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JOINT ARMY-NAVY AIRCRAFT
INSTRUMENTATION RESEARCH

ANALYSIS OF PICTORIAL DISPLAYS

THIRD QUARTERLY REPORT

MARCH 1965

AEROSPACE GROUP
HUGHES
DISPLAY SYSTEMS DEPT
HUGHES AIRCRAFT COMPANY
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RESEARCH AND DEVELOPMENT DIVISION
HUGHES AIRCRAFT COMPANY
CULVER CITY, CALIFORNIA

This report presents work which was performed under the Joint Army-Navy Aircraft Instrumentation Research (JANAIR) Project, a research and development program directed by the United States Navy, Office of Naval Research. Special guidance is provided to the program for the Army Material Command, the Office of Naval Research and the Bureau of Naval Weapons through an organization known as the JANAIR Committee. The Committee is currently composed of the following representatives:

U. S. Navy, Office of Naval Research
Capt. J. D. Kuser

U. S. Navy, Bureau of Naval Weapons
CDR W. A. Engdahl

U. S. Army, Material Command
Mr. W. C. Robinson

The goals of JANAIR are:

a. The Joint Army-Navy Aircraft Instrumentation Research (JANAIR) project, is a research project, the objective of which is to improve the state of the art of piloted aircraft instrumentation.

b. The JANAIR Project is to be responsive to specific problems assigned, and shall provide guidance for aircraft instrumentation research and development programs.

c. The JANAIR Project will conduct feasibility studies and develop concepts in support of service requirements.

d. These efforts shall result in reports and the knowledge to form the basis for development of improved instrumentation systems, components, and subsystems.

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1. INTRODUCTION

This document is a substantive report on the work accomplished during the third quarter. The objectives of the study are by no means complete but partial solutions are presented here to afford the reader some idea of the output of the study, the scope of the work, the direction in which the program is headed, and the format that will be used to report the results. Two topics will be discussed:

1. Pictorial display potential
2. Display requirements

2. PICTORIAL DISPLAY POTENTIAL

The greatest potential use for aircraft pictorial displays lies in their use for those crew tasks that demand the observation of the relations between a great many inherently related variables. These tasks are:

1. Observation of aircraft performance
2. Navigation
3. Target recognition
4. Tactics

Observation of Aircraft Performance

Simply, this is observation of the rotation and translation of the aircraft with respect to a significant set of objects or conventions. Thus, the pilot may be interested in how he is pitched up with respect to the horizontal (rotation-convention), how high he is above sea level (translation-convention), how he is rolled with respect to a carrier deck (rotation-real object), or whether his velocity vector intersects the mountain ahead (translation-real object). Almost always the pilot is interested in the simultaneous observation of all of these relationships. It is also characteristic that each of these relationships is to be held within certain limits. As soon as these relationships and their associated values have been stated a set of goals has been established for the pilot, usually by the pilot. At this point two things may be said:

1. The goals are not independent but are hierarchically related.
2. The information lends itself to pictorial display.

If the goals are selected by the pilot then the hierarchical nature of the goal structure and the pilot's task may be explained by the following argument.

There is a hierarchy of tasks that comprises the pilot's total job with respect to aircraft performance. The major tasks in that hierarchy are as follows:

1. Select the end goal. This may be a target, an airdrop, a rendezvous point or any position defined by the coordinates of space and time. The terminal goal may be selected by operations or by the pilot - in most cases for tactical reasons. It has been included here for the sake of completeness.

2. Program a spatial and temporal path to the end goal in both the horizontal plane and in the vertical plane. During flight a comparison of actual with programmed path will be made. Predicted path may also be shown.

3. Program the attitude, flight vector, and thrust of the aircraft to attain the desired path. During flight a comparison of actual with desired values will be made.

4. Program the force and position of the controls to attain the desired attitude, flight vector, and thrust.

Thus the end goal sets, in part, the criteria for the next subordinate task in the hierarchy, the programming of a path to the goal taking due regard for environmental factors. This path in turn represents a fine grain set of temporal-spatial subgoals which may be achieved by generating an attitude, velocity vector, and thrust program for the aircraft. Then again, to realize these thrust and attitude goals the pilot must program the actual control inputs. There is even another step, the programming of the neuro-muscular acts. Viewed in this fashion, it is clear that the tasks of the pilot at the various levels in the hierarchy are all interrelated and, in fact, each of the supraordinate goals partially sets the criteria for the adjacent subordinate task. In fact, in a conventional aircraft the pilot's real function is to convert the supraordinate goals into the subordinate program, and, all his training is directed towards this end. The skilled pilot has developed this ability to the extent that general mission requirements have been converted into specific programs for each individual instrument on his panel so that there is always a "command" on each and every gauge even though such command may be in the head of the pilot.

The relationship between this system of interrelated pilot functions and certain other considerations that affect his programming at various levels is indicated in Figure 1. In the Figure, the inner loop is the lowest loop that displays only a steering signal. Shown are two higher order loops but, of

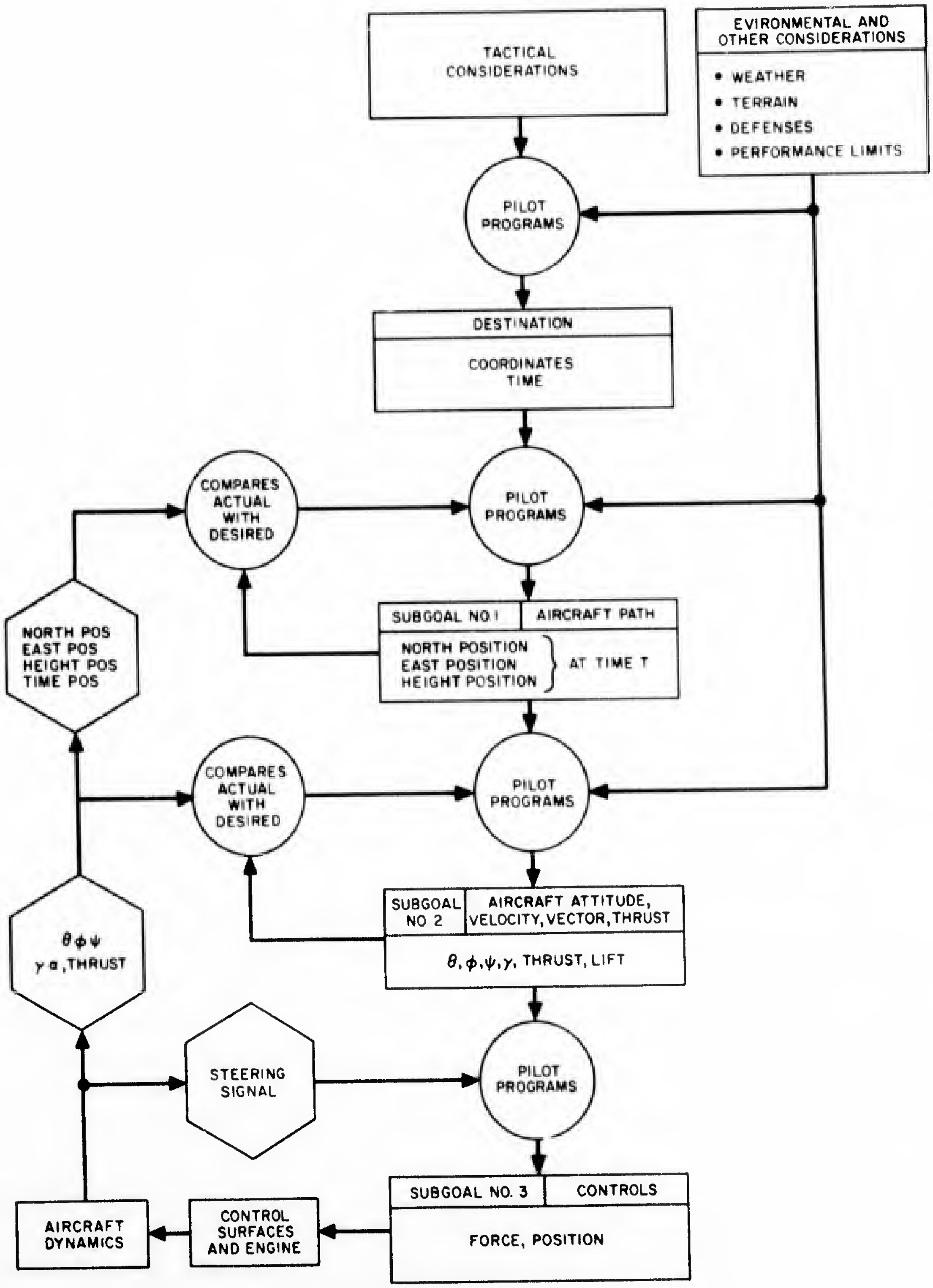

Figure 1. Pilot Task Hierarchy

course, one more higher loop should be shown if the pilot needs to select a destination.

If this way of formulating the relationship between the pilot's tasks is correct, then it is clear that a program at any given level cannot be generated unless the goals of the function at least one level above are known. It is equally clear that the pilot cannot make a decision about the appropriateness of the response of an automatic system at one level unless he has information about the program at the next supraordinate level. In short, he cannot program without hierarchical information, and thus the display should contain such information.

Pictorial displays used for the observation of aircraft performance can best be examined in those phases of the aircraft's mission where performance is critical. The critical phases chosen for study in this program are:

1. Landing
2. Low level flight
3. Point to point navigation
4. Weapon delivery - air
5. Weapon delivery - ground

Navigation

The utility of pictorial displays for navigation has been recognized for centuries for all maps are pictorial displays. Their use for navigation requires no justification and the understanding of how they are used requires no explication. The main issues are not whether to use a pictorial display for this function but what the design characteristics of such displays should be. Designs will vary because of the variety of aircraft and missions under consideration. In addition to map type displays for enroute navigation, the potential use of these displays is being particularly studied in certain selected mission phases. These are:

1. The use of maps or similar type pictorial information on the HSI of a helicopter during the last phases of a landing.

2. The use of map displays during low level missions in order to:
    a. aid in check point identification - visual sighting
    b. aid in check point identification - radar updating
    c. aid in planning and executing terrain avoidance

Target Recognition

As used in this context, target recognition implies the ability of the operator to classify or name an object or place on the grounds of the output of one or more of the sensors aboard the aircraft. In the first go around, only those sensors that map a contrast pattern are being considered. Such sensors include radar, IR, TV, and perhaps lasers.

While it is acknowledged that target recognition is affected by a host of variables, the model we use to describe the operator's performance ignores most of them that cannot be altered by equipment design. What we want to know eventually is how changes in system characteristics affect target recognition capability. Chief among the characteristics subject to design maneuver are:

1. Physical property sensed
2. System resolution
3. System field of view or coverage
4. System dynamic range
5. System sampling rate

One of these characteristics, system resolution, has been studied extensively. The upshot of these studies can be summarized as follows. Objects can be identified on the grounds of context as well as by shape. An interpreter may infer that a blob on the end of a runway is an aircraft. Such inferences are often erroneous for the context is often insufficient, and a system that yields finer grain data by increasing sensor resolution will increase the confidence that can be placed on any inference. In order that an object be correctly identified by its familiar shape when it is isolated and not embedded in a context, somewhere between 10 and 100 adjacent resolution cells must be "placed" on the object.[1] For example, for an object 30 feet on a side to be recognized on the grounds of its visual pattern alone requires a contrast sensor with a minimum resolution of 3 to 10 feet.

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[1] We presume recognition is direct in the sense that if the real shape of the object is known to the observer, he will recognize it in the display. Non-pictorial or transformed target signatures may be learned but the observer must be trained to associate the unique signature with the object.

Most of the data on this topic has dealt with photo-interpretation and has been collected in the laboratory under noise-free, good contrast conditions. As an example of the relationship that holds between sensor resolution and object recognition an examination of photographs made from the output of a high resolution IR detector AAR-9 (XA-2) was made. The sensor has a resolution of 0.3° and the IR "pictures" were taken vertically at 1,000 feet on a clear night. At this altitude the angular resolution of the sensor yields a ground resolution of about five feet. Large aircraft - KC-135, B-47, etc., - can be identified directly by shape. Smaller aircraft - F-89, F-100 - can be discriminated on the grounds of wing sweep and wing tanks. Still smaller aircraft (sic!) remain "unidentified." In plan view, fighter aircraft of the F-89, F-100 type can be contained in a square about 40 feet on a side. This implies that the sensor yield was approximately 64 resolution cells "on the target."

Although the generalization is hazardous, as a working rule we assume the requirement for a resolution of 1/10 target size (linear dimension) for target recognition independent of context. The exceptions to this rule are long linear targets: roads, railways, rivers, etc.

There are some secondary characteristics, secondary only in the sense that they are not subject directly to design control, that are so critical that their effect must and is being considered. These are:

1. The nature of the briefing or reference materials.
2. The complexity of the background in which the target is embedded.
3. The amount of time the operator has to examine the live sensor imagery.

Numerous studies have shown the overriding importance of reference material when the operator's task is target recognition. In general, the more closely the reference material resembles the live display with respect to orientation, content, scale factor, grey scale, and resolution, the easier it is to identify and recognize the target. The importance of such briefing materials suggests the use of two displays; one for live and one for stored data. This topic will be explored more fully under display requirements.

The complexity of the background and in particular the similarity of the background to the target, will increase the number of alternatives from which the observer must select and will obviously affect recognition performance.

A set of curves illustrating the effects of complexity on time to recognize a target is shown in Figure 2. These data are inferred from an earlier study done in this laboratory and are meant to show the general nature of the function rather than to be used literally as a design aid.

The time available to the operator to find and recognize the target is largely dictated by the nature of the mission and the speed of the vehicle. Where thorough briefing has occurred and access to good reference materials is at hand, the observer is able to do much better than might be expected because the reference material in effect directs his attention to critical parts of the live display with the consequence that the time available is spent only in examining these critical areas. There are, however, cases where briefing is inadequate, and it is of interest to know how much live data the operator can process.

In the ideal display of sensor data, the dimensions of each sensor resolution cell as displayed should be at least twice as fine as the eye's resolution which results in a negligible loss of effective resolution. In practice this ideal situation is usually compromised, and an effort is made to provide display resolution only equal to that of the eye. We have drawn a series of charts that illustrate the size of the display needed for the latter case if each displayed sensor cell is dimensioned to subtend 1, 5, or 10 minutes of arc at the observer's eye (see Figure 3). For example, a sensor with 5-foot resolution covering 10,000 feet on the ground requires a display 6.96 inches in diameter if viewed at 12 inches and each sensor cell subtends one minute of visual arc at the eye. For pattern sensors, the importance of matching the display resolution to the eye's resolution is tied to the operator's ability to recognize targets. As was previously stated, resolution is one of the key factors in target identification. Targets smaller than 10 times the resolution limit of the system will be difficult to identify except on the grounds of context. Let us now suppose the operator is looking for a very small target and has no a priori data about its probable position.

It is possible to estimate the minimum time it will take a hypothetical observer to scan a display of any given size under these conditions if some simplifying assumptions are made. The image on the eye must be stationary if

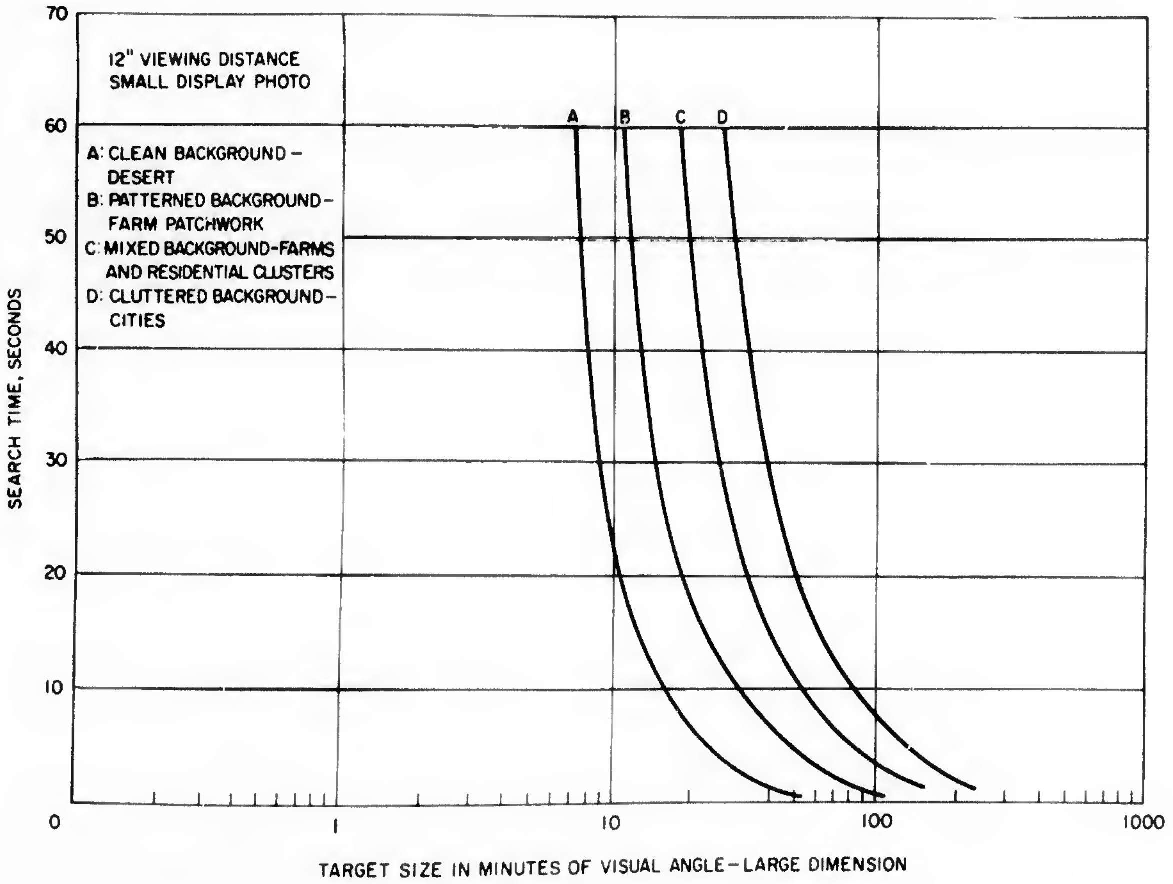

Figure 2. Effects of Background Complexity on Time to Recognize a Target.

