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AIRPORT MARKING AND LIGHTING SYSTEMS.
A SUMMARY OF OPERATIONAL TESTS AND
HUMAN FACTORS

William A. Lybrand, et al.

Human Sciences Research Incorporated

Prepared for

Federal Aviation Agency

May 1959

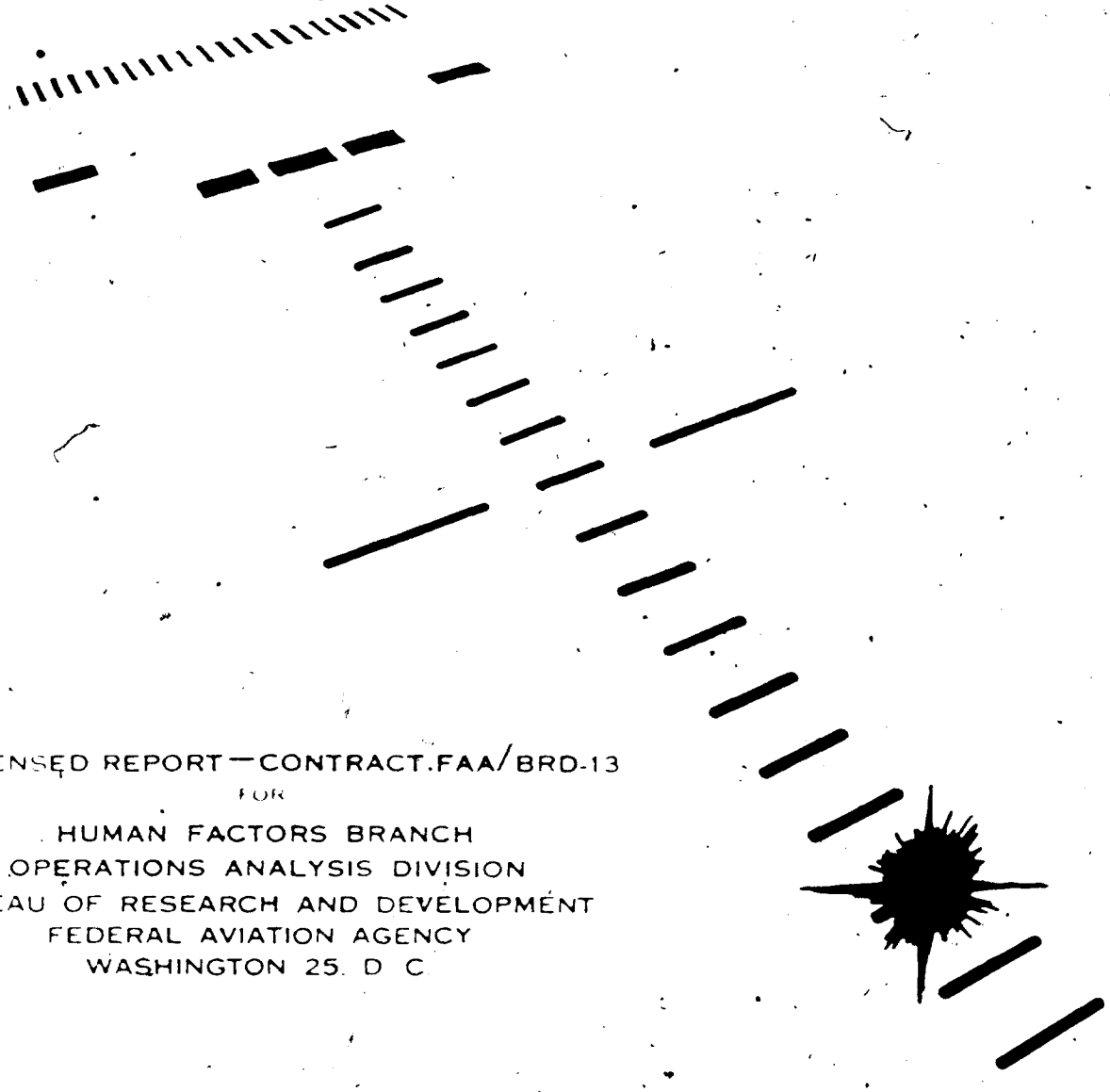
Airport Marking and Lighting Systems

a summary of

Operational Tests

and

Human Factors



CONDENSED REPORT—CONTRACT FAA/BRD-13

FOR

HUMAN FACTORS BRANCH
OPERATIONS ANALYSIS DIVISION
BUREAU OF RESEARCH AND DEVELOPMENT
FEDERAL AVIATION AGENCY
WASHINGTON 25, D. C.

HUMAN SCIENCES RESEARCH, INC.

1408 NORTH FILLMORE STREET
ARLINGTON 1, VIRGINIA

HSR - RR - 59/6 - MK
May 1959

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Foreword

This condensed version of the Final Report on Federal Aviation Agency Contract FAA/BRD-13 contains summary statements of the current state-of-the-art in airport marking and lighting, and recommended future research and development. The information represents major conclusions of research conducted under that contract.

Bringing the principal and important findings of a research project to the attention of all persons who have an interest is a difficult task at best. In addition, research end-results properly are included in the context of final reports which are written primarily for a technical audience and which frequently are quite lengthy. These necessary aspects of scientific research reporting make wide-spread distribution of final reports costly, and after distribution, tend to discourage report reading by non-technical readers.

This report has been prepared to help overcome such problems. It is intended for non-technical readers in management or supervisory positions in the aviation industry, and in pertinent government agencies and departments. The report describes, within a few minutes reading time, what is known now and what needs to be learned and developed in operational airport marking and lighting.

The authors express their appreciation to the following persons who willingly contributed their time and experience to the study.

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Organization of Report

Purpose

In the past, research, development and evaluation of airport marking and lighting systems were done by many different civilian and military groups located in all parts of the country. The Federal Aviation Agency (FAA) now has the responsibility of ensuring effective airport marking and lighting for the common national aviation system.

In order to discharge this responsibility, it was necessary for FAA to have a single over-all picture of the knowledge gained previously and to pinpoint gaps in that knowledge. Such a review was required as a first step in efficiently programming and coordinating future research and development aimed at meeting operational marking and lighting requirements.

The underlying objective of this study, then, was to survey the current state-of-the-art in airport marking and lighting. This general objective was translated into three more specific study purposes:

> To bring together results of operational tests conducted during the past 15 years.
>
> To identify problems on which immediate and future research and development are required.
>
> To review human factors research data relevant to the problems identified and to apply this data to problem analysis.

To achieve these study purposes, information and data from the following sources were collected, sifted, analyzed, and brought together.

Results of tests in operational conditions of airport marking and lighting systems during the period 1946-1959.

