunnel Display for Flight-Path Following. Hampton, Va.: NASA Langley Research Center, NASA Technical Paper 1736, December 1980.
53. Livingston, C.G. Cruise Control of Turbojet Aircraft. El Segundo, Ca.: Douglas Aircraft Co., DAC LB 31183A (Rev 2/5/65), Jan. 1963.
54. Cahow, J.N. Advanced Army Aircraft Instrumentation System First Quarterly Program Report. El Segundo, Ca.: Douglas Aircraft Co., DAC Rpt ES-40634A, June 1962.
55. Soliday, S.M. and Milligan, J.R. Simulation of Low Altitude High Speed Mission Performance: Vol III, Evaluation of Navigational Displays in Terrain - Following Penetration Missions. Los Angeles, Ca.: North American Aviation, Tech Report SEG-TR-66-67, Vol. III, Feb. 1967.
56. Silsby, N.S. and Fischer, M.C. A Simulator Study of a Pictorial Navigation Display in Instrument Departures of the Supersonic Transport. Hampton, Va.: NASA Langley Research Center, NASA-TN-D-4029, July 1967.
57. Johnson, S. L. and Roscoe, S. N. What Moves, the Airplane or the World? Savoy, Illinois: University of Illinois, Aviation Research Laboratory, Technical Report ONR-70-1, June 1970.
58. Dukes, T. A. An Integrated Display for Trajectory Control of Helicopters and VTOL Aircraft. Wright-Patterson AFB, Oh.: In Proceedings of the Sixth Annual Conference on Manual Control. April 1970.
59. Skovholt, R.L. Integrated Advanced Electronic Display Systems. Patuxent River, Md.: Presented at Second Advanced Aircrew Display Symposium, Naval Air Test Center, April 1975.
60. Shearer, J.P. Preliminary V/STOL Control-Display Subsystem Requirements Study. Wright-Patterson AFB, Oh.: USAF Flight Dynamics Laboratory, FDL-TDR-64-85, June 1964 AD 610 746.
61. Naval Air Development Center. VFA-V/STOL Crew Loading Analysis. Warminster, Pa.: Crew Systems Department NADC, Second Report: Cockpit Configuration, Jun 1974.

62. Frost, J. S. Electroluminescent Pictorial Status Displays. New York, N.Y.:
Presented at the 6th National Symposium on Information Displays, Sept. 1965.

7. BIBLIOGRAPHY

The following documents were reviewed in the course of compiling this report. This list is by no means exhaustive. There are certainly more documents relevant to this endeavor. We came across many references (contained in the documents we reviewed) to other documents which we could not physically locate. We feel reasonably assured, however, that our efforts have provided a broad base from which to compile this report.

Abbott, B. A. and Dougherty, D. J. Contact Analog Simulator Evaluations, Altitude and Ground Speed Judgements. Fort Worth, Tx.: Bell Helicopter Company, TR E228-421-015, March 1964. AD467 203.

Adam, G. D. Area Coverage Displays and Course-Line Computer Experimentation. Washington, D. C.: FAA, FAA-RD-64-19, February 1964.

Adamson, J. C. A Helicopter Simulator Study of Control Display Tradeoffs in a Decelerating Approach. Princeton, N. J.: Princeton Univ., May 1977, AD A051 242.

Advisory Group for Aerospace Research & Development. Human Factors in the Design and Evaluation of Aviation Maps. AGARD-AG-225, Jun 79.

Advisory Group for Aerospace Research & Development. Problems of the Cockpit Environment. AGARD-CP-55, Mar 1970.

Advisory Group for Aerospace Research & Development. Advanced Control System Concepts. AGARD-CP-58, No date.

Advisory Group for Aerospace Research & Development. Guidance and Control Display. AGARD-CP-96, Feb. 1972.

Advisory Group for Aerospace Research & Development. The Guidance and Control of V/STOL Aircraft and Helicopters at Night and in Poor Visibility. AGARD-CP-148, 1975.

Advisory Group for Aerospace Research & Development. Electronic Airborne Displays. AGARD-CP-167, Apr 1975.

Advisory Group for Aerospace Research & Development. Visual Presentation of Cockpit Information Including Special Devices Used for Particular Conditions of Flying. AGARD-CP-201, Nov 1976.

Advisory Group for Aerospace Research & Development. Electro-Optical Systems. AGARD-LS-76, May 1975.

Advisory Group for Aerospace Research & Development. Problems of the Cockpit Environment. AGARD Extended Summaries 4, Nov 68.

Air Force Institute of Technology/Air Force Flight Dynamics Laboratory, Sixth Annual Conference on Manual Control, Wright Patterson AFB, OH: April 1970.

Anderson, P.A. and Toivanen, M.L. Display and System Requirements for Low-Visibility Formation Flight: Summary of Results. Minneapolis, Minn.: Honeywell, JANAIR Rpt 710803, Apr 1972.

Andres, J.R. Instrument Technique Development Program. Wright-Patterson AFB, Oh.: Wright Aeronautical Development Center, WADC-TR-60-30, Wright Patterson AFB, Ohio: Feb. 1960.

Anon. Vertical Display Indicator. Digest of USN Electronics, 18-24. February 1963.

Army Mater/ial Command. Advanced Army Aircraft Instrumentation System (AAAIS). Report 12.1.1.1(2), December 1966.

Artwick, B. A. A Versatile Computer-Generated Dynamic Flight Display. Savoy, Ill.: University of Illinois, Aviation Research Laboratory, TR ARL-76-5/ONR-76-4, May 1976.

Austin, W.R., Sykora, D.L., and Bordonaro, S.W. Synthesized ADI for Pitchscale Appraisal. Wright-Patterson AFB, OH: Flight Dynamics Laboratory, AFFDL-TR-67-36, May 1967.

Baciak, A. M. and Wild, J. W. Integrated Instruments: A Fuel System Indicator for Fighter-Bomber Aircraft. Wright-Patterson AFB, OH: Wright Aeronautical Development Center, WADC-TR-58-212, June 1958, AD 155 514.

Baker, C. H. Review of Selected Aspects of the ANIP Program (2nd). Human Factors Research Inc., January 1969.

Baker, C.A. and Grether, W.F. Visual Presentation of Information. Wright-Patterson AFB, OH: Wright Air Development Center, WADC-TR-54-160, Aug 1954.

Baron, S. and Levison, W.H. A Manual Control Theory Analysis of Vertical Situation Displays for STOL Aircraft. Washington, D.C.: NASA, NASA-CR-114620, Apr 1973.

Baty, D.L., Wempe, T.E., and Huff, E.M. A Study on Aircraft Map Display Location and Orientation. IEEE Transactions on Systems, Man, and Cybernetics, Nov 1974.

Baty, D.L. An Advanced Cockpit Instrumentation System: The Coordinated Cockpit Display. Moffett Field, CA.: Ames Research Center, NASA-TM-78559, Jul 1979.

Baty, D.L. Rationale and Description of a Coordinated Cockpit Display for Aircraft Flight Managements. Moffett Field, CA.: NASA Ames Research Center, NASA TM X-3457, Nov. 1976.