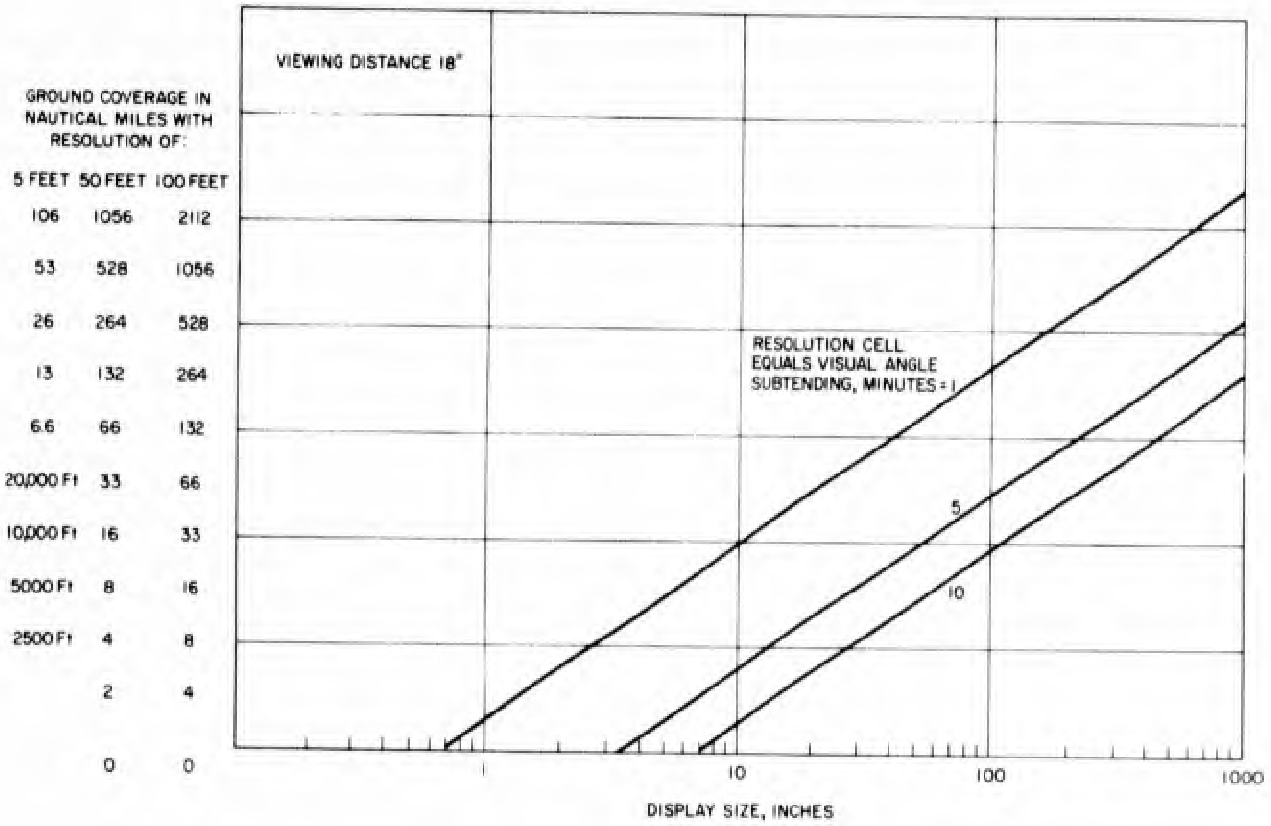

Figure 3. Display Size, Coverage, and Ground Resolution.

the observer is to see anything. Thus in scanning a display, the eye dwells momentarily on a patch, then slews quickly to the next patch and so on until the display is visually scanned. In order to determine the time it will take to search a display, we need to know the patch size, the dwell time, the slew time, and the scan pattern. Patch size can be estimated by examining the acuity characteristics of the eye. Acuity varies with the distribution of retinal cones and thus with the angular distance of the observed target from the optical axis (fovea) of the eye as shown in Figure 4. For purposes of this analysis a value of plus and minus three degrees will be used as the limit of a useful cone of vision. Patch size will be computed by calculating the size of the square subtended by 6 degrees and will therefore vary with observation distance. Ford[2] et al found that the average dwell time on large displays is 0.28 seconds. Enoch[3] in a similar study found that dwell time varied with display size, but the data from the two studies are in fair agreement, and a dwell time of 0.33 seconds will be used in this analysis. Slew time is negligible and the observer will look about three times per second. Scan patterns for real men vary with a host of factors. For our purposes, however, we assume that the man scans the display in a raster fashion, completely, with butted patches, and no overlap. With these assumptions it is now possible to compute the time it takes to scan a display of any size from any viewing distance. The results of these computations are shown in Figure 5.

Tactics

No work has been done in tactics except the brief material discussed in the section on Display Requirements.

The views discussed in this section represent our notion of how the crew operates as it carries out the various functions described. These notions have led to the selection of pictorial displays as having potential in the applications that will be described in the following section.

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[2] Ford, A., White, C. T. Lichterstein, M. Analysis of Eye Movements During Free Search, <u>JRL. Opt. Soc. Amer</u>., March 1959, V-49.

[3] Enoch, J. M., Effect of the Size of a Complex Display Upon Visual Search, <u>JRL, Opt. Soc. Amer</u>., March, 1959, V-49.

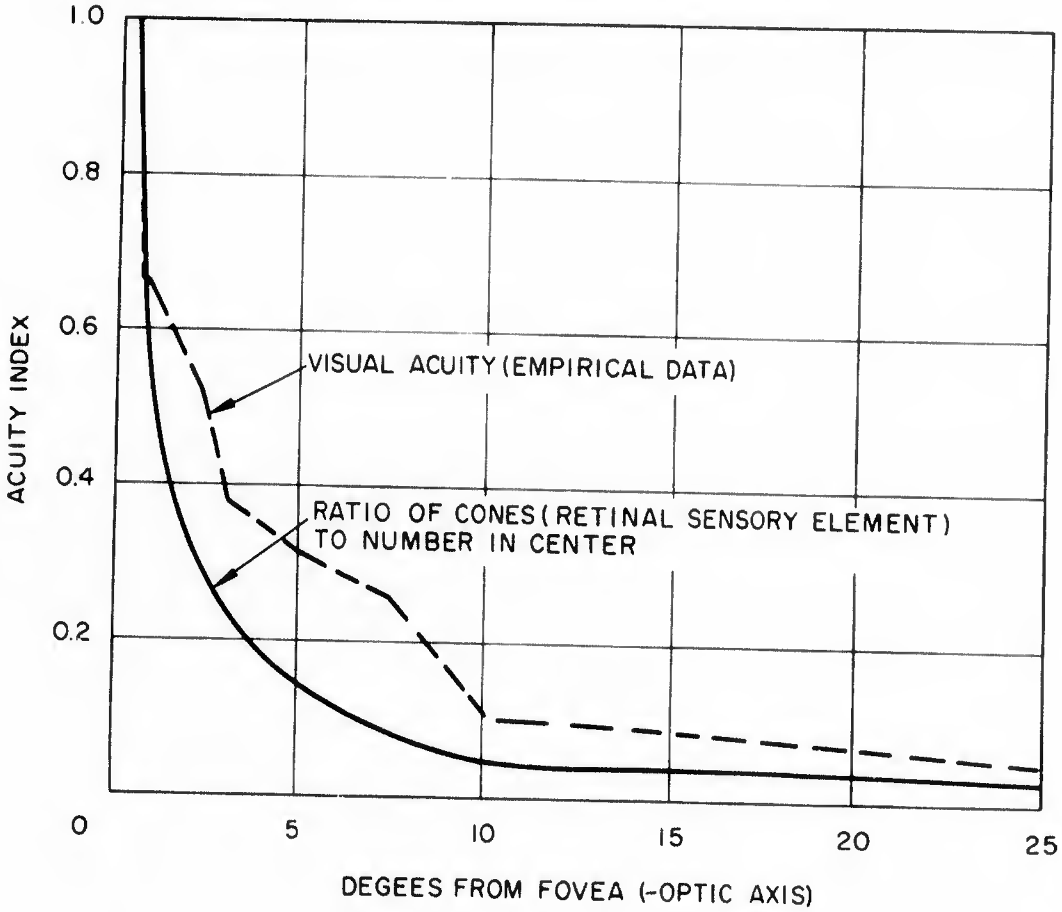


Figure 4. Visual Acuity as a Function of Angle Off Optical Axis.

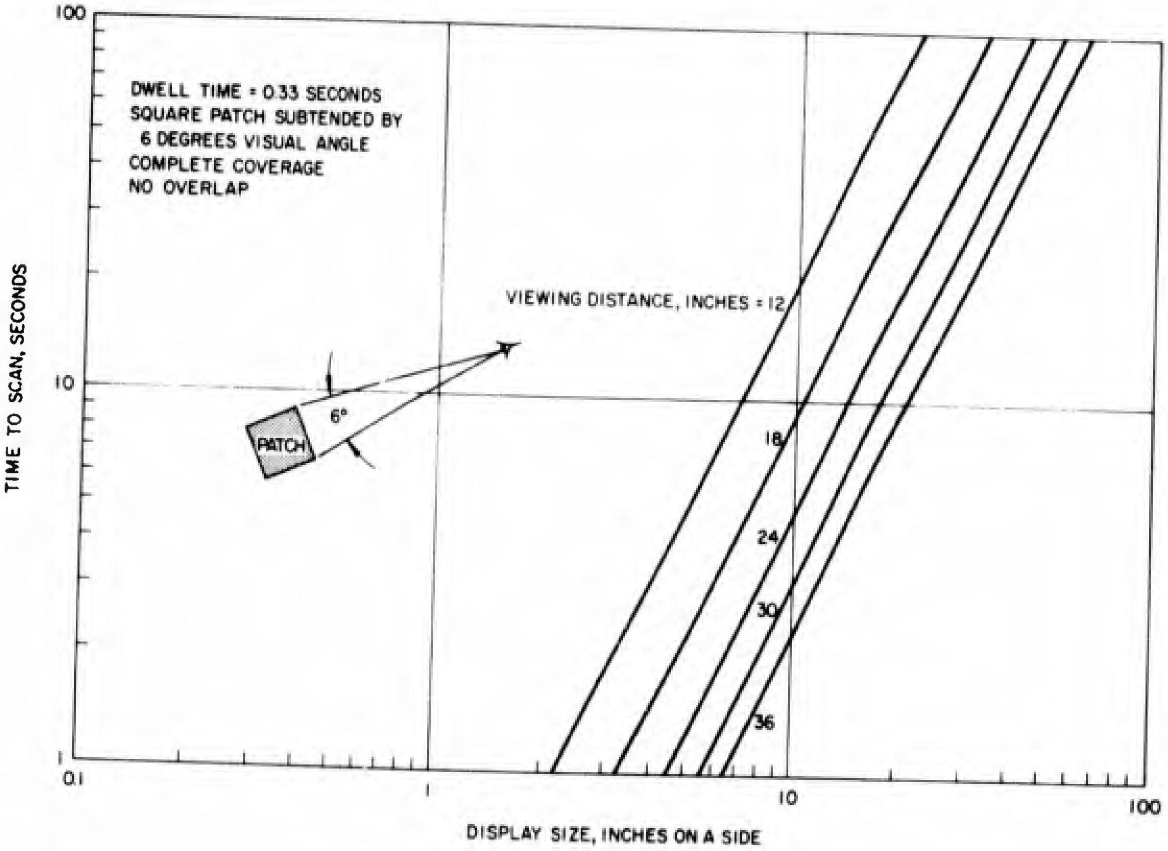


Figure 5. Time to Scan a Display.

3. DISPLAY REQUIREMENTS

While it is relatively easy to say a display has potential for such and such or not for so and so, we have taken the view that such statements are both harmless and useless. What is needed is a description of the characteristics such pictorial displays would need if they were to realize their presumed potential. Rather than throw out a possible application for a raster scan pictorial display on the grounds of what we know about the present or predicted state of the art, we have sought to describe what it would take to make a display work for a particular application. In short, we have tried to avoid the pose of omniscience.

Inevitably, we have already rejected some applications either because they are trivial or are thought to be completely inappropriate. The applications we are studying were developed in part from the rationale described previously, in part by agreement with the JANAIR committee, and in part by the exercise of engineering judgment. These applications consist of the items on the left hand side of the chart illustrated in Figure 6. There are 28 items listed in this column. For most of these a pictorial display has been conceived or is already in existence. Each of these may potentially be displayed by a raster scan device. The items along the top of the chart are the terms in which the display interface is described. There are 11 items in this row.

Because we must examine a variety of aircraft, it is not possible to characterize each cell entry in the chart by a single value or set of values. We are attempting two outputs. First; establish the rules by which the desired characteristics may be obtained. Second; if an absolute value or range of values can be stated it will be; if not, an example illustrating the use of the rule will be developed. The job, while formidable, is not as impossible as it would at first appear. There are not really 28 x 11 cells to be considered. There are large clusters - for example, the brightness column - where one discussion will suffice for all displays. Cells where no new material needs to be developed are shaded **grey**.

On the chart the potential applications are numbered from 1-28 and the characteristics labeled from A-K. As it is not possible to fill in the chart in this document, each of the chart cells will be treated as a separate item

APPLICATIONS	CREW TASK	DISPLAY TYPE		MISSION PHASE	INDEX NO.	SYMBOLOGY AND CONTENT A	INFORMATION REQUIRED OR DRIVING SIGNALS B	DATA RATE C	COVERAGE OR FIELD OF VIEW D	MINIMUM DISPLAY SIZE E	MAGNIFICATION OR GAIN F	MIN. NUMBER OF LINES (RESOLUTION) G	FIELD RATE H	HIGHLIGHT – BRIGHTNESS AND CONTRAST I	GREY SCALE J	NOISE OR OSCILLATION LIMITS K
COMPUTED AND CLEAR PLOT DISPLAYS	FLIGHT PERFORMANCE	PANEL MOUNTED VSI	SKELETAL	LANDING	1	90	90	80	80	80	80	80	100	90	▨	0
				LOW LEVEL-HIGH SPEED	2	90	90	80	80	80	80	80	▨	▨	▨	0
				NAVIG.-PT. TO PT	3	90	70	50	80	80	80	80	▨	▨	▨	0
				WPN DELY-AIR	4	0	0	0	0	0	0	0	▨	▨	▨	0
			CONTACT ANALOG	LANDING	5	100	100	90	90	80	80	90	▨	80	80	0
				LOW LEVEL	6	100	100	50	50	50	50	▨	▨	▨	▨	0
				NAVIG. PT. TO PT.	7	100	100	50	50	50	50	▨	▨	▨	▨	0
				WPN DELY-AIR	8	100	100	0	0	0	0	▨	▨	▨	▨	0
				WPN DELY-GND	9	100	100	0	0	0	0	▨	▨	▨	▨	0
		HUD	SKELETAL	LANDING	10	90	90	▨	▨	N.A.	80	0	▨	90	▨	0
				LOW LEVEL-HIGH SPEED	11	90	90	▨	▨	N.A.	80	0	▨	▨	▨	0
				WPN DELY-AIR	12	0	0	0	▨	N.A.	0	0	▨	▨	▨	0
				WPN DELY-GND	13	0	0	0	▨	N.A.	0	0	▨	▨	▨	0
			CONTACT ANALOG	LANDING	14	▨	▨	▨	90	N.A.	50	90	▨	80	80	0
				LOW LEVEL	15	▨	▨	▨	50	N.A.	50	▨	▨	▨	▨	0
				NAVIG. PT. TO PT.	16	▨	▨	▨	50	N.A.	50	▨	▨	▨	▨	0
				WPN DELY-AIR	17	▨	▨	▨	0	N.A.	0	▨	▨	▨	▨	0
				WPN DELY-GND	18	▨	▨	▨	0	N.A.	0	▨	▨	▨	▨	0
	NAVIGATION	HSI	MAPS	LANDING	19	10	10	10	10	10	N.A.	10	▨	30	0	0
				LOW LEVEL	20	10	10	10	10	10	N.A.	10	▨	▨	▨	0
				NAVIG. PT. TO PT.	21	50	50	50	50	50	N.A.	10	▨	▨	▨	0
	TACTICS	HSI	SKELETAL	WPN DELY-AIR	22	100	100	100	80	80	N.A.	10	▨	▨	▨	0
				ASW	23	0	0	0	0	0	0	0	▨	▨	▨	0
			PHOTOS (ANALOG)	WPN DELY-GND	24	10	N.A.	0	0	0	N.A.	0	▨	30	0	0
DISPLAYS OF RAW DATA	FLIGHT PERFORMANCE	VSI	TV (ANALOG)	LANDING	25	80	80	80	80	80	90	80	▨	30	0	0
	TARGET RECOGNITION	VSI	TV	LOW LEVEL	26	10	10	10	60	30	60	60	50	10	0	0
				WPN DELY-GND	27	30	30	30					▨	30	0	0
		HSI	TV IR RADAR LASER	WPN DELY-GND	28	0	0	0	0	0	0	0	50	30	0	0

Figure 6. Chart Showing Applications and Requirements Studied. Figures in Cells are Percentage of Task Completed.

and the 1-A, 3-B system will be used to reference the discussions to the chart. The remainder of this section will consist of discussions of the cell entries where reasonable progress has been made. The estimated percent completion of each cell entry is noted as a small figure in each cell of the master chart.