Studies and analyses of the pilot's tasks by individuals, groups, and agencies.

Interviews with commercial and military pilots and with research personnel.

Data on basic human capabilities and limitations, particularly in the area of vision and perception.

Today's Marking and Lighting Systems

Installation of marking and lighting systems at airports across the country has not been uniform or regular. Therefore, it is difficult to find more than a few airports with the same over-all system.

A composite picture of systems in use at "typical" heavy-traffic airports today would look like the following.

Airport Beacon

Alternate green and white flashes, 12 per minute. (Dual white flashes at military airports.) Purpose of the beacon is to present a distinctive signal which will clearly locate and identify the airport from as great a distance as possible, usually in Visual Flight Rules (VFR) conditions.

Approach Lights (Instrument Approach Runways Only)

Single row of red lights extending from left edge of runway, dual row of white lights extending from both edges of runway, or single row of white lights on extended centerline of runway. The latter centerline system has been adopted as the national standard, and is programmed for installation in the near future on most instrument approach runways. Purpose of approach lights is to provide guidance to runway in poor visibility conditions. Sequenced flashing lights with the centerline lights is an optional feature of the national standard for aiding initial identification of the approach light system. (See Figure 1.)

Threshold Lights

A continuous or split row of aviation-green lights extending across the end of the runway. Their purpose is to clearly define the beginning of the paved runway. (See Figure 2.)

Runway Marks

White centerline painted in 120-foot stripes with 80-foot spacing to define the center of the runway. White runway number just beyond threshold to indicate magnetic direction of the runway. Eight threshold lines extending 150 feet down the runway to accentuate the threshold. (See Figure 2.)

Runway Lights

White runway edge lights along both edges of the runway at uniform intervals (typically 200 feet). The major function of runway lights is to define the side boundaries of the runway.

Taxiway Marks

A yellow continuous centerline is used to indicate the center of the taxiway for daytime operations.

Taxiway Lights

Aviation-blue (in some cases, yellow) edge lighting along both sides of the taxiway.

Runway and Taxiway Signs

Contain useful information as to distance remaining to end of runway, destination signs, etc. The number, type, and construction of these signs vary considerably from airport to airport. (See Figures 2 and 3.)