Baxter, J.R. Projected Symbolic Displays for General Aircraft. Melbourne, Aus.: Aeronautical Research Lab, Australian Defense Scientific Service, ARL/HE 14, Mar 1963.

Baxter, J.R. and Workman, J.D. Review of Projected Displays of Flight Information and Recommendations for Further Development. Melbourne, Aus.: Human Aeronautical Res Lab, Aust Defense Scientific Service, Engineering Rpt #2, Aug. 1962.

Bell Helicopter Co. Joint Army-Navy Aircraft Instrumentation Research Progress Report. Ft. Worth, TX,: TR D228-100-008, Apr 1964. AD 435 733.

Bendix Aviation Corp. Design for Legibility of Visual Displays. Baltimore, MD.: Bendix Radio Div, Human Factors Group, Rpt 481-1016-97A, Feb 1959, AD 230 062.

Besco, R. O. Manual Attitude Control Systems, Vol 2, Display Format Considerations. Culver City, Ca.: Hughes Aircraft Co., P 64-22, March 1964.

Boyer, R. Assessments of Cockpit Displays. ESRO-TT-31, March 1974.

Beyer, R. Efficiency Studies on Cockpit Displays. NASA TT F-14, 846. March 1973.

Blair, W.C. and Plath, D.W. Project Subic: Ship Control XI, Steering and Diving with the Combined Instrument Panel and a Contact Analog-Roadway Display. Groton, Conn.: General Dynamics - Elec Boat Div, TR-SPD-10-078, Sept 1960. AD 250 362.

Bloomfield, J.R., Pratt, P.D., Hughes, R.J., and Williams, L.G. Feasibility of Multisensor Combined Displays. Arlington, VA: ONR, ONR CR213-140-1, Dec 1976. AD A036 285.

Blount, E., Dowling, C. E., Kay, H., McCormick, R. E., Sellers, E. R. Technical and Operational Evaluation of the Type-4 Pictorial-Display Equipment. Washington, D.C.: Civil Aeronautics Administration, CAA-TDR-242, June 1954.

Born, G. J., Dukes, T. A., Durbin, E. J., and Sun, P. B. Phases I and II, Flight Path Control and Performance Analysis. Phase III, Integrated Display. Fort Monmouth, N. J.: Avionics Laboratory, ECOM-0161-72-7, July 1974. AD A002 014.

Bradley, W.A. An Empirical Evaluation of the Kaiser Contact Analog Display. Warminster, Pa.: Naval Air Development Center, NADC-AI-6030, May 1960.

Breitmaier, W.A. An Apparatus for Evaluating Pilot Reference of Electronic Display Information and Formats. Warminster, Pa.: Naval Air Development Center, NADC-76195-40, Jul 1976.

Bruckner, L.A. and Mills, C.F. The Interactive Use of Computer Drawn Faces to Study Multidimensional Data. Los Alamos, NM: Los Alamos Scientific Laboratory, LA-7752-MS, Mar 1979.

Bunker, W.M. and Hartz, R.A. Perspective Display Simulation of Terrain. Wright-Patterson AFB, OH: Human Resources Laboratory, AFHRL-TR-76-39, Jun 1976.

Burke, J.E., Huchingson, R.D., Koppa, R.J., and Sewell, H.E., Jr. First and Second Simulator Evaluations of Advanced Integrated Display and Control Systems. Washington, D.C.: NASA, NASA CR-762, June 1967.

Burton, G.T., Clay, B.R., Croce, R.F., Gore, D.A. and Tetrev, R.E. Holographic Horizontal Situation Display Extension. Warminster, PA: Naval Air Development Center, NADC-75343-30, Dec 1975.

Buyan, J.R. Manned Military Spacecraft Displays. Vandenberg AFB, CA: Space Sys Div., USAF (SSD) TDR-63-303, Jan 1964.

Cahow, J. W. Advanced Army Aircraft Instrumentation System, Rpt. 1. Long Beach, Ca.: Douglas Aircraft Co., TR-SCL-5804B, February 1965, AD 480980.

Cahow, J.N. Advanced Army Aircraft Instrumentation System First Quarterly Program Report. El Segundo, Ca.: Douglas Aircraft Co., DAC Rpt ES-40634A, June 1962.

Carel, W.L. Analysis of Pictorial Displays First Quarterly Rpt. Culver City, CA: Hughes Aircraft Co., Rpt No. 2732.01/19, Sept 1964.

Carel, W.L. Pictorial Displays for Flight. Culver City, Ca.: Hughes Aircraft Co., JANAIR TR 2732.01/40, Dec. 1965.

Casey, S.M., Breitmaier, W.A. and Nason, W.E. Cerebral Activation and the Placement of Visual Displays. Warminster, PA: Naval Air Development Center, NADC-77247-40, Aug 1977.

Chapanis, A. How We See: Summary of Basic Principles. Washington, D.C.: National Research Council, Human Factors in Undersea Warfare, 1949.

Chien, R.T. On the Importance of Program Intelligence to Advanced Automation in Flight Operations. Wright-Patterson AFB, OH: Avionics Laboratory, AFAL-TR-77-20, Apr 1977.

Christ, R. E. and Teichner, W. H. Color Research for Visual Displays. Las Cruces, N. M.: New Mexico State University, JANAIR 730703, July 1973.

Clement, W. F., Allen, R. W., and Graham, D. Pilot Experiments for a Theory of Integrated Display Format. Hawthorne, Ca.: Systems Technology, Inc., JANAIR 711107, October 1971.

Clement, W.F. Investigation of the Use of an Electronic Multifunction Display and an Electromechanical Horizontal Situation Indicator for Guidance and Control of Power-Lift Short-Haul Aircraft. Moffett Field, CA: Ames Research Center, NASA-CR-137922, Aug 1976.

Cloud, E.L., Fendley, J. N., and Stinnett, T. A. Combat Energy Maneuverability Display. Pacuxent River, Md.: Presented at Second Advanced Aircrew Display Symposium, Naval Air Test Center, April 1975.

Colgan, A.R. Integrated Cockpit Display System. Wright-Patterson AFB, Oh.: Avionics Laboratory, AFAL-TR-73-50, Jan 1973.

Collins Radio Company. Letdown and Low-Approach System. Des Moines, Iowa. January 1960.

Conover, D.W. and Kraft, C.L. Use of Color in Coding Displays. Wright-Patterson AFB, Oh.: Aerospace Medical Laboratory, WADC-TR-55-471, Oct 1958.

Cosley, D.H. and Dale, H.E. SST Technology Follow-On Program Phase II, ADEDS Flight Test Report Vol. 1, Flight Test Plan. Seattle, Wa.: Boeing Co., Rpt No. FAA-SS-73-22-1, Feb. 1974.

Crook, M. N., Raben, M. W., and Wade, E. A. Trends and Developments in Visual Displays. Arlington, Va.: ONR, NR-196015, December 1967. AD 673 091.

Cross, K. D. and Bittner, A. C., Jr. Accuracy of Altitude, Roll Angle, and Pitch Angle Judgements as a Function of Size of Vertical Contact Analog Display. Arlington, Va.: Office of Naval Research, NMC-TM-69-2, January 1969.