1-A SYMBOLOGY - FLIGHT PERFORMANCE - PANEL MOUNTED SKELETAL DISPLAY - LANDING

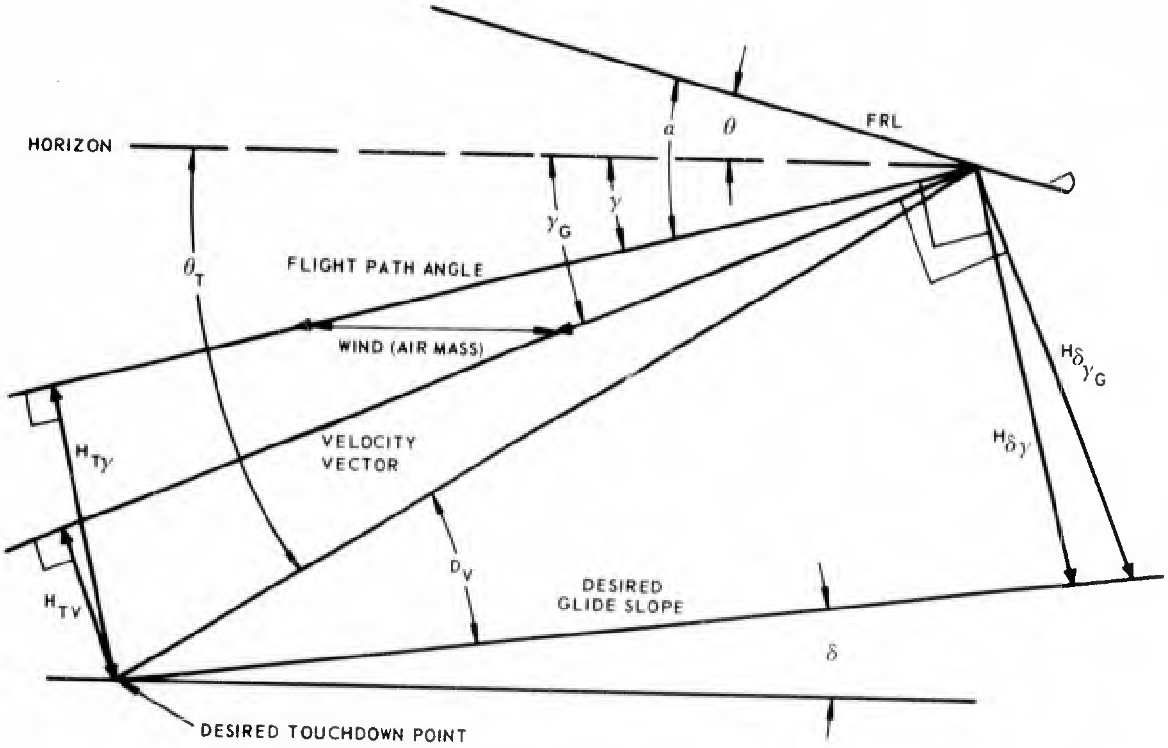
We have drawn up a series of flight performance displays for landing that embody the principles expounded in the previous discussion of flight performance. These displays show the relationships between a set of inherently related variables by use of a pictorial code. In drawing these display interfaces we have deliberately used what is probably non-optimum shape coding for the various symbols used. In a final design, the physiognomic properties of such symbols are important in order to take the "nonsense" out of the usual assemblage of squares, circles, diamonds and the like. For this initial effort we have chosen to ignore symbol shape in order to emphasize the notion that in pictorial displays for flight performance, the way the symbol moves and its relationship to other symbols and their movements is more important than what the individual symbols look like statically. In too many cases the static appearances of competing displays are very similar, and it is only when they move that the striking difference between an organized display and a bag of worms becomes evident. Symbol kinematics are more important than symbol physiognomy.

It is, of course, not possible to illustrate kinematics in this report, but we have done the next best thing and that is to describe the signals that drive each symbol so that the interested reader - and he will indeed have to be interested - may go through the exercise of visualizing what happens in response to control actions or aircraft maneuvers.

Figures 7 and 8 illustrate the nomenclature used to describe the positioning and action of the display symbols. Figure 9 is a sketch of three different landing situations used to demonstrate how the display will appear in different situations, and Table I presents the numerical values used to draw the displays. Figure 10 is an annotated sketch of a representative pictorial landing display as it would appear in situation I. Figure 11 shows sketches of the display as it would appear in the situations described in Figure 9 and Table I.

To these displays could be added altitude, angle of attack, and stick commands.

These particular displays evidence certain characteristics desirable in pictorial displays. A pictorial topology is maintained between the position of various symbols. If, in the real world, A is to the left of B is to left of C, so it is also on the display.



θ = AIRCRAFT PITCH

α = ANGLE OF ATTACK

γ = FLIGHT PATH ANGLE

γ_G = VELOCITY VECTOR, i.e., FLIGHT PATH ANGLE WITH RESPECT TO GROUND

θ_T = DEPRESSION ANGLE OF LINE OF SIGHT TO DESIRED TOUCHDOWN POINT

D_V = ANGULAR DISPLACEMENT OFF DESIRED GLIDE SLOPE (VERTICAL DEVIATION)

δ = DEPRESSION ANGLE OF DESIRED GLIDE SLOPE

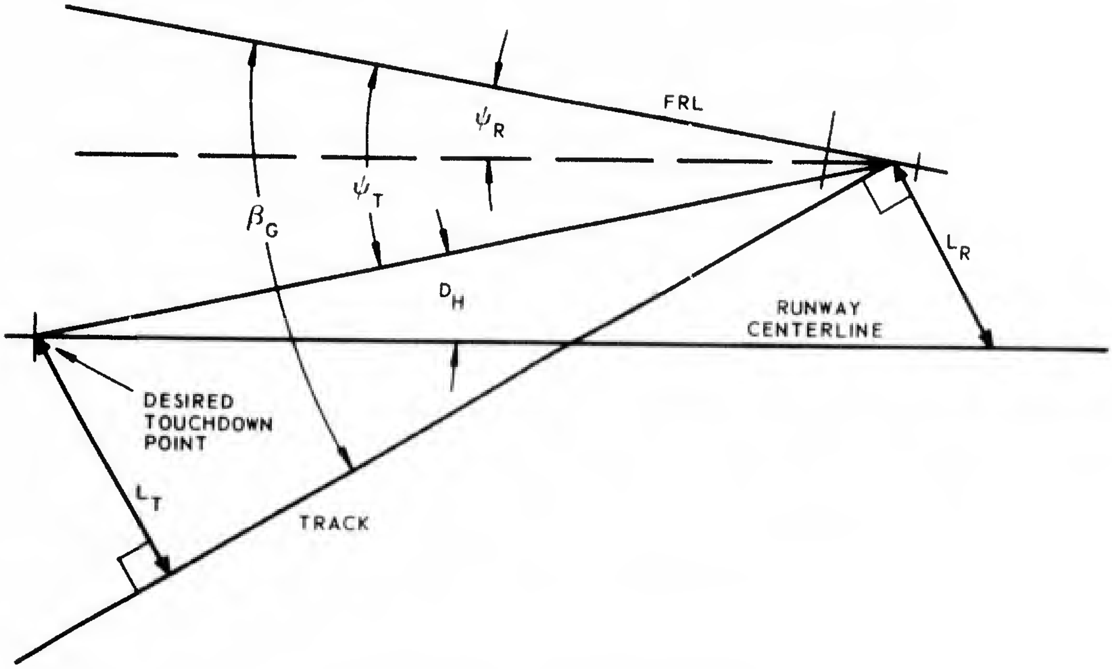
$H_{\delta\gamma_G}$ = DISTANCE FROM VELOCITY VECTOR TO GLIDE SLOPE – $\perp$ TO V.V. (HEIGHT ABOVE GLIDE SLOPE)

$H_{\delta\gamma}$ = DISTANCE FROM FLIGHT PATH ANGLE TO GLIDESLOPE – $\perp$ TO γ

$H_{T\gamma}$ = HEIGHT OF FLIGHT PATH ABOVE TOUCHDOWN POINT

$H_{T\gamma_G}$ = HEIGHT OF VELOCITY VECTOR ABOVE TOUCHDOWN POINT

Figure 7. Nomenclature, Side Elevation.



ψ_R = HEADING WITH RESPECT TO RUNWAY HEADING

ψ_T = BEARING OF TOUCHDOWN POINT

β_G = DRIFT ANGLE

D_H = ANGULAR DISPLACEMENT OFF RUNWAY CENTERLINE (HORIZONTAL DEVIATION)

L_R = DISTANCE TO RUNWAY CENTERLINE (⊥ TO TRACK)

L_T = DISTANCE FROM TRACK TO TOUCHDOWN POINT (⊥ TO TRACK)

Figure 8. Nomenclature, Plan View.

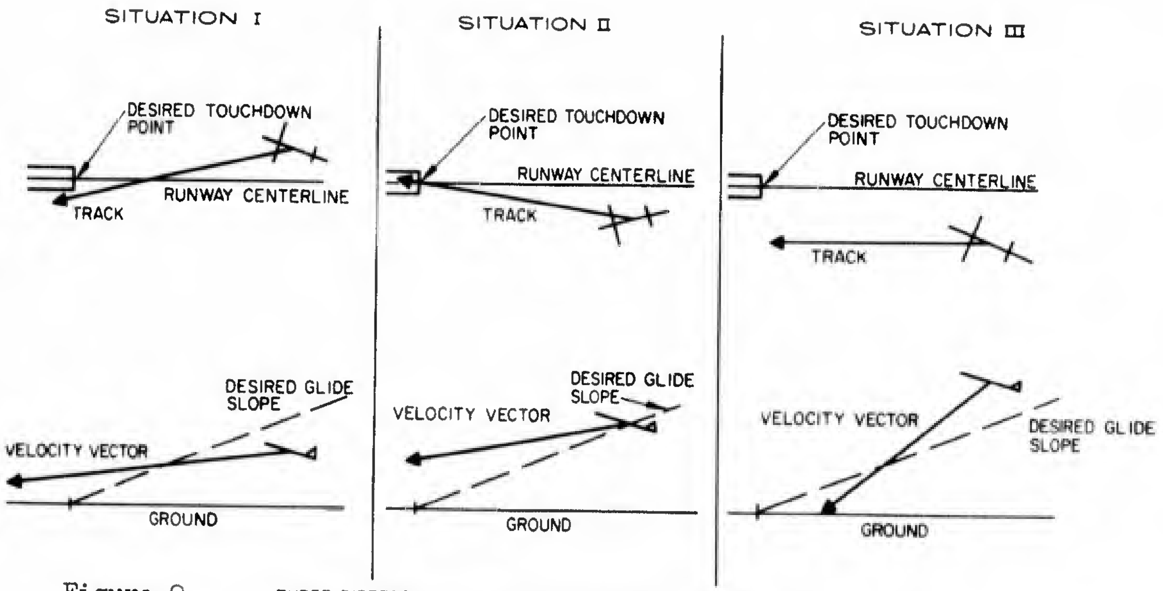
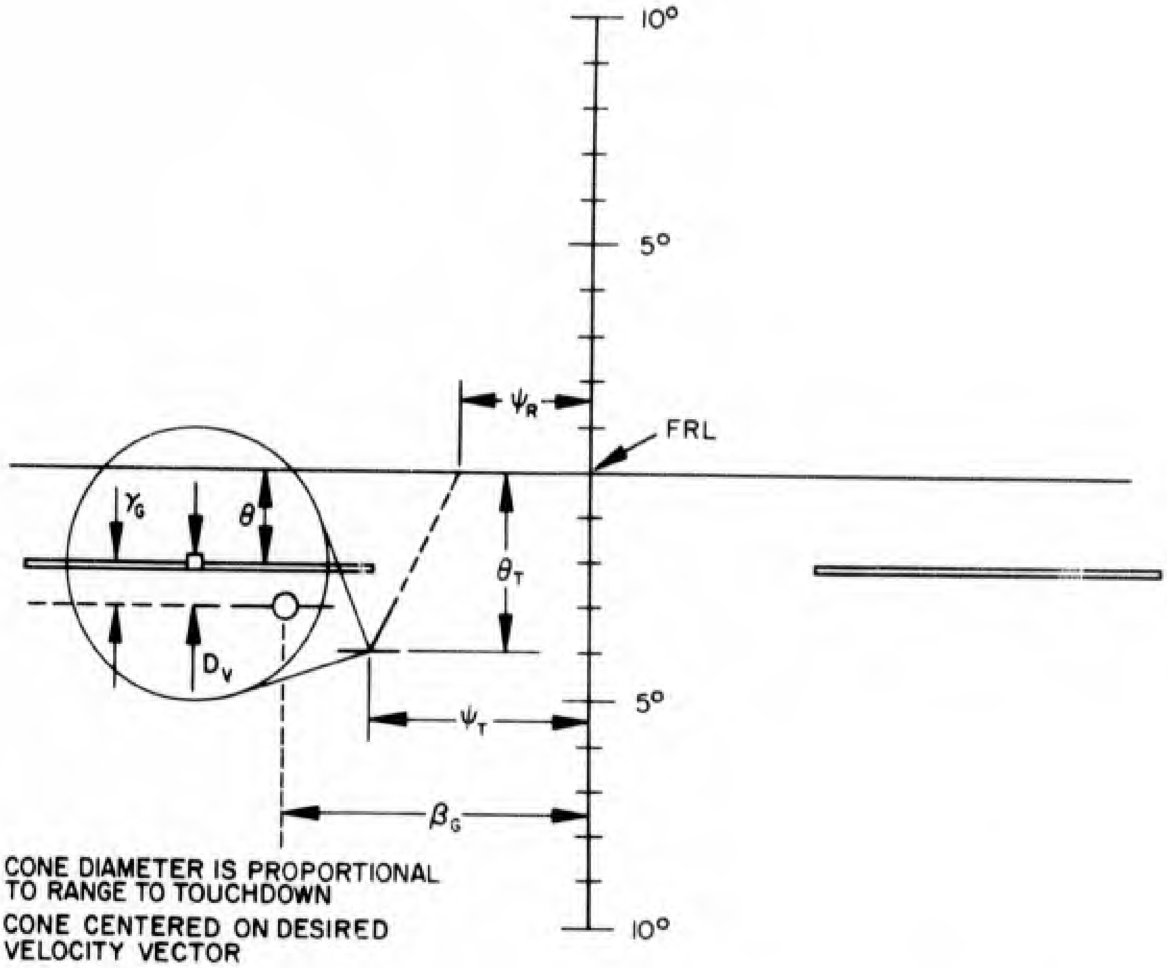


Figure 9. THREE DIFFERENT SITUATIONS ILLUSTRATED IN THE DISPLAYS
NOT TO SCALE, ALL ANGLES EXAGGERATED
SEE TABLE I FOR ACTUAL VALUES

Table I - Actual Values Used in Situations Above.

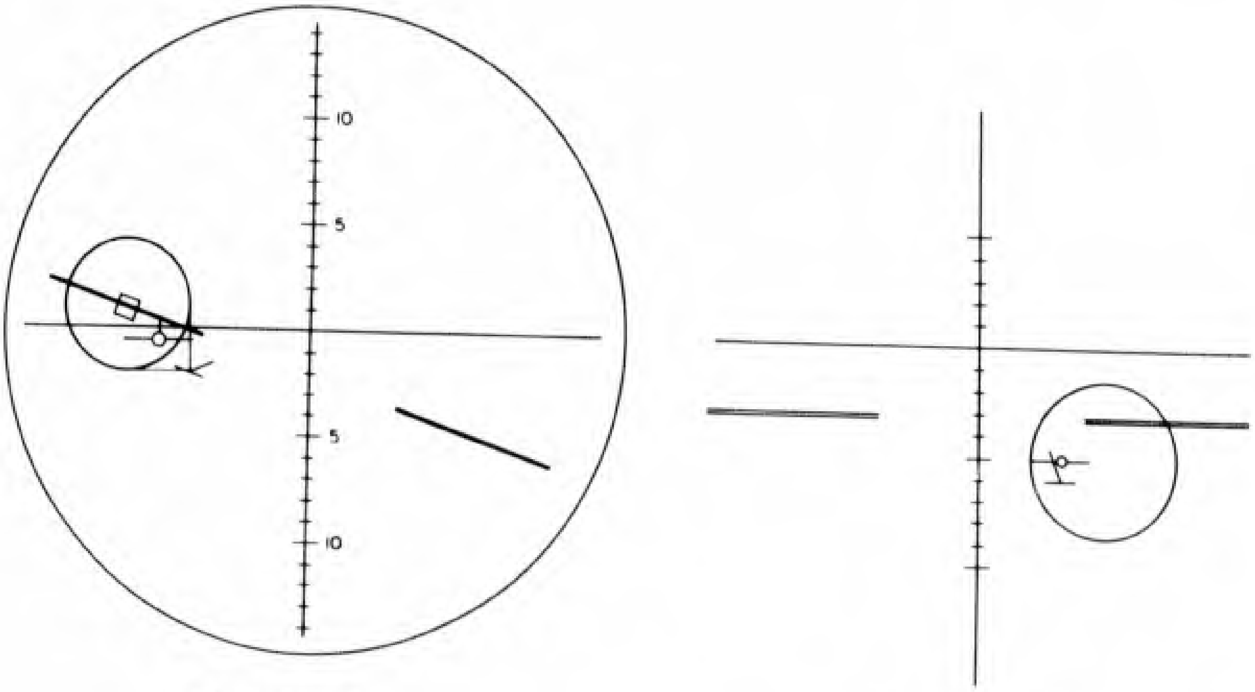
	SITUATION		
	I	II	III
θ, PITCH	2°	3°	1°
α, ANGLE OF ATTACK	3°	5°	6°
γ, FLIGHT PATH ANGLE	1°	2°	5°
γ_G, VELOCITY VECTOR	1°	2°	5°
θ_T, DEPRESSION ANGLE OF TOUCHDOWN POINT	2°	3°	4°
D_V, VERTICAL ANGLE OFF GLIDE SLOPE	1°	0	1°
δ, DESIRED GLIDE SLOPE	3°	3°	3°
ψ_R, HEADING WITH RESPECT TO RUNWAY HEADING	3°	2°	5°
ψ_T, BEARING OF TOUCHDOWN POINT	5°	4°	1.5°
β_G, DRIFT ANGLE	7°	4°	5°
D_H, HORIZONTAL ANGLE OFF RUNWAY CENTERLINE	2°	2°	3.5°
L_R, DISTANCE TO RUNWAY CENTERLINE (LATERAL OFFSET)	175'	175'	310'
L_T, DISTANCE FROM EXTRAPOLATED TRACK TO TOUCHDOWN POINT	130'	0	310'
$H_{\delta\gamma_G}$, HEIGHT OF VELOCITY VECTOR ABOVE OR BELOW GLIDE SLOPE	90'	0	90'
$H_{\delta\gamma}$, HEIGHT OF FLIGHT PATH ANGLE ABOVE OR BELOW GLIDE SLOPE			
$H_{T\gamma_G}$, HEIGHT OF VELOCITY VECTOR ABOVE OR BELOW TOUCHDOWN POINT	90'	90'	80'
$H_{T\gamma}$, HEIGHT OF FLIGHT PATH ANGLE ABOVE OR BELOW TOUCHDOWN POINT			
R, RANGE TO TOUCHDOWN POINT		5000'	