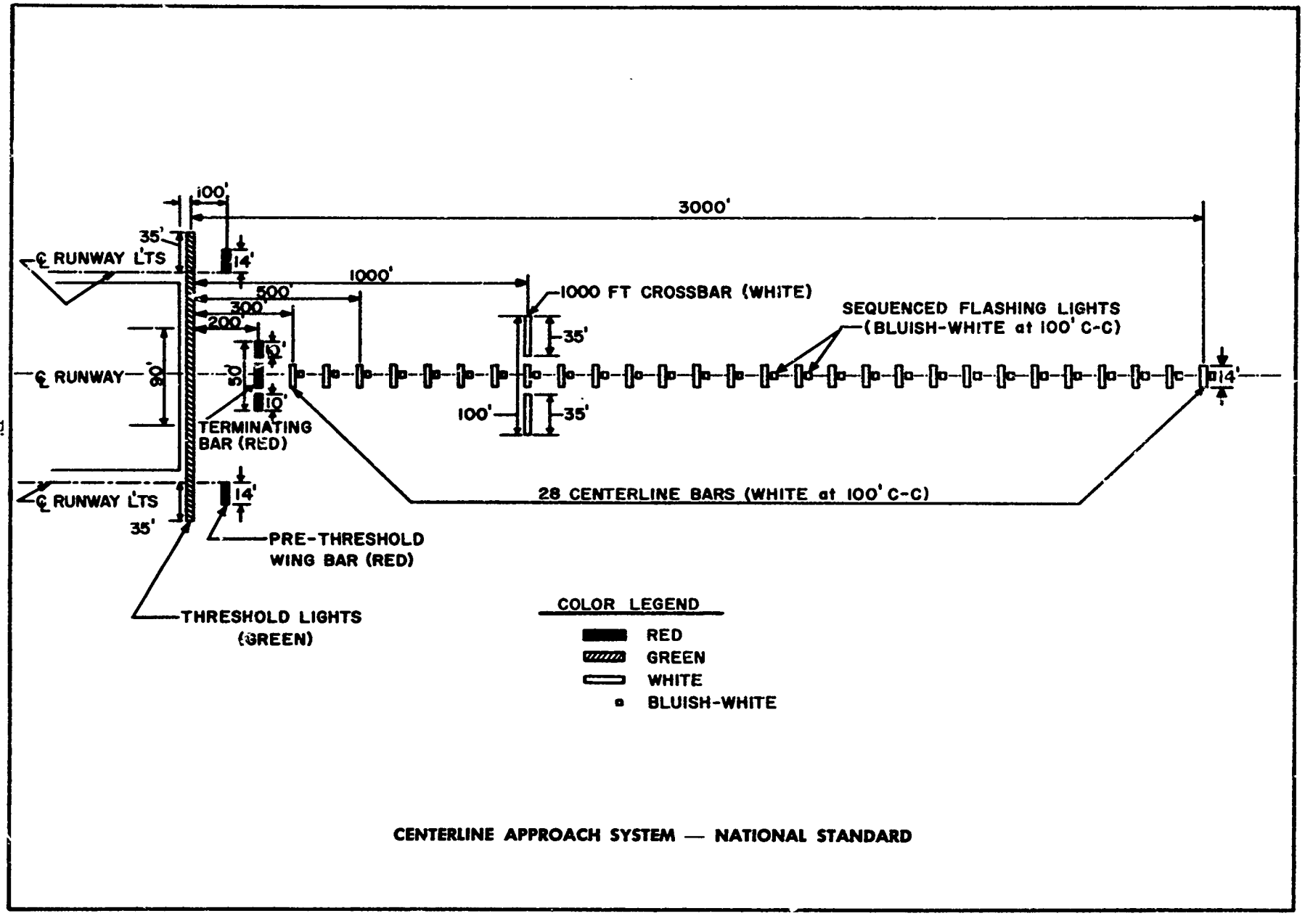


Figure 1

CENTERLINE APPROACH SYSTEM — NATIONAL STANDARD

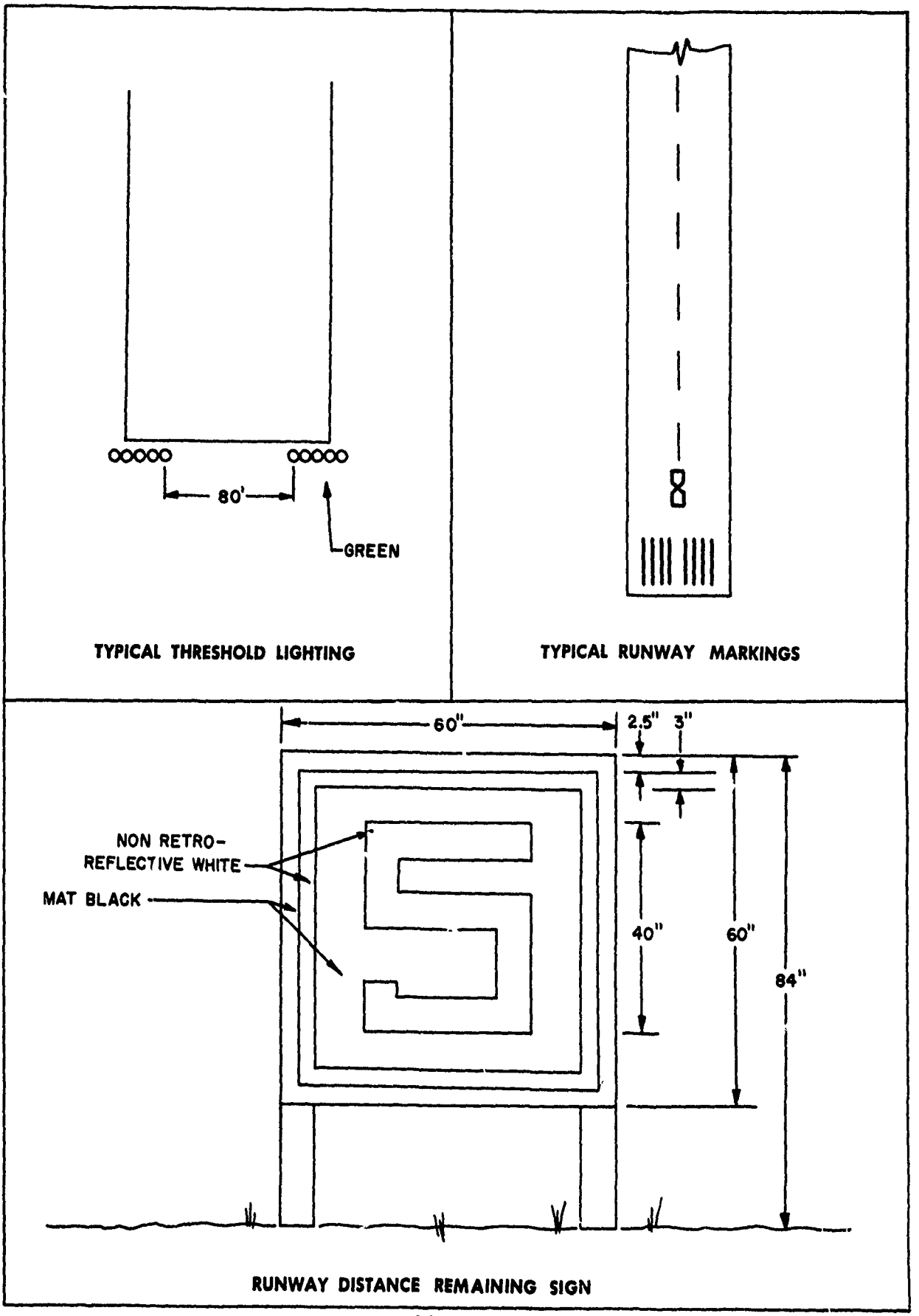
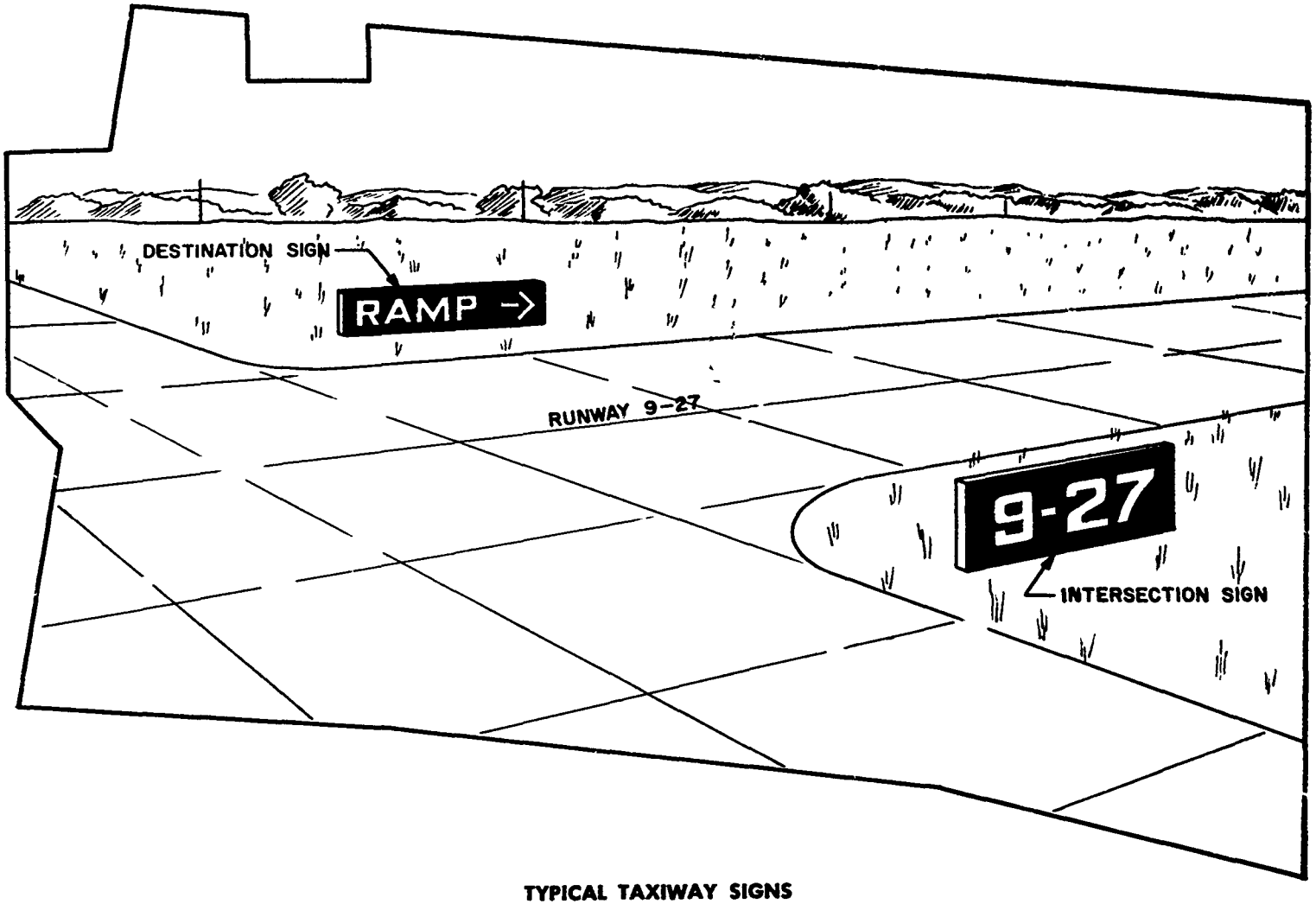