Cross, K. D. and Bittner, A. C. Jr. JANAIR vertical Contact Analog Display Evaluation Program (Annual Report January 1967 - January 1968). Pt. Mugu, Ca.: Naval Missile Center, TM68-23, JANAIR 680713, January 1969. AD 833 302.

Cross, K. D. and Cavaliero, F. R. Utility of the Vertical Contact Analog Display for Carrier Landings: A Diagnostic Evaluation. Pt. Mugu, Ca.: Naval Missile Center, TP-71-52, JANAIR 701212, September 1971.

Cross, K. D., Powers, O. M., Cavallero, F. R. and Bittner, A. C., Jr. JANAIR Vertical Contact Analog Display Evaluation Program (Annual Report January 1968 - January 1969). Pt. Mugu, Ca.: Naval Missile Center, TP-70-12, JANAIR 690111, March 1970.

Curtin, J. G., Emery, J. H. Dougherty, D. J., and Elam, C. B. Flight Evaluation of the Contact Analog Pictorial Display. Fort Worth, Tx.: Bell Helicopter Company, TR D228-420-009, Feb 1966. AD 640 597.

Curtin, J. G., Emery, J. H., Elam, C. B., and Dougherty, D. J. Flight Evaluation of the Contact Analog Pictorial Display System. Fort Worth, Tx.: Bell Helicopter Co., JANAIR TR D228-420-009, NORR 4429(00), February 1966. AD 640 597.

Dale, H.E. and Cosley, D.H. Advanced Electronic Display System (ADEDS) - Flt Test Rpt, Vol I, Flt Test Plan. Washington, D.C.: FAA, FAA-SS-73-22, Jan 1974.

Daly, L., Collins, D.J., and Ruby, R.A. Advanced Integrated Aircraft Displays and Augmented Flight Control Vol II: Appendices. Savoy, Ill.: University of Illinois, Aviation Research Laboratory, ARL-75-12/ONR-75-2, Jun 1975.

Davis, W. S. G. Study to Improve the Presentation of Control Surface Information. Fort Worth, Tx.: Convair, Internal Furnishings Rpt 201, July 1958.

DeMaio, D. A. An Airspace Utilization Model for V/STOL Terminal Operations. Cambridge, Mass.: MIT, TE-45, January 1971.

DeMars, S.A. Human Factors Considerations for the Use of Color in Display Systems. Houston, Tx.: J.F. Kennedy Space Center, Systems Engineering Division, NASA TR-1329, Jan 1975.

Deese, J. Complexity of Contour in the Recognition of Visual Form. Wright-Patterson AFB, Oh.: WADC-TR-56-60, Feb 1956. AD 094 610.

Dougherty, D. J. Final Technical Report, JANAIR Contract 4429(00). Fort Worth, Tx.: Bell Helicopter Company, TR D228-420-009, Feb 1966. AD 645 492.

Dougherty, D.J. Final Technical Rpt. Fort Worth Tx.: Bell Helicopter JANAIR, TR-D228-100-011, Feb 1966.

Dougherty, D.J., Abbott, B.A., Matheny, W.G. and Willis, J.M. Study of Simulated Rotary Wing Hovering Performance as a Function of Symbol Heading Using a Moving Symbol-Fixed Map Pictorial Position Display. Ft. Worth, Tx.: Bell Helicopter Co., Rpt. No. D228-421 -500, Sept. 1961.

Dougherty, D. J., Emery, J. H., and Curtin, J. G., Comparison of Perceptual Work Load in Flying Standard Instrumentation and the Contact Analog Vertical Display. Ft. Worth, Tx.: Bell Helicopter, Co., TR D228-421-019, Dec. 1964. AD 610 617.

Douglas Aircraft. Advanced Army Aircraft Instrumentation System. El Segundo, Ca.: Report No. ES-40634A, June 1962.

Douglas Aircraft. Airborne Research Systems (Fixed Wing-General Attack Mission). El Segundo, Ca.: Report No. ES-40026-A, Aug. 1961.

Douglas Aircraft Co. ANIP Flight Path Generator, Final Report and Maintenance Instructions: Phase II. Long Beach, Ca.: May 1961.

Douglas Aircraft. ANIP: Army Navy Instrumentation Program. El Segundo, Ca.: ANIP Rpt ES-29101, (No Date).

Douglas Aircraft. Army-Navy Instrumentation Program. El Segundo, Ca.: ES-29101, Contract NONK1076(00), (No Date).

Douglas Aircraft Co. Army-Navy Instrumentation Program Airborne Research Systems - Fixed Wing. Long Beach, Ca.: Aug. 1961. AD 812 861.

Douglas Aircraft. Army-Navy Instrumentation Program - Fixed Wing Research Phase. El Segundo, Ca. DAC Rpt. 44241, May 1963, (AD 647297).

Douglas Aircraft Co. Army-Navy Instrumentation Program, Historical Report, Long Beach, Ca.: Jun 1962. AD 610-249.

Douglas Aircraft Co. Army-Navy Instrumentation Program, Human Factors. Long Beach, Ca.: Rpt. No. ES 40394, Aug 1961.

Douglas Aircraft Co. Human Factors on ANIP. Long Beach, Ca.: DAC-56-436, Jun 1960.

Douglass, M.E. Integrated Engine Instrumentation System. Wright-Patterson AFB, Oh.: Symposium on the USAF Flight Control Display Integration Program, WADC Symp 58804, Feb 1958.

Dowd, C. Integrated Displays and E-O Sensors for F-14 CILOP Program. Patuxent River, Md.: Presented at Fourth Advanced Aircrew Display Symposium, Naval Air Test Center, May 1978.

Dukes, T. A. An Integrated Display for Trajectory Control of Helicopters and VTOL Aircraft Wright-Patterson AFB, Oh.: In Proceedings of the Sixth Annual Conference on Manual Control. April 1970.

Dunham, R.E., Jr. and Sommer, R.W. Evaluation of a Contact-Analog Display in Landing Approaches with a Helicopter. Hampton, Va.: Langley Research Center, NASA-TN-D-5241, Jun 1969.

Eddowes, E.E. and Newgent, W.L. An Integrated Display System for High Performance Aircraft: Human Factors and Engineering Design Recommendations. St. Louis, Mo.: McDonnell Aircraft Company, MDC Rept B608, Apr. 1965.

Elam, C.B. and Emery, J.H. Effect of Stimulus Ambiguity in the Display of Attitude Information. Fort Worth, Tx.: Bell Helicopter Co., Rpt D228-421013, Sept. 1962.

Elam, C.B., Emery, J.H., and Matheny, W.G. Redundancy in the Display of Spatial Orientation, Fort Worth, Tx.: Bell Helicopter Co., TRD228-421-009, Sept. 1961, AD 267 357.

Elam, C.B., Emery, J.H., and Matheny, W.G. Tracking Performance as Affected by the Position of the Attitude Display. Fort Worth, Tx.: Bell Helicopter Co., TR D228-421-010, Mar. 1962. AD 273 967.

Ellis, D., Steinman, L., and Ludwig, F. The Tunnel Display Concept. New York City, NY.: 6th Annual Mtg of the American Astronautical Society, AAS Paper 60-24, Jan 1960.