CONE DIAMETER IS PROPORTIONAL TO RANGE TO TOUCHDOWN

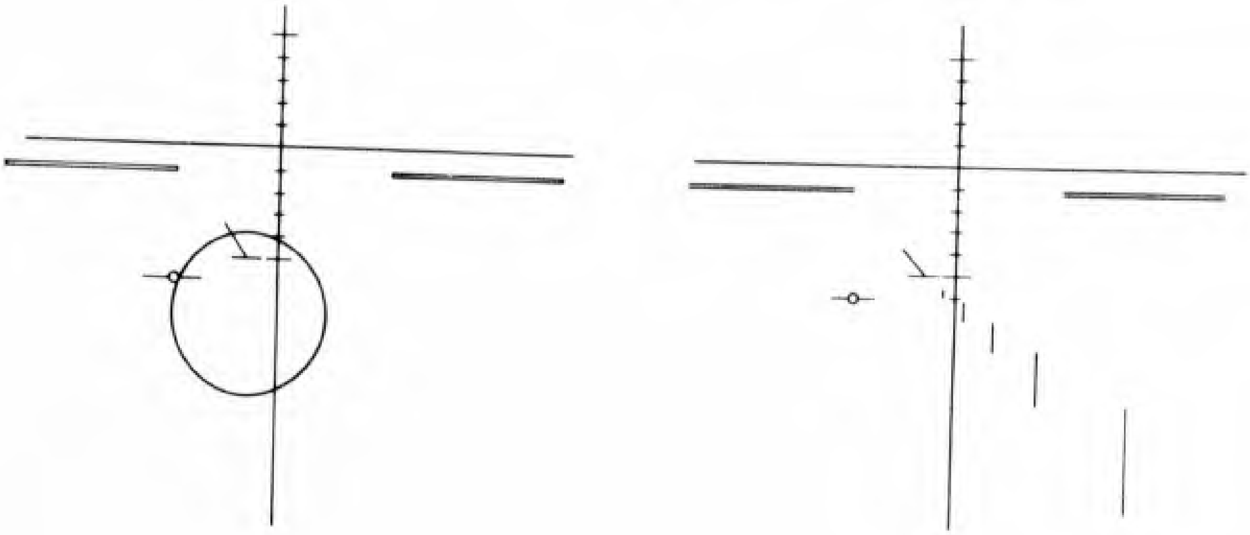
CONE CENTERED ON DESIRED VELOCITY VECTOR

Figure 10. Pictorial Skeletal Landing Display Situation I.



Situation I

Situation II



SLIGHTLY DIFFERENT CODING. POLE
TOPS SHOW DESIRED VELOCITY VECTOR

Situation III

Situation III

Figure 11. Pictorial Skeletal Landing Display in Various Situations.

The shape of the symbols themselves would undoubtedly benefit from improvement; for it is a requirement that they be easily discriminable from each other and easily associated with the referent object.

In the particular set of displays the information presented is situational with the errors sorted out so that the pilot is not reduced to tracking a compensatory dot.

While not stereoscopic, the displays are three dimensional so that the trajectory of the aircraft is represented. Therefore as the aircraft moves in translation the display inherently allows the pilot to anticipate events.

1-B INFORMATION REQUIRED - FLIGHT PERFORMANCE - PANEL MOUNTED SKELETAL DISPLAY - LANDING

There are many ways of sensing data that either directly or by computation may yield signals appropriate for driving the display symbols. It should be noted that even if the display is not exactly as described in section 1-A, the kind of information embodied in that display will be required if the display is to be used for landing and the signals required will be essentially as described here. This, in fact, is the type of information needed for a skeletal landing display.

$$\theta \quad \phi \quad \psi_T \quad \theta_T \quad \gamma_G \quad \beta_G \quad D_V$$

$$D_H \quad R_T \quad \psi_R \quad H \quad \alpha$$

See Table I for Symbol Definition

1-C DATA RATE - FLIGHT PERFORMANCE - PANEL MOUNTED SKELETAL DISPLAY - LANDING

Data rate as used in this context will mean the updating rate of a variable. Data rate will affect the utility of the display in two ways: control performance on the one hand and pilot acceptance of appearance on the other.

1. Variables important for performance.

1.1 The primary determinant of data rate is the natural frequency or display speed of the displayed variable. In general the update rate should be at least double the natural frequency of the displayed variable for double the response rate of the pilot - whichever is lower. If the response rate of the pilot is taken to be four cps, then the update rate for rapidly changing variables should be about eight cps. For slowly changing variables the speed with which events are changing would be the controlling factor.

1.2 The larger the anticipation interval - the further ahead in time that the pilot can see - the slower may be the update rate. The exact nature of the relationship is unknown. It seems intuitively obvious that a low data rate with a large anticipation interval will yield performance that is highly smoothed.

1.3 Variables displayed linearly as opposed to nonlinearly permit slower data rates. This is because, paradoxically, they provide less information, prediction is easier, and the required data rate may be slower.

For the skeletal landing display the estimated performance update minimums are:

1. All display elements respond to aircraft rotation at 6-8 cps.
2. The update requirements for display elements that provide translation information are uncertain at this time, but they will probably vary from 1/2 to 8 cps depending on the considerations discussed above.

2. Variables important for appearance

The primary consideration is to prevent jumpiness in the display. This is a visual problem and has nothing to do with the control bandwidth of the pilot. Although no hard evidence exists, observations and experience dictate the following:

1. All display elements respond to aircraft rotation at 60 cps.
2. The update requirements for display elements that provide translation information are uncertain at this time but from observation are presumed to vary from 1-30 cps. The region from 5-15 cps may prove particularly annoying however.

1-D COVERAGE OR FIELD OF VIEW - FLIGHT PERFORMANCE - PANEL MOUNTED SKELETAL DISPLAY - LANDING

The problem is twofold: to determine the necessary azimuth coverage and elevation coverage. The derivation of the azimuth field of view will depend on consideration of the following:

1. The accuracy with which the aircraft is delivered to the landing gate.
2. The probable centerline intercept angle and subsequent bracketing angles.
3. The maximum drift angle expected.
4. The presence or absence of an HSI or reasonable chart substitute that could be used in the early phases of the landing.

For the elevation field of view the primary considerations are:

1. The maximum angle of attack of the aircraft.
2. The maximum approach angle used.

Both of these quantities, if displayed pictorially, are below the FRL. It should be noted that the FRL need not be centered vertically on the display if only the landing case is being considered. However, if the same display is to be used in other modes, care must be taken not to change basic meanings of reference marks such as the FRL.

From these considerations, the estimated field of view for a fixed wing aircraft whose stall angle is 15° is:

azimuth; between plus and minus 20 and plus and minus 30 degrees.
elevation; plus 5 to minus 20 degrees.

In practice, the chosen coverage will interact with display size and display gain so that one can be traded off against the other if the need arises. These trade-offs can only be made in a display where there is no requirement for registration of display elements with parts of the natural visual environment.

1-E MINIMUM DISPLAY SIZE - FLIGHT PERFORMANCE - PANEL MOUNTED SKELETAL DISPLAY - LANDING

Other than available panel space, display size will be determined by:

1. Coverage required
2. Magnification or gain
3. Minimum number of lines (resolution)
4. Viewing distance (if size is expressed in inches rather than degrees)
5. An assumed acuity limit for the pilot of one minute of visual arc.

Suppose, for example, the following conditions:

1. Coverage: 30 degrees
2. Magnification: 1.00
3. Viewing distance: 24 inches
4. Minimum number of lines: 400
5. Visual acuity: 1 minute

If we consider only items 1, 2, and 3 the display size will be about 13". If we consider only 3, 4, and 5 the size will be about 2-3/4".

It can be seen that these variables interact and the choice for any particular aircraft system must be worked out for the individual case.

1-F MAGNIFICATION OR GAIN - FLIGHT PERFORMANCE - PANEL MOUNTED SKELETAL DISPLAY - LANDING

The considerations that will determine the magnification characteristics of this type display are:

1. The readout and control accuracy required for each displayed variable.
2. The limits on display size.
3. The field of view or coverage requirements.
4. The distortion permissible.

In the display illustrated the gain is uniform throughout. It is felt that a different gain for one or two variables to buy, for example, increased sensitivity cannot be recommended until some empirical work has been done on the problem.

Also in the display illustrated, the overall gain or magnification is intended to be the same as "contact flight" so the display size and scale are such that a representation of one degree on the display corresponds to one degree at the pilot's eye. When this condition is met, the magnification is 1.00. It is interesting to note that, for the most part, this results in a display of information several times more sensitive than that afforded by a complement of standard instruments.

1-G MINIMUM NUMBER OF LINES (RESOLUTION) - FLIGHT PERFORMANCE - PANEL MOUNTED SKELETAL DISPLAY - LANDING

To determine display resolution for this type display the primary considerations are:

1. The accuracy with which each displayed variable must be read out.
2. The visual range required (if an object on the display changes its size as a function of range - this does not occur in the display shown in Figure 11.
3. Symbol sizes.
4. Display size.
5. Desirable picture "crispness."
6. The resolution of the eye under the conditions of viewing.

For displays to be viewed in daylight, the line brightness will necessarily be quite high, and the observer's acuity at about its limit which we will take to be 1 minute. This means that the display resolution should center around this value so that the number of lines per degree at the eye should be on the order of 60. The raster structure should not be visible at 120 lines per degree and should be visible but unobjectionable at 30. To increase the line structure beyond 120 lines per degree of visual angle would buy nothing unless one were dealing with a very bright, high contrast display where vernier movements of display elements had to be detected. It is assumed that the horizontal resolution is at least equal to the vertical resolution. For this particular display there is no reason to have the resolution differ in the two axes. When used at very dim brightness levels the resolution requirements can be relaxed but always should be approximately matched to the eye's resolving capability.

1-H <u>FIELD RATE</u> - FLIGHT PERFORMANCE - PANEL MOUNTED SKELETAL DISPLAY - <u>LANDING</u>

The required field rate is derived solely from the characteristics of the eye. A flicker free image is required. Figure 12 shows two of the most important conditions that determine critical flicker fusion - CFF.

For phosphors with any appreciable memory the curve on the left is of overriding importance for the difference in CFF between different duty cycles is only marked if the change in the duty cycle is large and the display elements are very bright. From the left hand curve we can see that for displays of sufficient brightness for daylight viewing, a field rate of at least 60 cps is required. If we were dealing only with a very dim display at low light levels then it is interesting to note that a field rate of around 15 cps would yield a flicker free image.

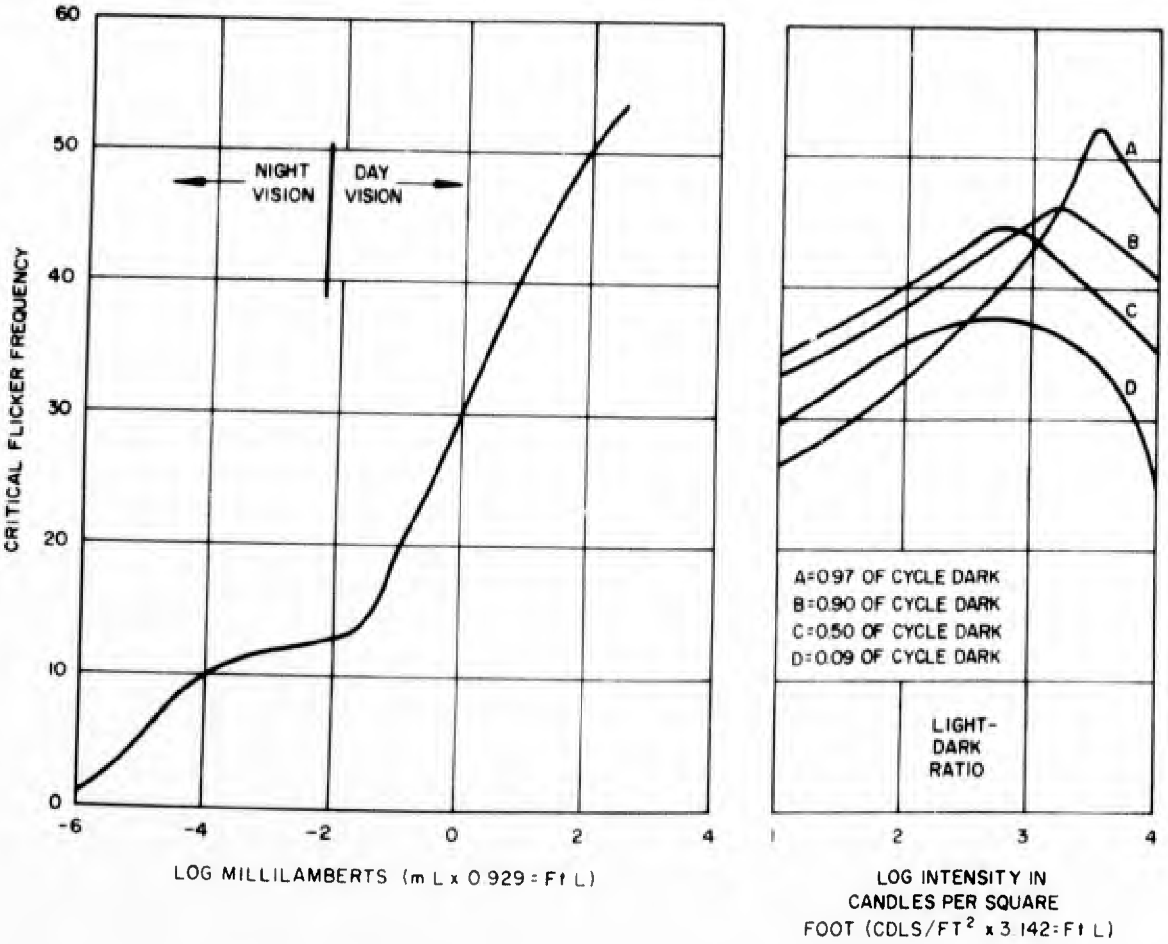


Figure 12. Some Important Determinants of CFF.

1-I HIGHLIGHT BRIGHTNESS AND CONTRAST - FLIGHT PERFORMANCE - PANEL MOUNTED SKELETAL DISPLAY - LANDING

The main problem is to get the display bright enough to see in bright daylight so very little time will be spent on viewing requirements at low light levels except in the instances noted.

The effects on visibility of color, angle off optical axis, adaptation time, target shape, viewing time, drugs, and operator idiosyncrasies will not be considered. The critical variables that will be examined are:

1. Brightness contrast
2. Highlight brightness
3. Image element size
4. Display resolution
5. Motion
6. Critical flicker fusion

The basic data to provide the starting point for all generalizations was generated in Blackwell's study of the contrast thresholds of the human eye. The curves in Figure 13 are plotted from data gathered in that study and they show the 50% threshold as a function of background brightness, contrast, and target size. The 50% threshold is the level at which the target was detected 50% of the time. Figure 14 (adapted from Blackwell) is a conversion curve that may be used to estimate thresholds other than the 50%.

The background brightness in a skeletal display is the brightness of the tube face where there is no image. The level of this background brightness may be markedly different from the surround brightness - for example, the sky. As long as the ratio of the surround brightness to the background brightness stays below 10, there is no marked effect on the contrast threshold. If the surround is brighter than the background by more than a ratio of 10, then the surround will start to affect the contrast required in varying degree. Figure 15 shows these effects. The dotted line represents data taken from a small experiment conducted at General Electric Company, Ithaca. The smooth curve is a generalization based on the data and shows a correction factor as a function of the ratio between surround and background brightness. Although a generalization, it is felt to be valid where the background brightness exceeds 10 FtL.