80'
GREEN
TYPICAL THRESHOLD LIGHTING
TYPICAL RUNWAY MARKINGS
60"
2.5"
3"
NON RETRO-
REFLECTIVE WHITE
MAT BLACK
40"
60"
84"
RUNWAY DISTANCE REMAINING SIGN

Figure 2



TYPICAL TAXIWAY SIGNS

Figure 3

The Job Today's Systems are Doing

The fundamental purpose of airport marking and lighting is to provide the pilot with visual information he needs to safely and effectively fly his aircraft. In this study, the pilot's visual information requirements were used as the standard against which today's marking and lighting systems were evaluated. In other words, two basic questions were asked.

(1) What are the functions that today's systems should be performing?

(2) How well are they performing these functions?

Functional information requirements were established by pilot interviews and by technical analyses of pilot tasks. How well today's systems are doing was determined through a review of operational tests on the systems, as well as through pilot interviews.

Results of these analyses are summarized next according to separate parts of pilot flight tasks in which airport marking and lighting (AML) are used. Pilot information requirements are presented first; unresolved problems of presenting this information are identified.

Initial Approach (Visual Flight Rules)

Information Pilot Requires from AML

Identification of airport.

Identification of and aircraft location with respect to duty runway.

Airport beacons are frequently indistinguishable at night from surrounding flashing lights. Airport area color and brightness contrast with the surrounding area in day operations are often below the pilot's basic capabilities to detect contrast.

At many airports, runway color and brightness contrast with the airport area is inadequate in day operations for distinguishing the duty runway from other runways and surrounding highways. The same inadequacy exists with runway edge lights currently used at night. There are no specially designed systems in use at present to aid duty runway identification. Beacons designed for use in the approach area and at the end of the runway have been proposed and are being developed. These beacons should aid airport identification as well as duty runway identification.

Circling (Visual Flight Rules)

Information Pilot Requires from AML

Changes and rates of change in:

Direction of flight path with respect to duty runway.

Distance from runway edges.

Distance from runway threshold.

Again, at many airports, runway-surrounding area color and brightness contrasts are inadequate sources of required information, as are runway edge lights. No specially designed systems are in use at present to provide circling guidance, but circling guidance lights are under development to help estimate distance from runway edges and to estimate direction of flight path with respect to the duty runway. These lights, plus the developments mentioned under Initial Approach should aid in estimating distance from the runway threshold.

Final Approach

Information Pilot Requires from AML

Identification of duty runway area.

Distance to threshold when threshold is not visible.

Changes and rates of change in:

Distance between aircraft and point at which glide path will meet the ground.

Attitude of aircraft--pitch, roll, heading-line of flight coordination.

Glide path with respect to extended runway centerline, and to an ideal glide slope (angle to ground).

In VFR operations, both day and night, the most serious operational problem existing is establishing and maintaining a proper glide path so that the approach is not too high or too low. This is especially critical for jet operations. A number of angle-of-approach indicators have been proposed and are being developed. In the United States and Great Britain, the Mirror Landing System is in operational use on Naval aircraft carriers. (See Figure 4.) The recently developed Royal Aircraft Establishment System (see Figure 5) is installed at London Airport, and the Australian Precision Visual Glide Path System is in service at Nandi Airport in the Fiji Islands. (See Figure 6.)

In instrument flight rules (IFR) operations, the centerline approach system is most satisfactory, for the most part. Pilots report problems with glare in the final portion of the approach, roll guidance, and estimating distance still to go to touchdown. It is felt that relatively minor modifications to the system will overcome these limitations (see Recommended Future R & D).

In both VFR and IFR operations, judgments by the pilot of rate-of-closure with the ground are very critical. Not enough is known about this basic human capability to suggest ways of patterning marks and lights to aid the pilot on the basis of such fundamental knowledge.

Flareout and Landing

Information Pilot Requires from AML

Identification of safe landing area.

Changes and rates of change in:

Distance between aircraft and point at which glide path will meet the ground.

Attitude of aircraft--pitch, roll, heading-line of flight coordination.

Glide path with respect to extended runway centerline and to an ideal glide slope (angle to ground).

Displacement of ground roll from an "ideal" roll parallel to runway edges.

Runway length remaining.

Identification of duty runway exits.

The most critical problem still remaining is the oft-discussed "black-hole" situation, namely, the lack of any really effective guidance for the pilot after he no longer sees the threshold lights. The problem is related to high approach-light intensity and to the fact that runway edge lights are in the outer regions of the pilot's vision where his acuity is less good. To overcome this problem, development is underway on patterns of flush lights imbedded in the runway surface and on floodlighting of the runway surface.

Judging the direction of ground roll after touchdown at night is reported as difficult in poor visibility conditions. Low-intensity flush lights (termed "button" lights) are under development to improve this guidance and to identify safe runway exit paths. Pilots also report difficulties in reading runway distance markers.