Emery, J. H. and Dougherty, D. J. Contact Analog Simulator Evaluations: Climbout, Low Cruise and Descend Maneuvers. Fort Worth, Tx.: Bell Helicopter Company, TR D228-421-017, May 1964. AD 603 744.

Emery, J. H. and Dougherty, D. J. Contact Analog Simulator Evaluations: The Influence of Screen Size and Image Field. Fort Worth, Tx.: Bell Helicopter Company, TR D228-420-007, April 1965. AD 633 107.

Emery, J. H. and Koch, C. A. Contact Analog Simulator Evaluations: Numeric Agumentation of Grid Plane Encodement. Fort Worth, Tx.: Bell Helicopter Company, TR D228-420-007, December 1965. AD 633 107.

Emery, J.H., Koch, C.A., and Curtin, J.G. Contact Analog Simulator Evaluation: Investigations of Director Symbols, Display Alteration, and the Presentation of Secondary Flight Information. Ft. Worth Tx.: Bell Helicopter Co., JANAIR-TR-D228-420-008, Jan. 1967.

Faison, W. E. and Sluka, A. L. Dynamic Simulation Studies of Pictorial Navigation Displays as Aids to Air Traffic Control in a High-Density Terminal Area and a Medium-Density Terminal Area. Washington, D. C.: Federal Aviation Administration, November 1961.

Fisher, R. B. and Sunkes, J. A. Preliminary Study of Pilot Operational Capabilities in the Use of the CAA Pictorial Position Indicator and the Avion Pictorial Navigation Display in the Terminal Area. Washington, D. C.: FAA, TR D-2-5213, February 1960.

Fogel, L. J. A Suggested Flight Display and Control Design for Advanced Interceptor Aircraft. San Diego, Ca.: Convair, Rpt ZG-8-041, January 1957.

Fountain, W.T. and Cone, D.R. Horizontal Situation Display (HSD). Rome AFB, N.Y.: Rome Air Development Center, RADC-TR-73-23L, Aug. 1973.

Frost, J.S. Electroluminescent Pictorial Status Displays. New York City, N.Y.: 6th Natl Symposium on Information Displays, Sept. 1965.

Frost, J.S. and Sullivan, N. F. Integrated Displays for Multicrew Military Aircraft. Information Display 9(2), 1972.

Frost, J.S. and Wright, R.H. Functional Evaluation of Electroluminescent Pictorial Status Displays, Anaheim, Ca.: North American Aviation, C7-L794/ 301, Jul. 1967.

Gaito, J. Human Engineering Investigations of Aircraft Cockpit Visual Displays, Part 18. Size and Shape of Numerals and Letters for Displays. I. Perceptual Development with Single and Multiple Straight and Curved Line Forms. Phila., Pa.: U. S. Naval Air Materiel Center, NAMC-ACEL-351, Oct. 1957.

Gebhard, J.W. Psychological Problems in Coding the Information for Visual Displays. Washington, D.C.: ONR, USN Spec Devices Center, Proj NR 784-001, May 1949.

General Electric Co. A Multi-Purpose Flight Display System for Aircraft and Spacecraft. Binghamton, N. Y.: Aircraft Equipment Div., AD-30, December 1970.

General Electric Co. Digital Computer Paints Landscape in New Cockpit Display System. Utica, N. Y.: Light Military Electronics Department, (no date).

General Electric Co. Visual Factors in the Contact Analog. Ithaca, N. Y.: Summary 1961, NGrr 1076(00), (no date), AD 263820.

Gilfillian Electronic Systems. Final Engineering Report, Pictorial Situation Indicator. Los Angeles, Ca.: Air Force Cont No. 33(600)-41265, January 1962.

Green, G.N. Head-Up Display Symbolology. Farnborough, England: Royal Aircraft Estab, TR 77050, Apr. 1977.

Greer, P.E. and Hanking, J.R. Application of ATOS to the A-7E and a Projected Future Tactical Aircraft. Warminster, Pa.: Naval Air Development Center, NADC-78032-60, Dec. 1977.

Grunwald, A.J., Robertson, J.R., and Hatfield, I.J. Evaluation of a Computer-Generated Perspective Tunnel Display for Flight-Path Following. Hampton, Va.: NASA, Langley Research Center, NASA Technical Paper 1736, December 1980.

Guttman, E. S. Air-Navigation Horizontal Situation Display. Electrical Communication 43(2) 1968, 150-153.

Hainsworth, T.E., Lukso, R., Hardwicke, R., Fellingner, J., Lensing, L., and Ranford, A. V/STOL Control-Display System Requirements and Simulation Study. Wright-Patterson AFB, Oh.: Flight Dynamics Laboratory, AFFDL-TR-65-24, Jul 1965. AD 470 958.

Hardzinski, M. and Pachella, R. G. A Psychophysical Analysis of Complex Integrated Displays. Arlington, Va.: ONR, 014523-2-T, TR-59, February 1977. AD A039 260.

Hershberger, M. L. and Guerin, D. F. Binocular Rivalry in Helmet-Mounted Display Applications. Wright-Patterson AFB, Oh.: Aerospace Medical Research Laboratory, AMRL-TR-75-48, June 1975.

Hopkins, C.O. Human Performance in Aviation Systems. Washington, D.C.: AF Office of Scientific Research, AFOSR-TR-78-0080, Jul 1977.

Howard, J.H. Electronic Information Display Systems. Washington, D.C.: Spartan Books, Inc., 1963.

Hubner, J. and Blose, L. E. Preliminary Flight Evaluation of the F-111B Primary Flight Displays. Patuxent River, Md.: NATC, ST-46-R-066, June 1966.

Hughes Aircraft Co. Manual Attitude Control Systems: Vol II Display Format Considerations. Culver City, Ca.: Hughes Display Systems Dept., P64-22, Mar 1964.

Hummel, T.L. A Digital Computer-Generated Contact Analog Landing Display. Savoy, Ill.: University of Illinois, Aviation Research Laboratory, ARL-73-9/AFOSR-73-5, May 1973.

Hummel, T. L., Williges, B. H., and Roscoe, S. N. A Computer-Generated Display to Isolate Essential Visual Cues in Landing. Washington, D. C.: AFOSR, AFOSR-TR-72-2436, January 1972.

JANAIK. Bibliography of the Joint Army-Navy Aircraft Instrumentation Research Program. Washington, D. C.: JANAIK Rpt 720101, August 1972.

Johns Hopkins University. Preliminary Recommendations on the Types of Visual Codes Proposed for the Integrated Electronic Display System. Baltimore, Md.: ONR Rpt 166-I-105, November 1949, AD 644 644.

Johnson, D. and Jones, R. W. Head-Up Display of Approach Information. In AGARD Extended Summaries 4, November 1968. AD 685 268.

Johnson, S. L. and Roscoe, S. N. What Moves, the Airplane or the World? Savoy, Ill.: University of Illinois, Aviation Research Laboratory, TR ONR-70-1, June 1970. AD 713 179.

Johnson, S. L., Williges, R. C., and Roscoe, S. N. A New Approach to Motion Relations for Flight Director Displays. Savoy, Ill.: University of Illinois, Aviation Research Laboratory, TR ARL-71-20/ONR-71-3/AFOSR-71-6, October 1971. AD 735 916.