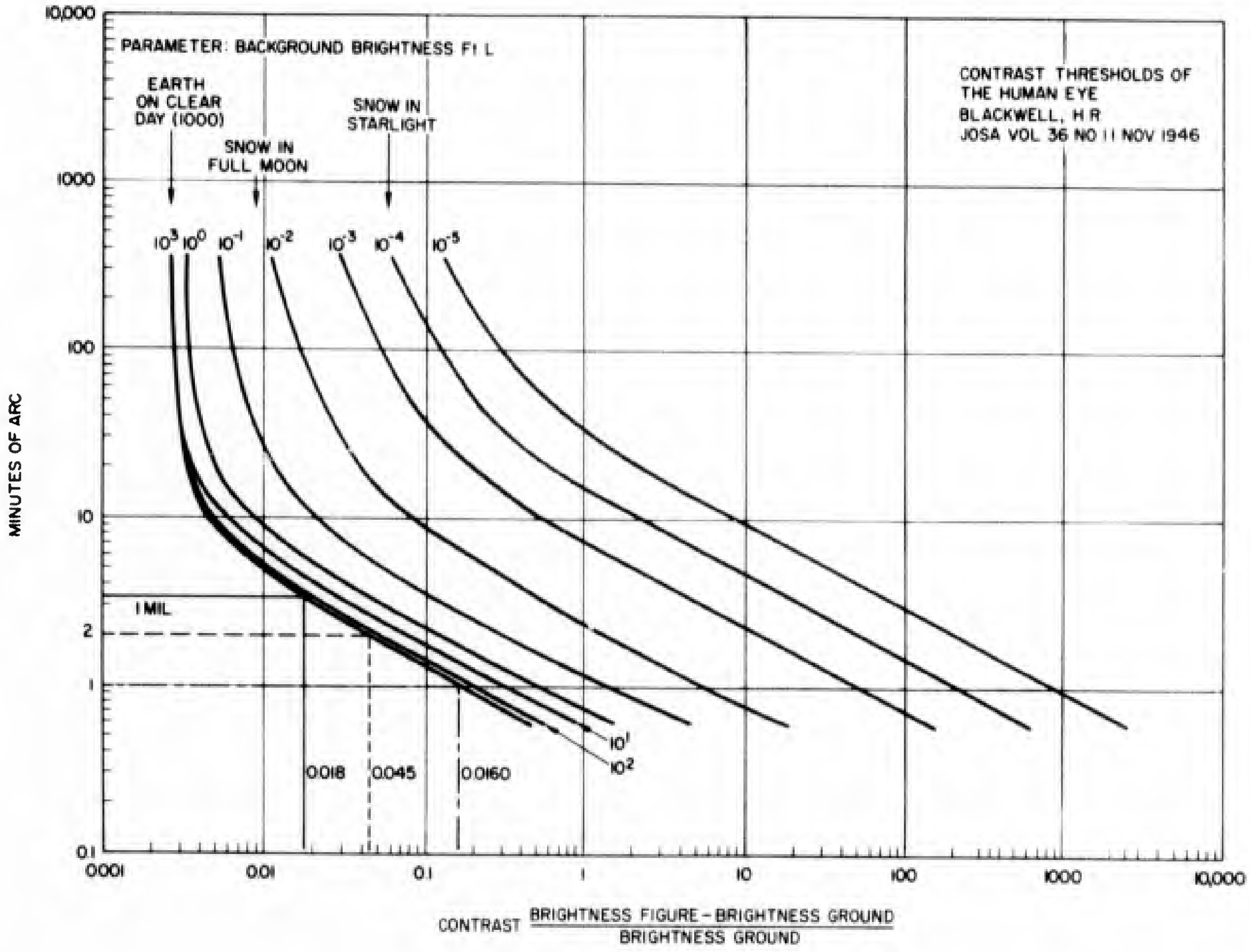


Figure 13. Contrast Thresholds of the Eye.

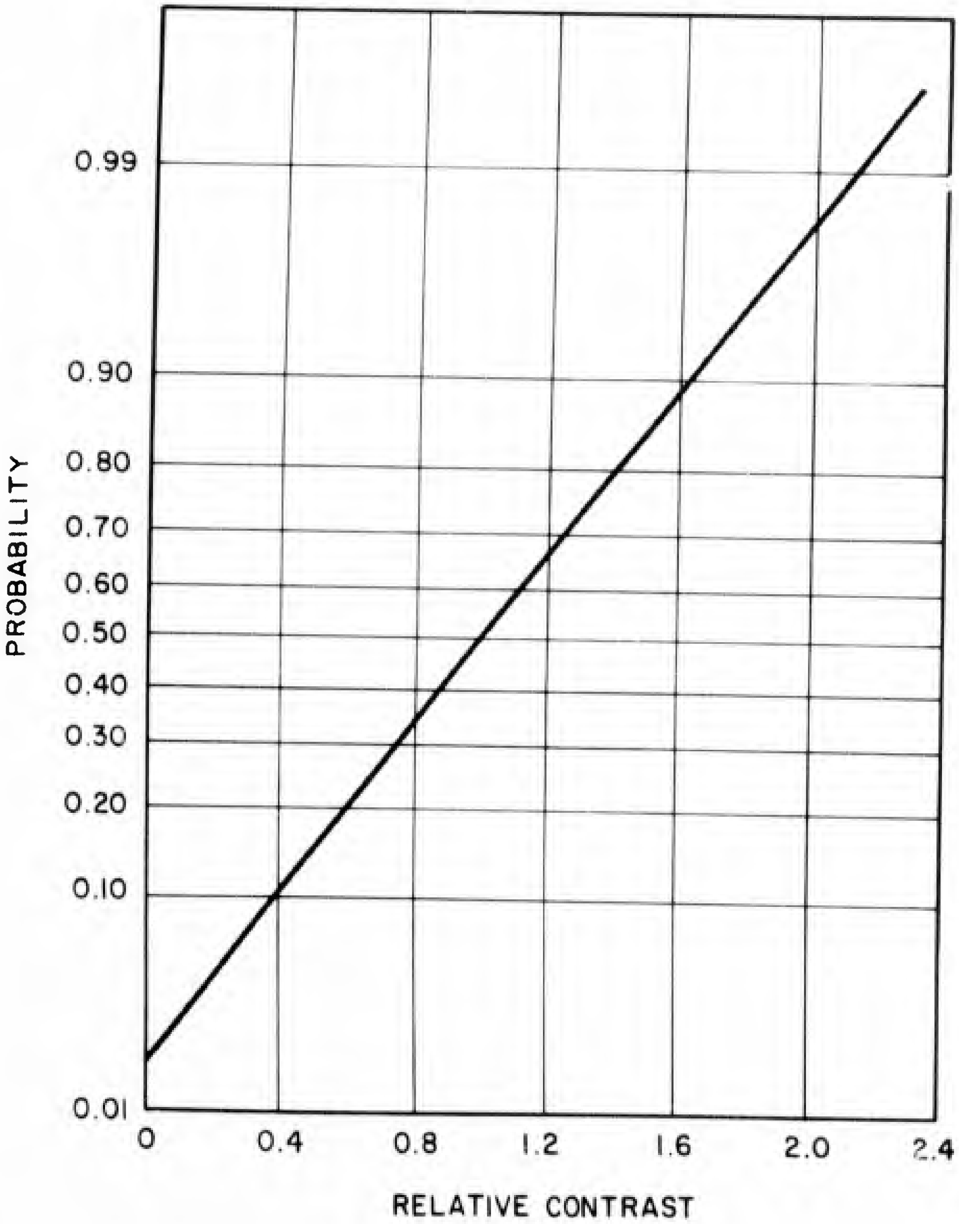


Figure 14. Curve to Convert 50% Threshold to Other Probabilities.

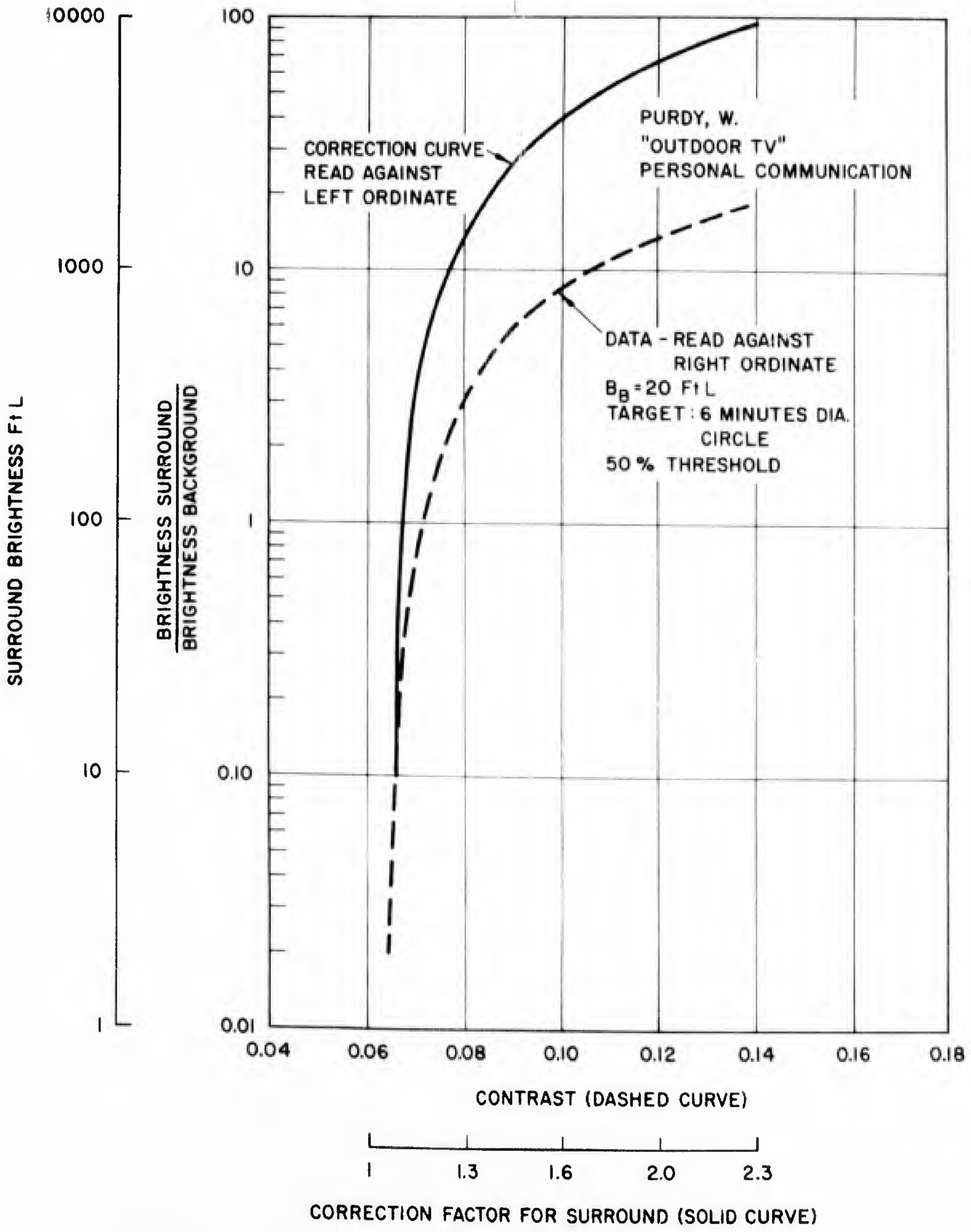


Figure 15. Effects of Surround on Contrast Threshold.

Figure 16 shows how acuity is affected by contrast and background brightness. In the skeletal display the requirement is not only that a thin line element be visible but that readout accuracy be maintained by requiring that the separation between two elements be visually resolved when the separation is equal to a line width. For this reason the curves in Figures 13 and the curves in Figure 16 will in each such case be compared, and in calculating the brightness requirements the most demanding value will be used.

Figure 17 shows how acuity is affected by image motion.

The information contained in these Figures may be used to estimate the minimum required brightness and contrast of the skeletal displays. The best way to show how this information may be used is by using a series of representative examples. Suppose the following:

> We wish to paint the symbols shown in the skeletal panel mounted landing display illustrated in Figure 11 with lines 1 mil in width. (1 mil is about 3.4 minutes of arc.) The display is panel mounted, the tube background brightness is assumed to be 20 FtL and the surround brightness (the sky) is about 2,000 FtL. From Figure 13 we find that the required contrast for 50% threshold is about .03. Although our image is only 1 mil wide it is in essence a long line, and from corollary data it is known that such lines are somewhat easier to detect than simple patches.
>
> However, the line was made 1 mil wide in order to retain precise readout accuracy and we should therefore like to be able to resolve two lines separated by one mil. Figure 16 shows that the contrast required for that order of acuity is closer to .05. This more stringent value will therefore be used.
>
> To raise the probability of detection to .9999, Figure 14 is consulted, and it is found that .05 must be multiplied by a factor of 3. Even at this level of contrast the image is ghostly. Muller[4] has shown that this latter value (.15) must be again multiplied by a factor of at least five before the image is

---

[4] Muller, P. An Investigation of Reticle Display Parameters, TIS R56 EL C54, General Electric Company, Ithaca, N.Y., 15 July 1956.

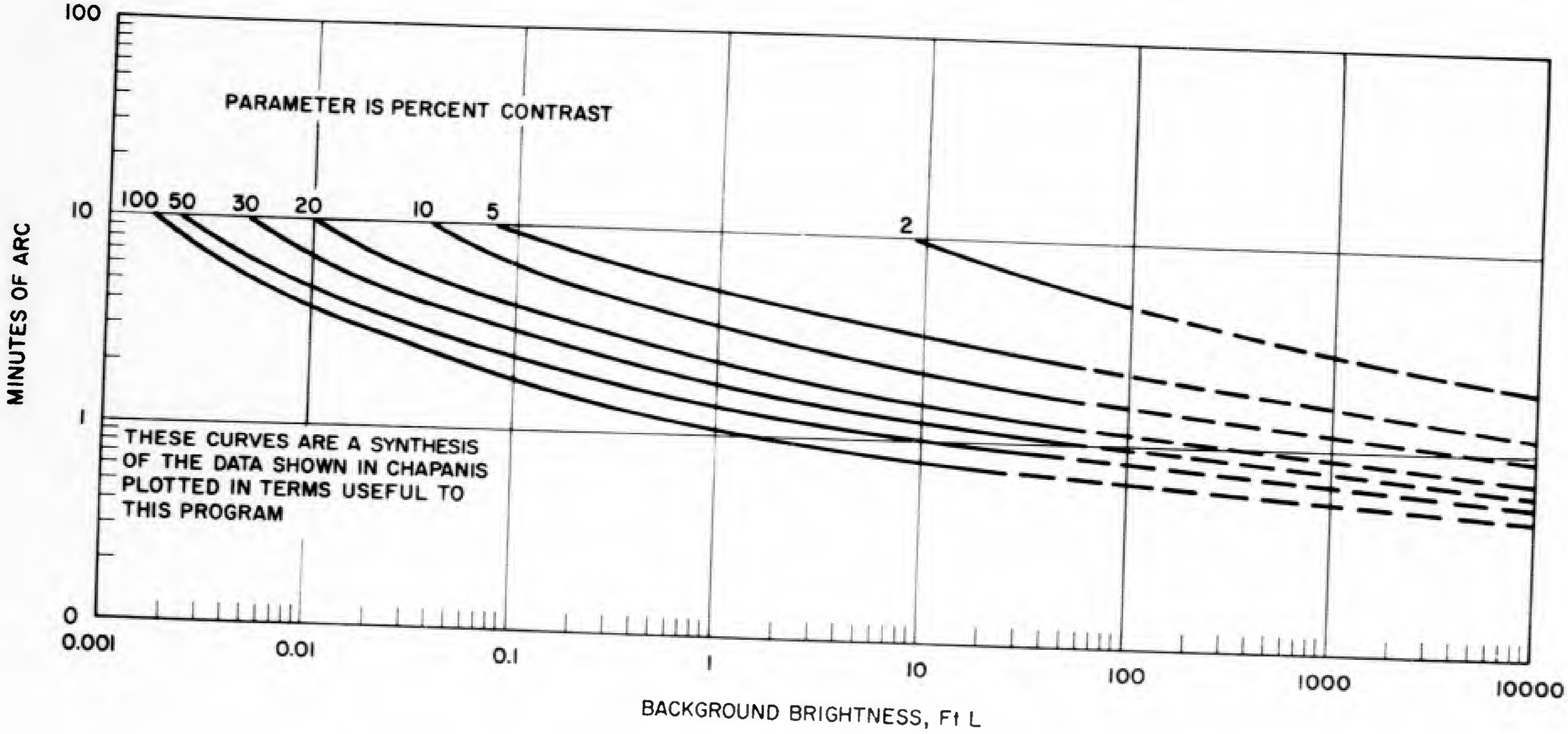
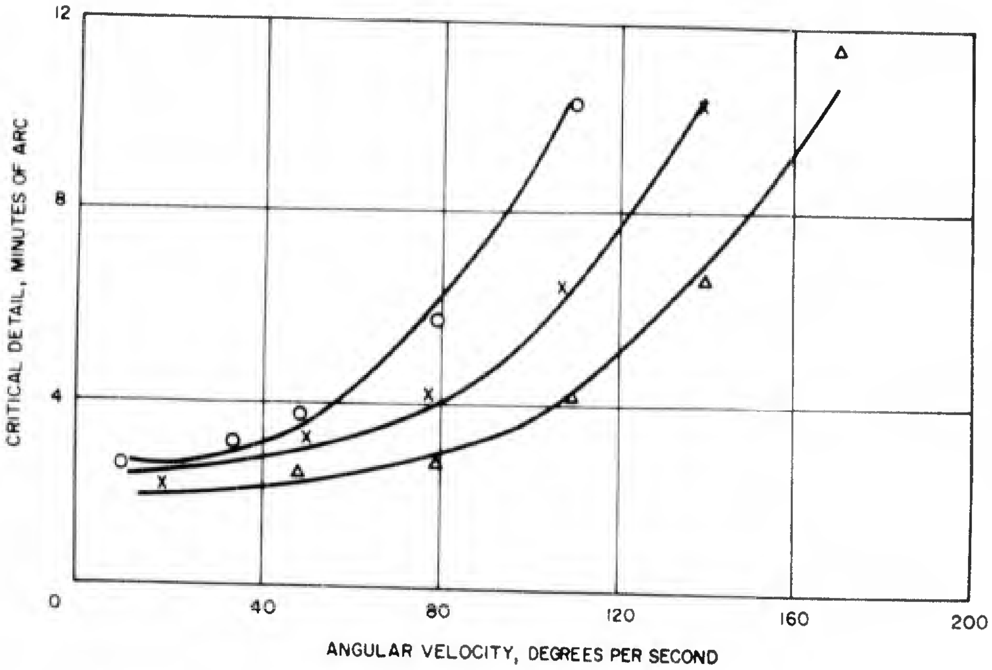


Figure 16. Visual Acuity as a Function of Contrast.

From: Ludvigh, E., and Miller, J. W.
"A Study of Dynamic Visual Acuity"
Project NM 001 067.01.01
Rept. No. 1, USN School of Aviation Medicine
Pensacola, Fla., March 1953.