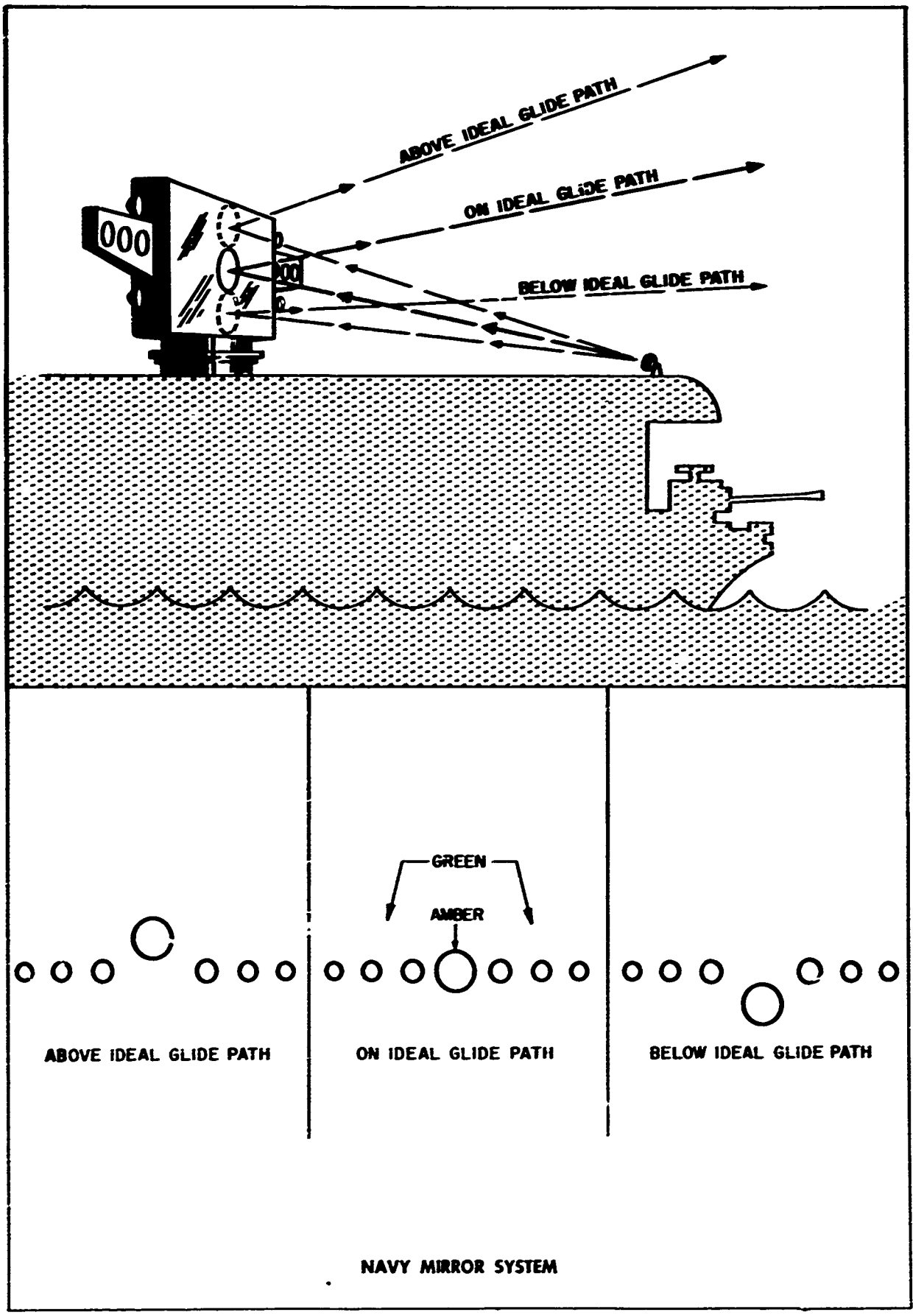
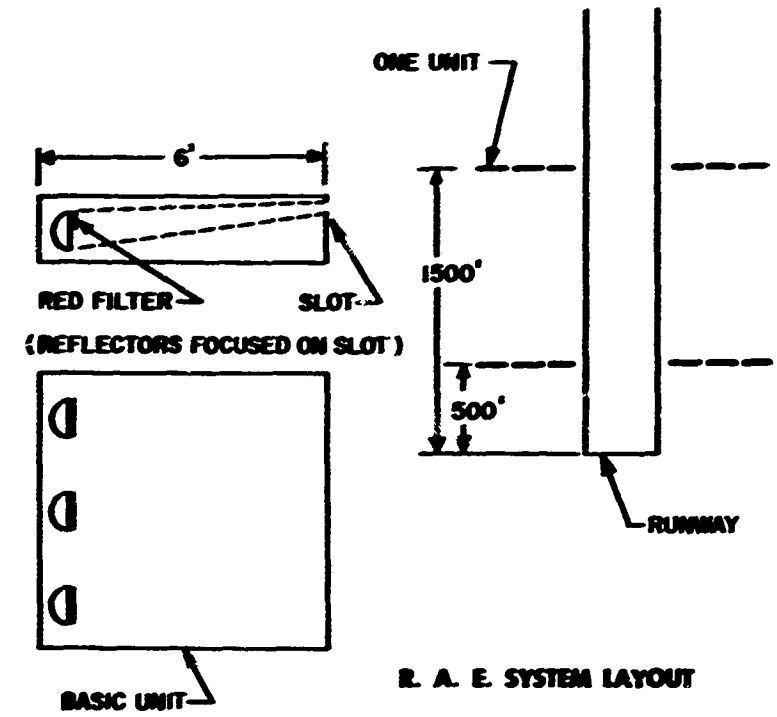

ABOVE IDEAL GLIDE PATH
ON IDEAL GLIDE PATH
BELOW IDEAL GLIDE PATH
GREEN
AMBER
ABOVE IDEAL GLIDE PATH
ON IDEAL GLIDE PATH
BELOW IDEAL GLIDE PATH
NAVY MIRROR SYSTEM

Figure 4



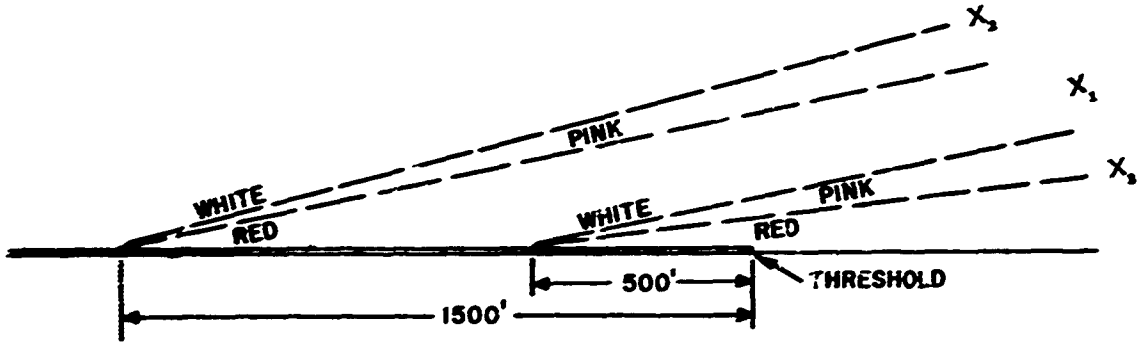
R. A. E. SYSTEM LAYOUT

REMARKS:

X_1 If pilot stays within ideal glide path limits, near light bar will be white, far light bar will be red.

X_2 If pilot goes above ideal glide path, near light bar will stay white, but far light bar will turn first pink, then white.

X_3 If pilot goes below ideal glide path, far light bar will stay red, but near light bar will turn first pink, then red.