Kaehler, R.C. and Romano, S. Navigation and Energy Display Requirements for Pilot Controlled Satelloid Flight. New York City, N.Y.: 6th Annual Mtg of the American Astronautical Society, AAS Paper 60-26, Jan 1960.

Kearns, J.H. and Ritchie, M.L. Cockpit Control-Display Subsystem Engineering. Wright-Patterson AFB, Oh.: Aeronautical Systems Div., ASD Tech Rpt 61-545, Oct 1961.

Kelley, C.R., Goff, J.D., Strudwick, P.H., and Ketchel, J M. Human Factors Report on the Vertical/Head-up Display. Palo Alto, Ca.: Kaiser Aerospace & Elec Corp, Contr No. AF33(657)-8260, Apr 1965.

Kelley, C.R., deGroot, S., and Bowen, H.M. Relative Motion III: Some Relative Motion Problems in Aviation. Washington, D.C.: NAVTRADEVCEEN TR-316-2, Naval Training Devices Center, Jan. 1961.

Kennedy, J.L. A Display Technique for Planning. Rand Corp., P-965, Oct. 1956.

Ketchal, J.M. and Jenney, L.J. Electronic and Optically Generated Aircraft Displays - A Study of Standardization Requirements. Washington, D.C.: Office of Naval Research, JANAIR Rpt 680505, May 1968.

Kingston, W.W. Visual Display Techniques in Vehicle Stabilization and Control. New York City, N.Y.: 6th National Symposium on Information Displays, Sept. 1965.

Knox, C.E. and Leavitt, J. Description of Path-in-the-Sky Contact Analog Piloting Display. Moffett Field, Ca.: Ames Research Center, NASA-TM-74057, Oct. 1977.

LaForge, E.F. and Kennedy, E.J. Accuracy in Estimation of Deviations from Glidepath as a Function of Display Configuration. Rome AFB, N.Y.: Rome Air Development Center, RADC-TN-59-140, Jun. 1959.

LaFranchi, V. E. Experimental Results of a Simulated Flight Test Using Various Contact Analog Texture Formats. Washington, D. C.: Naval Air Development Center, NADC-AM-6645, August 1966.

LaFranchi, V. E. and Dafrico, R. Simulation Tests of Terrain Following Flights Using an IHAS Vertical Situation Display in the Shades of Gray Mode. Warminster, Pa.: Naval Air Development Center, NADC-SD-6827, January 1969.

Lear Siegler, Inc. Preliminary V/STOL Control-Display Subsystem Requirements Study. Wright-Patterson AFB, Oh.: Flight Dynamics Laboratory, FDL-TDR-64- 85, Jun 1964.

Lear Siegler, Inc. State of the Art for V/STOL Control Display. Wright-Patterson AFB, Oh.: Flight Dynamics Lab, RTD-TDR-63-4167, Oct. 1963. AD 613 523.

Leibowitz, H. and Moore, D. Role of Changes in Accommodation and Convergence in the Perception of Size. J. of the Optical Soc of America, 56(8), Aug. 1966.

Lightstone, J.L., J.L. Janowski, G.A., Zavich, V., Brown, T.G., Smith, K.C., and Volsen, A.J. Operation of the F/A-18 Avionic Subsystem. St. Louis, Mo.: McDonnell Aircraft Co., Report No. MDC A5769, Jan. 1979.

Lincoln, R., Palmer, E.A., and Wempe, T. Effect of Pictorial Display Configuration on the Frequency of Control Reversals During Aircraft Landing Approaches. Moffett Field, Ca.: Ames Research Center, NASA-TM-X-62191, Oct. 1972.

Lintern, G. Transfer of Landing Skill after Training with Supplementary Visual Cues. Human Factors, 22(1), 81-88, 1980.

Livingston, C. G. Cruise Control of Turbojet Aircraft. Long Beach, Ca.: Douglas Aircraft Co., LB 31183A, January 1963.

Lovo, F.R. Chromo-Isometric Display Technique. Point Mugu, Ca.: Naval Missile Center, USN(NMC)TM-67-75, Jan. 1968.

Lowry, P. The Impact of Electronic Displays on Aircraft Control. In AGARD CP-58, September 1968.

Martin, C.P., Long, G.E., and Ritchie, M.L. Control-Display Study for Orbital Rendezvous, Vol II. Wright-Patterson AFB, Oh.: Flight Dynamics Laboratory, FDL-TDR-64-94, Vol II, Oct. 1964.

Mayer, J.M. A New Concept in the Generation of Pictorial Data. Wright-Patterson AFB, Oh.: Symposium on the USAF Flight Control Display Integration Program, WADC Symp 58B04, Feb. 1958.

Mayo, A.M. Progress from the Army Navy Instrumentation Program. Dallas, Tx.: Paper presented at ANIP Symposium, Sept. 1959.

Mazza, J.D. A Comparison of Integrated and Conventional Cockpit Warning Systems. Monterey, Ca.: Naval Postgraduate School, Masters Thesis, Sept. 1977. AD A048 670.

McCormick, R. E. and McKnight, F. S. The Type-4 Pictorial Computer with Automatic Chart Selection. Pt 2 Technical and Operational Evaluation. Washington, D. C.: Civil Aeronautics Administration, CAA-TDR-241, June 1954.

McDade, J.L. An Investigation of Advanced Pilots Vertical Display Techniques. Palos Verde, Ca.: Northrop Corp, NORT-71-295-2, Jan 1973.

McDonnell Aircraft Co. Cockpit Controls, Displays, and Instruments. St. Louis, Mo.: McDonnell Aircraft Co., MDC A3200 Vol II, Book 16-5, Dec. 1974.

McKnight, F. S. A Preliminary Study of Operational Advantages of Pictorial Navigation Displays. Washington, D. C.: Civil Aeronautics Administration, TR-241, June 1954.

McLane, R. C. and Wolf, J. D. A Comparative Evaluation of Pictorial vs. Symbolic Displays for Submersibles. San Diego, Ca.: Presented at the AIAA/USN Marine Systems and ASW Conference, AIAA Paper No. 65-246, Mar. 1965.

McLane, R. C. and Wolf, J. D. Experimental Evaluation of Symbolic and Pictorial Displays for Submarine Control. St. Paul, Minn.: Honeywell, Systems and Research Div., 1550-FR1, September 1965, AD 621 870.

Meister, D. and Sullivan, D.J. Guide to Human Engineering Design for Visual Displays. Canoga Park, Ca.: The Bunker-Ramo Corp, NR196-080, Contract No. NO0014-68-C-0278, Aug. 1969.

Miller, J.W. Visual Display and Control Problems Related to Flight at Low Altitude. Anaheim, Ca.: ONR Symp Rpt ACR-95, Mar. 1964.

Morello, S. A., Knox, C. E., and Steinmetz, G. G. Flight Test Evaluation of Two Electronic Display Formats for Approach to Landing Under Instrument Conditions. Hampton, Va.: NASA Langley Research Center, NASA TP-1085, December 1977.