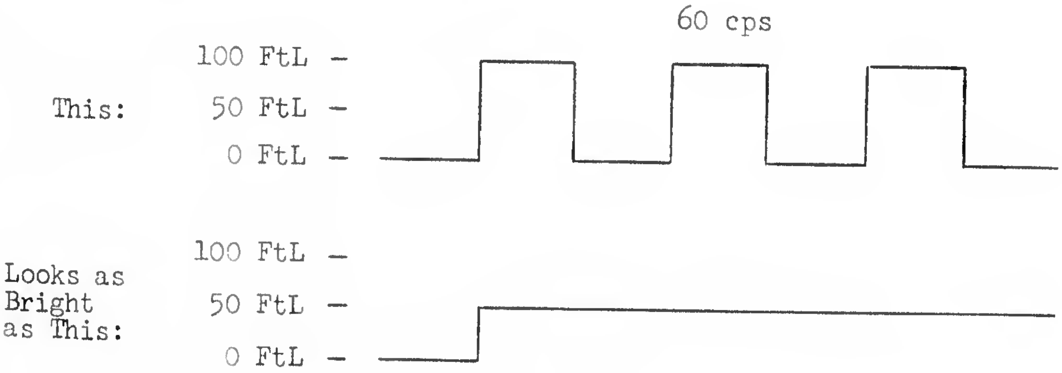
MEAN THRESHOLDS OF ALL SUBJECTS
WITH REGARD TO GROUP
CIRCLES, CROSSES, AND DIAMONDS REPRESENT
EXPERIMENTALLY DETERMINED POINTS.
LINES ARE GRAPHS OR THE EQUATION $y = a + bx^3$

Figure 17. Acuity and Image Motion.

bright enough to be viewed comfortably. The required contrast is now .75.

However, because of the large brightness difference between surround and background, the curves illustrated in Figure 15 must be consulted. It is found that we must multiply by about 1.2. The required contrast is now .9. Using the equation $\frac{B_f - B_g}{B_g} = .9$ it is found that the minimum integrated brightness for the lines under these conditions is approximately 38 FtL. It should be emphasized that these are minimum values and are by no means ideal.

It is convenient to specify the brightness required in terms of the integrated brightness even though the raster scan is physically intermittent. At a 60 cps frame rate the apparent brightness will be that of the equivalent amount of luminous energy spread over a reasonable integrating interval - say two or three seconds.



The peak brightness required to reach the needed integrated brightness level will depend primarily on system duty cycle and phosphor decay characteristics.

At this point it will be useful to utilize a constant, K, that will consist of the value necessary to raise a 50% threshold to 99% and "Muller's constant," the factor of 5, to raise the image from a ghost to a more substantial picture. The value of this constant K to be used in subsequent analyses will be 15.

2-A SYMBOLOGY - FLIGHT PERFORMANCE - PANEL MOUNTED SKELETAL DISPLAY - TERRAIN FOLLOWING

In a fashion similar to that described in section 1-A, we have sketched a representative pictorial terrain following display. In order to aid the reader in visualizing the actual situation represented in the display a plot of the environmental situation is shown in Figures 18 and 19. Figure 18 is a side profile of a 4 mile portion of NOTS track No. 10 from Woodford to Bear Mountain. Figure 19 is a plot of four transverse profiles from the same position. Figure 20 shows what the profile would look like on one type of E-scope. Figure 21 is an annotated sketch of the terrain following display and Figure 22 is the sketch of the display as it would appear to the pilot. If Figure 22 is compared with Figure 19 it will be seen that the hurdles are the terrain elevations at the stated ranges dead ahead.

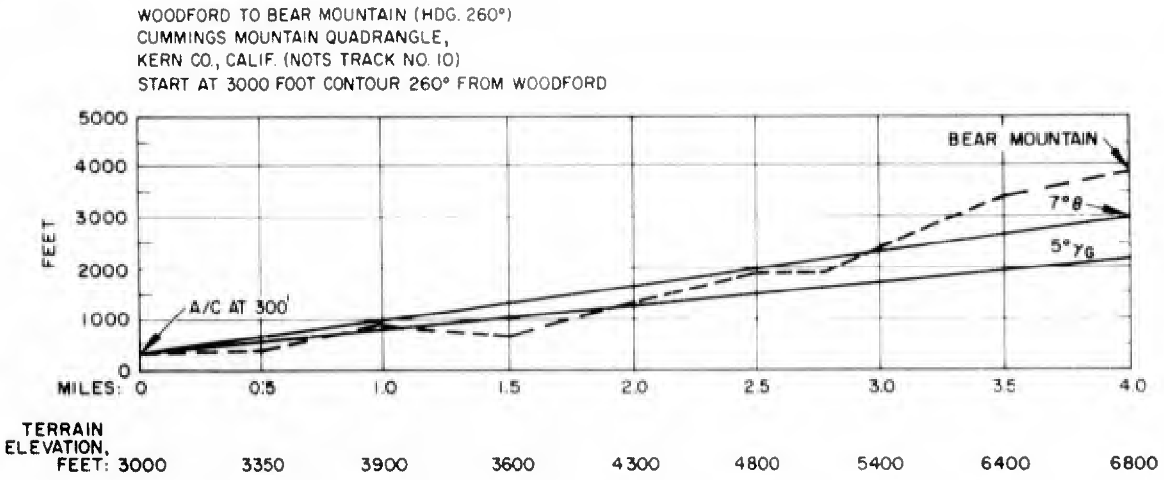


Figure 18. Side Profile.

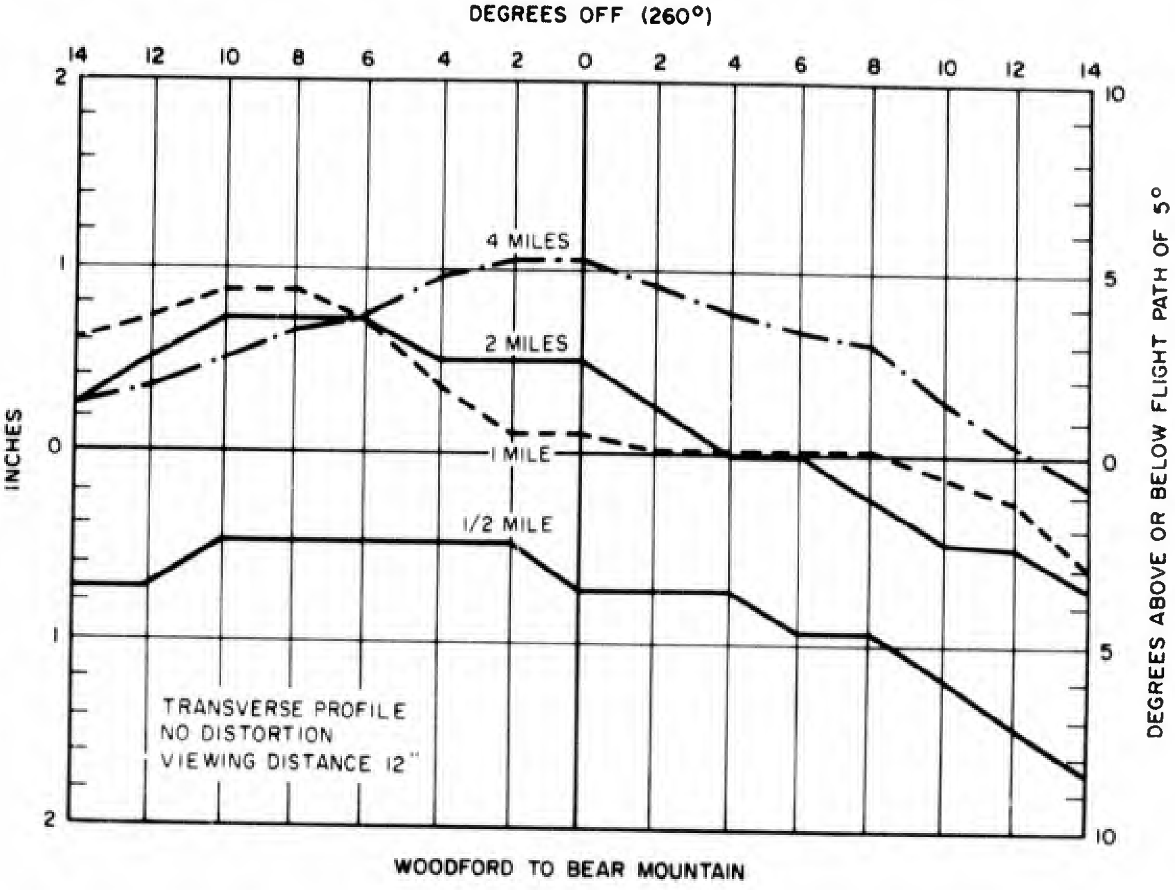


Figure 19. Transverse Profile.

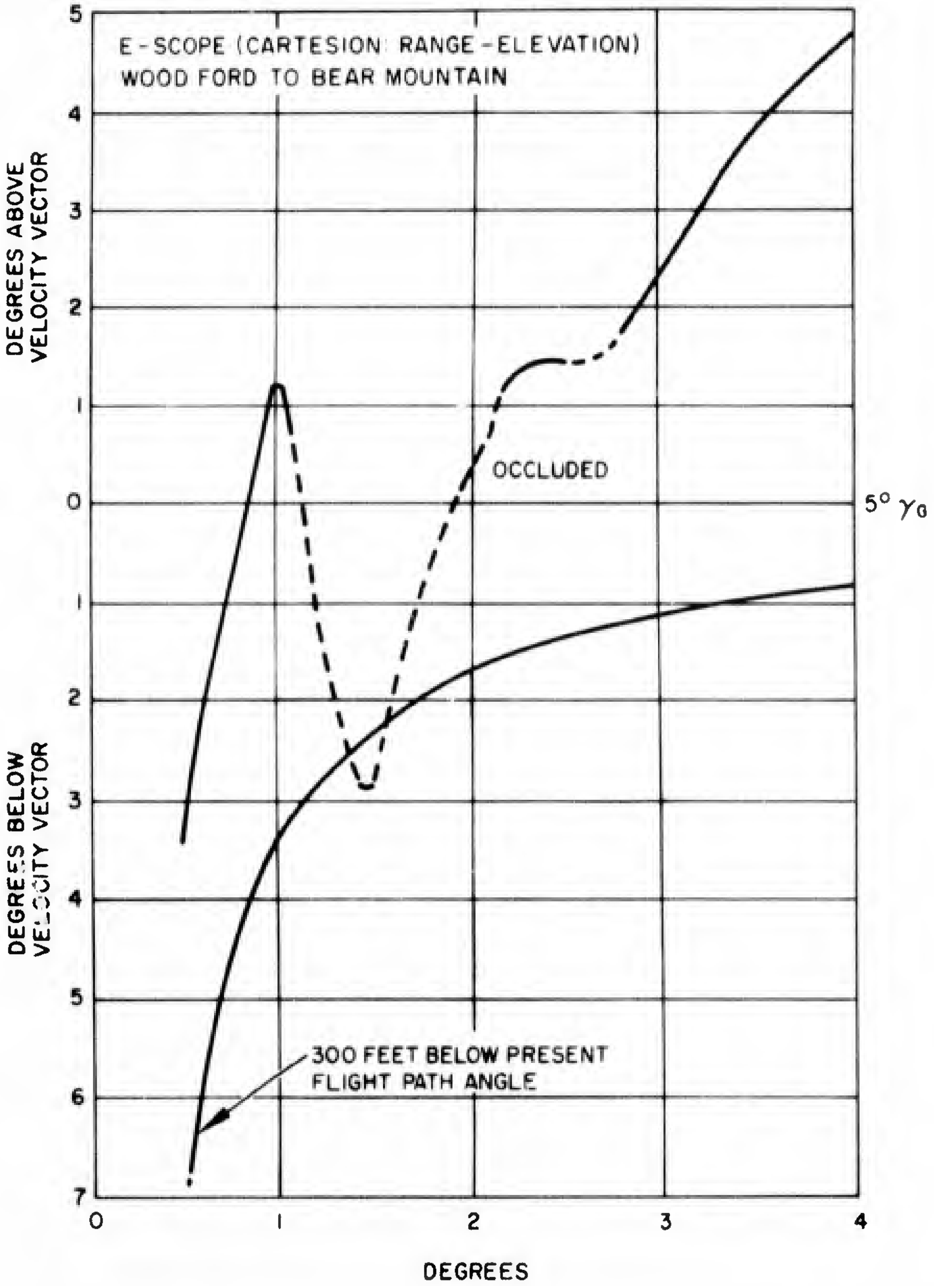


Figure 20. E-Scope Display

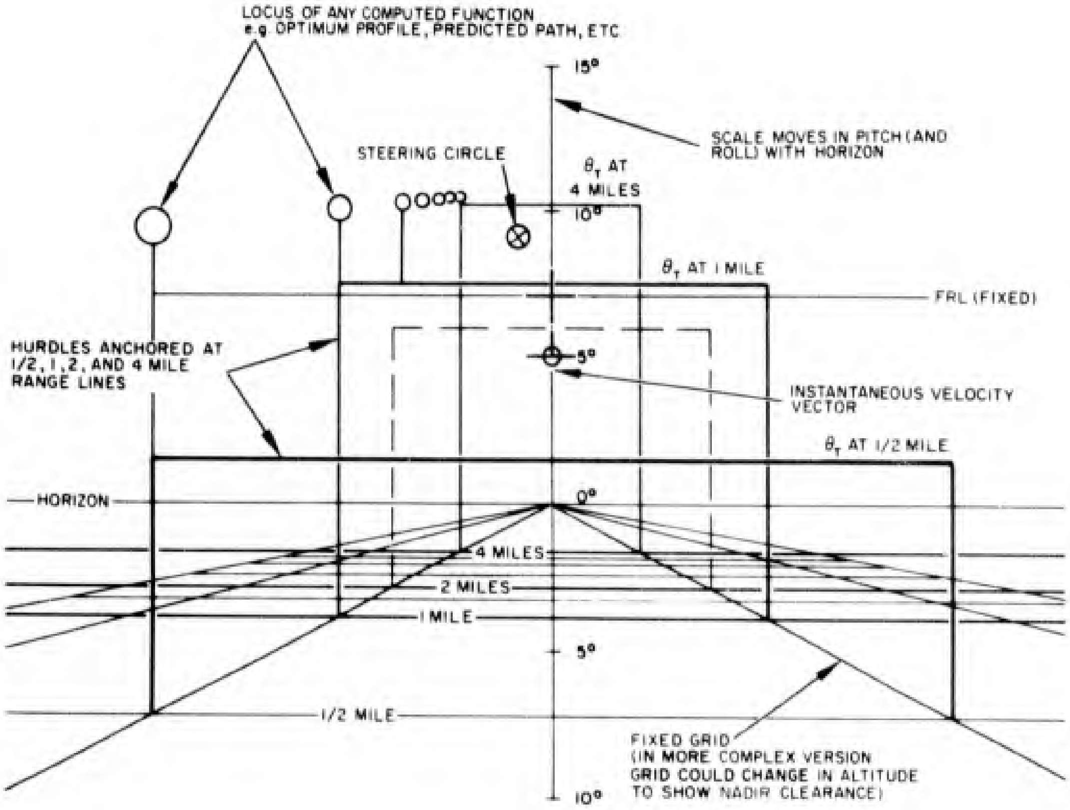


Figure 21. Terrain Following Pictorial Skeletal Display at Mile 0. (See Figure 18.)

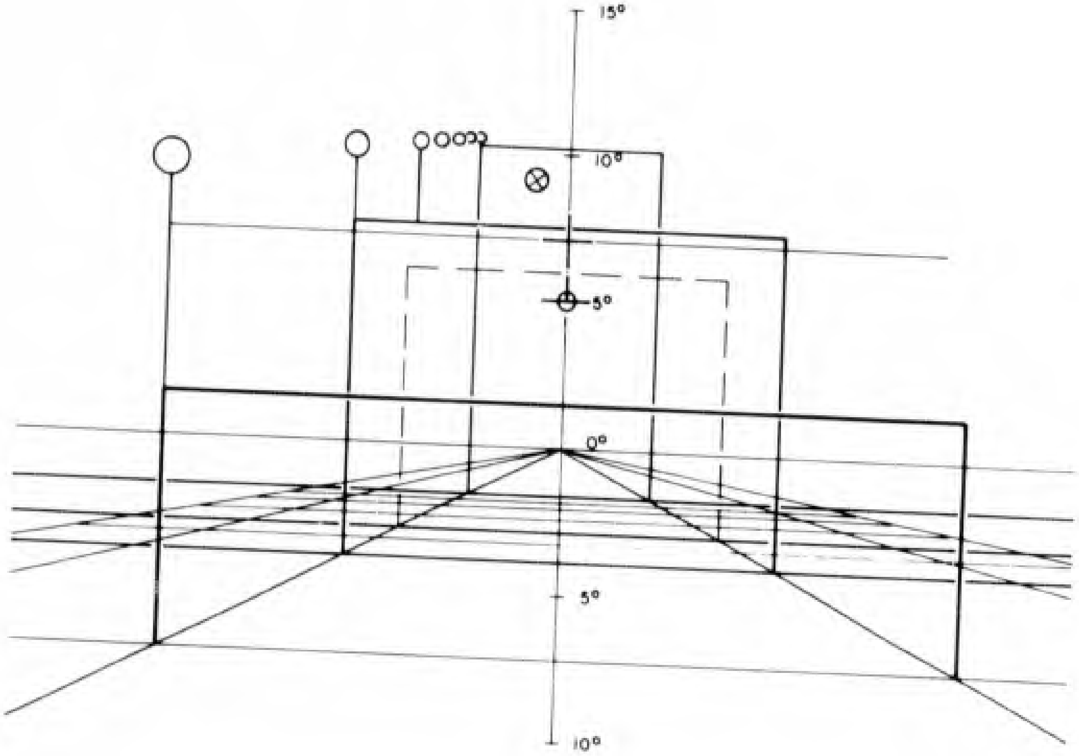


Figure 22. Terrain Following Pictorial Skeletal Display at Mile 0. (See Figure 18.)