R. A. E. SYSTEM LIGHT CODING

Figure 5

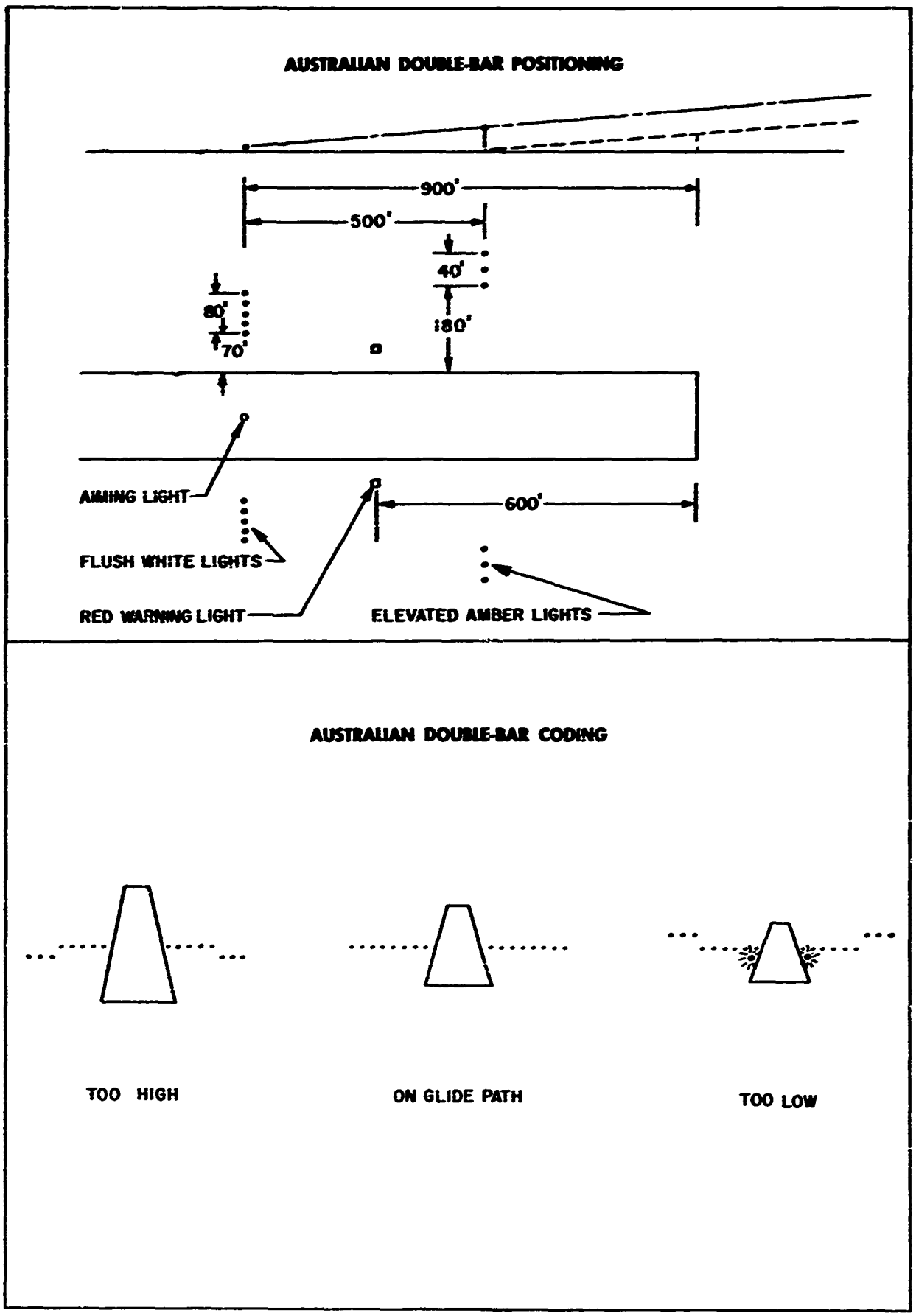

AUSTRALIAN DOUBLE-BAR POSITIONING
900'
500'
40'
80'
180'
70'
AIMING LIGHT
600'
FLUSH WHITE LIGHTS
RED WARNING LIGHT
ELEVATED AMBER LIGHTS
AUSTRALIAN DOUBLE-BAR CODING
TOO HIGH
ON GLIDE PATH
TOO LOW

Figure 6

Turnoff and Taxiing

Information Pilot Requires from AML

- Identification of duty runway exits.
- Identification of safe taxiing and parking areas.
- Changes and rates of change in:
  - Direction of ground roll with respect to sides of taxiway.
  - Distance of aircraft structures from limits of safe taxiing and parking area.
- Taxi route information, particularly at intersections.

Runway exits frequently are difficult to distinguish from regular runway edge light spacings, and blend into an apparent "maze" of blue taxiway lights at some airports. Unless thoroughly and currently familiar with the airport, ground taxiing along a tower-specified route is practically impossible in low visibility conditions. Highway-type signs and intersection traffic lights have been proposed as partial solutions.

Takeoff

Information Pilot Requires from AML

- Distance of initial aircraft position from runway edges and threshold.
- Runway length remaining.
- Changes and rates of change in:
  - Direction of ground roll with respect to runway edges.
  - Attitude of aircraft after breaking ground--pitch, roll, heading-line of flight coordination.

Problems of knowing runway distance remaining and keeping direction of roll straight down the runway are similar to those identified

for Flareout and Landing. What tends to solve those problems also will solve takeoff guidance problems.

General

A number of problems were identified which are not specific to any particular AML system.

Standardized operational test procedures are badly needed and currently are under development. Accelerated work in this area is urgently required. Objective flight performance measures are needed to supplement pilot opinion, which has been used almost exclusively as the sole testing yardstick.

The time-lag between development of a system and its ultimate installation and use is exceedingly large. In the past, this may have been due to the time required to find a compromise among too many opinions, to reconcile too many rivalries, and to satisfy too many pressures. The outlook is better for the future, for the final authority that must be asserted is centralized in the FAA.

A visual flight simulator in which proposed designs can be screened before expensive operational testing would have been most useful in the past. A simulator developed specifically for this purpose would appear to be a most economical and sound investment. An approach, landing, and takeoff training simulator has been adapted for research purposes at National Aviation Facilities Experimental Center (NAFEC) in Atlantic City, New Jersey At present, it does not have any objective flight performance recording capabilities, and is lacking in the brightness and color capabilities which are important for certain research purposes. It currently is being used to screen various light patterns on the runway for flareout and touchdown guidance.

There is a large question concerning what parts of the AML system should be standardized (the same for every airport) and which parts need only to be compatible--their functioning does not interfere with the functioning of other parts, or do not require basically different judgments on the part of the pilot. A resolution of this problem would go far toward rapid installation of effective and safe AML systems at all airports.

Current Operational Testing

At the present time, major emphasis is being focused on the following operational test projects.

Beacons

The usefulness of beacons as visual aids for locating and identifying the active runway in VFR conditions is being actively explored. The more promising of these appear to be: a system of two rotating beacons recently tested at Arcata, California and soon to be further evaluated at El Toro, California and Oceana, Virginia; identification lights placed at corners of the end of the runway soon to be service tested at Norfolk, Virginia.