Muller, P.F., Jr., Sidorsky, R.C., Slivinske, A.J., Alluisi, E.A., and Fitts, P.M. Symbolic Coding of Information on CRT and Similar Displays. Wright-Patterson AFB, Oh.: WADC-TR-55-375, Oct. 1955, AD 103 239.

Musgrave, J.S. Cockpit and Controls-Display Design Criteria for Tactical STOL and V/STOL Aircraft. Wright-Patterson AFB, Oh.: Flight Dynamics Lab, AFFDL-TR-72-72, Nov. 1972.

Myers, W.S. Accommodation Effects in Multi Color Displays. Wright-Patterson AFB, Oh.: Flight Dynamics Lab, AFFDL-TR-67-161, Dec. 1967.

NASA. Space Vehicle Displays Design Criteria. Washington, D.C.: NASA SP-8086, Mar. 1972.

NASA. Visual Information Display Systems. Washington, D.C.: NASA SP-5049, 1968.

NASA. Seventh Annual Conference on Manual Control. Los Angeles, Ca.: NASA-SP-281, Jun. 1971.

Naish, J.M. and Miller, D. An Experimental Evaluation of Head-Up Display Formats. Moffett Field, Ca.: NASA Ames Research Center, NASA TP-1550, July 1980.

Narva, M.A. Evaluation of Decision Making Performance on Three Pictorial Navigation Displays. Wright-Patterson AFB, Oh.: Wright Aeronautical Development Center, WADC TR 58-49, Nov. 1958. AD 142 329.

Narva, M.A., Gainer, C.A., and Muckler, F.A. Integrated Instruments: Information Requirements for Fuel Management. Wright-Patterson AFB Oh.: Wright Aeronautical Development Center, WADD-TR-60-638, Dec. 1960. AD 252 053.

Newman, K.M. and Davis, A.K. Multidimensional Nonredundant Encoding of a Visual Symbolic Display. San Diego, Ca.: Navy Electronics Laboratory, Jul. 1961.

Niwa, J. S., Parks, D. L., and Jansen, G. L. Flight Test of an All Weather Landing Monitor - Microvision with Aiding Symbology. Seattle, Wa.: Boeing Aircraft Co., Rpt D6-55002 TN-1, December 1969.

Norden. Norden Advanced Cockpit Displays. Norwalk, Conn.: United Aircraft Corp., Norden Div., (no date).

Nordstrom, L. Eye level Flight Information by a Perspective Pole-Track. Linkoping, Sweden: Saab Aircraft Co., TN 58, Jan. 1965.

Olson, B. A., Anderson, P. A., Baker, C. A., Clifford, R. R., King, W. J., Lovinger, D. N., and Wolf, J. D. Display and Control Requirements Study for a V/STOL Tactical Aircraft, Vol I Analysis. Wright-Patterson AFB, Oh.: Flight Dynamics Laboratory, AFFDL-TR -66-114, August 1967.

Orrick, W.P., Jr., and York, P. E. Head-Up Display Symbology. Warminster, Pa.: Naval Air Development Center, NADC-73267-40, Dec. 1975.

Osterman, L.O. and Mulley, W.G. Advanced Integrated Display System (AIDS) for V/STOL Aircraft. AIAA Paper, AIAA-P-77-600, 1977.

Palmer, E. and Wempe, T. Pilot Performance with a Simulated ILS Independence Pictorial Display. Los Angeles, Ca.: In NASA SP-281, Jun. 1971.

Panigrahi, G. Penetron Land Color Display System (PFNTECOST) and Some Observations Concerning Color Perception. UIUCDCS-R-73-538, Oct. 1973.

Parks, D. L. An Aided Perspective Display as an All Weather Landing Monitor. San Francisco, Ca.: Presented to the 14th Annual Meeting of the Human Factors Society, October 1970.

Passman, H.M. Control Units and Remote Indicators for Airborne Electronic Equipment. Wright-Patterson AFB, Oh.: Symposium on the USAF Flight Control Display Integration Program, WADC Symp 58B04, Feb. 1958.

Payne, T.A. A Study of the Moving Figure and Orientation of Symbols on Pictorial Aircraft Instrument Displays for Navigation. Port Washington, N.Y.: ONR, Special Devices Center, SPECDEVGEN 71-16-6, Jul. 1950.

Payne, T.A. A Study of the Moving Part, Heading Presentation, and Map Detail on Pictorial Air Navigation Displays. Port Washington, N. Y.: ONR, Special Devices Center, TR SPECDEVGEN 71-16-10, November 1952.

Pelton, F.M. Advance Concepts for Terrain Avoidance (ADCON). Wright-Patterson AFB, Oh.: ASD, ASD-TR-61-468, Oct. 1961.

Pfeiffer, M.G., Clark, W.C., and Danaher, J.W. Pilot's Visual Task: Study of Visual Display Requirements. Washington, D.C.: Naval Training Devices Center, NAVTRADEVGEN 783-1, Mar. 1963.

Pizzicara, D.J. Computers and Displays/Controls State of the Art Technology Studies. Woodland Hills, Ca.: Litcon Systems, Inc., Rpt. 4902, Feb. 1966.

Polyhemus, W. L. Navigation Displays Requirements for High Performance Aircraft. Long Beach, Ca.: Paper presented to the Annual Meeting of the Institute of Navigation, June 1965.

Powrie, S. R. Energy Management Display for Air Combat Maneuvering. Naval Postgraduate School, March 1977. AD A040 198.

Probst, H.C. and Oliver, D.A. The Display of Multi-Dimensional Flows in Turbomachinery. Cambridge, Mass.: Mass. Inst. Tech, MIT-GTL-R-111, Aug. 1972.

Rabideau, G.F. and Semple, C.A., Jr. Human Engineering Support to Air Force Flight Control and Flight Display Integration Program. Wright-Patterson AFB, Oh.: Flight Dynamics Lab, AFFDL-TR-66-157, Jan. 1966.

Ragan, J.J. Tracking Performance Related to Display Control Configurations. Washington, D.C.: Naval Training Devices Center, NAVTRADEVCEEN 322-1-2, Jan. 1959.

Ritchie, Inc. Airborne Evaluation of Display Concepts. Dayton, Oh.: Monthly Tech Rpt 65-21, Oct. 1965.

Kitchie, Inc. Research in New Techniques for Control Display. Dayton, Oh.: TR 74-006, November 1964.

Ritchie, M.L. and Bamford, H.E., Jr. Investigations in Instrument Integration. Wright-Patterson AFB, Oh.: Symposium on the USAF Flight Control Display Integration Program. WADC Symp 58B04, Feb. 1958.

Rizy, E.F. Color Specifications for Additive Color Group Displays. Griffiss AFB, NY.: Aug. 1965, AD 621 068.

Roscoe, S.N. Airborne Displays for Flight and Navigation. Culver City, Ca.: Hughes Aircraft Co., TM-686, September 1967.

Roscoe, S.N. Airborne Displays for Flight and Navigation. Culver City, Ca.: Hughes Aircraft, TM887, Sept. 1967.

Roscoe, S.N. Aviation Psychology. Ames, Iowa: Iowa State Univ Press, 1960.

Roscoe, S.N. Flight by Periscope. University of Illinois Bulletin 48 (55), March 1951.