2-B SIGNALS REQUIRED - FLIGHT PERFORMANCE - PANEL MOUNTED SKELETAL DISPLAY - TERRAIN FOLLOWING

θ, Φ, γ_G, elevation angle of terrain at 1/2, 1, 2, and 4 miles (or other suitable intervals), plus internal computation to draw the display.

2-D <u>COVERAGE OR FIELD OF VIEW</u> - FLIGHT PERFORMANCE - PANEL MOUNTED SKELETAL DISPLAY - <u>TERRAIN FOLLOWING</u>

<u>Azimuth</u> - Not applicable unless a heading index is added.

<u>Elevation</u> - The chief variables to be considered in elevation coverage are the g limits of the aircraft, the aircraft speed, the characteristics of the terrain, and the clearance desired. The intent is to keep the terrain hurdles within the field of view through the expected maneuver envelope of the aircraft. For this mode the displayed elevation should be symmetrical and the display should be centered around the FRL. Below the FRL the most critical case is reached in an overshoot where the close hurdles may disappear unless care is taken to provide adequate coverage. Above the FRL, the coverage must be equal to the steepest slope of the terrain averaged over a half mile and referenced to the FRL.

3-A SYMBOLOGY - FLIGHT REFERENCE - PANEL MOUNTED SKELETAL DISPLAY - POINT TO POINT NAVIGATION

The display illustrated in Figure 11 may be altered slightly to serve as a flight display during the navigation mode. The runway symbol will be omitted. The "localizer-glide slope" should now indicate an altitude-course line command. Supplementary "horizon lines" for large pitch angles could be added and suitably coded.

3-B <u>SIGNALS REQUIRED</u> - FLIGHT PERFORMANCE - PANEL MOUNTED SKELETAL DISPLAY - <u>POINT TO POINT NAVIGATION</u>

$\theta \quad \phi \quad \gamma_G \quad \beta_G \quad H_C \quad L_C \quad \psi_C$

H_c = altitude error from command

L_c = lateral error from command

ψ_c = heading error from command

3-D COVERAGE OR FIELD OF VIEW - FLIGHT PERFORMANCE - PANEL MOUNTED SKELETAL DISPLAY - POINT TO POINT NAVIGATION

Azimuth - Azimuth coverage should be related to the standard turn rate and the time it takes to roll out to a heading. In order to provide the pilot a sufficient anticipation interval of the order of 6 seconds, the likely minimum coverage for high speed aircraft should be about plus and minus 10°.

Elevation - The criteria from 1-D apply here also. In addition, pitch maneuvers will be much larger than in landing and it is not desirable to have the horizon disappear at the slightest pitch change. Recommended minimum; plus and minus 15°.

Both azimuth and elevation coverage in this mode should not, in a given system, differ markedly from the coverage used in other modes or else the change in display gain may lead to pilot difficulty.

5-A SYMBOLOGY AND CONTENT - FLIGHT PERFORMANCE - PANEL MOUNTED CONTACT ANALOG - LANDING

The contact analog display is the point perspective projection of a three-dimensional model to a picture plane. The model contains 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 hallmark of a contact analog is the display of surfaces whose kinematics are similar to those of real surfaces in the natural visual environment. In the microcosm of the panel mounted display where magnification may be other than unity, the displayed surfaces will still follow the laws of motion perspective and thus provide information coded in a fashion analogous to the coding provided in visual contact flight.

As far as the writer knows there are two designs for contact analog displays that meet the criteria suggested above: the one by Norden and the one by General Electric. Because I am most familiar with the General Electric development, the features of that particular design as well as the G.E. nomenclature will be used to illustrate the contact analog. This is without prejudice to Norden and implies no evaluation; it is only done for the sake of convenience.

We must assume for this report that the display is familiar to most of our readers and we shall not burden these pages with a long description of its characteristics.

Figure 23 is a pilot's eye view of the display in one mode of operation. This sequence illustrates a change in heading and altitude with reference to the ground plane. The complete display has the following elements (only the ground plane is shown in the illustration).

1. A ground plane (six degrees of freedom).
2. A sky plane (three degrees of freedom - rotation only).
3. A flight path (six degrees of freedom).
4. A few three dimensional objects - obstacles or similar objects (six degrees of freedom).
5. A ground patch - runway, checkpoint, I.P., or target (six degrees of freedom).
6. Numerous symbols in the display plane.

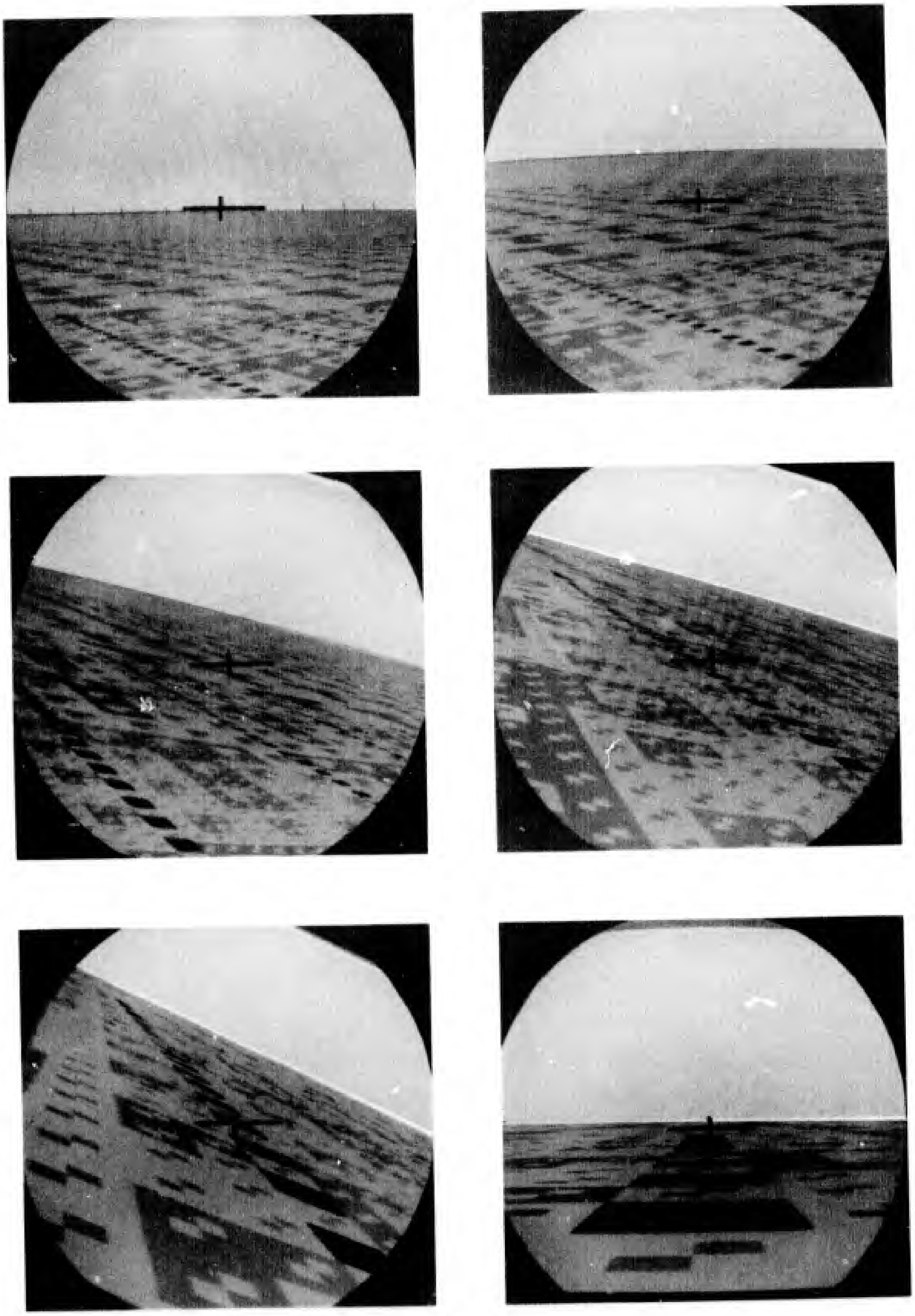


Figure 23. Partial Contact Analog Display.

5-B INFORMATION REQUIRED OR DRIVING SIGNALS - FLIGHT PERFORMANCE - PANEL MOUNTED CONTACT ANALOG - LANDING

The nomenclature used is shown in Figure 24.

Ground plane: θ_{ea} ϕ $\dot{\psi}_a$ $\dot{H}_a$ $\dot{S}_x$ $\dot{S}_y$

where:

$\dot{S}_x$ = x velocity

$\dot{S}_y$ = y velocity

Flight path: Same as ground plane plus:

$\dot{S}_{xf}$ $\dot{S}_{yf}$ H_f D_f θ_f ψ_f for each segment

and information to specify segment start and finish

Runway: X position, Y position
heading
width
length

Other: Initial conditions for all elements: scale, magnification, trim, etc.

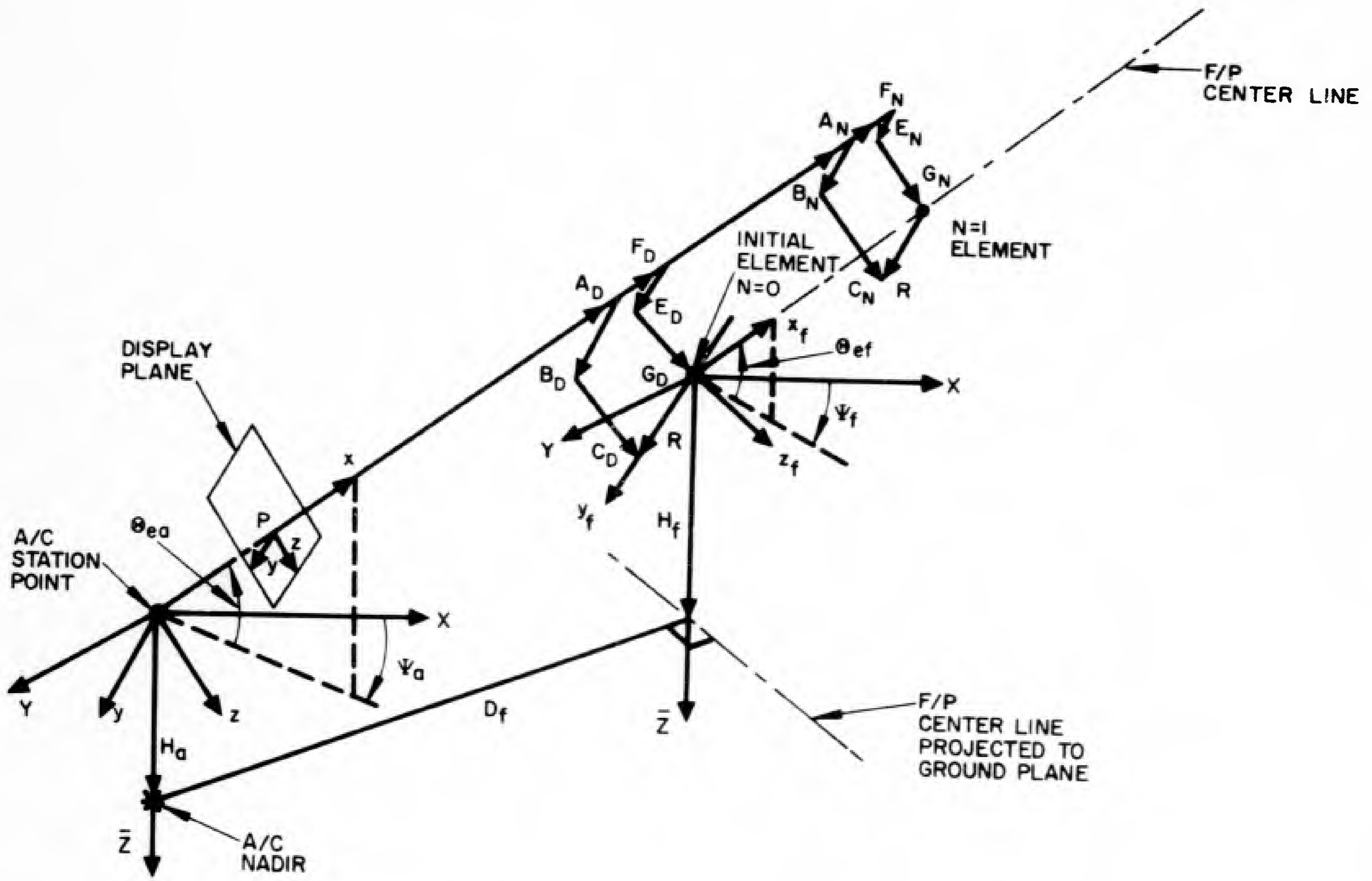


Figure 24. Geometry and Nomenclature of Flight Path.

Taken from:
General Electric Computed
Pictorial Displays, General
Electric Company, Advanced
Electronics Center, Ithaca, N.Y.

5-C DATA RATE - FLIGHT PERFORMANCE - PANEL MOUNTED CONTACT ANALOG - LANDING

The arguments developed in 1-C are also valid here. There are some additional points that should be made.

All display elements respond to aircraft rotation at sixty cps.

If the display is to be used all the way to touchdown the recommended data rate for response of all display elements to translation is thirty cps.

For other cases the updating rate will depend on the visual range - particularly the updating rate for the flight path and runway. The visual range will depend on the display-computer resolution if the runway is painted in perspective in its true size. For these cases the further ahead the pilot can see the slower the data rate required. If he has very little anticipatory information, thirty cps is completely safe, eight cps will show only a few percent performance degradation, two to three cps perhaps ten percent degradation, and rates slower than that cannot be recommended unless anticipation is provided.

5-F MAGNIFICATION OR GAIN - FLIGHT PERFORMANCE - PANEL MOUNTED CONTACT ANALOG - LANDING

There shall be no differential magnification of the various surface elements painted in perspective. Elements in the model may change size, e.g., conceivably to gain detection range the runway could change size in the model as a function of range until a range is reached where it can easily be seen on the display at its true size and then locked in at its true size. However, magnification strictly defined, takes place in the perspective transformation to the picture plane, and differential magnification cannot be recommmended unless it can be shown to be beneficial by incontrovertible empirical data.

The most pronounced effect of magnification is on display sensitivity. In this particular display, magnification will also affect the perceived attitude of the aircraft any time the horizon is not on the display. This effect has been much discussed in other reports and will not be belabored here. Theoretically any distortion is undesirable but, in practice, considerable distortion is tolerated if the face of the display medium can be seen. What would happen if the tube face per se could be rendered invisible as, for example, in a high quality head-up display where the image is at virtual infinity is unknown. For practical purposes the magnification limits in panel mounted contact analog displays are in the range 0.33 to 2.0.

5-G MINIMUM NUMBER OF LINES (RESOLUTION) - FLIGHT PERFORMANCE - PANEL MOUNTED CONTACT ANALOG - LANDING

The requirements are similar to those of 1-G. However, because visual range is so important in the contact analog if it is to be used for actual landing and because texture elements (which make things visible) foreshorten more rapidly than they change size laterally as a function of depression angle, it would probably be advantageous to have more resolution in the vertical axis of the generation-display system. In a raster scan display this might mean as much as twice as many lines as there are resolution elements along a line. The contact analog is peculiar in that the display symbol generator is often the limiting factor in resolving display elements for these elements are outputs of this very generator and it would do no good to improve the tube resolution unless there is a corresponding improvement in the capacity of the generator-computer.

5-I HIGHLIGHT BRIGHTNESS AND CONTRAST - FLIGHT PERFORMANCE - PANEL MOUNTED CONTACT ANALOG - LANDING

Let us now consider a more complex display like a contact analog that uses patches of black and white to paint the necessary surfaces. In an achromatic contact analog, brightness will be used to code elements in the display so such elements will need to be visually discriminable in brightness. For example, the flight patch should be brighter than the ground, and other symbols may be brighter than the flight path. Several brightness levels are required rather than the two values used in the examples cited previously.

The needed grey scale may be calculated in the same way as the other examples although at the slight additional hazard of an unjustified extrapolation. Assume again a background brightness of 20 FtL, a surround brightness of 2,000 FtL, and that the smallest patch we want to see subtends 1 mil on a side. From the example, in 1-I, the patch brightness was estimated to be 38 FtL. The ground plane, then, would be formed of patches of 20 FtL and 38 FtL. Once again it should be remembered that such contrasts as these, whilst clearly visible, are not what could be called good quality. However, let us use 20 and 38 for the ground. If the sky is not patterned it may be 20 FtL. If it is patterned then the sky "ground" should be brighter than the ground "ground."

For patches this large we find from Figure 13 that the 50% threshold contrast is .003. Using the same correction factors as before, we find the required contrast is .054, so the sky "ground" should be about 21 FtL. The sky "figure" should be about 40 FtL.

Elements comprising the flight path should be still brighter. They must be seen against a background of at least 40 FtL. The required contrast for 1 mil patches is still about 0.9 so the path brightness needs to be about 76 FtL.

Still other symbols need to be seen against the brightest parts of the flight path. Calculating as before it is found that these should be minimally 111 FtL.

Indices

6-9 FLIGHT PERFORMANCE - PANEL MOUNTED CONTACT ANALOG

These displays are completely developed insofar as symbology is concerned. The signals required to drive the various elements are fairly well known, although how this information is sensed and processed is not known in all instances. We anticipate no difficulties in completing the cell entries in the master chart for this particular group.

Indices

10-13 FLIGHT PERFORMANCE - HUD SKELETAL DISPLAY

With few exceptions the requirements for the HUD skeletal displays are the same as those for the panel mounted skeletal displays. The major differences arise because of the probable need for registry of HUD display elements with parts of the natural environment and because of visibility problems associated with any HUD display. A discussion of the visibility problems follows on the next page.