Runway Lights

This is currently the area of most activity. An experimental system of floodlighting the landing mat has been tested and still is in use at Washington National Airport. Variations of narrow-gauge* lighting schemes are being service tested at: Gatwick, United Kingdom; Idlewild, New York; Copenhagen, Denmark; Bogota, Columbia; and Dow Air Force Base, Maine. The operational suitability test on the system at Dow was completed this year and included a low-intensity flush fixture for centerline rollout guidance. Similar semi-flush fixtures, variously called "button" or "pancake" lights, are being used in centerline and narrow-gauge configurations under evaluation at San Francisco and NAFEC. An extensive operational test program at NAFEC is in progress and will compare high, medium, and low-intensity narrow-gauge configurations and

* In this context, gauge refers to the distance between two rows of lights running parallel to the longitudinal axis of the runway. Narrow-gauge refers to a system in which the rows are relatively close together (e.g., 60 feet).

floodlighting systems with improved fixtures in each class. Operational tests of visual glide path indicators and simulator experiments on approach and runway lighting patterns are also underway at NAFEC. All of the systems under test or development are designed to be used with centerline high-intensity approach lights.

Runway Marking Materials

Experiments and tests of runway marking materials, including retroreflective paints, have just been completed at Washington National Airport and are being continued at NAFEC.

Taxiway Lights

New edge lights are being service tested at Idlewild. Centerline (flush) taxiway lights were given preliminary evaluation at Indianapolis and are being further tested at NAFEC.

Recommended Future R&D

Recommendations are divided into three groups: those involving basic research studies, those which could be resolved if and when a suitable visual simulator is developed (simulators have been found to be a valuable research tool in England), and those involving operational tests. Taken as a whole, the recommendations cover the problem areas discussed in preceding sections of this report.

Basic Research Studies — Development of Components

For Circling Guidance:

Feasibility study of guidance markers for pilots in the initial stages of a circling approach.

For Final Approach and Flareout and Landing Guidance:

Determination of optimal region of guidance, based on:

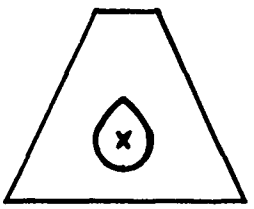
Average lateral and vertical displacement errors from prescribed flight path (at visual contact) for various types of electronically-guided approaches (e. g., instrument landing systems, ground controlled approach systems, etc.).

Minimum time remaining for correcting flight path errors, at final approach altitudes, of representative range of aircraft types.

Determination of basic human capabilities for making rate-of-closure judgments, such as those capabilities involving the "lane of no perceptible movement". (See Figure 7.)

Feasibility study on techniques of projecting air speed and vertical speed displays on windscreens. It is felt that this approach will help alleviate the difficulties in determining runway distance-to-go by not requiring changes in focus of eyes.

Investigation of methods of relating control of runway light intensity to transmissivity conditions.

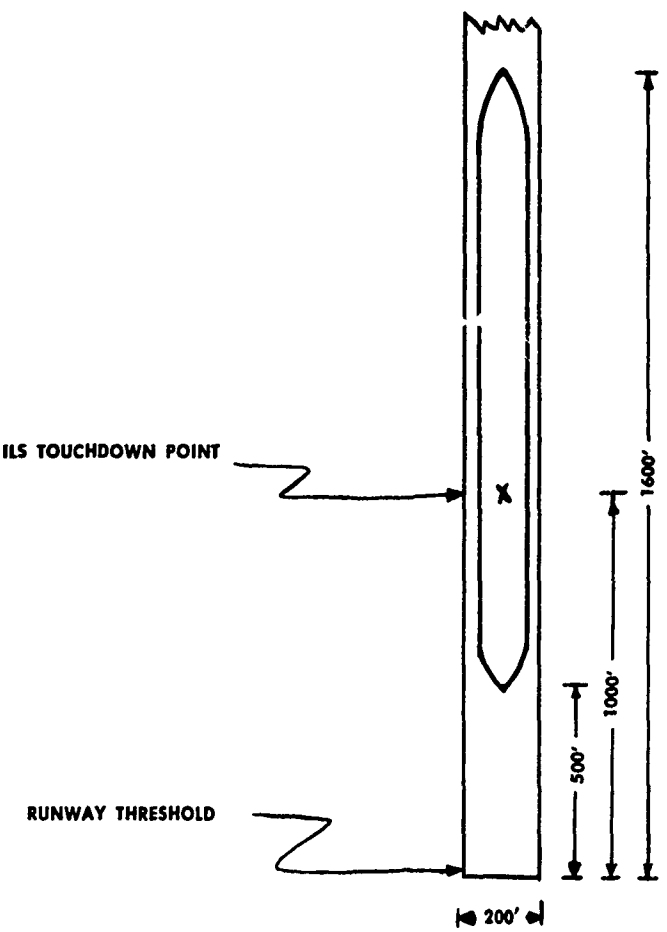


PERSPECTIVE VIEW

AIRCRAFT POSITION = 4000' FROM TOUCHDOWN POINT

AIRSPEED = 125 MPH

ANGLE OF APPROACH = 3°



PLAN VIEW

Notes:

(1) X = Point of intersection of glide path with runway.

(2) The portion of the runway defined by the closed line around X has an apparent movement rate which is below the human's capability to detect rate. Thus, the pilot cannot be getting useful rate information from visual cues in this area.

(3) This diagram is applicable to only one point in the approach. The analysis needs to be conducted for the entire approach so that placement of lights and marks can be made on the runway and its surround so as to optimally aid the pilot make rate-of-closure-with-the-runway judgments.

LANE OF NO PERCEPTIBLE MOVEMENT
AT ONE POINT IN FINAL APPROACH

Figure 7

For General AML System Design, Evaluation, and Installation:

Determination of current and projected traffic loads (nature and volume) of each class of airport.

Development of standards for making parts of AML systems compatible with one another (e. g., so that approach-light intensities do not interfere with runway light guidance).

Determination of which AML system parts should be identical from airport to airport, and which should be viewed from a compatibility standard.

Accelerated development of comprehensive, standardized operational tests of AML design effectiveness, including both objective flight performance and pilot opinion measures.

Determination of special pilot AML information requirements of rotary wing, VTOL, and other short-takeoff aircraft.

Semi-Operational (Simulator) Evaluations

For Final Approach Guidance:

Addition of "cross bars" to centerline approach system. (See Figure 8.)

Angle-of-approach indicators for VFR approaches. (If feasible: otherwise, operational tests should be conducted.)