Roscoe, S.N. How Big the Moon, How Fat the Eye. Savoy, Ill.: University of Illinois, Aviation Research Lab, ARL-77-9/AFOSR-77-8, Jun. 1977.

Roscoe, S.N., Eisele, J.E., and Bergman, C.A. Advanced Integrated Aircraft Displays and Augmented Flight Control. Vol I. Savoy, Ill.: University of Illinois, Aviation Research Laboratory, TR AKL-75-12/ONR-75-2, June 1975.

Rosenquist, D. E., McDowell, H. V., Upton, H. W., and Dougherty, D. J. Joint Army-Navy Aircraft Instrumentation Research Progress Report. Fort Worth, Tx.: Bell Helicopter Co., JANAIR TR D228-100-008, July 1963.

Runnels, R. L. Display Formats Manual. Philco Ford, PHO-TR-515, January 1973.

Sampson, P.B. and Wade, E.A. Literature Survey on Human Factors in Visual Displays. Rome, N.Y.: Rome Air Devel Center, RADC-TR-61-95, Jun. 1961.

Schaefer, C.F. and Williams, P.R. A Study of Display Integration for Hypersonic Research Vehicles, 1st Qtrly Prog Rpt. Washington, D.C.: NASA, NASA-CR-77937, Sept. 1963.

Schattenmann, W. and Wilckens, V. Comparison of Contact Analog Channel Display and Conventional Instrumentation by Means of Simulator Studies. DGLR-Paper-72-100, 1972.

Schattenmann, W. and Wilckens, V. Comparison of the Contact Analog Channel Display and of Conventional Instrumentations on a Fixed Base Simulator. DLR-FB-73-57, 1973.

Schofield, L. B. and Hoey, R. G. Cockpit Displays for Pilot Control During Hypersonic Lifting Re-Entry. Edwards AFB, Ca.: AFFTC, AFFTC-TDR-62-38, February 1963.

Semple, C.A., Jr., Heapy, R.J., Conway, E.J., Jr., and Burnette, K.T. Analysis of Human Factors Data for Electronic Flight Display Systems. Wright-Patterson AFB, Oh.: Flight Dynamics Lab, AFFDL-TR-60-174, Jan. 1971, AD 884 770.

Sgro, J.A. and Dougherty, D.J. Contact Analog Simulator Evaluations Hovering and Air Taxi Maneuvers. Fort Worth, Tx.: Bell Helicopter Co., TR D228-421-016, Jul. 1963.

Shearer, J.P. Preliminary V/STOL Control-Display Subsystem Requirements Study. Wright-Patterson AFB, Oh.: USAF Flight Dynamics Laboratory, FDL-TDR-64-85, June 1964. AD 610 746.

Shrager, J.J. Advanced Flight Control and Electronic Display Systems for All-Weather Flight Operations: A Literature Review and Bibliography. Washington, D.C.: FAA, FAA-NA-73-78, Jun. 1974.

Sidorsky, R. C. and Allen, F. L. Ship Control - 9: An Evaluation of a Horizon-at-Infinity in a Contact Analog Display. Arlington, Va.: Office of Naval Research, August 1959. AD 213 615.

Siegel, A.I. and Fischl, M.A. Dimensions of Visual Information Displays. Wayne, Pa.: Applied Psychological Svcs, ONR Contr N00014-66-C0183, Sept. 1967, AD 661 346.

Sigaan, M. Course Line Computer/Pictorial Display. Washington, D.C.: FAA, FAA-RD-68-56, Oct. 1968. AD 696 575.

Silsby, N. S. and Fischer, M. C. A Simulator Study of a Pictorial Navigation Display in Instrument Departures of the Supersonic Transport. Hampton, Va.: NASA Langley Research Center, NASA-TN-D-4029, July 1967.

Simonelli, N.M. and Roscoe, S.N. Apparent Size and Visual Accommodation Under Day and Night Conditions. Champaign, Ill.: Univ of Illinois, Eng Psy-79-3/AFOSR-79-3, Jun. 1979.

Skovholt, R.L. Integrated Advanced Electronic Display Systems. Patuxent River, Md.: Presented at Second Advanced Aircrew Display Symposium, Naval Air Test Center, April 1975.

Smith, S.L. Display Color Coding for Visual Separability. Bedford, Mass.: Mitre Corp., MTS-10, Aug. 1963. AD 462 872.

Smyth, R.K. State of the Art Survey of Technologies Applicable to NASA's Aeronautics, Avionics, and Controls Program. Washington, D.C.: NASA, NASA-CR-159050, May 1979.

Snyder, Harry L. Human Visual Performance and Flat Panel Display Image Quality. Virginia Polytech Institute & State University, HFL-80-1/ONR-80-1, July 1980.

Soliday, S.M. and Milligan, J.R. Simulation of Low Altitude High Speed Mission Performance: Vol III, Evaluation of Navigational Displays in Terrain - Following Penetration Missions. North American Aviation, Tech Report SEG-TR-66-67, Vol. III, Feb. 1967.

Sommer, R.W. and Dunham, R.E., Jr. Evaluation of a Contact-Analog Display in Landing Approaches with a Helicopter. Hampton, Va.: Langley Research Center, NASA TN-D-5241, Jun. 1969.

Sperry Flight Systems Division. Electronic Display Systems. Phoenix, Az.: Displays Brochure, (No Date).

Stein, W. Data Display Study - Final Report. Ft. Monmouth, N. J.: U. S. Army Signal Research and Development Laboratory, February 1961. AD 470 059.

Steinmetz, G. G., Morello, S. A., Knox, C. E., and Person, L. H., Jr. A Piloted Simulation Evaluation of Two Electronic Display Formats for Approach and Landing. Hampton, VA.: NASA Langley Research Center, NASA TN D-8183, April 1976.

Stenger, T., Dungan, W., and Reynolds, R. Computer Image Generation Texture Study. Wright-Patterson AFB, Oh.: Human Resources Labortary, AFHRL-TR-79-2, Aug. 1979. AD A074 019.

Streeter, E., Dupuis, T.A., Carel, W.L., Gunther, J.E., Craig, D.W. and Opitek, E.W. Research on Visual Display Integration for Advanced Fighter Aircraft. Wright-Patterson AFB, Oh.: Aerospace Medical Research Lab., AMRL-TR-78-121, (Confidential), Mar. 1979.

Sullivan, D.J. and Meister, D. Research Requirements for the Human Engineering Design of Visual Displays. Canoga Park, Ca.: Bunker-Ramo Corp, Rept H0069-9U6, Dec. 1969.

Summers, L.G., Wolbers, H.L., and Carhart, N.A. An Introduction to the Specification of Optimum Visual Display Design Characteristics. Santa Monica, Ca.: Douglas Aircraft Co., Jun. 1961.

Tidd, L.B., Allen, R.C., and Leatham, D.W. Operational Test and Evaluation of Bendix Doppler Pictorial Display. Tactical Air Command, TAC-TR-61-36, May 1962.

U.S. Army Human Engineering Lab. Survey of Advanced Attitude Displays. Aberdeen Proving Ground, MD, Jan. 1967.