Any requirement for registry of HUD display elements with objects on the earth's surface immediately sets the magnification factor for the display and, depending on the mode of flight, the field of view and the display size as well.

Index
10-I BRIGHTNESS AND CONTRAST - HUD SKELETAL DISPLAY - LANDING

The pattern is the same as used in the skeletal landing display with a line width of 1 mil and a background brightness of 2,000 FtL (the sky). From Figure 13 the 50% contrast threshold is .018. From Figure 16 the contrast required is less than .02. Let us use .018. Multiplying by K yields .27. At the eye, therefore, we need 2,540 FtL. Two thousand FtL are already supplied by the background, so we need add 540 FtL. With a neutral combining glass, the total light loss through the optical train may be 80%.

Therefore, the average brightness of the pattern on the tube face needs to be on the order of 2,700 FtL.

The same 1 mil pattern in a HUD against a background brightness of 10,000 FtL will require an average brightness of 12,500 FtL.

Indices
14-18 FLIGHT PERFORMANCE - HUD CONTACT ANALOG

The requirements here will be essentially the same as those developed for indices 5-9. The main differences will be those arising from visibility and registry requirements.

Indices
19-21 NAVIGATION - HSI - MAPS

Analysis of problems associated with the development of map displays in this laboratory have provided the starting point for the study of requirements for raster scan map displays. These analyses have not as yet been fitted into the Procrustean chart we have chosen as the reporting format for this program and our discussion will be general, conventional, and brief.

The mission phases that will receive emphasis are landing, low level flight, and point-to-point navigation.

If a mission phase is to be accomplished in a certain area, the display of this area must contain coded information about significant features such as altitude of peaks, navigation aids, terrain elevations, cities, airdromes, etc. This information is called map content. A raster display may require different methods of displaying map content than is used in hand held maps or in optical projection displays. The differences arise mostly because of loss of resolution through the display medium and the loss of color as a coding dimension. Appropriate abbreviations and physiognomic symbols will therefore be developed.

Scale factors are determined chiefly by the speed of the aircraft on the one hand and the readout accuracy required on the other. The scale factor chosen will determine the area displayed and the content density. A study of the most dense section of a particular coverage using the static symbology that will display the information without clutter will have a secondary effect on choice of the scale factor.

Superimposed Symbols

In addition to map content, useful symbols to present information about the vehicle position and heading, destination, lateral and forward motion, altitude, and fuel range can be presented on the raster scan map display. Not all are applicable to all vehicles for all missions; some will be selected for presentation when needed.

Ownship Symbol - Ownship position and heading relative to the map should be displayed for all mission phases. Two methods can be used to display this information; the moving symbol with the map North up and stationary or the moving map with either heading up or North up and the symbol stationary at the center of the display. For the VTOL landing, studies have indicated the moving-map/fixed-symbol configuration is the superior method.[5] For some mission phases the moving-symbol/fixed map is more applicable.

Two problems arise when the map display is heading up and used for VTOL landing. The first is the coding and labeling on the moving map which should be chosen so that it is readable at all angles of rotation. The second is that the display should have the sensitivity required for precision landing. The accuracy required has an effect on the map coverage selected for VTOl landing because the error will be a percentage of the display diameter. This relationship is:

$$\text{Map ground coverage diameter} = \frac{\text{Maximum allowable ground error}}{\text{Percent of display error}}$$

Destination Symbol - The destination symbol is applicable in a navigation system where steering information is available. The operator would have the capability of manually positioning a symbol to the desired destination and entering this information in the computer. The computer would then have the destination location, ownships location and heading and from this the correct steering information could be obtained.

Hovering Lines - Lateral and forward velocity information relative to the earth would be necessary for a display for VTOL landing. The hovering lines would be presented on the display as a grid that would indicate the vehicle's motion relative to the ground. The grid motion would be continuous and a non-linear motion scale would accentuate small velocities and limit large velocity presentations.

Fuel Range - A fuel range circle would indicate the maximum flight distance before the fuel supply would be depleted. The fuel circle would be applicable to navigation where a number of alternates are available.

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[5] Dougherty, Abbott, Matheny, and Wallis. The Experimental Comparison of Three Dynamic Map Display Configurations in a Simulated Steep Gradient Vehicle Environment. Bell Helicopter Co., April 1962. Contract No. 1670(00).

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22 TACTICS - HSI - SKELETAL - WEAPON DELIVERY, AIR

Figure 25 are photographs of the Tactical Information Display of the Phoenix fire control system. The symbols are characteristic of all clearplot tactical displays and are positioned by a most complex airborne system. The inputs to the display may have their origin in a data link message, an ownship sensor, or simply by operator conversation with the on-board computer. We have spent and shall spend very little time on this type of display.

Some idea of a contrast and resolution comparison between the standard CRT and a TV presentation may be gleaned from comparing Figure 25 with 26. Figure 26 shows the same TID symbology on a closed-loop standard black and white TV. Noticeable is the marked difference in brightness contrast - which we saw in 1-I is of critical importance - and the difference in resolution. The crowding of the symbols on this display is not particularly unusual and gives some idea of what a raster scan display would have to be to equal the performance of a display that writes the symbols caligraphically.

Figure 25. Tactical Information Display.

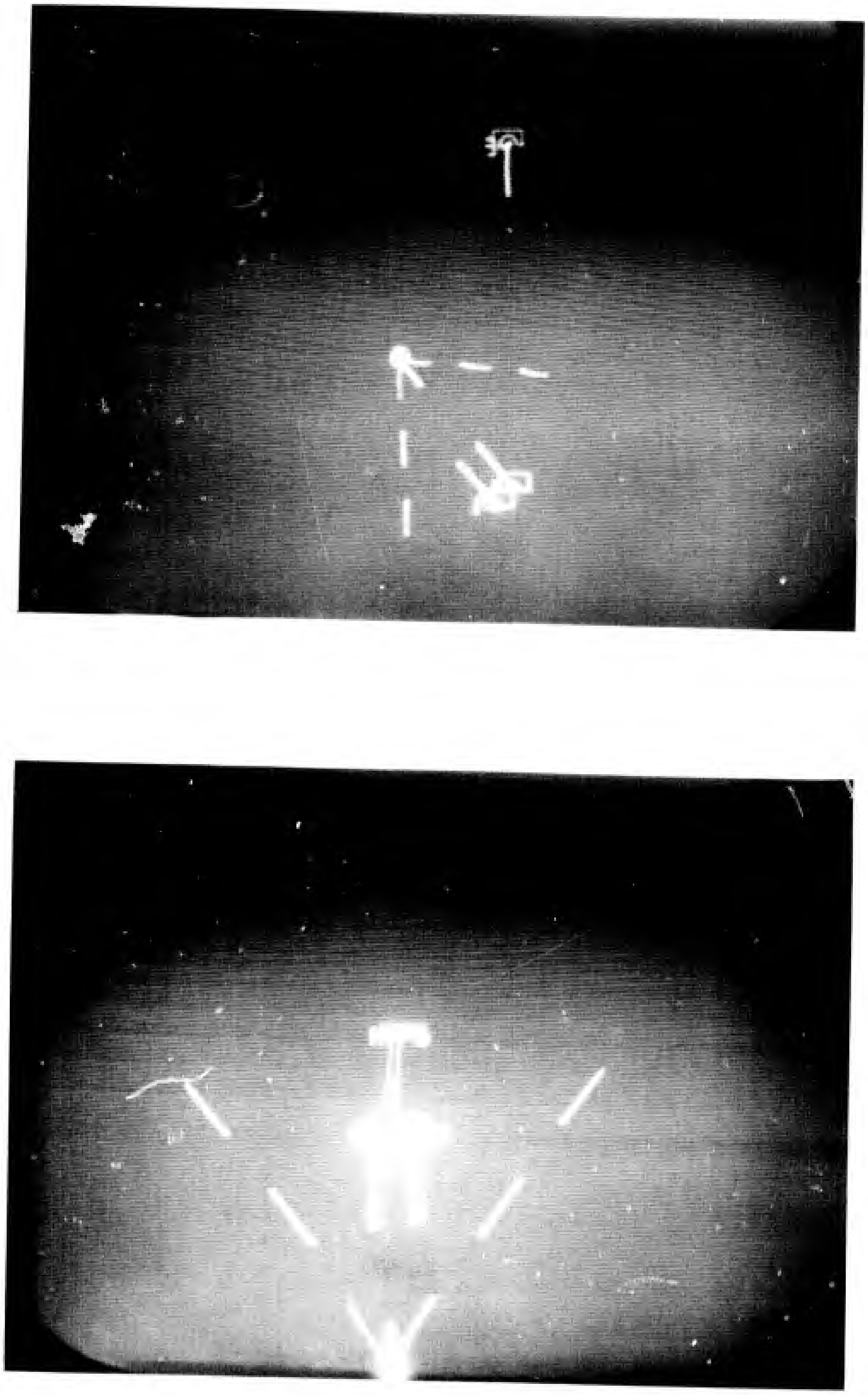

Figure 26. Tactical Information-TV.

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24 **TACTICS - HSI - PHOTOGRAPHS - WEAPON DELIVERY GROUND**

This display was put in this category out of convenience and is simply a display of reference material other than maps that would be used as an aid in target recognition. Target is used in the broad sense to mean landmark, IP, checkpoint, target and the like. As was discussed in an earlier section, the importance of briefing or reference material on the operator's ability to acquire and recognize targets visually cannot be too strongly emphasized. We have included it as an item to be studied even though the sensor and data processing requirements are usually not integral to the airborne system.

The display will ordinarily be of photographs, radar prediction maps, radar imagery, or any other patterned material that will help the operator identify the target. It could even display a verbal "key" of the type used in photointerpretation, although we do not believe this is apt to be the case in operational aircraft. (In fact a display of stored material could be used for many purposes - check lists, test routines, etc.)

When used as a display of reference material the considerations discussed in the section on target recognition should be borne in mind; mainly that the closer the reference material resembles the live display the easier it is to pick out targets. This means that displays for this use should be tailored to match the characteristics of the live displays of raw data. The relative advantages of having reference materials that are identical to the live display versus reference materials that are abstracted, are all in favor of the identical material provided the material is indeed identical. As the material departs from literal identity it may be better to use abstract material that emphasizes features of the target important for recognition. A library of reference material, easily retrieved, will also be of considerable aid in planning or dry running a mission.

The problems associated with a display of this type, in addition to the standard ones of visibility and legibility, will be concerned with rapid access to and retrieval of materials from what may be a rather large library.

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25 FLIGHT PERFORMANCE - VSI - TV - LANDING

This item was discussed in the first quarterly report and will be summarized in the final report.

In that report it will be shown that, with appropriate gain, the TV display would be aided by the symbology illustrated in 1-A.

Index
26 <u>TARGET RECOGNITION</u> - VSI - TV - <u>LOW LEVEL FLIGHT</u>

Considerable study has been given to the use of low-light-level TV for application to low-level flight. This work is still in progress.

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27 TARGET RECOGNITION -VSI - TV - WEAPON DELIVERY GROUND

Figure 27 illustrates a display that might be used for TV guidance of an ASM. In this particular case the pickup tube may be in the head of the missile and the monitor back at the mother aircraft.

Considerable analytic and experimental work has been done at this laboratory on this problem on other programs and this work will be drawn on heavily to aid in completing the chart entries. Of particular interest is the effect of bandwidth compression and noise on picture quality and therefore, presumably, target acquisition capability.

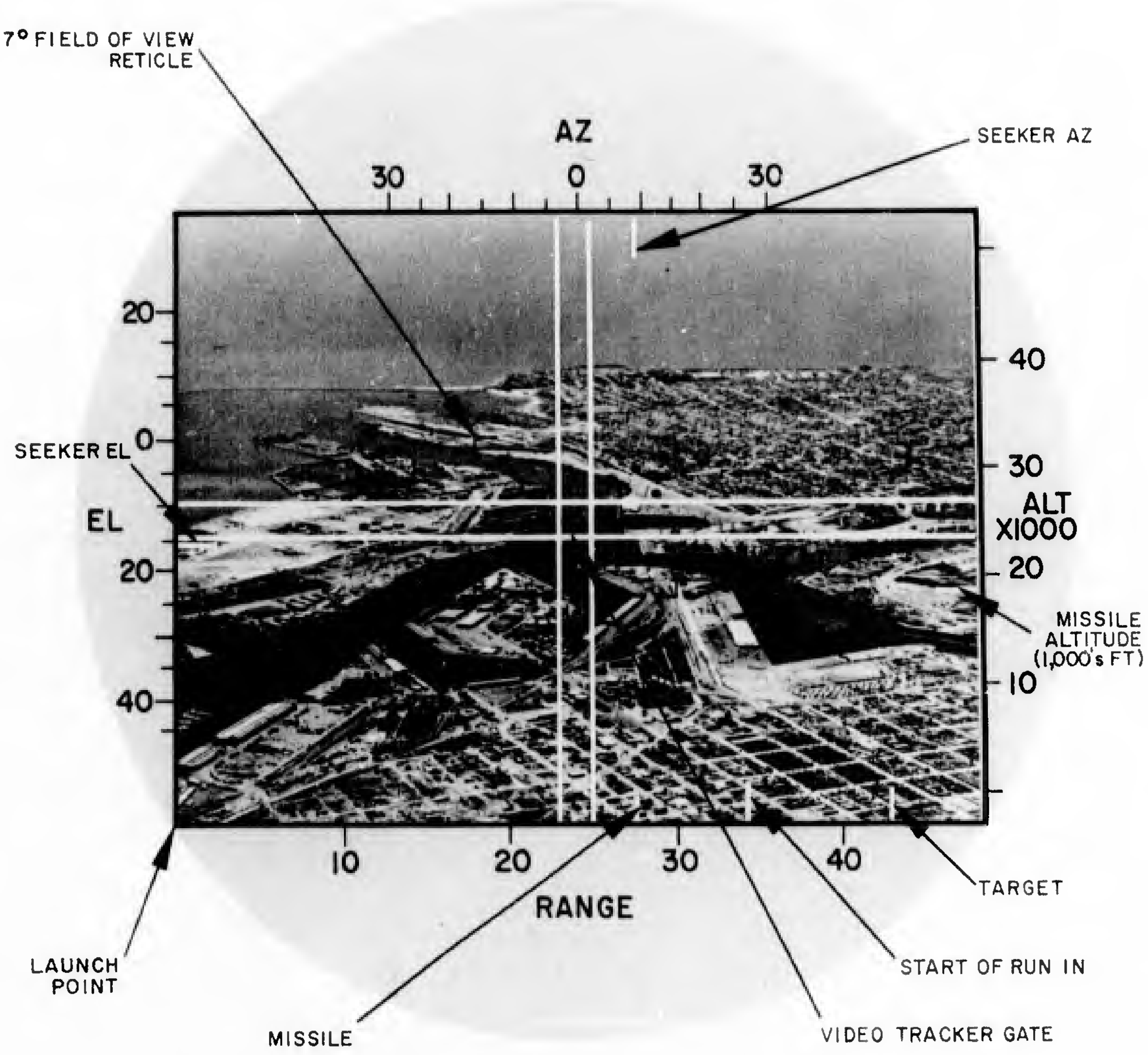

Figure 27. TV Display for Missile Guidance.

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4. SCHEDULE

The manpower schedule to date is shown in Figure 28.

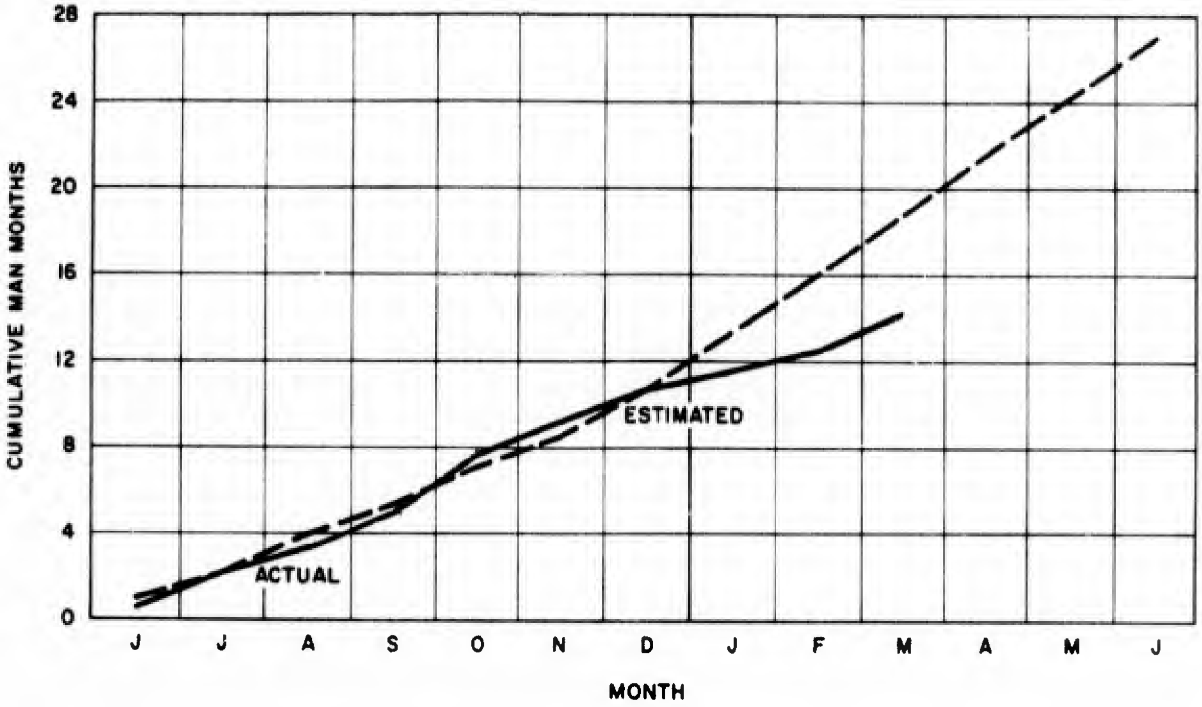

Figure 28. Schedule