For Flareout and Landing Guidance:

Patterns of high intensity and low intensity flush lights, and runway markings (see Figure 8 and Chapter III of the Final Report for recommended patterns).

Operational and Service Testing

For Initial Approach and Circling Guidance:

Approach beacons. (Presently programmed for El Toro, California and Oceana, Virginia.)

Runway identification lights. (Presently programmed for Norfolk, Virginia.)

Circling guidance lights.

For Final Approach Guidance:

Sequenced, flashing condenser-discharge lights installed only in the outer 1000 (or 1500) feet of centerline approach system. (See Figure 8.)

Differential intensity settings of 14-foot light bars on outer and inner portions (1500 feet each, or 3 settings--one for every 1000 feet) of centerline approach system. (See Figure 8.)

For Flareout and Landing Guidance:

Initial testing of relative merits of flush lighting (high intensity and low intensity) vs. floodlighting with specially marked runways. (Presently programmed for NAFEC.)

For Turnoff and Taxiing Guidance:

Low-intensity centerline lights (runway, exit and taxiways).

Highway-type signs and intersection traffic lights.

For Takeoff:

Recommendations for other flight modes cover current problems in takeoff guidance.

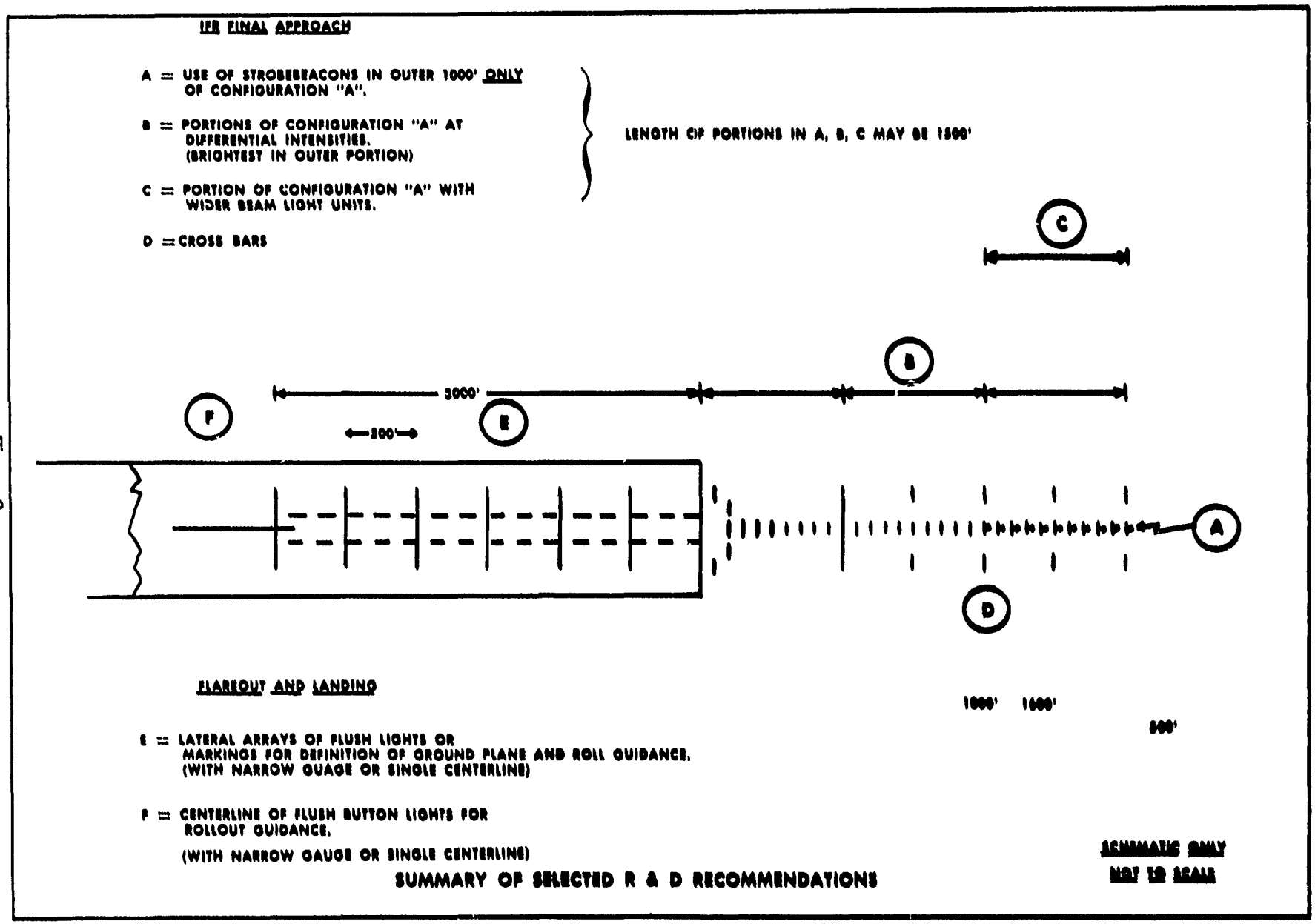

IFR FINAL APPROACH
A = USE OF STROBEBEACONS IN OUTER 1000' ONLY OF CONFIGURATION "A".
B = PORTIONS OF CONFIGURATION "A" AT DIFFERENTIAL INTENSITIES. (BRIGHTEST IN OUTER PORTION)
C = PORTION OF CONFIGURATION "A" WITH WIDER BEAM LIGHT UNITS.
D = CROSS BARS
LENGTH OF PORTIONS IN A, B, C MAY BE 1500'
C
B
3000'
F
E
300'
A
D
FLAREOUT AND LANDING
1000'
1000'
500'
E = LATERAL ARRAYS OF FLUSH LIGHTS OR MARKINGS FOR DEFINITION OF GROUND PLANE AND ROLL GUIDANCE. (WITH NARROW GUAGE OR SINGLE CENTERLINE)
F = CENTERLINE OF FLUSH BUTTON LIGHTS FOR ROLLOUT GUIDANCE.
(WITH NARROW GAUGE OR SINGLE CENTERLINE)
SCHEMATIC ONLY
NOT TO SCALE
SUMMARY OF SELECTED R & D RECOMMENDATIONS

Figure 8

Selected References

The interested or curious reader who would like to examine the logical development of the summary statements in this Condensed Report is referred to the Final Report referenced first below. The Technical Appendix to the Final Report, referenced second, contains abstracts of 168 studies reviewed in the research, as well as bibliographic references to many more. The Appendix was prepared as a ready handbook of information on marking and lighting for airport design engineers and research personnel, but also is an ideal source for the casual reader who wishes to acquire a rapid overview of marking and lighting literature. The remaining references are particularly relevant or competent studies of various aspects of marking and lighting problems.

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