U.S. Navy Air Material Center. Human Engineering Investigations of Aircraft Cockpit Visual Displays. Phila, Pa.: Air Crew Equip Lab, NAMC-ACEL-479, Jun 1962.

Upton, H.W., Willis, J.M., and Dougherty, D.J. 1964 Annual Joint Army-Navy Aircraft Instrumentation Research Progress Report. Fort Worth, Tx.: Bell Helicopter Co., TR D228-100-009, Aug. 1969.

Vaccaro, J., Jr. ANIP DV-4, Design Report on Horizontal Display. Warminster, Pa.: Naval Air Development Center, NADC-AI5950, Jul 1959.

Van Houtte, N.A.J. A Perspective Glideslope Indicating System. Wright-Patterson AFB, Oh.: In Proceedings of the Sixth Annual Conference on Manual Control. April 1970.

Ver Hulst, J. Stereo Display for Target Acquisition and Identification. Wright-Patterson AFB, Oh.: Avionics Lab, AFAL-TR-74-33, Sept. 1974.

Vircks, R. M. Investigation of Head Movement and Intensity as Depth Cues in a Perspective Contact Analog Display. Cambridge, Mass.: MIT Thesis, September 1968.

Walters, D. J. The Electronic Display of Primary Flight Data. In AGARD CP-55, November 1968.

Wang, P.C.C. (ed). Graphical Representations of Multivariate Data. New York City, N.Y.: Academic Press, 1978.

Warner, D.A. Flight Path Displays. Wright-Patterson AFB, Oh.: USAF Flight Dynamics Laboratory, AFFDL-TR-79-3075, June 1979.

Warner, J. D. Advanced Display Systems for New Commercial Aircraft. San Francisco, Ca.: Presented to the 14th Annual Meeting of the Human Factors Society, October 1970.

Warner, J. D. and Fadden, D. M. Computer-Generated Map Displays. In Proceedings of the FAA Symposium on Area Navigation. January 1972.

Watler, J.F., Jr. The Maneuvering Flight Path Display. Patuxent River, Md.: Presented at the Third Advanced Aircrew Display Symposium, Naval Air Test Center, May 1976.

Watler, J.F., Jr., and Mulley, W.G. Feasibility Demonstration of the Earth-Referenced Maneuvering Flight Path Display. Hollywood, Fl.: AIAA Guidance & Control Conference, Aug. 1977.

Welde, W.L. Airborne Evaluation of Display Concepts. Dayton, Oh.: Ritchie, Inc., Rpt. USAF 65-16, Aug. 1965.

Welter, N.E. Army-Navy Instrumentation Program Rotary Wing Phase. New York City, N.Y.: IAS 29th Annual Mtg, IAS Paper 61-56, Jan. 1961.

Wempe, T.E. Fixed-Base Simulator Evaluation of a Pilot's Terrain-Following Display with Various Modes of Presenting Information. Moffett Field, Ca.: Ames Research Center, NASA TN-D-1827, Nov. 1964.

Westinghouse Electric Corp. Plasma Display for Aircraft Altimeter. Pittsburgh, Pa.: TM SP-130.11.4, February 1968.

White, R.T. Display Technology: An Annotated Bibliography. Long Beach, Ca.: Douglas Aircraft Co., IRAD MDC J5794, Dec. 1973.

Whitham, D. Engine Control and Instruments Presentation. In AGARD CP-55, November 1968.

Wild, J.W. Methods of System Integration. Wright-Patterson AFB, Oh.: Symposium on the USAF Flight Control Display Integration Program, WADC Symp 58B04, Feb. 1958.

Wilkerson, L.E. and Matheny, W.G. An Evaluation of a Grid Encodement of the Ground Plane as a Helicopter Hovering Display. Ft. Worth, Tx.: Bell Helicopter Co., TR D228-421-008, Oct. 1961. AD 268 273.

Wilkerson, L.E. and Matheny, W.G. Rate Discrimination and Control in a Multiple Tracking Task. Ft. Worth, Tx.: Bell Helicopter Co., TR D228-420-005, Sept. 1961. AD 264 122.

Williams, A.C., Jr., Adelson, M., and Ritchie, M.L. Program of Human Engineering Research on the Design of Aircraft Instrument Displays and Controls. Wright-Patterson AFB, Oh.: Aerospace Medical Research Lab, WADC TR 56-526, Dec. 1956.

Williams, P. R. Technical Progress Report on Universal Contact Analog Display (UCAD) Research. Norwalk, Conn.: United Aircraft Corp., Phase I, Systems Analysis 1161-R-0011, April 1965. AD 616 650.

Williams, P. R. and Kronholm, M. B. Technical Report on Simulation Studies of an Integrated Electronic Vertical Display. Norwalk, Conn.: United Aircraft Corp., Norden Div., Technical Report 1161-R-0021, December 1965. AD 629 157.

Williams, P. R., Harper, H. P. and Kronholm, M. B. An Evaluation of an Integrated V/STOL Display Concept. IEEE Transactions on Human Factors in Electronics 8(2): 158-165, June 1967.

Williamson, W. R. A Prototype Peripheral Vision Aircraft Attitude Display. Wright-Patterson AFB, Oh.: Flight Dynamics Laboratory, AFFDL-TR-66-91, October 1966.

Willich, W. and Edwards, R.E. Analysis and Flight Simulator Evaluation of an Advanced Fighter Cockpit Configuration. Wright-Patterson AFB, Oh.: USAF Avionics Laboratory, AFAL-TR-75-36, Mar. 1975.

Winblade, R. L. Current Research on Advanced Cockpit Display Systems. In AGARD-491, October 1964. AD 476 053.

Wolbers, H.L. Information Requirements of Long Range Displays. Dallas, Tx.: Paper presented at Human Factors Session of ANIP Symp, Sept. 1959.

Wolf, J. D. Display and Related System Requirements for IFR Steep Approach: Final Report. Minneapolis, Minn.: Honeywell, Inc., JANAIR TR 711106, December 1971.

Wolf, J. D. and Hoppe, R. B. Aircraft Displays for Steep Angle Approaches. Minneapolis, Minn.: Honeywell, Inc., JANAIR TR 681215, December 1968. AD 709 475.

Wooding, H. C. and Simpson, J. A. Final Technical Report on Integrated Electronic Vertical Display (IEVD) Research. Norwalk, Conn.: United Aircraft Corp., Norden Div, JANAIR TR 580611, June 1968. AD 709 460.

Wooding, H. C. and Simpson, J. A. Interim Technical Report on Integrated Electronic Vertical Display Research. Norwalk, Conn.: United Aircraft Corp., Norden Div., Rpt 1161-R-0028, February 1967.

Wright, R. H. and Waller, T. G. Pictorial Navigation Displays and Low Altitude Navigation. Washington, D. C.: George Washington Univ., DA 44-188-ARO-2, April 1964. AD 601 711.

Zipoy, D.R., Premselaar, S.J., Gargett, R.E. Belyea, I.L., and Hall, H.J., Jr. Integrated Information Presentation and Control System Study. Wright-Patterson AFB, Oh.: Flight Dynamics Lab, AFFDL-TR-79-79, Vol 1, Aug. 1970.